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Effect of High Temperature on Fruit Quality Parameters of Contrasting Tomato Genotypes

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The study was undertaken to evaluate the fruit quality parameters of six contrasting tomato genotypes including three susceptible (Arka Abha, IIHR-2627 and IIHR-2914) and three tolerant (IIHR-2202, IIHR-2745 and IIHR-2841) to high temperature stress. After flower initiation, tomato genotypes were grown under polytunnel to expose them to high temperature (40±2°C) till the time of harvesting. Uniformly ripen healthy fruits were harvested and analyzed for fruit quality parameters comprises total phenols, total flavonoids, antioxidant capacity in terms of FRAP (Ferric Reducing Antioxidant Potential) and DPPH (2,2-Diphenyl-1-picrylhydrazyl), total carotenoids, lycopene, total sugars, vitamin C, Total Soluble Solids (TSS) and Titrable Acidity (TA). Results revealed that there were significant differences between the genotypes in tomato fruit quality parameters. High temperature reduced total carotenoids and lycopene content in tomato fruits and it was decreased significantly in Arka Abha and IIHR-2914 compared to other genotypes. IIHR-2202 recorded very high antioxidant capacity in terms of FRAP, DPPH radical scavenging ability under high temperature stress. TA and TSS increased significantly in all the genotypes under high temperature stress. Tolerant genotypes recorded higher total phenols and total flavonoids content both under control and high temperature stress conditions. Genotypic variations were observed in the above stated biochemical parameters to high temperature stress. Based on these results, two genotypes namely IIHR-2841 and IIHR-2202 were found to be good at maintaining the all quality parameters under high temperature stress compared to Arka Abha and IIHR-2914.

Introduction

Tomato (*Solanum lycopersicum* L.) is the main vegetable crop extensively grown all over the globe. In the lists of food commodities tomato placed at a ninth position and is the second most essential vegetable crop around the globe, next to potato and it is also widely used as a model crop for source-sink studies and stress. The increasing food demand and the threat of heavy crop losses due to global climate change impose the need for urgent development of strategies to substantially improve food production. Improving crop productivity plays a prominent role in achieving plant breeder's

goals. A recent scenario of global warming affected agricultural production and productivity (Ainsworth and Ort, 2010), and the most essential goal of plant breeders is to develop high yielding cultivars that are resistant to biotic and abiotic stress factors.

Among all the abiotic stresses, the chronic and abrupt heating, high-temperature stress is the foremost limiting factor for completion of the normal plant life cycle (Williams *et al.*, 2012). Heat stress disrupts normal metabolic functions of the plants and has an adverse effect on normal growth, photosynthetic efficiency, respiration, pollen dispense, fertilization, water relations, hormone production, which is especially well-studied in the plants (Wahid *et al*., 2007; Rennenberg *et al*., 2010).

High temperature stress induces morphological, anatomical, physiological, biochemical and genetic responses in plants (Camejo *et al*., 2005; Min *et al*., 2014), which additionally decreases crop yield and its quality. However, the response and susceptibility of plants to high temperature vary between genotypes to genotypes and also the developmental stages (Wahid *et al*., 2007). Variation in the response of cultivars to high temperature stress is not only in the vegetative organs (Camejo *et al*., 2006) but also in the reproductive organs (Firon *et al*., 2006).

The reproductive phase is considered as a highly sensitive stage to high temperature stress in tomato (Sato *et al*., 2000). The floral organs were most adversely affected at the initial stages of development (Wahid *et al*., 2007). As anthesis is the crucial stage for the determination of the productivity of the crop, heat tolerance at this stage is very important. Harel *et al.*, (2014) studied the relationship between the reproductive stage of tomato and the average daily temperature and found that the fruit number, the percentage of fruit set and fruit weight per plant were decreased with increase in air temperature from 25 to 29°C. At high temperature, plants tend to transpire more, and in such situations, yield reduction is mainly caused by the impaired pollen, another development, and reduced pollen viability. The values higher than 35°C will also reduce the fruit set and delay the development of normal fruit colors (Sato *et al.*, 2006). During the late maturation growth stage, tomato fruits also become more sensitive to high temperatures, and the rates of fruit growth volume are affected.

Shi and Maguer (2000) observed the inhibition of lycopene production at relatively higher temperatures (38°C). Shivashankara *et al*., (2015) also observed variations among tomato genotypes for fruit quality parameters at elevated temperature. Increase in temperature improved TSS and titrable acidity but decreased total sugars, lycopene, and total carotenoids concentration in five genotypes of tomato.

Although sufficient literature is available on fruit quality parameters in different tomato genotypes (Valverde *et al*., 2002; Erge *et al*., 2011; Kavitha *et al*., 2014; Shivashankara *et al*., 2014), studies on contrasting genotypes to high temperature stress in terms of quality of the fruits are scanty and this information is essential to identify varieties suited to a changing climate. Therefore, the present study was set in a polytunnel to study the effect of high temperature on fruit quality parameters in six contrasting tomato genotypes.

Materials and Methods

On the basis of our earlier studies on temperature induction response (TIR), three tolerant genotypes viz., IIHR-2202, IIHR-2745, and IIHR-2841 and three susceptible genotypes viz., Arka Abha, IIHR-2627 and

IIHR-2914 were used for evaluating their fruit quality attributes under high temperature stress condition. The current research work was conducted at ICAR-Indian Institute of Horticultural Research, Bengaluru during the months of February to June (summer) 2018. Bengaluru is located at 13°58' N latitude, 78°E longitude and 890 m above mean sea level. Seeds were sown in portrays in the third week of February 2018 and seedlings were transplanted in the field after 35 days of sowing. The experiment was set out in a completely randomized block design with five replications. Recommended agronomic practices and plant protection measures were followed to raise the crop. At the early flowering stage (30 Days after transplanting), the temperature stress (40±2°C) was imposed using polytunnel. Recorded daily temperature and relative humidity (RH) during experiment period (last 40 days of the fruiting season) for control genotypes are shown in Figure 1. At the end of stress, uniformly ripen tomato fruits were harvested and subjected for analysis of different quality parameters.

TSS

TSS in terms of °Brix units was measured in fresh tomato juice using a digital refractometer (Model DG-NXT, ARKO India Ltd).

Titrable acidity

Titration method was used to estimate titrable acidity (AOAC, 2000). Five tomatoes from each genotype were homogenized in a mixer to a fine puree. Five grams of homogenized tomato puree was extracted with distilled water and made up the volume to 50 mL. Ten mL of filtrate was titrated against 0.01 N NaOH using a drop of phenolphthalein indicator. Acidity was calculated as using citric acid as standard equivalents and expressed as percent of acidity.

Vitamin C (Ascorbic acid)

Vitamin C content was estimated by the 2, 6-dichlorophenol indophenol (DCPIP) method (AOAC, 2006). Five grams of tomato puree was taken and thoroughly mixed with 4 per cent oxalic acid solution, ground and the volume made up to 50 mL. Vitamin C content exists in the sample was measured by titrating 10 mL of the extract against DCPIP. Vitamin C content was calculated as milligrams of ascorbic acid equivalents per 100-gram fresh weight using L-ascorbic acid standard curve.

Total phenols

Folin–Ciocalteu's reagent (FCR) method was used to estimate the total phenols content (Singleton and Rossi, 1965). Five grams of tomato puree was extracted with 80% methanol and made up to 50 mL. A known volume of an aliquot (0.5 mL) was used for the estimation. The blue color developed after mixing with FCR and sodium carbonate reagent was read at 700 nm using a UV-VIS spectrophotometer. Results were expressed as mg of Gallic acid equivalents per 100 g fresh weight.

Total flavonoids

Total flavonoid content in tomato fruit was estimated by using the method developed by Chun *et al*., (2003). Flavonoids present in the 80% methanol extract were estimated using 5% $NaNO_2$ and 10% $AlCl_3$. The intensity of color developed was read at 510 nm and expressed as catechin equivalents.

FRAP assay

Antioxidant capacity was determined using the FRAP method (Benzie and Strain, 1996). A known volume (0.2 mL) of methanol extract was thoroughly mixed with 1.8 mL of FRAP reagent. Incubated at room temperature for 30 min and the absorbance were read at

593nm. The results were expressed as mg of ascorbic acid equivalent antioxidant capacity (AEAC) per 100 g fresh weight.

DPPH activity

Radical scavenging ability was estimated using the method developed by Kang and Saltveit (2002). A known volume (0.2 mL) of methanol extract was taken in a test tube and 0.3 mL of acetate buffer added followed by 2.5 mL of DPPH solution and mixed well. Read the absorbance of the solution spectrophotometrically at 517nm after 30 min of incubation.

Total carotenoids and lycopene content

Total carotenoids and lycopene content were analyzed by spectrophotometry method (Lichtenthaler, 1987). A known quantity of tomato sample was extracted using 100% acetone until the residue becomes colorless and then into the pure hexane. The absorbance was read at 470 nm for total carotenoids and 503 nm for lycopene. Calculated the content using standard β-carotene or lycopene and express as mg/100g fresh weight using a standard curve.

Statistical analysis

ANOVA was carried out for obtained data to understand the significance statistically between the different genotypes. Results were analyzed using the two-factor analysis with replications using OPSTAT software. Test of means was done using least significant difference (LSD) at 5% probability. To understand the amount of variability within the group, error bars were used.

Results and Discussion

Uniformly ripened tomato fruits were harvested and subjected to analysis for different quality parameters. High temperature severely affected the important yield components such as fruit number and fruit weight thereby potential yield was markedly reduced. Average fruit weight of 115.20 g was recorded in IIHR-2841 as against 41.20 g in Arka Abha under normal condition. But there was a significant decrease in fruit weight in all the susceptible genotypes especially in Arka Abha (23.98 g) as compared to tolerant genotypes under stress (Fig. 2), which was also supported by the Umesh Singh *et al*., (2015).

Changes in fruit quality attribute in six contrasting tomato genotypes in both control and temperature stress conditions are presented in Table 1. Titrable acidity ranged from 0.42 to 0.56 under control whereas 0.50 to 0.68 under stress conditions. IIHR-2202 and IIHR-2745 showed a very meager increase in acidity under stress compared to control as that of IIHR-2627 and Arka Abha. It is reported by earlier workers that acids to sugars ratios are vital components which imparts tomato fruit flavor (Kaur *et al.,* 2013; George *et al*., 2004). Under high temperature stress conditions, increase in titrable acidity has been reported by Khanal (2012).

Total sugars content decreased significantly in all the genotypes under high temperatures stress conditions compared to control. IIHR-2841 recorded higher total sugar content both in control and stress. Arka Abha and IIHR-2914 genotypes showed lesser total sugars compared to tolerant genotypes.

Temperature stress is known to affect fruit maturity and growth through influencing acid invertase and sucrose synthase enzyme regulation and also regulation of sugar transport into the tomato fruit (Fleisher *et al*., 2006). Shivashankara *et al.,* (2015) reported a decrease in total sugar content in five genotypes of tomato fruit under temperature stress. Gautier (2005) also reported reduced in total sugar content in cherry tomato when

increased fruit temperatures. All these studies support our results in tomato fruit.

Vitamin C content did not show any significant differences among the susceptible genotypes but all tolerant genotypes showed higher vitamin C under temperature stress conditions compared to control. IIHR-2627 recorded the lowest vitamin C content both in control and high temperature stress whereas IIHR-2202 showed the highest vitamin C content under stress (Table 1). Hernandez *et al*., (2018) reported that vitamin C content was increased when the heat stress was imposed during flowering and fruit set stages, indicating that its plant metabolism adapted to high temperature.

The sugars are the largest contributor to the total soluble solids content in tomato fruits (Selahle *et al*., 2014). In general, TSS ranged from 4 to 6 °Brix in tomato fruits of different genotypes. The change in the glucose to fructose ratio and the organic acids content in the tomatoes is the main cause for changes in the TSS. Moreover, for the taste of tomatoes, TSS was reported as a beneficial indicator (Klunklin and Savage, 2017). In our study, TSS increased in all the genotypes under temperature stress compared to control, which is also supported by Shivashankara *et al*., (2015). IIHR-2841 and IIHR-2202 recorded highest TSS in both the treatments (Table 1).

Total phenols and total flavonoids were increased with increase in temperature in all the genotypes. However, the genotypes IIHR-2841 and IIHR-2202 showed a significant increase in total phenols content under high temperature stress compared to control (Table 1).

As phenolic substances are reported to have a protective effect on ascorbic acid (Toor and Savage, 2006), the presence of phenolics and flavonoids in tomato fruits may have helped to maintain the vitamin C level. A significant increase in total phenolic acids and flavonoids under high temperature were also reported in strawberry (Wang and Zheng, 2001) and also in other crops (Toor *et al*., 2006; Wang, 2006).

Radical scavenging ability and total antioxidant capacity were assessed using DPPH and FRAP methods respectively. All the genotypes recorded significantly higher FRAP and DPPH under control conditions. Significant differences in the DPPH activity in susceptible genotypes between control and temperature stress treatment. Shivashankara *et al.*, (2015) also reported lower antioxidant capacity under elevated temperature. Arka Abha genotype recorded lowest DPPH values followed by IIHR-2914 in control as well as in stress condition (Table 1). Total antioxidant capacity (FRAP) also showed higher values in tolerant genotypes under both condition as compared to susceptible genotypes. IIHR-2202 recorded higher FRAP in both conditions.

Lycopene constitutes 80-90 per cent of the total carotenoids in tomato fruits (Sharma *et al*., 1996). It is reported that lycopene can exist as different conformational isomers, but the predominant form found in tomato fruits (around 95%) in all-trans-lycopene forms. Many factors affect the lycopene content in tomato fruits to mention few maturity, cultivar-specific and temperature. As tomatoes ripened, carotenoids, as well as lycopene content, increased within the plastids (Valverde *et al*., 2002). In our study, all the tomato genotypes recorded higher carotenoids and lycopene content in control conditions, however susceptible genotypes accumulated lesser contents compared to tolerant genotypes both under control and stress conditions. IIHR-2202 and IIHR-2841 showed higher content of these compounds in both conditions (Fig. 3).

Table.1 Changes in fruit quality parameters of six tomato genotypes at high temperature conditions*

	Varieties	Treatment	Total phenols (mg)	Total Flavonoids (mg)	FRAP (mg)	DPPH (mg)	Acidity (%)	Vitamin C (mg)	TSS (°Brix)	Total Sugars (g)
Tolerant	IIHR-2745	Control	27.64±0.33	8.89±0.32	25.18±1.02	42.47±1.35	0.56±0.02	15.0±0.51	3.5±0.08	1.85±0.07
		Stress	31.49±1.13	10.81±0.04	19.26±0.12	41.21±1.33	0.58±0.01	19.5±0.70	4.1±0.11	1.56±0.04
	IIHR 2841	Control	29.12±0.71	9.26±0.37	31.92±0.95	49.62±0.99	0.48±0.01	10.5±0.10	4.6±0.13	3.07±0.04
		Stress	37.61±0.72	11.01±0.23	26.64±0.19	46.63±1.88	0.58±0.00	15.0±0.24	5.1±0.22	2.15±0.02
	IIHR 2202	Control	27.97±0.35	10.26±0.28	33.50±0.55	46.68±0.25	0.48±0.02	16.0±0.66	4.5±0.17	2.50±0.05
		Stress	36.41±0.30	11.62±0.26	30.29±0.40	47.21±1.07	0.50±0.01	19.8±0.47	4.9±0.06	1.91±0.02
Susceptible	Arka abha	Control	25.68±0.74	8.78±0.38	24.61±0.05	37.64±1.59	0.42±0.00	14.5±0.02	3.7±0.01	2.29±0.10
		Stress	27.41±1.13	11.42±0.22	18.42±0.58	32.49±1.14	0.66±0.01	14.0±0.38	4.0±0.07	1.41±0.03
	IIHR 2914	Control	28.46±0.72	5.07±0.16	20.23±0.23	39.36±0.69	0.48±0.01	16.0±0.13	4.0±0.06	2.34±0.07
		Stress	29.45±0.46	6.83±0.16	16.41±0.50	35.24±1.48	0.63±0.00	18.0±0.27	4.4±0.07	1.40±0.01
	IIHR 2627	Control	26.26±0.30	7.45±0.04	22.85±0.87	43.44±1.14	0.55±0.00	10.0±0.27	4.3±0.17	2.54±0.05
		Stress	25.68±0.97	8.20±0.29	18.13±0.59	34.20±0.18	0.68±0.01	11.0±0.44	4.4±0.17	1.69±0.04
		Mean	**29.43±0.63**	**9.13±0.23**	**23.95±0.50**	**41.35±1.09**	**0.55±0.01**	**14.94±0.35**	**4.29±0.11**	**2.06±0.04**
	CD for Varieties (P=0.05)		**0.897**	**0.315**	**0.862**	**1.432**	**0.013**	**0.472**	**0.156**	**0.064**
	CD for Treatment (P=0.05)		**0.518**	**0.182**	**0.498**	**0.827**	**0.008**	**0.273**	**0.090**	**0.037**
	CD for V x T (P=0.05)		**1.268**	**0.445**	**1.219**	**2.025**	**0.019**	**0.668**	**0.220**	**0.091**

* All values per 100g fresh weight of the fruit'

Fig.1 Daily Maximum/Minimum temperature (°C) and Relative humidity (%) during the last 40 days of the experimental period for control genotypes

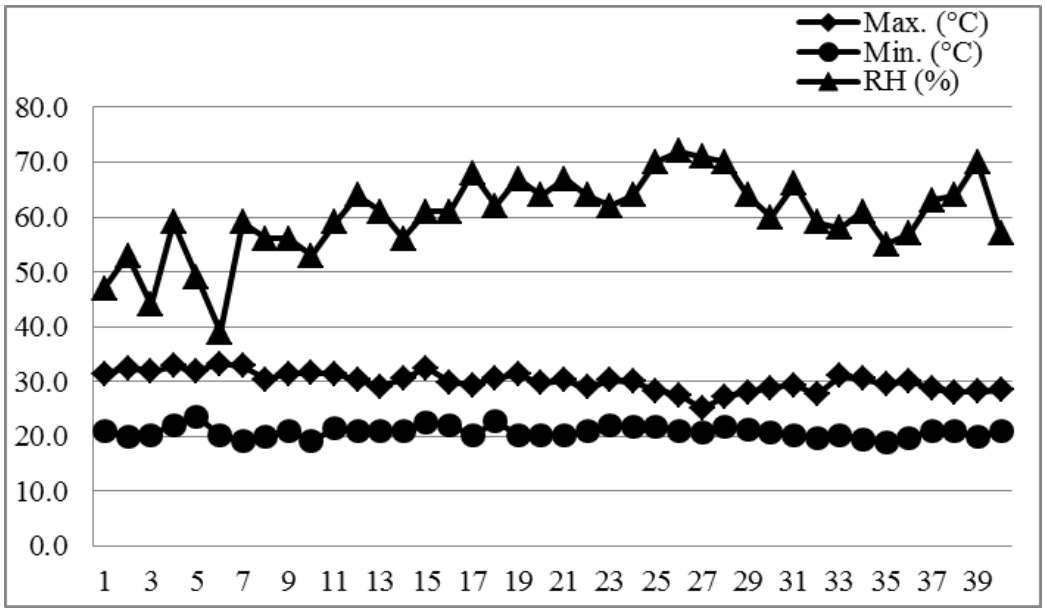


Fig.2 Average fruit weight in six tomato genotypes under high temperature conditions

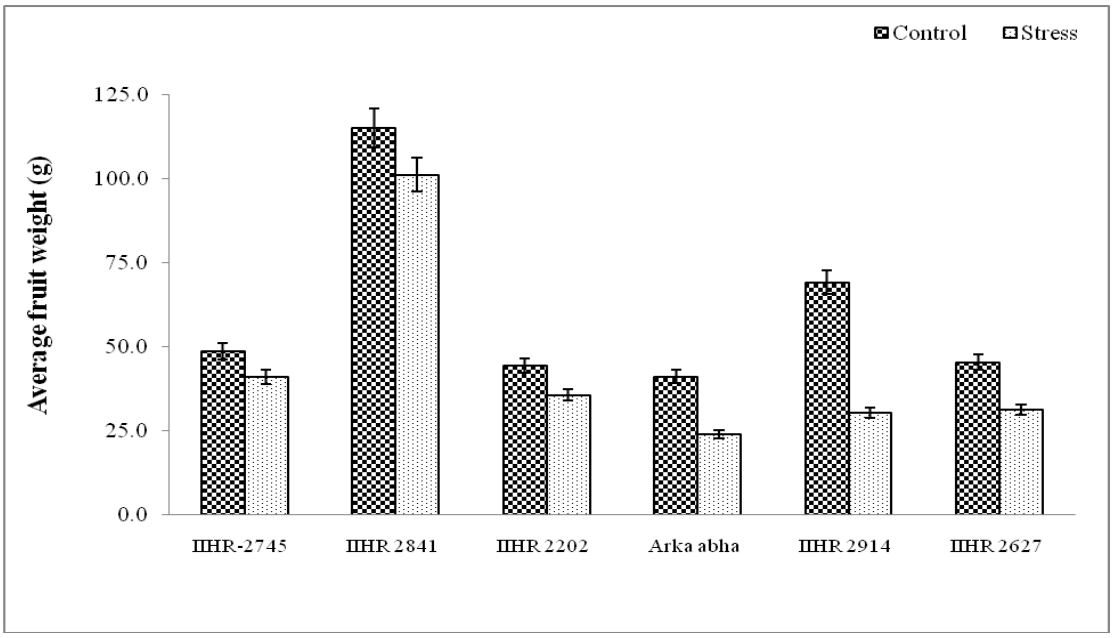
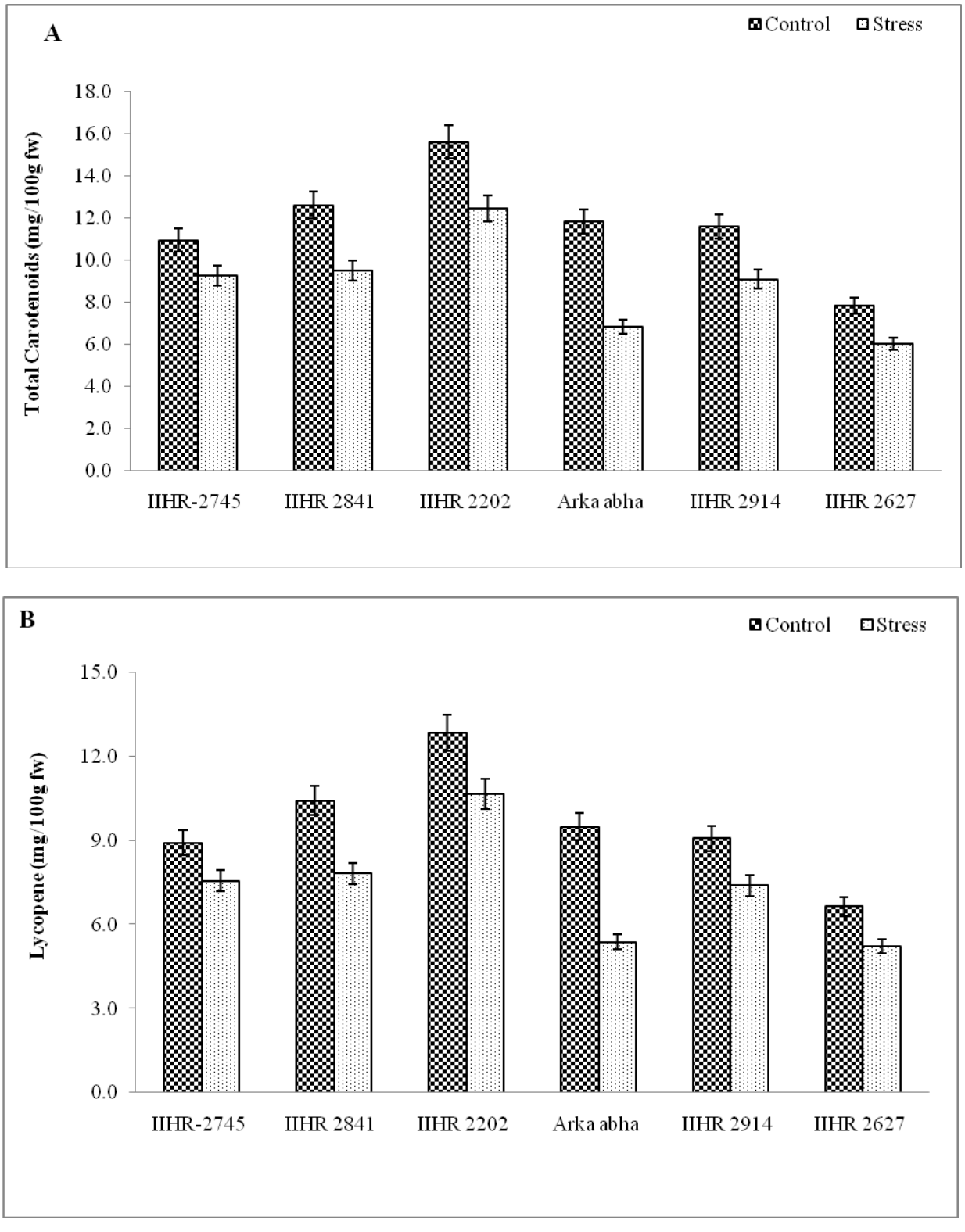


Fig.3 Total carotenoids (A) and lycopene content (B) in six tomato genotypes under high temperature conditions



Carotenoids content significantly reduced in susceptible genotypes as that of tolerant genotypes under high temperature stress, especially Arka Abha showed a remarkable decrease in both total carotenoids and lycopene content under stress conditions. The temperature had a significant influence on total carotenoids and lycopene content. During fruit ripening, temperature plays a more important role in lycopene biosynthesis than it does during the fruit growth period. High temperature may lead to degradation of lycopene (Demiray *et al*., 2013), in addition to a reduced biosynthesis (Helyes *et al*., 2007).

In conclusion, changes in fruit quality parameters in six contrasting genotypes under high temperature stress were studied and this is the first time that a cumulative work on quality parameters and antioxidant properties of fruits which were selected from control and high temperature stress conditions have been assessed. The quality parameters of the fruits (total phenolics, total flavonoids, acidity, TSS and vitamin C) were not decreased by high temperature. However, there was a decrease in total carotenoids, lycopene, total sugar content and also antioxidant compounds, which are the main quality attributes in terms of marketability purpose. Tolerant genotypes maintained the quality attributes under stress effectively by different mechanisms as that of susceptible genotypes. IIHR-2202 and IIHR-2841 were found to be good at maintaining all the quality parameters at high temperature compared to other genotypes. So, these genotypes could be used for the cultivation at high temperature regimes.

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