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Effect of Deficit Irrigation on Total Yield, Fruit Physical Characteristics, and Nutritional Value of Four Drought Tolerant Tomato (*Solanum lycopersicum* L.) Genotypes

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ABSTRACT

Water deficit is a major factor limiting plant water productivity and fruit quantity and quality, particularly in arid and semi-arid regions of the world. The total yield, fruit physical characteristics, and nutritional value of four drought tolerant tomato genotypes (KSU-TOM-102, KSU-TOM-106, KSU-TOM-107 and TL–01860) were evaluated in response to deficit irrigation (DI) under field conditions. Three levels of crop Evapo-Ttranspiration (ETc; 50, 75, and 100%) were applied at three different growth stages (vegetative, flowering, and fruiting) to the four tomato genotypes. Tomato genotypes differed in their responses to water deficit. Among different genotypes, KSU-TOM-102 recorded the highest average total yield (89.54 t ha^{-1}) under irrigation treatment with 100% of ETc during all stages as well as 75% of ETc during the fruiting stage. However, in general, total yield decreased under water deficit. Fruits quality characteristics were significantly (P≤ 0.05) affected by irrigation water treatments, tomato genotypes, and their interactions. Irrigation with water at 50% ETc at all growth stages significantly (P≤ 0.05) increased vitamin C, titratable acidity, total soluble solids and total sugar contents for tomato 'KSU-TOM-107' followed by 'KSU-TOM-102'. However, this increase in nutritional value was accompanied with decrease in total yields by nearly 40-50%. KSU-TOM-102 irrigated at 75% ETc at fruiting stage or vegetative stage recorded 0 and 12% reduction of the total yield, respectively, while maintaining good nutritional value as compared with 100% ETc during all stages. Therefore, these treatments can be recommended as irrigation management strategy for tomato 'KSU-TOM-102' production under field conditions.

Keywords: Nutritional value, Tomato quality, Water saving, Water stress.

INTRODUCTION

Tomato fruit is an important source of the antioxidant lycopene, which has a protective role against cancer or cardiovascular diseases (Heber and Lu, 2002), vitamin A (β-carotene) and vitamin C (ascorbic acid), which are important for human health (Raiola *et al.*, 2014). The nutritional value of tomato fruit is important for both fresh market and processing tomatoes (Cuartero and Fernandez-Munoz, 1999). Fruit quality of tomato is strongly dependent on genotype and field management and, in particular, on water availability (Yuan *et al.*, 2016). Deficit irrigation is an optimization strategy that involves application of water below full crop-water requirement (evapotranspiration) to maximize water use efficiency (Zegbe-Dominguez *et al.*, 2003). Deficit irrigation during non-critical stages may be less

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detrimental; the flowering and fruit setting stages are the most sensitive to water deficits (Harmanto *et al*., 2005; Kuşçu *et al*., 2014). Deficit irrigation studies on tomato were conducted to balance the fruit yield and quality under greenhouse or open field. Several studies revealed that a consistent improvement in tomato fruit quality could be achieved with deficit irrigation (Khapte *et al*., 2019; Nangare *et al*., 2016; Patanè and Cosentino, 2010; Patanè *et al*., 2011; Wang *et al*., 2015). Under water deficit, an overall decrease in yield while increase in fruit quality traits such as total soluble solids, titratable acidity and vitamin C contents were reported (Patanè *et al*., 2011, Jiang *et al*., 2019, Shao *et al*., 2015). However, the effects of water deficit on tomato yield and quality are genotype-dependent. Fullana-Pericàs *et al*. (2019) reported that large trait diversity in yield and fruit quality among tomato genotypes were observed under water deficit. Vilas Boas *et al*. (2019) also reported that genotypes and irrigation regime impacted fruit quality of tomato. The findings by Fullana-Pericàs *et al*. (2019) and Vilas Boas *et al*. (2019) highlight the potential of exploring cultivation of tomato landraces and drought tolerant genotypes under water deficit.

In arid regions such as Saudi Arabia, where water shortage and long summer droughts prevail, fruit nutritional value and fruit quantity are of increasing concern. Therefore, deficit irrigation strategies as well as drought tolerant genotypes are quite important in these environments. This study was conducted to assess the effects of water stress at different growth stages on total yield, fruit physical characteristics and nutritional value of four drought tolerant tomato genotypes.

MATERIALS AND METHODS

Experimental Site and Soil Analysis

Field experiments were conducted at the Dirab Agricultural Research and Experimental Station Farm of the College of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia (24° 39ˉ N, 46° 44ˉ E) during 2015 and 2016 seasons. Soil samples were collected from the experimental site (depth up to 30 cm) for analysis of their physical and chemical properties according to the method described by Black *et al*. (1965). The physical and chemical properties are presented in Table 1. The hydrometer method was employed to determine particle size analyses (Bouyoucos, 1951). The pH and Electrical Conductivity (EC) of the soil were measured using a pH meter (Orion star A211; Thermo Fisher Scientific, Waltham, MA) and a conductivity meter (Orion star A212; Thermo Fisher Scientific), respectively. Potassium (K^+) and sodium (Na^+) were measured using a microprocessor flame photometer (Model 1382; ESICO, Haryana, India). EDTA-di sodium, silver nitrate, hydrochloric acid solutions were used for, respectively, determination of Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chlorine (Cl^-), and bicarbonate (HCO_3^{-1}) by titration, and

Table 1. Physical and chemical properties of the experimental soil.

Parameters	Soil depth (cm) 0-30
Coarse sand (%)	49.23
Fine sand (%)	31.07
Silt (%)	12.22
Clay (%)	7.48
Texture class	Sandy loam
Organic matter content (%)	0.14
$CaCO_3$ (%)	25.31
Saturation water content (%; *w/w*)	0.347
Field capacity (%; *w/w*)	16.6
Permanent wilting point (%; *w/w*)	6.5
pH	7.9
Electrical conductivity (dS. m^{-1})	2.2
Ca^{2+} (me L^{-1})	14.2
Mg^{2+} (me L^{-1})	0.8
Na^+ (me L^{-1})	1.3
K^+ (me L^{-1})	0.32
HCO_3 (me L^{-1})	3.11
Cl^- (me L-^{1})	4.89
SO_4^{-2} (me L^{-1})	8.62

Sulfate (SO_4^{-2}) was determined using a Digital Turbidity Meter (DRT 100B, HF scientific, Inc., Ft. Meyer, FL).

Plant Materials, Growth Conditions, and Experimental Design

Four tomato (*Solanum lycopersicum* L.) genotypes including three improved genotypes KSU-TOM-102, KSU-TOM-106, KSU-TOM-107 and one drought-tolerant breeding line TL–01860 were used in this study. The three improved genotypes were produced through the tomato breeding program at the Vegetable Improvement Unit, College of Food and Agriculture Sciences, King Saud University and tested for drought tolerance (Alsadon *et al*., 2007; Wahb-Allah *et al*., 2011). The drought-Tolerant breeding Line (TL–01860) was obtained from Asian Vegetables Research and Development Centre (AVRDC) Shanhua, Taiwan. Meteorological variables including the daily air temperature and humidity during the entire duration of experiments (Figure 1) were measured by an automatic weather station near the study area. During the experimental period, the average temperature was 23.9°C, the average humidity was 28.3% at 2 m above ground.

Seeds of each genotype were sown in JV7 pellets, in fiber glass greenhouse under controlled conditions at 25±1°C day and 20±1°C night temperature, on January 5th, 2015 and January 7th, 2016, in the first and second seasons, respectively. The seedlings of tomato genotypes were transplanted in the open field on February 3rd and 5th of 2015 and 2016 seasons, respectively. The experimental area consisted of 18 rows, 41 meters long and 150 cm wide. The planting distance was 50 cm between plants.

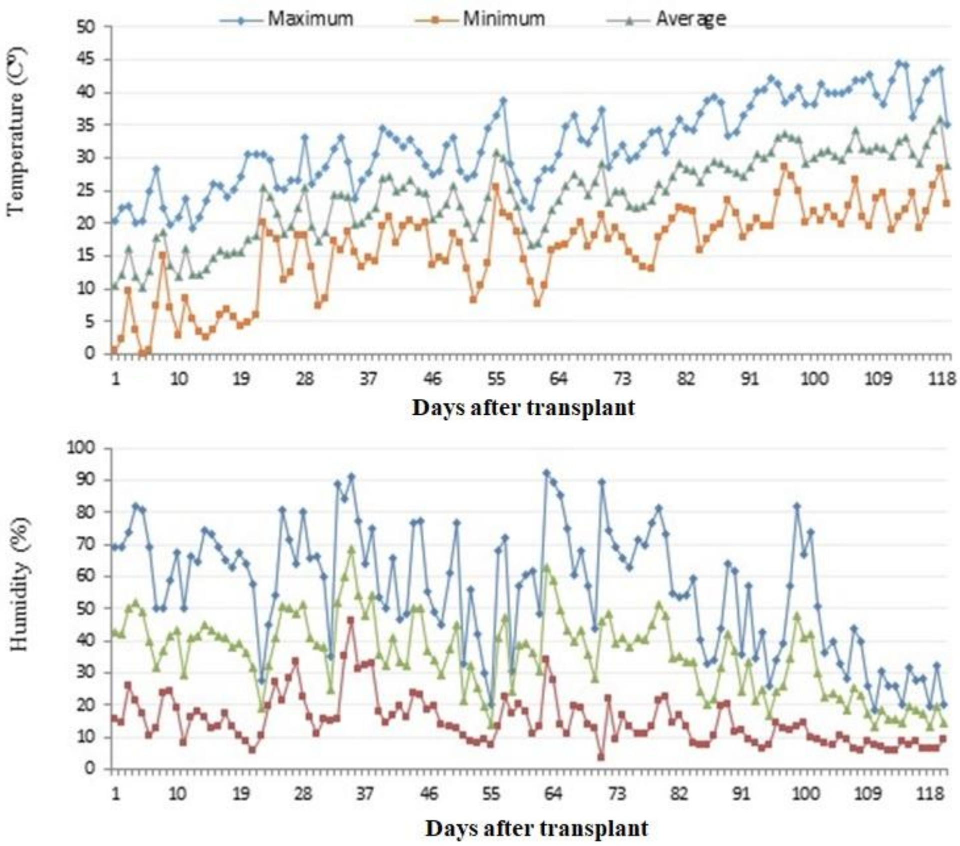

Figure 1. Mean daily air temperature and humidity during the field experiment.

Irrigation water treatments were applied by drip irrigation at seven days after transplanting. Fertilization was applied as commonly recommended in commercial tomato production. Other recommended agricultural practices of tomato production, plant protection against weeds, diseases and insects, were performed as commonly used in the commercial production of tomato (Jones, 2008).

The experimental design used in this study was Randomized Complete Block (RCBD) in a split- plot system, with three replicates. Each replicate contained thirty-six treatments, which represented the combinations of nine irrigation treatments and four tomato genotypes. The water deficit (irrigation levels) treatments were randomly allocated to the main plots, whereas, the four tomato genotypes were arranged in sub-plots.

Irrigation Treatments

Nine irrigation treatments were applied during three development stages of tomato plant (Table 2). The amount of irrigation water was estimated using ETc for tomatoes; which, were calculated by the FAO Penman Monteith method (Harmanto *et al*., 2005) with data from the meteorological station near the study area using the crop coefficient (Kc) values as follows:

$$ET_{crop}= Kc \times ET_0$$

Where, crop coefficient at the initial growth stage (Kc_{ini})= 0.60, during the mid-season stage (Kc_{mid})= 1.11, at the end of growth stage (Kc_{end}) = 0.80, ET_0= Reference ET, measured by means of a Class A Pan (mm).

The irrigation water quality had pH 6.44 and Sodium Adsorption Ratio (SAR) 7.75; EC of 0.91 dS m^{-1}. The growing season was divided into three growth stages i.e. vegetative growth stage (from the beginning of transplanting till the beginning of 50% flowering); flowering stage (from the beginning of 50% flowering till the formation of first full-sized 50% green fruit); fruiting stage (from the development and ripening of fruits till the termination of the experiment) (Table 2).

Measurements of Total Yield, Fruit Physical Traits and Fruit Nutritional Quality Traits

During the growing seasons, a random sample of three plants from each experimental unit (sub-plot) were taken for fruit physical traits. Average fruit fresh and dry weight (grams), fruit dimensions (length and diameter, centimeters) were measured. The total harvested fruits from each plot all over the harvesting seasons were weighed, and then the global yield as tons per hectare was calculated. The fruits were dried at 70°C in an air-drying oven for 48 hours. Vitamin C content, total soluble solid

Table 2. Irrigation water treatments for the different growth stages of four tomato genotypes. [a]

Treatments	Description	Water consumptive use (m^3/ha)	
		1st season	2nd season
IW-1	Irrigation at 100% of ETc during the entire growth stages.	3375	3656
IW-2	Irrigation at 75% of ETc during the entire growth stages	2531	2742
IW-3	Irrigation at 50 % of ETc during the entire growth stages	1688	1828
IW-4	Irrigation at 75% of ETc during the vegetative[1] growth stage [a]	3188	3469
IW-5	Irrigation at 75% of ETc at during the flowering[2] stage [a]	3094	3305
IW-6	Irrigation at 75% of ETc during the fruiting[3] stage [a]	3000	3281
IW-7	Irrigation at 50% of ETc during the vegetative[1] growth stage [a]	2970	3181
IW-8	Irrigation at 50% of ETc during the flowering[2] stage [a]	2813	2953
IW-9	Irrigation at 50 % of ETc during the fruiting[3] stage [a]	2625	2906

[a] Vegetative growth stage starts from the beginning of transplanting till the beginning of flowering. Flowering stage stars from the beginning of flowering till the formation of first full-sized green fruit. Fruiting stage starts from formation of first full-sized green fruit till the termination of the experiment.
[b] For treatments (IW-4 to IW-9), the two other growth stages were irrigated at 100% of ETc.

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content, titratable acidity, and total sugar content were determined. The content of vitamin C was measured using the classical titration method with 2, 6-dichlorophenol indophenol solution and was expressed in milligrams of ascorbic acid per 100 g Fresh Weight (FW) (Association of Official Analytical Chemists, 2005). Total soluble solids were determined by a Portable digital Refractometer (PR-101; Palette Series, Atago Co., Ltd., Tokyo, Japan). Titratable acidity was determined by titration of the fruit homogenate (5.0 g) with 0.1M sodium hydroxide (NaOH) at pH 8.1, using citric acid as a control. Percentage of total sugars was determined using Association of Official Analytical Chemists (2005) standard procedures.

Statistical Analysis

All collected data were arranged and statistically analysed using the statistical analysis software (SAS GLM procedure version 9.2, SAS Institute Ltd., North Carolina, USA). The differences among the means were tested, using LSD test at 0.05 level according to Steel and Torrie (1980).

RESULTS AND DISCUSSION

Total Yield and Fruit Physical Characteristics

The comparisons among the mean values of fruit length, fruit diameter, fruit fresh weight, fruit dry weight and total yield reflected significant differences, but with different magnitudes, in both seasons. The highest significant mean values for fruit length, fruit diameter, fruit fresh weight and total yield were obtained using the Irrigation Water treatment (IW-1) at 100% ETc, during all growth stages, in both the seasons (Table 3), while the application of Irrigation Water treatment at 50% ETc (IW-3) during all growth stages gave the lowest mean values of fruit diameter, fruit fresh weight and total yield. These results agree with Sivakumar and Srividhya (2016) and Birhanu and Tilahun (2010) who reported that fruit weight was reduced as irrigation water volume reduced.

Concerning the trait of fruit dry weight, the significant highest mean value was recorded in the treatment (IW-3) at 50% ETc through all growth stages, in both seasons, while the significant lowest mean value of this trait was in the treatment (IW-1) at 100% ETc during all growth stages in both seasons. These results confirm previous findings of Kumar *et al*. (2015) for fruit dry matter; Sibomana *et al*. (2013) for fruit diameter; Shamim *et al*. (2014) for fruit fresh weight; Wahb-Allah *et al*. (2011) and Okunlola *et al*. (2015) for fruit weight, fruit length and fruit dry weight. It has been reported that water stress significantly reduced such traits.

The results reflected generally significant differences among genotypes regarding the mean values of fruit physical characters. The Genotype KSU-TOM-102 (G-1) produced the highest significant values of fruit length, fruit diameter, fruit fresh weight and total yield, in both seasons. Nevertheless, the Genotype KSU-TOM-107 (G-3) followed by KSU-TOM-106 (G-2) recorded the highest mean values of fruit dry weight, with no significant differences; but they differed significantly in comparison with the other genotypes. On the contrary, the Genotype KSU-TOM-107 (G-3) had the lowest mean values of fruit length, fruit diameter and fruit fresh weight, while, the Genotypes KSU-TOM-102 (G-1) and TL-01860 (G-4) obtained the lowest mean values for the fruit dry weight, in both growing seasons. These results confirmed the findings of Nahar and Ullah (2012) who observed that there were significant differences in fruit characteristics among tomato genotypes.

Fruit Nutritional Value

The highest values of fruit quality characteristics (ascorbic acid, titratable

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Table 3. Effects of genotypes and irrigation treatments on fruit physical characteristics and total yield of tomato genotypes during the two growing seasons of 2015 and 2016.

Treatments		Fruit length (cm)		Fruit diameter (cm)		Fruit fresh weight (g)		Fruit dry weight (%)		Total yield (T ha^{-1})	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Genotypes[a]	G-1	5.98 a	6.00 a	5.68 a	5.59 a	82.85 a	86.55 a	5.92 b	5.99 b	69.23 a	75.28 a
	G-2	4.74 b	4.52 b	5.33 b	5.50 a	70.12 c	72.99 c	6.19 a	6.26 a	49.48 c	53.42 c
	G-3	3.66 d	4.40 c	3.26 d	3.79 c	34.60 d	35.16 d	6.24 a	6.31 a	46.89 d	48.82 d
	G-4	4.56 c	4.63 b	4.41 c	4.33 b	80.77 b	84.34 b	5.97 b	6.03 b	50.09 b	53.83 b
Irrigation levels[b]	IW-1	4.96 a	5.44 a	5.08 a	5.01 ba	73.36 a	76.44 a	5.25 h	5.25 h	65.96 a	71.90 a
	IW-2	4.65 dc	4.81 dc	4.56 c	4.83 bc	67.32 d	70.01 d	6.63 b	6.73 b	45.84 f	48.69 f
	IW-3	4.46 d	4.54 e	4.18 d	4.49 d	60.50 h	62.74 h	7.57 a	7.75 a	38.42 g	40.51 g
	IW-4	4.89 ba	5.11 b	4.96 ba	5.07 a	69.18 c	71.99 c	5.38 g	5.66 f	57.26 b	61.29 b
	IW-5	4.70 bc	4.65 dc	4.57 c	4.48 d	68.94 c	71.74 c	5.88 e	5.93 e	55.53 c	59.35 c
	IW-6	4.75 bac	4.69 dce	4.75 bac	4.93 ba	71.92 b	74.91 b	6.03 d	6.09 d	65.75 a	71.80 a
	IW-7	4.81 bac	5.15 b	4.78 bac	4.88 bac	64.99 f	67.53 f	5.63 f	5.39 g	52.42 d	54.43 d
	IW-8	4.65 dc	4.76 dc	4.51 dc	4.71 c	61.72 g	64.05 g	5.10 d	6.08 d	48.62 e	51.59 e
	IW-9	4.74 bc	4.83 c	4.64 bc	4.81 bc	65.85 e	68.44 e	6.35 c	6.43 c	55.52 c	61.00 b

[a] G-1= KSU-TOM-102, G-2= KSU-TOM-106, G-3= KSU-TOM-107, and G-4= TL–01860. [b] IW-1= 100% ETc at all growth stages; IW-2= 75% ETc at all growth stages; IW-3= 50% ETc at all growth stages; IW-4= 75% ETc at vegetative stage; IW-5= 75% ETc at reproductive stage; IW-6= 75% ETc at fruiting stage; IW-7= 50% ETc at vegetative stage; IW-8= 50% ETc at reproductive stage; IW-9= 50% ETc at fruiting stage. (a-h) Means followed by the same letter in each season are not significantly different at 0.05 level.

Table 4. Effect of genotypes and irrigation treatments on fruit nutritional value of tomato genotypes during the two growing seasons of 2015 and 2016.

Treatments		Ascorbic acid (mg 100 g^{-1})		Titratable acidity (gm 100 ml^{-1} citric acid)		TSS (%)		Total sugars content (%)	
		2015	2016	2015	2016	2015	2016	2015	2016
Genotypes [a]	G-1	25.39 b	23.91 b	0.478 b	0.466 b	4.95 b	5.32 b	4.68 b	4.81 b
	G-2	22.81 d	21.37 d	0.456 d	0.445 d	4.29 d	4.66 d	4.13 d	4.25 d
	G-3	26.60 a	25.12 a	0.488 a	0.476 a	5.14 a	5.50 a	4.94 a	5.08 a
	G-4	24.25 c	22.82 c	0.466 c	0.455 c	4.56 c	4.93 c	4.36 c	4.48 c
Irrigation levels [b]	IW-1	21.97 h	20.57 h	0.319 i	0.311 i	3.51 h	3.87 h	3.34 i	3.43 i
	IW-2	26.53 b	25.13 b	0.590 c	0.575 c	5.51 c	5.87 c	5.33 c	5.47 c
	IW-3	29.01 a	27.10 a	0.598 a	0.583 a	6.11 a	6.48 a	5.84 a	6.01 a
	IW-4	22.27 g	20.87 g	0.327 h	0.379 g	3.67 g	4.04 g	3.55 h	3.65 h
	IW-5	23.74 e	22.34 e	0.395 f	0.385 f	3.94 f	4.31 f	3.78 f	3.89 f
	IW-6	24.93 c	23.53 c	0.580 d	0.566 d	5.150 d	5.52 d	4.97 d	5.11 d
	IW-7	23.34 f	21.94 f	0.389 g	0.318 h	3.88 f	4.24 f	3.73 g	3.83 g
	IW-8	24.42 d	23.02 d	0.458 e	0.446 e	5.06 e	5.42 e	4.86 e	4.99 e
	IW-9	26.65 b	25.25 b	0.595 b	0.579 b	5.79 b	6.16 b	5.36 b	5.51 b

[a] G-1= KSU-TOM-102, G-2= KSU-TOM-106, G-3= KSU-TOM-107, and G-4= TL–01860. [b] IW-1= 100% ETc at all growth stages; IW-2= 75% ETc at all growth stages; IW-3= 50% ETc at all growth stages; IW-4= 75% ETc at vegetative stage; IW-5= 75% ETc at reproductive stage; IW-6= 75% ETc at fruiting stage; IW-7= 50% ETc at vegetative stage; IW-8= 50% ETc at reproductive stage; IW-9= 50% ETc at fruiting stage. (a-i) Means followed by the same letter in each season are not significantly different at 0.05 level.

acidity, total soluble solids and total sugar contents) were affected by the irrigation treatment: The highest was recorded in 50% ETc during all growth stages (IW-3), followed by those of the treatments IW-2, and IW-6 at 75% ETc during all growth stages and fruiting stages, respectively, and IW-9 at 50% ETc during fruiting stage, in both seasons (Table 4). On the contrary, the significant lowest values of fruit quality characteristics were recorded in treatment receiving Irrigation Water at 100% ETc (IW-1). The correlation analysis (Figure 2) revealed that the values of these characteristics negatively correlated with increasing amount of irrigation water.

The Genotype KSU-TOM-107 (G-3) obtained the significantly highest concentrations of fruit chemical contents (ascorbic acid, titratable acidity, total soluble solids and total sugar contents), followed by the Genotype KSU-TOM-102 (G-1), in both growing seasons, while the lowest concentrations of these traits was recorded in genotype KSU-TOM-106. Significant differences in chemical compositions of tomato fruits are genotype-dependant (Dumas *et al*., 2003; Fullana-Pericàs *et al*., 2019; Vilas Boas *et al*., 2019). The chemical contents of tomato fruit mostly depend on genetic and environmental factors (Javanmardi and Kubota, 2006). Positive relationships of TSS, reducing sugars and organic acids content with soil water deficit during fruit enlargement and ripening were noticed. With water stress, the flux of the phloem sap supplied to the fruit decreased but the concentration of solute in sap increased (Ho, 1996), which resulted in a reduced water uptake from fruits and a low

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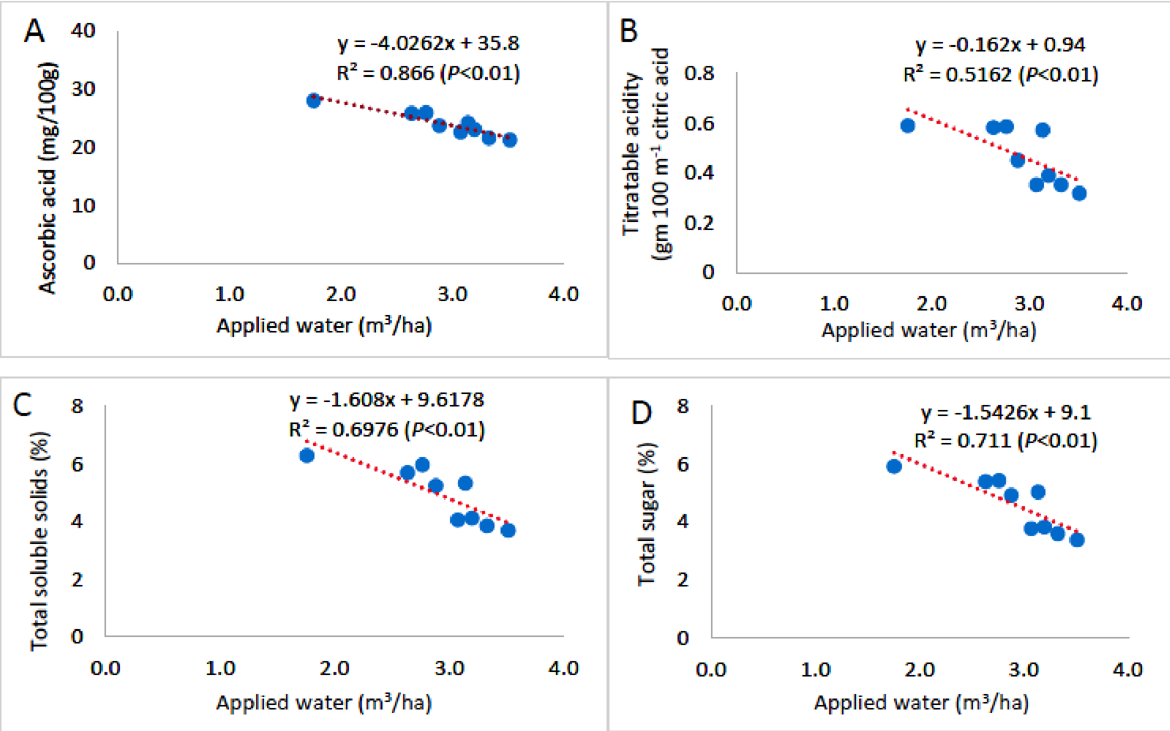

Figure 2. Relationships between ascorbic acid (A), titratable acidity (B), total soluble solids (C), total sugar contents (D) and applied water.

dilution in the fruits. This would lead to an increase in the concentration of dry matter, sugar, acid and various other compounds of the fruit. Previous studies showed that water stress could promote chemical contents such as vitamin C, soluble solids, titratable acidity and total sugars and further quality characteristics in fruit (Favati *et al*., 2009; Patanè and Cosentino, 2010; Patanè *et al*., 2011; Zegbe-Domınguez *et al*., 2003).

Interaction Effects among Irrigation Water Treatments and Tomato Genotypes

The comparisons among the mean values of the studied fruit characteristics i.e., fruit length, fruit diameter, fruit fresh weight, fruit dry weight and total yield, as affected by the different treatment combinations of irrigation and genotypes are listed in Table 5. These reflect, generally, significant differences, but with different magnitudes in the two seasons. The results showed that the highest fruit length was obtained in treatment combination of irrigation water treatment IW-6 and genotypes G-2, followed by the treatment combination IW-1 with the genotype G-1, while the lowest fruit length was observed in the interaction of treatment IW-3 with the genotype G-3, regardless of seasons. The result of the interaction showed that the highest fruit diameter was recorded in the treatment combination IW-1 with the genotype G-2, whereas the lowest fruit diameter was observed in the treatment combination IW-8 with genotype G-3 in both the seasons. The results of the first order interaction showed that the highest fruit fresh weight was in the treatment combination IW-1 with genotype G-1, followed by treatment IW-6 with the genotype (G-1) in both seasons. The lowest fruit fresh weight was observed in the treatment combination IW-3 with the genotype G-3 in both seasons. These results confirmed the findings of Shamim *et al*. (2014) and Kenneth *et al*. (2017), who concluded that the response to water stress was mainly dependent on the genotype and,

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Table 5. Interaction effects of genotypes and irrigation treatments on fruit physical characteristics of tomato genotypes during 2015 and 2016 seasons.

Irrigation levels [b]	Genotypes [a]	Fruit length (cm)		Fruit diameter (cm)		Fruit fresh weight (g)		Fruit dry weight (%)		Total yield (T ha^{-1})	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
IW-1	G-1	6.39 a	6.39 a	5.46d-g	5.46d-f	89.43 a	93.56 a	5.29pq	5.29pq	85.36 a	93.72 a
	G-2	5.57c-e	5.64cd	6.63 a	6.30 a	87.61 c	80.97 i	5.41op	5.43oq	59.65 h	64.86 f
	G-3	3.67lm	5.10fg	3.60m-o	3.97k-n	38.78 p	39.60 p	5.29pq	5.30pq	57.42 i	62.09 g
	G-4	4.23h-j	4.63hi	4.63h-k	4.33jk	77.61 i	91.62 c	5.02 r	5.00 r	61.40 g	66.91 e
IW-2	G-1	6.08ab	4.63hi	4.63h-k	5.91a-c	82.68 e	86.37 e	6.71 e	6.81 e	56.68 i	60.66 h
	G-2	4.17h-k	4.17k-n	4.61n-k	5.14e-h	80.27 g	73.05 m	6.61ef	6.59 f	43.99 pq	46.46 p
	G-3	3.77k-m	4.37i-m	3.10op	3.80l-o	36.15 q	36.81 q	6.49 f	6.80 e	40.17 s	42.54 r
	G-4	4.57gh	4.60h-j	4.60h-k	4.47ij	70.18 m	83.80 g	6.70 e	6.71ef	42.54 r	45.09 q
IW-3	G-1	5.53de	5.53de	4.43j-l	5.10f-h	75.90 j	79.15 j	6.68 e	7.26 c	52.04 kl	55.78 j
	G-2	4.31h-j	4.31i-m	4.90g-j	4.90gh	74.96 k	65.37 o	8.09 b	5.21 q	35.07 u	36.78 t
	G-3	2.40 n	3.80 o	2.77 p	3.53 o	28.17 v	28.30 v	8.40 a	8.64 a	29.82 v	30.55 u
	G-4	4.40h-j	4.50i-k	4.60h-k	4.43ij	62.97 o	78.14 k	7.11 c	8.32 b	36.77 t	38.93 s
IW-4	G-1	6.18ab	6.18ab	6.07a-d	6.07ab	85.32 d	89.19 d	5.41op	5.74lm	76.31 b	82.50 b
	G-2	5.13ef	5.13fg	5.54c-g	5.54c-e	83.38 e	76.14 l	5.50no	5.63mn	50.60 mn	53.68 k
	G-3	4.00j-m	4.90gh	3.87l-n	4.30jk	34.96 rs	35.54 rs	5.31pq	5.73lm	49.08 o	52.33 lm
	G-4	4.23h-j	4.23k-n	4.37j-l	4.37jk	73.08 l	87.11 e	5.31pq	6.06ij	53.05 jk	56.66 j
IW-5	G-1	5.51de	5.51de	6.16a-c	4.80hi	85.46 d	89.33 d	5.70lm	5.74lm	67.70 d	77.44 c
	G-2	4.07i-l	4.07m-o	5.17f-i	5.17e-h	82.79 e	75.75 l	6.11hi	6.07ij	49.73 no	53.95 k
	G-3	4.33h-j	4.10m-o	2.87 p	3.87l-o	34.81 s	35.38 s	6.01ij	5.85kl	53.28 j	52.09 m
	G-4	4.90fg	4.90gh	4.10k-m	4.10j-m	72.71 l	86.49 e	5.71lm	6.17hi	51.41 lm	53.89 k
IW-6	G-1	5.80b-d	5.90bc	5.88b-e	5.80b-d	88.53 b	92.61 b	5.81kl	6.28gh	85.58 a	93.62 a
	G-2	6.40 a	4.40i-m	4.40j-l	5.73b-d	84.77 d	78.18 k	5.80kl	6.40 g	57.61 i	64.76 f
	G-3	3.60 m	3.97no	4.23j-m	3.80l-o	39.39 p	40.26 p	6.31 g	5.42op	57.06 i	61.99 g
	G-4	4.40h-j	4.50i-k	4.50i-l	4.40ij	74.99 k	88.59 d	6.20gh	5.84kl	62.74 f	66.81 e
IW-7	G-1	5.98a-c	5.98 b	6.27ab	6.27 a	81.22 f	84.82 f	5.22 q	5.31pq	66.47 e	69.68 d
	G-2	4.27h-j	4.27ef	5.43d-g	5.43d-f	79.49gh	71.16 n	6.00ij	5.31pq	48.93 o	50.07 o
	G-3	3.73k-m	5.10fg	3.27n-p	3.67no	30.84 u	31.15 u	5.60mn	6.38 g	45.10 p	47.15 p
	G-4	5.27ef	5.27ef	4.17k-m	4.17j-l	68.40 n	82.97 gh	5.71lm	5.52no	49.16 o	50.83 no
IW-8	G-1	5.98a-c	5.98 b	5.27e-h	5.27b-d	75.93 j	79.18 j	6.21gh	5.95jk	61.16 g	67.11 e
	G-2	4.47g-i	4.47i-l	5.77b-f	5.77b-d	74.96 k	65.77 o	6.08hi	5.84kl	48.92 o	53.38 kl
	G-3	3.67lm	4.13l-o	2.67 p	3.47 o	32.66 t	33.09 t	5.80kl	6.37 g	41.23 s	38.87 s
	G-4	4.47g-i	4.47i-l	4.33j-l	4.33jk	63.34 o	78.14 k	5.90jk	6.15hi	43.18 qr	46.99 p
IW-9	G-1	6.18ab	6.16ab	5.71b-f	5.71b-d	81.19 f	84.78 f	6.28 g	6.16hi	71.80 c	77.04 c
	G-2	4.23gh	4.23k-n	5.50c-g	5.50c-f	78.76 h	70.51 n	6.11hi	7.03 d	50.84 mn	56.80 j
	G-3	3.73h-j	4.10m-o	3.00op	3.73m-o	35.66 n	36.28qr	6.90 d	5.00 r	48.86 o	51.78 mn
	G-4	4.60k-m	4.60h-j	4.37j-l	4.37jk	67.79 qr	82.19 h	6.10hi	6.17hi	50.59 mn	58.38 i

[a] G-1= KSU-TOM-102, G-2= KSU-TOM-106, G-3= KSU-TOM-107, and G-4= TL–01860. [b] IW-1= 100% ETc at all growth stages; IW-2= 75% ETc at all growth stages; IW-3= 50% ETc at all growth stages; IW-4= 75% ETc at vegetative stage; IW-5= 75% ETc at reproductive stage; IW-6= 75% ETc at fruiting stage; IW-7= 50% ETc at vegetative stage; IW-8= 50% ETc at reproductive stage; IW-9= 50% ETc at fruiting stage. (a-v) Means followed by the same letter in each season are not significantly different at 0.05 level.

reduction in moisture significantly reduced the fruit weight. The comparison among the mean values of fruit dry weight, as affected by the interaction between irrigation water treatments and tomato genotypes, are presented in Table 4, during the two seasons. In both seasons, the highest fruit dry weight was observed in the treatment combination IW-3 with the genotype G-3, while the lowest was obtained in the treatment combination IW-1 with the genotype G-4.

In both seasons, tomato total yields were highest for genotype (G-1) under irrigation treatments at 100% of ETc during all growth

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Table 6. Interaction effects of genotypes and irrigation treatments on fruit nutritional value of tomato genotypes during 2015 and 2016 seasons.

Irrigation levels [b]	Genotypes [a]	Ascorbic acid (mg 100 g^{-1})		Titratable acidity (gm 100 ml^{-1} citric acid)		TSS (%)		Total sugars content (%)	
		2015	2016	2015	2016	2015	2016	2015	2016
IW-1	G-1	22.49 k	21.09 j	0.324 r	0.316 r	3.61 p	3.98 q	3.45 s	3.54 t
	G-2	19.47 o	18.07 m	0.305 t	0.297 t	3.11 r	3.48 s	2.95 w	3.03 y
	G-3	23.71 j	22.31 i	0.335 q	0.327 q	3.90no	4.27op	3.74 q	3.85 r
	G-4	22.22kl	20.82 j	0.313 s	0.305 s	3.40 q	3.78 r	3.22 u	3.31 w
IW-2	G-1	26.76 d	25.36 c	0.595 c	0.580 c	5.71de	6.07de	5.55 e	5.70ef
	G-2	25.51gh	24.11 g	0.574 e	0.559 e	5.11 i	5.48 i	4.97 j	5.11 k
	G-3	28.46 c	27.06 b	0.604 b	0.589 b	5.79 d	6.16 d	5.56 e	5.71 e
	G-4	25.40gh	24.00 g	0.586 d	0.572 d	5.43gh	5.79gh	5.22 h	5.37 i
IW-3	G-1	30.31 a	28.20 a	0.604 b	0.588 b	6.25 b	6.62 b	5.96 b	6.12 b
	G-2	26.50de	24.73d-f	0.583 d	0.568 d	5.73de	6.10de	5.48 f	5.63fg
	G-3	30.49 a	28.39 a	0.614 a	0.599 a	6.39 b	6.76 b	6.23 a	6.40 a
	G-4	28.75 c	27.08 b	0.593 c	0.578 c	6.09 c	6.45 c	5.70 d	5.86 d
IW-4	G-1	23.26 j	21.86 i	0.335 q	0.384 m	3.79 o	4.16 p	3.75 q	3.85 r
	G-2	20.18 n	18.78 l	0.304 t	0.364 o	3.23 r	3.60 s	3.11 v	3.20 x
	G-3	23.71 j	22.31 i	0.343 p	0.393 l	4.15 m	4.51 l	3.92 p	4.02 q
	G-4	21.94lm	20.54jk	0.325 r	0.374 n	3.51pq	3.88 qr	3.43 s	3.52tu
IW-5	G-1	24.51 i	23.11 h	0.398 m	0.388 k	4.09 m	4.45mn	3.91 p	4.02 q
	G-2	22.47kl	21.07 j	0.383 n	0.373 n	3.49pq	3.86qr	3.36 t	3.48uv
	G-3	25.51gh	24.11 g	0.414 k	0.403 k	4.38 l	4.75 l	4.22 o	4.34 p
	G-4	22.46kl	21.06 j	0.387 n	0.377 n	3.81 o	4.17 p	3.63 r	3.73 s
IW-6	G-1	26.40de	25.00c-e	0.587 d	0.572 d	5.33 h	5.70 h	5.12 i	5.26 j
	G-2	22.47kl	21.07 j	0.564 f	0.549 f	4.63 k	5.00 k	4.55 m	4.68 n
	G-3	26.40de	25.00c-e	0.596 c	0.581 c	5.63ef	6.00ef	5.39 g	5.54 h
	G-4	24.47i	23.07 h	0.576 e	0.561 e	5.01ij	5.37ij	4.81 k	4.95 l
IW-7	G-1	23.60 j	22.20 i	0.394 m	0.326 q	4.00mn	4.37no	3.88 p	3.99 q
	G-2	21.60 m	20.20 k	0.374 o	0.297 t	3.49pq	3.86qr	3.35 t	3.45 v
	G-3	25.72fg	24.32fg	0.403 l	0.334 p	4.43 l	4.80 l	4.23 o	4.35 p
	G-4	22.44kl	21.04 j	0.384 n	0.316 r	3.60 p	3.96 q	3.46 s	3.55 t
IW-8	G-1	24.52 i	23.12 h	0.465 h	0.453 h	5.10 i	5.47 i	5.02 j	5.16 k
	G-2	21.64 m	20.24 k	0.436 j	0.425 j	4.71 k	5.07 k	4.45 n	4.57 o
	G-3	26.08 ef	24.68ef	0.482 g	0.469 g	5.49fg	5.86fg	5.28 h	5.43 i
	G-4	25.42 gh	24.02 g	0.447 i	0.436 i	4.92 j	5.29 j	4.67 l	4.80 m
IW-9	G-1	26.67 d	25.27cd	0.603 b	0.588 b	6.69 a	7.05 a	5.48 f	5.63 g
	G-2	25.43 gh	24.03 g	0.584 d	0.568 d	5.11 i	5.48 i	4.97 j	5.11 k
	G-3	29.32 b	27.92 a	0.604 b	0.588 b	6.08 c	6.45 c	5.88 c	6.04 c
	G-4	25.18 h	23.78 g	0.587 d	0.572 d	5.29 h	5.66 h	5.12 i	5.26 j

[a] G-1= KSU-TOM-102, G-2= KSU-TOM-106, G-3= KSU-TOM-107, and G-4= TL–01860. [b] IW-1= 100% ETc at all growth stages; IW-2= 75% ETc at all growth stages; IW-3= 50% ETc at all growth stages; IW-4= 75% ETc at vegetative stage; IW-5= 75% ETc at reproductive stage; IW-6= 75% ETc at fruiting stage; IW-7= 50% ETc at vegetative stage; IW-8= 50% ETc at reproductive stage; IW-9= 50% ETc at fruiting stage. (a-y) Means followed by the same letter in each season are not significantly different at 0.05 level.

stages (IT-1) and at 75% of ETc at fruiting stage (IT-6), followed by the combination between the same genotype (G-1) and irrigation treatment at 75% of ETc at the vegetative stage (IT-4). The lowest values (reduction up to 50% in total yield) were observed in genotype G-3 irrigated at 50% of ETc during all growth stages (IT-3). Under water deficit, some tomato genotypes

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had up to 80% reduction in fruit yield (Sivakumar, 2014).

The interaction effects among irrigation water treatments and tomato genotypes, during the two seasons, are presented in Table 6. The results revealed that the interaction between the treatment IW-3 with the genotypes G-1 or G-3 resulted in the significantly highest values of ascorbic acid and titratable acidity contents in both seasons. The results showed also that the significant highest values of the total soluble solids content was obtained in treatment combination involving irrigation treatment IW-9 with the genotype G-1, followed by treatment IW-3 with either genotypes G-1 or G-3, in both seasons. In this respect, this result suggests generally that water shortage led to a reduction in water content of the fruit and, hence, increased the soluble solids content in the fruit (Zhang *et al*., 2017). The highest values of the total sugars content were obtained in the combined irrigation water treatment IW-3 with the genotype G-3, in the two growing seasons. The quality parameters like TSS, ascorbic acid, acidity and sugar contents were improved considerably with deficit irrigation. It has earlier been reported that the depletion in soil moisture could reduce the transport of water may be reduced but not the photo-assimilates (Zegbe *et al*., 2006).

CONCLUSIONS

It is concluded that both irrigation treatments and genotypes showed significant effects on total yield and fruit nutritional value. Among different genotypes, KSU-TOM-102 recorded the highest total yield while KSU-TOM-107 recorded the highest nutritional value. Under different irrigation treatments, 75% ETc at fruiting stage did not decrease the total yield of KSU-TOM-102, while 75% ETc at vegetative stage recorded 12% loss in total yield of this genotype. ETc (50%) at all growth stages significantly ($P \leq 0.05$) increased nutritional value for tomato ‘KSU-TOM-107’ followed by ‘KSU-TOM-102’, but losses up to 50% in total yield were recorded. Therefore, 75% ETc at fruiting stage or vegetative stage could be applied for tomato ‘KSU-TOM-102’ production under open field conditions, while maintaining good nutritional value as compared with 100% ETc.

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اثر کم آبیاری بر عملکرد کل، ویژگی های فیزیکی میوه، و ارزش غذایی چهار ژنوتیپ مقاوم به خشکی گوجه فرنگی(*Solanum lycopersicum* L.)

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چکیده

کم آبیاری یک عامل محدود کننده عمده در بهره وری آب در گیاه، و کمیت و کیفیت میوه در جهان و به ویژه در مناطق خشک و نیمه خشک است. در این پژوهش، عملکرد کل، ویژگی های فیزیکی، و ارزش غذایی چهار ژنو تیپ گوجه فرنگی مقاوم به خشکی (شامل KSU-TOM-102, KSU-TOM-106, KSU-TOM-107 , TL–01860) در واکنش به کم آبیاری(DI) در

شرایط مزرعه بررسی شد. به این منظور، سه تیمار تبخیر و تعرق گیاهی (۵۰٪، ۷۵٪، و ۱۰۰ ٪ ET_c) در سه مرحله رشد (سبزینه، گلدهی، و میوه دهی) روی چهار ژنوتیپ گوجه فرنگی اعمال شد. این ژنوتیپ ها واکنش های متفاوتی به کم آبیاری نشان دادند. در میان آنها، ژنوتیپ KSU-TOM-102 در تیمار ۱۰۰٪ ET_c در همه مراحل رشد و۷۵٪ ET_c درمرحله میوه دهی، بیشترین میانگین عملکرد کل (۸۹/۵۴ تن در هکتار) را تولید کرد. اما به طور کلی، عملکرد کل در شرایط کم آبیاری کاهش داشت. نیز، ویژگی های کیفیتی میوه به طور معناداری ($P<0.05$) تحت تاثیر تیمارهای آبیاری، نوع ژنوتیپ گوجه فرنگی، و برهمکنش آنها قرار گرفت. آبیاری با تیمار ۵۰٪ ET_c در همه مراحل رشد به طور معناداری ($P<0.05$) به افزایش ویتامین C ، اسیدیته قابل تیتر، کل جامدات محلول، و محتوای کل قند در ژنوتیپ KSU-TOM-107 و بعد از آن KSU-TOM-102 منجر شد. اما، این افزایش در ارزش غذایی با کاهش عملکرد کل به میزان ۵۰–۴۰ ٪ همراه بود. ژنوتیپ KSU-TOM-102 با تیمار۷۵٪ ET_c در مرحله میوه دهی یا سبزینه، کاهشی در حد، به ترتیب ۰ ٪ و ۱۲٪ داشت در حالیکه از نظر ارزش غذایی در مقایسه با ۱۰۰ ٪ ET_c در همه مراحل رشد، در حد خوب بود. بنا بر این، این تیمارها را می توان به عنوان تیمار مدیریت آبیاری برای تولید ژنوتیپ KSU-TOM-102 در شرایط مزرعه توصیه کرد.

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