Response of Watermelon Plants Grafted onto different Rootstocks to Deficit Irrigation

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Abstract: The present study was conducted to examine the response of grafted watermelon (cv. Aswan) plants to deficit irrigation by using different cucurbit rootstocks viz. Giada, Shintoza, Strong toza, Ferro and Pumpkin, compared with un-grafted plants. Water treatments were applied in a field experiment under 100%, 70% and 50% of Evapotranspiration (ET). Results indicated decrease in vegetative growth (number of leaves and branches, length of the main stem), leaf relative water content, reproductive growth and fruit yield, under water stress, as compared to the control (100% ET). Results also showed reduced N, P and K contents in the leaves under water stress condition. However, proline content and antioxidant enzymes: superoxide dismutase (SOD) and catalase (CAT) were higher in water stressed plants than those receiving 100% water. Under severe water stress, all graft combinations had generally better growth and yield performance than un-grafted plants. The grafted plants of Aswan/Ferro significantly recorded the lowest decline in number of fruits/plant, total yield and flesh SSC under 50% ET irrigation treatment, as well as the lowest decline in N and P content. It is concluded that grafting watermelon plants onto specific rootstock had the potential to increase water stress tolerance. This was associated with increase in proline, and the activities of SOD and CAT in their leaves.

Keywords: *Citrullus lanatus*, grafting, growth, yield, water stress, antioxidant enzymes.

INTRODUCTION

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. and Nakai) is one of the most economically important vegetable crops in Egypt and is widely cultivated worldwide. World total production was 100.42 million tons, approximately 3.08 million hectares were planted yearly all over the world, with an average of 32.58 tons/ha (FAOSTAT, 2019). Egypt is ranked the ninth in watermelon production in the world, with total production of 1.58 million tons from around 0.049 million hectares with, an average of 32.55 tons/ha (FAOSTAT, 2019). Watermelon is a warm, dry climate crop with maximum and minimum temperatures for growth are about 35 and 18°C respectively. The optimum soil temperature for root growth is in the range of 20 to 35°C. Under these conditions, water requirement of watermelon crop is high, between 400-600 mm (Doorenbos and Kassam, 1979), therefore, deficit irrigation could largely affect its field performance

Drought is multidimensional in nature and affect plants at various levels. Under persisted drought, many plants will dehydrate and die (Lisar *et al*., 2012). Water stress adversely impacts many aspects of the physiology of plants, especially photosynthetic capacity, and if the stress is prolonged, plant growth and productivity are severely diminished. Plants have evolved complex physiological and biochemical adaptations to adjust and adapt to a variety of environmental stresses including water stress (Osakabe *et al*., 2014). Limited leaf growth and increased stomatal resistance to gas exchanges are associated with a decrease of water and mineral nutrients flow from roots, which affects net assimilation, thereby decreasing the production and allocation of carbohydrates to plant parts, including the fruits (Atkinson *et al*., 1999; Shaw *et al*., 2002).

In watermelon, the yield and its components, the sensitive periods to soil water deficits and yield response factors were determined under the condition of which 0, 25, 50, 75 and 100% of water requirement were supplied (Erdem *et al*., 2003). Flowering was the most sensitive period to water deficits and the yield response factors which relate relative yield decrease to relative evapotranspiration deficit were found to be 1.27 for the whole growing season and 0.68, 0.63, 0.50, 0.47, 0.29 for flowering, fruit growth, late vegetative, total vegetative, early vegetative periods, respectively. In a recent report, watermelon subjected to deficit irrigation had resulted in significant decreases in several growth and yield attributes (Pereira *et al.*, 2020).

Reduce losses in production under water deficiency would be to graft onto rootstocks capable of reducing the harmful effect of water stress in the scion shoot. Rouphael *et al*. (2008) studied the drought stress effect on grafted mini-watermelon plants under open field conditions. The irrigation treatments were 1.0, 0.75, and 0.5 evapotranspiration rates. They found that total yield, marketable yield, mean fruit mass, fruit number of watermelons were significantly influenced by irrigation rate and grafting combination. The total and marketable yields were higher by 115% and 61% in grafted than in non-grafted plants, respectively.

Drought stress also has effects on fruit quality of grafted mini-watermelon plants. The total soluble solid was significantly affected by grafting combination and irrigation rate.Titratable acidity (%) was higher in grafted than in non-grafted plants (Rouphael *et al*., 2008). In contrast, no significant differences among treatments were observed for shape index, fruit dry matter %, and TSS contents. Moreover, Proietti *et al*. (2008) demonstrated that fruit quality in mini-watermelon grafted onto a squash hybrid rootstock and grown under different irrigation regimes was slightly affected by drought, with an increase in K and Mg concentrations in fruit, especially with 0.5 ET. Lycopene, and total vitamin C contents in grafted plants were higher by 40.5% and 7.3%, respectively than those from non-grafted plants.

Özmen *et al*. (2015) determined the effects of deficit irrigation on nitrogen consumption, yield, and quality in grafted and non-grafted watermelon and found that nitrogen consumption was 16% lower in grafted plants than in non-grafted plants. On the other hand, consumption of nitrogen was higher in low irrigation plants than in moderate full irrigation plants by 28% and 23%, respectively. By grafting, the average amount of nitrogen content in seeds, pulps and peels for grafted plants were 30, 43 and 56% more than those of non-grafted plants, respectively.

Under abiotic stress, increase production of reactive oxygen species (ROS), which causes damage to different plant parts, is well documented (Parida and Das, 2005). Stimulation of antioxidant capacity through the synthesis of ROS scavenging is a possible strategy to reduce the effects of oxidative stress via increasing antioxidant enzyme activities. Increase in the activities of superoxide dismutase (SOD), catalase (CAT), and malondialdehyde (MDA) were recorded in grafted and non-grafted tomato plants under water stress (Sánchez-Rodríguez *et al*., 2012). Also, Penella *et al*. (2014) reported an increase in the accumulation of proline in pepper seedlings by drought, and the maximum increase was found in grafted plants.

The use of grafted watermelon may reduce the negative effect of abiotic stresses. However, the rootstock genotypes which would be able to enhance tolerance to deficit water stress are not well documented. Physiological and biochemical parameters associated with water stress need to be examined to determine the mechanism of tolerance of grafted plants. The objective of the present study was to examine the degree of tolerance of grafted watermelon to deficit irrigation by using different rootstocks compared with un-grafted plants in a field experiment under sufficient irrigation (100% ET), and deficit irrigation of 70% and 50% ET. Accordingly, vegetative growth, water use efficiency, marketable yield and fruit quality characteristics, proline content and antioxidant enzyme activities were investigated.

MATERIALS AND METHODS:

Plant materials and grafting technique:

Commercial watermelon hybrid ‘Aswan F_1’ (Sakata, Japan) was used as scion and grafted onto several hybrid rootstocks ‘Giada F_1’, ‘Shintoza F_1’ ‘Strong tosa F_1’, and ‘Ferro F_1’ (*Cucurbita maxima* x *Cucurbita moschata*), released by Nunhems Zaden (The Netherlands), G.S.I Seeds (The Netherlands), Syengenta Seeds (The Netherlands) and Rijk-Zwaan, respectively. The last rootstock ‘Pumpkin’ is a local variety.The method of grafting was splice graft method (one cotyledon graft), as described by Hassell *et al.* (2008).

The experiment was conducted during the summer season 2015 at the Experimental Farm of the Faculty of Agriculture, Suez Canal University, Ismailia, Egypt (30° 58′ N latitude, 32° 23′ E longitude 13 m above sea level. The soil was loamy sand with a textural analysis of (Clay 10%, Silt 5% and Sand 85%).Chemical properties of the soil in the experimental farm was EC (dSm^{-1})=1.23, pH =7.37, Ca^{2+}= 8.40 $meql^{-1}$, Mg^{2+}=1.83 $meql^{-1}$, Na^{+}= 1.46 $meql^{-1}$, K^{+}= 1.2 $meql^{-1}$,Cl^{-} = 2.19 $meql^{-1}$, HCO_3^{-} =3.11 $meql^{-1}$, SO_4^{2-} = 7.02 $meql^{-1}$, CO_3^{2-} = 0.36 $meql^{-1}$. The cultivation was carried out using a drip irrigation system, with 4 L/h dripper's flow rate. Irrigation tubes were allocated 2 m between each row. The grafted and un-grafted plants were planted in the soil 1 m between plants. The experiment was arranged in split plot design with 3 replicates, each consisting of 6 plants. Main plots were allocated to the three water treatments, while sub-plots were the six combinations of scion/rootstocks resulting in 18 treatments. The grafted seedlings and control (un-grafted) were cultivated in the soil from March 18 to June 26. Fertigation regime took place two weeks after planting and terminated two weeks before fruit harvesting. Total amounts per feddan (4200 m^2) of N, P, K, Ca and Mg were 52.8, 13.7, 66, 9.5, and 4.4 kg, respectively. Sources of fertilizers were ammonium nitrate (33.5 % N), phosphoric acid (70%), potassium sulfate (48 % K_2O), calcium nitrate (15.5%) and magnesium sulfate (18.3%).

Three irrigation levels were examined: 100 % full irrigation, 70 % of full irrigation and 50 % of full irrigation. The treatments were applied daily from 1 April to 12 June, and were scheduled weekly. The weekly ETc was calculated from the equation ETc = ETo x Kc (crop coefficient), The ETo was estimated by the FAO Penman–Monteith method (Allen *et al*., 1998). The crop coefficients (Kc) were used according to Doorenbos and Kassam (1979). The ETc for the three irrigation treatments were 486.2, 340.34 and 243.1 mm. Monthly averages of the air temperature, humidity and evaporation during the experiment are presented in Table (1).

Table (1): Monthly averages of air temperature, humidity, wind speed and evaporation (ET_o) during the experiment

Months	Temperature		Humidity	Wind speed (km/h)	ET_o
	Maximum	Minimum	(%)		(mm)
March	24	15	59.5	7	3.41
April	26	16	53.0	12	4.96
May	31	19	53.5	8	6.00
June	33	22	47.5	9	6.83

Source: Central laboratory for Agricultural climate, Ismailia station, Egypt.

Parameters measured

Vegetative growth traits and relative water contents

Vegetative growth was measured 8 weeks after planting, by counting leaves number, branches number and main stem length of four plants chosen randomly from each plot. Leaves dry matter percentage (DM %) was measured by weighting 20 leaves (five leaves x four plants) and then dried in an oven at 70°C for three days to determine dry weight (DW). leaves dry matter (DM %) was calculated using the following formula: leaf dry weight (g)/leaf fresh weight (g) x 100. Leaf relative water content (LRWC) was measured by taking the fourth leaf from the top of three plants per treatment and weighted as fresh weight (FW). The leaves were then rinsed in deionized water and blotted carefully with tissue paper, then weighted as fresh at full turgor (TW). Leaves were then put into a forced air oven at 70°C for three days to determine (DW). According to Yamasaki and Dillenburg (1999), the LRWC was calculated using the following formula: LRWC= (FW – DW) / (TW – DW) x 100.

Flowering, fruit yield and quality traits

Numbers of male and female flowers per plant during the flowering period were recorded. Fruits were harvested during July, 2015, and the total number of fruits per plant, total yield of fruits (Kg/plant) and average fruit weight (Kg/fruit) were recorded after excluding un-marketable fruits. Water use efficiency (WUE) was calculated as the marketable fruit yield per unit area divided by the amount of irrigation water added to this area, according to Howell *et al.* (1990). Soluble solid contents (SSC) of the fruits was obtained using juice of fruit from the central endocarp with the use of a hand refractometer according to A.O.A.C. (1996). For determination of carotenoids, five grams of the juice were extracted repeatedly with acetone in a blender until the residue was colorless, according to Ranganna (1977), an aliquot was measured in a one cm cell at 503 nm in Spectrophotometer (model, Unico UV/Vis 2100.USA) using petroleum ether as blank. The following equation was used: mg of lycopene/100 g FW= (3.1206 x optical density (OD) of sample x volume made up x dilution x 100) / (1 x wt. of samples x 1000).

Macro-nutrient determination

Fifteen leaves were taken from 3 plants for all treatments. The leaves were dried at 70˚C for 48 hours and grounded. Half gram of sample was digested by sulfuric acid and hydrogen peroxide according to Jackson (1967). After proper dilution of digested material, nitrogen was determined using modified Kheldahl method according to Jackson (1967). Phosphorus was determined using Spectrophotometer according to Black *et al.* (1965). Potassium was determined by using flame photometer according to Jackson (1967).

Proline content and antioxidant enzyme activities

Proline was estimated using the method described by Sadasivam and Manickam (1992), where the fourth leaf from the top of three plants per treatment was taken. The toluene layer was separated and the red color intensity was measured at 520 nm. A series of standards with pure proline were run in a similar way to prepare standard curves.

Superoxide dismutase (SOD) level was determined by using bio-diagnostic kit No.SD2521 and the spectrophotometer (U/V Spectrophotometer spectronic 1201, Milton Roy, U.S.A) based on the method of Nishikimi *et al.* (1972). Color of the reduced dye was measured at 560 nm for 5 minute for control. Catalase (CAT) activity was measured using bio-diagnostic kit No. 2517 and the spectrophotometric method described by Aebi (1984). The absorbance was measured at 510 nm.

Statistical analysis:

Statistical analysis was performed with the aid of the SPSS 14 for Windows statistical package (IBM Corp., New York, USA). Data were evaluated by analysis of variance for the main and interaction effects. The means of values were compared by Duncan Multiple Range Test (DMRT) at p=0.05, according to Snedecor and Cochran (1989).

RESULTS

Vegetative growth and LRWC

Results in Table (2) showed significant differences among the genotypes of the rootstockson leaves number, length of main stem and leaf dry mass.

The grafted plant, especially Aswan/Ferro had the highest values of leaves number and length of main stem, compared to un-grafted plants. However, rootstocks had no significant effect on number of branches. The accumulation of dry matter (DM%) was significantly higher in the graft combination Aswan/Ferro, Aswan/Giada and Aswan/Shintoza. The results also showed significant influence of the graft combinations on leaf relative water content (LRWC), and the un-grafted plants (Aswan control) showed the lowest LRWC as compared to grafted plants (Table 2).

Deficit irrigation (50% ET) resulted in significant decline in number of leaves (28%), length of the main stem (18%), number of lateral branches (21%) and LRWC (6.7), while DM% was not affected. In addition, the interaction (I x G) did not significantly affect most vegetative growth parameters, except leaf dry mass (Table 2).

Table (2): Effect of deficient irrigation rates and grafting combinations on vegetative growth and LRWC of watermelon plants

Treatments	Leaves number	Lateral stem number	Length of main stem (m)	Leaves DM (%)	LRWC (%)
Graft combinations:					
Aswan/Giada	122.66 a	15.11 a	2.46 a	44.33 a	91.56 a
Aswan/Shintoza	126.66 a	14.88 a	2.43 a	41.89 a	91.72 a
Aswan/Strong Toza	115.88 ab	13.88 a	2.16 bc	40.78 ab	87.20 ab
Aswan/Ferro	127.00 a	14.77 a	2.32 ab	40.00 ab	89.41 ab
Aswan/Pumpkin	108.44 b	12.55 a	2.11 c	36.78 b	87.41 ab
Aswan Control	074.33 c	12.44 a	1.85 d	26.89 c	82.87 b
Irrigation:					
100%	123.93 a	15.11 a	2.45 a	39.78 a	91.11 a
70%	124.50 a	14.83 a	2.22 b	38.44 a	89.06 ab
50%	089.05 b	11.88 b	2.00 c	37.11 a	84.92 b
Significance:					
Graft combination (G)	***	ns	***	***	*
Irrigation (I)	***	**	***	ns	*
I*G	ns	ns	ns	*	Ns

Values followed by the same letters within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test

Reproductive development, fruit yield and WUE

Results (Table 3) showed that the genotype of the rootstock significantly affected number of male and female flowers in grafted watermelon plants, and the grafted plant had the highest male (Aswan/Shintoza) and female (Aswan/Ferro) flowers as compared to un-grafted plants. Irrigation treatments did not significantly affect number of female flowers. However, number of male flowers was significantly the least at 50% ET.

The results also showed significant differences among the graft combinations on fruit number. In this respect, grafted plants of Aswan/Giada produced the highest number of fruits compared to the other combinations. The rootstock genotype significantly affected average fruit weight and marketable fruit yield, and the highest values were recorded in grafted plants compared to un-grafted ones, over all irrigation treatments (Table 3). Plants of Aswan/Giada significantly produced the highest fruit number and total yield, while Aswan/Ferro plants had the highest mean fruit weight. All graft combinations, except Aswan/Pumbkin, had significantly higher WUE than un-grafted plants. Specifically, plants of Aswan/Giada, followed by Aswan/Ferro had the highest WUE (about 10 times) over un-grafted plants.

Irrigation treatments had significant influence on mean fruit weight and total marketable fruit yield, but not fruit number per plant (Table 3). Increasing water stress, up to 50%, had resulted in 14.3 and 24% reduction on fruit weight and yield, respectively. On the other hand, WUE was the highest (16.75 kg/m^3) at the highest water deficit level. Results of ANOVA indicated no significant interaction (I x G) effects on watermelon fruiting characteristics, or the value of WUE (Table 3).

Fruit SSC and lycopene contents

Results showed significant effect of the graft combinations on fruit flesh SSC, where Aswan/Giada recorded the highest SSC%, with an average of 11.06%, followed by Aswan/Shintoza with an average of 10.66% (Fig. 1A). Un-grafted watermelon plants were found to be the lowest in SSC, with an average of 8.55%. Deficit irrigation treatments and the interaction (I x G) significantly affected SSC%. At the highest water deficiency (50% ET), SSC slightly decreased by 7% compared to the control.

Deficit irrigation rates, rootstock genotype and the interaction effects showed different responses on lycopene content of watermelon fruit. Results also indicated gradual decreases in lycopene content with the increase in water deficiency. The grafted plants had the highest values of lycopene as compared to un-grafted plants. The highest lycopene content was found in watermelon grafted on Giada rootstock, as shown in Fig. (1B).

Table (3): Effect of deficient irrigation rates and grafting combinations on flowering traits, fruit number, average fruit weight, marketable yield and WUE of watermelon

Treatments	Flowers no.		Fruit (no./plant)	Fruit weight (kg/fruit)	yield (ton/fed.)	WUE
	Male	Female				(Kg/m^3
Graft combinations:						
Aswan/Giada	42.77 ab	18.88 a	2.88 a	6.16 ab	35.55 a	24.96 a
Aswan/Shintoza	44.00 a	16.33 b	1.88 b	6.03 bc	22.26 b	15.32 c
Aswan/Strong toza	40.88 b	16.22 b	2.11 b	5.59 c	23.08 b	16.19 bc
Aswan/Ferro	41.44 b	19.44 a	2.22 b	6.52 a	28.23 b	20.18 b
Aswan/Pumpkin	36.11 c	15.55 b	1.11 c	4.42 d	09.70 c	6.72 d
Aswan Control	33.55 d	10.33 c	1.00 c	2.14 e	04.28 c	2.86 d
Irrigation:						
100%	42.22 a	16.16 a	1.88 a	5.66 a	22.51 a	11.02 b
70%	39.33 b	16.05 a	2.05 a	4.95 b	21.93 a	15.34 a
50%	37.83 c	16.16 a	1.66 a	4.82 b	17.10 b	16.75 a
Significance:						
Graft combination (G)	***	***	***	***	***	***
Irrigation (I)	***	ns	ns	***	*	**
I*G	*	ns	ns	ns	ns	Ns

Values followed by the same letters within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test

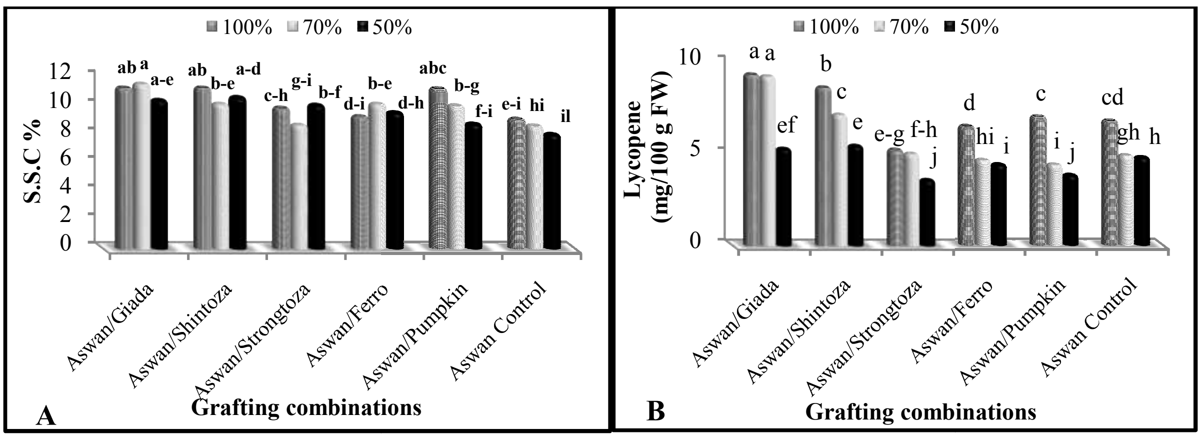

Figure (1): Effect of the interaction between irrigation rates and graft combinations on S.S.C (A) and lycopene (B) contents of watermelon fruits

Macronutrient contents

Major macronutrient contents in watermelon were significantly affected by the graft combinations (Table 4). Generally, leaves of all the grafted plants had more N, P and K than un-grafted plants. The highest N was recorded in Aswan/Giada and Aswan/Shintoza, while leaves of Aswan/Giada followed by Aswan/Ferro had the highest P and K. Moderate (70% ET) and high (50% ET) water stress had resulted in 25 and 37.2% reduction in N, 5.3 and 16.7% reduction in P, 25.2 and 48.7% reduction in K, respectively, compared to the control. These results (Table 4) indicated gradual decline in N, P, and K with the increase in water deficiency. The interaction (I x G) was significant for N and K, but not P.

Proline content and antioxidant enzyme activities

Differences among the irrigation treatments (I), graft combinations (G) and the interaction (I x G) were detected in watermelon plant contents of proline, and the activities of the two antioxidant enzymes: superoxide dismutase (SOD) and catalase (CAT) as shown in Table (4). The highest proline and enzyme activities were found at high deficit irrigation level (50% ET). The percentage of increase in proline SOD and CAT were 47.5%. 21% and 17.4%, respectively, over the control. The effect of rootstock genotype showed that, the highest proline was found in plants of the graft combination Aswan/Strong tozawith an average of 279(µg/g FW), as tested over all irrigation treatments. Watermelon grafted on Ferro rootstock recorded the highest SOD (4946 U/g FW) and CAT (42.25 U/g FW). Un-grafted plants (Aswan control) had the lowest proline, SOD and CAT (Table 4).

The interaction (I x G) significantly affected proline, SOD and CAT. Significant increase in these substances was detected with each increase in water stress level. However, the magnitude of increase varied among the examined graft combinations. In this respect, Aswan/Giada or Aswan/Pumpkin had the highest increase (about 3x) in proline at 50% ET compared to the rest of the rootstocks (Fig. 2A). Similarly, Aswan/Giada recorded the highest increase in SOD activity under 50% ET, compared to the other graft combinations (Fig.2B).

Table (4): Effect of deficient irrigation rates and grafting combinations on N, P, K, proline contents, and enzyme (SOD and CAT) activities in watermelon leaves

Treatments	N	P	K	Proline	SOD	Catalase
		(mg/g^{-1})		(µg/g FW)	(U/g FW)	(U/g FW)
Graft combinations:						
Aswan/Giada	38.86 a	3.11 a	13.67 a	134.55 e	4532.88 c	40.26 d
Aswan/Shintoza	37.68 a	2.93 abc	07.98 c	258.88 b	4363.00 e	41.48 bc
Aswan/Strong toza	27.43 cd	2.86 bc	08.09 c	279.11 a	4436.77 d	41.68 b
Aswan/Ferro	38.00 a	3.06 ab	09.49 b	180.66 c	4946.11 a	42.25 a
Aswan/Pumpkin	31.56 b	2.88 abc	07.06 d	166.88 d	4881.44 b	41.04 c
Aswan Control	25.01 d	2.78 c	06.27 d	109.88 f	3009.77 f	37.11 e
Irrigation:						
100%	40.00 a	3.17 a	11.63 a	130.94 c	3818.88 c	36.36 c
70%	29.69 b	3.00 b	08.70 b	184.66 b	4421.05 b	41.50 b
50%	25.12 c	2.64 c	05.96 c	249.38 a	4845.05 a	44.05 a
Significance:						
Graft combination (G)	***	*	***	***	***	***
Irrigation (I)	***	***	***	***	***	***
I*G	***	ns	***	***	***	***

Values followed by the same letters within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test

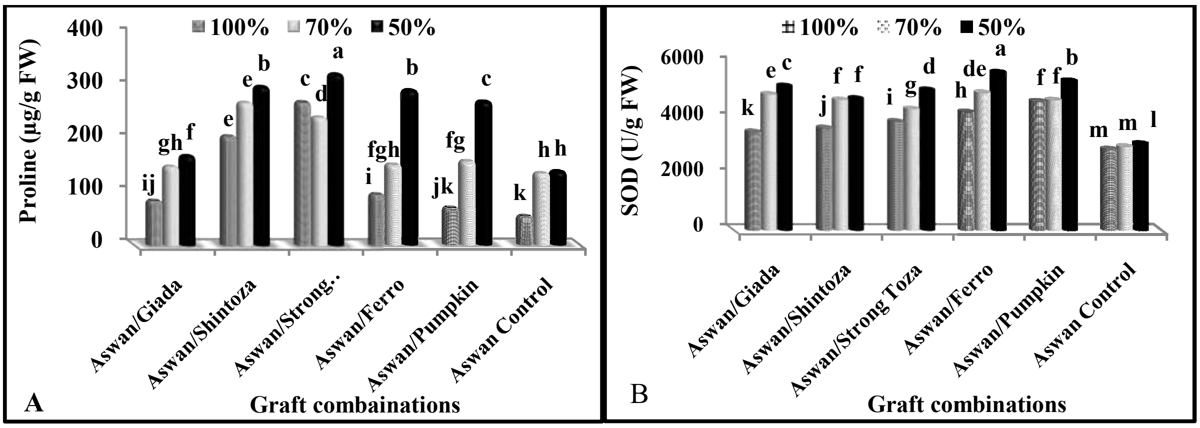

Figure (2): Effect of the interaction between irrigation rates and graft combinations on proline (A) and SOD (B) contents of watermelon leaves

DISCUSSION

Results of the present investigation indicated that, at the highest water stress level (50% of ET), significant decline in number of leaves, length of main stem, % DM and LRWC were observed, in addition to lower numbers of male and female flowers, as compared to the sufficient water treatment (100% ET). Similar findings were reported by Pereira *et al*. (2020). Data also revealed that the highest yield components of watermelon plants were achieved at 100% ET, including average fruit weight and marketable fruit yield. The decline in most vegetative growth traits might explain the lower yield attributes under the highest water stress treatment. In line with our results, Schwarz *et al*. (2010) related yield losses under deficit water to the decrease in plant vegetative growth and development. In addition, vegetative parts of the plant represent a major source of assimilates allocated to the reproductive and fruiting sites as the sink of assimilates. This was evident on the measured decline in photosynthetic pigment contents (data not shown). Our results also indicated significant decline in major macronutrients (N, P, and K) contents under 50% ET compared to 100% ET, which could also contribute to the observed decline in growth and yield under deficit irrigation. In harmony with our results, it was reported that under limited water supply, plants increase root/shoot ratio, decrease water and mineral nutrients flow from the roots which affects net assimilation, thereby decreasing the production and allocation of carbohydrates to several plant parts (Atkinson *et al*., 1999; Shaw *et al*., 2002; Chaves *et al*., 2003). Sufficient irrigation was also shown to increase yield of field grown watermelons (Erdem and Yuksel 2003; Bhatt *et al*., 2015; Abdelkhalik *et al*., 2019), vegetative growth of cantaloupe and its chlorophyll index (Mirabad *et al*., 2013), and nitrogen use efficiency in tomato (Sánchez-Rodríguez *et al*., 2010).

A major point of the present experiment was to screen watermelon plants grafted onto several cucurbit rootstocks for their tolerance to deficit irrigation. As tested over the three water deficiency treatments, results indicated significant differences among the examined graft combinations (Aswan/Giada, Aswan/Shintoza, Aswan/Strong Toza, Aswan/Ferro and Aswan/Pumpkin) in several vegetative, reproduction and yield characteristics, as compared to un-grafted plants (control). Results indicated that grafted plants had the highest number of leaves, length of main stem and number of branches/plant. The graft combinations of Aswan/Giada, Aswan/Shintoza, in addition to Aswan/Ferro and Aswan/Strong Toza had more vegetative growth than un-grafted plants. These results are in harmony with the previous work of Mohamed *et al*. (2014) in grafted watermelon cv. Aswan and Mirabad *et al.* (2013) on grafted pepper. The different genetic background of the different rootstocks, associated with their different rooting and tolerance characteristics to biotic and abiotic stress could explain the observed different impacts of rootstock on vegetative growth and yield.

To examine which rootstock genotype was able to withstand (tolerate) irrigation deficiency, we examined the % increase or decrease in each vegetative or yield trait under 50% ET as compared to the control (100% ET). It was found that plants of Aswan/Ferro recorded the highest number of fruits per plant and marketable yield at 100% and 70%, and the % decrease in these two parameters at 50% ET was the lowest, among other graft combinations, indicating its relative tolerance to deficit irrigation. In addition, Aswan/Ferro plants had the highest fruit number/plant (2.88) as an average over the 3 tested water treatments, therefore the increase in marketable yield of Aswan/Ferro was due more to increase in fruit number than mean fruit weight.

Generally, fruits of grafted plants had more SSC and lycopene contents, and the graft combination Aswan/Ferro was the highest in fruit SSC at the lowest irrigation level (50% ET), followed by Aswan/Shintoza which recorded the highest SSC% at 50% ET treatment. Leskovar *et al*. (2004) found increase in sugar content and no change in lycopene contents in response to deficit irrigation. On mini-watermelon, Rouphael *et al*. (2008) observed no significant difference among water stress treatments on fruit shape index or SSC, but they recorded differences in SSC contents among the different graft combination. Our results also showed that Aswan/Giada and Aswan/Ferro recorded the lowest decline in N and P contents under water stress, as compared to other graft combinations.

Water stress resulted in significant increase in proline content (about 2x) in plants under 50% ET compared to those under 100% ET. Enzymes activities were also higher at 50% ET than at 100% ET when tested over all graft combinations. Plants of Aswan/ Strong toza recorded the highest proline contents. SOD and CAT activities were the highest in Aswan/Ferro, while un-grafted plants recorded the lowest SOD and CAT activities. The increase in proline content at 50% ET was the highest in Aswan/Ferro (3x) among all graft combinations. In accordance with our results, several other reports indicated significant increase in proline and antioxidant enzyme activities under water stress in grafted tomato (Sánchez-Rodríguez *et al*., 2012), melon (Kavas *et al*., 2013), pepper (Penella *et al*., 2014) and watermelon (Mo *et al*., 2016), who also showed differences among different graft combinations in proline contents. Maintaining of turgor by increasing the concentration of solutes (proline) is one of the main mechanisms to keep physiological activity upon the decrease in water potential (Ober *et al*., 2005). According to the above analysis, we suggest that the relative ability of watermelon plants grafted on Ferro or Strong Toza to withstand deficit irrigation more than other rootstocks was due to their ability to increase proline contents, SOD and CAT activities under water stress. In this regards, it was shown that the stimulation of the plant antioxidant capacity is one of the most important mechanisms of protection against the harmful impact of oxygen radicals (Sherwin and Farrant, 1998).Superoxide dismutase is known as a catalyst which can changes superoxide radicals into hydrogen peroxide, and working among other enzymes as secondary defense against ROS (Alscher *et al*., 2002; Tan *et al*., 2006).

In conclusion, the present study indicated that grafting watermelon plants onto specific rootstock, *i.e.* Giada or Ferro, improved their tolerance to deficit irrigation via stronger growth, enhanced nutrient uptake, and efficient antioxidant system.

REFERENCES

AOAC (1996). Official Methods of Analysis, 12th ed. Washington, DC: AOAC.

Abdelkhalik, A., N. Pascual, L. Najera, A. Giner, C. Baixauli and B. Pascual (2019). Yield response of seedless watermelon to different drip irrigation strategies under Mediterranean conditions. Agricultural Water Management, 212: 99-110.

Aebi, H. (1984). Catalase *in vitro*. *Methods in Enzymology,* 105: 121-126.

Allen, R.G., L. S. Pereira, D. Raes and M. Smith (1998). Crop Evapotranspiration-Guidelines for computing crop water requirements. FAO Irrigation and Drainage, 56, FAO, Rome.

Alscher, R. G., N. Erturk and L. S. Heath (2002). Role of superoxide dismutases (SODs) in controlling oxidative stress in plants. Journal of Experimental Botany, 53(372): 1331-1341.

Atkinson, C. J., M. Policarpo, A. D. Webster and A. M. Kuden (1999). Drought tolerance of apple rootstocks: production and partitioning of dry matter. Plant and Soil, 206(2): 223-235.

Bhatt, R. M., K. K. Upreti, M. H. Divya, S. Bhat, C. B. Pavithra and A. T. Sadashiva (2015). Interspecific grafting to enhance physiological resilience to flooding stress in tomato (*Solanum lycopersicum* L.). Scientia Horticulturae, 182: 8-17.

Black, C. A., D. D. Evans and R. C. Dinauer (1965). Methods of soil analysis. Madison, WI: American Society of Agronomy, 9: 653-708.

Chaves, M. M., J. P. Maroco and J. S. Pereira (2003). Understanding plant responses to drought from genes to the whole plant. Functional Plant Biology, 30(3): 239-264.

Doorenbos, J. and A. H. Kassam (1979). Yield response to water. FAOIrrigation and Drainage, 33: 257.

Erdem, Y. and A. N. Yuksel (2003). Yield response of watermelon to irrigation shortage. Scientia Horticulturae, 98(4): 365-383.

FAOSTAT (2019): available at https://www.fao.org/faostat/en/#data

Hassell, R. L., F. Memmott and D. G. Liere (2008). Grafting methods for watermelon production. HortScience, 43(6): 1677-1679.

Howell, T. A., R. H. Cuenca and K. H. Solomon (1990). Crop yield response. Management of Farm Irrigation Systems. pp. 93-122.

Jackson, M. L. (1967). Soil Chemical Analysis.Prentice-Hall, Inc., Englewood Cliffs, N.J., Library of Congress, USA.

Kavas, M., M. C. Baloğlu, O. Akça, F. S. Köse and D. Gökçay (2013). Effect of drought stress on oxidative damage and antioxidant enzyme activity in melon seedlings. Turkish Journal of Biology, 37(4): 491- 498.

Leskovar, D., H. Bang, K. Crosby, N. Maness, A. Franco and P. Perkins-Veazie (2004). Lycopene, carbohydrates, ascorbic acid and yield components of diploid and triploid watermelon cultivars are affected by deficit irrigation. The Journal of Horticultural Science and Biotechnology, 79(1): 75-81.

Lisar, S. Y. S., R. Motafakkerazad, M. M. Hossain and I. M. M. Rahman (2012). Water stress in plants: Causes, effects and responses. In *Water Stress*; M. Rahman and H. Hasegawa, Eds.; In Tech: Rijeka, Croatia, pp. 1-14.

Mirabad, A. A., M. Lotfi and M. R. Roozban (2013). Impact of water-deficit stress on growth, yield and sugar content of cantaloupe (*Cucumis melo* L.). International Journal of Agriculture and Crop Sciences, 6(10): 605.

Mo, Y., Y. Wang, R. Yang, J. Zheng, C. Liu, H. Li, J. Ma, Y. Zhang, C. Wei and X. Zhang (2016). Regulation of plant growth, photosynthesis, antioxidation and osmosis by an *Arbuscular Mycorrhizal*fungus in watermelon seedlings under well-watered and drought conditions. Frontiers in Plant Science, *7*: 644.

Mohamed, F. H., K. A. El-Hamed, M. W. M. Elwan and M. N. E. Hussien (2014). Evaluation of different grafting methods and rootstocks in watermelon grown in Egypt. Scientia Horticulturae, 168: 145-150.

Nishikimi, M., N. A. Rao and K. Yagi (1972). The occurrence of superoxide anion in the reaction of reduced phenazine methosulfate and molecular oxygen. Biochemical and Biophysical Research Communications, 46(2): 849-854.

Ober, E. S., M. Le Bloa, C. J. Clark, A. Royal, K. W. Jaggard and J. D. Pidgeon (2005). Evaluation of physiological traits as indirect selection criteria for drought tolerance in sugar beet. Field Crops Research, 91(2): 231-249.

Osakabe, Y., K. Osakabe, K. Shinozaki and L. S. P. Tran (2014). Response of plants to water stress. Frontiers in Plant Science, 5: 86.

Özmen, S., R. Kanber, N. Sarı and M. Ünlü (2015). The effects of deficit irrigation on nitrogen consumption, yield, and quality in drip irrigated grafted and ungrafted watermelon. Journal of Integrative Agriculture, 14(5): 966-976.

Parida, A. K. and A. B. Das (2005). Salt tolerance and salinity effects on plants: A review. Ecotoxicology. Environ. Saf., 60: 324-349.

Penella, C., S. G. Nebauer, A. San Bautista, S. López-Galarza and A. Calatayud (2014). Rootstock alleviates PEG-induced water stress in grafted pepper seedlings: Physiological responses. Journal of Plant Physiology, 171(10): 842-851.

Pereira, L., E. M. Silva, J. J. Lascedra, R. F. Ratke, C. J. Lima and T. O. Santos (2020). Phytochemical parameters and yield of watermelon plants under different irrigation and nitrogen levels. Comunicata Scientiae, 11: e3131.

Proietti, S., Y. Rouphael, G. Colla, M. Cardarelli, M. De Agazio, M. Zacchini, E. Rea, S. Moscatello and A. Battistelli (2008). Fruit quality of mini-watermelon as affected by grafting and irrigation regimes. Journal of the Science of Food and Agriculture, 88(6): 1107-1114.

Ranganna, S. (1977). Manual of analysis of fruit and vegetable products. Tata Mcagaw hill Publishing Company Limited. New Delhi, India.

Rouphael, Y., M. Cardarelli, G. Colla and E. Rea (2008). Yield, mineral composition, water relations, and water use efficiency of grafted mini-watermelon plants under deficit irrigation. HortScience*,* 43: 730–736.

Sadasivam, S. and A. Manickam (1992). Biochemical methods for agricultural sciences. Wiley Eastern Limited.

Sánchez-Rodríguez, E., M. Del Mar Rubio-Wilhelmi, B. Blasco, R. Leyva, L. Romero and J. M. Ruiz (2012). Antioxidant response resides in the shoot in reciprocal grafts of drought-tolerant and drought-sensitive cultivars in tomato under water stress. Plant Science, 188: 89-96.

Sánchez-Rodríguez, E., M. M. Rubio-Wilhelmi, B. Blasco, R. Leyva, L. Romero and J. M. Ruiz (2010). Grafting between two cultivars of cherry tomato differing in their tolerance to drought: effect in nitrogen-use efficiency. Acta Horticulturae, 923: 261-267.

Schwarz, D., Y. Rouphael, G. Colla and J. H. Venema (2010). Grafting as a tool to improve tolerance of vegetables to abiotic stresses: Thermal stress, water stress and organic pollutants. Scientia Horticulturae, 127(2): 162-171.

Sherwin, H. W. and Farrant (1998). Protection mechanisms against excess light in the resurrection plants (*Craterostigma wilmsii* and *Xerophytes viscosa*). Plant growth regulation, 24: 203-210.

Shaw, B., T. H. Thomas and D. T. Cooke (2002). Responses of sugar beet (*Beta vulgaris* L.) to drought and nutrient deficiency stress. Plant Growth Regulation, 37(1): 77-83.

Snedecor, G. W. and W. G. Cochran (1989). Statistical methods 8th Edition. Ames: Iowa State University Press.

Tan, Y., Z. Liang, H. Shao and F. Du (2006). Effect of water deficits on the activity of antioxidative enzymes and osmoregulation among three different genotypes of *Radix astragali* at seeding stage. Colloids and surfaces B: Biointerfaces, 49(1): 60-65.

Yamasaki, S. and L. R. Dillenburg (1999). Measurements of leaf relative water content in *Araucaria angustifolia*. Revista Brasilleira de fisiologia vegetal, 11(2): 69-75.

استجابة نباتات البطيخ المطعومة على أصول مختلفة لنقص ماء الري

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أجريت هذه الدراسة لاختبار نباتات البطيخ صنف أسوان المطعومة على أصول مختلفة (جيادا-شنتوزا- سترونج توزا-والقرع العسلي) مقارنة بالنباتات غير المطعومة. وذلك لاختبار درجة تحملها للإجهاد المائي في تجربة حقلية استخدمت معاملات ري: كافية (١٠٠% من البخرنتح) و متوسطة (٧٠%) ومنخفضة (٥٠%) حيث دلت النتائج علي انخفاض معنوي في النمو الخضري (عدد الأوراق والأفرع الجانبية وطول الساق الرئيسي) والرطوبة النسبية بالأوراق والنمو والزهري ومحصول الثمار وانخفاض تركيز النتروجين والفوسفور والبوتاسيوم في الأوراق وذلك تحت تأثير الإجهاد المائي (٥٠% من البخر نتح) مقارنة بالكونترول (١٠٠% من البخرنتح)، إلا أن محتواها من البرولين ونشاط الإنزيمات المضادة للأكسدة(سوبر اوكسيد ديسميوتيز والكتاليز) كان اعلي تحت ظروف الإجهاد المائي، كما أظهرت النباتات المطعومة علي أي من الأصول المختبرة سلوكا متميزا في النمو والمحصول عن تلك غير المطعومة تحت ظروف نقص مياه الري خاصة تلك المطعومة علي الأصل فيرو والتي أظهرت اقل انخفاضا في عدد الثمار والمحصول الكلي للنبات ونسبة المواد الصلبة الذائبة عند أعلي مستوي من الإجهاد المائي وكذلك أقل انخفاضا في تركيز النتروجين والفوسفور في الأوراق، وعليه يمكن اعتبار نباتات البطيخ المطعومة علي الأصل فيرو مقاومة للإجهاد المائي وكان ذلك مصحوبا بارتفاع مستوي البرولين والإنزيمات المضادة للأكسدة.