Asian Journal of Crop Science

ISSN 1994-7879

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Asian Journal of Crop Science 6 (2): 112-122, 2014
ISSN 1994-7879 / DOI: 10.3923/ajcs.2014.112.122
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Effectiveness of Grafting for the Improvement of Salinity and Drought Tolerance in Tomato (*Solanum lycopersicon* L.)

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ABSTRACT

Grafting is considered to be an environmentally friendly technique for reducing the yield losses caused by salinity and/or drought. Therefore, the present study aims to employ grafting for improvement the tolerance of tomato (*Solanum lycopersicon* L.) to salt and drought stresses. Two greenhouse experiments were conducted during the 2011/2012 and 2012/2013 seasons. Each experiment included 12 treatments, representing all combinations of 2 grafting treatments (Farida cv grafted onto Unifort rootstock and ungrafted Farida cv) and 6 abiotic stress treatments (salt stress and/or water stress). The stress treatments consisted of two levels of salinity (non-saline water with an average Electrical Conductivity (EC) of 1.2 dS m^{-1} and saline water with an EC of 4.5 dS m^{-1}) applied at three irrigation rates (100, 75 and 50% of crop Evapotranspiration (ETc)). The results demonstrated that the grafted plants had significantly higher values for vegetative growth, yield and Water Use Efficiency (WUE) in comparison with the un-grafted plants. Conversely, grafted plants had significantly lower values for fruit quality traits vitamin C and Total Soluble Solid (TSS) and leaf concentrations of Na^+, Cl^- and proline. The interaction effects indicated that under the water stress and the salt stress treatments, grafting alleviated the negative effects of these stresses on most of the studied traits. The positive effects of grafting on plant growth and productivity support the feasibility of the technique as a method for improving salt and drought tolerance in tomato grown under greenhouse conditions.

Key words: Abiotic stress, rootstock, proline, water quality, water stress, salt stress, fruit quality, water use efficiency

INTRODUCTION

Environmental stresses represent the most important limiting factors for plant growth and horticultural productivity worldwide. Drought and salinity are the major environmental factors underlying reduced plant productivity (Schwarz *et al.*, 2010). The development of stress-tolerant crops through the selection and breeding of cultivars able to produce economic yields under saline or drought conditions is vital to minimising the detrimental effects of these stresses (Cuartero *et al.*, 2006). However, the genetically complex nature of drought and salinity tolerance make this task extremely difficult (Ashraf and Foolad, 2007). Consequently, the search for alternative strategies to generate improved abiotic stress tolerance is of great importance.

Grafting is currently regarded as a rapid alternative to the relatively slow methods of breeding for increasing the environmental stress tolerance of fruiting vegetables (Flores *et al*., 2010). The grafting of elite commercial cultivars onto selected vigorous rootstocks is a special technique for adapting these plants to environmental stresses (Lee and Oda, 2003). Grafting has been used for more than 50 years for vegetable production in many parts of the world. Recently, the technique has been widely used to enhance tolerance against abiotic stresses such as saline soils (Colla *et al*., 2010) and to provide resistance against drought (De Magalhaes Erismann *et al*., 2008). Grafting can increase the tolerance of vegetables to salinity and promote water use efficiency (Oztekin *et al*., 2007) and the technique has been proven to increase tomato plant vigour, water consumption and yield under saline conditions (Tuzel and Oztekin, 2009).

The shortage of high-quality water is becoming a limiting factor for agricultural development. Therefore, strategies for the effective use of available saline water should receive more attention. One potential approach to reduce production losses and improve water use efficiency under drought conditions for high-yielding genotypes is the grafting of these high-yielding varieties onto rootstocks capable of mitigating the effects of water stress on the shoot.

Tomato (*Solanum lycopersicon* L.) is one of the most important food crops in the world. The crop can serve as a model for saline land recovery and poor-quality water use because of the wealth of physiological and genetic knowledge already existing for the species and tomatoes are already grown on a large scale in areas where saline conditions are problematic (Reina-Sanchez *et al*., 2005). Most commercial tomato cultivars are sensitive to moderate levels of salinity (Dehyer and Gordon, 2005) and drought (Foolad, 2004) at all developmental stages. Grafting is considered to be an environmentally friendly technique for reducing the yield losses caused by salinity and/or drought. Therefore, the present research aims to employ grafting to improve the tolerance of tomato to salt and water stresses and to determine how grafting might alleviate the adverse effects of these stresses on agronomic performance.

MATERIALS AND METHODS

Experimental site and plant materials: Two greenhouse experiments were conducted during the 2011/2012 and 2012/2013 seasons at the Agricultural Research and Experimental Station, Faculty of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia. Two tomato (*Solanum lycopersicum* L.) hybrid cultivars, 'Farida' (Golden Valley Seed Company, USA) and 'Unifort' (De Ruiter Seed Company, Netherland) were used as the scion and rootstock, respectively. Seeds were sown on 1 and 4 Sep. for the first and second seasons, respectively. The tube grafting method was used to graft the seedlings when the scion had grown 2 true leaves and the rootstock had grown 2-3 true leaves. The 'Unifort' rootstock and the 'Farida' scion were both cut at a slant. A plastic tube was placed onto the cut end of the 'Unifort' rootstock and the cut end of the 'Farida' scion was then inserted into the tube in direct contact with the rootstock (Marsic and Osvald, 2004). The grafted seedlings were kept for one week under controlled conditions (24-26°C, 90-95% RH and 45% shading) to enhance their survival rate. The seedlings were then transferred to a fiberglass greenhouse 10 days after sowing.

Abiotic stress treatments: Each experiment included 12 treatments, representing all combinations of the 2 grafting treatments (grafted and un-grafted) and the 6 abiotic stress treatments (salt stress and/or water stress). The stress treatments consisted of two levels of salinity (non-saline water with average Electrical Conductivity (EC) of 1.2 dS m^{-1} and saline water with an EC of 4.5 dS m^{-1}) applied at three irrigation rates (100, 75 and 50% of crop evapotranspiration (ETc)). The six abiotic stress treatments were as follows:

- **T1:** Irrigation using non-saline water at 100% of ETc, representing normal irrigation water requirements and considered as a control treatment (without any stress)
- **T2:** Irrigation using non-saline water at 75% of ETc, representing moderate water stress
- **T3:** Irrigation using non-saline water at 50% of ETc, representing high water stress
- **T4:** Irrigation using saline water at 100% of ETc, representing salt stress only
- **T5:** Irrigation using saline water at 75% of ETc, representing both salt and moderate water stresses
- **T6:** Irrigation using saline water at 50% of ETc, representing both salt and high water stresses

Experimental design: The experimental layout was a split-plot system in a randomised complete block design, with three replications. The grafting and abiotic stress treatments were randomly distributed as the main plots and subplots, respectively. The subplot area was 8 m^2 and included 16 plants. A total of 576 plants were used in each experiment.

Data recorded: At 60 days after transplantation, random samples of four plants from each subplot were chosen to measure leaf area (using a Portable Area Metre (LI-COR model 3000A)) and leaf fresh and dry weights. Leaf samples from the upper leaves (3 or 4 cluster) were collected, washed in distilled water and dried at 70°C in a forced air-oven until they reached a constant weight. The dried leaf samples were ground and used to determine the concentrations of Na^+ and Cl^-. Extraction and estimation of free proline in fresh leaf samples was conducted according to the method of AOAC (1995). The total tomato fruit weight throughout the entire harvesting period was recorded for each experimental unit and converted into total yield ha^{-1}. The average fruit weight was calculated by dividing the total weight of the fruits harvested from each subplot over the whole season by the number of fruits. Five fruit samples, taken from five plants from each subplot, were collected at the peak of harvest for fruit quality analysis. The homogenised fruit juice was subjected to the following analyses: Total soluble solids (TSS, °Brix) using a portable digital refractometer (PR-101, ATAGO, Japan), vitamin C (mg 100 g^{-1} FW, as ascorbic acid) using a 2,6, dichlorophenol-indophenol solution that was standardised in a solution of ascorbic acid with a known concentration (Patane *et al*., 2011) and titratable acidity (TA % FW) (AOAC, 1995).

Water use Efficiency (WUE) was used to compare the different irrigation water treatments and was calculated from the total fresh fruit yield and the total water use (WUE = total fresh yield/total water applied) according to (Lovelli *et al*., 2007).

Statistical analysis: Data were subjected to analysis of variance using the SAS version 8.1 computer program (SAS, 2008). Treatment means were compared using a revised Least Significant Difference (LSD) test at the 0.05 level of significance (Snedecor and Cochran, 1989).

RESULTS AND DISCUSSION

Vegetative growth traits: The grafted Farida plants were more vigorous than the un-grafted plants, as shown by their higher leaf area and heavier fresh and dry weights (Table 1). In the first season, grafting enhanced these three traits by approximately 12.1% (from 7699.3 to 8630.8 cm^2), 11.1% (from 711.4 to 790.3 g) and 11.3% (from 83.5 to 92.9 g) , respectively. While, in the second

Table 1: Leaf area, leaf fresh weight and leaf dry weight of tomato as affected by grafting, abiotic stress treatments and the interaction effect in the 2011/2012 and 2012/2013 seasons

Abiotic stress treatments	Leaf area (cm^2) Un-grafted	Grafted	Average	Leaf fresh weight (g) Un-grafted	Grafted	Average	Leaf dry weight (g) Un-grafted	Grafted	Average
First season (2011/2012)									
T1	9450.0^{c}	10678.5^{a}	10064.3^{A}	838.0^{b}	938.6^{a}	888.3^{A}	108.0^{a}	120.9^{a}	114.5^{A}
T2	9110.0^{c}	10112.1^{b}	9611.1^{B}	794.0^{c}	873.4^{b}	833.7^{B}	88.5^{c}	97.4^{b}	92.9^{B}
T3	7815.0^{e}	8518.3^{d}	8166.7^{D}	722.0^{d}	779.8^{c}	750.9^{C}	74.5^{d}	80.5^{d}	77.5^{C}
T4	7843.5^{e}	9098.5^{c}	8470.9^{C}	737.4^{d}	848.1^{b}	793^{BC}	99.4^{b}	114.3^{a}	106.8^{A}
T5	6741.4^{f}	7617.8^{e}	7179.6^{E}	635.2^{e}	711.4^{d}	673.3^{D}	73.5^{d}	82.3^{c}	77.8^{C}
T6	5236.0^{h}	5759.7^{g}	5497.8^{F}	541.7^{g}	590.4^{f}	566.1^{E}	57.4^{e}	62.5^{e}	59.9^{D}
Average	7699.3^{B}	8630.8^{A}		711.4^{B}	790.3^{A}		83.5^{B}	92.9^{A}	
Second season (2012/2013)									
T1	9590.0^{c}	11028.5^{a}	10309.3^{A}	819.0^{c}	933.7^{a}	876.3^{A}	98.3^{b}	112.0^{a}	105.2^{A}
T2	9140.0^{c}	10128.2^{b}	9634.1^{B}	774.0^{d}	866.9^{b}	820.4^{B}	85.4^{c}	95.6^{b}	90.5^{B}
T3	7970.0^{e}	8567.0^{d}	8268.5^{D}	711.0^{e}	782.1^{c}	746.5^{C}	72.3^{d}	79.5^{c}	75.9^{C}
T4	7955.6^{e}	9325.1^{c}	8640.3^{C}	728.9^{e}	849^{bc}	789^{BC}	91.4^{b}	106.5^{a}	98.9^{A}
T5	6755.0^{f}	7717.7^{e}	7234.8^{E}	611.4^{f}	694.0^{e}	652.7^{D}	71.7^{d}	81.4^{c}	76.6^{C}
T6	5419.6^{g}	6503.5^{f}	5961.5^{F}	533.3^{g}	613.2^{f}	573.2^{E}	56.4^{f}	64.8^{e}	60.6^{D}
Average	7805.0^{B}	8877.8^{A}		696.3^{B}	789.8^{A}		79.3^{B}	90.0^{A}	

T1: Irrigation using non-saline water (NS) at 100% of ETc, T2: Irrigation using NS at 75% of ETc, T3: Irrigation using NS at 50% of ETc, T4: Irrigation using saline water (S) at 100% of ETc, T5: Irrigation using S at 75% of ETc, T6: Irrigation using S at 50% of Etc

season the traits were increased by 13.7% (from 7805.0 to 8877.8 cm^2), 13.4% (from 696.3 to 789.8 g) and 13.5% (from 79.3 to 90.0 g), respectively. These results are in accordance with the findings of Khah *et al.* (2006) and Karaca *et al.* (2012), who found that grafted plants were more vigorous than ungrafted plants. The effect of grafting on tomato growth traits indicated a positive interaction between the scion and the rootstock. Romano and Paratore (2001) reported that the dry weight of the aerial organs of grafted tomato plants ('Rita x Beaufort') was greater than that of self-rooted plants.

All of the stress treatments caused significant decreases in vegetative growth traits in comparison with the control treatment (T1). The greatest leaf area and fresh weight was observed for the control treatment (no stress), followed by the moderate water stress treatment (T2). Leaf dry weight was not significantly affected by salt stress treatment (T4) in either season. Plants in the salt and high water stress treatment (T6) had the lowest values for the vegetative growth traits. These results are in agreement with those of (El-Zeiny and Ibrahim, 2006), who demonstrated that tomato plants grown under 80 or 100% ETc exhibited vigorous vegetative growth in comparison with plants grown at a lower irrigation level (40% of the calculated water requirement). Maggio *et al.* (2007) reported that there was an approximately 6% reduction in plant dry mass per one dS m^{-1} increase until approximately 9 dS m^{-1}.

The interaction effects followed the same trends as the main effects of the stress treatments, with significant increases in the vegetative growth traits observed using the grafted Farida plants. The highest values for the three traits were recorded when the grafted plants were combined with the full irrigation treatment, followed by the treatment of grafted plants under moderate water stress for the leaf area and fresh weight traits. For the dry weight trait, however, the grafted plants under the salt stress treatment had the highest value. The lowest values for the three traits were obtained for un-grafted plants under the combined salt and high water stresses. The enhancement in vegetative growth associated with the increase in irrigation level may be attributed to the appropriate balance of moisture content resulting in the plant tissues. This moisture balance creates suitable conditions for nutrient uptake, photosynthesis and metabolite translocation which hastens the rate of plant growth (Ezzo *et al*., 2010). The data clarified that grafting improved the vegetative growth traits under salt stress (comparison between T4 with and without grafting). These results illustrated that the adverse effects of salt stress can be reduced by grafting.

Fruit yield and water use efficiency (WUE): The average fruit weight, total yield and WUE of un-grafted Farida tomato plants were statistically lower than the corresponding values for 'Farida' plants grafted onto 'Unifort' rootstock (Table 2). Grafting increased both average fruit weight and total yield by approximately 13.1% (from 103.1 to 116.6 g) and 17.4% (from 101.17 to 118.77 ton ha^{-1}) in the first season and by 13.5% (from 106.0 to 120.3 g) and 17.1% (from 101.86 to 119.26 ton ha^{-1}) in the second season, respectively. Similar results were obtained by Turhan *et al*. (2011) and Echevarria *et al*. (2012), who reported that grafted tomato plants produced bigger and more numerous fruits than ungrafted ones. Rouphael *et al*. (2010) affirmed that the average fruit weight and size of solanaceous fruits are often affected by grafting and these traits are fundamental constituents of total fruit yield. The WUE of the grafted tomato plants increased by 16.7 and 16.5% for first and second season, respectively, in comparison with un-grafted plants, even though both grafted and ungrafted treatments were supplied with the same amounts of water. The grafting technique may therefore improve the WUE of tomato production. This result is supported by the findings of Schwarz *et al*. (2010), who indicated that grafting high-yielding tomato genotypes onto suitable rootstocks could mitigate the effects of water stress on plant shoots, reducing losses in production and improving WUE under water shortage conditions.

Table 2: Average fruit weight, total yield and water use efficiency (WUE) of tomato as affected by grafting, abiotic stress treatments and the interaction effect in the 2011/2012 and 2012/2013 seasons

Abiotic stress	Average fruit weight (g)			Total yield (ton ha^{-1})			WUE (kg M^{-3})		
treatments	Un-grafted	Grafted	Average	Un-grafted	Grafted	Average	Un-grafted	Grafted	Average
First season (2011/2012)									
T1	147.4^{ab}	150.4^{a}	148.9^{A}	130.827^{b}	154.376^{a}	142.601^{A}	31.20^{fg}	36.75^{de}	33.95^{C}
T2	123.6^{c}	144.6^{b}	134.1^{B}	112.517^{e}	130.519^{b}	121.518^{B}	35.72^{de}	41.43^{c}	38.57^{B}
T3	97.6^{f}	109.3^{d}	103.5^{D}	103.119^{f}	116.525^{d}	109.822^{D}	46.87^{b}	52.96^{a}	49.92^{A}
T4	101.4^{e}	123.6^{c}	112.5^{C}	102.33^{fg}	125.865^{c}	114.097^{C}	24.36^{h}	29.96^{g}	27.16^{D}
T5	83.4^{g}	97.7^{f}	90.5^{E}	83.923^{h}	99.868^{g}	91.895^{E}	26.64^{h}	31.70^{fg}	29.17^{D}
T6	64.7^{i}	73.8^{h}	69.3^{F}	74.337^{k}	85.487^{h}	79.912^{F}	33.78^{ef}	38.86^{cd}	36.32^{BC}
Average	103.1^{B}	116.6^{A}		101.17B	118.77^{A}		33.09^{B}	38.61^{A}	
Second season (2012/2013)									
T1	149.6^{b}	152.9^{ab}	151.3^{A}	132.216^{b}	155.354^{a}	143.785^{A}	31.48^{fg}	36.98^{de}	34.23^{C}
T2	132.3^{c}	154.9^{a}	143.6^{B}	113.277^{e}	131.741^{b}	122.509^{B}	35.96^{de}	41.82^{c}	38.89^{B}
T3	99.7^{f}	111.9^{e}	105.8^{D}	103.227^{f}	116.36^{d}	109.781^{D}	46.92^{b}	52.88^{a}	49.90^{A}
T4	102.1^{f}	125.0^{d}	113.6^{C}	102.94^{fg}	125.591^{c}	114.267^{C}	24.51^{h}	29.90^{g}	27.20^{D}
T5	86.9^{g}	101.7^{f}	94.3^{E}	84.617^{h}	100.018^{g}	92.318^{E}	26.86^{h}	31.75^{fg}	29.31^{D}
T6	65.5^{i}	75.0^{h}	70.3^{F}	74.868^{k}	86.548^{h}	80.708^{F}	34.03^{ef}	39.34^{cd}	36.68^{BC}
Average	106.0^{B}	120.3^{A}		101.86^{B}	119.26^{A}		33.29^{B}	38.78^{A}	

T1: Irrigation using non-saline water (NS) at 100% of ETc, T2: Irrigation using NS at 75% of ETc, T3: Irrigation using NS at 50% of ETc, T4: Irrigation using saline water (S) at 100% of ETc, T5: Irrigation using S at 75% of ETc, T6: Irrigation using S at 50% of Etc

The stress treatments significantly decreased both average fruit weight and total yield (Table 2). The lowest reduction of these two traits was observed under the moderate water stress (T2) treatment and the greatest reduction was observed when both salt and high water stresses were applied (T6). These results illustrated that when the two stress types were combined, serious reductions in average fruit weight and total fruit yield were induced. The lower fruit yield of the ungrafted plants was attributed to a reduction in the average fruit weight (Table 2). The higher fruit yields of the 'Farida' tomato grafted onto 'Unifort' can most likely be attributed to the vigorous root system of the 'Unifort' rootstock (Rumbos *et al*., 2011). When the rootstock possesses a vigorous root system, the grafted vegetable plants are able to absorb water and nutrients more efficiently than they could through the scion roots, as has been reported by several authors (Marsic and Osvald, 2004; Oztekin *et al*., 2009; Khah, 2011).

Both moderate and high water stress treatments (T2 and T3) significantly increased WUE due to the reductions in the quantity of water applied in these treatments. Conversely, salt stress alone (T4) and the combination of salt and moderate water stresses (T5) both significantly decreased WUE. In these treatments, total yield was significantly reduced, resulting in decreased WUE. T6 (combined salt and high water stresses) had a non-significant effect on WUE because this treatment decreased both yield and applied water at approximately equal rates.

The interaction between the grafting and stress treatments showed significant differences for the yield and WUE traits (Table 2). The grafted plants under the control treatment showed increases in average fruit weight and total yield over the un-grafted plants of 2.0 and 18.0% in the first season and by 2.2. and 17.5% in the second season, respectively. Under the moderate water stress treatment and the salt stress treatment, grafting clearly alleviated the negative effects of stress on average fruit weight and total yield. Similar findings were obtained by Fernandez-Garcia *et al*. (2004), who reported that tomato fruit yield increased in grafted plants under well-watered conditions and that this increase was primarily associated with increasing mean fruit weight and number of fruits plant^{-1}. The lowest fruit yields were observed in ungrafted plants under both salt and high water stresses, a result likely due to the smaller and lighter fruits resulting from the combination of water deficiency and a poor root system (Lee, 1994). The results indicate that grafting led to a vigorous root system under the available water irrigation which in turn enhanced growth and increased fruit yield. The small yield reductions observed for grafted plants under the moderate water stress (from 130.827 to 130.519 ton ha^{-1} in the first season and from 132.216 to 131.741 ton ha^{-1} in the second season) and under the high water stress (from 130.827 to 116.525 ton ha^{-1} in the first season and from 132.216 to 116.360 ton ha^{-1} in the second season) treatments are acceptable for the farmer, as these losses were the result of approximately 25 and 50% reductions in irrigation, respectively. This finding supports the argument of Patane *et al*. (2011) that, under water shortage in arid and semiarid areas, maximising water use is more valuable to the farmer than maximising crop yield. The highest WUE value in this study was recorded for grafted tomato plants under high water stress. Conversely, the lowest WUE value was recorded in un-grafted plants under salt stress in both the first and second seasons.

Fruit quality traits: Fruits of 'Farida' tomatoes grafted onto 'Unifort' rootstock tended to have lower values of vit. C and TSS compared with ungrafted 'Farida' fruits. Titratable Acidity (TA) was not significantly affected by grafting (Table 3). Ungrafted fruits accumulated higher vit. C and TSS contents in comparison with grafted fruits. This finding is in agreement with those of

Table 3: Vitamin C, total soluble solids (TSS) and titratable acidity of tomato as affected by grafting, abiotic stress treatments and the interaction effect in the 2011/2012 and 2012/2013 seasons

Abiotic stress treatments	Vitamin C (mg/100 g FW)			TSS (%)			TA (%)		
	Un-grafted	Grafted	Average	Un-grafted	Grafted	Average	Un-grafted	Grafted	Average
First season (2011/2012)									
T1	20.93^{h}	19.46^{i}	20.20^{A}	4.62^{g}	4.65^{g}	4.63^{E}	0.566^{g}	0.582^{f}	0.574^{D}
T2	24.08^{b}	22.87^{e}	23.48^{B}	5.83^{d}	5.54^{e}	5.68^{C}	0.588^{ef}	0.603^{c}	0.595^{C}
T3	24.64^{a}	23.65^{c}	24.14^{A}	6.47^{bc}	6.28^{c}	6.38^{B}	0.598^{cd}	0.610^{b}	0.604^{B}
T4	2.68^{e}	21.32^{gh}	21.99^{D}	5.02^{f}	4.76^{g}	4.89^{D}	0.594^{d}	0.564^{g}	0.579^{D}
T5	23.17^{de}	22.24^{f}	22.70^{C}	6.58^{b}	6.38^{c}	6.48^{B}	0.611^{b}	0.593^{de}	0.602^{B}
T6	23.38^{cd}	21.74^{g}	22.56^{C}	6.83^{a}	6.69^{ab}	6.76^{A}	0.622^{a}	0.610^{b}	0.616^{A}
Average	23.14^{A}	21.88^{B}		5.89 A	5.72 B		0.596 A	0.593A	
Second season (2012/2013)									
T1	21.96^{e}	20.46^{f}	21.21^{C}	4.78^{h}	4.81^{h}	4.79^{E}	0.554^{h}	0.571^{g}	0.563^{D}
T2	23.90^{c}	22.73^{d}	23.31^{B}	5.99^{d}	5.72^{e}	5.85^{C}	0.588^{ef}	0.603^{d}	0.595^{C}
T3	24.76^{a}	23.87^{c}	24.32^{A}	6.68^{bc}	6.50^{c}	6.59^{B}	0.605^{d}	0.618^{b}	0.611^{B}
T4	24.05^{c}	22.72^{d}	23.38^{B}	5.45^{f}	5.18^{g}	5.32^{D}	0.580^{f}	0.553^{h}	0.567^{D}
T5	24.55^{ab}	23.74^{c}	24.14^{A}	6.77^{ab}	6.59^{bc}	6.68^{AB}	0.611^{cd}	0.593^{e}	0.602^{C}
T6	24.41^{b}	22.92^{d}	23.66^{B}	6.89^{a}	6.77^{ab}	6.83^{A}	0.628^{a}	0.617^{bc}	0.622^{A}
Average	23.94^{A}	22.74^{B}		6.09^{A}	5.93^{B}		0.594^{A}	0.592^{A}	

T1: Irrigation using non-saline water (NS) at 100% of ETc, T2: Irrigation using NS at 75% of ETc, T3: Irrigation using NS at 50% of ETc, T4: Irrigation using saline water (S) at 100% of ETc, T5: Irrigation using S at 75% of ETc, T6: Irrigation using S at 50% of Etc

Rouphael *et al*. (2010) and Turhan *et al*. (2011), who demonstrated that vit. C content was strongly reduced by grafting. The obtained results also agree with those reported by Flores *et al*. (2010) and Turhan *et al*. (2011), whose data indicated that the use of rootstock improved the TSS of grafted tomato fruits.

All of the stress treatments significantly increased vit. C, TSS and TA levels, with the exception of the salt stress treatment which had no significant effect on TA (Table 3). These results may be attributable to the reduction of fruit size under abiotic stress which has been associated with the reduction of water content rather than the reduction of assimilates incorporated into the fruit (Ho, 1996). This observation might explain why the values of the fruit chemical composition traits under the stress treatments were higher than those under the control treatment. Similar results were obtained by Patane *et al*. (2011), who reported that vit. C and TA contents were augmented under a limited irrigation level (50% ETc) in comparison with the full water level (100% ETc). Favati *et al*. (2009) indicated that a shortage of water positively affected vit. C content in processed tomato. The higher TSS contents observed under the stress treatments are vital for the processing industry, as tomatoes with high TSS contents require less energy for drying and improve processing efficiency (Johnstone *et al*., 2005; Favati *et al*., 2009). The interaction effects between grafting and abiotic stress on fruit quality traits generated the highest vit. C value in un-grafted plants under high water stress (T3), while the highest TSS and TA traits were seen in un-grafted plants under both salt and high water stresses (T6). Conversely, the lowest values for the three traits were detected in the control treatment (T1).

Na^{+}, Cl^{-} and proline concentrations: Grafted 'Farida' tomatoes on 'Unifort' rootstock tended to have lower values of Na^{+}, Cl^{-} and proline compared with un-grafted plants. Grafting reduced the leaf concentrations of these three traits (Table 4). T4, T5 and T6 all significantly increased leaf Na^{+} and Cl^{-} concentrations, while T2 and T3 had non-significant effects on the two traits

Table 4: Leaf concentrations of Na^+, Cl^- and proline of tomato as affected by grafting, abiotic stress treatments and the interaction effect in the 2011/2012 and 2012/2013 seasons

Abiotic stress treatments	Na^+ (mg/100 g DW)			Cl^- (mg/100 g DW			Proline (mg/100 g FW)		
	Un-grafted	Grafted	Average	Un-grafted	Grafted	Average	Un-grafted	Grafted	Average
First season (2011/2012)									
T1	290^{ef}	284^{f}	287^{C}	552^{de}	535^{e}	543^{C}	2.41^{g}	2.36^{g}	2.38^{A}
T2	300^{e}	297^{ef}	298^{BC}	550^{de}	539^{e}	544^{C}	2.98^{f}	2.83^{fg}	2.91^{B}
T3	320^{d}	307^{de}	313^{B}	557^{d}	529^{e}	543^{C}	3.61^{e}	3.32^{ef}	3.46^{C}
T4	705^{ab}	583^{c}	644^{A}	820^{a}	720^{b}	770^{A}	4.45^{cd}	4.00^{de}	4.22^{D}
T5	700^{b}	574^{c}	637^{A}	827^{a}	661^{b}	744^{B}	5.12^{b}	4.50c	4.81^{E}
T6	720^{a}	576^{c}	648^{A}	830^{a}	690^{b}	760^{A}	5.71^{a}	4.85^{bc}	5.28^{F}
Average	506^{A}	437^{B}		689^{A}	612^{B}		4.05^{A}	3.64^{B}	
Second season (2012/2013)									
T1	304^{e}	295^{e}	299^{D}	579^{e}	550^{f}	564^{C}	2.53^{h}	2.45^{h}	2.79^{A}
T2	312^{d}	305^{e}	308^{CD}	572^{e}	549^{f}	560^{CD}	3.09^{fg}	2.91^{gh}	3.00^{B}
T3	329^{d}	313^{de}	321^{C}	573^{e}	533^{g}	553^{D}	3.71^{ef}	3.38^{fg}	3.54^{C}
T4	708^{a}	588^{b}	468^{A}	836^{a}	677^{c}	756^{A}	4.53c	4.03^{de}	4.28^{D}
T5	707^{a}	572^{bc}	640^{A}	835^{a}	650^{d}	742^{B}	5.17^{b}	4.44^{cd}	4.80^{E}
T6	712^{a}	563^{c}	637^{B}	821^{b}	690^{c}	755^{A}	5.82^{a}	4.83^{bc}	5.32^{F}
Average	512^{A}	439^{B}		702^{A}	608^{B}		4.14^{A}	3.67^{B}	

T1: Irrigation using non-saline water (NS) at 100% of ETc, T2: Irrigation using NS at 75% of ETc, T3: Irrigation using NS at 50% of ETc, T4: Irrigation using saline water (S) at 100% of ETc, T5: Irrigation using S at 75% of ETc, T6: Irrigation using S at 50% of ETc

(Table 4). The increased Na^+ and Cl^- concentrations in the leaves lowered the osmotic potential, contributing to the maintenance of the water potential difference between the leaves and the soil required to obtain water from the saline solution (Cuartero and Fernandez-Munoz, 1998). Proline content increased significantly as abiotic stress increased. These results are in agreement with the previous work of Zahra *et al.* (2010). Under salt stress conditions, proline accumulation in the plant has been shown to increase for the adjustment of osmoregulation (Aziz *et al.*, 1999). Proline has been proposed as a compatible solute for the adjustment of the osmotic potential in the cytoplasm. Thus, proline can be used as a metabolic marker of stress Zahra *et al.* (2010).

The interaction between grafting and stress treatment had a significant influence on leaf proline, Na^+ and Cl^- concentrations. The highest values for these three traits were observed for un-grafted plants under the T4 and T6 treatments. The values of the three traits in the grafted tomato plants under these treatments were statistically lower than the corresponding values for the un-grafted plants. These results illustrated that grafting may reduce the negative effects of salt and high water stress treatments and could improve salt and drought tolerance in tomato plants through reducing the concentrations of Na^+ and Cl^- in leaf tissue. The present results agree with those of other studies which have reported the ability of rootstock to reduce the accumulation of Na^+ and Cl^- in the leaves of grafted plants (Estan *et al.*, 2005; Martinez-Rodriguez *et al.*, 2008).

CONCLUSION

The positive effects of grafting on plant growth and productivity, in addition to its resultant increases in WUE, support the feasibility of the technique as a method for improving salt and drought tolerance in tomato cultivars grown under greenhouse conditions. Grafted tomato plants under moderate water stress (75% ETc) can conserve approximately 25% of irrigation water without any significant reduction in the total yield. Tomato plants could also be grown under salt stress (EC 4.5 dS m^{-1}) using the grafting technique with satisfactory productivity (reduction in total yield of only 4-5%, compared with 21-22% under salt stress without grafting). Grafting represents a viable alternative strategy for the improvement of salt and water stress tolerance in tomato, particularly when using a suitable rootstock.

ACKNOWLEDGMENT

We would like to express our deep thanks to the Deanship of Scientific Research, King Saud University and Agricultural Research Center, College of Food and Agriculture Sciences for financial support.

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