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Responses of grafted tomato (*Solanum lycopersicon* L.) to abiotic stresses in Saudi Arabia

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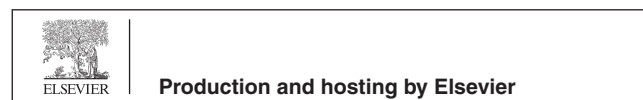
Abstract Quantity and quality of irrigation water are considered the most imperative limiting factors for plant production in arid environment. Adoptions of strategies can minimize crop water consumption while nonexistent yield reduction is considered challenge for scholars especially in arid environment. Grafting is regarded as a promising tool to avoid or reduce yield loss caused by abiotic stresses. Tomato (*Solanum lycopersium* Mill.), commercial cultivar Faridah was grafted on Uni-fort rootstock and grown under regulated deficit irrigation (RDI) (100%, 80% and 60% ET_c), using two types of irrigation water, fresh (EC = 0.86 dS/m) and brackish (EC = 3.52 dS/m). The effects of grafting and RDI on water use efficiency, vegetative growth, yield, fruit quality were investigated. Plant vegetative growth was reduced under water and salinity stresses. Grafting the plant significantly improves the vegetative growth under both conditions. The results showed that crop yield, Ca⁺² and K⁺ were considerably increased in grafted tomato compared to non-grafted plants under water and salinity stresses. Grafted tomato plants accumulated less Na⁺ and Cl⁻, especially under high levels of salinity compared to non-grafted plants. Grafting tomato plants showed a slight decrease on the fruit quality traits such as vitamin C, titratable acidity (TA) and total soluble solids (TSS). This study confirmed that grafted tomato plants can mitigate undesirable impact of salt stress on growth and fruit quality.

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1. Introduction

Tomato plant (*Solanum lycopersium* Mill.) is among the highly cultivated vegetable crops worldwide. Yet, the abiotic stresses such as salinity and water stress are capable of reducing the production and thus cause severe constrains to growth. Tomato was considered one of the main greenhouse crops worldwide. In 2012, more than 500 thousand tons of tomatoes

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were produced in Saudi Arabia. Most of that production (60%) was grown on soil in greenhouses (MOA, 2012). Tomato growth on soil was inhibited by suboptimal conditions such as water and salinity stresses (Schwarz et al., 2010). Most commercial tomato cultivars are sensitive to salinity (Dehyer and Gordon, 2005) or to water stress (Foolad, 2004).

Mitigate negative salinity effect will have a positive impact on tomato production. Improving salt tolerance by traditional breeding programs has a limited success and cultivar development has been tedious (Cuartero et al., 2006). Vegetable grafting was found to be a rapid alternative to the relatively slow methods of breeding at the increasing environmental stress (Flores et al., 2010). Grafting currently became a global practice on vegetable production in many parts of the world. The cultivated area of grafted tomato has increased in recent years worldwide and has been recently introduced in Saudi Arabia. This technique has been used to enhance tolerance against abiotic stresses such as water and salinity stresses (Colla et al., 2010). Besides the positive impact of grafting on improving the salt tolerance it also promotes water use efficiency (Oztekin et al., 2007), and this technique has been proven to increase tomato plant vigor, water consumption and yield under saline conditions (Tuzel and Oztekin, 2009).

The objectives of introducing grafted tomato is to obtain a cultivar with higher production and quality (Lee, 1994), to reduce infection from soil-borne diseases caused by pathogens (McAvoy et al., 2012) and to increase tolerance to abiotic stresses (Keatinge et al., 2014).

Grafting of commercial tomato into selected rootstocks capable of reducing the effect of salinity will avoid or reduce losses in production caused by salinity or water stress. Recent studies showed that the use of the suitable rootstocks will help to improve salinity and water stresses in tomato (Schwarz et al., 2010; Keatinge et al., 2014). Turhan et al. (2011) reported that grafting of tomato plants on tolerance rootstocks to abiotic stresses has positively increased the yield, particularly under greenhouse conditions. Also, Oztekin et al. (2007) concluded that grafting can increase the tolerance of tomato to salinity and promote water use efficiency.

In Saudi Arabia, with scarcity of irrigation water, the use of brackish water in agricultural production has been increased in recent years. One potential approach to reduce production losses under abiotic stresses is using grafting of high yield varieties on suitable rootstocks capable of mitigating the effects of abiotic stresses. The present study aims to investigate the response of grafted tomato plant to salinity and water stresses.

2. Materials and methods

2.1. Experimental site and tomato plant materials

The study was conducted in a controlled polyethylene greenhouse at College of Agriculture Experimental Station 40 km Southwest of Riyadh, Saudi Arabia, during 2011/2012 and 2012/2013 seasons. The soil was non-saline (EC ranged from 2.2 to 2.4 dS/m), calcareous (CaCO₃ ranged from 26% to 32%), sandy in texture and had a pH ranging from 7.9 to 8.4. Faridah tomato cultivar (Golden Valley Seed Company, USA) was used as a scion while Unifor (DeRuiter Seed Company, Netherland) was used as a rootstock. Both cultivars belong to the round type tomato group (*S. lycopersicum* Mill.).

The choice of a rootstock was determined based on the recommendation by the company and that rootstock Unifort is characterized by a similar spectrum of resistance/tolerance to abiotic stresses (Rumbos et al., 2011). The seeds of scion "Faridah" were sown on the 19th of Sept. for 2011/2012 and 2012/2013 seasons. Seeds of the scion were sown three days earlier than the seeds of rootstock to ensure optimum stem diameter between both scion and rootstock at grafting time due to the variations in the growth vigor (Khah et al., 2006). When the seedlings of rootstock and scion had 3 true leaves on the 9th of Oct., tube grafting was applied. Plastic tube was placed onto the cut end of both scion and rootstock at 45°. The cut end of scion was then inserted into tube in direct contact with the cut of rootstock (Marsic and Osvold, 2004). Grafted seedlings were kept for 10 days under moist and dark conditions to enhance the survival rate. The grafted seedling was then transplanted to a greenhouse on the 19th of Oct. The experiment was laid out in split-split-plot system in randomized complete blocks design (RCBD) with two water quality (brackish water and fresh water) as main treatments, grafting and non-grafting as sub-plot treatments, and irrigation levels as sub-sub-plots. The two irrigation water quality are used; fresh water with an EC of 0.52 dS/m and brackish water with an EC of 3.5 dS/m. The irrigation treatments composed of irrigation water at three levels of crop evapotranspiration (ETc): 60%, 80% and 100% ETc. The total number of treatments was 12 with three replications for each treatment (Table 1).

The fresh water had pH 6.44 and sodium adsorption ratio (SAR) 4.33; while the brackish water pH and SAR were 7.3 and 4.49, respectively. Irrigation scheduling methods were based on pan evaporations, which are available and easy to use in the greenhouse. Crop evapotranspiration ETc was calculated using the following equation:

$$ETc = E_o \times K_p \times K_c$$

Table 1 Water level treatments for grafting and non-grafting tomato plants at each source of water quality (fresh and brackish water).

DI treatments	Description
T1	100% ETc with ECw (0.52 dS/m), grafted tomato
T2	80% ETc with ECw (0.52 dS/m), grafted tomato
T3	60% ETc with ECw (0.52 dS/m), grafted tomato
T4	100% ETc with ECw (0.52 dS/m), non-grafted tomato
T5	80% ETc with ECw (0.52 dS/m), non-grafted tomato
T6	60% ETc with ECw (0.52 dS/m), non-grafted tomato
T7	100% ETc with ECw (3.76 dS/m), grafted tomato
T8	80% ETc with ECw (3.76 dS/m), grafted tomato
T9	60% ETc with ECw (3.76 dS/m), grafted tomato
T10	100% ETc with ECw (3.76 dS/m), non-grafted tomato
T11	80% ETc with ECw (3.76 dS/m), non-grafted tomato
T12	60% ETc with ECw (3.76 dS/m), non-grafted tomato

Table 2 Effect of grafting technique on tomato plant growth traits.

Grafting treatment	Stem diameter (mm)	Plant height (cm)	Shoot fresh weight (g)	Root fresh weight (gm)
<i>First season 2011/2012</i>				
Grafted	13.08	195.7	971.06	42.22
Non-grafted	12.62	188.0	910.78	43.28
LSD 0.05	0.289	3.47	44.82	2.91
<i>Second season 2012/2013</i>				
Grafted	13.12	197.72	973.97	41.78
Non-grafted	12.61	189.17	918.94	42.33
LSD 0.05	0.083	1.047	13.36	1.34

where,

ETc = maximum daily crop evapotranspiration in mm.

Eo = evaporation from a class A pan in mm.

Kp = crop coefficient with ranges between 0.7 and 0.9.

Kc = crop coefficient with ranges between 0.4 and 1.2 depending on growth stage.

The Kp and Kc were calculated according to Allen et al. (1998).

At the fruiting stage, three representative plant samples were randomly chosen from each sub-plot and separated into roots, stems and leaves to evaluate the plant growth. The plant parts were dried at 70 °C in a forced-air oven until the weight became constant and the total dry weight was determined. The total tomato fruit weight through the entire harvesting period for each experimental unit was recorded and converted into total tomato fruit yield per ha. A random fruit sample (10 fruits) was taken from each experimental unit at the peak of harvest for laboratory analyses. The homogenized fruit juice was subjected to the following determinations: total soluble solids (TSS), vitamin C content, and the titratable acidity (TA) according to AOAC (1995) procedures. Na⁺, Ca⁺² and K⁺ concentrations were determinate in the leaves according to Westerman and Woolley (1990) and Cl⁻ according to Yeo et al. (1977).

Data were analyzed using statistical analysis system (SAS) version 8.1 (SAS, 2008). An analysis of variance was con-

ducted separately within each year for different growth variables. Least significant difference (LSD) test at 0.05 level was carried out on the means as described by Snedecor and Cochran (1989).

3. Results and discussions

3.1. Impact of grafting on tomato plant growth traits

Grafting tomato plant had a significant effect on plant vegetative growth (Table 2). The result showed a significant increase in stem diameter, plant height and shoot fresh weight of grafted plant compared to non grafted plant in both growing seasons. While, no significant effect was observed on root fresh weight. These results are supported by the findings of Khah et al. (2006) and Karaca et al. (2012). They found that grafted tomato plants were more vigorous than non-grafted plants.

3.1.1. Interaction effects between grafting and both water levels and salinity stresses on tomato plant growth traits

The interaction effects between grafting and water stress (Table 3) and between grafting and salinity stress (Table 4) followed the same trends as the main effects of the grafting on tomato plant growth (Table 2). The highest vegetative growth traits were recorded when the grafted plants were combined with the highest level of irrigation water treatment (100%

Table 3 Effect of grafting technique on tomato plant growth traits under different levels of water stresses.

Grafting treatment	Water stress level (% ETc)	Stem diameter (mm)	Plant height (cm)	Shoot fresh weight (g)	Root fresh weight (g)
<i>First season 2011/2012</i>					
Grafted	100	14.60	213.2	1150.3	51.83
	80	12.57	191.3	910.0	33.83
	60	12.10	182.7	852.8	41.00
Non-grafted	100	13.23	197.8	1021.8	41.00
	80	13.02	191.5	958.0	44.17
	60	11.62	174.7	752.5	39.67
LSD 0.05		2.17	18.5	226.8	31.68
<i>Second season 2012/2013</i>					
Grafted	100	14.87	219.3	1137.7	51.67
	80	12.60	192.0	926.3	32.50
	60	12.15	181.8	857.0	41.17
Non-grafted	100	13.28	202.8	1053.0	41.00
	80	13.01	190.5	940.2	47.67
	60	11.52	174.2	763.7	38.33
LSD 0.05		2.39	18.0	142.4	31.68

Table 4 Effect of grafting technique on tomato plant growth traits under different levels of irrigation water salinity.

Salinity water treatment (dS/m)	Grafting treatment	Stem diameter (mm)	Plant height (cm)	Shoot fresh weight (g)	Root fresh weight (gm)
<i>First season 2011/2012</i>					
Fresh (0.52)	Grafted	14.12	199.2	1123.3	45.22
	Non-grafted	13.36	191.4	1013.8	46.78
Brackish (3.76)	Grafted	11.96	192.2	818.8	39.22
	Non-grafted	11.89	184.6	807.8	39.78
LSD 0.05		1.63	0.23	204.2	2.07
<i>Second season 2012/2013</i>					
Fresh (0.52)	Grafted	14.34	200.6	1129.2	44.89
	Non-grafted	13.44	191.7	1016.2	46.67
Brackish (3.76)	Grafted	12.07	194.9	818.1	38.67
	Non-grafted	11.77	186.7	821.7	38.00
LSD 0.05		1.24	6.91	241.5	5.06

Table 5 Effect of grafting technique on fruit yield and quality of tomato plants.

Grafting treatment	Total yield (kg/m ²)	TSS (%)	TA (%)	Vitamin C (mg/100 g)
<i>First season 2011/2012</i>				
Grafted	13.02	5.49	0.534	18.18
Non-grafted	12.02	5.57	0.549	18.29
LSD 0.05	0.442	0.115	0.085	0.509
<i>Second season 2012/2013</i>				
Grafted	13.26	5.46	0.549	18.31
Non-grafted	12.37	5.61	0.557	18.46
LSD 0.05	0.066	0.058	0.011	0.091

ETc), followed by the treatment of grafted plants under moderate water stress (80% ETc) (Table 3). The grafted plants under the salt stress treatment also had higher values of vegetative growth traits compared to non-grafted plants (Table 4). Ezzo et al. (2010) reported that improvement in vegetative growth traits under a higher level of irrigation water could

Table 7 Effect of grafting technique on fruit yield and quality of tomato plants under different levels of irrigation water salinity.

Salinity treatment (dS/m)	Grafting treatment	Total yield (kg/m ²)	TSS (%)	TA (%)	Vitamin C (mg/100 g)
<i>First season 2011/2012</i>					
0.52	Grafted	13.75	5.20	0.55	17.04
	Non-grafted	13.36	5.07	0.54	16.60
3.76	Grafted	12.30	5.78	0.51	19.31
	Non-grafted	10.69	6.08	0.55	19.98
LSD 0.05		2.53	0.90	0.09	2.30
<i>Second season 2012/2013</i>					
0.52	Grafted	13.95	5.17	0.56	17.14
	Non-grafted	13.62	5.08	0.56	16.68
3.76	Grafted	12.56	5.76	0.54	19.47
	Non-grafted	11.13	6.13	0.55	20.23
LSD 0.05		2.30	0.97	0.02	5.56

be attributed to better water content in plant tissue which enhanced water uptake. The data clearly indicate that vegetative growth of tomato plants were improved by grafting under

Table 6 Effect of grafting technique on fruit yield and quality of tomato plants under different levels of water stresses.

Grafting treatment	Water stress level (% ETc)	Total yield (kg/m ²)	TSS (%)	TA (%)	Vitamin C (mg/100 g)
<i>First season 2011/2012</i>					
Grafted	100	16.12	5.05	0.49	16.65
	80	12.67	5.75	0.56	19.32
	60	10.28	5.67	0.54	18.57
Non-grafted	100	14.70	5.53	0.49	18.02
	80	12.48	5.23	0.54	17.45
	60	8.88	5.95	0.61	19.40
LSD 0.05		1.70	1.27	0.11	4.15
<i>Second season 2012/2013</i>					
Grafted	100	16.31	4.97	0.48	16.75
	80	12.80	5.70	0.56	19.48
	60	10.66	5.72	0.57	18.68
Non-grafted	100	15.19	5.47	0.50	18.25
	80	12.86	5.37	0.54	17.50
	60	9.06	5.98	0.63	19.62
LSD 0.05		2.05	1.02	0.14	4.47

Table 8 Effect of grafting technique on nutrient composition of tomato leaves.

Grafting treatment	Ca (meq/100 g DW)	K (meq/100 g DW)	Na (meq/100 g DW)	Cl (meq/100 g DW)
<i>First season 2011/2012</i>				
Grafted	79.67	74.97	11.01	83.48
Non-grafted	77.35	73.90	11.20	83.95
LSD 0.05	0.824	0.391	0.102	0.226
<i>Second season 2012/2013</i>				
Grafted	79.70	74.87	11.17	83.61
Non-grafted	77.00	73.57	11.33	84.05
LSD 0.05	0.270	0.277	0.091	0.089

water and salinity stresses. These results illustrated that the adverse effects of salt stress can be reduced by grafting. These results were in agreement with several investigators who found an improvement in tomato growth and yield by grafting under water stress (Bhatt et al., 2002) and also under salinity stress conditions (Flores et al., 2010; Voutsela et al., 2012).

3.2. Yield and quality of tomato fruit

Grafting tomato plants resulted in a higher total yield compared to non-grafted plants (Table 5). The total yield was increased by almost 8.0% in the first season and by 7.0% in the second season. The improvement in the total yield of grafted tomato plants could be attributed to the vigorous plant growth (Table 2). Similar results were reported by Turhan et al. (2011) and Echevarria et al. (2012) who found that grafting tomato plants improved the yield and its components.

Fruit quality traits including TSS, TA and vitamin C were significantly decreased in the fruit of grafted tomato plants (Table 5). Similar result was reported by Rouphael et al. (2010) and Turhan et al. (2011) who found a reduction in tomato fruit quality of grafting plants compared to non-grafted plants.

The same trend was observed on the grafted plants grown under water and salinity stresses. Total yield was significantly increased by grafting under different levels of water stress (Table 6). The percentage of increase was 13.6% in the first season and 15.0% in the second season under the highest level of water stress (60% ETc). While, under saline condition the total yield was increased by 13.0% and 11.0% in the first and second seasons, respectively (Table 7). Similar findings

Table 9 Effect of grafting technique on nutrient compositions of tomato leaves under different levels of water stresses.

Grafting treatment	Water stress level (% ETc)	Ca (meq/100 g DW)	K (meq/100 g DW)	Na (meq/100 g DW)	Cl (meq/100 g DW)
<i>First season 2011/2012</i>					
Grafted	100	84.97	76.82	10.67	81.91
	80	79.61	75.42	11.00	83.72
	60	74.44	72.67	11.37	84.81
Non-grafted	100	81.29	76.33	10.78	83.35
	80	77.73	73.38	11.27	83.45
	60	73.03	71.99	11.56	85.03
LSD 0.05		2.857	2.023	0.183	2.113
<i>Second season 2012/2013</i>					
Grafted	100	85.53	77.16	10.92	81.92
	80	79.50	75.12	11.15	83.86
	60	74.07	72.32	11.45	85.07
Non-grafted	100	81.63	76.40	10.87	83.55
	80	77.65	72.89	11.37	83.60
	60	71.73	71.42	11.77	85.01
LSD 0.05		2.553	1.939	0.453	2.489

Table 10 Effect of grafting technique on nutrient compositions of tomato leaves under different levels of irrigation water salinity.

Salinity treatment (dS/m)	Grafting treatment	Ca (meq/100 g DW)	K (meq/100 g DW)	Na (meq/100 g DW)	Cl (meq/100 g DW)
<i>First season 2011/2012</i>					
0.52	Grafted	84.66	76.81	10.47	81.57
	Non-grafted	82.30	75.64	10.67	81.64
3.76	Grafted	74.68	73.13	11.56	85.39
	Non-grafted	72.41	72.15	11.70	86.25
LSD 0.05		0.184	0.396	0.039	1.625
<i>Second season 2012/2013</i>					
0.52	Grafted	84.72	76.72	10.73	81.74
	Non-grafted	82.27	75.45	10.78	81.73
3.76	Grafted	74.68	73.02	11.62	85.49
	Non-grafted	71.73	71.69	11.88	86.38
LSD 0.05		0.049	0.131	0.412	1.858

were obtained by Fernandez-Garcia et al. (2004), who reported that tomato fruit yield increased in grafted plants under well-watered and water stress conditions and that increase was primarily associated with the increasing mean fruit weight and number of fruits per plant. The lowest fruit yield was observed in non grafted plants under both high salt and water stresses is likely due to the combination effect of water deficiency and a poor root system (Lee, 1994). Grafting tended to reduce some tomato fruit quality traits such as TA and vitamin C, under stress and non stress conditions although some results are not significant (Tables 6 and 7).

3.3. Grafting and nutrient content

Leaf nutrient content was also affected by grafting tomato plants. The grafted plants seem to accumulate more Ca^{+2} and K^{+} in the leaves while the levels of Na^{+} and Cl^{-} were decreased (Table 8). Reduction in Na^{+} and Cl^{-} contents caused by grafting tomato plants was also reported by Martinez-Rodriguez et al. (2002). Estan et al. (2005) reported that the positive effect of grafting on tomato plant may be attributed to the restriction of Na^{+} and Cl^{-} movement to scion vegetative growth.

Similar trend of leaf nutrient content was observed on the grafted plants grown under water and salinity stresses (Tables 9 and 10). A higher K^{+} content of tomato plants seems to be related to the improvement in salt tolerance in grafted plants (Yong et al., 2009; Huang et al., 2009). Albacete et al. (2009) reported that salt tolerance of grafted tomato plants was associated with xylem K^{+} but not Na^{+} . However, Colla et al. (2010) reported that the direct relationship between leaf K^{+} homeostasis and salinity tolerance of grafted plant has not yet been established.

4. Conclusions

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 cultivars grown under greenhouse conditions. Grafted tomato improved the yield under water and salt stresses. Tomato plants could also be grown under salt stress (EC 3.76 dS/m) using the grafting technique with satisfactory productivity. Grafting represents a viable alternative strategy for the improvement in salt and water stresses tolerance in tomato plant. Grafting is an integrative reciprocal process and, therefore, both scion and rootstock can influence salt tolerance of grafted plants. Grafted plants grow under saline and/or water stress conditions often exhibiting better growth and yield and lower accumulation of Na^{+} and Cl^{-} in shoots than non-grafted plants.

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