Grafting improves cucumber water stress tolerance in Saudi Arabia

Abdulaziz R. Al-Harbi, Abdulrasoul M. Al-Omran, Khadiga Alharbi

*Department of Plant Production, College of Food and Agricultural Sciences, King Saud University, Saudi Arabia
bDepartment of Soil Science, College of Food and Agricultural Sciences, King Saud University, Saudi Arabia
cBiology Department, College of Science, Princess Nourah Bint Abdulrahman University, Saudi Arabia

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A B S T R A C T
Water scarcity is a major limiting factor for crop productivity in arid and semi-arid areas. Grafting elite commercial cultivars onto selected vigorous rootstocks is considered as a useful strategy to alleviate the impact of environmental stresses. This study aims to investigate the feasibility of using grafting to improve fruit yield and quality of cucumber under water stress conditions. Alosama F1 cucumber cultivar (Cucumis sativus L.) was grafted onto Affyne (Cucumis sativus L.) and Shintoza A90 (Cucurbita maxima × C. moschata) rootstocks. Non-grafted plants were used as control. All genotypes were grown under three surface drip irrigation regimes: 50%, 75% and 100% of the crop evapotranspiration (ETc), which represent high-water stress, moderate-water stress and non-water stress conditions, respectively. Yield and fruit quality traits were analyzed and assessed. In comparison to the non-grafted plants, the best grafting treatment under water stress was Alosama F1 grafted onto Shintoza A90 rootstock. It had an overall improved yield and fruit quality under water stress owing to an increase in the total fruit yield by 27%, from 4.815 kg plant⁻¹ in non-grafted treatment to 6.149 kg plant⁻¹ in graft treatment under moderate-water stress, total soluble solid contents (13%), titratable acidity (39%) and vitamin C (33%).

1. Introduction

Environmental stresses represent the most important limiting conditions for horticultural productivity and plant exploitation worldwide. Plant species adapt to this adverse condition in different ways. Some plants can (a) complete their life cycle under optimum conditions, (b) reduce water loss by reducing leaf size or stomata pores, (c) maintain growth even during water deficit by retaining water content, or (d) increase water use efficiency (WUE) with limited available water (Bressan et al., 2002).

Grafting elite commercial cultivars onto selected vigorous rootstocks is a special method of adapting plants to counteract environmental stresses (Lee and Oda, 2003). Grafting is currently regarded as a rapid alternative tool to the relatively slow breeding methodology for increasing the environmental-stress tolerance of fruiting vegetables (Flores et al., 2010). Potential approach to reduce losses in production and improve water use efficiency under drought conditions in high-yielding genotypes would be to graft these varieties onto proper rootstocks capable of reducing the effect of water stress on the shoot and to increase tolerance to abiotic stresses (Keatinge et al. 2014).

Cucumber (Cucumis sativus L.) is one of the main greenhouse vegetable crops widely grown in Saudi Arabia. The total greenhouse area for cucumber production in 2013 was 2605 hectares produced 236,087 tons (Ministry of Agriculture, 2014). Major factor influencing growth and yield of cucumber is water quantity. Nuysal et al. (2010) studied the effects of different rootstocks on plant growth, yield, fruit quality and water consumption in cucumber. The highest yield was obtained from Nun 9075 (19.02 kg m⁻²), which was 24.5 and 23.5% higher than in the non-grafted and self-
2. Materials and methods

2.1. Experimental site and plant materials

Two greenhouse experiments were conducted during the 2014 and 2015 seasons at the Agricultural Research and Experimental Station, Faculty of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia. Responses of commercial cultivars of cucumber grafted on two different rootstocks to water stress (drought) was investigated using three surface drip irrigation regimes: 50%, 75% and 100% of the crop evapotranspiration (ETc), which represent high-water stress, moderate-water stress and low-water stress conditions, respectively. The same irrigation set time and irrigation frequency were applied for each treatment, but different irrigation rate were obtained by using different emitters.

2.2. Grafting and water stress treatments

Alosama F1 cucumber cultivar (Cucumis sativus L.) was used as a scion while Affyne (Cucumis sativus L.) and Shintoza (Cucurbita maxima × Cucurbita moschata) genotypes were used as rootstocks. Non-grafted plants were used as control. Plastic tube grafting was applied to seedlings, when the scions had 2 true leaves and the rootstock had 2–3 true leaves. Rootstocks were cut at a slant and scions were cut by the same way. Grafted seedlings were kept for 5 days under controlled conditions (90–95% RH, 24–26 ºC and 45% shading) to enhance the survival rate. Non-grafted seedlings (control plants) were produced at the same nursery under identical conditions and were planted in the greenhouse at the same time.

The seeds of the cucumber genotypes were sown in seedling trays on 10/1/2014 and 3/9/2015 for the first and second seasons, respectively. Seven-day-old grafts of the cultivars onto their rootstocks were performed. Ten days-old seedlings transplanted onto soil in the fiberglass greenhouse.

The temperature and relative humidity was set to approximately 27 ± 0.5 ºC and 80 ± 2%, during the growth. Fertilization and other cultural practices was applied as commonly recommended in commercial cucumber production. The soil texture was determined, and a mechanical soil analysis was conducted and presented in Table 1.

The quantity of irrigation water supplied was scheduled based on the crop evapotranspiration (ETc) calculated using the Penman Monteith equation with data from the meteorological station near the study area matched with the crop coefficient values of the cucumber in the region. The irrigation water was applied at a target rate of 50%, 75% and 100% ETc, using emitters with different irrigation rate (4, 6 and 8 liter per hour). Drip tubing (GR type, 16 mm diameter) with 50 cm emitter spacing built in was used in irrigation as described in (Al-Harbi et al., 2017).

The field water productivity (also known as WUE, which is the relationship between crop yield and water applied) was calculated using Eq. (1), expressed as kg/m² or Ton/ha.

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\text{WUE} = \frac{\text{Yield (Kg ton)}}{\text{Water Applied (m³)}}
\]

2.3. Experimental layout

The experimental layout was a split plot in a randomized complete block design with four replications. The water stress treatments were randomly allocated to the main plots, whereas the grafting treatments were arranged in the sub-plots. The planting distance was 50 and 100 cm between plants and rows, respectively.

2.4. Measurement of traits

Random samples of four plants from each experimental unit were chosen at 45 days after transplanting to measure vegetative growth traits. Vine fresh and dry weights were measured. Vine dry weight samples (each about 50 g) were determined by drying at 70 ºC until constant weight, using a forced-air oven. Total yield (all the collected fruits) was determined. Samples of five ripe fruits (from the third-fourth trusses) representing each sub-plot were picked for analysis of the fruit quality traits; total soluble solids (TSS, %), vitamin C (mg 100 g⁻¹ fw) and titratable acidity (TA, %).

An extract was obtained by blending and filtering flesh of each fruit sample. TSS (%) was determined using a digital refractometer (PR-101 model, ATAGO, Japan). For determination of TA, 10 g of extracted juice was taken and carefully mixed with 50 ml of distilled water. The mixture was then titrated by 0.1 N NaOH until a pH value reached 8.1. The volume of the sodium hydroxide added to the solution, was multiplied by a correction factor of 0.064 to estimate TA as the percentage of citric acid equivalents in the fruit juice (Turhan and Seniz, 2009). Vitamin C (mg 100 g⁻¹ fw, as ascorbic acid) was measured in cucumber extract using 2, 6 dichlorophenol-indophenol dye (Patane et al., 2011).

Sampling locations for both soil water content and soil salinity were 0.15 m from the plant at the soil surface and 0.15 m depth intervals down to 0.60 m depth. The electrical conductivity of saturated extract (ECe, dS/m) was determined for each sample then

### Table 1

| Parameters | Soil depth, cm |
|------------|----------------|
|            | 0–15 | 15–30 | 30–50 | 50–70 |
| Particle – size distribution, % | |
| Sand        | 93.0  | 89.0  | 89.0  | 89.0  |
| Silt        | 1.0   | 6.0   | 4.0   | 6.0   |
| Clay        | 6.0   | 5.0   | 7.0   | 5.0   |
| Textural class | Sand | Sand | Sand | Sand |
| Organic matter content, % | 0.03  | 0.13  | 0.16  | 0.02  |
| CaCO₃, %    | 32.0  | 27.0  | 24.0  | 30.0  |
| Saturation water content, %/w/w | 27.2  | 28.3  | 29.3  | 29.8  |
| Field capacity, %/w/w | 14.8  | 16.4  | 17.3  | 16.8  |
| Permanent wilting point, %/w/w | 6.4   | 7.2   | 6.7   | 6.3   |
| Plant available water, %/w/w | 8.4   | 9.2   | 10.4  | 10.5  |
| pH          | 7.51  | 7.72  | 7.92  | 8.05  |
| Electrical conductivity (EC, dS/m) | 2.75  | 2.65  | 2.00  | 1.80  |
| Soluble cations, meq/L | |
| Ca²⁺        | 16.4  | 11.1  | 11.1  | 9.1   |
| Mg²⁺        | 6.0   | 6.7   | 5.6   | 5.0   |
| Na⁺         | 11.0  | 14.4  | 6.5   | 6.4   |
| K⁺          | 1.5   | 2.1   | 1.7   | 1.5   |
| Soluble anions, meq/L | |
| CO₃⁻        | Tr.   | Tr.   | Tr.   | Tr.   |
| HCO₃⁻       | 3.9   | 4.0   | 2.0   | 4.0   |
| Cl⁻         | 9.8   | 10.5  | 7.0   | 5.0   |
| SO₄²⁻       | 12.8  | 13.9  | 10.9  | 8.7   |
| SAR         | 3.29  | 4.83  | 2.18  | 2.41  |
Effect of grafting using different rootstocks on leaf dry weight, stem dry weight and root dry weight at flowering growth stage of cucumber cultivar Alosama F1 grown under different level of water stress.

### Table 2

| Water stress level (% of ETc) | Leaf dry weight (g) | Stem dry weight (g) | Root dry weight (g) |
|------------------------------|---------------------|---------------------|---------------------|
|                              | Non-grafted         | Grafted on Shintoza | Grafted on Affyne   | Average |
|                              |                     |                     |                     |         |
| First Season (2014)          |                     |                     |                     |         |
| 100% of ETc                  | 182.3               | 334.6               | 326.7               | 281.2 a |
| 75% of ETc                   | 164.5               | 305.7               | 293.4               | 254.5 b |
| 50% of ETc                   | 137.2               | 261.6               | 236.2               | 218.3 c |
| Average                      | 161.3 c             | 300.6 a             | 292.1 b             | 245.3 c |

Second Season (2015)

| 100% of ETc                  | 172.4               | 319.6               | 309.2               | 267.0 a |
| 75% of ETc                   | 161.2               | 300.6               | 288.7               | 250.1 b |
| 50% of ETc                   | 135.4               | 249.1               | 227.1               | 203.8 c |
| Average                      | 156.3 c             | 289.7 a             | 273.0 b             | 249.3 c |

* Treatment means with the same letter are not significant using LSD test at 5% level.

### Table 3

Effect of grafting using different rootstocks on leaf fresh weight, stem fresh weight and root fresh weight at flowering growth stage of cucumber cultivar Alosama F1 grown under different level of water stress.

| Water stress level (% of ETc) | Leaf fresh weight (g) | Stem fresh weight (g) | Root fresh weight (g) |
|------------------------------|-----------------------|-----------------------|-----------------------|
|                              | Non-grafted           | Grafted on Shintoza   | Grafted on Affyne     | Average |
|                              |                       |                       |                       |         |
| First Season (2014)          |                       |                       |                       |         |
| 100% of ETc                  | 33.9                  | 45.8                  | 40.6                  | 40.1 a  |
| 75% of ETc                   | 26.7                  | 39.6                  | 38.1                  | 34.8 b  |
| 50% of ETc                   | 21.2                  | 32.7                  | 30.4                  | 28.1 c  |
| Average                      | 27.2 c                | 39.3 a                | 36.3 b                | 32.5 c  |

Second Season (2015)

| 100% of ETc                  | 31.9                  | 44.6                  | 41.3                  | 39.2 a  |
| 75% of ETc                   | 25.4                  | 37.2                  | 36.2                  | 32.9 b  |
| 50% of ETc                   | 20.6                  | 30.1                  | 28.2                  | 26.3 c  |
| Average                      | 25.9 b                | 37.3 a                | 35.2 a                | 33.5 b  |

* Treatment means with the same letter are not significant using LSD test at 5% level.

### Table 4

Effect of grafting using different rootstocks on average fruit weight, total yield and water use efficiency (WUE) of cucumber cultivar Alosama F1 grown under different level of water stress.

| Water stress level (% of ETc) | Average fruit weight (g) | Total yield (kg/plant) | WUE (kg M⁻²) |
|------------------------------|--------------------------|------------------------|--------------|
|                              | Non-grafted              | Grafted on Shintoza    | Grafted on Affyne | Average |
|                              |                          |                        |              |
| First Season (2014)          |                          |                        |              |
| 100% of ETc                  | 104.3                    | 130.2                  | 116.3        | 116.9 a |
| 75% of ETc                   | 93.5                     | 112.6                  | 107.6        | 104.5 b |
| 50% of ETc                   | 78.6                     | 98.6                   | 99.0         | 92.0 c  |
| Average                      | 92.1 c                   | 113.8 a                | 107.6 b      | 98.0 b  |

Second Season (2015)

| 100% of ETc                  | 103.7                    | 117.3                  | 114.5        | 111.8 a |
| 75% of ETc                   | 90.3                     | 106.4                  | 103.1        | 99.9 b  |
| 50% of ETc                   | 74.9                     | 92.5                   | 91.7         | 86.3 c  |
| Average                      | 89.6 b                   | 105.4 a                | 103.1 a      | 97.0 b  |

* Treatment means with the same letter are not significant using LSD test at 5% level.

In order to determine the root distribution, photos were taken using a digital camera from the soil profile at the root zone with the dimensions of 25 cm from the plant at the two directions left, right and 60 cm depth. Then, photographs were transferred as a background for the dimensions of the Surfer Software program and took the X and Y dimensions of the root as described by FAO (1977) and reported by (Al-Omran et al., 2010; Al-Omran et al., 2012). Then, the X and Y dimensions were drawn using Microsoft Excel program. Soil water contents were determined by gravimetric method.

2.5 Statistical analysis

Data were subjected to analysis of variance using Statistical Analysis System (SAS) version 8.1 (SAS Institute, 2008). Differences between the means were evaluated for significance using a Revised Least Significant Difference (L.S.D.) test at 0.05 level, as described by Steel and Torrie (1980).
Table 5
Effect of grafting using different rootstocks on Vitamin C, Total soluble solids (TSS) and titratable acidity of cucumber cultivar Alosama F1 grown under different level of water stress.

| Water stress level (% of ETc) | Vitamin C (mg/100 g FW) | TSS (%) | TA (%) |
|-------------------------------|--------------------------|---------|--------|
|                               | Non-grafted | Grafted on Shintoza | Grafted on Affyne | Average | Non-grafted | Grafted on Shintoza | Grafted on Affyne | Average | Non-grafted | Grafted on Shintoza | Grafted on Affyne | Average |
| First Season (2014)           |             |                       |                     |         |             |                       |                     |         |             |                       |                     |         |
| 100 % of ETc                  | 3.2         | 4.3                   | 3.6                 | 3.7 **c** | 3.3         | 3.9                   | 3.6                 | 3.6 **c** | 0.14        | 0.20                   | 0.15                 | 0.16 **c** |
| 75 % of ETc                   | 3.6         | 4.8                   | 4.7                 | 4.3 **b** | 3.8         | 4.3                   | 4.1                 | 4.0 **b** | 0.16        | 0.22                   | 0.17                 | 0.18 **b** |
| 50 % of ETc                   | 4.2         | 6.0                   | 5.7                 | 5.3 **a** | 4.1         | 4.9                   | 4.7                 | 4.5 **a** | 0.18        | 0.25                   | 0.19                 | 0.20 **a** |
| Average                       | 3.6 **c**   | 5.0 **a**             | 4.6 **b**           | 4.8 **a** | 3.7 **b**   | 4.3 **a**             | 4.1 **a**           | 4.4 **a** | 0.16 **c** | 0.22 **a**             | 0.17 **b**           | 0.18 **b** |
| Second Season (2015)          |             |                       |                     |         |             |                       |                     |         |             |                       |                     |         |
| 100 % of ETc                  | 3.3         | 4.4                   | 4.1                 | 3.9 **c** | 3.1         | 3.4                   | 4                   | 3.5 **c** | 0.14        | 0.15                   | 0.16                 | 0.15 **b** |
| 75 % of ETc                   | 3.5         | 4.6                   | 4.5                 | 4.2 **b** | 3.6         | 3.8                   | 4.3                 | 3.9 **b** | 0.14        | 0.20                   | 0.21                 | 0.19 **a** |
| 50 % of ETc                   | 4.1         | 5.8                   | 5.4                 | 5.1 **a** | 4.0         | 4.3                   | 4.6                 | 4.3 **a** | 0.14        | 0.16                   | 0.17                 | 0.16 **b** |
| Average                       | 3.6 **c**   | 4.9 **a**             | 4.6 **b**           | 4.8 **a** | 3.5 **c**   | 3.8 **b**             | 4.3 **a**           | 4.4 **a** | 0.14 **c** | 0.17 **b**             | 0.18 **a**           |

* Treatment means with the same letter are not significant using LSD test at 5% level.

Fig. 1. Soil Water content for: (a) Alosama F1 ungrafted and irrigated with 100% ETc, (b) Alosama F1 grafted onto Shintoza A90 and irrigated with 100% ETc, (c) Alosama F1 grafted onto Affyne and irrigated with 100% ETc, (d) Alosama F1 ungrafted and irrigated with 50% ETc, (e) Alosama F1 grafted onto Shintoza A90 and irrigated with 50% ETc, (f) Alosama F1 grafted onto Affyne and irrigated with 50% ETc.
3. Results and discussion

3.1. Growth parameters

The grafted plants were more vigorous than the un-grafted plants, as shown by their heavier fresh and dry weights (Tables 2 and 3). In the first season, grafting on Shintoza enhanced the leaf, stem and root fresh weight from 261.6 to 334.6 g, 160.2 to 182.3 g and 20.5 to 32.7 g, respectively. While, in the second season the traits were increased from 2156.2 to 326.7 g, from 151.9 to 171.2 g and from 19.2 to 26.8 g (Table 2). The same trend was reported for leaf, stem and root dry weight (Table 2). 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 non-grafted plants. The effect of grafting on cucumber growth traits indicated a positive interaction between the scion and the rootstock. The stress treatments caused significant decreases in vegetative growth traits in comparison with the control treatment (100% of ETc). The greatest fresh weight was observed for the control treatment, followed by the moderate water stress treatment (75% of ETc). These results are in agreement with those of Nuysal et al. (2010) who demonstrated that cucumber plants grown under 80% or 100% ETc exhibited vigorous vegetative growth in comparison with plants grown at a lower irrigation level. The highest values for the three traits were recorded when the grafted on Shintoza plants were combined with the full irrigation treatment, followed by the treatment of grafted plants under moderate water stress for fresh and dry weight traits. 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. These results illustrated that the adverse effects of water stress can be reduced by grafting.

The average fruit weight, total yield and WUE of non-grafted plants were statistically lower than the corresponding values for plants grafted on Shintoza rootstock (Table 4). Grafting on Shintoza increased both average fruit weight and total yield by approximately 23.5% and 21.5% in the first season, and by 17.6% and 25.5% in the second season, respectively. The WUE of the grafted cucumber plants on Shintoza increased by 19.4% and 22.1% in the first season, and by 13.1% and 36.4% in the second season, respectively. 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.

Fruits of cucumber grafted onto Shintoza rootstock tended to have higher values of vit. C, TSS and TA compared with non-grafted fruits (Table 5). Grafted fruits accumulated higher vitamin
C and TSS contents in comparison with grafted fruits. This finding is in agreement with those of (Turhan et al. 2011), whom demonstrated that vit. C content was strongly reduced by grafting and that the use of rootstock improved the TSS of grafted tomato fruits. The water stress treatments significantly increased vit. C, TSS and TA levels. 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. 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.

3.2. Soil water content, salt and roots distributions

Soil water contents and salt distributions data in the root zone area for the treatments at the end of the experiment were graphically drawn on surface contour bases of selected treatments presented in Figs. 1 and 2. The figures indicated that soil water contents generally low in surface in both grafted and non-grafted plants and water content increase gradually with depth. Similarly, Al-Omran et al. (2010) reported that soil water content was less in surface layer in the root zone, but showed a gradual increase with soil depth.

In non-grafted treatment, soil water content was low in the surface (3.0–5.0%) at ETc 100% and increased gradually with depth to (8.0–9.0%) of 50 cm depth, while with 50%ETc, the soil water content in surface ranged (from 3 to 5%) and (5.5 to 6.5%) at 50 cm depth. This trend could be due to water evaporation from surface which decreased soil water content in the surface and gradually increase with depth related to the capillarity of the soil. The grafted with ETc100% treatment showed higher soil water content below 35 cm depth indicating higher infiltration and water loss below root zone. This trend is not clear at 50%ETc treatments (Fig. 1d and e).

The salt distribution in the root zone area showed an adverse trend when compared with soil water distribution (Fig. 2); it was high on the surface and decreased gradually with depth to the lowest value at 50 cm depth. The figure also showed that in all treatments lower ECe near emitters and increased away from the emitter. Salt accumulation appears to be reversibly related to soil water content in both grafted and non-grafted crops, but it appears that the higher application rate at ETc 100% alleviate the harmful effect of salts and create more suitable conditions for root growth mainly in the top 30 cm depth as reflected on the root distribution Fig. 3. The deeper root was observed with irrigation treatment of 50% ETc when compared with 100% ETc. It seems treatment of 50% Etc enhance root growth to deeper layer.

4. Conclusions

Grafting cucumber has improved growth and yield of the plant. Variations in yield and fruit quality could be attributed to the different growth parameters of cucumber cultivars. Alosama F1 cultivar was grafted onto Affyne and Shintoza A90 rootstocks. The use of a vigorous rootstock Shintoza, and in combination with a vigorous commercial cultivar Alosama as a scion can increase crop yield and improve fruit quality characteristics under water stress conditions. The obtained results realized many benefits including high marketable yield with saving water, which is the main target for greenhouse-cucumber producer. In addition to, better fruit quality, in terms of high TSS and VC contents, both are criterion for better quality of cucumber.

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References

Al-Harbi, A., Hejazi, A., Al-Omran, A.M., 2017. Response of grafted tomato (Solanum lycopersicon L.) to abiotic stresses in Saudi Arabia. Saudi J. Biol. Sci. 24 (6), 1274–1280.

Al-Omran, A.M., Al-Harbi, A.R., Wahb-Allah, M.A., Nadeem, M., El-Eter, A., 2010. Impact of irrigation water quality, irrigation systems, irrigation rates and soil amendments on tomato production in sandy calcareous soil. Turk J. Agric. 34, 59–73.

Al-Omran, A.M., Al-Harbi, A.R., Wahb-Allah, M.A., Nadeem, M., El-Eter, A., 2012. Management of irrigation water salinity in tomato production under calcareous sandy soils and drip irrigation. J. Agric. Sci. Technol. 14, 939–950.

Bressan, R.A., Hasegawa P.M., Locy, R.D., 2002. Stress physiology. In: Plant physiology, 3rd edited by Taiz, L., Zeiger, E., Sunderland, MA: Sinauer Associates Inc, pp 591–623.

FAO, 1977. Guidelines for soil profile description, second ed. Rome.

Flores, F.B., Sanchez-Bel, P., Estan, M.T., Martinez-Rodriguez, M.M., Moyano, E., Morales, B., Campos, J.F., Gracia-Abellan, J.O., Ega, M.I., Fernandez-Garcia, N., Romojaro, F., Bolarin, M.C., 2010. The effectiveness of grafting to improve tomato fruit quality. Sci. Hortic. 125, 211–217.

Golden Software, 2002. Contouring and 3D surface mapping for scientists and engineers version 7. Golden Software, Inc. www.goldensoftware.com.

Karaca, F., Yetisir, H., Solnaz, L., Candir, E., Kurt, S., Sari, N., Güler, Ü., 2012. Rootstock potential of Turkish Lagenaria siceraria germplasm for watermelon: plant growth, yield and quality. Turk J. Hortic For 36, 167–177.

Keatinge, J.D.H., Lin, L.-J., Ebert, A.W., Chen, W.Y., Hughes, J.d'A., Luther, G.C., Wang, J.-F., Ravshankar, M., 2014. Overcoming biotic and abiotic stresses in the Solanaceae through grafting: current status and future perspectives. Biol. Agric Hortic. https://doi.org/10.1080/01448756.2014.964317.

Khah, E.M., Kakava, E., Mavromatis, A., Chachalis, D., Goulas, C., 2006. Effect of grafting on growth and yield of tomato (Lycopersicon esculentum Mill.) in greenhouse and open-field. J. Applied Hortic. 8, 3–7.

Lee, J.M., Oda, M., 2003. Grafting of herbaceous vegetable and ornamental crops. Hortic. Rev. 28, 61–124.

Ministry of Agriculture, Agriculture statistical Yearbook. Volume 27. Riyadh, Kingdom of Saudi Arabia. 2014.

Nuyals, N., Tuzel, Y., Oztekin, G.B., Tuzel, I.H., 2010. Effect of Different Rootstocks on the Plant Growth, Yield, Fruit Quality and Water Consumption of Cucumber in Greenhouse Conditions. 28th International Horticultural Congress, Lisbon 2010.

Oztekin, G.B., Tuzel, Y., Tuzel, I.H., Gül, A., 2007. Effects of Grafting in Saline Conditions. International Horticultural congress and Exhibition (IHC 2006), Global Horticulture: Diversity and Harmony, 13–19 August 2006, Seoul, Acta Hort., 761, 349–355.

Patane, C., Tringali, S., Sortino, O., 2011. Effects of deficit irrigation on biomass, yield, water productivity and fruit quality of processing tomato under semi-arid Mediterranean climate conditions. Sci. Hortic. 129, 590–596.

Statistical Analysis System (SAS) Institute, 2008. Cary, NC; USA.

Steel, R.G., Torrie, J.H., 1980. Principles and procedures of statistics. McGraw-Hill, New York.

Turhan, A., Ozmen, N., Serbeci, M., Seniz, V., 2011. Effects of grafting on different rootstocks on tomato fruit yield and quality. Hortic. Sci. (Prague) 38 (4), 142–149.

Turhan, A., Seniz, V., 2009. Estimation of certain chemical constituents of fruits of selected tomato genotypes grown in Turkey. Afr. J. Agric. Res. 4 (10), 1086–1092.