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RESEARCH

Utilization of grafting technique for sustaining cantaloupe productivity and quality under deficit irrigation water

M. I. Ezzo, Ahmed S. Mohamed, Ahmed A. Glala and Said A. Saleh*

Abstract

Background: Water use efficiency (WUE) is becoming a decisive factor for agricultural expansion to face water shortage. To meet the needs of high population density in Egypt, we have to use modern irrigation systems and new cultivation technologies. The current study is aiming to apply grafting technique for ameliorating the impact of deficit water on cantaloupe productivity and fruit quality. Two commercial cultivars (*Ideal* and *Veleta*) were grafted on two rootstocks (Cobalt and Strong-Tosa) and self-grafting. The seedlings were treated with three different irrigation levels: 100, 75, and 50% of Class A pan Evapotranspiration (ETc).

Results: The results showed that moderate irrigation level (75% ETc) increased the early yield, fruits number, by 15.3 and 17.4%, respectively, compared to control irrigation treatment (100% ETc). No significant variation was found concerning total yield between 100 and 75% ETc, so this led to an increase in WUE of moderate irrigation level (75% ETc) by 34.3%, compared to control irrigation treatment (100% ETc). Increasing deficit levels up to 50% ETc reduced the total yield by 47.4%, but it increased the WUE by 8.8%, compared to the non-deficit irrigation level (100% ETc). Meanwhile, grafting both cultivars on Cobalt rootstock improved the fruit number, total yield, and WUE by 39.2%, 26.9%, and 24.1%, respectively when irrigated with the moderate irrigation level (75% ETc), as compared to the non-grafted plants which recorded the highest decrease when irrigated with deficit irrigation level (50% ETc).

Conclusion: Finally, the combination treatments of Ideal/Strong-Tosa, Veleta/Cobalt, or Ideal/Cobalt irrigated with moderate irrigation level (75% ETc) increased the WUE by 97.3, 83.4, and 65%, respectively, compared to the control treatment (non-grafted plants of the same cv. at 100% ETc) and recorded higher flesh thickness, TSS and firmness.

Keywords: *Cucumis melo*, Cantaloupe, Grafting, Rootstock-scion, Deficit irrigation water, Fruit quality yield, Water use efficiency

Background

Cantaloupe (*Cucumis melo* L.) is a high economic vegetable crop in many countries including Egypt. It is grown in practically every country in the world under outdoor fields or greenhouses (Glala et al. 2010). The cultivated area of cantaloupe in Egypt is 66,434 feddan with a total production of 846,936 tons and an average of 12.749 ton per fed, while exports of cantaloupe fruits amounted 2689.88 ton per year (Ministry of Agric, Egypt 2015). Fruits are consumed in summer period and are popular because the pulp of the fruit is very refreshing, high nutritional, and sweet with a pleasant aroma.

The most important problems facing the horizontal expansion of cantaloupe in greenhouses or in open field are the water shortage, especially in the new reclaimed lands. Whereas, deficit irrigation had an opposite influence on production of fruits (Al-Mefleh et al. 2012; de Azevedo 2016; Elvis et al. 2017) and physical fruit quality expressed as weight, length, diameter average weight, and size are severely decreased (Zeng et al. 2009; de Azevedo 2016 as well as on watermelon Ibrahim 2012 and Elvis et al. 2017). This leads the researcher to use some new trends to mitigate these negative impacts. The grafting technique is one of the most modern trends used to improve the productivity of vegetable plants,

* Correspondence: said_abohesham@yahoo.com
Horticultural Crops Technology Department, National Research Centre, Dokki, Giza, Egypt

especially under adverse environmental conditions. The advantages of grafting depend on using suitable rootstock capable to reduce the effects of biotic and abiotic stresses (Colla et al. 2014). Grafting vegetables on to resistant rootstocks offers numerous advantages on growth and yield, i.e., improving water use efficiency and tolerance to deficit irrigation (Wahb-Allah 2014; Özmen et al. 2015) and increase yield and fruit quality in many crops such as cucumber (Hsiu-Fung and Yung-Fu 2013), melon (Liu et al. 2011), and watermelon (Mohamed et al. 2014). Accordingly, the present study was conducted to investigate the possibility of using grafting as a new promising technique for ameliorating the negative effects of deficit irrigation water on cantaloupe yield and fruit quality.

Material and methods

This study was carried out in a private farm, Kalyobiya Governorate, Egypt during 2015 and 2016 autumn seasons to investigate the possibility of improving production and quality of cantaloupe yield under deficit of irrigation water by using grafting technique. Commercial cantaloupe cultivars (*Cucmis. melo* var. *reticulates*) *Veleta RZ* (Rijk-Zwaan Co.) and *Ideal* (Syngenta Co.) were used as scions while the *Cobalt* (Rijk-Zwaan Co.) and *Strong-Tosa* (Syngenta Co.) were used as rootstocks. A modified tongue approach grafting method was used to produce the grafted seedlings. The grafted seedling and the control (non-grafted) were transplanted under net house condition, on the 21st of July in both investigation seasons. The plants were transplanted on ridges of 1.5 m width, on one side of the ridge at 50 cm apart.

Experimental soil was clay soil in texture with pH of 8.0 and EC of 1.3 ds/m. Underground water with pH of 7.8 and EC of 0.8 ds/m was used in the experimental site. Three irrigation levels were used, i.e., 100% crop water requirement (ETc) "as a control treatment," 75% ETc "as a moderate treatment," and 50% ETc "as a deficit water treatment." Class A pan evapotranspiration equation was used to calculate the daily amount of irrigation water. The total amount of added water through the drip irrigation system was measured by ginger for each water regime treatment. The average amounts of applied irrigation water in 100% ETc treatment were 1.500, 3.400, 4.250, and 3.600 litter in August, September, October, and November, respectively. Then, amounts were reduced to 75% and 50% to apply 75% ETc and 50% ETc treatments. A split split-plot designed was adopted with three replicates where water regimes were placed in main plots; meanwhile, cultivars in sub plots and rootstocks in sub-sub plots.

Yield of the first tow pickings was considered as early yield as well as number of fruits per plant and total yield per plant (g) were calculated in the end of the growing season. Water use efficiency (WUE) was calculated as the total yield divided by the amount of irrigation water applied according to Howell et al. (1990). The fruit length and diameter were measured to calculate fruit shape index (fruit length/fruit diameter). Finally, average fruit weight (g), flesh thickness of fruit (cm), and seed cavity diameter (cm) as well as fruit firmness and total soluble solids percentage (A.O.A.C. 1990) were measured. Data were subjected to the statistical analysis by the method of Duncan's multiple range tests as reported by Gomez and Gomez (1984). Statistical analysis was performed with SAS computer software.

The obtained results of both seasons were used to evaluate the effect of deficit stress. Drought resistance indices were defined according to Ibrahim (2011) by the following formula:

1. Stress susceptibility index = $(1\text{-}Ys/Yw)/D$ (Fisher and Maure 1978).
2. Relative yield reduction = $1\text{-}Ys/Yw$ (Hiller and Clark 1971).

Where Ys is the mean of yield under a deficit water, Yw is the mean of yield under well-watered conditions, and D is the environmental stress intensity = 1-(mean yield of all varieties under deficit/mean yield of all treatments under well-watered conditions). The relative yield under deficit water was calculated as the yield of a specific genotype under deficit irrigation divided by that of the highest yielding genotype in the population of the experiment.

Based on the average of two seasons, the total yield was used to calculate the costs, benefits, and saving of using grafted and non-grafted cantaloupe plants grown under deficit irrigation water.

Results

Effect of grafting technique (cultivars "scions" and rootstocks) under deficit of irrigation on the physical quality of cantaloupe fruits

Data presented in Tables 1, 2, and 3 showed the effect of deficit irrigation rates, cultivars, rootstocks, and their interaction on fruit shape index, average fruit weight, flesh thickness of fruit, seed cavity diameter, fruit firmness, and total soluble solid (TSS), respectively.

All fruits quality parameters except for fruit shape index (average fruit weight (g), flesh thickness of fruit, seed cavity diameter, fruit firmness, and TSS) were positively affected by irrigation levels. Where, average fruit weight and flesh thickness of fruit were decreased by increasing deficit rates, and the opposite trend with regard to fruit firmness and TSS, which were increased by increasing deficit rates. These results are in agreement with those of Ibrahim (2012), Li et al. (2012), and de Azevedo (2016). Most fruits quality parameters, i.e., fruit shape index, average fruit

Table 1 Effect of deficit irrigation rates (% ETc), cultivars, and rootstocks on fruit shape index and average fruit weight (g) of cantaloupe plants during 2015 and 2016 seasons

		Fruit shape index								Average fruit weight (g)							
		First season (2015)				Second season (2016)				First season (2015)				Second season (2016)			
cv.	Rootstock	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean
Veleta	*Cobalt*	0.98^{A-E}	0.98^{A-E}	1.03^{A}	0.99a	0.97^{ABC}	0.98^{AB}	0.98^{AB}	0.97a	1255^{BC}	1097^{DE}	808^{HI}	1053ab	1279^{ABC}	1193^{CD}	844^{F}	1105ab
	Strong-Tosa	1.00^{ABC}	0.99^{A-D}	1.00^{ABC}	0.99a	0.96^{A-D}	0.98^{AB}	1.001^{A}	0.98a	1167^{CD}	904^{GH}	597^{J}	889b	1032^{E}	910^{F}	624^{G}	855c
	Non-grafted	1.01^{AB}	1.00^{AB}	1.03^{A}	1.01a	0.97^{ABC}	0.98^{AB}	0.99^{A}	0.98a	1200^{BC}	904^{GH}	591^{J}	898b	1131^{D}	1014^{E}	591^{G}	912bc
	Mean	0.99a	0.99a	1.02a		0.97a	0.98ab	0.99a		1207b	968c	665d		1147b	1039c	686e	
Mean of *Veleta cv.*		1.0 A				0.98 A				947 B				957 B			
Ideal	*Cobalt*	0.94^{A-F}	0.93^{B-F}	0.90^{F}	0.92b	0.92^{EF}	0.93^{DEF}	0.91^{EF}	0.92b	1299^{B}	1056^{EF}	726^{I}	1027ab	1296^{AB}	1170^{D}	852^{F}	1106ab
	Strong-Tosa	0.93^{B-F}	0.93^{B-F}	0.87^{F}	0.91b	0.93^{DEF}	0.91^{EF}	0.90^{F}	0.91b	1421^{A}	1164^{CD}	885^{GH}	1157a	1367^{A}	1196^{CD}	902^{F}	1155a
	Non-grafted	0.96^{A-F}	0.91^{DEF}	0.91^{DEF}	0.92b	0.94^{C-F}	0.95^{B-E}	0.90^{F}	0.93b	1254^{BC}	963^{FG}	618^{J}	945b	1215^{BCD}	1137^{D}	651^{G}	1001bc
	Mean	0.94b	0.92b	0.90b		0.93c	0.93c	0.90d		1324a	1061c	743d		1293a	1168b	802d	
Mean of *Ideal cv.*		0.92 B				0.92 B				1043 A				1087 A			
		Rootstocks and water levels															
Cobalt		0.96a	0.95a	0.96a	0.96A	0.94a	0.95a	0.94a	0.95A	1277a	1076b	767d	1040A	1287a	1181abc	848d	1105A
Strong-Tosa		0.96a	0.96a	0.94a	0.95A	0.95a	0.94a	0.95 a	0.95A	1294a	1034bc	741d	1023A	1200ab	1053c	763d	1005B
Non-grafted		0.98a	0.95a	0.97a	0.97A	0.95a	0.96a	0.95a	0.96A	1227a	933c	605e	921B	1173abc	1076bc	621e	956C
Mean		0.96A	0.95A	0.96A		0.95A	0.95A	0.95A		1266A	1015B	704C		1220A	1103B	744C	

Table 2 Effect of deficit irrigation rates, cultivars and rootstocks on flesh thickness (cm) and seed cavity diameter of fruit for cantaloupe plants during 2015 and 2016 seasons

		Flesh thickness (cm)								Seed cavity diameter (g)							
		First season (2015)				Second season (2016)				First season (2015)				Second season (2016)			
cv.	Rootstock	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean
Veleta	*Cobalt*	4.1^{B}	3.2^{D}	2.5^{FG}	3.2bc	3.9^{BC}	3.7^{CD}	3.0^{GHI}	3.6a	3.80^{B-E}	5.02^{A}	4.94^{A}	4.58a	4.67^{AB}	4.57^{AB}	4.46^{AB}	4.57ab
	Strong-Tosa	2.9^{DE}	3.0^{D}	2.5^{FG}	2.8c	3.3^{EFG}	2.8^{IJ}	2.3^{K}	2.8c	4.90^{A}	4.00^{A-E}	3.10^{E}	4.00ab	5.23^{A}	4.57^{AB}	3.39^{CD}	4.40b
	Non-grafted	3.5^{C}	2.7^{EF}	2.4^{G}	2.9c	3.3^{FE}	2.8^{I}	2.5^{JK}	2.9bc	3.60^{CDE}	4.30^{A-D}	3.17^{E}	3.69b	5.03^{A}	4.67^{AB}	2.88^{D}	4.19b
	Mean	3.5b	3.0c	2.5d		3.5a	3.1b	2.6c		4.10a	4.44a	3.73b		4.98a	4.60a	3.58a	
Mean of *Veleta cv.*		3.0 B				3.1 B				4.09 A				4.39 A			
Ideal	*Cobalt*	3.9^{B}	3.6^{C}	3.1^{D}	3.5^{ab}	3.9^{BC}	3.5^{DE}	2.7^{IJ}	3.4ab	4.47^{ABC}	4.77^{AB}	4.70^{AB}	4.64a	5.17^{A}	5.33^{A}	5.03^{A}	5.18a
	Strong-Tosa	4.4^{A}	4.2^{AB}	3.1^{D}	3.9^{a}	4.3^{A}	4.2^{AB}	2.9^{HI}	3.8a	3.63^{CDE}	3.33^{DE}	3.77^{CDE}	3.58b	4.17^{AB}	3.47^{CD}	4.43^{AB}	4.02b
	Non-grafted	3.5^{C}	3.1^{D}	2.6^{FG}	3.0^{bc}	3.4^{EF}	3.2^{FGH}	2.5^{JK}	3.0bc	4.40^{ABC}	4.37^{ABC}	3.27^{E}	4.01ab	4.07^{BC}	4.40^{AB}	3.43^{CD}	4.10b
	Mean	3.9a	3.6ab	2.9c		3.9a	3.6a	2.7c		4.17a	4.16a	3.91a		4.62a	4.40a	4.30a	
Mean of *Ideal cv.*		3.5 A				3.4 A				4.08 A				4.57 A			
		Rootstocks and water levels															
Cobalt		3.9a	3.4b	2.7c	3.4A	3.9a	3.6ab	2.8de	3.5A	4.13abc	4.89a	4.82a	4.61A	4.92a	4.95a	4.75ab	4.87A
Strong-Tosa		3.7ab	3.6ab	2.8c	3.3A	3.8ab	3.5ab	2.6de	3.3B	4.27ab	3.67bcd	3.43cd	3.79B	4.88a	4.02bc	3.91c	4.21B
Non-grafted		3.5b	2.9c	2.5c	3.0B	3.3bc	3.0cd	2.5e	2.9C	4.00bc	4.33ab	3.22d	3.85B	4.55 abc	4.53abc	3.16d	4.35B
Mean		3.7A	3.3B	2.7C		3.7A	3.4B	2.7C		4.13A	4.30A	3.82B		4.80A	4.50AB	3.94B	

Table 3 Effect of deficit irrigation rates, cultivars and rootstocks on firmness and TSS of fruit for cantaloupe plants during 2015 and 2016 seasons

		Fruits firmness								TSS							
		First season (2015)				Second season (2016)				First season (2015)				Second season (2016)			
cv.	Rootstock	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean
Veleta	*Cobalt*	17.7^{G}	20.3^{F}	25.0^{BC}	21.0a	17.3^{F}	21.7^{E}	24.3^{C}	21.1a	9.0^{EF}	10.4^{CDE}	12.2^{ABC}	10.5a	8.6^{CD}	10.4^{B}	12.2^{A}	10.4a
	Strong-Tosa	18.7^{GF}	20.3^{F}	25.7^{BC}	21.5a	18.0^{F}	21.3^{E}	24.0^{CD}	21.1a	9.3^{DEF}	10.5^{CDE}	12.0^{ABC}	10.6a	8.4^{D}	10.2^{B}	11.7^{A}	10.6a
	Non-grafted	19.0^{GF}	22.3^{E}	26.0^{BC}	22.4a	18.7^{F}	22.7^{DE}	26.0^{B}	22.4a	8.7^{F}	10.5^{CDE}	12.0^{ABC}	10.4a	8.7^{CD}	10.5^{B}	11.7^{A}	10.3a
	Mean	18.4e	21.0d	25.5b		18.0d	21.8c	24.7b		9.0c	10.5b	12.1a		8.6c	10.4b	11.9a	
Mean of *Veleta cv.*		21.6 B				21.5 B				10.5 A				10.3 A			
Ideal	*Cobalt*	17.7^{G}	22.0^{E}	26.6^{AB}	22.1a	18.3^{F}	21.7^{E}	26.3^{AB}	22.1a	9.0^{EF}	10.5^{CDE}	12.0^{ABC}	10.5a	8.7^{CD}	9.6^{BC}	11.7^{A}	10.0a
	Strong-Tosa	18.7^{GF}	23.0^{DE}	26.7^{AB}	22.8a	18.7^{F}	23.0^{CDE}	26.0^{B}	22.5a	9.6^{DEF}	10.8^{BCD}	12.6^{A}	11.0a	9.0^{CD}	10.2^{B}	12.0^{A}	11.0a
	Non-grafted	19.0^{GF}	24.3^{CD}	28.0^{A}	23.8a	19.0^{F}	23.0^{CDE}	27.7^{A}	23.2a	8.7^{F}	10.8^{BCD}	12.3^{AB}	10.6a	8.4^{D}	10.2^{B}	11.7^{A}	10.6a
	Mean	18.4e	23.1c	27.1a		18.6d	22.5c	26.6a		9.1c	10.7b	12.3a		8.7c	10.0b	11.8a	
Mean of *Ideal cv.*		22.8 A				22.6 A				10.7 A				10.2 A			
		Rootstocks and water levels															
Cobalt		17.6d	21.2c	25.8a	21.5C	17.8d	21.6c	25.3b	21.6B	9.0c	10.4b	12.1a	10.5A	8.6c	10.0b	11.9a	10.2A
Strong-Tosa		18.6d	21.6c	26.1a	22.2B	18.3d	22.1c	25.0b	21.8B	9.5c	10.7b	12.3a	10.8A	8.7c	10.2b	11.9a	10.3A
Non-grafted		19.0d	23.3b	27.0a	23.1A	18.8d	22.8c	26.8a	22.8A	8.7c	10.7b	12.2a	10.5A	8.6c	10.4b	11.7a	10.2A
Mean		18.4C	22.0B	26.3A		18.3C	22.2B	25.7A		9.1C	10.6B	12.2A		8.6C	10.2B	11.8A	

weight, flesh thickness of fruit, and fruit firmness, were significantly affected by the *cvs*. *Veleta* and *Ideal*. Where, *Ideal* cultivar fruits recorded the highest values of all fruits quality parameters, except for fruit shape index. In general, *Ideal* cultivar fruits were bigger and heavier than those of *cv. Veleta*, while *Veleta* fruits were the longer little than those of *Ideal*, and the opposite trend at the fruit diameter all over the growing seasons, this led to increase in the value of fruit shape index with *cv. Veleta*. Fruit quality expressed as average fruit weight, flesh thickness, and seed cavity diameter were positively affected by *Cobalt* rootstock, while there were no significant responses regarding to other parameters (fruit shape index, fruit firmness, and TSS). The obtained results are matched with those reported by Rouphael et al. (2012) and Proietti et al. (2008).

Effect of grafting technique (cultivars and rootstocks) under deficit irrigation on fruit yield and its components of cantaloupe plants

Data presented in Tables 4 and 5 indicate the effect of deficit irrigation rates, cultivars, rootstocks, and their interaction on early yield, fruits number, total yield (g/plant), and WUE, respectively.

The effect of deficit irrigation levels was very clear, where the moderate level (75% ETc) showed higher significant positive effects on early yield, fruits number, and WUE. Whereas irrigation with moderate level (75% ETc) increased the early yield, fruits number by 15.3 and 17.4%, respectively, comparing with control of irrigation water (100% ETc). No significant effect was found between 100 and 75% ETc on the total yield, so that this led to increase the WUE of moderate level (75% ETc) by 34.3%, compared to non-deficit irrigation level (100% ETc). Meanwhile, increasing deficit levels up to 50% ETc reduced the fruits number and total yield by 9.9% and 47.4%, respectively, but increased the WUE by 8.8%, comparing with non-deficit irrigation level (100% ETc). The obtained results are matched with those reported by Yildirim et al. (2009) and Al-Mefleh et al. (2012), who reported that there were no significant differences on total yield between high level and medium level of irrigation water. Concerning the effect of cultivars, *cv. Ideal* recorded the highest values of early yield, fruits number, total yield, and WUE, compared with *cv. Veleta.* The effect of rootstocks was very clear, where *Cobalt* showed higher significant positive effect on early yield, fruits number, total yield, and WUE. Grafting on *Cobalt* rootstock increased the fruits number, total yield, and WUE by 18.0%, 33.3%, and 36.3%, respectively, comparing

Table 4 Effect of deficit irrigation rates (% ETc), cultivars and rootstocks on early yield (g/plant) and fruits number/plant of cantaloupe plants during 2015 and 2016 seasons

		Early yield								Fruits number/plant							
		First season (2015)				Second season (2016)				First season (2015)				Second season (2016)			
cv.	Rootstock	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean
Veleta	*Cobalt*	1149DE	1661^{A}	773^{F}	1195 a	1149DE	1661^{A}	773^{F}	1195 a	4.0^{AB}	4.7^{A}	3.3^{BC}	4.0a	4.0^{AB}	4.3^{A}	3.0^{CD}	3.7ab
	Strong-Tosa	1144DE	1088^{E}	397^{I}	876 b	1144DE	1088^{E}	397^{I}	876 b	1.3^{E}	2.0^{DE}	1.3^{E}	1.5c	1.3^{E}	1.0^{E}	1.0^{E}	1.2d
	Non-grafted	1176DE	1371^{B}	564^{H}	1037 ab	1176DE	1371^{B}	564^{H}	1037 ab	3.0^{BCD}	3.3^{BC}	2.7^{CD}	3.0b	3.3^{BCD}	3.7^{ABC}	3.0^{CD}	3.3bc
	Mean	1156 b	11373 a	578 c		1156 b	11373 a	578 c		2.8b	3.3ab	2.4b		2.8ab	3.1ab	2.3b	
Mean of *Veleta cv.*		1036 B				790 B				2.8 B				2.7 B			
Ideal	*Cobalt*	1273^{BC}	1340^{B}	690^{FG}	1101ab	956^{EFG}	1135^{DEF}	843^{FG}	945b	3.0^{BCD}	3.7^{BC}	3.0^{BCD}	3.2b	3.3^{BCD}	4.0^{AB}	3.0^{CD}	3.4bc
	Strong-Tosa	1361^{B}	1516^{AB}	551^{H}	1142a	856^{EFG}	1629^{A}	1186^{CDE}	1274a	3.7^{BC}	4.7^{A}	3.3^{BC}	3.8a	4.0^{AB}	4.3^{A}	4.0^{AB}	4.1a
	Non-grafted	1206^{CD}	1276^{BC}	626^{GH}	1036ab	1203^{CD}	1144^{C-F}	645^{G}	997ab	2.7^{CD}	3.3^{BC}	2.7^{CD}	2.8b	3.0^{CD}	3.3^{BCD}	2.7^{D}	3.0c
	Mean	1280ab	1377a	622c		1022a	1302a	891ab		3.1ab	3.9a	3.0ab		3.4a	3.9a	3.2ab	
Mean of *Ideal cv.*		1093 A				1072 A				3.3 A				3.5 A			
		Rootstocks and water levels															
Cobalt		1211c	1500a	732c	1148A	1069ab	1358a	839ab	1088A	3.5ab	4.2a	3.2ab	3.6A	3.7ab	4.2a	3.0ab	3.6A
Strong-Tosa		1252b	1302b	474d	1009B	665b	815ab	593b	691B	2.5b	3.3ab	2.3b	2.7B	2.7b	2.8ab	2.5b	2.6C
Non-grafted		1191b	1323b	595cd	1036B	1169ab	1259ab	615b	1014A	2.8b	3.3ab	2.7b	2.9B	3.2ab	3.5ab	2.8 b	3.1B
Mean		1218B	1375A	600C		967B	1144A	682C		2.9AB	3.6A	2.7B		3.2A	3.5A	2.7 B	

Table 5 Effect of deficit irrigation rates, cultivars and rootstocks on fruit yield (g/plant) and WUE of cantaloupe plants during 2015 and 2016 seasons

		Total yield								WUE							
		First season (2015)				Second season (2016)				First season (2015)				Second season (2016)			
cv.	Rootstock	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean
Veleta	*Cobalt*	5021^{B}	4886^{B}	2694^{F}	4200a	5117^{AB}	5167^{AB}	2532^{D}	4272ab	45.6^{DE}	59.6^{B}	49.0^{CD}	51.4a	46.5^{C}	63.0^{A}	46.0^{C}	51.6ab
	Strong-Tosa	1556^{H}	1807^{GH}	796^{I}	1386c	1376^{E}	1213^{E}	624^{E}	1071d	14.1^{L}	22.0^{J}	14.5^{L}	16.9d	12.5^{F}	14.8^{F}	11.3^{F}	12.9d
	Non-grafted	3600^{CD}	3012^{FE}	1577^{H}	2730b	3770^{C}	3506^{C}	1774^{E}	3017c	32.7^{HIJ}	36.7^{GH}	28.7^{J}	32.7c	34.3^{DE}	42.8^{CD}	32.3^{E}	34.3c
	Mean	3392a	3235ab	1689c		3421abc	3295bc	1643d		30.8b	39.5ab	30.7b		31.1c	40.2bc	29.9c	
Mean of *Veleta cv.*		2772 B				2787 B				33.7 B				32.9 B			
Ideal	*Cobalt*	3896^{C}	3521^{CD}	2178^{G}	3198b	3887^{C}	4680^{B}	2555^{D}	3707bc	35.4^{GHI}	42.9^{EF}	39.6^{FG}	39.3b	35.3^{DE}	57.1^{B}	46.5^{C}	42.3b
	Strong-Tosa	5212^{AB}	5432^{A}	2948^{FE}	4530a	5470^{A}	5188^{AB}	3592^{C}	4750a	47.4^{DE}	66.2^{A}	53.6^{C}	55.7a	49.7^{BC}	63.3^{A}	65.3^{A}	57.3a
	Non-grafted	3344^{DE}	3212^{DE}	1648^{H}	2735b	3645^{C}	3790^{C}	1736^{E}	3057c	30.4^{IJ}	39.2^{FG}	30.0^{J}	33.2c	33.1^{E}	46.2^{C}	31.6^{E}	34.8c
	Mean	4150a	4055a	2258bc		4334ab	4553a	2628cd		37.7ab	49.5a	41.1ab		39.4bc	55.5a	47.8ab	
Mean of *Ideal cv.*		3488 A				3838 A				42.7 A				44.8 A			
		Rootstocks and water levels															
Cobalt		4459a	4203a	2436bcd	3699A	4502ab	4924a	2544bcd	3990A	40.5ab	51.3a	44.3ab	45.4A	40.9b	60.0a	46.2ab	47.0A
Strong-Tosa		3384ab	3620ab	1872cd	2959B	3423abc	3200bcd	2108cd	2910B	30.8b	44.1ab	34.0ab	36.3B	31.1b	39.0b	38.3b	36.2B
Non-grafted		3472ab	3112abc	1612d	2732C	3708abc	3648abc	1755d	3037B	31.6b	38.0ab	29.3b	32.9C	33.7b	44.5ab	31.9b	34.6B
Mean		3771A	3645A	1973B		3878A	3924A	2135B		34.3B	44.5A	35.9B		35.3B	47.9A	38.8B	

with non-grafted plants. The obtained results are matched with those reported by Rouphael et al. (2012), Proietti et al. (2008), and Özmen et al. (2015), who noticed that grafted watermelon plants gave the highest fruit yields, comparing with non-grafted plants.

The early yield, fruits number, total yield, and WUE were not significantly affected by the interaction between cultivars and irrigation levels treatments. Even so, *Ideal cv*. recorded the highest increase at two levels 100 and 75% ETc and the lowest decrease at 50% ETc (high deficit irrigation level). Such results have coincided with those found by EL-Tawashy (2016) who reported that *cv. Magenta* produced higher yield per plant, compared to *cv. Visa* when irrigated by 20 m^3, compared to 10 m^3 water/fed. The interaction between rootstocks and deficit irrigation rates treatments improved the early yield, fruits number, total yield, and WUE. The highest increase on early yield (21%), fruits number (39.2%), total yield (26.9%), and WUE (24.1%) was represented in *Cobalt* rootstock when irrigated by the moderate level (75% ETc). Meanwhile, non-grafted plants recorded the highest decrease when irrigated with high deficit irrigation level (50% ETc). Also, the interaction between cultivars and rootstocks treatments improved fruits number, total yield, and WUE by grafted *Ideal cv*. on *Strong-Tosa* rootstock and combination of *Veleta*/*Cobalt*. Where, *Ideal*/*Strong-Tosa* combination improved fruits number, total yield, and WUE by 35.6, 75.6, and 33.8%, respectively, comparing with non-grafted plants of *cv. Ideal*, but this increase was 22.6, 47.4, and 42.8% by the combination of *Veleta*/*Cobalt*, comparing with non-grafted plants of *cv. Veleta*. The obtained results are matched with those reported by Rouphael et al. (2012), Proietti et al. (2008), Özmen et al. (2015), and Hussien (2016), who showed that grafted watermelon plants gave the highest fruit yields, comparing with non-grafted plants under various levels of irrigation water.

The best interaction effects among the three studied factors could be summarized in the combination of *Ideal*/*Strong-Tosa* or *Veleta*/*Cobalt*, followed by *Ideal*/*Cobalt* with non-deficit irrigation level (100% ETc) and medium (75% ETc) of deficit irrigation levels as shown in Tables 4 and 5. The total yield of cantaloupe plants was decreased when non-grafted and grafted plants were grown under high deficit irrigation level (50% ETc). However, the % decline varied according to the rootstock used. In this respect, the lowest decrease of the total yield was in the graft combination *Ideal*/*Strong-Tosa* or *Veleta*/*Cobal*, followed by *Ideal*/*Cobalt*. While, the graft combination *Veleta*/*Strong-Tosa* and non-grafted plants for both cultivars recorded the highest % decline, as compared to the general control (non-grafted plants at 100% ETc). Concerning fruits number and WUE, combination of *Ideal*/*Strong-Tosa*, *Veleta*/*Cobalt*, and *Ideal*/*Cobalt* recorded increase on fruits number and not decline on WUE at the high deficit irrigation level (50% ETc) as shown in Table 5.

In general, the sharp deficit water (50% ETc) reduced the fruits number and total yield by 9.9 and 47.4%, respectively, but increased the WUE by 8.8%, compared to non-deficit irrigation level (100% ETc). Meanwhile, grafting both cultivars on rootstocks improved fruit number, total yield, and WUE. Where, the highest increase on fruit number (39.2%), total yield (26.9%), and WUE (24.1%) were represented in *Cobalt* rootstock when irrigated with the moderate level (75% ETc). Meanwhile, non-grafted plants recorded the highest decrease when irrigated by high deficit irrigation level (50% ETc).

Evaluation of deficit resistance

Yield losses from the normal level due to water stress are useful in assessing drought resistance. A larger value of relative yield reduction (RY) may show more sensitivity to stress, thus a smaller value of relative yield reduction is favored. Presented data in Table 6 explain that *cv. Ideal* had the smallest relative yield reduction value (RY = 45%), as compared to *cv. Veleta*, which recorded the largest relative yield reduction value (RY = 52%), so *cv. Ideal* was the best cultivar based on this index. The obtained results coincide with those obtained by Ibrahim (2011), who noticed that *cv. Ananas El-Dokki* had the smallest relative yield reduction value (26%), comparing with *Ismaelawi cv*. (28%). Concerning the test of rootstocks, *Cobalt* rootstock had the smallest relative yield reduction value (RY = 44%), comparing with non-grafted of both *cvs*, which recorded the largest relative yield reduction value (RY = 54%), so *Cobalt* rootstock was the best rootstock to use as rootstock for grafting cantaloupe plants based on this index. Moreover, grafting *cv. Ideal* on rootstock *Cobalt* or *Strong-Tosa* recorded the lowest relative yield reduction values (39 and 44%, respectively).

The stress susceptibility index (SSI) appeared to be a suitable selection index to distinguish resistant cultivars or rootstocks as well as their interaction. Genotypes with low SSI values (less than 1) can be considered to be drought resistant (Fisher and Maure 1978), because they exhibited smaller yield reductions under water stress, comparing with well-watered conditions. The cultivar *Ideal* and rootstock *Cobalt* as well as the interaction of their (*Ideal*/*Cobalt*) were relatively drought-resistant (SSI values < 1).

SSI values are not enough to determine the drought-tolerant genotypes; this could be done with the help of relative yield under water stress estimate. The mean relative yields values under imposed water stress was 0.63 (Table 6). The cultivar *Ideal* was relatively high yielding under water stress (RY_s > mean RY_s), comparing

Table 6 Average yields of grafted and non-grafted cantaloupe plants (based on the average of two seasons) under normal (*Yw*) and stress (*Ys*) conditions, stress susceptibility index (SSI), relative yield reduction, and relative yield under water stress (RY_S)

cv.	Rootstock	Total yield g/plant		Relative yield reduction (%) (RY)	Stress susceptibility index (SSI)	Relative yield under water stress (RY_S)
		Y_W	Y_S			
Veleta	*Cobalt*	5069	RY_1	48	1.02	0.80
	Strong-Tosa	1466	710	52	1.09	0.22
	Non-grafted	3685	1675	55	1.15	0.51
Mean *Veleta*		3407	1666	52	1.09	0.51
Ideal	*Cobalt*	3892	2366	39	0.83	0.72
	Strong-Tosa	5848	3270	44	0.93	1.00
	Non- grafted	3494	1692	52	1.09	0.52
Mean *Ideal*		4411	2443	45	0.95	0.75
Cobalt		4481	2490	44	0.93	0.76
Strong-Tosa		3657	1990	48	1.01	0.61
Non-grafted		3590	1684	54	1.12	0.51
Mean		3909	2054			0.63

with *cv. Veleta* (RY_s < mean RY_s). These results are in agreement with those obtained by Ibrahim (2011) who found that melon *cv. Albasosi* was relatively high yielding under water stress (RY > mean RY), while Shahd El-Dokki and Ananas El-Dokki were relatively low yielding (RY < mean RY). Regarding the test of rootstocks, *Cobalt* rootstock was relatively high yielding under water stress (RY_s > mean RY_s), while non-grafted plants of the two cultivars were relatively low yielding (RY_s < mean RY_s). Furthermore, grafted plants as *Ideal*/*Strong-Tosa*, *Veleta*/*Cobalt*, and *Ideal*/*Cobalt* were relatively high yielding under water stress (RY_s > mean RY_s), while non-grafted plants either *cv. Veleta* or *cv. Ideal* and graft combination *Veleta*/*Strong-Tosa* were relatively low yielding (RY_s < mean RY_s).

Finally, when cantaloupe plants have to be irrigated with high deficit irrigation, it is recommended to graft the preferred cultivar on *Cobalt* rootstock, which is a more tolerant rootstocks among the studied rootstocks included non-grafted plants, and could be further tested for their other drought conferring characteristics. Such results coincide with those found by Hussien (2016), who noticed that rootstock *Giada* obtained relative tolerance to irrigation deficit, followed by Ferro rootstock.

Calculation of costs and benefits of applied treatments

Costs and benefits of grafted and non-grafted plants grown under deficit irrigation water were calculated as average between both seasons as shown in Table 7. The same results in Table 7 show no significant differences among the irrigation water treatments on the costs (1) (L.E). Whereas the highest benefit (3) (9.77 and 9.80 L.E./plant) and income (4) (7.40 and 7.46 L.E./plant) were obtained with irrigation rate of 100 and 75% ETc, respectively. While, the lowest benefit (3) (5.14 L.E./plant) and income (4) (2.82 L.E./plant) were obtained with cantaloupe plants irrigated by 50% ETc of irrigation water. It is due to yield increasing of the plants irrigated with 75% ETc (3.920 kg/plant) and 100% ETc (3.910 kg/plant), compared to 50% ETc (2.050 kg/plant). Although the plants of *cv. Ideal* recorded the higher costs (1) (2.45 L.E./plant), compared to those of *Veleta* plants (2.25 L.E./plant), *cv. Ideal* recorded the highest benefit (3) (9.53 L.E./plant) and income (4) (7.08 L.E./plant), compared to those of *Veleta* plants which recorded the lowest benefit (3) (6.95L.E./plant) and income (4) (4.70 L.E./plant). It is due to increasing the yield of *Ideal cv.* (3.81 kg/plant), compared to those of *Veleta* plants (2.78 kg/plant).

The highest benefit (3) (9.61 L.E./plant) and income (4) (7.16 L.E./plant) were represented when both cantaloupe cultivars were grafted on rootstock *Cobalt*, although the grafted plants recorded the higher costs (1) (2.46 L.E./plant), comparing with non-grafted plants (2.13 L.E./plant). It is due to increasing the yield of grafted plants on *Cobalt* rootstock (3.84 kg/plant), compared to those of non-grafted plants (2.89 kg/plant).

The plants of *cv. Ideal* recorded the highest yield (2) (4.41 and 4.58 kg/plant) when irrigated with 100% and 75% ETc, respectively, compared to *Veleta* plants (3.406 and 3.265 kg/plant) at the same level of irrigation water. Accordingly, the *Ideal* plants recorded the highest benefit (3) (11.03 and 11.45 L.E./plant) and income (4) (8.55 and 9.00 L.E./plant), whereas the lower benefit (3) (4.167 L.E./plant) and income (4) (1.95 L.E./plant) resulted when

Table 7 Effect of deficit irrigation rates, cultivars and rootstocks on costs and benefits of cantaloupe plants as the average between seasons 2015 and 2016

cv.	Rootstock	Average between seasons 2015 and 2016															
		Costs[a] (L.E./plant)				Yield[b] (kg/plant)				Benefits[c] (L.E./plant)				Saving[d] (L.E./plant)			
		100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean
Veleta	*Cobalt*	2.36	2.33	2.30	2.33	5.069	5.027	2.613	4.236	12.67	12.57	6.53	10.59	10.31	10.24	4.23	8.26
	Strong Tosa	2.36	2.33	2.30	2.33	1.466	1.510	0.710	1.228	3.67	3.77	1.78	3.07	1.31	1.44	lose	0.74
	Non-grafted	2.11	2.08	2.05	2.08	3.685	3.259	1.675	2.873	9.21	8.14	4.19	7.18	7.10	6.06	2.14	5.1
	Mean	2.28	2.25	2.22		3.406	3.265	1.666		8.52	8.16	4.167		6.24	5.9	1.95	
Mean of *Veleta*			2.25			2.78			6.95					4.70			
Ideal	*Cobalt*	2.61	2.58	2.55	2.58	3.892	4.101	2.366	3.45	9.73	10.25	5.92	8.63	7.12	7.67	3.37	6.05
	Strong Tosa	2.61	2.58	2.55	2.58	5.848	6.135	3.270	5.08	14.62	15.34	8.18	12.71	12.01	12.76	5.63	10.13
	Non-grafted	2.21	2.18	2.15	2.18	3.494	3.501	1.692	2.90	8.74	8.75	4.23	7.24	6.53	6.57	2.08	5.06
	Mean	2.48	2.45	2.42		4.41	4.58	2.44	9.00	11.03	11.45	6.11		8.55	9.00	3.69	
Mean of *Ideal*			2.45			3.81			9.53					7.08			
Rootstocks and water levels																	
Cobalt		2.49	2.46	2.43	2.46	4.48	4.56	2.49	3.84	11.20	11.41	6.23	9.61	8.72	8.96	3.80	7.16
Strong Tosa		2.49	2.46	2.43	2.46	3.66	3.82	1.99	3.15	9.15	9.56	4.98	7.89	6.66	7.10	2.56	5.44
Non-grafted		2.16	2.13	2.10	2.13	3.59	3.38	1.68	2.89	8.98	8.45	4.21	7.21	6.82	6.32	2.11	5.08
Mean water		2.38	2.35	2.32		3.91	3.92	2.05		9.77	9.80	5.14		7.40	7.46	2.82	

[a]Costs included the price of treatments (Seedling and water amounts) where:
Grafted *Veleta* =2.25 L.E., non-grafted *Veleta* =2 L.E (0.75 seedling + 1.25 controlling soil diseases such as fusarium welt)
Grafted *Ideal* =2.35 L.E., non-grafted *Ideal* =2.10 L.E. (0.85 seedling + 1.25 controlling soil diseases such as fusarium welt)
1 M^3 of water = 1 L.E. (100% ETc = 110 liter = 0.11 L.E., 75% ETc = 85 liter = 0.085 L.E. and 50% ETc = 55 liter = 0.055 L.E
[b]Yield (kg/plant) under treatments
[c]Benefits were calculated as average price/2.5 L.E./kg
[d]Saving (L.E./plant) = Benefits – Costs

Veleta cv. plants were irrigated with 50% ETc of irrigation levels. Regarding the interactions between rootstocks and deficit irrigation, the highest benefit (3) (11.20 and 11.41 L.E./plant) and income (4) (8.72 and 8.96 L.E./plant) were represented in rootstock *Cobalt* and irrigated with 100% and 75% ETc of irrigation levels. Meanwhile, the lowest benefit (3) (4.21 L.E./plant) and income (4) (2.11 L.E./plant) were obtained with non-grafted plants and irrigated with 50% ETc level. This is due to increasing the yield (2) (4.48 or4.56 kg/plant) of grafting plants on *Cobalt* rootstock and irrigated with 100% or 75% ETc of irrigation levels as well as lower the yield (2) (1.68 kg/plant) of non-grafted plants. However, the grafted plants recorded the highest costs (1) (L.E./plant) compared to non-grafted plants at all irrigation levels.

Concerning the interactions of cultivars X rootstocks, the grafted combinations of *Ideal*/*Strong-Tosa*, followed by *Veleta*/*Cobalt*, then *Ideal*/*Cobalt* obtained the highest benefit (3) (12.71, 10.51, and 8.63 L.E./plant) and income (4) (10.13, 8.26, and 6.05 L.E./plant), respectively. The lowest benefit (3) (7.18 and 7.24 L.E./plant) and income (4) (5.1 and 5.06 L.E./plant) were obtained by *Veleta* and *Ideal* plants on its own roots, respectively. Whereas, this is due to increase the yield (2) of these graft combinations, compared to non-grafted plants.

Discussion

According to the aforementioned results, it could be concluded that increasing deficit irrigation levels had deleterious effects on vegetative growth characteristics and then yield and its components of cantaloupe plants. Consequently, both levels (100 and 75% ETc) showed significant positive effects on total yield, compared to deficit irrigation level (50% ETc). This might be due to the increase in vegetative growth characteristics, which reflected a significant increase in dry matter contents, and consequently total fruit yield. Increasing deficit level up to 50% ETc decreased water absorption, so that decreasing essential nutrients. Also, water stress (by the deficit of irrigation) had an opposite influence on many aspects of plant physiology, especially photosynthetic capacity. Consequently, if the drought stress is prolonged, plant growth and production are severely decreased, plants dehydrate and finally will die (Lisar et al. 2012). Restricted water supply is a major problem that might affect plant growth, then fruit yield and quality. This assumption is emphasized by more reduction in plant growth under the high deficit irrigation level (50% ETc) and can interpret the obtained results.

Generally, when cantaloupe plants have to be irrigated with moderate (75% ETc) or high (50% ETc) deficit irrigation water, it is recommended to graft the preferred

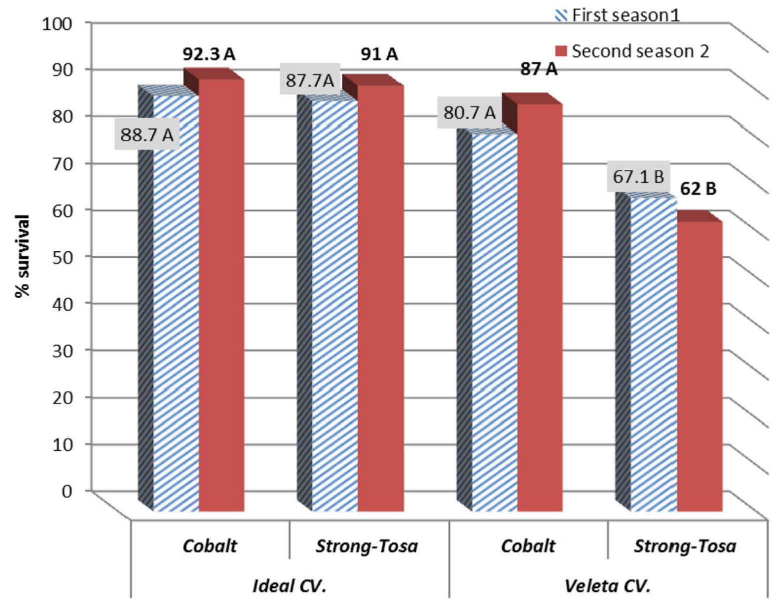

Fig. 1 % survival of cantaloupe seedling during 2015 and 2016 seasons

cultivar on *Cobalt* rootstock, which is compatible with many cultivars and it was the most superior rootstock in its effect on cantaloupe production parameters without any negative effect on fruit quality. Whereas, the grafting technique led to sustaining total yield under the high deficit irrigation level (50% ETc), compared to non-grafted plants, due to the grafting technique improved vegetative growth characters, i.e., stem length, leaves numbers, fresh and dry weights of shoots under the deficit irrigation level (50% ETc). This clarified that the positive effect of grafting on cantaloupe yield got its highest level with the combination of *Ideal/Strong-Tosa*, *Veleta/Cobalt*, and *Ideal/Cobalt* at all investigated irrigation levels. Because, the graft combination of *Ideal/Strong-Tosa*, *Veleta/Cobalt*, and *Ideal/Cobalt* resulted in the highest values of vegetative growth characters under all irrigation levels. This could be attributed to compatibility between *Ideal cv*. and *Cobalt* or *Strong-Tosa* rootstock as well as between *Veleta cv*. and *Cobalt* rootstock and confirms this variance of seedling survival during grafting phase, as shown in Fig. 1. This finding might be due to the strength of these rootstock, compared to non-grafted plants **(**Zaki et al. 2015; Zaki et al. 2018). Also, this finding might be due to the improvement of some physiological and biochemical acclimation in grafted plants to be adapted to a variety of environmental stresses (Osakabe et al. 2014; Zaki et al. 2015; Zaki et al. 2018). The highest improvement resulted from grafting was detected with medium and highest deficit levels (75 and 50% ETc) of irrigation water.

Economically also, the graft combination *Ideal/Strong-Tosa* resulted in the highest benefit (3) (15.34 and 14.62 L.E./plant) and income (4) (12.76 and 12.01 L.E./plant) at 75and 100% ETc, respectively. Also under both 75 and 100% ETc of irrigation levels, the graft combination of *Veleta/Cobalt* showed the highest benefit (3) (12.67 and 12.67 L.E./plant) and income (4) (10.31 and 10.24 L.E./plant), as shown in Table 7.

Conclusion

It could be concluded that we have to use grafted seedlings of commercial cantaloupe cultivars under deficit irrigation water. It is recommended to use the grafted combinations of *Veleta/Cobalt* and *Ideal/Strong-Tosa*, where these combinations increased the WUE with 97.3 and 83.4, respectively at 75% Etc, compared to the control treatment (non-grafted plants of the same cv. at 100% ETc) and improved the average fruit weight, flesh percentage, flesh thickness, TSS, and firmness.

Abbreviations

ETc: Crop water requirement; Fed: Feddan; TSS: Total soluble solid; WUE: Water use efficiency

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Authors' contributions

This work is a combined effort of all of the authors. MI Ezzo and AS Mohamed conducted the field experiments and performed the chemical analysis of the samples. MI Ezzo and AA Glala designed this work and coordinated the data collection and analysis. AA Glala and SA Saleh wrote the manuscript and revised it. All authors read and approved the final manuscript.

Authors' information
Dr. Mohamed Ibrahiem Ezzo is an Assistant Professor. Dr. Ahmed Salem Mohamed is a Researcher. Dr. Ahmed Abd-Alla Glala is a Professor. Dr. Said Abdelhalim Saleh is a Professor. All authors are working at the Department of Horticultural Crops Technology, Agricultural and Biological Division, National Research Centre, Dokki, Giza, Egypt.

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