Journal of Applied Horticulture, 24(1): 53-59, 2022
DOI: https://doi.org/10.37855/jah.2022.v24i01.10

Journal of Applied Horticulture
ISSN: 0972-1045

Grafting as a tool for improved water use efficiency, physio-biochemical attributes of cucumber plants under deficit irrigation

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Abstract

The study was conducted during the summer seasons of 2018 and 2019 under net house conditions at the Eastern Experimental Station of the Faculty of Agriculture, Cairo University to investigate the effect of some cucurbit rootstocks on the growth, quality, yield and chemical compositions of cucumber under drought stress. The study included 12 treatments that were arranged in a split-plot design with three replicates. The main plot included two levels of water irrigation (50 or100%) and sub main plot included five rootstocks *viz*., 1-Bottle Gourd (*Legenaria siceraria*), 2-Luffa (*Luffa aegyptiaca*), 3-Squash (*Cucurbita pepo*), 4- Pumpkin (*Cucurbita maxima*) and 5-Shintoza (*Cucurbita maxima* × *Cucurbita moschata*), in addition, to control treatment (Cucumber, cv. Hayel, without grafting). The results indicated that drought stress treatment (50%) significantly reduced leaf area and fruit length compared with normal irrigation (100%). Also, no significant differences were noticed between the water regime treatments (50 or 100%) on plant height, photosynthesis, stomatal conductance, transpiration, chlorophyll readings, fruit quality (fruit weight, fruit diameter and fruit TSS), total yield and K%. On the other hand, grafted cucumber onto *Luffa* rootstock caused a significant decrease in plant height, fruit weight and P and K% in leaves, whereas grafting onto bottle gourd significantly increased leaf area and total yield of cucumber, as compared with control.

Key words: Cucumber, grafting, rootstock, drought stress, vegetative growth, fruit characters, yield, nutrients

Introduction

Cucumber (*Cucumis sativus* L.) is a widely cultivated vegetable belonging to the Cucurbitaceae (gourd family). It is one of the most important crops grown in Egypt, with a total cultivated area of 16104 ha, producing 364571 tons (FAO, 2019). Drought can be considered a common abiotic factor that inhibits plant growth worldwide and is becoming a major restriction on agricultural production (Zhang *et al.,* 2019). Drought stress can indirectly or directly affect a plant's physiological functioning indirectly or directly, thereby disturbing its growth, metabolism and development **(**Akram *et al.,* 2016**)**.

Drought generally decreases the nutrient uptake by the root and transport to the shoot due to a limited transpiration rate affecting active transport and membrane permeability (Mao *et al..,* 2003).

Nowadays, Egypt faces a problem with the quantities of irrigation water because the Egyptian water budget is fixed, so the key step of the Egyptian strategy is to increase crop productivity from the region with the lowest irrigation water to conserve irrigation water. In crop production, water productivity can be optimized within the deficit irrigation concept instead of achieving maximum yield from a unit area by complete irrigation (Sánchez-Rodríguez *et al.,* 2013).

Grafting plants into rootstocks capable of raising the water use efficiency (WUE) of crops will be one way to prevent or decrease yield losses caused by drought conditions **(**Zhang *et al.,* 2020**)**. Although only the hybrid cucumber cultivars are intensively grown in the greenhouses in the different parts of the country, the critical problem is the low yield due to unfavorable soil properties, soil-borne diseases, and successive cropping method. The use of grafted seedlings has become a globally important agricultural practice in many parts of the world for the production and protection of cucurbitaceous crops from soil-borne pathogens and nematodes in the absence of crop rotation, especially since 2005 when the application of methyl bromide was prohibited (Lee *et al.*, 2010). However, the impact of grafting on cucurbits includes not only stronger resistance against pathogens but also a higher tolerance to abiotic stress conditions such as salinity, heavy metals, nutrient stress, thermal stress, water stress, organic pollutants, and alkalinity (Rouphael *et al.* 2008; Savvas *et al.*, 2009; Schwarz *et al.*, 2010; Colla *et al.*, 2010 and 2011). Several interspecific hybrids of Cucurbita species have been used commercially worldwide as cucumber rootstocks (Uysal *et al.*, 2012; El-Sayed *et al.*, 2014; Guan *et al.*, 2020). The performance of the grafted plants depends on many factors, such as the compatibility between rootstock with the scion (Edelstein *et al.*, 2004), the environmental conditions (Guan *et al.*, 2020) and the population of soil-borne diseases and grafting technique (Noor *et al.*, 2019; Cansev and Ozgur, 2020). Therefore, some rootstocks have been reported to positively affect yield and fruit quality (Ruiz and Romero, 1999), and others reported a decrease in plant growth, yield and fruit quality (Farhadia and Rezaie, 2015 and Farhadia *et al.,* 2016). Grafting may enhance the yield and uptake of macronutrients such as phosphorus and nitrogen (Ruiz and Romero, 1999).

The current study aimed to increase the productivity of cucumber plants under drought conditions without negative effects on fruit quality by using grafting onto some rootstocks to investigate the effect of some cucurbit rootstocks on growth, quality, yield and chemical compositions of cucumber under drought stress.

Materials and methods

Plant materials, treatments and growth conditions: The experiment was conducted under net house conditions at the Eastern Experimental Station of the Faculty of Agriculture, Cairo University, during the summer seasons on 2018 and 2019. The present study included 12 treatments arranged in a split-plot design with three replicates. The main plot included two levels of water irrigation (50 and 100%) and sub main plot included five rootstocks, 1-Bottle Gourd (*Legenaria siceraria*), 2-Luffa (*Luffa aegyptiaca*), 3-Squash (*Cucurbita pepo*), 4- Pumpkin (*Cucurbita maxima*) and 5-Shintoza (*Cucurbita maxima* × *Cucurbita moschata*), in addition to control treatment (Cucumber, cv. Hayel, without grafting). Seeds of rootstocks were sown, 15 days before scion seeds, on 27 February 2018 and on 12 February 2019 in the seedling-trays (84 eyes) filled with mixture of peat moss and vermiculite (1:1 v:v). Rootstocks were transplanted before the grafting in black plastic bags, 20 cm^2 in diameter, and filled with a mixture of peat moss and vermiculite (1:1 v:v). Grafting (Hole insertion grafting) started when the second true leaf of the rootstock and the first true leaf of the scion were established. Then the grafted plants were kept for 10-15 days under 90-95% RH and 45% shading conditions at a temperature between 27 to 30 °C for healing. Successfully grafted plants were transplanted in plastic pots, 50 cm diameter, in net greenhouse on 26 March 2018 and 22 March 2019. Each plot included 5 plants. Water was supplied daily to maintain the soil moisture level close to field capacity during the first one week of plant growth after that plants were irrigated with 100 and 50% of the water holding capacity.

Determination of growth parameters: Three plants of each treatment were randomly labelled 60 days after transplanting to determine growth parameters (plant height, leaf area of the 4^{th} leaf from meristem tip, chlorophyll readings). Leaf area was measured by portable leaf area meter (Biovis Leaf Av., Expert Vision Labs Pvt. Ltd., India) and chlorophyll readings were measured by SPAD 502 chlorophyll meter.

Also, photosynthesis rate, stomatal conductance, and transpiration rate were measured 60 days after transplanting between 11:00 am and 1:00 pm, using Li-1600 Steady State Porometer, LI-COR,USA.

Determination of total yield: Harvest started on 15th April in the first season and 12 April in the second season, and continued up to 25 June in the first season and 20 June in the second season. 8 pickings were taken during this period. All over the harvesting season total yield including the number and weight of fruits (g/ plant) from each plant were calculated.

Determination of fruit quality parameters: Three fruits were taken from each experimental plot at the fifth harvest to estimate fruit characters (fruit weight, length, diameter, and TSS% using Zeiss laboratory refractometer).

Determination of nutrient concentrations: Total nitrogen (N), phosphorus (P) and potassium (K) concentrations were determined in cucumber leaves 60 days after transplanting. Leaves were dried at 70°C for 48 h and wet digestion of 0.2 g fine powder of dry material was carried out with sulphuric and perchloric acids, as described by Piper (1947). Nitrogen was determined with the modified "Micro Kjeldahl" apparatus, as described by Cottenie *et al.* (1982). Phosphorus was determined by spectrophotometric method using the stannous chloride method according to (A.O.A.C. 1975). Potassium was measured with a flame photometer according to the method described by Brown and Lilliland (1964).

Statistical Analysis: All data concerning growth, yield, fruit characters, physiological parameters and chemical properties of cucumber plants were analyzed using split-plot design. Data were treated by analysis of variance with using MSTAT-C v. 2.1 and means were compared by the least significant difference test (LSD) at a 5 % level of probability as given by Snedecor and Cochran (1976).

Results

Growth parameter (plant height, leaf area and chlorophyll), 60 days after transplanting: Data in Table 1 show no significant differences between the treatments of 50 % and 100 % of water requirements on plant height, leaf area and chlorophyll of cucumber in both seasons, except leaf area in the second season which significantly decreased with drought stress treatment (50% of water requirements), as compared with normal irrigation (100% of water requirement). Grafting onto luffa rootstock in both seasons gave a significant reduction in cucumber plant height, however grafting onto bottle gourd in the second season significantly increased leaf area. All rootstocks did not significantly affect plant height, leaf area and chlorophyll in both seasons.

Regarding the interaction between water regime and grafting rootstocks, only grafting cucumber onto luffa rootstock at 50% and 100% of water requirements gave a significant reduction in plant height in the first season as well as using bottle gourd as rootstock at normal irrigation (100%) gave significant increment in leaf area in the second season as compared with non-grafted cucumber. In contrast, all rootstocks at 50and 100% of water requirements in both seasons did not show any significant differences in chlorophyll reading compared to control.

Photosynthesis, stomatal conductance and transpiration of cucumber leaves, 60 days after transplanting: As shown in Table 2, using water regime treatment or grafting rootstocks and also their interaction did not have any significant effects on photosynthesis, stomatal conductance and transpiration of cucumber leaves in both seasons as compared with control treatment.

Effect cucumber total yield: No significant differences were noticed between the treatments of water regime (50 and 100%) on total yield in both seasons (Table 3)

With respect to effect of rootstocks on the total yield of cucumber, data in Table 3 revealed that only using bottle gourd as a rootstock in the first season gave significant higher total yield as compared with control, whereas, in the second season, using pumpkin, Shintoza and bottle gourd, as rootstocks for cucumber grafting significantly increased total yield, as compared with control treatment.

Table 1. Effect of water regime, grafting rootstock and their interactions on cucumber growth parameter (plant height, leaf area and chlorophyll reading), 60 days after transplanting (2018 and 2019)

Treatment		2018			2019		
		Plant height (cm)	Leaf area (cm^2)	Chlorophyll (%)	Plant height (cm)	Leaf area (cm^2)	Chlorophyll (%)
Water regime (A)	Rootstock						
50%	Bottle gourd	69.50	2.96	39.17	76.67	8.82	41.03
	Shintoza	56.17	2.94	42.70	74.00	9.97	42.43
	Luffa	28.67	2.47	36.67	66.67	9.50	41.65
	Pumpkin	55.67	2.70	38.72	63.33	8.36	41.55
	Squash	55.00	3.06	39.25	65.67	8.06	43.83
	Non-grafted	69.33	2.95	38.63	78.67	8.97	45.83
Mean		55.72	2.84	39.08	70.83	8.95	42.72
100%	Bottle gourd	72.83	3.29	40.00	90.33	13.26	43.75
	Shintoza	71.83	2.66	38.25	86.00	10.86	42.07
	Luffa	30.67	3.89	35.28	64.67	11.22	40.63
	Pumpkin	69.50	3.40	38.23	88.33	10.61	42.27
	Squash	65.17	3.50	38.23	82.67	11.27	40.15
	Non-grafted	70.83	3.29	38.97	79.00	10.48	41.85
Mean		63.47	3.34	38.16	81.83	11.28	41.79
Grafting rootstock (B)							
Bottle gourd		71.17	3.12	39.24	83.50	11.04	42.39
Shintoza		64.00	2.80	40.50	80.00	10.41	42.25
Luffa		29.67	3.18	35.97	65.67	10.36	41.14
Pumpkin		62.58	3.05	38.47	75.83	9.48	41.91
Squash		60.08	3.28	38.74	74.17	9.66	41.99
Non-grafted		70.08	3.12	38.80	78.83	9.73	43.84

Table 2. Effect of water regime, grafting rootstock and their interactions on photosynthesis, stomatal conductance and transpiration of cucumber leaves, 60 days after transplanting, of 2018 and 2019 seasons

		2018				2019			
Treatment	Rootstock	Photosynthesis (µmol CO_2 m^{-2} S^{-1})	Stomatal conductance - (mmol CO_2 m^{-2} S^{-1})	Transpiration (mmol H_2O m^{-2} S^{-1})	Total yield (g/plant)	Photosynthesis (µmol CO_2 m^{-2} S^{-1})	Stomatal conductance (mmol CO_2 m^{-2} S^{-1})	Transpiration - (mmol H_2O m^{-2} S^{-1})	Total yield (g/plant)
Water regime (A)									
50%	Bottle gourd	536.3	531.3	0.060	3597	634.5	450.2	0.091	1972
	Shintoza	603.3	513.3	0.068	2208	656.5	377.3	0.078	2090
	Luffa	398.3	601.0	0.062	1930	603.1	471.8	0.067	870
	Pumpkin	576.3	696.0	0.050	1867	666.6	492.2	0.105	2705
	Squash	626.6	437.0	0.052	1583	665.0	420.5	0.061	2067
	Non-grafted	609.9	656.0	0.057	1208	633.3	589.5	0.080	1398
Mean		558.5	572.4	0.058	2066	643.6	466.9	0.070	1850
100%	Bottle gourd	506.6	556.7	0.060	3522	621.6	437.8	0.055	3281
	Shintoza	503.3	677.3	0.064	3490	619.8	590.7	0.063	2929
	Luffa	540.0	652.7	0.053	2462	683.1	528.8	0.062	1053
	Pumpkin	513.6	717.3	0.049	2133	628.3	528.3	0.061	5180
	Squash	616.6	665.7	0.055	2034	654.8	559.3	0.064	2532
	Non-grafted	559.8	616.7	0.056	2397	654.2	499.2	0.063	1139
Mean		540.0	647.7	0.056	2673	643.2	524.0	0.091	2686
Grafting rootstock (B)									
Bottle gourd		521.5	544.0	0.060	3559	628.0	444.0	0.075	2626
Shintoza		553.3	595.3	0.066	2849	638.1	484.0	0.073	2510
Luffa		469.1	626.8	0.058	2196	643.1	500.3	0.070	961.7
Pumpkin		545.0	706.7	0.050	2000	647.4	510.3	0.065	3943
Squash		621.6	551.3	0.054	1809	659.9	489.9	0.083	2299
Non-grafted		584.9	636.3	0.056	1803	643.7	544.3	0.063	1269
LSD at 0.05	A	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	B	129.3	146.3	N.S.	1181	N.S.	N.S.	N.S.	1007
	AB	182.8	207	N.S.	1670	73.3	158.2	N.S.	1424

Table 3. Effect of water regime, grafting rootstock and their interactions on fruits quality of cucumber (fruit weight, fruit length, fruit diameter and TSS), at fifth harvest (2018 and 2019)

Water regime (A)	Grafting rootstock	2018				2019			
		Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	TSS (%)	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	TSS (%)
50%	Bottle gourd	75.50	12.57	2.17	3.33	65.33	13.83	2.13	3.60
	Shintoza	77.00	11.17	2.83	3.53	67.00	11.07	2.77	3.67
	Luffa	77.50	8.667	2.73	3.03	48.67	11.00	2.70	3.00
	Pumpkin	71.50	12.33	2.43	3.43	68.33	14.53	2.20	3.73
	Squash	67.50	11.90	2.47	3.60	69.67	12.80	2.20	4.20
	Non-grafted	73.33	11.77	2.40	3.00	74.33	13.17	2.37	3.07
Mean		73.72	11.40	2.51	3.32	65.56	12.73	2.39	3.54
100%	Bottle gourd	76.80	11.93	2.37	3.33	72.67	15.17	2.23	3.73
	Shintoza	80.33	13.10	2.43	3.33	71.00	14.00	2.27	3.50
	Luffa	84.90	13.63	2.73	3.00	70.00	16.33	2.80	3.00
	Pumpkin	67.40	12.43	2.43	3.40	77.33	13.80	2.23	3.67
	Squash	74.83	11.37	2.23	3.67	65.67	13.00	2.17	4.03
	Non-grafted	82.50	11.93	2.40	3.13	71.00	14.77	2.40	3.50
Mean		77.79	12.40	2.43	3.31	71.28	14.51	2.35	3.57
Grafting rootstock (B)									
Bottle gourd		76.15	12.25	2.27	3.33	69.00	14.50	2.18	3.67
Shintoza		78.67	12.13	2.63	3.43	69.00	12.53	2.52	3.58
Luffa		81.20	11.15	2.73	3.02	59.33	13.67	2.75	3.00
Pumpkin		69.45	12.38	2.43	3.42	72.83	14.17	2.22	3.70
Squash		71.17	11.63	2.35	3.63	67.67	12.90	2.18	4.12
Non-grafted		77.92	11.85	2.40	3.07	72.67	13.97	2.38	3.28
LSD at 0.05	A	N.S.	N.S.	N.S.	N.S.	N.S.	0.23	N.S.	N.S.
	B	N.S.	1.00	1.00	0.47	10.95	1.04	0.22	0.53
	AB	N.S.	1.42	1.42	0.67	15.48	1.48	0.31	0.75

Concerning the interaction between the water regime and grafting rootstocks, it was evident from the data (Table 3) in the first season that the highest values of total yield were achieved by using bottle gourd as a rootstock in both 50 or 100% of water regimes, while, in the second season, using pumpkin as rootstock gave the best total yield in both 50 and 100% of water requirements.

Fruits quality of cucumbe: Drought stress treatment (50% of water requirements) caused a significant reduction only in cucumber fruit length in second season, as compared with normal irrigation (100% of water requirements). On the contrary, there no significant differences were recorded in fruit weight, fruit diameter and fruit TSS using both water regime treatments in the two seasons (Table 4).

With regard to the effect of using grafting rootstocks on fruit quality, only, in the second season, grafting cucumber onto luffa had a significant decrease in fruit weight. The same rootstock had significant increment in fruit diameter compared to non-grafted ones. Also, grafted cucumber onto shintoza and squash rootstocks in the second season had significant decrease in cucumber fruit length, whereas TSS was significantly higher using squash as rootstock in both seasons compared with control.

The interaction between water regime and grafting rootstocks showed that grafting cucumber on luffa rootstock significantly decreased fruit weight and fruit length in the second season and fruit length in the first season at drought treatment (50%), as compared with control. Also, using shintoza rootstock at drought treatment (50%) and squash rootstock at 100% of water regime treatment led to a significant decrease in fruit length in the second season. On the other hand, fruit length, at 100% of water regime treatment, and fruit diameter, at 50 and 100% of water regime treatment, significantly increased using luffa as rootstock, only in the second season. In contrast, shintoza rootstock significantly improved fruit diameter at drought treatment (50%) in the second season, as compared with control. Additionally, in the second season, TSS % in cucumber fruit significantly increased using squash as rootstock only at drought treatment (50%).

Nitrogen, phosphorus and potassium concentrations of cucumber leaves,: Data in Table 5 showed that there no significant differences were remarked between drought treatment (50%) and normal irrigation treatment (100%) on translocation of N, P and K from roots to cucumber leaves in both seasons, except N % in the first season as well as P % in the second season that were significantly lower in normal irrigation treatment than drought treatment.

As compared with the control, all rootstocks did not significantly affect N and K content of cucumber leaves in the first season, while using pumpkin, shintoza and squash rootstocks gave a significant increment in P% of cucumber leaves in the first season. In the second season, using shintoza or squash rootstocks in the case of N%, using bottle gourd or luffa rootstocks in the case of P%, and using luffa rootstock in the case of K% significantly decreased the accumulation of elements in cucumber leaves, as compared with control.

With regard to the interaction between water regime and grafting rootstocks, it was evident from the data of the two seasons that all grafting rootstocks in 50 or 100% of water requirements, except grafting onto luffa rootstock at drought treatment (50%) in the first season and grafting onto shintoza and squash rootstocks at normal irrigation treatment (100%) in the second season caused a significant reduction in N% of cucumber leaves, as compared with control. Respect of P%, using pumpkin as rootstock at both

Table 4. Effect of water regime, grafting rootstock and their interactions on nitrogen, phosphorus and potassium concentrations of cucumber leaves, 60 days after transplanting, of 2018 and 2019

Treatment		2018			2019		
Water regime (A)	Grafting rootstock	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
50%	Bottle gourd	5.39	0.25	3.00	4.54	0.50	3.89
	Shintoza	5.48	0.27	3.23	4.57	0.79	4.57
	Luffa	5.08	0.23	3.04	4.59	0.50	3.50
	Pumpkin	5.27	0.37	3.19	5.07	0.56	3.93
	Squash	5.56	0.270	3.42	4.66	0.64	4.43
	Non-grafted	5.87	0.19	2.77	5.32	0.76	4.35
Mean		5.44	0.26	3.11	4.79	0.63	3.61
100%	Bottle gourd	4.79	0.16	3.24	4.64	0.45	3.78
	Shintoza	4.67	0.26	2.73	4.00	0.52	3.50
	Luffa	5.42	0.25	3.07	4.80	0.49	3.50
	Pumpkin	5.02	0.34	3.07	5.62	0.65	3.50
	Squash	5.01	0.25	3.23	3.98	0.51	3.71
	Non-grafted	4.68	0.18	3.14	4.93	0.48	3.64
Mean		4.93	0.24	3.08	4.66	0.52	4.11
Grafting rootstock (B)							
Bottle gourd		5.092	0.21	3.12	4.59	0.48	3.84
Shintoza		5.077	0.26	2.98	4.29	0.66	4.04
Luffa		5.250	0.24	3.06	4.70	0.50	3.50
Pumpkin		5.147	0.36	3.13	5.35	0.61	3.71
Squash		5.287	0.26	3.33	4.32	0.58	4.07
Non-grafted		5.278	0.18	2.95	5.13	0.62	4.00
LSD at 0.05	A	0.36	N.S.	N.S.	N.S.	0.04	N.S.
	B	N.S.	0.06	0.23	0.60	0.06	0.29
	AB	0.78	0.09	0.32	0.84	0.09	0.41

drought treatment and normal irrigation treatment significantly increased P% of cucumber leaves in the first season, whereas using all rootstocks, except shintoza, at drought treatment in the second season caused a significant reduction in P% of cucumber leaves *vice versa* the concentration of P, at normal irrigation treatment, was significantly higher with using pumpkin rootstock than using control treatment. Moreover, using squash, pumpkin or shintoza at drought treatment significantly increased K% of cucumber leaves in the first season, whereas using shintoza only at normal irrigation treatment caused a significant reduction in K% compared with control. In the second season, grafted cucumber onto luffa, bottle gourd, and pumpkin rootstocks at drought treatment significantly reduced K% in cucumber leaves, compared with non-grafted treatment.

Discussion

Cucumber Growth Parameters: The water regime treatment did not significantly affect cucumber plant height, leaf area, or chlorophyll readings in both seasons, except for a decrease in leaf area during the second season under drought treatment (50%). The negative impact on leaf area in the second season could be attributed to drought stress affecting the plant's physiological functions, aggravated by a delayed planting date that exposed the plants to high temperatures. This finding is consistent with prior research by Akram *et al*. (2016) and Abd El-Mageed and Semida (2015) who also reported decreased cucumber leaf area under water stress conditions. Similarly, Abdelaziz and Taha (2018) observed a significant reduction in tomato plant growth under water-deficit conditions.

Grafting cucumber onto luffa rootstock significantly reduced plant height in both seasons, while grafting onto bottle gourd in the second season significantly increased leaf area. However, no significant effects on plant height, leaf area, or chlorophyll readings were observed with other rootstocks in both seasons. The varying effects of rootstocks on cucumber growth might be due to differences in root volume and compatibility with the scion. Previous research by Huaifu *et al*. (2006) showed that cucumber grafted on smooth luffa had significantly higher plant height and stem thickness compared to non-grafted plants. In contrast, Abd-Alla (2002) reported higher leaf area values in cucumber plants grafted onto Fig. leaf gourd and bottle gourd compared to other rootstocks.

Photosynthesis, stomatal conductance, and transpiration: Water regime treatment and grafting rootstocks did not significantly affect cucumber leaf photosynthesis, stomatal conductance, or transpiration in both seasons when compared to the control treatment. These results suggest that grafting rootstocks may improve water use efficiency (WUE) in cucumber, helping to mitigate the adverse effects of drought conditions. This finding aligns with Zhang *et al*. (2020), who also reported increased WUE due to grafting. However, Naz *et al*. (2016) found significantly reduced photosynthetic rate and stomatal conductance of cucumber under drought stress. Additionally, Mao *et al*. (2003) observed limited transpiration rates in plants under drought stress.

Cucumber total yield: The water regime treatments (50% and 100%) did not result in significant differences in cucumber total yield in both seasons. This indicates that water productivity can be optimized using deficit irrigation instead of striving for maximum yield from complete irrigation. These findings are consistent with Sánchez-Rodríguez *et al*. (2013), who highlighted the effectiveness of deficit irrigation in water productivity. Kireva and Mihov (2019) reported the highest long-fruit cucumber yield at 120% of irrigation rate and the lowest at 40% of the irrigation rate, with only slight yield increases (2 to 5%) with a 20% increase in irrigation rate. Moreover, Al-Harbi *et al*. (2018) observed reduced cucumber yield under water stress treatments.

Grafting cucumber onto specific rootstocks, such as bottle gourd in the first season, and pumpkin, shintoza, and bottle gourd in the second season, significantly increased total yield compared to the control treatment. Farhadia and Rezaie (2015) found that the rootstock ES107 resulted in significantly lower fruit number and total yield compared to non-grafted cucumber, while RZ426 showed higher values. Similar results were observed for cucumber grown hydroponically in a greenhouse by Farhadia *et al*. (2016), where specific rootstocks significantly increased total yield and fruit number compared to the non-grafted control.

Fruit Quality: Drought stress treatment (50%) caused a significant reduction in cucumber fruit length in the second season compared to normal irrigation (100%). However, no significant differences were observed in fruit weight, diameter, or total soluble solids (TSS) using both water regime treatments in both seasons. These results may be attributed to unaffected photosynthesis processes under drought stress, which helped improve fruit quality parameters.

Grafting cucumber onto luffa rootstock significantly reduced fruit weight and increased fruit diameter in the first season. Grafting onto shintoza and squash rootstocks in the second season significantly reduced cucumber fruit length, while squash rootstock increased TSS in both seasons. This finding is in line with Kabeel (1999) and Abd-Alla (2002), who reported increased TSS% in fruits grafted onto pumpkin or squash rootstocks. Additionally, El-Sayed *et al*. (2014) found that grafting cucumber onto Ferro rootstock increased fruit physical characters.

NPK content of cucumber leaves: Drought stress (50%) did not affect N, P, and K translocation from cucumber roots to leaves in both seasons. This is likely due to unaffected photosynthesis, stomatal conductance, and transpiration processes under drought stress, allowing the plant to maintain continuous nutrient absorption. This result contradicts Mao *et al*. (2003), who reported decreased nutrient uptake and transport under drought conditions.

Regarding grafting rootstocks, all rootstocks did not significantly affect N and K percentages of cucumber leaves in the first season. However, using pumpkin, shintoza, and squash rootstocks significantly increased P% of cucumber leaves in the first season. In the second season, using shintoza or squash rootstocks for N%, bottle gourd or luffa rootstocks for P%, and luffa rootstock for K% significantly decreased nutrient accumulation in cucumber leaves compared to the control treatment. The positive effects of grafting on increasing nutrient concentrations in leaves may be due to the stronger roots of rootstocks, encouraging better water and nutrient absorption from the soil. This finding is supported by Canizares *et al*. (2005), El-Sayed *et al*. (2014), Kumar *et al*. (2015), and Ceylan *et al*. (2018), who also observed increased macro and micro element uptake due to grafting.

The study revealed that water regime treatment and grafting rootstocks can influence cucumber growth parameters, yield, fruit quality, and nutrient content. While the water regime treatment did not significantly affect most growth parameters, grafting onto specific rootstocks showed significant effects on cucumber plant height and leaf area. Moreover, grafting rootstocks demonstrated the potential to improve water use efficiency, which may be beneficial in mitigating drought stress effects. The study also highlighted the importance of selecting appropriate rootstocks to enhance cucumber yield and fruit quality. However, more research is needed to understand the underlying mechanisms behind these effects and optimize cucumber production under different environmental conditions.

References

Abd-Alla, M.A. 2002. Effect of soil solarization, fertilizer sort and grafting on growth and productivity of cucumber crop (*Curcumis sativa*, L.). Ph.D. Thesis, Fac. *Agric. Kafr El-Sheikh, Tanta Univ. Egypt*, PP, 98.

Abdelaziz, E. and S.S. Taha, 2018. Foliar potassium and zinc stimulates tomato growth, yield and enzymes activity to tolerate water stress in soilless culture. *Journal Food, Agriculture & Environment*, 16 (2): 113-118.

Abd El-Mageed, T.A. and W.M. Semida, 2015. Organo mineral fertilizer can mitigate water stress for cucumber production (*Cucumis sativus* L.). *Agricultural Water Management*, 159(1): 10.

Akram, N.A, M. Waseem, R. Ameen and M. Ashraf, 2016. Trehalose pretreatment induces drought tolerance in radish (*Raphanus sativus* L.) plants: some key physio-biochemical traits. *Acta Physiologia Eplantarum*, 38(1): 3.

A.l. Harbi, A.R., A.M. A.l. Omran and K. Alharbi, 2018. Grafting improves cucumber water stress tolerance in Saudi Arabia. *Saudi Journal Biological Sciences*, 25(2): 298-304.

AOAC, 1975. *Official Methods of Analysis of the Association of Official Analysis Chemists*, 12th ed., Association of Official Analytical Chemists, Washington. C. 200044.

Brown, J.D. and O. Lilliland, 1964. Rapid determination of potassium and sodium in plant materials and soil extracts by flame photometer. In *Proceedings of the Society for Horticultural Science,* 48: 341-346.

Canizares, K.A., J. Rodrigues, R. Goto and R. Boas, 2005. Influence of irrigation water enriched with carbon dioxide and grafting on the nutrient content of cucumber plants. *Hort. Brasileira*, 23(1): 9- 14.

Cansev, A. and M. Ozgur, 2020. Grafting cucumber seedlings on (*Cucurbita* spp) comparison of different grafting methods, scions and their performance. *Journal Food Agriculture Environment,* 8(3&4): 804-809.

Ceylan, S., O. Alan and O.L. ELmaci, 2018. Effects of grafting on nutrient element content and yield in watermelon. *Ege Üniv. Ziraat Fak. Derg*., 2018, 55(1): 67-74.

Colla, G., Y. Rouphael, M. Cardarelli, A. Salerno and E. Rea, 2011. The effectiveness of grafting to improve alkalinity tolerance in watermelon. *Environ. Exp. Bot*, 68: 283-291.

Colla, G., C.M.C. Suarez, M. Cardarelli and Y. Rouphael, 2010. Improving nitrogen use efficiency in melon by grafting. *HortScience*, 45: 559-565.

Cotteñie, A., M. Verloo, L. Kiekens, G. Velghe and R. Camerlynch, 1982. Chemical Analysis of Plant and Soils. *Laboratory of Analyticcal and Agrochemistry State Univ., Ghent Belgium*.

Edelstein, M., Y. Burger, C. Horev, A. Porat, A. Meir and R. Cohen, 2004. Assessing the effect of genetic and anatomic variation of Cucurbita rootstocks on vigour, survival and yield of grafted melons. *J. Hort. Sci. Biotechnol*., 79: 370-374.

EL-Sayed, S.F., H.A. Hassan, A. Abdel-Wahab, and A.A. Gebrael, 2014. Effect of grafting on the cucumber yield and quality under high and low temperature. *J. Plant Production, Mansoura Univ.,* 5(3): 443-456.

FAO, 2019. Statistics at FAO. Available online: www.fao.org.

Farhadia, A., H. Aroeii, H. Nemati, R. Salehi and F. Giuffrida, 2016.

The effectiveness of different rootstocks for improving yield and growth of cucumber cultivated hydroponically in a greenhouse. *Horticulturae*, 2(1), doi: 10.3390/horticulturae2010001 www.mdpi.com/journal/horticulturae

Farhadia, A. and M. Rezaie, 2015. Evaluation of quantitative and qualitative traits of greenhouse cucumber (*Cucumissativus* L. 'Khassib') grafted on different cucurbita rootstocks. *Acta Hort*. 1086: 279-283.

Guan, W., D. Haseman and D. Nowaskie, 2020. Rootstock evaluation for grafted cucumbers grown in high tunnels: Yield and plant growth. *HortScience*. https: //doi.org/10.21273/HORTSCI14867-20

Huaifu, F., G. Shirong, Z. Runhua, L. Nana, C. Congcong and D. Changxia, 2006. Effects of grafting on growth and physiological metabolism in cucumber seedlings under hypoxia stress. *Acta Hort. Sinica*, 33(6): 1225-1230.

Kabeel, S.M, 1999. Effect of some cucurbits rootstocks on growth, yield and resistance to some soil pests of cucumber under plastic houses. *Ph.D. Thesis, Fac. Agric., Moshtohor, Zagazig Univ. Egypt*, 79p.

Kireva, R. and M. Mihov, 2019. Irrigation regime for long-fruit cucumbers grown under greenhouse conditions. *Mechanization in Agriculture & Conserving of the Resources*, 65(4): 153-155.

Kumar, P., M. Edelstein, M. Cardarelli, E. Ferri and G. Colla, 2015. Grafting affects growth, yield, nutrient uptake, and partitioning under cadmium stress in tomato. *HortScience*: 50(11): 1654-1661.

Lee, J.M., C. Kubota, S.J. Tsao, Z. Bie, E.P. Hoyos and O.M. MorraL, 2010. Current status of vegetable grafting: diusion, grafting techniques, automation. *Sci. Hortic*., 127: 93-105.

Mao, X., M. Liu, X. Wang, C. Liu, Z. Hou and J. Shi, 2003. Effects of deficit irrigation on yield and water use of greenhouse grown cucumber in the North China Plain. *Agric. Water Manage*. 61: 219-228.

Naz, H.I.R.A., N.A. Akram and M. Ashraf, 2016. Impact of ascorbic acid on growth and some physiological attributes of cucumber (*Cucumis sativus*) plants under water-deficit conditions. *Pak. J. Bot.*, 48(3): 877-883.

Noor, R.S., Z. Wang, M. Umair, M. Yaseen, M. Ameen, S. Rehman, M.U. Khan, M. Imran, W. Ahmed and Y. Sun, 2019. Interactive effects of grafting techniques and scion-rootstocks combinations on vegetative growth, yield and quality of cucumber (*Cucumis sativus* L.). *Agronomy*, 9, 288; doi: 10.3390/agronomy9060288, www.mdpi.com/journal/agronomy.

Piper, C.S. 1947. *Soil and Plant Analysis*. Adelaide, UK: The University of Adelaide, 368p.

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

Ruiz, J.M. and L. Romero, 1999. Nitrogen efficiency and metabolism in grafted melon plants. *Scientia Horticulturae*, 81: 113-123.

Sánchez-Rodríguez, E., L. Romero and J.M. Ruiz, 2013. Role of grafting in resistance to water stress in tomato plants: ammonia production and assimilation. *Journal of plant growth regulation*, *32*(4): 831-842.

Savvas, D., D. Papastavrou, G. Ntatsi, A. Ropokis, C. Olympios, H. Hartmann and D. Schwarz, 2009. Interactive effects of grafting and Mn-supply level on growth, yield and nutrient uptake by tomato. *HortSci*., 44: 1978-1982.

Schwarz, D., Y. Rouphael, G. Colla and J.K. Venema, 2010. Grafting as a tool to improve tolerance of vegetables to abiotic stresses: thermal stress, water stress and organic pollutants.-*Sci. Hort*. 127: 162-171.

Snedecor, G.A. and W.G. Cochran, 1976. Statistical Method. Iowa State Univ. Press, Ames.

Uysal, N., Y. Tuzel, G.B. Oztekin and I.H. Tuzel, 2012. Effects of different rootstocks on greenhouse cucumber production. *Acta Hort*., 927: 281-290.

Yuan, L., S. Hu, Z. Okray, X. Ren, N. De Geest, A. Claeys, J. Yan, E. Bellefroid, B.A. Hassan and X.J Quan, 2016. The *Drosophila neurogenin* Tap functionally interacts with the Wnt-PCP pathway to regulate neuronal extension and guidance. *Development*, 143(15): 2760-2766.

Zhang, Z., B. Cao, S. Gao and K. Xu, 2019. Grafting improves tomato drought tolerance through enhancing photosynthetic capacity and reducing ROS accumulation. *Protoplasma*, 256(4): 1013-1024.

Zhang, Z., Y. Liu, B. Cao, Z. Chen and K. Xu, 2020. The effectiveness of grafting to improve drought tolerance in tomato. *Plant Growth Regulation*, 91(1): 157-167.

Received: October, 2021; Revised: December, 2021; Accepted: December, 2021