

The Influence of Irrigation Regimes on the Yield and Fruit Quality of Date Palm Trees

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One of the big problems in Saudia Arabia is the scarcity of irrigation water, and this extremely affects the yield of plant components. Consequently, determination of the best water irrigation requirements for the growth and productivity of date palm trees is needed. The current study was performed on three date palm cultivars: 'Khalas', 'Nabbut', and 'Rothana' to investigate the effect of 100% (19.2 m³), 80% (15.36 m³), 60% (11.52 m³), and 40% (7.68 m³) irrigation on the yield and fruit quality characteristics. The results showed that irrigation with 100% and 80% significantly increased the fruit yield, marketable fruit number, and fruit weight. Moreover, these regimes also greatly increased the fruit content from total and reduced sugars, and soluble solids compared with 40% and 60% regimes. The 100% and 80% irrigation regimes reduced the fruit acidity but the differences between 100%, 80%, 60%, and 40% water irrigation were not significant in 'Khalas' or 'Nabbut'. The effect of 100% was significant compared with the influence of 40%. The water footprint was significantly higher with 100% and 80% rather than with 60% or 40%.

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INTRODUCTION

Date palm (*Phoenix dactylifera* L.) represents 74% of the fruit trees cultivated area in the Kingdom of Saudi Arabia (Kassem 2007), and it is dominant in the arid and semi-arid zones characterized by water resource shortage (Shadeed 2013; Abd Elgawad *et al.* 2019). The cultivated area in Saudi Arabia is $\approx$ 157 thousand hectares, which produces $\approx$ 1.643 million tons (FAO 2025).

The shortage of available water is a significant environmental factor that restricts plant growth and photosynthesis. However, plants are known to use various strategies to cope with this challenge, and these strategies are linked to different adaptive traits. These traits can be seen through several responses, such as minimizing water loss and increasing water uptake, or maintaining significant internal water storage (Lambers *et al.* 2008). World water supplies are diminishing due to high temperatures, leading to abiotic stress in plants, especially when subjected to drought (Gamble *et al.* 2010). The crop coefficient for date palms varies throughout the growing season, ranging from 0.5 to 1.18 depending on the growth stage (Mazahrih *et al.* 2012). In arid Mediterranean countries, where water scarcity is prevalent, enhancing irrigation efficiency is crucial for sustaining date

production (Sperling *et al.* 2014). Extreme weather events such as heatwaves, droughts, and intense rainfall are increasingly common worldwide, impacting agricultural areas that depend on rain due to limited sustainable groundwater resources (Huber *et al.* 2016).

Sharma *et al.* (2020) noted that a lack of water can hinder chlorophyll production, resulting in its breakdown and lower chlorophyll levels, which may diminish the photosynthetic ability of plants.

A lack of water leads to the closing of stomata, which decreases the photosynthesis process in plants and impacts the ratio of carbon dioxide to oxygen in their leaves (Vaz *et al.* 2016; Ortega-Farias *et al.* 2021). Drought affects the transport and availability of soil nutrients (Vurukonda *et al.* 2016) as well as the morphological, physiological, and nutritional traits of plants. This includes factors like water content, leaf water potential, photosynthetic pigments, stomatal conductance, and the uptake of phosphorus and nitrogen (Meddich *et al.* 2018). Furthermore, water deficit is a significant environmental factor that reduces plant growth and production (Arora 2019). In arid and semi-arid regions, water shortage and ineffective irrigation water utilization are still the predominant factors affecting date palm cultivation because they often reduce the available groundwater (Baig *et al.* 2020). Proper water consumption in the tree system likely enhances and improves nutrient uptake (Mohammed *et al.* 2020).

Although resilient to extreme environmental factors such as drought and high summer heat, date palm is a water-demanding crop that needs sufficient water for optimal yield and quality production (Dhaouadi *et al.* 2021).

Water stress can reduce transpiration rates and lead to stomatal closure, which in turn impacts the transport of calcium ions from roots to shoots, ultimately lowering the calcium levels in plants (Li *et al.* 2021). Besides, water scarcity and salinity stress greatly affect the productivity of date palms, particularly in arid regions. This situation arises from low rainfall, excessive evapotranspiration, and inadequate irrigation practices. A major concern for agriculture in Saudi Arabia is water shortage, exacerbated by its dry, arid, to hyper-arid climate. Most regions receive under 100 mm of rainfall yearly, except the southwest area (Mohammed *et al.* 2021; Alnaim *et al.* 2022; Alotaibi *et al.* 2023).

Drought conditions (40% and 60%) led to a significant reduction in leaf growth, plant dry biomass, and other physiological and biochemical traits. However, date palm cultivars can thrive in moderate drought (80% ETc), demonstrating minimal effects on their phenotypic, physiological, and biochemical characteristics, which supports water conservation (Ali-Dinar *et al.* 2023). Cultivating date palms in the area is difficult because of factors including water scarcity and salinity in the soil and water (Hammami *et al.* 2024).

The amount of irrigation water applied was 50%, 65%, 82%, and 100% of the water needed by ‘Nab-but-Saif’ date palms to optimize irrigation efficiency, yields, and quality characteristics while grown on sandy loam soil in arid conditions. The research revealed that supplying 65% of the total water needed for irrigating date palms maximized yield at 46.1 kg per tree, resulting in the most efficient irrigation water use (IWU) of 0.8 m³/kg. Furthermore, reducing IWU while achieving production of 45.5 to 46 kg per tree increased water availability to 82% and 100% of the overall requirement. The results suggest that providing 34 m³ per tree annually in western Saudi Arabia significantly enhances the water use efficiency, productivity, and quality of the ‘Nab-but-Saif’ date palm variety (Ismail *et al.* 2014).

The current study aimed to investigate the impact of water levels on the yield and characteristics (both physical and chemical) of three date trees grown in the arid region of Saudi Arabia.

EXPERIMENTAL

Experimental Site Description and its Design

The present study was carried out during the two successive seasons of 2022 on 10-year-old date palm trees (*Phoenix dactylifera* L.) cvs. ‘Khalas’, ‘Nabbut’, and ‘Rothana’, planted at 10×10 m apart and grown under a drip irrigation system in sandy soil at Palm and Dates Research Center in Al-Ahsa, Saudi Arabia. The date palm cultivars were irrigated by 100% (19.2 m³), 80% (15.36 m³), 60% (11.52 m³), and 40% (7.68 m³).

The gross water requirements (GWR) were calculated using the following equation,

$$GWR = \frac{ETc \times S_e}{(1 - LR) \times Effir} \quad (1)$$

where GWR = gross water requirement (m³/ha), ETc = crop evapotranspiration (m³/ha), Effir = efficiency (%), 90%, LR = leaching requirements, and S_e = the percentage of evapotranspiration area.

The crop evapotranspiration (ETc) can be calculated as,

$$ETc = K_c \times ETr \quad (2)$$

where K_c = crop coefficient ranged from 0.8 to 1.0 depending on the month of the year, as noted in (Allen *et al.* 1998), ETr = ETo = Reference crop evapotranspiration (mm/day), ETc = Crop evapotranspiration (mm/day). The percentage of evapotranspiration area (S_e) is derived from the shaded area observed at noon in June, which signifies the peak net radiation period, and the actual area of each tree based on the equation detailed by Hellman (2010),

$$S_e = \frac{\text{Shaded area per tree}}{\text{Actual area}} \times 100 = \frac{\mu R^2}{10m \times 10m} \times 100 \quad (3)$$

where S_e is the percentage of evapotranspiration area, R is the radius of the tree (m), and shaded area = area of the shade of one tree measured at noon.

$$LR = (1 + x)^n = \frac{ECiw}{2MaxECe} \times \frac{1}{Ef} \quad (4)$$

In Eq. 4, LR represents the fraction of water that permeates the entire root zone and drains below. ECiw denotes the electrical conductivity of irrigation water measured in dS/m. ECe indicates the electrical conductivity of the soil saturation extract relevant to the crop, reflecting the allowable yield reduction (dS/m). Max ECe refers to the highest acceptable electrical conductivity of the soil saturation extract for that specific crop (dS/m). Ef signifies leaching efficiency, which is 90% for sandy and loamy sands.

The palm trees were uniformly selected as healthy and nearly the same in vigor and size. The physical and chemical analysis of the experimental soil is shown in Table 1. The data of the analysis of the irrigation water is shown in Table 2, and the average values of the climatic variables are in Table 3.

Table 1. The Physical and Chemical Features of the Experimental Soil

Texture	Mechanical Analysis			Soil Constants			CaCO ₃	O.M	Hydraulic Conductivity (cm/h)
	Sand	Silt	Clay	W.P%	F.C%	SP%			
Sandy loom	67.5	17.5	15	8.3	16.6	33.2	14.1	1.88	4.2

W.P%: Wilting Point; F.C%: Field Capacity; SP%; Saturation Point; O.M: Organic matter

Table 2. Analysis of the Irrigation Water

TDS (mg/L)	SAR	pH	μS/cm	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
998	3.66	7.5	1560	3.0	7.5	0.25	0	2.6	7.0	6.5

TDS (mg/L): Total Dissolved Solids; SAR: Sodium Adsorption Ratio; EC (dS/m): Electrical Conductivity

Table 3. The Average Values of the Climatic Variables

Stat	T-mean (°C)	T-max (°C)	T-min (°C)	Rainfall (mm)	Radiation (MJ/m ²)
Average	25.60	34.28	18.81	0.40	6.98
	Wind speed (m/s)	ET ₀ (mm)	K _c	ET _c (mm)	RH-min (%)
Average	2.08	6.30	0.91	5.88	20.96

ET_c: Crop Evapotranspiration (mmday⁻¹); ET₀: Reference Evapotranspiration (mmday⁻¹); K_c: Crop coefficients; Rh = Relative humidity

The treatments were arranged in a split plot with five replicates (five trees). The quantity of the irrigation water effect was investigated by studying their effects on the following parameters:

The palm yield

It was assessed in kg/tree and by the marketable and non-marketable fruit in kg. The differences between marketable and non-marketable fruits were measured based on the weight, size, and color

Fruit sampling

At fruits ripening (fruit reached full maturity and 100% yellow coloring), a sample of 50 fruit/replicate was randomly collected from each treatment to measure fruit physical characteristics and another sample of each treatment was collected to measure fruit chemical characteristics.

Fruit physical characteristics

Fresh fruit weight (g), dry weight (g), and then the wet percentage Average fruit weight, and Flesh weight (g) were measured. The wet percentage was calculated according to Eq 5:

$$\text{Wet \%} = \frac{\text{Fresh weight} - \text{dry weight}}{\text{Fresh weight}} \times 100 \quad (5)$$

Fruit chemical characteristics

The total soluble solids (TSS) percentage in the fruit juice was measured using a hand refractometer. The acidity of the fruit, expressed as malic acid units, was analyzed in the fruit juice through titration with 0.1N sodium hydroxide, with phenolphthalein as the indicator, following the method outlined in (AOAC 2005). Additionally, the total sugars and reducing sugars in the fruit were assessed using the phenol sulfuric acid method described in (Nielsen 2010). Non-reducing sugars were calculated by subtracting the amount of reducing sugars from the total sugars.

Statistical Analysis

The results were statistically analyzed with One-way analysis of variance (ANOVA) via CoHort Software (Pacific Grove, CA, USA), employing the least significant difference (LSD) at a 0.05% level to compare treatment means (Heiberger *et al.* 2015).

RESULTS

The data in Table 4 show that giving date palm 100% water percentage was more effective in increasing the fruit yield in date palm cvs. ‘Khalas’, ‘Nabbut’, and ‘Rothana’ in comparison to the addition of 80%, 60%, or 40%, respectively. Additionally, increasing the quantity of the given water was more effective than the small quantities of water. The water footprint (WFp) was high with the ‘Nabbut’ cultivar when the date palm trees were irrigated 100% compared with the other date palm cv. ‘Khalas’, ‘Nabbut’, and ‘Rothana’. The WFp with the three-date palm cvs. ‘Khalas’, ‘Nabbut’, and ‘Rothana’ were higher with the addition of 100% compared to 80%, 60%, and 40%. The results showed that the irrigation of date palm with 100% increased the quantity of marketable fruits, while the quantity of unmarketable fruits was reduced in the ‘Khalas’ date palm cultivar. Although using 100% water significantly increased the marketable fruit in ‘Rothana’ cultivar, the differences between using 100% and 80% were insignificant.

Table 4. The influence of the Water Irrigation Regimes on the Water Footprint, Yield, Marketable and Non-Marketable Fruit in Three Date Palm cvs. ‘Khalas’, ‘Nabbut’ and ‘Rothana’ during 2022 Season

Cultivar	Irrigation (%)	Water quantity (m ³ /palm)	WFp (water (L)/ fruit (kg))	Yield (kg/palm)	Marketable fruit (kg)	Non-marketable fruit (kg)
Khalas	100	19.2	0.34bc	57.25ab	48.00a	9.25b
	80	15.36	0.33bcd	46.00cd	34.50cd	11.50ab
	60	11.52	0.26efg	44.25cde	33.00cd	11.25ab
	40	7.68	0.19h	41.25ed	31.25cde	10.00ab
Nabbut	100	19.2	0.43a	45.00cd	35.50cd	9.50b
	80	15.36	0.37b	41.50cde	32.25cde	9.25b
	60	11.52	0.29de	40.25de	28.75de	11.50ab
	40	7.68	0.21gh	36.50e	25.00e	11.50ab
Rothana	100	19.2	0.29cde	65.12a	50.87a	14.25a
	80	15.36	0.27ef	57.37ab	44.37ab	13.00ab
	60	11.52	0.24fg	49.50bc	37.75bc	11.75ab
	40	7.68	0.18h	42.00cde	32.50cde	9.50b

The same letters in each column indicated no significant differences between the treatments.

The results in Table 5 show that the irrigation of date palm cultivars with the percentages of 100% increased the fruit content from TSS in the three date palm cultivars under study increased more than in the irrigated trees with 80%, 60%, and 40%. Additionally, 80% was also more effective in increasing the fruit content from TSS % than the addition of 60% or 40%. Regarding fruit content of acidity, the results indicated that irrigating the date palm by 40% resulted in significantly reduced acidity compared to

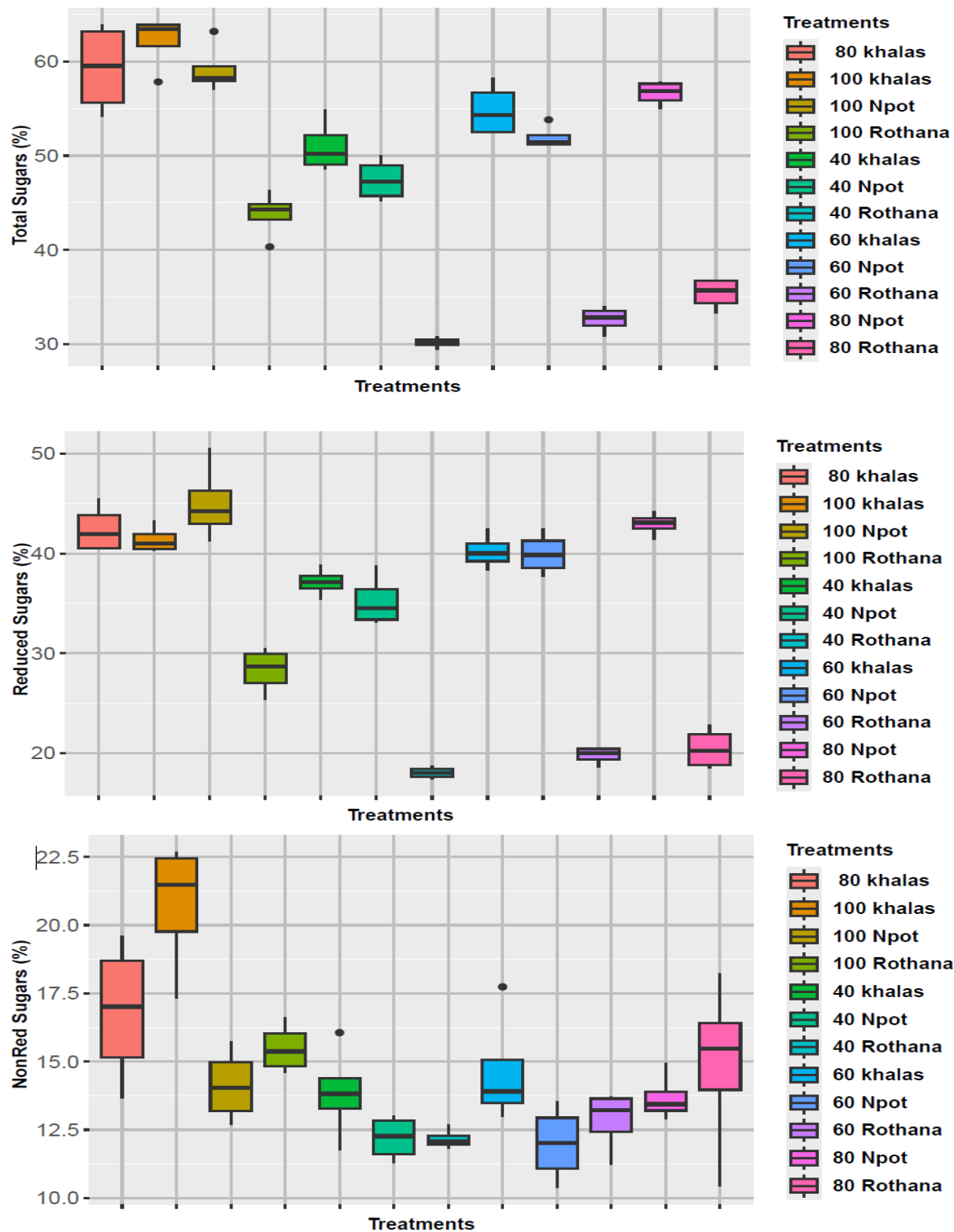
using 100% in the date palm cv. 'Rothana'. In date palm cvs. 'Khalas' or 'Nabbut', the differences between 40, 60, 80, or 100% were insignificant. The fresh weight of fruit was significantly increased by the irrigation of date palm trees by 100% in 'Rothana'. The quantity of water did not significantly affect the fruit weight in 'Khalas'. Fruit dry weight remarkably increased with the irrigation of date palm cv. 'Rothana' with 100%. In date palm cvs. 'Khalas' or 'Nabbut', the fruit dry weight did not significantly differ by the quantity of the irrigation. The percentages of irrigation did not differ substantially with the quantity of water in the three date palm cultivars.

Table 5. The Influence of the Water Irrigation Regimes on Fruit Content in Three Date Palm cvs. 'Khalas', 'Nabbut', and 'Rothana' during 2022 Season

Cultivar	Irrigation (%)	TSS (%)	Acidity (%)	Fresh Weight (g)	Fruit Dry Weight (g)	Fruit Wet Weight (%)
Khalas	100	74.25a	0.422c	11.53bc	9.96bc	13.72a
	80	74.25a	0.422c	11.63bc	9.91bc	14.80a
	60	73.95ab	0.462c	12.04bc	10.32bc	14.26a
	40	73.50ab	0.462c	11.83bc	10.02bc	15.37a
Nabbut	100	73.80ab	0.654ab	11.92bc	10.88b	8.68b
	80	69.95bc	0.721ab	11.97bc	10.36bc	13.43a
	60	67.70cd	0.694ab	10.46c	9.59bc	13.18a
	40	65.62de	0.727ab	11.05bc	8.89c	15.02a
Rothana	100	74.55a	0.628b	15.31a	13.10a	14.40a
	80	72.90ab	0.724ab	12.73b	11.01b	13.56a
	60	70.35abc	0.699ab	11.25bc	9.69bc	13.75a
	40	62.85e	0.742a	10.94bc	9.39bc	14.11a

The same letters in each column indicated that there are no significant differences between the treatments.

The results in Fig. 1 indicate that the irrigation of date palm cultivars with 100% increased the fruit content from total sugars compared to using 40 or 60% in the three date palm cultivars under study. The differences between 100, 80, 60, and 40% reduced sugar percentages in date palm cv. 'Khalas' were insignificant. Using 80 or 100% of water significantly increased the in 'Nabbut' date palm in contrast with using 40%. Sugar content of 'Rothana' date palm was increased extremely by adding 100% water rather than adding 40, 60, and 80%. Non-reduced sugar percentages were greatly increased using 100% water over 40 or 60% in 'Khalas' date palm cultivar. There were no significant differences between the usage of 40, 60, 80, and 100% water on the fruit content from non-reduced sugars in 'Nabbut' or 'Rothana' date cultivars. The fruit content from glucose was notably increased by the addition of 100 or 80% water rather than the using of 40 or 60% in 'Nabbut' date cultivar or using 40% in 'Rothana'. Fructose content in the fruits was markedly increased by using 100% compared to 60 or 40% in 'Khalas', 'Nabbut' or 'Rothana'. The differences between the effect of using 100 and 80% in 'Khalas' and 'Nabbut' on the fruit content from Fructose were not significant.



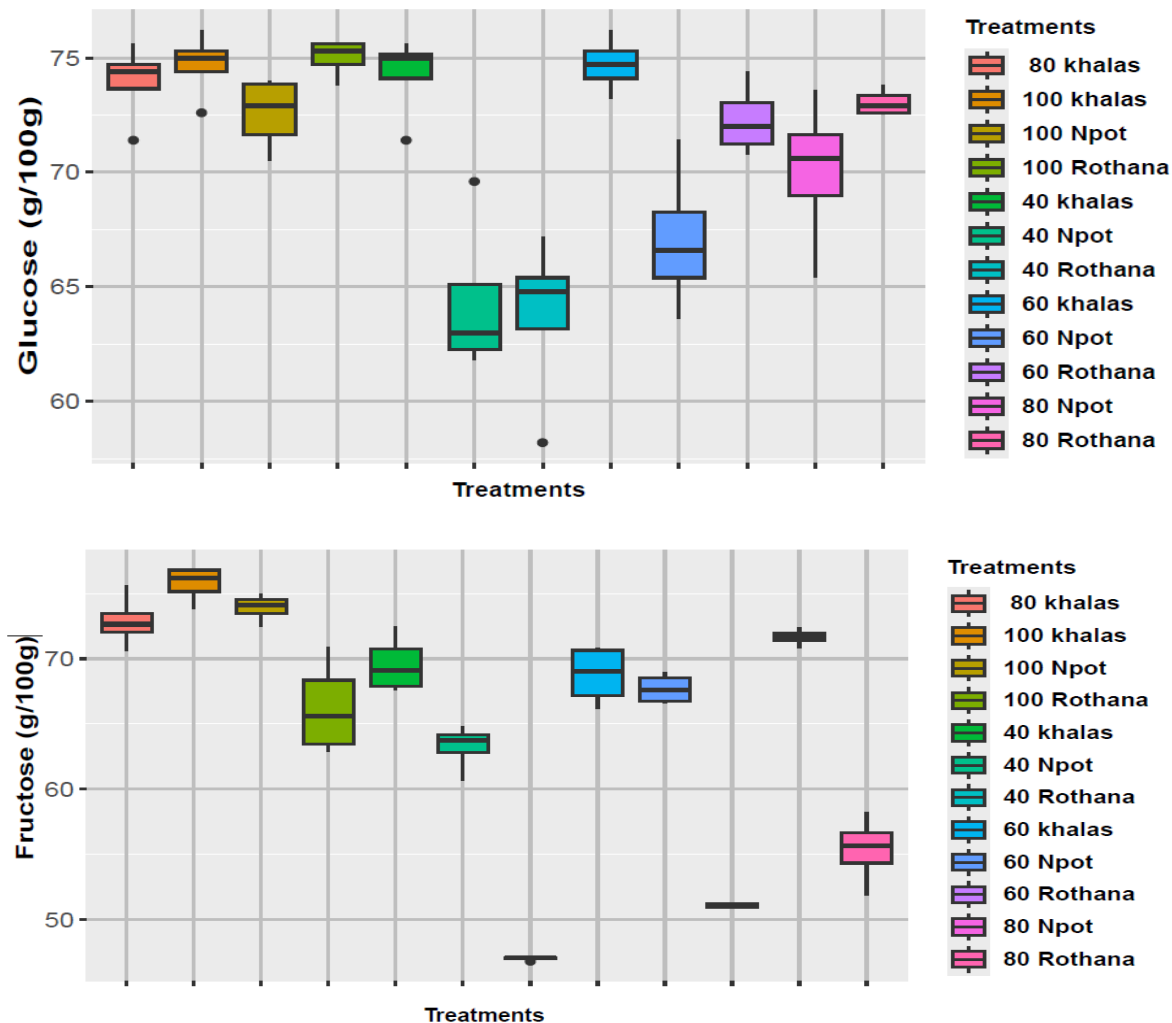


Fig. 1. The influence of water irrigation regimes on fruit content from total, reduced, non-reduced sugars, glucose and fructose in three date palm cvs. 'Khalas', 'Nabbut' and 'Rothana' during 2022 season

DISCUSSION

The results showed that the irrigation regimes controlled the performance of the date palm trees. The previous findings showed that improved soil water accessibility may have improved balanced root development and soil nutrient absorption, leading to an increase in production and its constituent parts (Bainbridge 2006). Hura *et al.* (2007) documented that the shortage of water lowered the leaf chlorophyll content, which consequently minimizes the process of photosynthesis and that consequently transforms the light energy into chemical energy. Shao *et al.* (2008) noted that changes in carbon allocation typically follow a decrease in water intake, which enhances fruit development and output. Under well-irrigated conditions, the fruit yield in apple was increased (Naor *et al.* 2008), as well as almond (Egea *et al.* 2010), and plum (Intrigliolo *et al.* 2013) compared to deficit irrigation. Lawlor and Tezara (2009) reported that under water deficit, plants adapt physiologically by adjusting stomatal behavior to water potential and recycling carbon dioxide during photosynthesis. The total productivity and fruit quality of many fruit species are adversely affected by limited amount of water available during the various

stages of fruit development, including flowering, fruit setting, and maturation (García-Tejero *et al.* 2010). Water limitation impacts fruit yield and quality, which varies according to the stages of vegetative and reproductive growth, the length and intensity of the water deficit, and the variation of species (Intrigliolo and Castel 2010). Moreover, the same authors also stated that the plants with lower water levels had higher concentrations of solutes and had collected more sugars, which raised the total soluble solids. Additionally, fruit tree productivity is also highly dependent on the quantity of irrigation (Ruiz-Sanchez *et al.* 2010). When water stress levels in Amri and Shamia date palm cultivars increased, water use efficiency also increased (Helaly and El-Hosieny 2011). Water stress reduced the photosynthetic rate and stomatal conductance in citrus but significantly enhanced water use efficiency under moderate water shortage (Ávila *et al.* 2012).

The results presented in this study indicate that the highest growth parameters and marketable yield for date palm fruit were observed at 100% crop evapotranspiration (ET_c), followed by 75% ET_c, and 50% ET_c. This may be due to the fact that water supplied at 100% ET_c adequately meets the crop's water requirements, whereas the other amounts do not (Ibrahim *et al.* 2012). Additionally, crop evapotranspiration is improved by increased irrigation, which raises crop productivity to some degree (Steduto *et al.* 2012). In areas with limited water resources, irrigation systems that are both modern and effective are necessary to preserve water without sacrificing crop quality and yield (Tindula *et al.* 2013). By providing the date palm with roughly 65% of its total water needs, the yield was increased, and a high CWP was attained (Ismail *et al.* 2014). Although the date palm grows well in areas with limited water supplies, it needs enough irrigation to sustain all of its metabolic processes and yield fruits of superior quality (Al-Yahyai and Khan 2015; Dhaoudi 2019). Proper irrigation water scheduling enhances crop yield and water use efficiency (Wen *et al.* 2017). Salazar *et al.* (2015) reported that limited water availability can influence hormones including abscisic acid and ethylene, which play crucial roles in leaf growth regulation. The differences in the rate of stomatal conductance, carbon absorption, and the pressure of turgidity of plant tissues account for the impact of water accessibility on plant growth (Mohamed *et al.* 2018). Al-Khateeb *et al.* (2019) found that in date palm, the water deficit significantly minimized the water use efficacy, photosynthesis process, rates of stomatal opening or transpiration. Besides, the absorption of minerals greatly increased by providing the quantity of water to the trees (Mohammed *et al.* 2020).

CONCLUSIONS

1. The fruit yield and fruit characteristics of date palm were greatly improved by raising the irrigation regimes, where 100% (19.2 m³) greatly increased the fruit yield and its components compared with 60% (11.52 m³) or 40% (7.68 m³) in the three-date palm cvs. 'Rothana', 'Nabbut', and 'Khalas'.
2. The water footprint was greatly higher when the date trees were irrigated with 100% or 80% than that with 60% or 40%.
3. It is recommended to use materials such as manure and humic acid to reduce the required quantity of water and raise the rate of preservation of water, as well as spraying antitranspirant materials, such as kaolin, to reduce the rate of evaporation from date palm trees.

Data Availability Statement

All the required data are included in the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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