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Evaluation of date palm fruits quality under different irrigation water salinity levels compared to the fruit available in the market

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Introduction: The date palm (*Phoenix dactylifera* L.) is a major component of the agro-food systems of the arid regions. Since it is an indigenous tree, it is an integral part of the local cultural heritage and social and economic life. Date palm cultivation in the region is challenging due to various factors such as water scarcity and soil and water salinity.

Methods: This research study was conducted to evaluate the quality of commonly sold date palm varieties in the UAE market and grown using saline water at the ICBA research station in Dubai. The study involved measuring physical parameters like fruit weight, size, dimensions, color, volume, Brix, protein, sucrose, glucose, fructose, sugars, phenols, sodium, and potassium, as well as analyzing how consumers perceive the fruit's quality attributes produced under varying salinity levels. The study evaluated Tamar dates' texture, flavor, aroma, taste, color, and appearance using a five-point scale from very poor to excellent.

Results and discussion: The study found that fruit quality is affected by salinity, and there is a significant interaction between variety and salinity treatments. Salinity affects date palm traits, but low to moderate levels do not affect fruit quality. Khalas, Sukkari, and Ajwa-Tul-Madinah are the least affected varieties. High salinity negatively impacts some varieties, leading to decreased fruit quality. However, it is also worth noting that salinity stress can increase the sugar concentration in fruit for specific varieties, as demonstrated in this study on fruit sugar content under such conditions. Among the tested dates, Sukkari from the market, Ajwa-Tul-Madinah irrigated with 5 and 10 dS m^{-1} have the highest sugar content and many other desirable characteristics. Hierarchical *k*-means clustering reveals that each genotype performs better under a specific level of salinity, allowing for targeted selection of genotypes for salinity mitigation. Sugar content is crucial in assessing date fruits irrigated with saline water. It should be included in the evaluation criteria to promote the use of saline water for date palm irrigation and save freshwater resources. The study provides valuable insights into different date palm varieties' behavior under varying salinity levels, enabling farmers to optimize production and establish new evaluation criteria.

KEYWORDS

date palm, fruit quality, salt stress, market evaluation criteria, sugar content in food

1 Introduction

Date palm (*Phoenix dactylifera* L.) is a valuable agricultural product that has its origins in the Arabian Peninsula, Middle East, and North Africa. This fruit crop is highly regarded for its ability to thrive in hot and arid climates and salty soil. Date palms are the most produced and consumed type of dates worldwide, with the Arabian Peninsula being their center of origin. They have been an essential part of farming systems for over 5,000 years, particularly in the Middle East oases, where they can withstand extreme climates (Zohary and Hopf, 2000). The date palm has had a significant impact on the economy, society, and environment. In the United Arab Emirates, the earliest evidence of date palm seed usage dates back to 5,290–4,940 Cal B.C. and 4,810–4,540 Cal B.C. on Dalma Island in Abu Dhabi (Beech and Glover, 2005). Technological advancements and government support for farmers have led to a remarkable increase in the number of date palm trees in the UAE, from 1.5 million to 18 million in just two decades. The actual date tree population in the UAE is about 40 million, with 8.5 million in the AL-AIN region alone (UAEU, 2022).

According to data from the Food and Agriculture Organization (FAO), date palm production covers an area of over 1.09 million hectares globally, with a total production exceeding 8.5 million tons per year. There are about 5 thousand date palm varieties worldwide, with 55.8% of global production concentrated in Asia and 43.4% in Africa. The Arab region accounts for more than 77% of date production, with approximately 160 million palm trees and about 6.6 million tons produced annually. The UAE is one of the top 10 date palm-producing countries, with 323,478 Metric Tons produced in 2019. In all Arab countries, date fruits are considered a staple food, providing many potential health benefits and being a significant source of nutrients. However, the scarcity of freshwater and global environmental issues such as salinity pose significant challenges to fruit tree growth, especially in low rainfall and high-temperature regions. The region faces a significant freshwater scarcity issue and high groundwater salinity makes growing different crops, including date palms, more challenging (Brook et al., 2006). Although date palms can tolerate salinity, excessive salt levels can hinder their growth and reduce fruit quality. Research has identified certain date palm varieties that can safely withstand moderate salinity levels (5 dS m^{-1}), but beyond 8 dS m^{-1}, excessive salt can have harmful effects. In the region, where palm trees are the most irrigated crop, it is crucial to use saline water judiciously to optimize water use efficiency (WUE). Proper guidance on WUE can help save scarce water resources in the region.

Date fruit is an exceptional source of sugar, energy, vitamins, minerals, and fiber. Consumers consider appearance, mouth feel, flavor, and nutritional value as important quality criteria for a product. A standardized scoring system for evaluating the total quality of a date (Tamar) based on consumer preferences was developed and tested for validity by Ismail et al. (2001).

Moreover, there is an urgent economic need to improve saltwater's proficiency in the production of date palm and improve the relationship between the quantity and quality of crop production according to the saltwater levels used for irrigation. This study evaluates the salinity tolerance of elite date palm varieties from the Arabian Peninsula to assess the fruit quality's long-term impact. Numerous research studies have been carried out in the UAE, including the longest-running large-scale experiment on date palm by ICBA. ICBA examined the impact of salinity on 18 elite date palm varieties from UAE, Saudi Arabia, and Iraq. The study involved subjecting all the elite varieties to varying concentrations of saline water irrigation (3, 5, 10, and 15 dS m^{-1}). The fruits of different varieties under different salinity levels were evaluated based on common marketable traits to ensure that the quality of the saline-irrigated tree fruits meets the standard as compared to the most predominant market varieties in the UAE (Fard, Lulu, Khalas, Sukkari, and Ajwa-Tul-Madinah). The long-term experiment aimed to determine whether date palm could withstand salinity stress and produce good fruit quality by using different salinity levels for irrigation (Dghaim et al., 2021; Al-Dakheel et al., 2022). The primary focus was on the quality of date palm fruits when using saline water for irrigation, as quality is a significant factor in determining market value.

2 Materials and methods

2.1 Field description and plant materials

Since 2001, an experiment has been conducted at the ICBA experiment station (25 13″ N and 55 17″ E) using both local and imported date palm varieties. This site is known to have one of the harshest environments in the region (Al-Muaini et al., 2019), with sandy, carbonatic, hyperthermic typic torripasmment soil and negligible organic matter levels.

The experiment involved growing 18 date palm varieties under three different salinity levels of irrigation water (5, 10, 15 dS m^{-1}), achieved by mixing highly saline groundwater (with ECw up to 25 dS m^{-1}, SAR >26 mmol/L, Na and Cl concentrations higher than 190 meq/L, and pH = 7.6) with low-salinity municipal water (less than 0.4 dS m^{-1}, SAR = 4 mmol/L, Na and Cl concentrations lower than 11 meq/L, and pH = 8.5). These three salinity levels were maintained throughout the cropping season each year.

The trees were planted systematically in rows within each salinity level, with a planting spacing of 8 by 8 meters and a 20 meters gap between each group of five plants. The total water supplied was calculated based on climatic and soil data to meet the water requirement of 850 mm, and standard UAE farming practices were applied. This study focuses on the behavior of five selected varieties, the most commonly found in the UAE market (Table 1). The used data were collected during 2019, 2020, and 2021 seasons.

2.2 Date palm fruits quality parameters

For this research, we collected date fruit samples from August and September. We placed them in labeled plastic bags with specific codes indicating their blocks and salinity levels. Each variety had three replicated samples. The measurements were taken at the Central Analytical Laboratory-ICBA.

To measure fruit length and diameter (cm), we used a digital Vernier caliper (Electronic Digital Vernier Caliper, LOUISWARE Stainless Steel Caliper 150 mm/0–6 inch). For fruit volume (mL), we used the water displacement method with a graduated cylinder filled with 30 mL of water to place the fruit. To measure flesh weight, seed weight (g/single fruit), and 50 fruits weight, we used an electronic balance. For fruit firmness, we used a firmness device (Hardness tester flat tip, model 53215TP, Italy). To determine each date palm fruit's sugar content (°Brix), we used a refractometer device (Mettler Toledo

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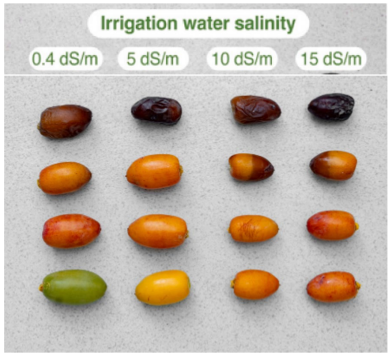
Refracto 30PX Portable Handheld Refractometer). We added 100 mg of date palm to a microcentrifuge tube and mixed it with 1 mL of distilled water. We then placed the sample in the refractometer device to obtain the sugar content value in °Brix. A more detailed sugar analysis was conducted for sucrose, glucose, fructose, total sugars, and phenols, which were tested using the high-performance liquid chromatography (HPLC) method. Protein content was determined using the AOAC 2001.11 method, which measures nitrogen levels through traditional Kjeldahl acid digestion. Nitrogenous compounds are converted to ammonia, which is then distilled and titrated. Finally,

TABLE 1 Date palm material tested, names, general description and origin.

Date palm varieties	General description	Effect of salinity on fruits
FARD	This variety is considered to be commercial. It has an oval and elongated shape with a pinkish-yellow color. The tamer is brown, the dates are dark brown, and the flavor is both sweet and pungent. The flesh is medium-thick with white pulp that has low fiber and pigments. The seed is small, and the fruit weighs an average amount. It is a semi-dry variety that is best eaten when it is in the tamer stage. The yield potential for this fruit is approximately 70–90 kg/tree. For tolerant to salinity, 50 reduction in yield will be noted if the electrical conductivity of the water exceeds 9 dS m^{-1} ECw. The distribution in the UAE: All UAE	
LULU	This variety is commonly used for commercial purposes. The fruit is oval-shaped and has a bright yellow color. When ripe, the rutab has an amber color and the tamer has a brown color. The flesh is thick, with less fibrous texture, and has a sweet and soft flavor. The seeds are small. The fruit has a medium weight on average and can be eaten at the rutab and tamer stages. The approximate yield potential per tree is between 70–90 kilograms. Salinity tolerance: 50% yield reduction at 12 dS m – 1 ECw. The distribution in the UAE: All UAE	
KHALAS	This is a popular variety in Gulf countries. The fruit is bright yellow in color, and the rutab stage fruit has a deep amber to reddish-brown color, while the tamer stage is light brown. The flesh is tender, translucent, and thick with a white color and slight yellowness. It is free from fiber and pigments and has a melting texture. The flavor is rich and delicious, which makes it an excellent quality fruit that can be eaten at both the rutab and tamer stages. Approximative yield potential kg/tree: 40–60. Salinity tolerance: 50% yield reduction at 8 dS m^{-1} ECw. The distribution in the UAE: all UAE	
SUKKARI	The dates of Sukkari variety are golden-brown in color and have a brown hue. They are medium size on average and have patches with lighter colors. The fruit has a firm exterior and a medium or small cone shape. This date is distinguishable from other cultivars by its characteristic sweetness and chewy flesh. It is best consumed during the rutab and tamer stages. Origin: Kingdom of Saudi Arabia (KSA). Approximative yield potential kg/tree: 50–70. Salinity tolerance: 50% yield reduction at 10 dS m^{-1} ECw. The distribution in the UAE: Very limited	

(Continued)

TABLE 1 (Continued)

Date palm varieties	General description	Effect of salinity on fruits
AJWA-TUL-MADINAH (Ajwa)	Ajwa is a date palm variety that is round-shaped, soft, and dark brown in color, appearing almost black with fine texture and white wrinkles. This highly esteemed date palm owes its reputation to its medicinal properties, which have been documented in prophetic medicine and make it a significant date variety for Muslims. Ajwa originated in Medina, Kingdom of Saudi Arabia (KSA), and has an approximate yield potential of 60–70 kg/tree. For salinity tolerance, according to the ICBA study, the yield reduction of Ajwa is 50% at 8 dS m^{-1} ECw. However, its distribution in the UAE is very limited	

sodium (Na) and potassium (K) were determined using an inductively coupled plasma-mass spectrometer (ICP-MS).

For the Sensory quality attributes, this study involved 51 individuals residing in Dubai, UAE, who were asked to taste various types of dates and evaluate the sensory quality attributes based on their personal preferences from very poor to excellent. The participants represented three groups based on their frequency of consuming date palms—regular date palm consumers are people from the countries' key date palm producers, mainly the Arab and Middle Eastern and North African region; Occasional date palm consumers, e.g., from Muslim countries no producer of dates, and non-consumers, e.g., from European countries and others.

The study evaluated the main quality attributes of Tamar dates—texture, flavor, aroma and taste, and color and appearance—using a five-point rating scale ranging from very poor to excellent. The scores were then translated into numerical values. A well-defined, standardized scoring system for evaluating the total quality of a date (Tamar) based on consumer preferences was developed and tested for validity by Ismail et al. (2001) and Jaradat (2014).

2.3 Statistical analysis

To analyze the data collected at the experimental site, the R software version 4.0.5 was utilized to create statistical analysis and graphs. An ANOVA was conducted to gauge the impact of variety and salinity on the parameters studied. Duncan's multiple range test was conducted to determine the significance of various salinity gradients and varieties on different parameters. The values were calculated at a probability level of $p \leq 0.05$. Furthermore, a non-parametric Kruskal–Wallis' test was performed to determine if the rank means of market fruits and experimental site fruits were similar, indicating whether both groups had the same median value. Spider chart was created using the R function "radarchart ()" from the library(fmsb). Lastly, the clustering was computed using the R function "hkmeans ()" from the factoextra package, which employed hierarchical *k*-means. To avoid the clustering algorithm's dependency on an arbitrary variable unit, the data was initially scaled/standardized using the R function "scale ()."

3 Results

3.1 Salinity effect on fruit quality

The purpose of analyzing the response of date palms to salinity levels is to assess how the genotype interacts with salinity. This evaluation involves examining how different date palm genotypes perform in terms of fruit quality values when exposed to varying levels of saline stress. Table 2 presents the analysis of variance (ANOVA) of the results obtained from five date palm genotypes evaluated under three salinity levels (5, 10, and 15 dS m^{-1}) concerning fruit quality variation. The analysis of variance revealed significant variations ($p \leq 0.001$) among variety (V), salinity (S), and variety × salinity (V × S) for fruit length (mm), fruit width (mm), fruit weight (g per single fruit), fruit volume (mL), firmness, sugar content, and seed flesh ratio (F. wt), as well as for the protein, sucrose, glucose, fructose, sugars, phenols sodium (Na) and potassium (K).

The results of the study indicate that the variety, salinity effect, and their interaction effects played a significant role in determining most of the fruit quality parameters tested, as presented in Table 2. The results revealed that the varietal effect had a significant impact on all the parameters studied, confirming that the quality of date palm fruits varies. Moreover, the interaction between variety and salinity was significant for most parameters, including the volume and size of fruits, along with sugar and protein content. This confirms that elevating the salinity of irrigation water significantly affects the behavior of the different date palm varieties regarding fruit quality. The findings shed light on the importance of varietal selection and water quality management in ensuring high-quality date palm fruits. The weight of individual fruits was reduced by almost 1 gram on average when the salinity of irrigation water was increased from 5 to 10 dS m^{-1} and by 1.5 grams when it reached 15 dS m^{-1}. The results also revealed a 27% difference in the weight of fruits between different varieties (Table 2). The protein content slightly increased with the increase in salinity, but this trend was not observed in all varieties. Generally, salinity decreased the total sugar content, primarily due to a significant decrease in the fructose component. It is worth noting that only the Sukkari variety contained sucrose. Date fruits are mainly composed of glucose and fructose, which are the reducing sugars. The

TABLE 2 Salinity and variety effect on fruit length (FL), fruit width (F. width), fruit weight (FW), fruit volume (FV), firmness (Fr), degree of sweetness (brix), seed flesh percentage (F/s), protein, sucrose, glucose, fructose, sugars, phenols, sodium (Na) and potassium (K).

Source of variation		FL (mm)	F. width (mm)	FW (g)	FV (mL)	Fr (kgf/cm^2)	Brix (% Brix)	F/s (ratio)	Protein (g/100 g)	Sucrose (g/100 g)	Glucose (g/100 g)	Fructose (g/100 g)	Sugars (g/100 g)	Phenols (mg GAE/100 g)	Na (mg/kg)	K (mg/kg)
Salinity																
5 dS m^{-1}		32.29a	23.20a	7.67a	7.67a	6.18b	70.44a	9.57b	2.73a	—	32.26a	30.94a	68.08a	374.80a	283.30c	6622.16b
10 dS m^{-1}		28.74b	23.26a	6.73b	6.73b	4.98c	69.12a	12.19a	2.86ab	—	31.24b	30.78a	68.06a	372.44a	306.92b	7239.01ab
15 dS m^{-1}		32.11a	22.27b	6.20c	6.20c	7.47a	66.40b	11.76a	2.92b	—	31.95a	30.33a	66.89b	344.04a	339.82a	7488.93a
Variety																
AJWA-TUL-MADINAH		29.52c	22.82b	7.11b	7.11b	6.02b	66.36ab	14.52a	2.96a	—	33.55b	31.65c	65.20c	422.86a	265.20d	8294.92a
FARD		33.44b	20.10c	5.89c	5.89c	3.96c	73.33a	10.23b	2.43ab	—	34.16b	34.84d	69.01a	322.80b	332.59b	7045.84bc
KHALAS		38.00a	23.51b	7.22b	7.22b	6.03b	65.89ab	8.54c	3.13b	—	35.82a	32.99b	68.81a	388.56a	274.09c	7455.17ab
LULU		20.82d	25.31a	6.00c	6.00c	6.65b	71.58ab	11.44b	2.90b	—	34.16b	33.76b	67.91ab	294.06b	470.41a	6356.58c
SUKKARI		33.44b	22.81b	8.11a	8.11a	8.39a	65.44b	11.13b	2.79b	22.88	21.39c	20.17d	67.45b	390.53a	207.78e	6431.01c
ANOVA	DF															
Variety (V)	4	375.1***	31.63***	7.744***	7.744***	22.715***	136.2^{ns}	42.98***	0.6064***	—	311.94***	322.9***	20.965***	25560***	89968***	5750459***
Salinity (S)	2	60***	4.59^{ns}	8.267***	8.267***	23.147***	102.5^{ns}	29.72***	0.1409*	—	4.06*	1.5^{ns}	6.898*	4,395^{ns}	12084***	2985656*
V × S	8	55.1***	4.12*	1.794***	1.794***	15.875***	195.5**	10.68***	0.1234*	—	1.71*	1.3^{ns}	8.557***	3,461^{ns}	5359***	1,631,344^{ns}
Residuals	30	4.1	1.52	0.311	0.311	2.228	79.3	2.65	0.0441	—	0.79	0.9	2.152	2,652	75	800,881

Different letters in the same line indicate significant differences at 0.05 by Duncan's LSD test. Asterisks indicate significance at *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$, and ns indicates no significance ($p > 0.05$). DF, degrees of freedom; kgf/cm^2, kilogram-force per square centimeter; GAE, gallic acid equivalents.

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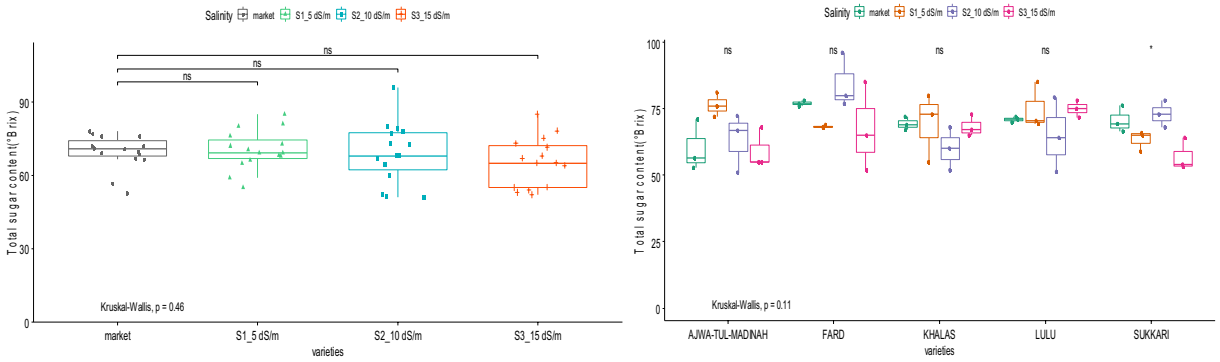

FIGURE 1
Boxplot presentation of the sugar content (Brix) for the five date palm varieties grown at different salinity (S1_5 dS/m, S2_10 dS/m and S3_15 dS/m; dS/m = dS m^{-1}) compared with the same varieties available in the market.

high content of reducing sugars indicates significant invertase activity and reduces sucrose levels (Elleuch et al., 2008).

The irrigation of date palm trees with saline water resulted in increased sodium levels in the fruits. Additionally, there was a rise in potassium levels.

The results showed that salinity does not significantly affect the phenolic content of five varieties of date palm and found that the concentration varied significantly among them. The Ajwa variety had the highest concentration (422.86 mg GAE/100 g), while Lulu had the lowest (294.09 mg GAE/100 g). This finding supports previous research that highlights the significance of date palm's rich energy and antioxidant properties for human health (EI-Far et al., 2019). The phenolic content in date flesh may contribute to its antioxidant activity. Other studies have also confirmed the high phenolic content and antioxidant activity of AJWA-TUL-MADINAH variety (Mohamed et al., 2021), which can help combat various toxicants and provide health benefits (AlFaris et al., 2021; Assirey, 2021). Selecting tolerant genotypes is a crucial factor in obtaining good market value for the date palms produced in a saline environment. The date palm is a resilient plant that can tolerate both drought and salt (Zaid and de Wet, 2000; Yaish and Kumar, 2015; Al Kharusi et al., 2017). Previous research has shown that certain cultivars of date palm can withstand high levels of salinity, with no noticeable impact on seedling growth (Ramoliya and Pandey, 2003; Alrasbi et al., 2010; Al Kharusi et al., 2017). The Khalas cultivar also exhibits strong salinity tolerance, surpassing other date palm cultivars in a controlled environment (Aljuburi, 1992; Al-Mulla et al., 2013). Date palm cultivars from Oman, such as Manoma and Umsila, have demonstrated superior salinity tolerance compared to other varieties by Al Kharusi et al. (2017). A recent study by Rashid (2018) focuses on the quality of date palm fruit. Fruit quality is determined by various attributes, properties, and characteristics that contribute to its overall value as a human food product. It is a measure of the fruit's excellence and is essential for both fresh fruit and its processed derivatives.

3.2 Comparison between dates produced at different salinity with dates available in the market

3.2.1 Salinity effects on the market values of dates

This study was conducted to evaluate the quality of five different date palm varieties, which are commonly sold in the UAE market and grown using saline water at the ICBA research station in Dubai. The analysis involved measuring physical parameters such as fruit weight, size, dimensions, color, and volume. To compare the differences in fruit quality among the different varieties, as well as those irrigated with varying levels of saline water, a Kruskal–Wallis test was carried out.

3.2.2 Fruit sugar content

In this study, we measured the sugar concentration (Brix) of five different date fruit varieties that were irrigated with three different salinity treatments. We found that there were no significant differences ($p = 0.46$) among the five varieties when comparing the treatments, as shown in Figure 1. However, when we analyzed the data based on each variety, we discovered that at a salinity level of 5 dS m^{-1}, the sugar content of Khalas, Ajwa, and Lulu varieties were comparable to those found in the commercial varieties available in the UAE market.

Our findings suggest that when Ajwa, Fard, and Sukkari date palms are irrigated with 10 dS m^{-1}, they have a better total sugar content. Research has shown that abiotic stress, such as salinity and water scarcity, may have a positive effect on plants. In fact, many farms around the world use deficit drip irrigation techniques to increase the sugar levels in fruits during their growth. Al-Yahyai and Al-Kharusi (2012) confirmed that date palms (cv. Khalas) grown in northern Oman and subjected to deficit irrigation treatments had the highest total sugar content.

Plant growth and yield can be significantly impacted by salinity, which is a major abiotic stress. As the salt level increases, the soil's osmotic potential decreases, resulting in water stress and obstructed absorption processes (Parida and Das, 2005). When plants are irrigated with saline water, it causes ionic imbalance and osmotic stress, which can affect yield levels. However, plants produce osmolytes, such as proline and soluble sugars, to protect their cells from the adverse effects of salt stress under saline conditions. This production may increase salinity tolerance and aid in osmotic adjustment.

Our research is consistent with previous studies indicating that water stress can have positive effects on various fruit crops. Salinity stress has been referred to as "physiological drought" in older references. Researchers have documented enhancements in the quality of apples, oranges, grapes, olives, apricots, plums, and pomegranates under water-stress conditions.

According to various researchers, salinity has a significant impact on plant growth and yield, as it is considered a major abiotic stress

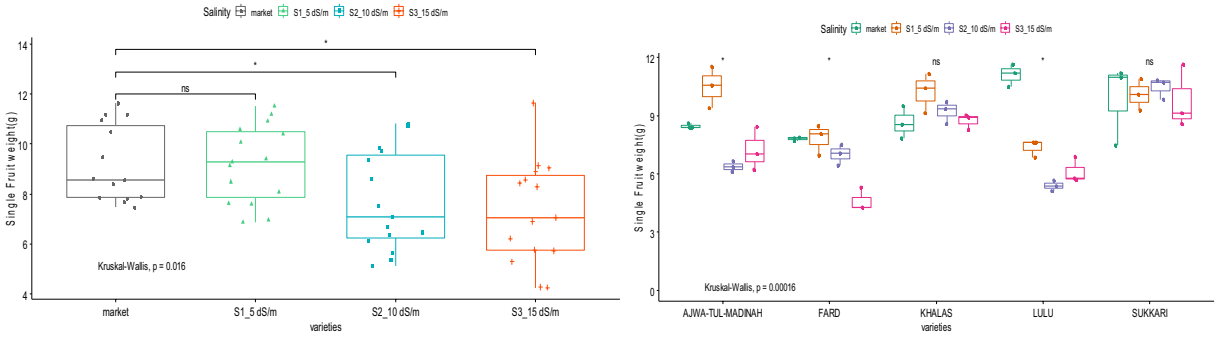

FIGURE 2
Boxplot presentation of the single fruit weight for the five date palm varieties grown at different salinity (S1_5 dS/m, S2_10 dS/m and S3_15 dS/m; dS/m = dS m^{-1}) compared with the same varieties available in the market.

(Gharsallah et al., 2016). When plants are irrigated with saline water, it results in ionic imbalance and osmotic stress, ultimately affecting the yield (Hammami et al., 2017; Rahneshan et al., 2018). Salinity stress can also raise the sugar concentration in fruit, as shown in a study of fruit sugar content under such conditions (Hepaksoy, 2004). Kumar et al. (2021) pointed out that plants produce osmolytes, such as proline and soluble sugars, to safeguard their cells against the harmful effects of salt stress in saline conditions. Moreover, these osmolytes help in regulating osmotic pressure, and their increased production can improve salinity tolerance (Rahneshan et al., 2018). On a similar note, Durán et al. (2021a,b) highlighted that mango fruits from water-stressed trees have higher Brix (total soluble solid) levels than those from non-water-stressed trees.

Multiple studies have confirmed that water stress can positively impact the quality of various fruit crops. Wang et al. (2019) found that apple fruit quality improved under water stress conditions. Similarly, Mossad et al. (2020) reported improvements in oranges (*Citrus sinensis* L.), Romero et al. (2016) for grapes (*Vitis vinifera* L.), Gonçalves et al. (2020) for olives (*Olea europea* L.), Pérez et al. (2016) for apricots (*Prunus armeniaca* L), Maatallah et al. (2015) for plums (*Prunus salicina* L.), and Cano et al. (2018) for pomegranates (*Punica granatum* L.).

3.2.3 Fruit weight

The weight of five varieties of date fruit was measured in grams, both when irrigated with three different levels of salinity and when purchased from the market. Results showed that the fruit weight was significantly affected by salinity treatments of 10 and 15 dS m^{-1} across all varieties, as seen in Figure 2. Additionally, a Boxplot presentation in Figure 2 revealed that Ajwa, Sukkari, and Khalas fruits grown using saline water of 5 dS m^{-1} had a noticeably higher weight compared to the same varieties available in the market. Out of the three salinity treatments, Khalas and Sukkari showed positive results when irrigated with 10 and 15 dS m^{-1}, outperforming the market brands. However, Fard's date showed a decrease in weight with an increase in salinity level to 15 dS m^{-1} when compared to the fruit market brand.

The weight of Lulu fruit was significantly impacted and reduced when irrigated with varying levels of salinity compared to the market brand. Fruit weight data analysis reveals that Khalas and Sukkari varieties can adapt well to high salinity, while Ajwa and Fard are better suited for moderate salinity. This information is crucial to maintain market standards for date palm fruit production when utilizing saline water for irrigation.

Based on consumer and market preferences in Saudi Arabia, Al-Abdoulhadi et al. (2011) categorized Khalas fruits into three groups: large (≥10 grams), medium (7–9 grams), and small (≤7 grams). Our study investigated the effect of salinity levels on these fruits and found that those irrigated with 5 dS m^{-1} can be classified as large, while those irrigated with 10 and 15 dS m^{-1} can be categorized as medium corresponding to Al-Abdoulhadi et al. (2011). This suggests that it is possible to produce dates under harsh salinity conditions.

Figure 3 presents a Boxplot showcasing the weight of 50 fruits, which is a crucial factor in assessing the quality of dates in the UAE market (Al Foah, Alsharif, 2020). According to the findings, the fruits grown using 5 dS m^{-1} salinity level weigh the same as those of the same variety available in the market. However, date palm cultivated at 10 dS m^{-1} (S2) had a negative impact on the weight of 50 fruits when compared to those available in the market (Figure 3).

Regarding the varieties, Lulu's fruit weight was significantly affected by high salinity stress (Figure 2), indicating that it is not suitable for growing under such conditions when it comes to the fruit market value. On the other hand, Khalas and Sukkari are more suitable for high salinity levels of 15 dS m^{-1}.

The results of the comparison test showed that there was no significant difference between the fruits available in the market and those irrigated with 5 dS m^{-1}. However, when the trees were irrigated with 10 and 15 dS m^{-1}, a difference was observed. Nonetheless, certain varieties like Sukkari and Khalas did not experience any negative impact after the use of saline water, as shown in Figure 3. The boxplot presentation illustrated the variability among the same variety irrigated with the same water quality (Figure 3). These findings emphasized the importance of sorting and grading dates, especially those from fields irrigated with saline water.

Siddiq and Greiby (2013) have pointed out that date grading and sorting cause significant delays in fruit packaging and marketing. Al-Ohali (2011) also noted that this process is both repetitive and time-consuming, requiring manual labor and visual inspection. Fortunately, with the advancements in machinery and the industrial sector, this activity can now be streamlined.

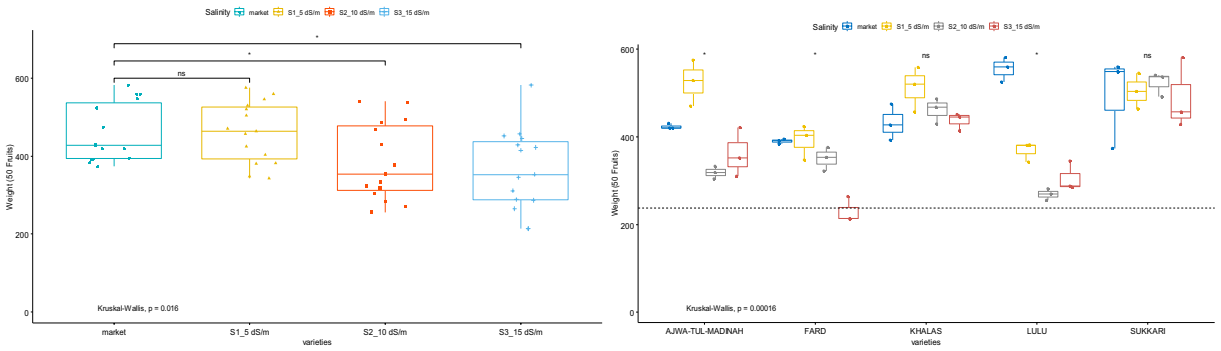

FIGURE 3
Boxplot presentation of the weight of 50 fruits for the five date palm varieties grown at different salinity (S1_5 dS/m, S2_10 dS/m and S3_15 dS/m; dS/m = dS m^{-1}) compared with the same varieties available in the market.

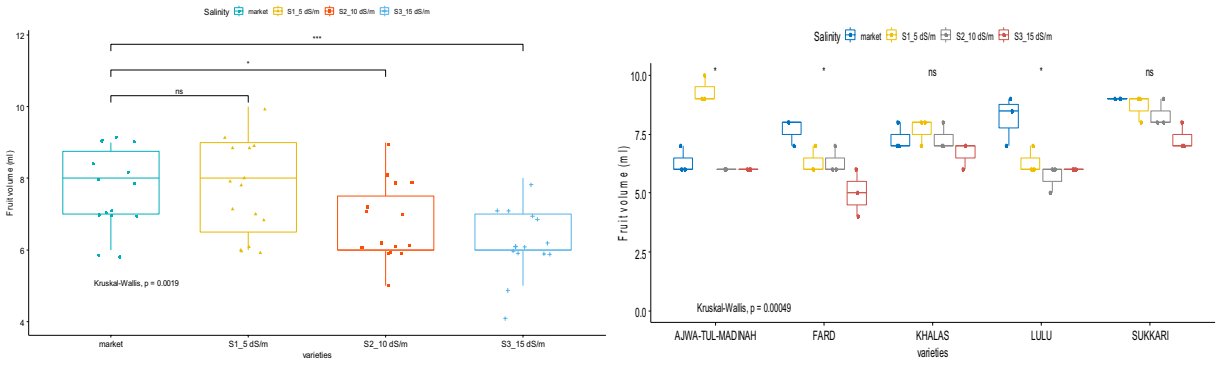

FIGURE 4
Boxplot presentation of the fruit volume for the five date palm varieties grown at different salinity (S1_5 dS/m, S2_10 dS/m and S3_15 dS/m; dS/m = dS m^{-1}) compared with the same varieties available in the market.

3.2.4 Fruits volume

The study involved measuring the volume of five varieties of date fruit under three different salinity treatments. Results showed that Fard date fruit is not significantly affected by a salinity level of 5 dS m^{-1} and 10 dS m^{-1}, with volumes similar to those available in the market. However, a high salinity level of 15 dS m^{-1} resulted in a slight decrease in volume (Figure 4). Khalas, on the other hand, had a higher volume than market fruits, and salinity did not significantly affect its volume. Sukkari was not affected by salinity levels of 5 to 10 dS m^{-1}, while Lulu exhibited a significant decrease in volume under high salinity. However, moderate salinity did not affect Lulu's volume, with its volume being almost the same as market fruits. Ajwa exhibited a significantly higher volume under a salinity level of 5 dS m^{-1}, while volumes under 10 and 15 dS m^{-1} were similar to the market fruits (Figure 4).

3.2.5 Fruit firmness

The study evaluated the firmness of five different types of date fruit when exposed to varying levels of salinity, comparing them to those available in the market. It was found that in general, salinity led to an increase in fruit hardness. Interestingly, the results showed that there was no significant difference between the market fruits and those irrigated with a high salinity level of 15 dS m^{-1} (Figure 5). When it comes to firmness, salinity levels of 5 dS m^{-1} and 10 dS m^{-1} had similar effects. However, the market fruits had the highest firmness. There was a notable difference in the firmness of the Fard and Sukkari varieties from the market fruits and those subjected to the three levels of salinity, which suggests that salinity stress influenced their texture. On the other hand, for Khalas, Fard, and LuLu date varieties, their firmness increased as the salinity levels increased, but they had lower firmness than the market brands. The research findings revealed a notable decline in the firmness of several date palm types, with the exception of Khalas and Ajwa varieties (Figure 5). The investigation also indicated that a rise in salinity levels contributed to a boost in fruit hardness, albeit at the expense of reduced fruit volume and water content, which consequently adversely affected their marketability. Additionally, the mechanical traits of date palms play a crucial role in determining their overall gustatory quality.

3.3 Sensory quality attributes

When making a purchase decision, product attributes are crucial for consumers. This study analyzes how consumers perceive the quality attributes of date palm fruits produced under

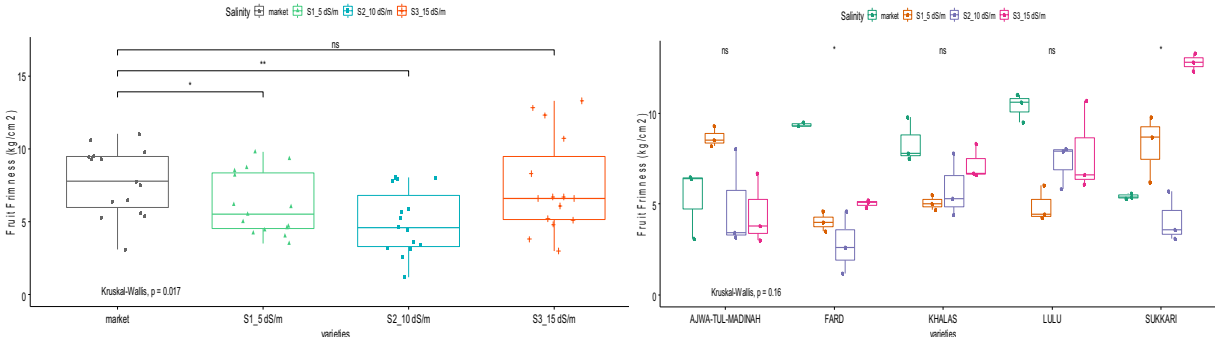

FIGURE 5
Boxplot presentation of the fruit firmness for the five date palm varieties grown at different salinity (S1_5 dS/m, S2_10 dS/m and S3_15 dS/m; dS/m = dS m^{-1}) compared with the same varieties available in the market.

varying salinity levels. The study assesses three key quality attributes ("texture," "flavor and aroma" "taste," and "color" and "appearance") of Tamar dates using a five-point scale (very poor, poor, satisfactory, good, and excellent). These scores were later converted into quantitative values.

The results obtained from consumer preferences indicate that the color and appearance of fruits from markets irrigated with 5 and 10 dS m^{-1} score similarly. There is no significant difference between them, as shown in Figure 6. Sukkari genotype irrigated with medium and high salinity does not show any negative impact, while Ajwa and Fard's color and appearance are affected by high salinity of 15 dS m^{-1} (Figure 6). The color and appearance of a product attract consumers and can lead to impulse purchases. Consumers generally have a preferred color for a specific item (Barrett et al., 2010). Siddiq and Greiby (2013) suggested that good-quality dates tend to be light brown and uniform in shape and length.

When assessing the quality of 203 date palm cultivars in the GCC and Middle East, fruit color was deemed the most significant attribute (Al-Abdoulhadi et al., 2011). Additionally, research on predictors for the economic value of date palm cultivars found that yellow fruit color held a 70 percent economic value in Saudi Arabia and the United Arab Emirates, while in Qatar it was 64 percent. In contrast, various shades of red were more prevalent in Bahrain, Kuwait, and Oman (Jaradat and Zaid, 2004).

Based on the results, it was found that most of the varieties received a lower score for texture when the salinity level was increased to 15 dS m^{-1}. However, salinity levels of 5 or 10 dS m^{-1} did not have a significant impact on the texture of the fruit (Figure 6). Good quality dates are characterized by a smooth texture and mouthfeel, as noted by Siddiq and Greiby (2013). The same authors also stated that the appearance and texture of date palm fruits are influenced by their moisture and sugar content.

When it comes to flavor, aroma, and taste, we notice a consistent pattern. However, the khalas and Lulu varieties begin to show signs of impact after being irrigated with a medium salinity of 10 dS m^{-1} (Figure 6). In 1959, Anon defined flavor as a combination of taste, smell, and pressure sensations, often accompanied by cutaneous sensations such as warmth, color, or mild pain. According to Barrett et al. (2010), the flavor is typically characterized by aroma and taste. This reinforces the idea that flavor, aroma, and taste are important factors that are linked to color, appearance, sweetness, fruit size, mouthfeel, mouth shear, and pit size. However, these factors affect different varieties in different ways, reaffirming the importance of selecting the right variety based on the salinity of the soil and water available at the farm level, as well as consumer and market preferences. For consumers, the key quality criteria for a product include appearance (including color, size, shape, condition, and absence of defects), mouthfeel or texture, flavor, and nutritional value (Wills et al., 1998). To assess the total quality of the date (Tamar) based on consumer preferences, a well-defined, standardized scoring system has been developed and tested for validity by many others, including Ismail et al. (2001).

3.4 Cluster analysis of the different date palm fruit packs (fruit from variety$_{(i)}$ grew under salinity$_{(S)}$)

The clustering of the different available interactions (fruit of a variety$_{(i)}$ grew under salinity$_{(S)}$) and Hierarchical clustering, also known as hierarchical cluster analysis (HCA) were used. Through this analysis, it is possible to determine the ideal genotype for cultivation under certain levels of salinity, resulting in optimal fruit quality. To prevent the clustering algorithm from being influenced by arbitrary variable units, the data was first scaled and standardized, as presented in Table 3. The high parameter values indicated that the specific group of samples (cluster) was characterized by a high level of that parameter and vice versa.

In Figure 7, the Fard variety irrigated with all irrigation salinity levels and Ajwa irrigated with 15 dS m^{-1} were grouped together as they have low Brix and small fruit volume (Table 3). The second group includes Sukkari from the market and Ajwa irrigated with 10 dS m^{-1}, and Ajwa irrigated with 5 dS m^{-1}, which have the highest sugar content and other desirable characteristics. Lulu irrigated with all three salinity levels, and Ajwa irrigated with 10 dS m^{-1} comprised the third group, with high sugar levels and seed flesh ratio, but have smaller fruit sizes in terms of length, volume, and weight. Finally, Khalas at all salinity levels, Sukkari irrigated with 5 dS m^{-1}, as well as Ajwa, Lulu, and Fard from the market are grouped in cluster 4. Based on the analysis, it can be concluded that cluster 4 exhibits favorable values for all the

FIGURE 6
Radar chart presentation of the fruit color, appearance, fruit texture, flavor, aroma and taste scoring for the five date palm varieties grown at different salinity compared with the same varieties available in the market.

TABLE 3 Standardized data of the different parameters for the cluster means analysis of hierarchical *k*-means clustering with 4 clusters.

Cluster	Fruit length	Fruit width	Fruit volume	Single fruit weight	Seed weight	Sugar content (Brix)	Firmness	Seed flesh ratio
1	0.101	−1.224	−0.899	−0.709	−0.628	−0.108	−0.905	−0.088
2	0.388	0.361	1.517	1.048	1.700	0.670	−0.209	0.845
3	−1.783	1.106	−0.899	−1.099	−0.455	0.127	−0.156	0.654
4	0.683	0.076	0.442	0.599	−0.017	−0.247	0.722	−0.589

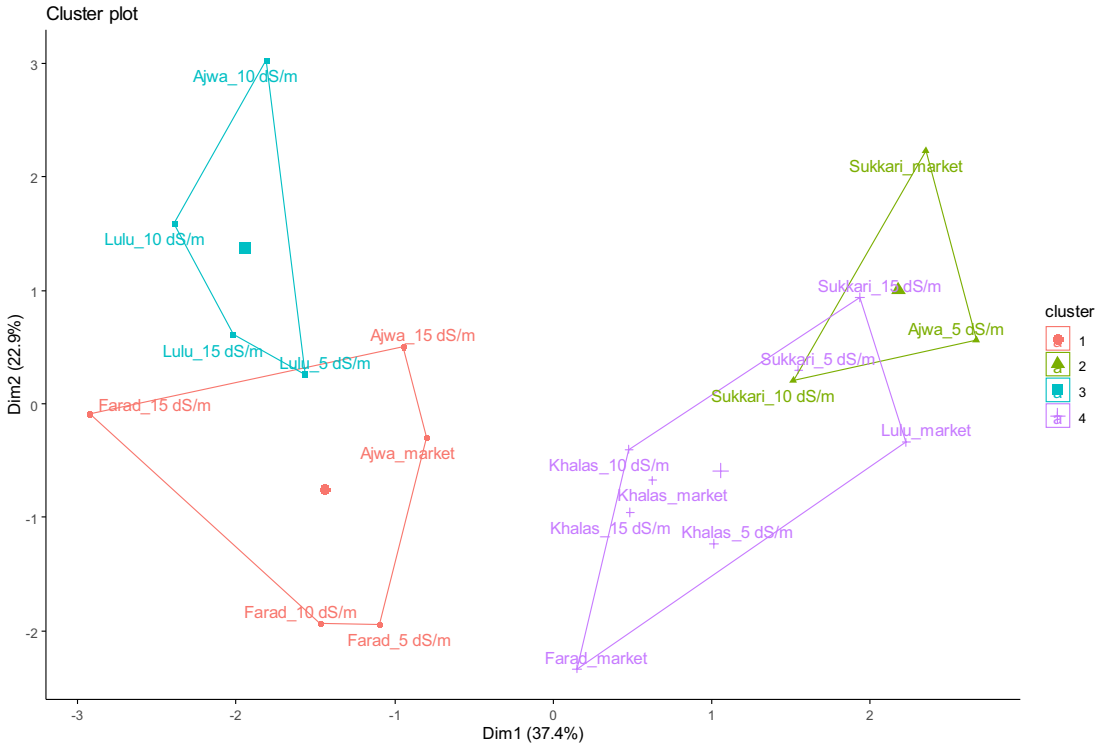

FIGURE 7
Regrouping of the similar dates coming from different genotypes and salinity in the irrigation water (hierarchical *k*-means clustering was used to group the sample from different varieties of fruit grown under specific salinity conditions. Sample are labeled with their variety name and salinity level, for example, Lulu_10 dS/m).

studied parameters except for the seed flesh ratio (−0.017) and Brix (−0.247). These two parameters are comparatively lower than those of groups 2 and 3, as indicated by the scaled and standardized numbers in Table 3. Additionally, even combinations of certain varieties under a specific salinity with lower sugar content and salinity levels can prove valuable in certain market scenarios. As noted by AlShwyeh and Almahasheer (2022), this information on fruit quality, particularly sugar content, can aid in maintaining a healthy diet, particularly for diabetic patients and their glucose consumption.

4 Conclusion

This study delved into the impact of saline water on the quality of date palm varieties available in the UAE market. The study measured fruit weight, size, color, and sugar content, and also took into consideration the consumers' perception of quality. Results showed that high salinity had a negative effect on some varieties, but it was also discovered that salinity stress could increase sugar concentration in specific varieties. Sugar content is a key factor for farmers looking to optimize production in saline conditions. This is a game-changer for those in the industry, providing valuable insights for enhancing the quality of date fruits.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation. However, in order to protect the privacy of the individuals involved in the survey related to the Sensory quality attributes, only limited details on the participants will be provided.

Author contributions

ZH: Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. HM: Data curation, Methodology, Writing – review & editing. AJ: Data curation, Writing – review & editing. RS: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Al Kharusi, L., Assaha, D. V. M., Al-Yahyai, R., and Yaish, M. W. (2017). Screening of date palm (*Phoenix dactylifera* L.) cultivars for salinity tolerance. *Forests* 8:136. doi: 10.3390/f8040136

Al-Abdoulhadi, I. A., Al-Ali, S., Khurshid, K., Al-Shryda, F., Al-Jabr, A. M., and Abdallah, A. B. (2011). Assessing fruit characteristics to standardize quality norms in date cultivars of Saudi Arabia. *Indian J. Sci. Technol.* 4, 1262–1266. doi: 10.17485/ijst/2011/v4i10.5

Al-Dakheel, A. J., Hussain, M. I., Abdulrahman, A., and Abdullah, A.-H. (2022). Long term assessment of salinity impact on fruit yield in eighteen date palm varieties. *Agric. Water Manag.* 269:107683. doi: 10.1016/j.agwat.2022.107683

AlFaris, N. A., AlTamimi, J. Z., AlGhamdi, F. A., Albaridi, N. A., Alzaheb, R. A., Aljabryn, D. H., et al. (2021). Total phenolic content in ripe date fruits (*Phoenix dactylifera* L.): a systematic review and meta-analysis. *Saudi J. Biol. Sci.* 28, 3566–3577. doi: 10.1016/j.sjbs.2021.03.033

Aljuburi, H. V. (1992). Effect of sodium chloride on seedling growth of four date palm varieties. *Ann. Arid Zone* 31, 259–262.

Al-Muaini, A., Green, S., Dakheel, A., Abdullah, A.-H., Abdelwahid, W., Dahr, A., et al. (2019). Irrigation management with saline groundwater of a date palm cultivar in the hyper-arid United Arab Emirates. *Agric. Water Manag.* 211, 123–131. doi: 10.1016/j.agwat.2018.09.042

Al-Mulla, L., Bhat, N. R., and Khalil, M. (2013). Salt-tolerance of tissue-cultured date palm cultivars under controlled environment. *Int. J. Food Vet. Agric. Eng.* 7, 468–471.

Al-Ohali, Y. (2011). Computer vision based date fruit grading system: design and implementation. *J. King Saud Univ. - Comput. Inf. Sci.* 23, 29–36. doi: 10.1016/j.jksuci.2010.03.003

Alrasbi, S. A. R., Hussain, N., and Schmeisky, H.. (2010). Evaluation of the growth of date palm seedlings irrigated with saline water in the Sultanate of Oman, in IV International Date Palm Conference, 882 233–246.

Alsharif, E.. (2020). Dates marketing season 2020, Oral Presentation. E. Alsharif Director of Manufacturing Department, Al Foah Company. 09 September, 2020, Abu Dhabi, United Arab Emirates.

Alshwyeh, H., and Almahasheer, H. (2022). Glucose content of 35 Saudi Arabian date fruits (*Phoenix dactylifera* L.). *J. Saudi Soc. Agric. Sci.* 21, 420–424. doi: 10.1016/j.jssas.2021.11.004

Al-Yahyai, R., and Al-Kharusi, L. (2012). Sub-optimal irrigation affects chemical quality attributes of dates during fruit development. *Afr. J. Agric. Res.* 7, 1498–1503. doi: 10.5897/AJAR11.1553

Assirey, E. A. (2021). The chemical composition, total phenolic and antioxidant content of four date palm Saudi cultivars. *J. Taibah Univ. Sci.* 2021 15, 282–287. doi: 10.1080/16583655.2021.1978805

Barrett, D. M., Beaulieu, J. C., and Shewfelt, R. (2010). Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. *Crit. Rev. Food Sci. Nutr.* 50, 369–389. doi: 10.1080/10408391003626322

Beech, M. J., and Glover, E. (2005). The environment and economy of an Ubaid-related settlement on Dalma Island, United Arab Emirates. *Paléorient* 31, 97–107. doi: 10.2307/41496724

Brook, M. C., Houqani, A., Darawsha, T., Al Alawneh, M., and Achary, S., (2006). Groundwater resources; development and Management in Abu Dhabi Emirate, UAE. In Proceedings of 3rd Joint UAE-Japan Symposium, Sustainable GCC Environment and Water Resources, EWR, 2006.

Cano, L. M., Galindo, A., Collado, G. J., Rodríguez, P., Cruz, Z. N., Legua, P., et al. (2018). Influence of deficit irrigation and crop load on the yield and fruit quality in wonderful and Mollar de Elche pomegranates. *J. Sci. Food Agric.* 98, 3098–3108. doi: 10.1002/jsfa.8810

Dghaim, R., Hammami, Z., Al Ghali, R., Smail, L., and Haroun, D. (2021). The mineral composition of date palm fruits (*Phoenix dactylifera* L.) under low to high salinity irrigation. *Molecules* 26:7361. doi: 10.3390/molecules26237361

Durán, Z. V. H., Franco, T. D., Cárceles, R. B., Gálvez, R. B., Cermeño, S. P., Cuadros, T. S., et al. (2021a, 2021). Mango fruit quality improvements in response to water stress: implications for adaptation under environmental constraints. *Hort. Sci.* 48, 1–11. doi: 10.17221/45/2020-HORTSCI

Durán, Z. V. H., García-Tejero, I. F., Rodríguez, B. C., Tarifa, D. F., Ruiz, B. G., and Sacristán, P. C. (2021b). "Deficit irrigation strategies for subtropical mango farming. A review" in *Agronomy for sustainable development* (Springer), 41:13.

EI-Far, H. A., Oyinloye, E. B., Sepehrimanesh, M., Allah, G. A. M., Abu-Reidh, I., Shaheen, M. H., et al. (2019). Novel findings and future directions for food and drug discovery. *Curr. Drug Discov. Technol.* 16, 2–10. doi: 10.2174/1570163815666180320111937

Elleuch, M., Besbes, S., Roiseux, O., Blecker, C., Deroanne, C., and Attia, H. (2008). Date flesh: chemical composition and characteristics of the dietary fiber. *Food Chem.* 111, 676–682. doi: 10.1016/j.foodchem.2008.04.036

Gharsallah, C., Fakhfakh, H., Grubb, D., and Gorsane, F. (2016). Effect of salt stress on ion concentration, proline content, antioxidant enzyme activities and gene expression in tomato cultivars. *AoB Plants* 8:plw055. doi: 10.1093/aobpla/plw055

Gonçalves, A., Silva, E., Brito, C., Martins, S., Pinto, L., Dinis, L. T., et al. (2020). Olive tree physiology and chemical composition of fruits are modulated by different deficit irrigation strategies. *J. Sci. Food Agric.* 100, 682–694. doi: 10.1002/jsfa.10064

Hammami, Z., Gauffreteau, A., BelhajFraj, M., Sahli, A., Jeuffroy, M.-H., Rezgui, S., et al. (2017). Predicting yield reduction in improved barley (*Hordeum vulgare* L.) varieties and landraces under salinity using selected tolerance traits. *Field Crop Res.* 211, 10–18. doi: 10.1016/j.fcr.2017.05.018

Hepaksoy, S. (2004). Effect of salinity on some fruit quality attributes and sugar composition of *Satsuma mandarin* cv. Owari. *Asian J. Plant Sci.* 3, 660–665. doi: 10.3923/ajps.2004.660.665

Ismail, B., Haffar, I., Baalbaki, R., and Henry, J. (2001). Development of a total quality scoring system based on consumer preference weightings and sensory profiles: application to fruit dates (Tamr). *Food Qual. Prefer.* 12, 499–506. doi: 10.1016/S0950-3293(01)00043-X

Jaradat, A. A. (2014). "Date palm: production" in *Dates: postharvest science, processing technology and health benefits*. eds. M. Siddiq, S. M. Aleid and A. A. Kader (West Sussex, UK: John Wiley & Sons, Ltd.), 29–55.

Jaradat, A. A., and Zaid, A. (2004). Quality traits of date palm fruits in a centre of origin and centre of diversity. *Food Agri. Environ.* 2, 208–217.

Kumar, S., Li, G., Yang, J., Huang, X., Ji, Q., Liu, Z., et al. (2021). Effect of salt stress on growth, physiological parameters, and ionic concentration of water dropwort (*Oenanthe javanica*) cultivars. *Front. Plant Sci.* 12:660409. doi: 10.3389/fpls.2021.660409

Maatallah, S., Guizani, M., Hjlaoui, H., Boughattas, N. E. H., Lopez, L. F., and Ennajeh, M. (2015). Improvement of fruit quality by moderate water deficit in three plum cultivars (*Prunus salicina* L.) cultivated in a semi-arid region. *Fruits* 70, 325–332. doi: 10.1051/fruits/2015023

Mohamed, H. I., El-Beltagi, H. S., Jain, S. M., and Al-Khayri, J. M. (2021). "Chapter 18—date palm(Phoenix dactylifera L.) secondary metabolites: bioactivity and pharmaceutical potential" in *Phytomedicine: a treasure of pharma-cologically active products from plants* (Academic Press), 483–531.

Mossad, A., Farina, V., and Lo Bianco, R. (2020). Fruit yield and quality of "Valencia" orange trees under long-term partial rootzone drying. *Agronomy* 10:164. doi: 10.3390/agronomy10020164

Parida, A. K., and Das, A. B. (2005). Salt tolerance and salinity effects on plants: a review. *Ecotoxicol. Environ. Saf.* 60, 324–349. doi: 10.1016/j.ecoenv.2004.06.010

Pérez, S. F., Mirás, A. J. M., Alcobendas, R., Alarcón, J. J., Mounzer, O., and Nicolás, E. (2016). Effects of regulated deficit irrigation on physiology, yield and fruit quality in apricot trees under Mediterranean conditions. *Span. J. Agric. Res.* 14:e1205. doi: 10.5424/sjar/2016144-9943

Rahneshan, Z., Nasibi, F., and Moghadam, A. A. (2018). Effects of salinity stress on some growth, physiological, biochemical parameters and nutrients in two pistachio (*Pistacia vera* L.) rootstocks. *J. Plant Interact.* 13, 73–82. doi: 10.1080/17429145.2018.1424355

Ramoliya, P., and Pandey, A. (2003). Soil salinity and water status affect the growth of *Phoenix dactylifera* seedlings. *N. Z. J. Crop Hortic. Sci.* 31, 345–353. doi: 10.1080/01140671.2003.9514270

Rashid, A.-Y.. (2018). Strategies to improve date palm production and hence dates quality in the Sultanate of Oman. UNCTAD-CAMS Joint Workshop for Dates Farmers and Stakeholders (Processors And Exporters) March 19–21, 2018 SQU, Oman. Available at: https://unctad.org/meeting/unctad-squ-workshop-date-palm-farmers-processors-and-exporters

Romero, P., García, G. J., Fernández, F. J. I., Gil, M. R., del Amor, S. F., and Martínez, C. A. (2016). Improving berry and wine quality attributes and vineyard economic efficiency by long-term deficit irrigation practices under semiarid conditions. *Sci. Hortic.* 203, 69–85. doi: 10.1016/j.scienta.2016.03.013

Siddiq, M., and Greiby, I., (2013). "Overview of date fruit production, postharvest handling, processing, and nutrition," in *Dates: postharvest science, processing technology and health benefitsm*. (Hoboken, NJ, USA: Wiley). 1–28.

UAEU, (2022) Available at: https://www.uaeu.ac.ae/en/research/centers/dpdrud/datepalmculture.shtml#:~:text=The%20actual%20date%20tree%20population,composes%20about%20120%20date20varieties

Wang, Y., Liu, L., Wang, Y., Tao, H., Fan, J., Zhao, Z., et al. (2019). Effects of soil water stress on fruit yield, quality and their relationship with sugar metabolism in "Gala" apple. *Sci. Hortic.* 258:108753. doi: 10.1016/j.scienta.2019.108753

Wills, R., McGladdon, B., Ghramdadi, D., and Joyce, D. (1998). *Post-harvest: an introduction to the physiology and handling of vegetables and ornamentals*, *4*. Australia: University of New South Wales Press, Ltd..

Yaish, M. W., and Kumar, P. P. (2015). Salt tolerance research in date palm tree (*Phoenix dactylifera* L.), past, present, and future perspectives. *Front. Plant Sci.* 6:348. doi: 10.3389/fpls.2015.00348

Zaid, A., and de Wet, P. F.. (2000). *Climatic requirements in date palm cultivation*, Rome: Food and Agriculture Organization of the United Nations.

Zohary, D., and Hopf, M.. (2000). *Domestication of plants in the old world*. *3* Oxford University Press, Oxford