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Original article

Physiological response, phytochemicals, antioxidant, and enzymatic activity of date palm (*Phoenix dactylifera* L.) cultivated under different storage time, harvesting Stages, and temperatures

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ABSTRACT

The quality of date palm is highly influenced by postharvest techniques, storage, and processing effects. Fruits stored at room temperature result in dehydration, whereas higher temperatures accelerate the enzymatic browning of fruit. This study aimed to enhance postharvest quality of date palms through improved harvesting and storage techniques. The fruits of date palm (*Phoenix dactylifera* L. cv. Dhakki) were harvested at khalal (mature, firm), rutab (fully ripe), or tamar (dry) stages and stored at different temperatures (12, 18, or 24 °C) for 0, 15, 30, or 45 days. The analysis of the data showed that the studied attributes significantly different at various ripening stages and storage temperatures. The fruits harvested at Khalal stage proved to be the best in retaining moisture content (23.16%), total soluble solids (20.36 °Brix), fruit juice pH (4.97), ascorbic acid (24.65 mg 100 g^{-1}), non-reducing sugars (26.84%), percent acidity (0.39%), antioxidant activity (211.0 mg 100 g^{-1}), total phenolic (40.07 mg100g^{-1}), flavonoids (45.8 mg 100 g^{-1}), tannin (70.7 mg100g^{-1}), catalase (1.82 U g^{-1}), peroxidase (1.4 U g^{-1}), soluble protein (38.2 mg kg^{-1}), brightness (29.9), chroma (16.4), hue angle (34.9), color (16.8), and with minimum weight loss (8.48%) as compared to fruit harvested at Rutab and Tamar stage. Regarding the means for storage temperature, the fruits stored at 12 ± 3 °C retained the highest moisture content (23.2%), total soluble solids (13.5 °Brix), fruit juice pH (5.42), percent acidity (0.29%), ascorbic acid (24.4 mg100g^{-1}), reducing sugars (31.1%), non-reducing sugars (26.5%), antioxidant activity (214.6 mg100g^{-1}), total phenolic (41.6 mg100 g^{-1}), flavonoids (44.7 mg100 g^{-1}), tannin (71.7 mg 100 g^{-1}), catalase (1.56 U g^{-1}), peroxidase (1.21 U g^{-1}), soluble protein (31.8 mg kg^{-1}), brightness (28.8), chroma (15.3), hue angle (29.6), color (16.2),with minimum weight loss (9.91%). It was concluded that for quality fruit production of date palm cv. Dhakki could be harvested at Khalal stage and stored at a temperature of 12 ± 3 °C.

1. Introduction

Date palm (Phoenix dactylifera L.) being a member of Palmaceae, has been cultivated (North Africa and the Middle East) for at least 5,000 years (Jatt et al., 2019). Out of 37 growing states in world, Egypt has more production followed by Saudi Arabia, Algeria, Iran or Iraq (FAO, 2011, 2012). With 1.092,000 ha of production from these states exported, there has been a universal demand of around 8.52 million tons over the past three decades (FAOSTAT, 2018). Pakistan (7.2 million tons per year) is on sixth position in international date palm production (Abul-Soad et al., 2015). Pakistan produces 325 cultivars (Jamil et al., 2010; Sajid

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et al., 2020; Gilani et al., 2021). Botanically, date palm (sole seed, fibrous endocarp, and fleshy pericarp) is a berry (Amira et al., 2011). The cultivated land area (92.145 thousand hectares) in Pakistan has 541.4 thousand tons production. All four provinces of Pakistan produce date (Markhand et al., 2010).

Date fruits are high-calorie foods and a rich source of necessary nutrients (for example, antioxidants minerals, carbohydrates, proteins, and fiber) (Noutfia and Ropelewska, 2023). Different products (food flavors, chutney, sugar, vinegar, dip, pickle, honey, beer, juice, wine, syrup, and paste) are also processed from date palm fruits (Ayub et al., 2023). Antioxidants inhibit different types of sicknesses, cancers, and slow aging (Dhahri et al., 2023).

According to several studies, the chemical components and functional composition of dates undergo significant changes as they mature, with amounts of reduced sugar rising and levels of fiber, minerals, and vitamins slowly declining (Kamal et al., 2023). Fruits go through five phases of development after pollination, according to changes in color, texture, scent, and flavor. Internationally recognized stages of dates are Hababouk, which is immature and tiny, Kimri, which is green with more water and less simple sugars, khalal, known as the colored stage, Rutab, the ripe stage, or Tamar, the final ripe stage (Mohamed et al., 2021). At the Khalal stage (50–85% water, yellow or red, and more firm or hard), fruits are physiologically developed. Dates become partly brownish with 30–45% water content at the Rutab stage (soft and perishable fibers). Tamar stage has less water (25–10%, soft or hard, amber to dark brown) (Abul-Soad et al., 2010). Hababook to Tamar stage in Fig. 1 contains 6 stages of ripening. 21–27 °C is optimum growing temperature (pollination to ripening) (Abd Elwahab et al., 2019). Date palm can be used as raw, stored, and also distributed based on their ripe stages, such as Khalal, Rutab, and Tamar (Muñoz-Bas et al., 2023). As it has been divided into four classes called fresh, wet, semi-dry, and dry. It should be stored below 10 °C, most adequate storage temperature is 0 °C in order to decline color degradation, microbe attack, and disease spread. Beside this, a lower temperature can affect quality and sensory attributes, although the proper temperature for storage is different for every cultivar and ripening stage. Such as Khalal (50–85% water content) and Tamar (<25% water content) can be kept for 12 months (0 °C with 85–95% relative humidity) to decline dehydration and ripening speed. On a commercial level, freezing and chilling temperatures are necessary (Jemni et al., 2019). Another limiting factor during storage is the relative humidity, which should be 65–75% to resist weight loss, disease, and microbe infestation.

However, the fruit begins to lose its firmness, color, taste or overall physiology once it is harvested, which eventually reduces its market value (Al-Qurashi and Awad, 2011). These alterations are a result of numerous ripening-related enzymes and hormone activities after harvest, reduce the fruit's firmness (soften the tissues) led to senescence (Abu-Shama et al., 2020). Therefore, to gain commercial advantages with lower quality deterioration (Aleid and Saikhan, 2017), it is essential to decline ripening speed and senescence (Mohamed et al., 2014), for which numerous methods (cold storage, modified atmosphere packaging) (Alsawmahi et al., 2018), or controlled atmosphere storage (CAS). When the fruit is subjected to storage, it faces lots of disease challenges besides fruit losses occur in Pakistan and other developing states (due to illiterate farmers) (Basit et al., 2019).

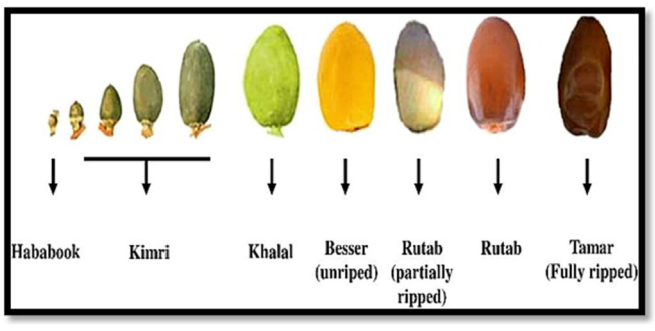

Fig. 1. Different maturation stages of date fruit from Hababook to Tamar stage.

Certain factors (cultivar, climatic situations, market requirement, and soluble tannin levels) should be kept in mind while picking date palm fruits (Ayub et al., 2023) because at roper harvest stage the risk of fruit cracking, high water loss, and pathogen attack declines (Mohamed et al., 2021). Enhanced temperature during storage and water content in date palms can lead to severe pathological and physiological incidences (Lobo et al., 2013). Date palm should be picked at proper stage (high quality) to avoid market loss followed by proper storage temperature (bruise and spoil at inadequate temperature). On a commercial level, advance picking tools should be used to reduce labor costs and energy consumption (Huntrods, 2011).

While, inquiring quality features, current investigation was carried out to inquire best storage temperature along with best picking stage while maintaining nutritious level. The aim of the study was to assess the effect of ripening stages (Khalal, Rutab, and Tamar), storage temperature (12, 28, and 24 °C), and different storage durations (0, 15, 30, and 45 days) on the fruit quality of date palm cv. Dhakki, antioxidant activity, antioxidant enzymes, and weight loss.

2. Materials and methods

2.1. Experimental site

Picking of date palm fruit was carried out at three different stages (Khalal, Rutab and Tamar) from Sanaullah Orchard, D.I. Khan, Pakistan. After sorting and grading, the fruit were kept in a cold storage ice chest and carried to the Postharvest Horticultural and Agricultural Chemistry Laboratory for further physiochemical analysis.

2.2. Storage conditions for date palm storage

Date palm fruits were harvested at three different ripening stages (Khalal, Rutab and Tamar) stored at three different temperatures (12, 28 and 2 °C) and storage duration (0, 15, 30 and 45 days). As the experiment was repeated three times so the total number of treatments was 27. The fruits from all treatments were kept in storage for 45 days. The fruits harvested at various ripening stages (Khalal, Rutab and Tamar) were stored at temperature of 12, 18 and 24 ± 2 °C with relative humidity of 67–70% in incubators at laboratories of Agriculture chemistry and stored at three different incubators and fix the temperature and Horticulture Department for analysis of various attributes at 15 days of intervals. The experiment was repeated three times with a factorial CRD (completely random) design.

2.3. Studied attributes

The different attributes of date palm fruits were studied as follows:

2.3.1. Moisture content and weight loss

The fruit were first weighed on a digital scale followed by recording dry weight (dried in oven). Moisture was calculated after each hour using formula described by (AOAC, 1990).

$$\text{Moisture content} = \frac{\text{Fresh weight} - \text{dry weight}}{\text{Fresh weight}} \times 100$$

Using below formula, weight loss after harvesting was checked periodically (storage = 0, 15, 30, and 45 days under 12, 18, or 24 °C,)

$$\text{Weightloss}(\%) = \frac{\text{Weight off reshfruits} - \text{weight after eachinterval}}{\text{Weight off reshfruits}} \times 100$$

2.3.2. Total soluble solid and titratable acidity (TSS:TA)

Refractometer (Zeiss, ATAGO model NAR-3 T, Japan) was used to measure total soluble solid (expressed as Brix) (Zeiss, ATAGO model NAR-3 T, Japan) after each storage interval. Titratable acidity (% citric acid) was calculated by standard procedure represented by AOAC (1990) through a titrometer by mixing juice, titrated with 0.1 M NaOH. The below formula was used for final reading.

$$\text{Titratableacidity}(\%) = \frac{\text{Normality of Na} \times \text{volume (mL) of 0.1 M NaOH} \times 0.0064 \times 100}{\text{weight of fruit (g)} \times \text{diluted sample (mL) (taken for titration)}} \times 100$$

2.3.3. Ascorbic acid content (mg 100 g^{-1})

Dye method using below formula was utilized to measure ascorbic acid (mg 100 g^{-1}) (Rangana, 1976).

$$\text{Ascorbicacid}(mg/100g) = \frac{\text{Dye factor} \times \text{Dye solution (mL)} \times 100}{\text{diluted sample (mL) (taken for titration)} \times \text{weight of fruit (g)}} \times 100$$

2.3.4. Fruit juice pH

pH meter (through inserting probe into fruit) was used for pH calculation.

2.3.5. Reducing and non-reducing sugar

The recommended procedure as noted by AOAC (1990) was utilized for calculation of reducing and non-reducing sugars.

2.3.6. Enzymatic activity

2.3.6.1. Catalase activity (unit g^{-1} protein). Abbasi et al. (1998) used a procedure to measure the catalase activity of date palm fruit. 2.9 mL of 15 M K_2HPO_4 buffer was added (at pH 7.0) in a cuvette A for buffer A, and similarly, buffer B was made by 2.9 mL addition of 12.5 mM H_2O_2 in 15 M K_2HPO_4 in another cuvette (to find buffer reaction). Each cuvette (100 µL = enzyme extract) was placed in gloomy box. At 45 and 60 s, an optical density of 240 nm was recorded when extracts were added to cuvettes. Using an Optima® 3000 Plus spectrophotometer, the differences in optical density were noted, from which catalase activity was measured.

2.3.6.2. Peroxidase activity. Briefly, 25 µL (20 mM), 75 µL (40 mM), and 625 µL (50 mM) of guaiacol (Sigma Aldrich, USA), H_2O_2, and potassium phosphate buffer (pH 5) were combined, respectively, to prepare the reaction mixture. The reaction mixture was added to with 25 µL of renal tissue supernatant, and absorbance was measured at 470 nm for 1 min (Naqvi et al., 2011).

2.3.7. Total phenolic content (mg of GAE per 100 g of dry matter)

Folin-Ciocalteu (FC) reagent was utilized to calculate total phenolic content with little changes (Velioglu et al., 1998). In test tubes, at room temperature, different things were added (100 µL of date extract, 50 µL of Folin-Ciocalteu reagent, and vortexing) following incubation (2 min). Furthermore, 2 mL of NaOH (6%) was poured following incubation (45 min). While at 750 nm (utilizing UV–visible spectrophotometer), the absorbance was measured using standard curve of gallic acid described amount.

2.3.8. Total tannin content (TTC; mg 100 g^{-1} CE)

Bentebba et al. (2020) procedure were used with minor modificationsto calculate tannin. A vanillin solution (prepared in absolute ethanol) of 1 mL of 4% and 0.2 mL of HCl (37%) was added to 0.4 mL of extract or catechin as a standard followed by dark incubation for 15 min, and then the absorbance was read by spectrometer at 500 nm after shaking.

2.3.9. Total flavonoid content (TFC; mg 100 g − 1 CE)

Flavonoids were recorded using proposed methods with slight changes (Kim et al., 2003). In a test tube with 250 µL of date extract, the $NaNO_2$ (5%) at 75 µL and vortexed were added following dark incubation (5 min). Furthermore, $AlCl_3$ (10%) at 75 µL was added, followed by vortexing and dark incubation for 6 min, followed by the further addition of NaOH (1 M) at 500 µL and raised thee volume using distilled water up to 2.5 mL. Then, using a spectrophotometer (Shimadzu, Kyoto, Japan), the absorbance was measured at 510 nm.

2.3.10. Antioxidant activities

The procedure developed by Amira et al., (2012) was used for antioxidant activities. In 5 mL of 0.004% DPPH in methanol, a 50 µL aliquot of 25, 50, 75, and 100 µg/mL of date extract were added. Absorbance (at room temperature) against a blank at 517 nm was recorded after 30 min of incubation. Butylated hydroxytoluene (BHT) was utilized as a positive control. The disappearance of DPPH was measured through microplates (BioTek, USA). Inhibition of free radicals by DPPH was measured in percent using the following formula:

$$I\% = \frac{\text{Absorbance of the only control reaction mixture} - \text{Absorbance of the examined sample}}{\text{Absorbance of the only control reaction mixtur}} \times 100$$

IC50 values = concentration of date fruit extracts that caused 50% neutralization of DPPH radicals, were measured from the plot of inhibition percentage against concentration.

2.3.11. Soluble protein contents

Bradford (1976), procedure was used for protein determination. Absorbance (at 595 nm) of 50 µL extract with 2 mL of Bradford reagent in microcentrifuge was calculated. The curve of different bovine serum albumin was used to detect proteins.

2.3.12. Fruit surface color

Hunter Lab calorimeter (Hunter Lab Inc., Reston, VA, USA) was used for surface color detection. The obtained values were showed as L* (brightness), a* (blue/yellow), or b* (red/green) (Ferrer et al., 2005), which was further utilized for hue angle ((ho), chroma (C*), and total color difference (ΔE*) calculations.

$$\text{ho} = 180^\circ + \arctan(b*/a*); (C*) = (a*2 + b*2)1/2$$

ΔE = [(L*−L*0) + (a*−a*0) + (b*−b*0)]1/2 (Maskan, 2001).

where L*0, a*0, and b*0 values were from control fruit at harvest time (day zero) (Feliziani et al., 2015).

2.4. Statistical analysis

The data were subjected to the analysis of variance (ANOVA) procedure using Statistix 8.1 (Tallahassee, FL, USA) statistical software, and significant differences among treatment means were calculated using the least significance difference test ($p \leq 0.05$) (Steel et al., 1997).

3. Results

3.1. Moisture content and weight loss of date palm fruit

Date palm moisture content and weight loss were significantly affected by the ripening stages (S), storage duration (D), and storage temperature (T) (Table 1). Although the interactions between ripening stages, temperature, and storage time were found to be non-significant, the interactions between SD (Fig. 2A) and TD (Fig. 3A) were shown to be significant. Fruit from date palms collected during the Khalal stage had the highest moisture content (23%) whereas fruit from Tamar stage had the lowest (15%) after

Table 1
Moisture content, weight loss, total soluble solids and fruit juice pH of date palm fruit as affected by ripening stages, storage temperatures and storage duration.

Treatments	Moisture content (%)	Weight loss (%)	TSS (%)	Fruit juice pH
Ripening stages (S)				
Khalal	23.2^{a}	8.48^{c}	20.4^{a}	4.97^{a}
Rutab	18.3^{b}	12.4^{b}	17.2^{b}	4.33^{b}
Tamar	15.1^{c}	14.5^{a}	12.8^{c}	3.81^{c}
LSD value	0.39	0.25	0.27	0.15
Storage temperature (T; °C)				
12	23.2^{a}	9.91^{c}	13.5^{c}	5.42^{a}
18	18.7^{b}	12.0^{b}	16.6^{b}	4.49^{b}
24	14.6^{c}	13.5^{a}	20.3^{a}	3.21^{c}
LSD value	0.39	0.25	0.27	0.15
Storage duration (D; Days)				
0	23.6^{a}	0.0^{d}	20.8^{a}	5.15^{a}
15	20.0^{b}	13.2^{c}	18.4^{b}	4.25^{b}
30	17.3^{c}	15.5^{b}	15.2^{c}	4.18^{b}
45	14.6^{d}	18.6^{a}	12.8^{d}	3.90^{c}
LSD value	0.46	0.29	0.32	0.17
Interactions				
S × T	ns	ns	ns	ns
S × D	**	**	*	**
T × D	***	**	**	***
S × T × D	ns	ns	ns	ns

Data collected form mean of three replicates. Mean values with different letters show significant differences and same letters indicate no statistically significant difference for all treatments according to the LSD test ($p < 0.05$).
ns = Non-significant; * and **= Significant at $p \leq 0.05$ and ***= Significant at $p \leq 0.01$.

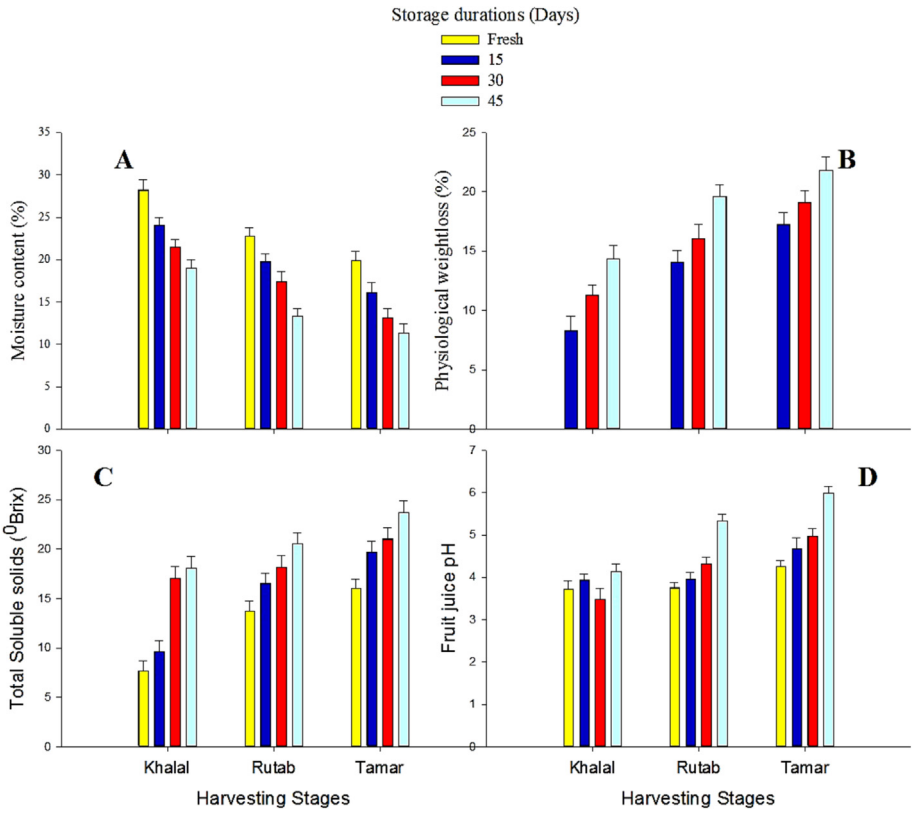

Fig. 2. Interactions of harvesting stages and storage duration on (A) Moisture content, (B) Physiological weight loss, (C) Total soluble solids and (D) Fruit juice pH of date palm. Data collected form mean of three replicates and vertical bars indicate standard error of means.

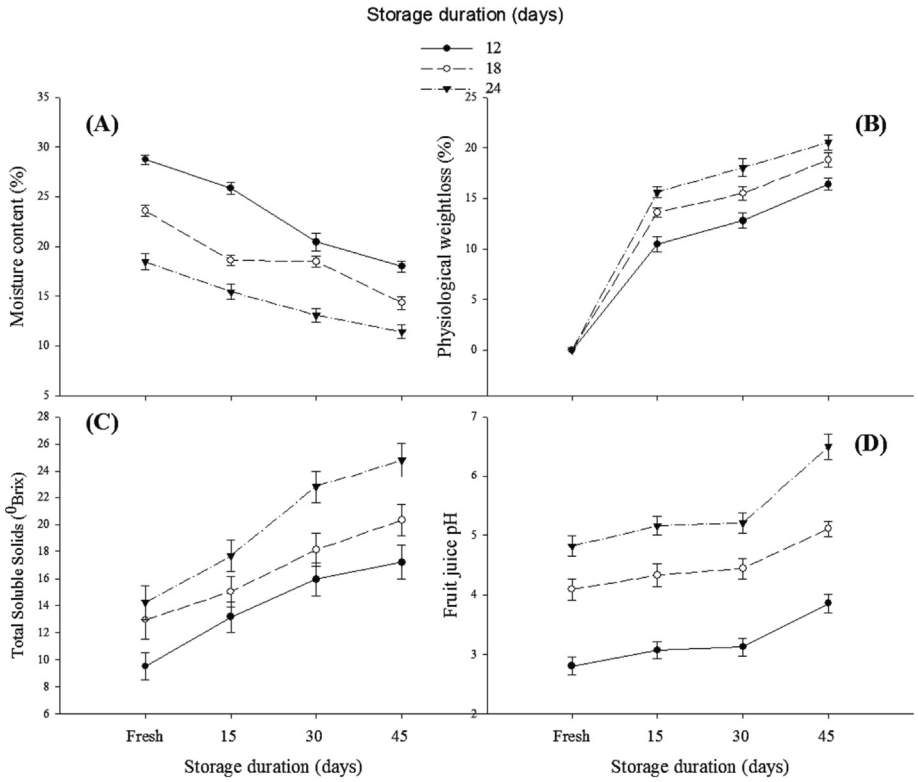

Fig. 3. Interactions of storage temperature and storage duration on (A) Moisture content, (B) Physiological weightloss, (C) Total soluble solids and (D) Fruit juice pH of date palm. Data collected form mean of three replicates and vertical bars indicate standard error of means.

storage. Regarding storage temperatures, fruit from date palms stored at 12 °C had a moisture content that was much higher (23%) than fruit stored at 24 °C (14.6%). During storage period, the maximum moisture content (23.6%) was observed in fresh fruit, while the lower moisture content (14.6%) was recorded in fruit stored for 45 days.

The fruits collected at the Tamar stage saw the most weight loss (14.5%), whereas the fruits gathered at Khalal stage and stored for 45 days experienced the lowest weight losses (8.5%) as shown in Table 1. Fruit held at 24 °C represented the highest percentage weight loss (13%) whereas fruit stored at 12 °C showed the lowest percentage weight loss (10%). Similarly increasing storage duration from 0 to 45 days leads to an increase in percent weight loss from (0 to 19%). The interaction of S × D (Fig. 2B) and T × D (Fig. 3B) was significant in weight loss. The maximum weight loss was noted in fruits picked at Tamar stage having storage of 45 days and the lowest weight loss in fresh fruits.

3.2. Total soluble solids of date palm fruit

A significant difference in total soluble solid (%) was observed for ripening stages (S), storage duration (D), storage temperatures (T), S × D (Fig. 2C), and T × D (Fig. 3C). As showed in Table 1, the combination of stages, temperature, or storage time was also determined to have no statistically significant impact. TSS of date palm fruit at each storage interval were considerably higher in fruit collected at Tamar stage (20.4%) and lower in the fruit harvested at Khalal stage (12.8%), according to the data. In terms of storage temperatures, fruit stored at 24 °C had a maximum TSS of 20.3%, whereas fruit stored at 12 °C had a minimum TSS of 13.5%. Similar to this, fruit that had just been picked had the highest TSS (20.8%), whereas fruit that had been stored for 45 days had the lowest TSS (12.8%).

3.3. Juice pH of date palm fruit

A significant difference ($P \leq 0.05$) was discovered regarding fruit juice pH at ripening stages (S), storage duration (D), or storage temperatures (T), S × D (Fig. 2D) and T × D (Fig. 3D), while the interaction of stages, temperature, and storage duration had non-significant difference on fruit juice pH (Table 1). Fruit harvested at the khalal stage expressed the highest fruit juice pH (4.97) and fruit picked at the tamar stage showed the lowest fruit juice pH (3.81). Similarly, regarding temperatures, the fruits stored at 12 °C exhibit the highest value of fruit juice pH (5.42), and the fruits stored at 24 °C showed the lowest fruit juice pH (3.21).

3.4. Titratable acidity of date palm fruit

Table 2 presents TA of date palm fruit. Storage duration, storage temperature, ripening stages and the interaction of S × D (Fig. 4A) and T × D (Fig. 5A) have considerably affected the TA of date palm fruit, while the other interactions were non-significant effect. Khalal stage picked fruit showed maximum (0.40%) titratable acidity, which is statistically similar to rutab-stage (0.38%) picked fruit. However, fruit taken at the Tamar stage of storage showed the lowest titratable acidity (0.28%). Similar to this, fruit from date palms stored at 24 °C showed the highest titratable acidity (0.41%), whereas fruit held at 12 °C displayed the lowest (0.29%) titratable acidity. With an extended storage time of 0–45 days, TA (0.41 to 0.29%) showed a decreasing tendency.

3.5. Ascorbic acid content

Ascorbic acid concentration (mg 100 g^{-1}) was significantly impacted by ripening stages (S), storage time (D), storage temperatures (T), SD (Fig. 4B), and TD (Fig. 5B), while other interactions

Table 2
Acidity, Ascorbic acid content, and reducing and non-reducing sugars of date palm fruit as affected by ripening stages, storage temperatures and storage duration.

Treatments	Acidity (%)	Ascorbic acid (mg 100 g^{-1})	Reducing sugar (%)	Non reducing sugar (%)
Ripening stages (S)				
Khalal	0.39[a]	24.6[a]	24.8[c]	26.8[a]
Rutab	0.38[a]	24.5[a]	28.4[b]	23.9[b]
Tamar	0.28[b]	17.7[b]	31.6[a]	21.4[c]
LSD value	0.01	0.15	0.13	0.25
Storage temperature (T; °C)				
12	0.29[c]	24.4[a]	31.1[a]	26.5[a]
18	0.34[b]	22.3[b]	28.3[b]	24.4[b]
24	0.41[a]	20.2[c]	25.4[c]	21.3[c]
LSD value	0.01	0.15	0.13	0.25
Storage duration (D; days)				
0	0.41[a]	29.2[a]	22.6[d]	31.9[a]
15	0.36[b]	26.2[b]	27.6[c]	26.1[b]
30	0.32[c]	20.5[c]	30.5[b]	21.9[c]
45	0.29[d]	13.3[d]	32.7[a]	16.4[d]
LSD value	0.04	0.17	0.15	0.25
Interactions				
S × T	ns	ns	ns	ns
S × D	*	**	**	***
T × D	*	***	***	ns
S × T × D	ns	ns	ns	ns

Data collected form mean of three replicates. Mean values with different letters show significant differences and same letters indicate no statistically significant difference for all treatments according to the LSD test ($p < 0.05$).
ns = Non-significant; * and **= Significant at $p \leq 0.05$ and ***= Significant at $p \leq 0.01$.

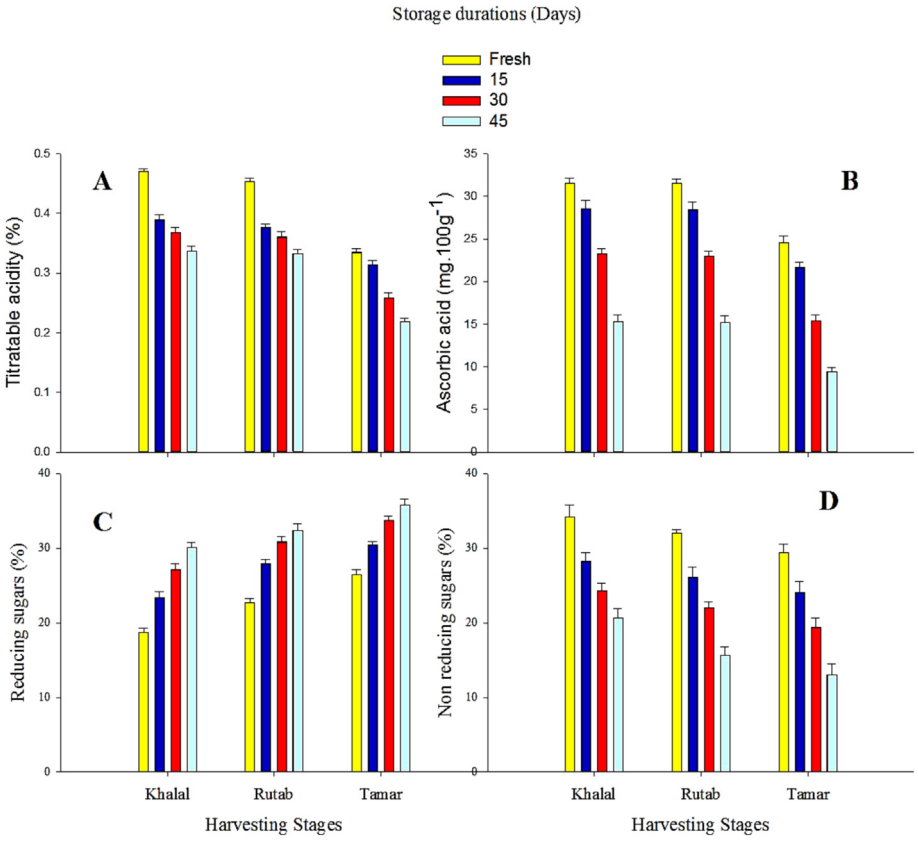

Fig. 4. Interactions of harvesting stages and storage duration on (A) Titratable acidity, (B) Ascorbic acid, (C) reducing sugars and (D) non-reducing sugars of date palm. Data collected form mean of three replicates and vertical bars indicate standard error of means.

were non-significant, according to an ANOVA reported in Table 2 (Table 2). Date palm fruit harvested in Khalal stage or stored for 45 days had the highest ascorbic acid concentration (24.6 mg 100 g^{-1}), which was statistically equivalent to fruit selected at the Rutab stage (24.5 mg 100 g^{-1}). Tamar stage-picked fruits had the lowest ascorbic acid concentration (17.7 mg 100 g^{-1}). Regarding storage temperatures, fruit stored at 24 °C had the highest ascorbic acid concentration (24.5 mg 100 g^{-1}), whereas fruit stored

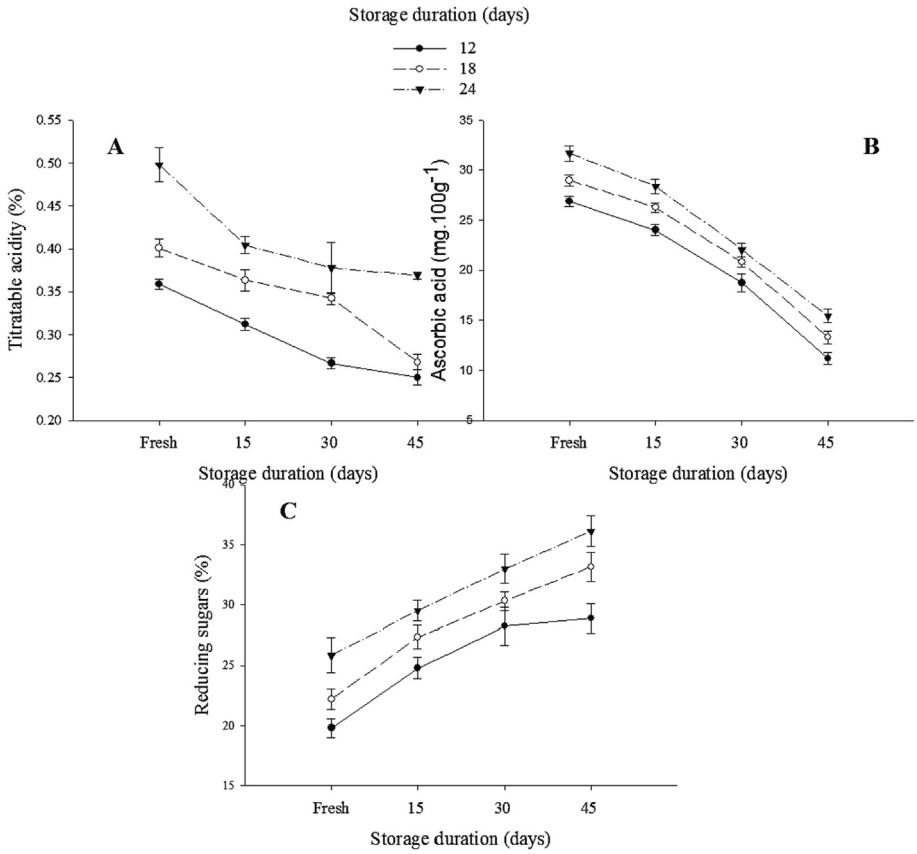

Fig. 5. Interactions of harvesting stages and storage duration on (A) Titratable acidity, (B) Ascorbic acid and (C) reducing sugars of date palm. Data collected form mean of three replicates and vertical bars indicate standard error of means.

at 12 °C had the lowest ascorbic acid content (20.2 mg 100 g^{-1}). From 0 to 45 days of storage, a reduction in vitamin C concentration (from 29.2 to 13.3 mg 100 g^{-1}) was observed.

3.6. Reducing and non-reducing sugar

The analysis of data (Table 2) showed a significant effect of ripening stages (S), storage duration (D), storage temperatures (T), S × D (Fig. 4C), and T × D (Fig. 5C) on the percent reducing sugar (%) of date palm fruit, while remaining interactions were non-significant. Fruits stored at 45 days of storage duration exhibit (31.6%) reduction in sugar picked at Tamar stage. Regarding storage temperatures, the highest percent reducing sugar (31.1%) was noted when fruit were stored at 24 °C, while the lowest value for percent reducing sugar (25.4%) was recorded in date palm fruit stored at 12 °C. Fruit harvested at Khalal stage showed the lowest value of reducing sugar (23.6%) in date palm fruit. The percent of decreasing sugar increased from fresh fruit to fruit preserved for 45 days (from 22.6% to 32.7%).

Table 2 showed that the non-reducing sugar (%) of date palm fruit was significantly impacted by ripening stages (S), storage time (D), storage temperatures (T), and SD (Fig. 4D), but other interactions were not statistically significant. According to data on the percent non-reducing sugar of date palm fruit at various ripening stages, the fruit picked at khalal stage and stored for 45 days had the highest value (26.8%), while the fruit picked at Tamar stage and stored for 45 days had the lowest value (21.4%). Regarding the range of storage temperatures, date palm fruit with non-reducing sugars was found to have the maximum value (26.4%) when kept at 24 °C and the lowest value (21.3%) when kept at 12 °C. From 0 to 45 days of storage, the non-reducing sugar was dramatically reduced from 31.9 to 16.4%.

3.7. Antioxidant activities

The interactions of S × D (Fig. 6A) and T × D (Fig. 7A) were significant, while other interactions were non-significant. Antioxidant activities were considerably affected by storage temperatures, durations, and harvesting stages. Fruits stored at control temperature represented minimum (82.29 mg kg^{-1}) antioxidant activities, while higher (214.58 mg kg^{-1}) activities were found in 12 °C stored fruits. Regarding means of harvesting stages, maximum (210.95 mg kg^{-1}) antioxidant activities were found in khalal stage-picked picked fruit showed minimum (88.02 mg kg^{-1}) antioxidant activities. Similarly, control samples exhibit the highest (267.26 mg kg^{-1}) antioxidant activity, while 45-day-old fruit showed the lowest (57.02) antioxidant activity (Table 3).

3.8. Total phenolic contents

Storage temperature, storage duration, and harvesting stages have significantly affected the phenolic content of date palm fruit. Furthermore, the interaction S × D (Fig. 6B) and T × D (Fig. 7B) had a significant effect on total phenols of date palm fruits. Highest TPC (31.42 mg of GAE 100 g^{-1}) was recorded in date palm at khalal stage, followed by tamar (27.37 mg of GAE 100 g^{-1}) and lowest TPC (21.16 mg of GAE 100 g^{-1}) was noted at rutab stage. Similarly, mean values for temperature, date palm stored at 12 °C recorded the highest total phenolic contents (41.61 mg of GAE 100 g^{-1}) while the lowest (26.65 mg of GAE 100 g^{-1}) was recorded in date

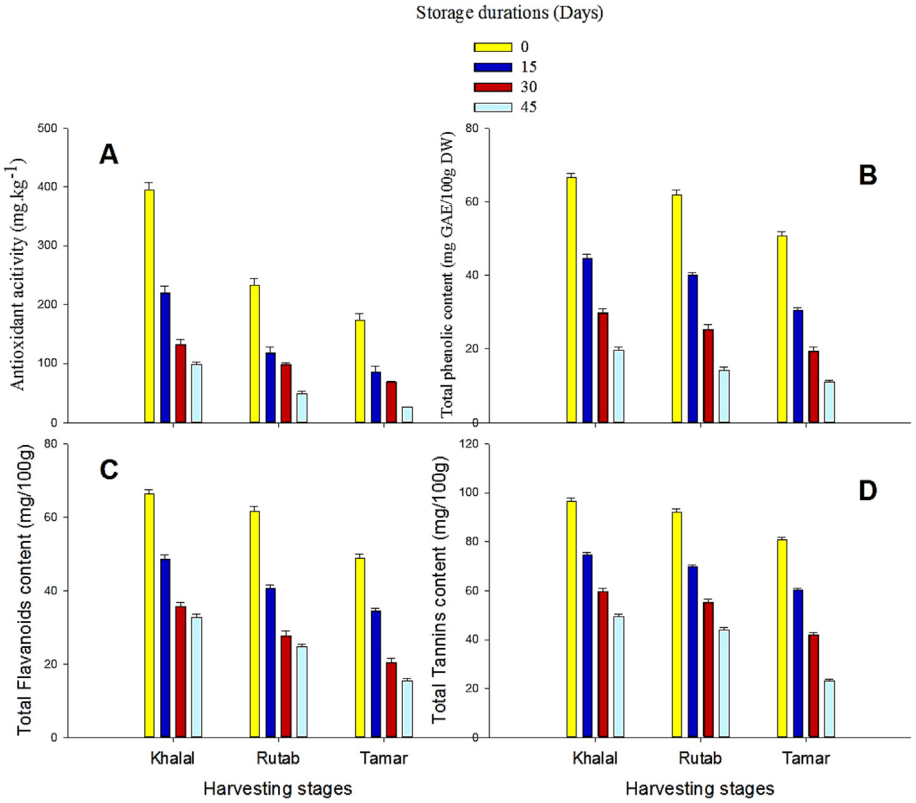

Fig. 6. Interactions of harvesting stages and storage duration on (A) fruit antioxidant, (B) total phenols, (C) flavonoids and (D) total tannin content of date palm. Data collected form mean of three replicates and vertical bars indicate standard error of means.

palm stored at 2 °C. For means of storage duration, more TPC (59.71 mg of GAE 100 g^{-1}) was noted in date palm stored for 0 days, while the lowest (14.79 mg of GAE 100 g^{-1}) total phenolic contents was recorded in date palm stored for 45 days (Table 3).

3.9. Total flavanoids content

Harvesting stages (S), storage duration, (D), and temperature (T), S × D (Fig. 6C) and T × D (Fig. 7C) interaction, had significant effect on flavonoids of date palm. The data for temperature showed that more (44.74 mg100g^{-1}) flavonoids content was observed in date palms at 12 °C followed by (37.83 mg 100 g^{-1}) at 18 °C while the lowest (31.79 mg 100 g^{-1}) flavonoids content was recorded at 24 °C temperature. Furthermore, the highest flavonoid content (58.93 mg 100 g^{-1}) was recorded in date palm stored at control, followed by flavonoid content (41.32 mg 100 g^{-1}) in date palm kept for 15 days in storage, while the lowest (24.28 mg 100 g^{-1}) flavonoid content was recorded at 45 days of storage duration. Regarding the means for the effect of stages, more flavonoids content (45.82 mg 100 g^{-1}) was recorded in date palm at khalal stage, while the lowest flavonoids content (29.84 mg 100 g^{-1}) was recorded at the rutab stage (Table 3).

3.10. Total tannin content

Harvesting stages (S), storage duration (D), and temperature (T), S × D (Fig. 6D) and T × D (Fig. 7D) interactions had significant effect on tannin content of date palm. Data for temperature showed that more (71.61 mg 100 g^{-1} CE) tannin content at 12 °C was observed at 120 °C in date palm, followed by (63.01 mg 100 g^{-1} CE) at 18 °C while lowest (52.30 mg 100 g^{-1} CE) tannin content was noted at 24 °C temperature. Regarding the means for storage duration, the highest tannin content (89.71 mg 100 g^{-1} CE) was noted in date palm stored at control, followed by a lower tannin content (68.32 mg 100 g^{-1} CE) in date palm stored for 15 days, while at 45 days of storage duration, the lowest (38.94 mg 100 g^{-1} CE) tannin content was noted. Regarding the means for the effect of stages, more tannin content (70.07 mg 100 g^{-1} CE) in date palm was recorded at khalal stage, while the lowest tannin content (51.55 mg 100 g^{-1} CE) was noted at rutab stage (Table 3).

3.11. Catalase activity

Catalase activity on date palm was considerably affected by harvesting stages, storage duration, and temperature, and the two way interactions (S × D) (Fig. 8A) and T × D (Fig. 9A) were also significant. At 12 °C, highest catalase activity (1.56 U g^{-1} FW) was noted, while the lowest (1.18 U g^{-1} FW) was recorded at 24 °C. Maximum (2.10 U g^{-1} FW) catalase activities were obtained for control fruits, while minimum (0.70 U g^{-1} FW) catalase activities were recorded in 45-day-old fruits. Similarly, date palm harvested at the khalal stage showed maximum (1.82 Ug^{-1} FW) catalase activity, while fruit picked at the rutab stage exhibited minimum (0.90 Ug^{-1} FW) catalase activity (Table 4).

3.12. Peroxidase activity

At the khalal stage, the peroxidase activity was noted at its maximum (1.40 U g^{-1} FW), then sharply decreased during the tamar stage (0.97 U g^{-1} FW), and finally reached its lowest level (0.59 U g^{-1} FW) at the rutab stage (Fig. 8B and 9B). The specific activity of peroxidase was maximum (1.21 U g^{-1} FW) at temperature 12 °C, then sharply decreased (1.01 U g^{-1} FW) at 18 °C and an

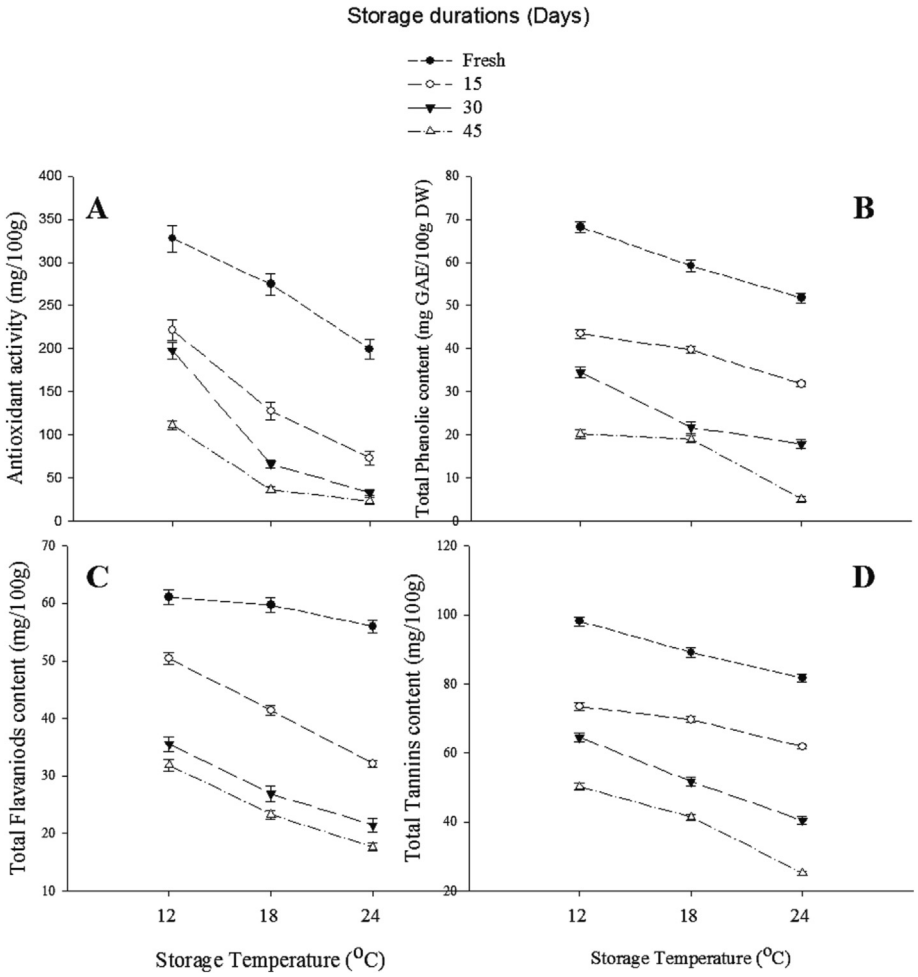

Fig. 7. Interactions of storage temperatures and storage duration on (A) antioxidant, (B) total phenols content, (C) total flavaniods and (D) total tannin content of date palm. Data collected form mean of three replicates and vertical bars indicate standard error of means.

Table 3
Antioxidant activity (AC), total phenols content (TPC), total flavonoids content (TFC) and total tannin content (TTC) of date palm fruit as affected by ripening stages, storage temperatures and storage duration.

Treatments	AC ($mg100g^{-1}$)	TPC (mg $GAE100g^{-1}$ DW)	TFC ($mg100g^{-1}$)	TTC ($mg100g^{-1}$)
Ripening stages (S)				
Khalal	210.95[a]	40.07 [a]	45.82 [a]	70.07 [a]
Rutab	124.12[b]	35.29[b]	38.71[b]	65.29[b]
Tamar	88.02[c]	27.81[c]	29.84[c]	51.55[c]
LSD value	0.72	0.46	0.31	0.60
Storage temperature (T; °C)				
12	214.58 [a]	41.61 [a]	44.74 [a]	71.61 [a]
18	126.23[b]	34.91[b]	37.83[b]	63.01[b]
24	82.29[c]	26.65[c]	31.79[c]	52.30[c]
LSD value	0.72	0.46	0.31	0.60
Storage duration (D; days)				
0	267.26 [a]	59.71 [a]	58.93 [a]	89.71 [a]
15	140.76[b]	38.32[b]	41.32[b]	68.32[b]
30	99.09[c]	24.73[c]	27.97[c]	52.24[c]
45	57.02 [d]	14.79 [d]	24.28 [d]	38.94 [d]
LSD value	0.84	0.53	0.36	0.70
Interactions				
S × T	ns	ns	ns	ns
S × D	*	**	**	***
T × D	*	***	***	*
S × T × D	ns	ns	ns	ns

Data collected form mean of three replicates. Mean values with different letters show significant differences and same letters indicate no statistically significant difference for all treatments according to the LSD test ($p < 0.05$).
ns = Non-significant; * and **= Significant at $p \leq 0.05$ and ***= Significant at $p \leq 0.01$.

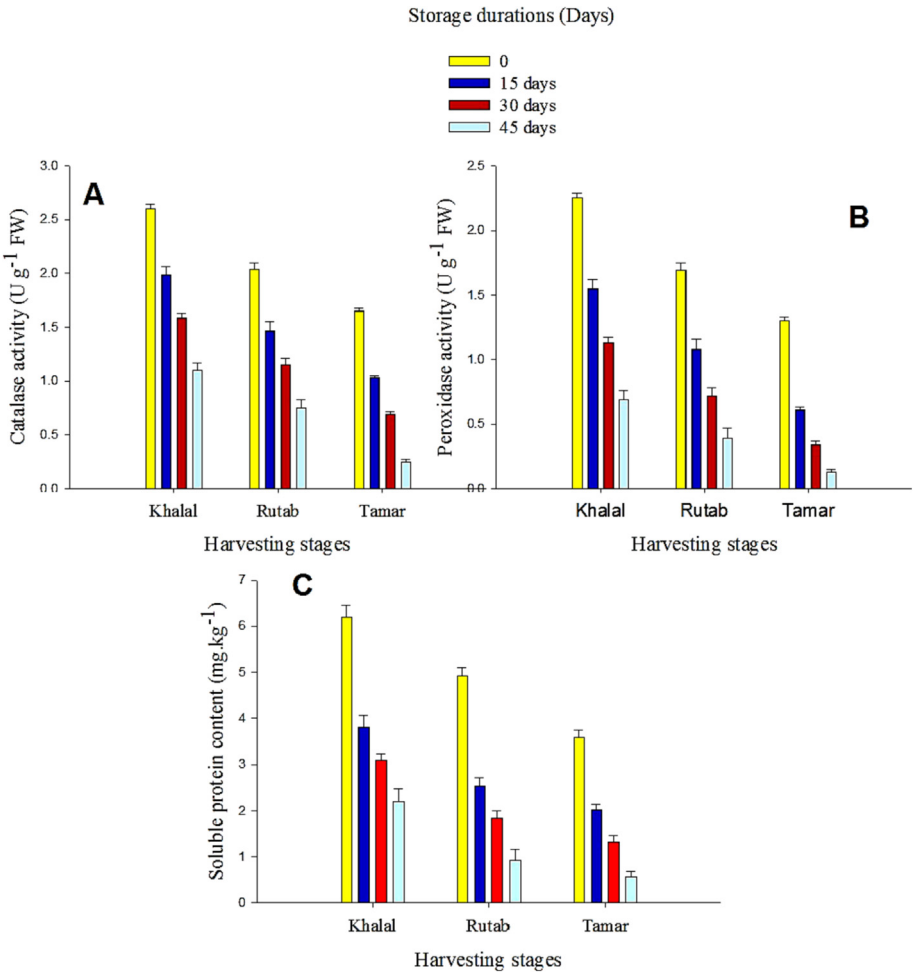

Fig. 8. Interactions of harvesting stages and storage duration on (A) catalase activity, (B) peroxidase activity and (C) soluble protein content of date palm. Data collected form mean of three replicates and vertical bars indicate standard error of means.

absolute decrease (0.74 U g^{-1} FW) was observed at 24 °C. Furthermore, at control storage, maximum (1.75 U g^{-1} FW) peroxidase activity was noted in fruits and then gradually decreased. The final decrease (0.40 U g^{-1} FW) of specific POD activity was recorded at 45 days of storage duration (Table 4).

3.13. Soluble protein contents

Regarding means for temperature, date palm stored at 12 °C recorded the highest soluble protein contents (3.18 kg^{-1}) while the lowest soluble protein contents (2.40 mg kg^{-1}) were recorded in date palm stored at 24 °C. Data recorded for storage duration showed that fruits at control storage have higher (4.90 mg kg^{-1}) soluble protein content, while 45-day-old fruits showed minimum (1.23 kg^{-1}) protein content (Table 4). Recorded data showed that khalal-stage fruits have the highest (3.82 $g100g^{-1}$) protein content, followed by rutab (2.56 g 100 g^{-1}) and finally, Tamar stage harvested fruits have the lowest (1.87 g 100 g^{-1}) soluble protein content (Fig. 8C and Fig. 9C).

3.14. Brightness (L*) and chroma (C*)

Highest L* (29.90) was recorded in datepalm at khalal stage, followed by tamar (26.85), and lowest L* (23.57) was recorded at rutab stage. Similarly, regarding means for temperature, date palm stored at 12 °C recorded the highest (28.77) L* while the lowest L* (24.88) was recorded in date palm stored at 24 °C. For means of storage duration, more L* (36.85) was observed in date palm stored at control, while the lowest L* (17.89) was recorded in date palm stored for 45 days. Highest C* (16.40) was recorded in date palm at khalal stage, followed by tamar (13.35), and lowest L* (10.07) was recorded at rutab stage (Table 5).

Similarly, regarding means for temperature, date palm stored at 12 °C recorded the highest (15.27) L* while the lowest L* (11.38) was recorded in date palm stored at 24 °C. For means of storage duration, more (22.85) L* was observed in date palm stored at control, while the lowest (5.89) L* was recorded in date palm stored for 45 days (Figs. 10 and 11A, B).

3.15. Total color difference (ΔE*)

Storage duration, storage temperature, and harvesting stages have considerably influenced fruit color and other valuable color attributes (such as ΔE, C*, L*). Similar to other biochemical attributes, the total color difference of date palms picked at the khalal stage represented the maximum (16.78) value, which decreased going towards the ripening stage. So, the minimum (12.02) total color difference was observed at the rutab stage (Table 5). Data regarding storage duration showed that control stored food showed a 0.00 value while it got enhanced, and 45 days of stored fruit showed 28.89 of ΔE*. 12 °C storage temperature exhibited

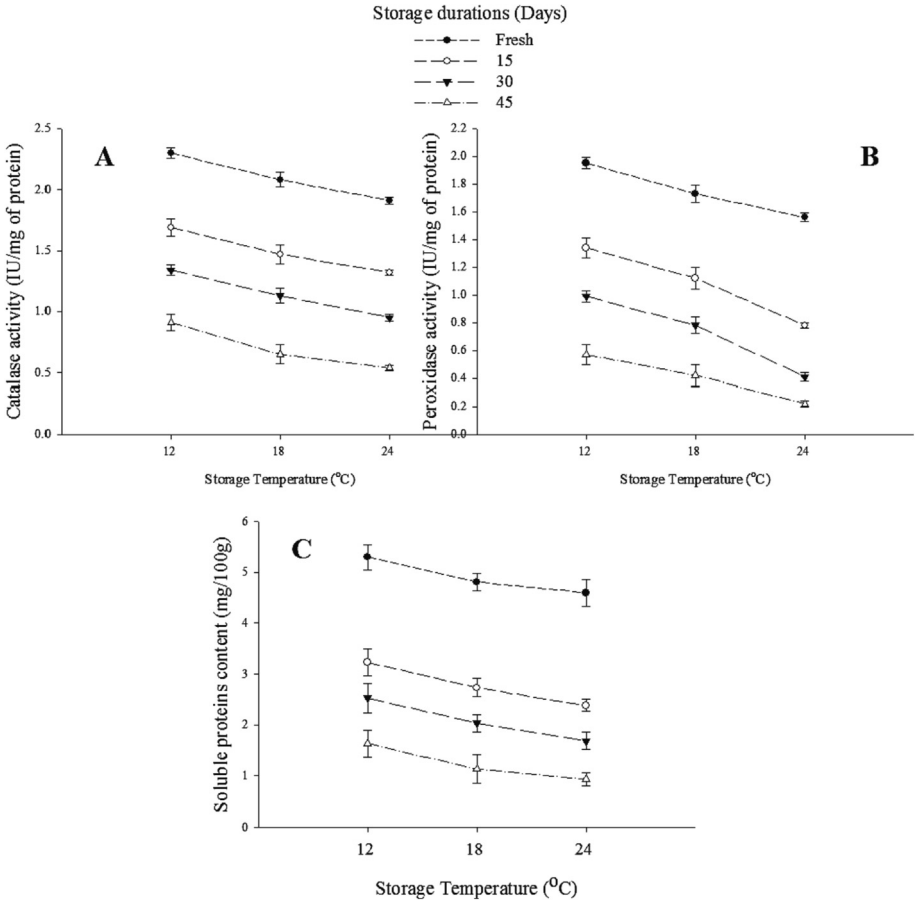

Fig. 9. Interactions of storage temperatures and storage duration on (A) catalase activity, (B) peroxidase activity and (C) soluble protein content of date palm. Data collected form mean of three replicates and vertical bars indicate standard error of means.

Table 4
Catalase activity, peroxidase activity and soluble protein content of date palm fruit as affected by ripening stages, storage temperatures and storage duration.

Treatments	Catalase activity (U g^{-1} FW)	Peroxidase activity (U g^{-1} FW)	Soluble protein content (mg.kg^{-1})
Ripening stages (S)			
Khalal	1.82 ^{a}	1.40 ^{a}	3.82 ^{a}
Rutab	1.35^{b}	0.97^{b}	2.56^{b}
Tamar	1.18^{c}	0.59^{c}	1.87^{c}
LSD value	0.020	0.021	0.031
Storage temperature (T; °C)			
12	1.56 ^{a}	1.21 ^{a}	3.18 ^{a}
18	1.33^{b}	1.01^{b}	2.68^{b}
24	1.18^{c}	0.74^{c}	2.40^{c}
LSD value	0.020	0.021	0.031
Storage duration (D; days)			
0	2.10 ^{a}	1.75 ^{a}	4.90 ^{a}
15	1.50^{b}	1.08^{b}	2.78^{b}
30	1.14^{c}	0.73^{c}	2.08^{c}
45	0.70 ^{d}	0.40 ^{d}	1.23 ^{d}
LSD value	0.023	0.025	0.036
Interactions			
S × T	ns	ns	ns
S × D	*	**	**
T × D	*	***	***
S × T × D	ns	ns	ns

Data collected form mean of three replicates. Mean values with different letters show significant differences and same letters indicate no statistically significant difference for all treatments according to the LSD test ($p < 0.05$).
ns = Non-significant; * and **= Significant at $p \leq 0.05$ and ***= Significant at $p \leq 0.01$.

Table 5
Brightness (L^*), Chroma (C^*), hue angle (h^0) and total color difference (ΔE^*) of Date palm fruit as affected by ripening stages, storage temperatures and storage duration.

Treatments	L^*	C^*	h^0	ΔE^*
Ripening stages (S)				
Khalal	29.90 ^{a}	16.40 ^{a}	34.90 ^{a}	16.78 ^{a}
Rutab	26.85^{b}	13.35^{b}	31.85^{b}	15.20^{b}
Tamar	23.57^{c}	10.07^{c}	28.57^{c}	12.02^{c}
LSD value	0.24	0.24	0.24	0.13
Storage temperature (T; °C)				
12	28.77 ^{a}	15.27 ^{a}	29.88 ^{a}	16.16 ^{a}
18	26.68^{b}	13.18^{b}	31.68^{b}	14.73^{b}
24	24.88^{c}	11.38^{c}	33.77^{c}	13.11^{c}
LSD value	0.24	0.24	0.24	0.13
Storage duration (D; days)				
0	36.85 ^{a}	22.85 ^{a}	22.89 ^{a}	0.00 ^{d}
15	28.93^{b}	14.93^{b}	28.43^{b}	5.89^{c}
30	23.43^{c}	9.43^{c}	33.93^{c}	23.89^{b}
45	17.89 ^{d}	5.89 ^{d}	41.85 ^{d}	28.89 ^{a}
LSD value	0.28	0.28	0.28	0.15
Interactions				
S × T	ns	ns	ns	ns
S × D	*	**	**	***
T × D	*	***	***	*
S × T × D	ns	ns	ns	ns

Data collected form mean of three replicates. Mean values with different letters show significant differences and same letters indicate no statistically significant difference for all treatments according to the LSD test ($p < 0.05$).
ns = Non-significant; * and **= Significant at $p \leq 0.05$ and ***= Significant at $p \leq 0.01$.

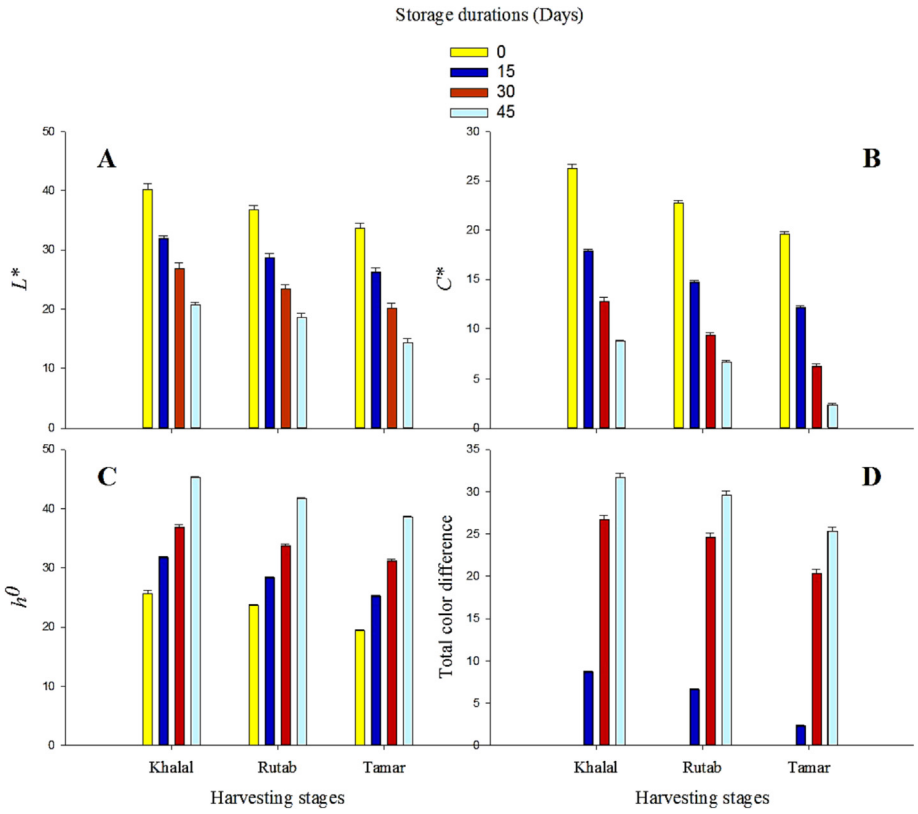

Fig. 10. Interactions of harvesting stages and storage duration on (A) brightness [L^*] (B) Chroma [C^*] (C) hue angle [h^0] (D) total color difference [ΔE^*] of date palm. Data collected form mean of three replicates and vertical bars indicate standard error of means.

maximum (16.16) ΔE followed by (14.73) at 18 °C while 24 °C showed minimum (13.11) ΔE (Fig. 10and Fig. 11C, D).

3.16. Principal component and correlation analysis

To assess the influence of ripening stages, storage temperatures, and storage duration on the studied attributes of date palm, the loading diagram and score of PCA are presented in Fig. 12. The first two components, i.e., Dim1 (PC1, 86.6%) and Dim2 (PC2, 8.9%), showed the highest contribution and represented 95% of the total variance in the dataset. Most of the studied attributes showed positive correlation with each other in PCA (PC1). In contrast, the negative correlation of color and hue angle was noticed with other analyzed traits of the data palm.

A Pearson's correlation analysis was performed between different attributes of the date palm (Fig. 13). The correlation analysis revealed that color and hue angle were negatively correlated with the studied attributes, i.e., antioxidants, phenols, flavonoids, tannin, catalase, peroxidase, soluble sugar proteins, L and C of date palm. In contrast, the other studied characteristics of data palm were in strong correlation with each other.

4. Discussion

During storage of horticultural crops respiration and transpiration process continue that decline fruit quality through water loss from different fruit plant which highly reduce fruit weight (wilting, shriveling and softening). Moisture content plays a crucial role in reducing the deterioration of fresh produce. Generally, a commodity with higher moisture content is extremely susceptible to decay and fruit rot. Similarly different physiological disorders were reported in date palm due to decline moisture content (Li et al., 2023). In addition, Sugri et al., (2021) declared reduction in commodities weight during storage. Rather than other stages (khalal and rutab), date palm picked at Tamar stages represent softness and turgidity loss during storage led to water reduction and weight loss (Bhatt and Jampala, 2020; Mohammed et al., 2020), could be due to starch transferring into soluble substances (Rastegar et al., 2012). It might also be due to presence and nature of waxy layer on fruit surface (Lobo et al., 2013). Similarly, certain things (high respiration rate, continuous water decline, slower ethylene production, metabolic activities, and respiration rate) also enhanced moisture in storage with lower storage (Kumar et al., 2017), as temperature and water content have indirect connection (Kumar et al., 2017).

Enhanced cell wall and hydrolytic enzymes are responsible for enhancement of TSS during storage and ripening (khalal stage) (Rastegar et al., 2012). During storage, TSS enhancement at khalal stage (ripened) might be due to polysaccharides conversion through hydrolytic enzymes into a simple substance, which may be further metabolized during respiration (Abbasi et al., 2011). Our results are similar to Manzano and Diaz (2001), who reported speedy carbohydrates transfer into organic acids during storage, while also enhanced of TSS with high temperature due to metabolism, ethylene production, and delayed senescence (Mukhtar et al., 2022). With decreasing storage temperature, the decline in TSS is probably due to a higher CO_2 concentration in the fruit, which reduces respiration and leads to later senescence and slower ripening (Sidhu et al., 2022).

Biochemical and catabolic reactions led to acids breakdown during storage led to enhancement of fruit juice pH of khalal picked dates rather than rutab and Tamar picked fruits (Rastegar

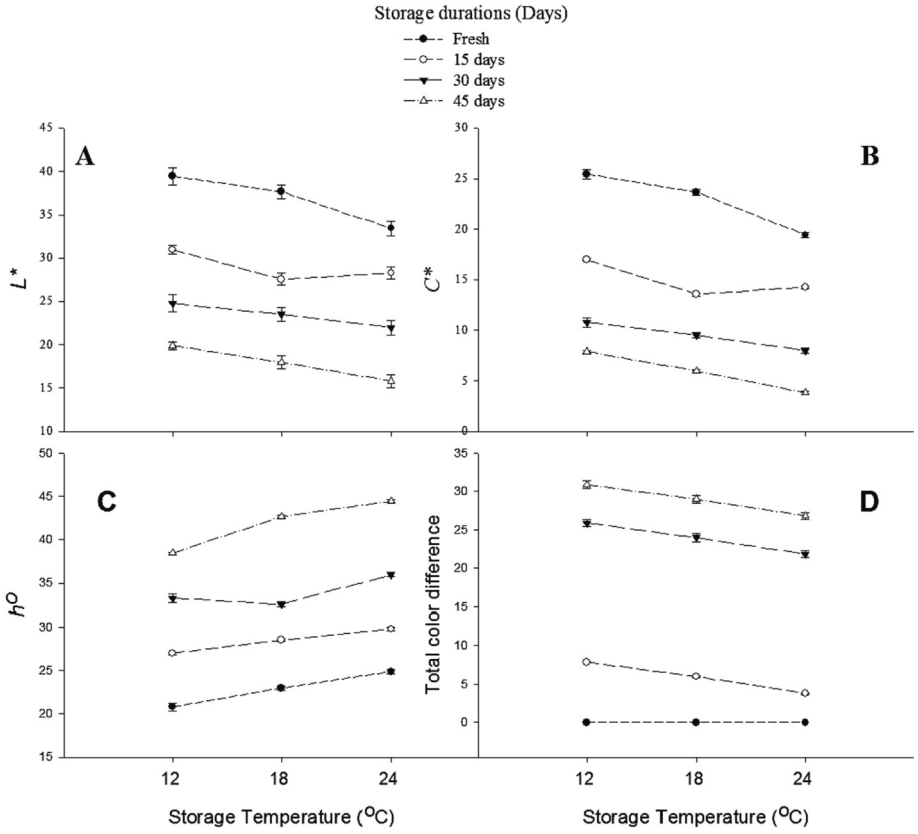

Fig. 11. Interactions of storage temperature and storage duration on (A) brightness [L^*] (B) Chroma [C^*] (C) hue angle [h^0] (D) total color difference [ΔE^*] of date palm. Data collected form mean of three replicates and vertical bars indicate standard error of means.

et al., 2012). Due to the influence of treatment, the decline in ripening speed, respiration, and other biochemical and metabolic activities occurred during storage due to enhanced temperature, leading to increased fruit juice pH (Jitareerat et al., 2007).

Fruits taste is strongly connected with TA, acids and sugars are responsible for TA decline of khalal picked fruits during storage led to respiration enhancement (Ali et al., 2011). Respiratory metabolism also led to reduction of TA (Hatami et al., 2023). Sugar formation as a result of acids transfers along decline of fruit juice acid during storage enhanced the TA level as temperature increased (Mezey and Mezeyová, 2018). Organic acids convert to organic compounds during ripening as a result of enhanced temperature, which increases TA in apple cultivars (Vallarino and Osorio, 2019). In grapefruit, the pH (hydrogen ion concentration) gets higher during storage, this lengthens the shelf life. On a cellular level, due to calcium, certain activities get changed, which decrease the acidity, as acidity and pH have an inverse link (Conway, 1987). Moreover, Dong et al., (2023) reported that pH gets enhanced due to catabolic activities and organic acids splitting as a result of respiration during storage.

Rather than other stages (khalal and rutab), ascorbic acid become fall (Tamar picked fruit) due to over ripening and aging, exposure to high or low temperature, light, or natural oxidation during storage (Aribi, 2023). In the presence of O_2 during storage, dehydroascorbic acid is formed from the splitting of ascorbic acid, resulting in a decrease in ascorbic acid at the Tamar stage as compared to other stages. Vitamin C shows the nutritional value of fruits. Due to its volatile nature during respiration, it evaporated from the surface led to ascorbic acid reduction (Ripasarda et al., 2011).

Fresh fruits have higher ascorbic acid than stored date palm at varying circumstances (Li et al., 2023). Bilska et al., (2019) reported role of ascorbic acid as free radical scavenging and electron donor for ascorbate peroxidase (H_2O_2 to H_2O). Similarly, enhanced respiration led to higher oxidation. Similar observations regarding ascorbic acid decline at various storage period were also noted by Samad et al. (2016).. A slow decline trend of vitamin C during storage of date palm was reported by Mohammed et al., (2021a, 2021b) due to instability.

Invertase enzyme action enhanced the reducing sugar linked with low respiratory metabolism (due to CO_2 action) during storage (Saway and Mashadi, 1983). Transfer of polysaccharides to water soluble sugars led to enhanced reducing sugars especially at Tamar stages rather than other stages as storage increases (Sarraf et al., 2021). Reducing sugar are actually the nonstructural fruits carbohydrates (Li et al., 2023). Sucrose conversion to glucose and fructose (primarily due to acids) occurs as a result of enhanced temperature, leading to increased reducing sugar. With increasing storage temperature, the reducing sugar content in date palm increased as storage extended (Echegaray et al., 2023). At time of edible maturity, starches (stored carbohydrates) get utilized and hydrolyzed led to decline of sugar (El-Gioushy et al., 2022). Enhanced respiration, sucrose hydrolysis to glucose and fructose, and their combined effect at higher temperatures led to enhanced reducing sugar, although this depends on varieties (Rastegar et al., 2012).

Non-reducing sugar decline about 31.9 to 16.4% occurs during storage (0–45 days). During storage at Tamar stage, non-reducing sugars fall due to sucrose utilization and speedy ethylene (at respiration) (Alam et al., 2023). Higher acidity and polysaccharide trans-

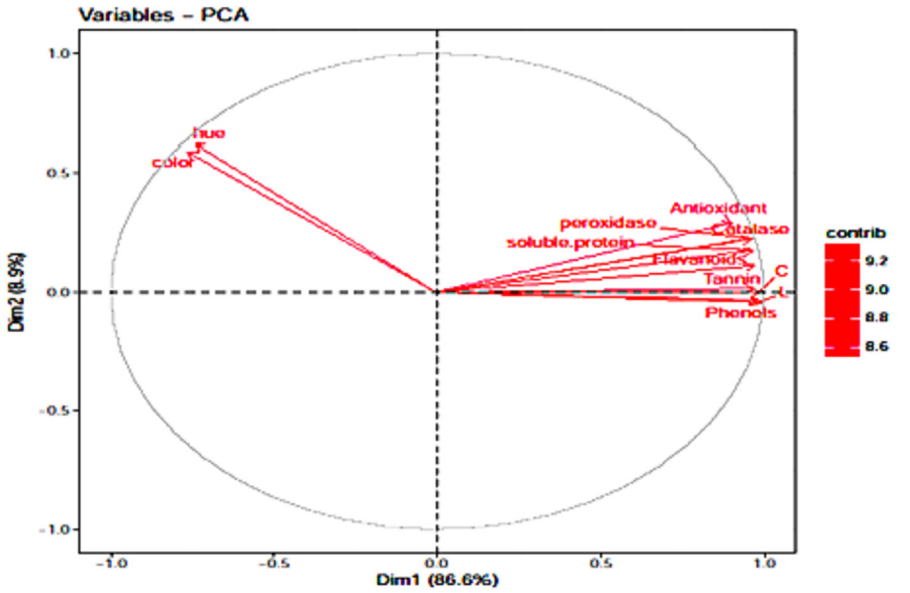

Fig. 12. Principal component analysis of studied attributes of date palm.

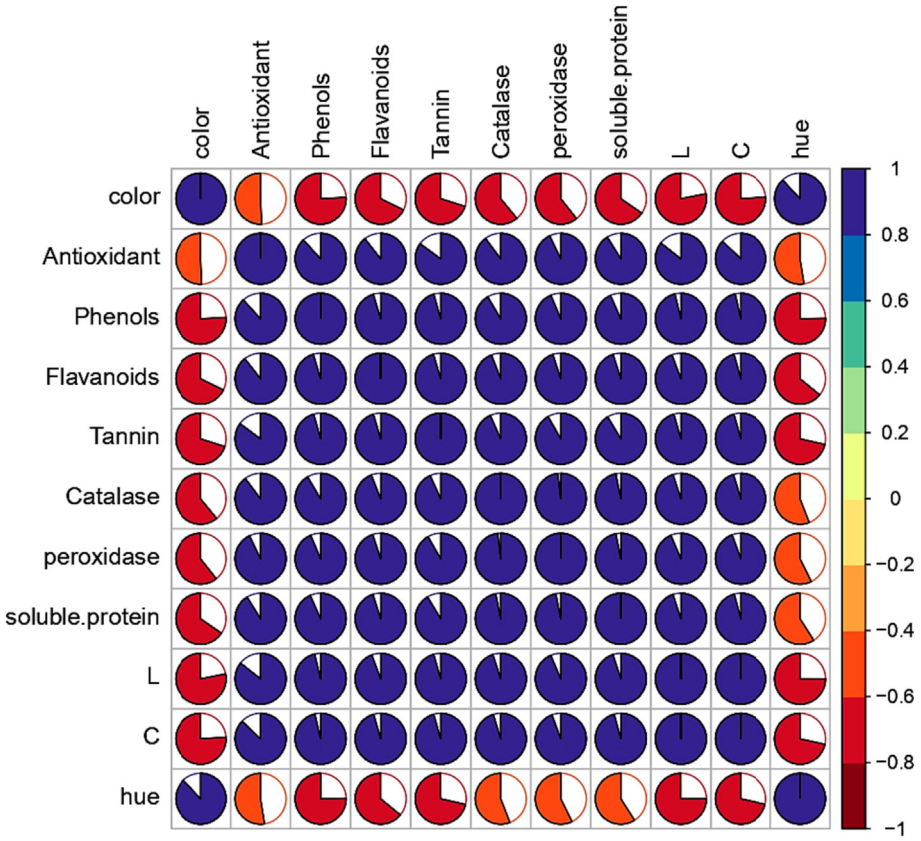

Fig. 13. Pearson correlation of analyzed attributes of date palm under ripening stages, storage temperatures and storage duration.

fer to monosaccharaides at higher temperature (during storage) led to lower non reducing sugars (Alam et al., 2023).

Presence of biochemical (polyphenols, tannins, carotenoids or vitamin (A) led to higher antioxidants (Alhaider et al., 2017; Khalid et al., 2017; Mohamed et al., 2023). Date palm, being a climacteric fruit, is highly prone to oxidative stress due to a decrease in free radical scavenging activity (Mohamed et al., 2014) due to which antioxidant activities get reduced from the early stage to

ripening in dates (Awad et al., 2011a). With the ripening of dates, antioxidants get lower, as khalal is a highly rich stage of antioxidant activity (Lemine et al., 2014). Evaluated FRSA observed in fruits influences antioxidant activities that further influence vitamins and polyphenolic compounds (Akhtar, 2010). Certain physical and chemical parameters (flesh firmness and peel color) in harvested fruit are highly influenced by antioxidant activities (Ghazzawy et al., 2023). With free radical production during senescence, high ROS (H_2O_2 and superoxide) are produced (Mohamed et al., 2023).

All plants carry out TPC synthesis, as it is a secondary metabolite having role in fruits sensory features (color and flavor) along other plant activities (photosynthesis, nutrient absorption, protein synthesis, and enzymatic activities) (Jha and Mohamed, 2022). Date palm is rich in phenols (Benmeddour et al., 2013). Similar to antioxidants, phenolic contents also reduced from early stage (khalal) to ripening stage (tamar) (Al-Turki et al., 2010; Awad et al., 2011a) due to polyphenol oxidases that oxidized TPC (Mohammed et al., 2020). Similar to other fruits, date also shows a decline trend of phenols with progressive maturation (Awad et al., 2011a). At khalal stage, the maximum phenolic acids (0.729 g/100 g) were observed by Lemine et al., (2014), while the lowest was found at tamar stage (0.559 g/100 g). 25% loss from early stage to ripening was recorded by Awad et al., (2011a), although date palms (Khalas and Shishi) showed increased amounts of phenols (stored at 4 °C for 6 months) that doubled by extending storage duration to 12 months (Al-Najada and Mohamed, 2014).

Flavonoids have a great role in antioxidant and anti-inflammatory activities found in many horticultural commodities (Moss and Ramji, 2016). High flavonoids (including catechin) in dates are present in palatable portions compared to date pits (Hammouda et al., 2013). Moving from the green stage to ripening, the flavonoid content declines in date palm fruit of seven different varieties (Lemine et al., 2014) and also in four other varieties of Tunisian dates (Amira et al., 2012).

Antioxidant enzymes are strongly connected with fruit ripening (Mahomoodally et al., 2023). In the control of reactive oxygen species (ROS), especially hydrogen peroxide, catalase works more properly as it has a great role in anti-oxidative enzymes, among others (Bettaieb et al., 2023). In order to resist oxidative injuries and hydrogen peroxide scavenging, enhanced catalase, phenolic, and antioxidant activities in cells are necessary (Bettaieb et aql., 2023). Similar to catalase activity, peroxidase activity in date palms was also noted in a declining trend moving from khalal (green stage) towards ripe stage (Tamar) (Awad et al., 2011a).

Moving from green stages of fruit towards ripe stages, the total soluble protein content gets reduced due to enhanced protease enzymatic activities (Rastegar et al., 2012) and also due to a reduction in the radical scavenging system due to the degradation of proteins by free radicals (El-Beltagi et al., 2019). Our results have strong accordance with results of Awad et al., (2011b), who observed higher soluble protein content at early stage (kimri) harvested date palm fruits while it was reduced in later stage (tamar) harvested fruits.

Buyers prefer fruits based on their good color represent quality, which shows their freshness and overall acceptability, and make it a basic standard parameter for buyers (FernÁndez-VÁzquez et al., 2011; Fatima et al., 2022, 2023). The market value of fruits gets reduced due to color degradation as a result of storage and ripening because of enzymatic activities (especially peroxidase and polyphenol oxidase) (Mortazavi et al., 2015), and phenolic content oxidation causes browning, which is a usual occurrence (Awad et al., 2011a). At different stages, the total color difference was observed in date palm, which is closely connected with the total phenolic content reduction that ultimately leads to the decline of color attributes known as ho, C*, L*. In the current experiment, color is maintained due to the control of browning reactions as a result of storage duration, harvesting phases, and storage temperatures.

5. Conclusions

The analysis of the data showed that the studied attributes significantly different at various ripening stages and storage temperatures. Maximum moisture, fruit juice pH, ascorbic acid content, titratable acidity, or non-reducing sugar were observed at khalal picked fruits, while khalal and rutab represents statistical similar results for fruit juice pH, titratable acidity or ascorbic acid. The best optimum storage temperature was 12 °C for majority of studied parameters. Moreover, at khalal stage and 12 °C improved the biochemical properties as well as increased the accumulation of sugar contents causing sweetness. Furthermore, at khalal stage and 12 °C considerably increased the phenolic content and DPPH scavenging potential, and flavonoid content, while also enhancing the sensory qualities like color. Therefore, it is concluded that best picking stage is khalal for cv. Dhakki and could be kept at 12 °C (for 45 days) with 60–70% relative humidity.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Abbasi, K.S., Anjum, N., Sammi, S., Masud, T., Ali, S., 2011. Effect of coatings and packaging material on the keeping quality of mangoes (*Mangifera indica* L.) stored at low temperature. Pak. J. Nutri. 10 (2), 129–138.

Abbasi, N.A., Kushad, M.M., Endress, A.G., 1998. Active oxygen-scavenging enzymes activities in developing apple flowers and fruits. Sci. Hortic. 74, 183–194.

Abd Elwahab, S.A., Allatif, A.M.A., Farid, M.A., Soliman, S.M., 2019. Effect of safe post-harvest alternatives on quality and storage life of "barhi" date palm. Plant Arch. 19, 3937–3945.

Abul-Soad, A.A., Markhand, G.S., Akhtar, N. 2010. Effect of Different Soil Types on Survival of Transplanted Banana (Grand Naine cv.) into Greenhouse. In: 28th International Horticulture Congress, Lisbon, Portugal. Abstracts Book Page754.

Abul-Soad, A.A., Mahdi, S.M., Markhand, G.S. 2015. Date palm status and perspective in Pakistan. In: Date Palm Genetic Resources and Utilization: Volume 2: Asia and Europe, pp.153-205.

Abu-Shama, H.S., Abou-Zaid, F.O.F., El-Sayed, E.Z., 2020. Effect of using edible coatings on fruit quality of Barhi date cultivar. Sci. Hortic. 265, 109262.

Akhtar, A. 2010. Relationship of antioxidants with qualitative changes in local cultivars of loquat (*Eriobotrya Japonica* L.) fruit during storage. Ph.D. Dissertation, Pir Mehr Ali Shah, Arid Agriculture University, Rawalpindi, Pakistan.

Alam, M.Z., Al-Hamimi, S., Ayyash, M., Rosa, C.T., Yahia, E.M., Haris, S., Al-Marzouqi, A.H., Kamal-Eldin, A., 2023. Contributing factors to quality of date (*Phoenix dactylifera* L.) fruit. Sci. Hort. 321, 112256.

Aleid, S., Saikhan, M., 2017. Effect of permeable modified atmosphere packaging on quality and shelf life of fresh Khenaizy dates stored at low temperature. J. Food Nutr. Res. 5, 503–509.

Alhaider, I.A., Mohamed, M.E., Ahmed, K., Kumar, A.H., 2017. Date palm (*Phoenix dactylifera*) fruits as a potential cardioprotective agent: The role of circulating progenitor cells. Front. Pharmacol. 8, 592.
Ali, S.G., Rab, A., Khan, N.U., Nawab, K., 2011. Enhanced proline synthesis may determine resistance to salt stress in tomato cultivars. Pak. J. Bot. 43 (6), 2707–2710.
Al-Najada, A.R., Mohamed, S.A., 2014. Changes of antioxidant capacity and oxidoreductases of Saudi date cultivars (*Phoenix dactylifera* L.) during storage. Sci. Hortic. 170, 275–280.
Al-Qurashi, A.D., Awad, M.A., 2011. Quality characteristics of bisir 'Barhee' dates during cold storage as affected by postharvest dipping in gibberellic acid, naphthaleneacetic acid and benzyladenine. Fruits 66, 343–352.
Alsawmahi, O.N., Al-Juhaimi, F., Alhamdan, A.M., Ghafoor, K., Adiamo, O.Q., Mohamed Ahmed, I.A., Hassan, B.H., Ehmed, K.A., Babiker, E.E., Abdelkarim, D., 2018. Phenolic, tannin, antioxidant, color, and sensory attributes of Barhi date (Phoenix dactylifera) fruit stored in modified atmosphere packages. J. Food Biochem. 42, 12576.
Al-Turki, S., Shahba, M.A., Stushnoff, C., 2010. Diversity of antioxidant properties and phenolic content of date palm (Phoenix dactylifera L.) fruits as affected by cultivar and location. J. Food Agric. Environ. 8, 253–260.
Amira, E.A., Guido, F., Behija, S.E., Manel, I., Nesrine, Z., Ali, F., Mohamed, H., Noureddine, H.A., Lotfi, A., 2011. Chemical and aroma volatile compositions of date palm (*Phoenix dactylifera* L.) fruits at three maturation stages. Food Chem. 127, 744–1754.
Amira, E.A., Saafi, E.B., Mechri, B., Lahouar, L., Issaoui, M., Hammami, M., Achour, L., 2012. Effects of the ripening stage on phenolic profile, phytochemical composition and antioxidant activity of date palm fruit. J. Agric. Food Chem. 60, 10896–10902.
AOAC, 1990. Association of Official Agriculture Chemist Official Methods of Analysis, ninth ed., 832.
Aribi, M.M., 2023. Date Harvest. In: Date Palm. GB: CABI, pp. 399-453.
Awad, M.A., Al-Qurashi, A.D., Mohamed, S.A., 2011a. Antioxidant capacity, antioxidant compounds and antioxidant enzyme activities in five date cultivars during development and ripening. Sci. Hortic. 129, 688–693.
Awad, M.A., Al-Qurashi, A.D., Mohamed, S.A., 2011b. Biochemical changes in fruit of an early and a late date palm cultivar during development and ripening. Int. J. Fruit Sci. 11, 167–183.
Ayub, M., Saeed, S., Ahmed, A., 2023. Morphological characterization of nine date palm varieties (*Phoenix dactylifera* L.) of Panjgur, Balochistan, Pakistan. Pure Appl. Biol. 12 (1), 252–260.
Basit, A., Ayaz, S., Rab, A., Ullah, I., Shah, S.T., Ahmad, I., Ullah, I., Khalid, M.A., 2019. Effect of stevia (*Stevia rebaudiana* L.) leaf extract on the quality and shelf life of lemon (*Citrus limon* L.). Pure Appl. Bio. 8 (2), 1456–1468.
Benmeddour, Z., Mehinagic, E., Le Meurlay, D., Louaileche, H., 2013. Phenolic composition and antioxidant capacities of ten Algerian date (*Phoenix dactylifera* L.) cultivars: a comparative study. J. Funct. Foods 5, 346–354.
Bentebba, F.Z., Zineb, G., Saidi, M., Bensaci, C., 2020. Effects of development and ripening stage on phytochemical compositions, antioxidant and antibacterial activities of date palm fruits. Asian J. Chem. 32, 415–419.
Bettaieb, I., Kilani, A., Ben Othman, K., Benabderrahim, M.A., Elfalleh, W., 2023. Phenolic profile, sugar composition, and antioxidant capacities of some common date palm (*Phoenix dactylifera* L.) cultivars as a potential nutraceutical and functional food ingredients. J. Food Qual. https://doi.org/10.1155/2023/2474900.
Bhatt, K., Jampala, S.S.M., 2020. Influence of pre-harvest foliar spray of fungal culture filtrates on post-harvest biology of date fruit harvested at Khalal stage. Postharvest Biol. Technol. 166, 111220.
Bilska, K., Wojciechowska, N., Alipour, S., Kalemba, E.M., 2019. Ascorbic acid—The little-known antioxidant in woody plants. Antioxidants 8 (12), 645.
Bradford, M.M., 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Ann. Biochem. 72, 248–254.
Conway, W.S., 1987. The effects of postharvest infiltration of calcium, magnesium, or strontium on decay, firmness, respiration and ethylene production in apples. J. Am. Soc. Hort. Sci. 112 (2), 300–303.
Dhahri, M., Sioud, S., Alsuhaymi, S., Almulhim, F., Haneef, A., Saoudi, A., Jaremko, M., Emwas, A.H., 2023. Extraction, characterization, and antioxidant activity of polysaccharides from ajwa seed and flesh. Separations 10 (2), 103.
Dong, M., Xin, R., Li, Z.Y., Li, Y.L., Huang, X.H., Dong, X.P., Zhu, B.W., Qin, L., 2023. Simultaneously quantification of organic acids metabolites by HPLC mass spectrometry to reveal the postharvest quality change in cherry tomato. J. Food Comp. Anal. 117, 105105.
Echegaray, N., Gullón, B., Pateiro, M., Amarowicz, R., Misihairabgwi, J.M., Lorenzo, J. M., 2023. Date fruit and its by-products as promising source of bioactive components: a review. Food Rev. Int. 39 (3), 1411–1432.
El-Beltagi, H.S., Mohamed, H.I., Abdelazeem, A.S., Youssef, R., Safwat, G., 2019. GC-MS analysis, antioxidant, antimicrobial and anticancer activities of extracts from *Ficus sycomorus* fruits and leaves. Not. Bot. Horti Agrobot. Cluj-Napoca 47 (2), 493–505.
El-Gioushy, S.F., El-Masry, A.M., Fikry, M., El-Kholy, M.F., Shaban, A.E., Sami, R., Algarni, E., Alshehry, G., Aljumayi, H., Benajiba, N., Al-Mushhin, A.A., 2022. Utilization of active edible films (Chitosan, chitosan nanoparticle, and CACL2) for enhancing the quality properties and the shelf life of Date palm fruits (Barhi cultivar) during cold storage. Coatings 12 (2), 255.
FAO. 2011. Food and Agriculture Organization. Available online with updates at http://faostat.fao.org/site/567/default.aspx#ancor.
FAO, 2012. Plant Production and Protection Paper No. 35. Date Production and Protection. FAO. Rome, pp. 198-294.
FAOFC Statistics, 2018. C Productions - QC (accessed on 28 August 2019). Available online: http://www.fao.org/faostat/en/#data.
Fatima, F., Basit, A., Ahmad, A., Sajid, M., Faiza, A., Mohamed, H.I., Elhakem, A., 2022. Enhancement of the fruit quality and postharvest life expectancy of mango fruit (*Mangifera indica* L.) applying ecofriendly bio-coatings. Not.Bot. Horti Agrobot. Cluj-Napoca 50 (4), 12917.
Fatima, F., Basit, A., Younas, M., Shah, S.T., Sajid, M., Aziz, I., Mohamed, H.I., 2023. Trends in potassium permanganate (ethylene absorbent) management strategies: towards mitigating postharvest losses and quality of mango (*Mangifera indica* L) fruit. Food Bioproc. Tech. 16, 2172–2183.
Feliziani, E., Landi, L., Romanazzi, G., 2015. Preharvest treatments with chitosan and other alternatives to conventional fungicides to control postharvest decay of strawberry. Carbohydr. Polym. 132, 111–117.
FernÁndez-VÁzquez, R., Stinco, C.M., MelÉndez-MartÍnez, A.J., Heredia, F.J., Vicario, I.M., 2011. Visual and instrumental evaluation of orange juice color: a consumers'preference study. J. Sens. Stud. 26, 436–444.
Ferrer, A., Remón, S., Negueruela, A.I., Oria, R., 2005. Changes during the ripening of the very late season Spanish peach cultivar Calanda: Feasibility of using CIELAB coordinates as maturity indices. Sci. Horti. 105 (4), 435–446.
Ghazzawy, H.S., Alqahtani, N., Munir, M., Alghanim, N.S., Mohammed, M., 2023. Combined impact of irrigation, potassium fertilizer, and thinning treatments on yield, skin separation, and physicochemical properties of date palm fruits. Plants 12 (5), 1003.
Gilani, S.A.Q., Basit, A., Sajid, M., Shah, S.T., Ullah, I., Mohamed, H.I., 2021. Gibberellic acid and boron enhance antioxidant activity, phenolic content, and yield quality in *Pyrus Communis* L. Gesunde Pflanz 73, 4. https://doi.org/10.1007/s10343-021-00555-5.
Hammouda, H.D., Chérif, J.K., Trabelsi-Ayadi, M., Baron, A., Guyot, S., 2013. Detailed polyphenol and tannin composition and its variability in Tunisian dates (*Phoenix dactylifera* L.) at different maturity stages. J. Agric. Food Chem. 61, 3252–3263.
Hatami, A., Jahromi, A.A., Ejraei, A., Jahromi, S.A.M., Khankahdani, H.H., 2023. Investigation of biochemical traits and mineral element content in the Shahani date fruit under the influence of the foliar application of organic matter and micro-elements. J. Saudi Soc. Agri. Sci. 22 (2), 121–132.
Huntrods, D., 2011. Date profile. Agricultural Marketing Resource Center Bulletin. USDA, Washington, DC. 3p.
Jamil, M.S., Nadeem, R., Hanif, M.A., Ali, M.A., Akhter, K., 2010. Proximate composition and mineral profile of eight different date (*Phoenix dactylifera* L.) varieties from Pakistan. Afr. J. Biotechnol. 9, 3252–3259.
Jatt, T., Lee, M.S., Rayburn, A.L., Jatoi, M.A., Mirani, A.A., 2019. Determination of genome size variations among different date palm cultivars (*Phoenix dactylifera* L.) by flow cytometry. 3. Biotech 9 (12), 457.
Jemni, M., Ramirez, J.G., Oton, M., Artés-Hernandez, F., Harbaoui, K., Namsi, A., Ferchichi, A., Artés, F., 2019. Chilling and freezing storage for keeping overall quality of "Deglet Nour" dates. J. Agric. Sci. Technol. 21, 63–76.
Jha, Y., Mohamed, H.I., 2022. Plant secondary metabolites as a tool to investigate biotic stress tolerance in plants: a review. Gesunde Pflanz. 74 (4), 771–790.
Jitareerat, P., Paumchai, S., Kanlayanarat, S., 2007. Effect of chitosan on ripening enzymatic activity, and disease development in mango (Mangifera indica L.) fruit. New Zeland J. Crop. Hort. Sci. 35, 211–218.
Kamal, H., Hamdi, M., Mudgil, P., Aldhaheri, M., Baig, M.A., Hassan, H.M., Alamri, A. S., Galanakis, C.M., Maqsood, S., 2023. Nutraceutical and bioactive potential of high-quality date fruit varieties (*Phoenix dactylifera* L.) as a function of in-vitro simulated gastrointestinal digestion. J. Pharmaceut. Biomed. Anal. 223, 115113.
Khalid, S., Khalid, N., Khan, R.S., Ahmed, H., Ahmad, A., 2017. A review on chemistry and pharmacology of Ajwa date fruit and pit. Trends Food Sci. Technol. 63, 60–69.
Kim, D.O., Chun, O.K., Kim, Y.J., Moon, H.Y., Lee, C.Y., 2003. Quantification of polyphenolics and their antioxidant capacity in fresh plums. J. Agric. Food Chem. 51, 6509–6515.
Kumar, P., Sethi, S., Sharma, R.R., Srivastav, M., Varghese, E., 2017. Effect of chitosan coating on postharvest life and quality of plum during storage at low temperature. Sci. Horti. 226, 104–109.
Lemine, M., Mint, F., Mohamed Ahmed, M.V.O., Maoulainine, B.M., Bouna, Z., et al., 2014. Antioxidant activity of various Mauritanian date palm (*Phoenix dactylifera* L.) fruits at two edible ripening stages. Food Sci. Nutr. 2, 700–705.
Li, J., Hussain, I., Azam, M., Khan, M.A., Akram, M.T., Naveed, K., Asif, M., Anjum, N., Zeng, J., Zhang, J., et al., 2023. Hot water treatment improves date drying and maintains phytochemicals and fruit quality characteristics of date palm (*Phoenix dactylifera*). Foods 12, 2405. https://doi.org/10.3390/foods12122405.
Lobo, M.G., Yahia, E.M., Kader, A.A., 2013. Biology and postharvest physiology of date fruit. Dates: postharvest science, processing technology and health benefits, pp. 57-80.
Mahomoodally, M.F., Khadaroo, S.K., Hosenally, M., Zengin, G., Rebezov, M., Ali Shariati, M., Khalid, A., Abdalla, A.N., Algarni, A.S., Simal-Gandara, J., 2023. Nutritional, medicinal and functional properties of different parts of the date palm and its fruit (*Phoenix dactylifera* L.)–A systematic review. Crit. Rev. Food Sci. Nut. https://doi.org/10.1080/10408398.2023.2191285.
Manzano, J.E., Diaz, A., 2001. Effect of storage time, temperature and wax coating on the quality of fruit of 'Valencia' orange (Citrus sinensis L.). Proc. Int'l. Soc. Tropical Hort. 44, 24–29.
Markhand, G.S., Abul-Soad, A.A., Mirbahar, A.A., Kanhar, N.A., 2010. Fruit characterization of Pakistani dates. Pak. J. Bot. 42, 3715–3722.

Maskan, M., 2001. Kinetics of colour change of kiwifruits during hot air and microwave drying. J. Food Eng. 48, 169–175.
Mezey, J., Mezeyová, I., 2018. Changes in the levels of selected organic acids and sugars in apple juice after cold storage. Czech J. Food Sci. 36 (2), 175–180.
Mohamed, S.A., Awad, M.A., Al-Qurashi, A.D., 2014. Antioxidant activity, antioxidant compounds, antioxidant and hydrolytic enzymes activities of 'Barhee' dates at harvest and during storage as affected by pre-harvest spray of some growth regulators. Sci. Hortic. 167, 91–99.
Mohamed, H.I., El-Beltagi, H.S., Jain, S.M., Al-Khayri, J.M., 2021. Date palm (*Phoenix dactylifera* L.) secondary metabolites: Bioactivity and pharmaceutical potential. In: Phytomedicine. Academic Press, pp. 483–531.
Mohamed, A.A., Sameeh, M.Y., El-Beltagi, H.S., 2023. Preparation of seaweed nanopowder particles using planetary ball milling and their effects on some secondary metabolites in date palm (*Phoenix dactylifera* L.) seedlings. Life 13, 39. https://doi.org/10.3390/life13010039.
Mohammed, M.E.A., Alhajhoj, M.R., Ali-Dinar, H.M., Munir, M., 2020. Impact of a novel water-saving subsurface irrigation system on water productivity, photosynthetic characteristics, yield, and fruit quality of date palm under arid conditions. Agronomy 10, 1265.
Mohammed, M., Riad, K., Alqahtani, N., 2021a. Efficient IoT-based control for a smart subsurface irrigation system to enhance irrigation management of date palm. Sensors 21, 39–42.
Mohammed, M., Sallam, A., Alqahtani, N., Munir, M., 2021b. The combined effects of precision-controlled temperature and relative humidity on artificial ripening and quality of date fruit. Foods 10 (11), 2636.
Mortazavi, S.M.H., Azizollahi, F., Moallemi, N., 2015. Some quality attributes and biochemical properties of nine iranian date (*Phoenix dactylifera* L.) cultivars at different stages of fruit development. Int. J. Hort. Sci. Technol. 2, 161–171.
Moss, J.W., Ramji, D.P., 2016. Nutraceutical therapies for atherosclerosis. Nat. Rev. Cardiol. 13, 513.
Mukhtar, S., Mohamed, H.I., Qazi, I.M., Basit, A., Javed, H., Shah, S.T., Ibrahim, A., Aziz, I., Ali, F., 2022. Correction: impact of pectin extracted from selected citrus fruit peel on overall quality of mango jam. J. Food Measur. Charact. 16 (6), 5079.
Muñoz-Bas, C., Muñoz-Tebar, N., Candela-Salvador, L., Pérez-Alvarez, J.A., Lorenzo, J. M., Viuda-Martos, M., Fernández-López, J., 2023. Quality characteristics of fresh date palm fruits of "Medjoul" and "Confitera" cv. from the Southeast of Spain (Elche Palm Grove). Foods 12 (14), 2659.
Naqvi, S.A., Khan, M.M., Shahid, M., Jaskani, M.J., Khan, I.A., Zuber, M., Zia, K.M., 2011. Biochemical profiling of mucilage extracted from seeds of different citrus rootstocks. Carbohyd. Polym. 83, 623–628.
Noutfia, Y., Ropelewska, E., 2023. Innovative models built based on image textures using traditional machine learning algorithms for distinguishing different varieties of moroccan date palm fruit (*Phoenix dactylifera* L.). Agriculture 13 (1), 26.
Rangana, S., 1976. In: Manual of analysis of fruit and vegetable products. McGraw Hill, New Delhi, p. 77.
Rastegar, S., Rahemi, M., Baghizadeh, A., Gholami, M., 2012. Enzyme activity and biochemical changes of three date palm cultivars with different softening pattern during ripening. Food Chem. 134, 1279–1286.
Ripasarda, P., Bellmo, S.E., Intelisano, S., 2011. Storage temperature effect on blood orange fruit quality. Agric. Food Chem. Washington D. C. Amer. Chem. Soci. 49 (7), 3230–3235.
Sajid, M., Basit, A., Ullah, Z., Shah, S.T., Ullah, I., Mohamed, H.I., Ullah, I., 2020. Chitosan-based foliar application modulated the yield and biochemical attributes of peach (*Prunus persica* L.) cv. Early Grand. Bull. Nat. Res. Centre 44 (150). https://doi.org/10.1186/s42269-020-00405-w.
Samad, M.A., Hashim, S.H., Simarani, K., Yaacob, J.S., 2016. Antibacterial properties and effects of fruit chilling and extract storage on antioxidant activity, total phenolic and anthocyanin content of four date palm (Phoenix dactylifera) cultivars. Molecules 21 (4), 419.
Sarraf, M., Jemni, M., Kahramano glu, I., Artés, F., Shahkoomahally, S., Namsi, A., Ihtisham, M., Brestic, M., Mohammadi, M., Rastogi, A., 2021. Commercial techniques for preserving date palm (Phoenix dactylifera) fruit quality and safety: a review. Saudi J. Biol. Sci. 28, 4408–4420.
Saway, W.M., Mashadi, A.S., 1983. Sugar, tannins, and vitamin contents of twenty-five date cultivars grown in Saudi Arabia. Proc. Date Palm syrup. King Faisal Univ., 468–479
Sidhu, A.R., Basit, A., Hayat, A., Mangrio, S., Arain, S., Khalid, T., Mohamed, H.I., Elhakem, A., 2022. Quality characteristics, phytochemical analysis, and antioxidant of extract *Cuscuta reflexa* (Roxb.). Not.e Bot. Horti Agrobot. Cluj-Napoca 50 (3), 12691.
Steel, R.G.D., Torrie, J.H., Dickey, D.A., 1997. Principles and Procedures of Statistics. A Biometrical Approach. McGraw Hill Book Co., Inc., New York.
Sugri, I., Abubakari, M., Owusu, R.K., Bidzakin, J.K., 2021. Postharvest losses and mitigating technologies: evidence from Upper East Region of Ghana. Sustainable Futures 3, 100048.
Vallarino, J.G., Osorio, S., 2019. Organic acids. In *Postharvest physiology and biochemistry of fruits and vegetables*. Woodhead Publishing, pp. 207-224.
Velioglu, Y.S., Mazza, G., Gao, L., Oomah, B.D., 1998. Antioxidant activity and total phenolics in selected fruits, vegetables, and grain products. J. Agric. Food Chem. 46, 4113–4117.