



Effects of Various Chemical Treatments on Ripening Acceleration and Quality Attributes of Sukkari Dates

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Abstract

This study aimed to investigate the accelerated ripening of sukkari dates and examine the resulting changes in color, pulp, carbohydrates, vitamins, and antioxidant capacity using a comprehensive set of nine individual treatments. Fresh dates at the Khalal stage were subjected to immersion in normal water for 5 h or hot water for 5 min, with or without the inclusion of NaCl (2%), potassium metabisulfite (PM, 0.5%), and acetic acid (AA, 1.5%), either individually or in combination. The treated dates were then allowed to ripen for 72 h in an aerated incubator at 40 °C. Evaluation of color shade, fruit weight, pulp texture, total soluble carbohydrates (TSC), total soluble sugars (TSS), beta-carotene, total polyphenols (TPC), total flavonoids (TFC), DPPH radical scavenging activity, FRAP value, and overall appearance assessed the efficacy of each treatment. Among the treatments, T₆ (normal water with 1.5% AA + 0.5% PM) and T₈ (hot water with 1.5% AA + 0.05% PM) exhibited superior acceptance levels, characterized by softness, reduced pungency, a rich brown color, and exceptional visual appeal, with more than 77% and 88% pulp and ripened fruit, respectively. Furthermore, T₆ demonstrated higher TSC (96.70 mg g⁻¹ FW), TSS (322.22 mg g⁻¹ FW), DPPH radical scavenging activity (92.84%), and FRAP value (0.40), while exhibiting lower levels of beta-carotene (4.91 mg 100 g⁻¹ FW), TPC (0.14 mg g⁻¹ FW), and TFC (0.31 mg g⁻¹ FW). Similarly, T₈ performed exceptionally well across all parameters except for beta-carotene.

Keywords Beta-carotene · DPPH radical scavenging activity · FRAP value pulp · Total polyphenol and total flavonoid

Introduction

Date palms (*Phoenix dactylifera*) are flowering plants in the Arecaceae family of palms, primarily cultivated for their edible fruit (Al-Shwyeh 2019). In 2020, the global production of palm dates amounted to around 9.5 million tons annually

(Fikry et al. 2023). They can withstand a wide range of temperatures and exhibit resistance to adverse environmental conditions, ranging from -6 to 50 °C. Additionally, they are tolerant to soil and water salinity. Date palms thrive in arid regions characterized by hot, dry weather and minimal rainfall (Allbed et al. 2017). While indigenous to Africa and the Persian Gulf and considered one of the ancient and main staple foods, the exact origin of date palms remains unknown (Shanta et al. 2021). The leading date palm producing countries worldwide include Iraq, Egypt, Saudi Arabia, Tunisia, Algeria, the UAE, Oman, Libya, Pakistan, and Sudan. Currently, there are approximately 2000 different date palm cultivars cultivated globally (Zihad et al. 2021).

The date palm fruit is an exceptional source of refined sugar, concentrated juice, confectionary pastes, and fermentation products owing to its elevated levels of mineral salts and vitamins (Assirey 2015). With a carbohydrate content of 70–80%, it serves as a potent supplier of readily available energy. Additionally, it boasts a rich profile of essential nutrients. The body efficiently absorbs fructose,

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glucose, and sucrose, which constitute the majority of carbohydrates found in dates. The high dietary fiber content of dates makes them suitable for incorporating into fiber-based food products and dietary supplements, further enhancing their nutritional value (Hazbavi et al. 2015). Furthermore, dates exhibit a notable presence of phenolics, flavonoids, and carotenoids, known for their anti-inflammatory, anti-mutagenic, and therapeutic properties (Tang et al. 2013).

The process of date ripening is intricate, involving the breakdown of chlorophyll, the formation of carotenoids, cell wall degradation, and starch conversion into sugars (Eltayeb et al. 1999). The maturity and ripening stage of dates play a crucial role in determining their sweetness, mouthfeel, and texture. Typically, dates are harvested and marketed in three distinct stages of development: mature firm (Besser or Khalal), half-ripe (Rutab), and fully ripe (Tamer). The selection of the optimal harvest stage is influenced by the cultivar's characteristics, particularly sugar and soluble tannin content, as well as climatic conditions and consumer demand (Awad 2007). After reaching maturity, dates have a limited shelf life, potentially leading to reduced antioxidant levels. The antioxidant phenolic composition of the fruit undergoes significant changes during the ripening process, which may impact its shelf life. Although extensive research has been conducted on the physical and chemical transformations occurring in date palm fruit during growth and development, limited publications exist on the total phenolic content (TPC), condensed tannin (CTC) contents, and antioxidant activity (AA) of date fruit throughout the maturation stages (Amira et al. 2012). Therefore, understanding the ripening process and evaluating parameters such as TSS (total soluble solids), TSC (total soluble carbohydrates), TPC, TFC (total flavonoid content), CTC, β -carotene, antioxidant capacity like TAC (total antioxidant capacity), DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity, and FRAP (ferric reducing antioxidant power) is essential. To address this, our research focuses on the ripening process and evaluates the aforementioned parameters for the sukkari date palm cultivar grown in the arid region of Saudi Arabia, specifically assessing the Khalal stage of date fruit.

The sukkari date fruit type holds the reputation of being the most renowned and premium variety of dates in Arab nations. It is characterized by its elongated shape and a rich golden brown color, facilitating its differentiation from other variants of date palm fruits. Derived from the Arabic word 'Sukkar,' meaning 'sugar,' its name aptly captures its exceptionally sweet taste. It is worth noting that common misspellings of this cultivar include sukkari, sukkary, and succary (Siddeeg et al. 2019). Sukkari dates are highly valued for their exceptional sweetness, often described as a luscious caramel-like flavor with hints of honey. They have a soft and tender texture, offering a delightful melt-in-mouth

experience (Siddeeg et al. 2019; Mani et al. 2022). Sukkari dates are not only cherished for their exquisite taste but also for their nutritional value. They are an excellent source of natural sugars, dietary fiber, and essential minerals such as potassium, magnesium, and iron. The high fiber content contributes to digestive health and aids in maintaining a healthy weight. These dates also contain vitamins, including vitamin A, vitamin B6, and vitamin K, which contribute to overall well-being (Vayalil 2012; Aljutaily et al. 2021).

The ripening of date fruit involves the application of various techniques. Traditional methods, commonly employed for ripening and curing, continue to be widely practiced. These methods typically entail exposing the fruits to the sun, spreading them out on mats. However, such practices often lead to suboptimal outcomes, as dusty conditions result in poor and inconsistent sundried product quality, accompanied by reduced yield. Furthermore, unfavorable weather conditions, including constant rain and strong winds, contribute to a significant portion of the harvested dates becoming susceptible to mold, fermentation, dust contamination, and damage from birds and insects (Saleem et al. 2005). These challenges have discouraged growers and severely impeded the continued cultivation and propagation of date palm varieties. To mitigate post-harvest losses and enhance produce quality, the adoption of appropriate scientific measures becomes imperative.

Previous studies have explored the ripening and curing of dates utilizing microwave radiation (Asif and Al Taher 1983), hot water, and heat treatments (Hazbavi et al. 2015). Although a few papers exist on the ripening of dates with salt and acetic acid, these studies are specific to particular varieties (Kalra et al. 1977; Saleem et al. 2005). However, limited information is available on the ripening of sukkari dates. Therefore, the primary objective of this study was to develop a method for the accelerated ripening of sukkari date fruit using acetic acid, sodium chloride, potassium metabisulfite, or a combination of these substances. Additionally, we aimed to investigate the physicochemical changes occurring during accelerated ripening and assess the suitability of these treatments as the optimal ripening method for commercial implementation, thereby improving the appearance of date palm fruit.

Materials and Methods

Sample Preparation

The sukkari dates were obtained from the germplasm of Bangladesh Sugarcrop Research Institute (BSRI), Ishurdi, Pabna. The fruits were harvested in the month of August at the fully mature Khalal stage. Healthy and non-infected

fruits were selected and brought to the research laboratory of the Department of Physiology and Sugar Chemistry, BSRI, Ishurdi, Pabna. The fruits were given preliminary treatments of cleaning and washing before being subjected to ripening inducer treatments with analytical reagent (AR) grade sodium chloride (2% w/v), acetic acid (AA, 1.5% v/v) and potassium metabisulfite (PM, 0.5% w/v). Several solutions of sodium chloride, acetic acid and potassium metabisulfite were made for the treatments (Table 1). Twenty fruits containing equal sized and maturity was taken in each tray. The samples were immersed in normal water for 5 h or in hot water for 5 min along with/without NaCl (2% w/v), potassium metabisulfite (PM, 0.5% w/v) and acetic acid (AA, 1.5% v/v) individually or in combined form at room temperature, allowed to drain and then spread out separately on stainless steel trays. The samples were incubated for 72 h in an aerated incubator at 40 °C. Each treatment was replicated three times. There is a control in which fresh fruits were incubated for 72 h at 40 °C after cleaning and washing with water to compare the effectiveness of the chemical treatments.

Data Collection of Morphological Parameters

Ripening parameters were estimated soon after harvesting and treatments. Twenty fruits were randomly chosen to determine the ripening percentage using the following equation.

$$\text{Ripening percentage (\%)} = \frac{\text{No of fruits ripened}}{\text{Total no of fruits under observation}} \times 100 \quad (1)$$

Changes in characteristics such as color, texture, average fruit weight and percent pulp were used to evaluate how well a treatment performed, whether it was applied alone or in combination. Visual observations and comparison with a horticultural color chart were used to record

the fruit's color (Kader 1992). The average fruit weight (g) was calculated by averaging the weights of the ten fruits. Similar methods were used to record average seed weight. Fruit's flesh or pulp weight was also measured after the seed was removed. Flesh weight ratio was calculated as:

$$\text{Flesh weight ratio} = \frac{\text{Flesh weight}}{\text{Fresh fruit weight}} \times 100 \quad (2)$$

After then, the following formula was used to estimate pulp percentage.

$$\text{Pulp percentage (\%)} = \frac{\text{Fruit weight} - \text{Seed weight}}{\text{Fruit weight}} \times 100 \quad (3)$$

An organoleptic test was performed for determining the acceptability of date fruits under different treatments by the methods of Jellinek (1985). The samples were distributed to a panel consisting of ten scientists from the Bangladesh Sugarcrop Research Institute. Initially, five date palm fruits from each treatment were presented to the panel members, who were asked to evaluate the tastiness of the fruits. Following this, the overall appearance was assessed by the panel members using a 10-point hedonic scale ranging from 1 to 10, where 1 = excellent, 2 = best, 3 = better, 4 = less better, 5 = very good, 6 = good, 7 = fair, 8 = less fair, 9 = poor, and 10 = very poor. The samples were evaluated twice, and the average values were recorded. The texture of the fruits was assessed using a hardness-testing device, as described by Baloch et al. (2003) with slight modifications. Briefly, the device operates on the principle of an aneroid sphygmomanometer. It consists of a glass barrel with an internal piston, a stainless steel bar with a 1 mm² penetrating surface, and a rubber blow ball attached to a pressure gauge. The barrel is connected to the pressure gauge, and the piston is mounted on the stainless steel bar. The barrel is fixed vertically on a stand so that the needle just touches the surface of the date.

To perform the hardness test, the selected date was placed on the base beneath the tip of the pressure needle. Air pressure was gradually applied to the piston, increasing the force on the penetrometer and pressure gauge. The maximum pressure was recorded as soon as the needle punctured the surface of the date. At least five readings were taken for each date, with ten dates randomly selected from the batch chosen for maturity evaluation. The mean pressure readings (mm Hg) were recorded. The fruits were categorized based on the recorded pressure values as follows: very soft (≥ 150 mm Hg), over soft (≥ 200 mm Hg), soft (≥ 250 mm Hg), less soft (≥ 275 mm Hg), and hard (≥ 300 mm Hg).

Table 1 Symbols for the sodium chloride, acetic acid treatment and potassium metabisulfite

Symbols	Treatments
T ₀	Control (Fresh fruit)
T ₁	Normal water
T ₂	Hot water
T ₃	Normal water + 0.5% P.M
T ₄	2% NaCl + 1.5% A. A
T ₅	2% NaCl + 1.5% A. A + 0.5% P.M
T ₆	1.5% A. A + 0.5% P.M
T ₇	Hot water + 0.05% P.M
T ₈	Hot water + 1.5% A. A + 0.05% P.M

Total Soluble Carbohydrate (TSC) and Total Soluble Sugar Content (TSS)

The homogenization of a 200 mg sample was carried out in 5 mL of 95% ethanol, followed by centrifugation at 3500 rpm for 10 min. The resulting supernatant was collected. Subsequently, the process was repeated using 70% ethanol (5 mL), and the combined supernatant was stored in a refrigerator at 4 °C for the determination of total soluble carbohydrates (TSC) and total soluble sugars (TSS) content.

TSC content was determined according to the method described earlier (Khoyerdı et al. 2016). Briefly, a 0.1 mL aliquot was combined with 1 mL anthrone solution (comprising 200 mg anthrone mixed with 100 mL of 72% sulfuric acid). The mixture underwent heating at 100 °C for 10 min, followed by cooling. The determination of total soluble carbohydrates utilized a standard curve, with a detection wavelength of 625 nm measured using a UV–Vis spectrophotometer (Jasco V-630, Jasco international co., ltd., Tokyo, Japan). The outcomes were expressed as mg g⁻¹ fresh weight.

For the analysis of sucrose content, 0.2 mL of the supernatant was combined with 0.1 mL of KOH (30%) and subjected to heating at 100 °C for 10 min. Following cooling to room temperature, 3 mL of anthrone solution (150 mg anthrone mixed with 100 ml 70% sulfuric acid) was added. After an additional ten minutes, the samples were cooled, and the absorbance was measured at 620 nm. The sucrose concentration was determined using a standard curve, and the outcomes were presented as mg g⁻¹ fresh weight (van Handel 1968).

Estimation of Beta-Carotene

Estimation of beta-carotene was done according to the method described earlier (Sarker and Oba 2018). In brief, a 200 mg fresh sample was ground thoroughly with 10 mL acetone (80%). After centrifugation of the extract for 4 min at 10,000× g, the supernatant was removed and made the final volume 20 mL by adding acetone. The optical density was measured with a spectrophotometer (Jasco V-630, Jasco international co., ltd., Tokyo, Japan) at 480 and 510 nm. The results were quantified as mg beta-carotene per 100 g FW by using the following formula:

$$\text{Beta - carotene} = \frac{7.6(\text{Abs. at } 480) - 1.49(\text{Abs. at } 510) \times \text{Final volume}}{(1000 \times \text{fresh weight of sample})} \quad (4)$$

Determination of Total Phenolic Content and Total Flavonoid Content

A 200 mg fresh sample was dissolved in 10 mL of ethanol (80%, v/v in water) and underwent sonication at 35 °C for 60 min. Following this, the resulting extracts were filtered through Advantech 5B filter paper (Tokoyo Roshi Kaisha Ltd., Saitama, Japan) and preserved in a refrigerator at 4 °C for further analysis.

Folin-Ciocalteu method was performed to estimate the total phenolic content (TPC) of the sample (Singleton and Rossi 1965). A reaction mixture comprised 1 mL of the sample, 200 µL of phenol reagent (1 N), and 1.8 mL of distilled water. After vortexing, 400 µL of Na₂CO₃ (10%, v/v in water) was introduced three minutes later. Subsequently, 600 µL of distilled water was added to reach the final volume of 4 mL, and the mixture was allowed to incubate at room temperature for 1 h. Absorbance was measured at 725 nm using a spectrophotometer (Jasco V-630, Jasco international co., ltd., Tokyo, Japan). The phenolic acid content was quantified based on a standard calibration curve of Gallic acid and expressed in µg g⁻¹ fresh weight.

The total flavonoid content (TFC) was estimated following the method described by Ghimeray et al. (2014). In brief, 500 µL of the extract was combined with 100 µL of Al(NO₃)₃ (10%, w/v) and 100 µL of potassium acetate (1 M) solution. Subsequently, 3.3 mL of distilled water was added to reach a final volume of 4 mL. The reaction mixture was vortexed and left to incubate at room temperature for 40 min, followed by measuring the absorbance at 415 nm using a UV–Vis spectrophotometer (Jasco V-630, Jasco international co., ltd., Tokyo, Japan). The total flavonoid content was quantified as mg g⁻¹ of Quercetin equivalent on a fresh weight basis.

Estimation of Antioxidant Capacity

The fresh sample (200 mg) was dissolved in 10 mL of ethanol (80%, v/v in water) followed by sonication at 35 °C for 60 min. Afterward, the extracts were filtered (Advantech 5B filter paper, Tokoyo Roshi Kaisha Ltd., Saitama, Japan) and kept in a refrigerator (4 °C for further analysis).

DPPH Free Radical Scavenging Assay

The DPPH free radical scavenging assay was conducted following the method described earlier (Islam et al. 2020). Initially, DPPH powder (5.914 mg) was dissolved in methanol (100 mL) to create a stock solution, maintaining an absorbance range between 1.1 and 1.3 using a spectrophotometer. Subsequently, 1 mL of the extract was vigorously

shaken with 3 mL of the DPPH solution and left in a dark room for 30 min at room temperature. A blank sample was generated by mixing 1 mL of distilled water with the DPPH solution instead of the extract. The absorbance was measured at 517 nm using a UV–Vis spectrophotometer (Jasco V-630, Jasco international co., Ltd., Tokyo, Japan). The scavenging capacity of the samples was calculated using the following formula, and the results were expressed as a percentage (%):

$$\text{Pulp percentage (\%)} = \frac{\text{Blank sample} - \text{Extract sample}}{\text{Blank sample}} \times 100 \quad (5)$$

Ferric Reducing Power Assay

The reducing potential of date extract was examined as described before (Oyaizu 1986). In this assay, 1 mL of plant extract was added to 2.5 mL of 0.2 M phosphate buffer (pH 6.6) and 2.5 mL of 1% potassium ferricyanide (w/v), mixed and incubated at 50 °C for 20 min. Then 2.5 mL of 10% TCA (trichloroacetic acid) was added to it, and the resultant mixture was centrifuged for 10 min at 3000 rpm. The supernatant (5 ml) was added to distilled water (5 mL) and 1 mL of 0.1% FeCl₃ solution (w/v), and the absorbance was taken at 700 nm in a UV–Vis spectrophotometer (Jasco V-630, Jasco international co., Ltd., Tokyo, Japan).

Total Antioxidant Capacity Assay

The total antioxidant capacity assay was performed using phosphomolybdenum method (Adnan et al. 2019), where ascorbic acid was used as a standard. In this assay, 0.3 mL of plant extract was mixed with 3 mL of reagent solution (prepared by using 28 mM sodium phosphate, 4 mM ammonium molybdate, and 0.6 M sulfuric acid) in the test tubes. The tubes were covered and incubated in a water bath for 90 min at 95 °C. After cooling, the absorbance of the mixture was taken at 695 nm in a UV–Vis spectrophotometer

(Jasco V-630, Jasco international co., Ltd., Tokyo, Japan) and the calculated values were presented as equivalent to ascorbic acid in mg AAg⁻¹ of fresh sample.

Statistical Analysis

All results were expressed as mean ± standard deviation (SD) in table and mean ± standard error (SE) in graphs, with three replications. Graphs were prepared using GraphPad Prism 5 (GraphPad Software, San Diego, CA, USA). Data presented in tables and graphs were analyzed using the Statistix 10 software (Analytical Software, Tallahassee, FL, USA) following a completely randomized design (CRD). Mean differences were compared using the Tukey HSD test, with *p* values ≤ 0.05 considered significant. Principal component analysis (PCA) was performed using OriginPro 10.0 (OriginLab Corporation, Northampton, MA, USA), and the Sankey diagram was created using the open-source statistical software R version 4.2.2, accessed on June 27, 2022.

Results

Changes in Fruit Color, Texture, Taste, and Overall Appearance

The color of a fruit serves as a crucial indicator, playing a pivotal role in the identification of fruit ripeness. The comprehensive spectrum of colors exhibited by sukkari dates is found in Table 2.

The impact of chemical treatments on the color of sukkari dates was significantly pronounced, particularly with the utilization of acetic acid and potassium metabisulfite treatments, resulting in an acceptable ripening color (Fig. 1). The collected data further elucidated that the combination of 1.5% acetic acid and 0.5% potassium metabisulfite ratio (T₆) yielded a desired brown hue, enhancing the attractiveness of the fruit. Notably, the treatment involving 1.5% acetic

Table 2 Effect of chemical treatment on color, texture, taste, and appearance of sukkari date

Treatment	Color of the treated fruits	Texture and taste of treated fruits	Appearance ^a
T ₀	Amber but less attractive	Hard and compact texture with pungent taste	7.14
T ₁	Amber but less attractive	Less soft without stickiness and slight pungency	6.29
T ₂	Light brown but less attractive	Soft texture with sweet taste	8.14
T ₃	Amber but less attractive	Less soft texture with less sweet	4.14
T ₄	Dark brown and medium attractive	Over Soft texture and rotten	7.28
T ₅	Amber but less attractive	Less soft texture with very sweet	4.57
T ₆	Brown and highly attractive	Soft, loose, sticky with very sweet	4.86
T ₇	Light brown and medium attractive	Soft and sticky with very sweet	4.42
T ₈	Brown and highly attractive	Very soft, sticky, juicy and very sweet	3.71

^aRanking value range from 1 to 10, 1 being the best



Fig. 1 Sukkari dates under different treatments

acid and 0.05% potassium metabisulfite combined with hot water (T_8) exhibited an exceptional color shine, surpassing the outcomes of all other treatments. Conversely, the color produced solely by potassium metabisulfite treatment did not meet the desired standards of appeal.

Fruit texture, particularly the firmness of the flesh, serves as a significant indicator of maturity when combined with other quality parameters. The fruits in the control group (T_0) exhibited a hard and compact texture. However, when treated with a combination of acetic acid, potassium metabisulfite, and hot water (T_2 , T_4 , T_6 , and T_7), the fruits acquired a very soft, sticky, and juicy texture (Table 2). It was observed that these treated samples were generally soft, with some of them being loose and sticky. Additionally, the fruits subjected to these treatments displayed increased flaccidity on the surface, while their firmness was enhanced toward the center. This observation suggests that the ripening process commenced at the fruit surface and gradually progressed toward the fruit core.

The taste of the fruits in the control condition exhibited a pungent flavor. However, the pungency was significantly reduced under different treatment conditions. Among the treated samples, those subjected to T_5 , T_6 , T_7 , and T_8 treatments displayed a notably sweet taste. Conversely, T_4 treatment resulted in fruit spoilage, leading to an unpleasant taste and odor.

In terms of overall ranking, the treatment involving normal water and potassium metabisulfite (T_3) resulted in an amber to light brown color of the fruits, which was comparatively less attractive. The fruits treated with 2% NaCl

and 1.5% acetic acid (T_4) also influenced the appearance, albeit to a lesser extent. Furthermore, T_4 treatment caused the fruits to become excessively soft and emit a foul odor.

Effect of Treatments on Morphophysiological Changes in Sukkari Dates

In general, the weight of the fruits and the percentage of pulp were observed to decrease across different treatment conditions when compared to the control group (Table 3). A noteworthy reduction was noted in the fruit weight across all treatments, while the percentages of pulp and the ratio of flesh weight experienced a significant decrease specifically in treatments T_1 (–13.19% and –10.42%), T_2 (–13.29% and –10.52%), and T_3 (–12.92% and –10.15%) in comparison with the control group. On the other hand, higher ripening % was observed in T_2 (90%), T_4 (88.33%), T_6 (88.33%), T_7 (90%) and T_8 (90%).

Total Soluble Carbohydrate (TSC) and Total Soluble Sugar Content (TSS)

Under different treatment conditions, both TSC and TSS exhibited notable variations (Fig. 2). Remarkably, the maximum TSC content was observed in treatments T_6 and T_8 , displaying an increase of 59.8% and 60.8%, respectively, compared to the control group. Furthermore, treatments T_5 , T_6 , and T_7 demonstrated significantly higher TSS levels, exhibiting enhancements of 23.7%, 21.09%, and 20.68% respectively, compared to the control group.

Table 3 Effect of sodium chloride and acetic acid singly and in combination on different quality parameters

Treatment	Fruit weight (g)	Flesh weight ratio	Pulp (%)	Ripening (%)
T ₀	20.96 ± 0.68 a	83.65 ± 1.29a	86.32 ± 1.85a	15.00 ± 4.08 c
T ₁	14.78 ± 0.32 b	74.94 ± 0.71b	74.93 ± 2.96 b	38.33 ± 6.24 b
T ₂	13.42 ± 0.88 b	74.85 ± 4.85b	74.84 ± 3.96 b	90.00 ± 4.08 a
T ₃	14.06 ± 2.01 b	75.16 ± 1.17b	75.16 ± 2.32 b	50.00 ± 4.08 b
T ₄	14.62 ± 0.60 b	76.77 ± 1.89ab	76.77 ± 1.54 ab	88.33 ± 2.36 a
T ₅	15.50 ± 1.34 b	77.20 ± 4.12ab	75.53 ± 5.22 ab	45.00 ± 4.08 b
T ₆	14.28 ± 0.55 b	77.98 ± 2.44ab	77.97 ± 1.99 ab	88.33 ± 6.24 a
T ₇	15.60 ± 1.07 b	77.25 ± 2.37ab	77.26 ± 1.94 ab	90.00 ± 4.08 a
T ₈	14.32 ± 0.19 b	79.49 ± 0.94ab	79.48 ± 3.98 ab	90.00 ± 4.08 a

Different letters indicate significant differences ($p < 0.05$) among the treatments within each parameter using Duncan's multiple range test. Values are expressed as the mean ± SD ($n = 3$)

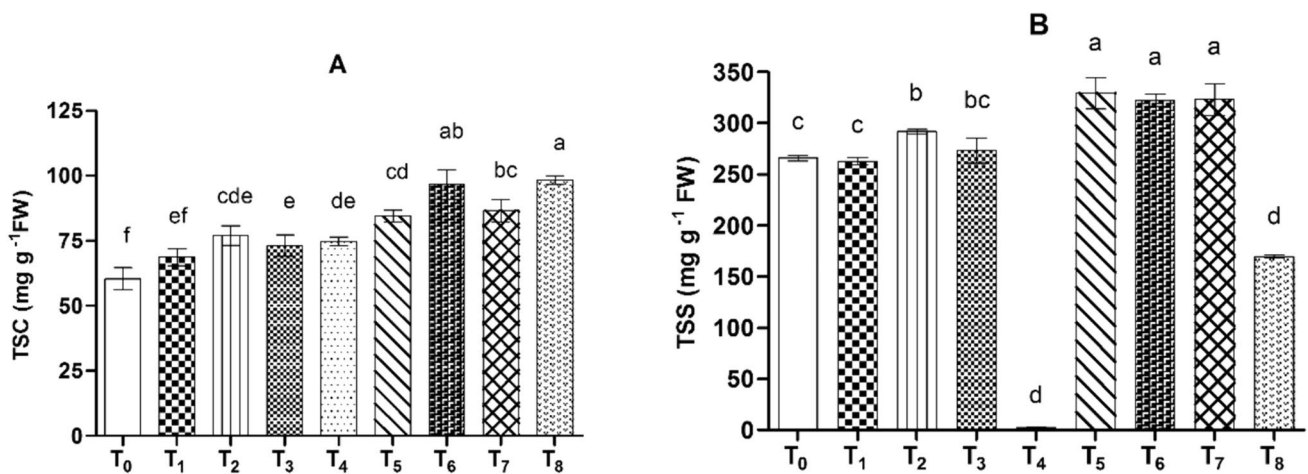


Fig. 2 Total carbohydrate content (TSC) (A), total sugar content (TSS) (B) of sukkari date palm under different treatment condition. Values are expressed as mean ± S.E. ($n = 3$). Different letters indicate

significant differences ($p < 0.05$) among the treatments within each parameter using Duncan's multiple range test

Total Phenolic Content (TPC) and Total Flavonoid Content (TFC)

It was shown that the different treatment had a significant effect ($p < 0.05$) on the phenolic and flavonoid content of sukkari date palm (Fig. 3). Among the different treatments, the higher TPC was accumulated in T₈ (0.76 mg g⁻¹ FW) followed by T₅ (0.76 mg g⁻¹ FW) which is 31.02% and 30.94% higher than control group. On the other hand, higher TFC content was found in T₅ (0.77 mg g⁻¹ FW) followed by T₇ (0.72 mg g⁻¹ FW) and T₈ (0.70 mg g⁻¹ FW) which is 25.42%, 20.64% and 18% higher than control group. Besides, lower TPC (-73.72% and -73.82%) and TFC (-49.14% and -45.67%) were

recorded in T₃ and T₆ treatments, respectively, compared to control group.

Beta-Carotene Content

Higher beta-carotene was recorded in T₃ (7.95 mg 100 g⁻¹ FW) and T₀ (7.72 mg 100 g⁻¹ FW), while opposite result was observed in T₄ (4 mg 100 g⁻¹ FW) (Fig. 4).

Antioxidant Capacity

DPPH Free Radical Scavenging Assay

The results of DPPH radical scavenging activity of extracts affected by different treatment were shown in

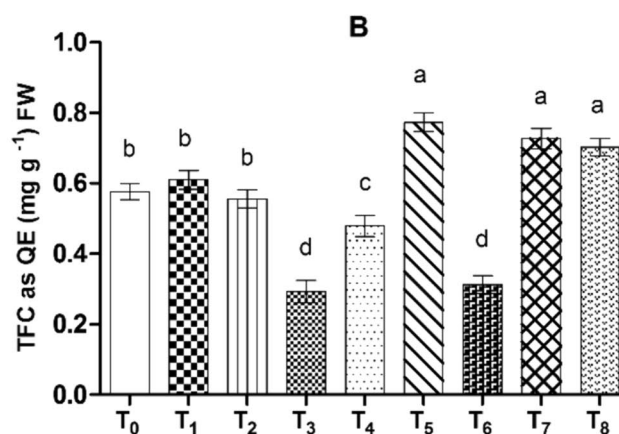
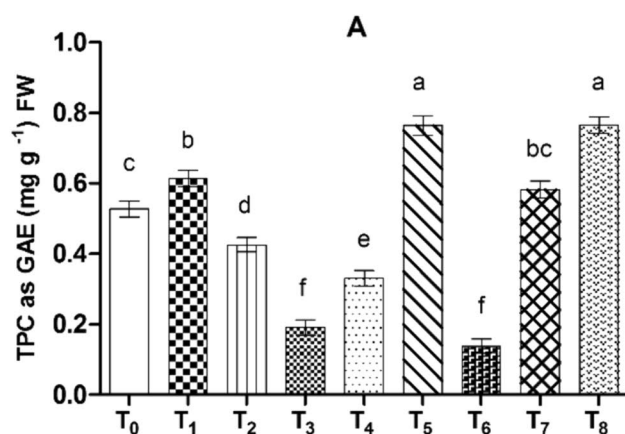


Fig. 3 Total phenolic content (TPC) (A), total flavonoid content (TFC) (B) of sukkari date palm under different treatment condition. Values are expressed as mean \pm S.E. ($n=3$). Different letters indicate

significant differences ($p<0.05$) among the treatments within each parameter using Duncan's multiple range test

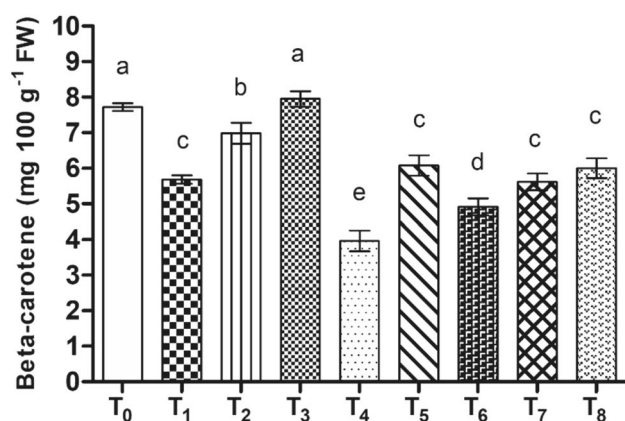


Fig. 4 Beta-carotene of sukkari date palm under different treatment condition. Values are expressed as mean \pm S.E. ($n=3$). Different letters indicate significant differences ($p<0.05$) among the treatments within each parameter using Duncan's multiple range test

Fig. 5. The highest DPPH was recorded in T₅ (66%) and the lowest was in T₄ (−59.2%) compared to control. Even though all the treatments exhibited a higher DPPH radical scavenging activity, T₀, T₂, T₃, T₅, T₇, and T₈ outperformed the others which are statistically similar.

Ferric Reducing Power Assay

The reducing power demonstrated significant differences ($p<0.05$) across various treatments (Fig. 5). The control condition exhibited the lowest ferric reducing antioxidant power (FRAP), which increased under the

different treatment conditions. The highest FRAP values were observed in treatments T₅ (72.87%) and T₈ (71.55%) compared to the control.

Total Antioxidant Capacity Assay

Phosphor molybdenum assay is a quantitative method to evaluate water-soluble and fat-soluble antioxidant capacity (total antioxidant capacity). The results of total antioxidant capacity of date under different treatment are shown in Fig. 5. Total antioxidant capacity was higher in T₁ (15.13%), T₈ (15%) and lower in T₅ (−34.38%) compared to control.

Discussion

Fruit color is crucial to the marketing value and quality index. Similarly, variation in the color is closely related to the ripening. During ripening and curing, dates undergo a color change that produces a range of colors from yellow to brown. The fruit's biological processes, which are triggered by chemical treatments, tend to modify the color (Saleem et al. 2010). All the treatments exerted a positive effect on this important property. The sukkari date while undergoing ripening changes color from light yellow at khalal to golden brown at the rutab stage. But the type of treatment used, and the level of ripening affected the color shade differently (Table 2). The fruits ripened under the influence of different chemicals changed color much earlier compared to the control treatment. This effect was highly pronounced in the treatments using a combination of acetic acid and potassium metabisulfite that gave a satisfactory ripening color. The results also suggested that three substances like

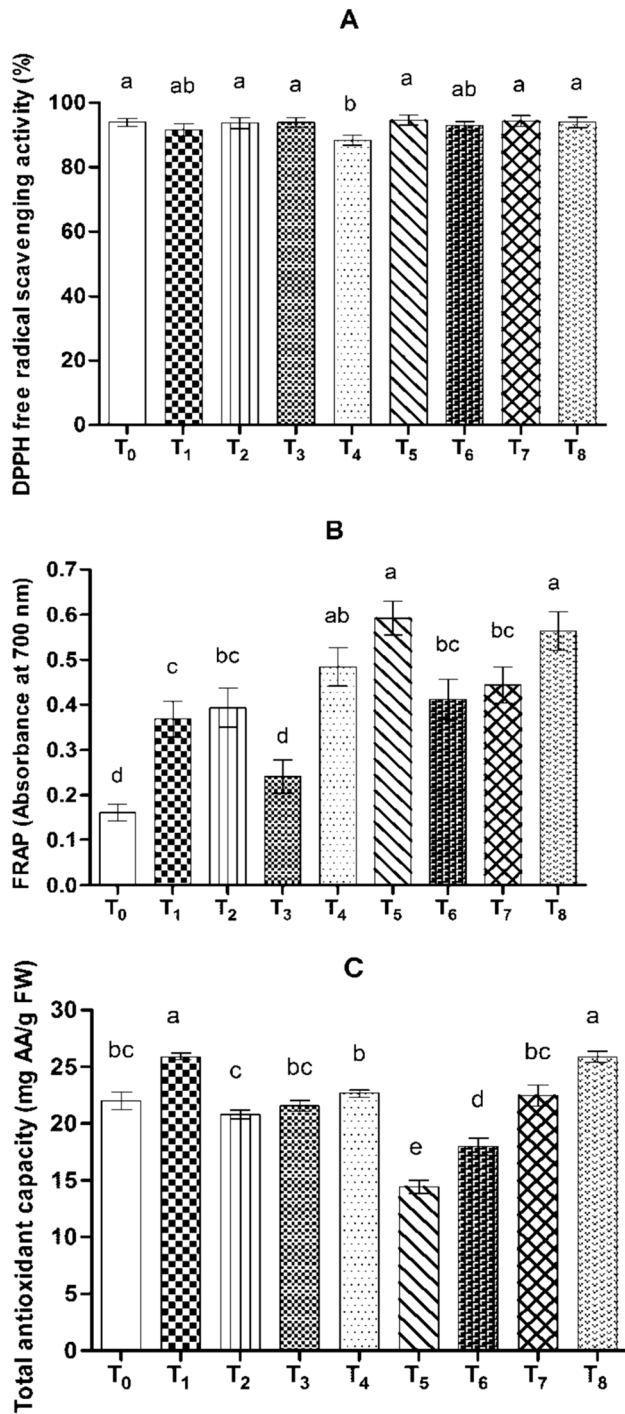


Fig. 5 DPPH free radical scavenging activity (A). Ferric reducing antioxidant power assay (FRAP) (B). Total antioxidant capacity (C) of sukari date palm under different treatment condition. Values are expressed as mean \pm S.E. ($n=3$). Different letters indicate significant differences ($p<0.05$) among the treatments within each parameter using Duncan's multiple range test

sodium chloride, acetic acid and potassium metabisulfite might be involved in adjustment of physiological and biochemical process like antioxidants, secondary metabolites

and enzymes to bring about the desired color change during ripening. The positive effect of sodium chloride and acetic acid on ripening of 'Khasab' dates was previously narrated (Afshari-Jouybari et al. 2014).

The fruits ripened by the control treatment exhibited a reduced softness throughout. However, the application of acetic acid in combination with potassium metabisulfite and hot water treatment resulted in a significant increase in the fruit's texture, rendering it notably softer. The surface ripening of the dates using salt and vinegar acid was another finding made by others (Yektankhodaei et al. 2007). However, most of the dates after treatment with combination of NaCl and acetic acid (T₄) became over soft and developed slightly disagreeable taste and flavor.

Fruits gave higher weight and pulp contents in control while it tends to decrease under various treatment conditions. This might be the reason of breakdown of starch into sugar (Adi et al. 2019). This finding is similar to the results from 'Khasab' date where weight and pulp percentage was lower in fruits treated with vinegar acid alone or in combination with salt as compared to the control samples (Asif and Al Taher 1983). However, a dissimilar finding was also narrated where treated dates had higher fruit weight and pulp contents than control (Saleem et al. 2005), where salt treated fruits gave the highest result. In the present study, a slight increase in fruit weight or pulp was seen in the case of T₄, T₅, T₆, T₇ and T₈ where NaCl, AA and PM were used in various combination.

Apparently, all the treatments helped induce ripening of sukari date to a certain degree (Table 3). However, the extent of ripening varied with the nature of the chemical and amount of the chemical application. In the context of unripe fruits, invertase predominantly exists in an intracellular or endoform configuration, where it can interact with the cellular protoplasm, leading to the formation of an insoluble compound. Once ripening begins, the invertase enters the extracellular space, or ectoform, and easily dissolves in water. Moreover, the softening of dates is facilitated by the action of hydrolytic enzymes, including polygalacturonase and cellulase. These enzymes serve to catalyze the hydrolysis of pectin and cellulose, which are integral structural components responsible for maintaining cell cohesion (Ayoub et al. 2023; Alsawmahi et al. 2018; Rastegar et al. 2012). The findings of the present study about the softening brought on by NaCl and acetic acid are consistent with certain earlier reports (Afshari-Jouybari et al. 2014; Kalra et al. 1977). These agents may cause softening and ripening by tearing the epidermal cells and the protoplasm, whereby invertase gets activated. It was observed that heat treatment of fruits killed the protoplasm but induced ripening by activating enzymes (Yi et al. 2021). Further, dissociation of cell walls occurs during natural softening of fruits (Alina et al. 2023). In our study, the effect of NaCl and acetic acid on sukari

dates was more pronounced compared to the control treatment. Although all of the treatments contributed to inducing the ripening of dates, the combinatorial use of NaCl, acetic acid (A.A.), and potassium metabisulfite (P.M.) resulted in a significant level of ripening. The findings are consistent with previous results that reported a progressive increase in 'dong' formation of 'Khadrawi' and 'Shamran' date cultivars as salt concentration increased. Furthermore, the addition of vinegar acid enhanced this effect (Kalra et al. 1977).

Total soluble sugar and carbohydrate content of date fruit was increased as the fruit ripened. Sugar content of date is one of the most important commercial characteristics that is significant for both fresh consumption and fruit processing (Fadel 2008). Dates are composed of 70% carbohydrates, which include principally reducing sugars like glucose and fructose, non-reducing sugars like sucrose, and trace amounts of polysaccharides like cellulose and starch (Al-Shahib and Marshall 2003; Al-Farsi and Lee 2008). The amount of reducing sugars starts to increase at the Kimri stage and maximum amount of sucrose rises at the Khalal stage. Due to moisture loss, the weight drops at the Rutab stage, and sucrose is converted into reducing sugars (Tafti and Fooladi 2006). At the Khalal and early rutab stages of ripening, sucrose makes up around 60% of the dry weight of dates (Samarawira 1983).

The moisture content is related to sugar content since dates with low moisture content contain high sugar and vice versa (Tafti and Fooladi 2006). It is indicated that recently harvested dates have higher water contents than total soluble solids. It shows that a decrease in moisture or water contents results in more concentrated fruits TSS. Further, water evaporates during incubation for ripening/ curing, and moreover, the insoluble fruit materials get solubilized simultaneously because of breaking down of polymers through ripening. In our study, it is indicated clearly that the treatment in combination with acetic acid and potassium metabisulfite with or without hot water has responded well giving a higher percentage of both TSC and TSS (Fig. 2). However, in the presence of NaCl, TSC exhibited a slight increase, while TSS experienced a significant reduction. Although the exact mechanism remains undisclosed by the current experiment, we hypothesize that this phenomenon may be attributed to the conversion of sucrose into reducing sugars under the influence of NaCl. Earlier study reported that the activity of NaCl was significantly more potent than that of acid, and in treatments combining it with acetic acid, the action of acid was more potent and effective than when applied alone (Thatai and Kalra 1982; Asif and Al Taher 1983; Cheema 1986; Ali 1989). However, some of the dates after treatment with sodium chloride and those from combination treatments became over soft and developed a disagreeable taste and flavor.

Secondary metabolites of different groups of molecules called polyphenols are substances that occur naturally (phenolic acids, flavonoids, phytoestrogens etc.) found in large quantities in cereals, fruits, vegetables, and beverages (Zihad et al. 2021). The presence of hydroxyl groups and the conjugated ring structure in phenolic compounds, as well as their capacity to scavenge free radicals, all contribute to their significant antioxidant activity. The most effective free radical scavengers against the majority of oxidizing chemicals among the several polyphenol groups are flavonoids (Saeed et al. 2012). Some studies reported that phenolic substance were high in the inedible Kimri stage of date and declined progressively as the date matured to Tamer stage in natural ripening condition (Zhu et al. 2002; Ahmed and Ramaswamy 2006). In our study, we used full matured dates of Khalal stage where the levels of TPC and TFC were observed slightly increased in the treatment combination involving acetic acid and potassium metabisulfite, with the addition of either NaCl or hot water (Fig. 3). The slight variation in phenolic compound might be the reason of varietal differences (Ghnimi et al. 2017) and antioxidative nature of preservatives used in the treatments (Carocho et al. 2018). On the other hand, beta-carotene decreased under most of the treatments compared to control. Concurrently, within these treatments, there was a progressive enhancement in the taste, flavor, and ripening of the dates. This phenomenon strongly supports the role of antioxidants in the maturation of dates. One of the primary functions of polyphenols in maturation is their transformation from a soluble form (resulting in astringent taste) to an insoluble form (rendering them tasteless), likely attributed to their interaction with proteins (Ashraf and Hamidi-Esfahani 2011).

DPPH is a suitable free radical used to determine the antioxidant properties or radical scavenging capacity. Free radicals, which are produced during the lipid peroxidation process, are thought to have a significant impact on a variety of chronic pathologies, including cancer and cardiovascular illnesses. The DPPH radical is frequently used to assess the capacity of various natural products to scavenge free radicals and is recognized as a model molecule for free radicals originating in lipids (Shahdadi et al. 2015).

One of the primary causes of several medical disorders in the human body is oxidative stress, which results from an imbalance between the body's natural defense mechanisms and the production of free radicals (McCord 2000). Several pathological conditions, such as degenerative diseases, cancer, and inflammatory diseases (Kohen and Nyska 2002), are caused by these unstable free radicals and reactive oxygen species (ROS), which can come from either internal or external sources (X-rays, industrial chemicals, tobacco smoke, air pollutants, etc.). They harm cellular macromolecules like protein, lipid, and DNA through electron pairing (Juan et al. 2021). The DPPH

free radical scavenging assay was used in this study to assess the date palms capacity to scavenge free radicals. The DPPH-based free radical scavenging method is one of the most accurate and simple ways to assess the antioxidant activity of natural compounds, with the benefit of being unaffected by adverse effects (Livani et al. 2013). The present study displayed almost similar DPPH radical scavenging activity of extracts in various treatment conditions (Fig. 5). Higher levels of phenolic compounds may have potential role on increased the DPPH radical scavenging activity as the fruits have been shown to have a strong relationship between their phenolic content and free radical scavenging (Gao et al. 2000; Jiménez-Escrig et al. 2001; Arabshahi-Delouee and Urooj 2007).

Antioxidant action is typically attributed to a variety of processes, including reducing capacity, prevention of chain initiation, radical scavenging, and peroxide's breakdown (Islam et al. 2022). The ability of bioactive substances to donate electrons, which reflects their reducing power, has been linked to antioxidant activity, according to numerous studies (Yen et al. 1993; Siddhuraju et al. 2002). Reducing power is thus a crucial indicator of the antioxidant activity of plant extracts. Different studies have indicated that the electron donation capacity (reflecting the reducing power) of bioactive compounds is associated with antioxidant activity (Beyhan et al. 2010). In this work, date extracts were assessed for their reducing capacity, or ability to donate electrons in the transition of Fe (III) to Fe (II), which is contributed through the reducing ability of the extracts. In a prior investigation, extracts from the reducing power exhibited substantial differences from the Khalal stage to the rutab stage, but no such variations were seen between the rutab stage and the Tamer stage. Khalal stage, which had the highest concentration of total phenolics, was the most effective reducing agent, whereas Tamer stage, which had the lowest concentration of phenolics, had the poorest reducing activity (Shahdadi et al. 2015). In our study, FRAP activity showed a linear increase with both TPC and TFC concentrations, and this relationship was most pronounced when using acetic acid and potassium metabisulfite, either with NaCl or hot water.

Total antioxidant capacity is a comprehensive method for assessing the antioxidant activity of plant extracts, and phenolics, flavonoids, and other reducing chemicals in the extract may contribute to some extent of the total antioxidant capacity (Kumar et al. 2014). The phosphomolybdenum method was used in this experiment to examine the overall antioxidant activity of the date extracts. The present study indicated that date fruits that were artificially ripened had higher levels of polyphenols than controls, which boosted their overall antioxidant capability. Significant amounts of polyphenols are found in the date extracts in both previous study (Sheikh et al. 2016) as well

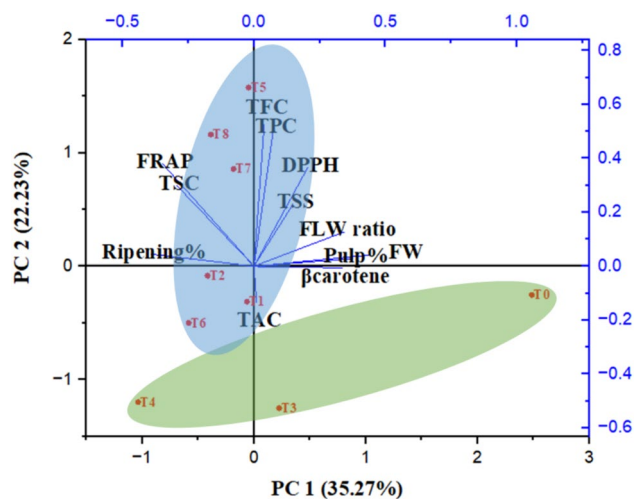


Fig. 6 Principal component analysis (PCA) to elucidate the variable treatment relationships under nine treatments. The lines starting from the central point of the biplots display negative or positive associations of different variables, and their proximity specifies the degree of correlation with specific treatment

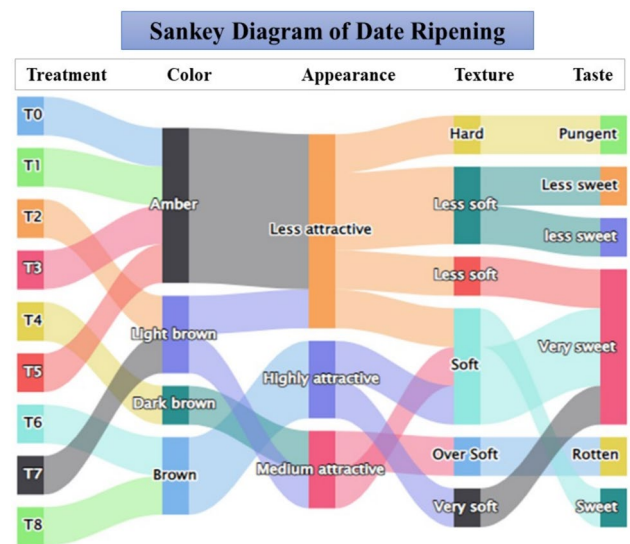


Fig. 7 Sankey diagram based on the color, appearance, texture and taste of sukkari dates

as present study, and the differences in these amounts can be directly related to the observed activity. This is because the total antioxidant capacity is directly proportional to the amount of polyphenols present in the extract (Zhu et al. 2004).

Principal Component Analysis and Sankey Diagram

The PCA analysis was conducted to determine the relationship between various morphophysiological parameters,

phenolic components, antioxidant characteristics, and their scavenging activity of sukkari date fruits under all treatment settings during artificial ripening (Fig. 6). The elements PC1 and PC2 together describe 57.5% of the data variability. Two groups may be found in this figure across all treatment scenarios. From the figure, the treatments T₀, T₃, and T₄ make up one group, while T₁, T₂, T₅, T₆, T₇ and T₈ make up the other groups. Most of the parameters closely associated with the second group. The findings also indicated a positive correlation among Pulp%, FLW ratio, FW, and β-carotene, while exhibiting an inverse association with ripening percentage.

Conversely, distinct treatments were observed to form coherent clusters in accordance with the evaluated parameters within the Sankey diagram (Fig. 7). An assessment of the treatments with regard to their overall visual attributes revealed that T₆ and T₈ exhibited a notably superior performance, in contrast to the other treatments, which demonstrated comparatively inferior results.

Conclusion

In conclusion, our study highlights the substantial impact of various chemical treatments on sukkari dates. The combination of 1.5% acetic acid and 0.5% potassium metabisulfite (T₆) yielded optimal color and texture, while T₈, incorporating hot water, enhanced the color further. Taste improved in T₅, T₆, T₇, and T₈, with a notable shift from pungency to sweetness. Some treatments, such as T₃ and T₄, had less favorable effects on appearance and resulted in spoilage. Importantly, T₆ and T₈ treatments led to higher total soluble carbohydrates (TSC) and total soluble solids (TSS), indicating enhanced sugar content. Phenolic and flavonoid content increased in T₈ and T₅, while beta-carotene levels varied. Antioxidant activity was significantly influenced by the treatments, with T₅ exhibiting the highest DPPH radical scavenging activity. Ferric reduction power was notably higher in T₅ and T₈. Total antioxidant capacity was higher in T₁ and T₈ but decreased in T₅. These findings underline the potential for specific chemical treatments to enhance the quality, ripening, and antioxidant properties of sukkari dates, offering opportunities to improve their appeal and nutritional value. Further, artificial ripening of date fruits will help to ensure consistent quality and year-round availability, meeting consumer demand and supporting a stable market supply chain.

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Data Availability Not applicable.

Declarations

Conflict of interest The authors have declared no conflict of interest.

Ethical Approval In this study, no animal or human subjects were involved. The authors wish to clarify that for the sensory analysis, all panelists were provided with a written consent form detailing the procedures, ranking scale, potential risks, and consent for the future publication of the research findings.

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