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Innovative date syrup processing with ohmic heating technology: Physiochemical characteristics, yield optimization, and sensory attributes

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A R T I C L E I N F O

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A B S T R A C T

The present study aimed to investigate the application of the ohmic heating (OH) technique in the production of date syrup from the date fruit of the Sukkary variety at different electric field strengths (EFS) (9, 10, and 11 V/cm). The results were compared to the conventional heating method (CH). The response surface methodology was used to optimize yield. The results showed that the time to reach the boiling point of dates and water mixture using OH was less than the CH by 80% for extracting and 900% for evaporation. In addition, the productivity of date syrup using OH at EFS of 11 V/cm was higher than the CH by 86.11%. There is no significant effect between OH at EFS of 11 V/cm and CH in moisture content, refractive index, density, TSS, and viscosity. The optimum level of EFS was 11.5 V/cm, which gave a higher yield (64.93%). OH, save consumed power and cost. The OH gave the highest scores of sensory characteristics compared to CH. Total sugars, monosaccharides, and ketone monosaccharides were detected in the date syrup, and the result was positive, while the quintuple sugars and multiple sugars were negative for all treatments. The OH reduced the cost by 85.78% compared with CH.

1. Introduction

Dates are one of the essential agricultural products in Iraq, as there are suitable varieties of high quality that may not be available in other global markets. Dates occupy an important economic position at the Iraqi level and in Basrah Governorate, contributing to increasing economic benefits and achieving national food security [1]. Dates are considered a food of high nutritional value because they contain carbohydrates, proteins, and mineral elements. It also contains essential nutrients in supplying humans with the thermal energy that the body needs, as it contains high sugars that reach about 80% of the weight of dates [2–4]. Dates are characterized by easy absorption and quick digestion and can be introduced into manufacturing industries to produce date syrup, date paste, and

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products [5–7]. The Al Sukkary type dates reduce blood sugar levels [8]. Also, date extracts can treat ischemia-reperfusion injury and stroke [9].

Date syrup is a manufacturing industry product with a high nutritional value. It is a thick liquid extracted by heat from the date fruit and is free of fibers, sediments, impurities, and foreign bodies, as it is consumed directly and used to manufacture sweets and pastries [10]. Date syrup contains 86.6% total sugars, 81.7% reducing sugars, and 4.9% sucrose. In addition, date syrup contains moisture (24.8%), acidity (0.02%), protein (2.1%), and ash (6.6%), calculated based on the dry weight. It also contains a good percentage of vitamins A and B [11]. In addition, date syrup is rich in many minerals [12]. The date syrup extracted by traditional methods suffers from a dark color resulting from the high temperature of the extraction for long periods, which results in the formation of colored substances such as caramel, which is formed due to interactions between sugars and amino acids. The phenomenon of thankfulness also occurs due to the accumulation and separation of sugars from the date syrup, as it can be overcome by adding citric acid.

Another problem is the lack of fluidity of date syrup due to the presence of pectic substances in molasses, which makes it look like jelly. Moreover, the occurrence of fermentation due to the low concentration of date syrup is more than 75% and contamination with bacteria due to lack of hygiene [11]. Two methods for extracting date syrup are thermal and hydraulic pressure [13]. Also, date syrup was extracted using microwave and ultrasound technologies [14]. Al-Hilphy, Al-Fekaiki [15] studied the Kinetic models for date hony pH development and found that date hony (extracted by hydraulic press) pH decreased as the storage period increased from 0 to 60 days. Assiry [16] discovered that the storage temperature and the number of dissolved particles impact how much the pH value decreases with time.

Ohmic heating is the passage of electric current through food via electrodes, and as a result, the food converts into electrical resistance and heats up. When designing an ohmic heating device, the type of product to be heated should be considered, such as the product's characteristics, the electrical conductivity of that material, and the heating coefficient [17,18]. One of the benefits of ohmic heating is the reduction in energy consumed and the speed of heating, the transfer of heat from inside the food to the outside, low pollution formation, low maintenance costs, and it is environmentally friendly [19,20]. There are no published studies on using ohmic heating in extracting date syrup from dates and steaming it. Therefore, the current study aimed to design a new system for extracting syrup from dates by ohmic heating to reduce energy requirements, increase the speed and efficiency of extraction, and improve the quality of produced date syrup.

2. Materials and methods

2.1. Date fruits

Shukri dates were obtained from the local market in Basrah, as they were washed to remove dirt. It was divided and then placed

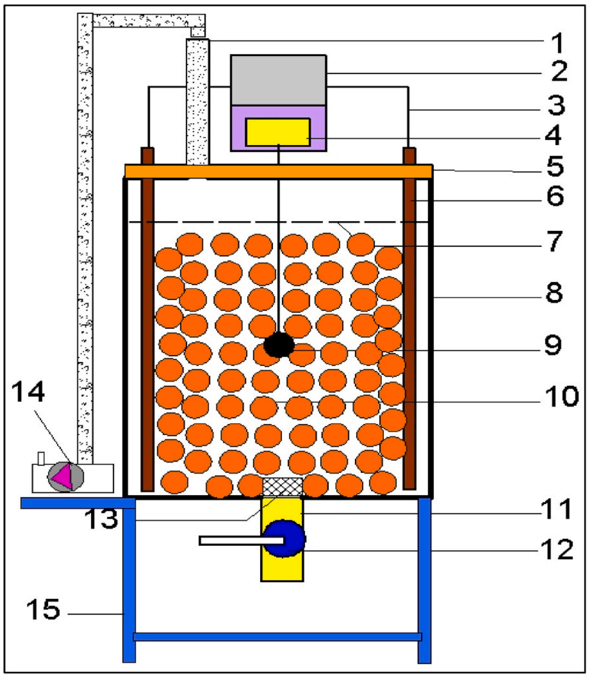

Fig. 1. Schematic diagram of an ohmic-heated date syrup extraction and evaporation device
1. pipe, 2. Voltage changer, 3. Electrical wires, 4. Digital temperature gauge, 5. Cap, 6. Electrode, 7. Water-juice level, 8. Heat-resistant plastic cylinder, 9. Thermocouple, 10. Dates and water mixture or date syrup, 11. Exit pipe of syrup, 12. Manual valve, 13. Filter, 14. Vacuum pump, 15. Base.

every 450 g in a polyethylene bag and stored at a temperature of 5 °C until use. The total quantity of dates was 5.40 kg.

2.2. Preparation of date syrup

Locally-sourced Shukri variety dates were pitted. The date flesh was then processed into date paste using an electric grinder. The prepared date dough was combined with distilled water in a weight-to-date ratio of 1:1.5. The mixture was then put into an electrode-equipped cylinder (OH system) and heated to a boiling point using various EFSs for 10–12 min. The date suspension was carefully processed through many layers of clothes. The filtered date suspension was placed in the evacuated OH cylinder and evaporated at various EFSs until the total soluble solids content reached 27%. To prevent any changes between the time they were prepared and the start of the experiment, the samples of clear date honey were stored in the refrigerator at 5 °C.

2.3. Date syrup extractor by ohmic heating

The ohmic-heated date syrup extraction device consists of a 2 l cylinder made of heat-resistant plastic (8) with a cover (5). The thermocouple was fixed at the bottom of the cylinder (9) (Fig. 1). The cylinder contains two stainless steel electrodes with a length of 250 mm, width of 70 mm, and thickness of 0.2 mm, and the distance between them was 100 mm. Electrodes attached to the upper end of the cap (5). In addition, there is a valve (12) to drain the product at the bottom of the cylinder, and there is a temperature gauge (4), a voltage changer (2) (0–230 V AC, 60 Hz), and electrical wires (3). The current was measured by a clamp meter. The total volume of the OH device is 0.12 m^3.

2.4. Extraction process by OH

A 450 g of dates were placed in the cylinder (9), and 1.125 L of water were added to it (w/v ratio 1:1.5). Three voltages (90, 100, and 110 V were applied, which were divided on the distance between electrodes of 10 cm to convert to EFSs of 9, 10, 11 V/cm) were used for the heating mixture to boil, then cooled to 50 °C and filtered by perforated clothes then collected and stored at 5 °C for the further use. The experiments were executed with triplicates.

2.5. Evaporation of date syrup by OH

A date syrup extractor by ohmic heating was also used for evaporating water from the filtered solution. A 500 ml filtered solution was put into a cylinder (9) instead date. After that, the vacuum pump (at 0.8 bar, 60 W) was connected to a cylinder (9) for the exit of vapor (1). The function of the vacuum pump is to withdraw evaporated water (vapor) from the filtered solution during heating. The filtered solution was heated by OH under vacuum (at 0.8 bar) for evaporating water till its concentration reached 72% total soluble sold. The experiments were replicated three times.

2.6. Conventional heating (CH)

A 450 g of dates were placed in a basin, and 1.125 L of water were added to it (w/v ratio 1:1.5). The mixture was heated under a vacuum (0.8 bar was used after preliminary experiments) to a boiling point, then cooled to 50 °C and filtered. Water evaporated from the filtered solution until the concentration reached 72% of the soluble solids [21].

2.7. Density

The density of date syrup was estimated according to the method mentioned in Pearson (1976) using a PyKnometer bottle with a volume of 100 cm^3. The density of date syrup during evaporation was calculated depending on the concentration and temperature, according to equations (1) and (2) [22].

$$p_t = \left(0.79 + 0.35 \times e^{0.0108 \times (TSS)} - 5.41 \times 10^{-4} \times T\right) \times 1000 \quad (1)$$

$$A = \frac{m}{p_t L} \quad (2)$$

Where T is the temperature (K), TSS is the total solid soluble, m is the mass of syrup sample (kg), p_t is the date syrup density (kg/m^3), L is the gap between electrodes (m), and A is the contact area (m^2).

2.8. Specific energy consumption (SEC)

SEC is given in equation (3) as follows [22];

$$SEC = \frac{\sum V\,I\,t + Q_{pump}}{m_W} \quad (3)$$

Where SEC is the specific energy consumption (kJ/kg), V is the voltage (V) and measured by a voltmeter, I is the current (A) and measured by clamp meter, t is the time (s), m_W is the evaporated water (kg), and Q_{pump} is the vacuum pump energy (kJ).

2.9. Energy efficiency

Thermal energy efficiency was calculated by using equation (4) [23];

$$\eta = \left(\frac{m\, C_p\, \Delta T + m_w \times \lambda + Q_{pump}}{\sum V \times I \times t}\right) \times 100 \tag{4}$$

Where η is the thermal energy efficiency (%), m is the mass of date syrup (kg), C_p is the specific heat (kJ/kg K), ΔT is the difference in temperature (°C), m_w is the mass of evaporated water (kg), m is the solution mass (kg), and λ is the latent heat of vaporization (kJ/kg).

Equation (5) was used to calculate the C_p as follows [22].

$$C_p = 837 + 3349\, X_w \tag{5}$$

X_w is the moisture fraction, C_p is the specific heat (kJ/kg °C), 837 and 3394 are constants of empirical equations.

2.10. Power consumption

Power consumption is measured by equation (6):

$$P = VIt \tag{6}$$

P is the power consumption (kWh), V is the voltage (V), I is the current (A), and t is the time (h). For conversion P from W to kWh, it was divided by 1000.

2.11. Refractive index and total soluble solids (TSS)

The refractive index of date syrup was measured at a temperature of 20 °C using the Abbe Refractometer manufactured in England, according to AOAC [24] Method 990.19. TSS was measured using a refractometer (Bellingham, UK), according to AOAC [24] Method 985.26.

2.12. Date syrup yield

Date syrup yield was calculated according to equation (7) as follows:

$$y = \frac{q}{f} \times 100 \tag{7}$$

Where y is the date syrup yield (%), f is the quantity of date used (kg), q is the quantity of date syrup (kg).

2.13. Optimization

Based on preliminary tests and published research, the values of the experimental conditions were chosen in a range. EFS (9–11 V/cm) was the independent factor considered in this investigation. Response surface methodology (RSM) was used for the prediction of date syrup yield (%) using L-optimal (Custom) design in Design-Expert version 13. The levels of electrical field strength (Table 1) were investigated. Nine experiments were used. Coded values of independent variables (−1.0, +1) were used. The coded values −1, 0, and +1 refer to the lowest, medium, and highest levels. According to equation (8), the prediction of the yield was carried out using the quadratic polynomial regression model;

Table 1
Matrix of L-optimal design for the independent variable (electrical field strength) and dependent variable (date syrup yield) for the experiment design.

Run	Electrical field strength (V/cm)	Date syrup yield (%)
1	9	35.21
2	9	35.00
3	11	59.43
4	10	47.1
5	10	47
6	11	59.2
7	9	34.78
8	9	34.98
9	10	47.09

$$Y = \beta_\circ + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} {X_i}^2 + \sum_{i<j=1}^{k-1} \sum^{k} \beta_{ij} X_i X_j \tag{8}$$

Where Y is the yield (%) i, $\beta_\circ$ is the intercept, β_i, β_{ii}, β_{ij} are the constants of the linear, quadratic, and interaction, i and j are some factors, Xi and Xj symbolize the coded independent variables. The best model was chosen based on the lower Std. Dev. and higher R^2, Adjusted R^2, Predicted R^2, and PRESS. Therefore, the linear model was chosen (Table 2). A numerical method was utilized to optimize date syrup yield with optimum conditions of Electrical field strength with a higher date syrup yield.

2.14. Chemical composition, color properties, and browning index (BI)

Chemical composition was measured as follows: moisture content AOAC [24] (Method 919.38), protein AOAC [24] (Method 920.52), ash AOAC [24] (Method 920.181), fiber AOAC [24] (Method 2011.25), sugar AOAC [24] (Method 977.20), pH and acidity [25]. For determining color components, a camera of 6 Megapixels was first used to capture pictures of date syrup, according to Al-Hilphy, Al-Fekaiki [15]. Then, an image processing method was used to determine the color characteristics of date syrup by Image J software, and the values of lightness (L^*), redness/greenness (a^*), and yellowness/blueness (b^*) were extracted. According to Yam and Papadakis [26], L^*, a^*, and b^* values were corrected. BI was calculated from equation (9) [27].

$$BI = \frac{(100(x - 0.31))}{0.172} \times 100 \tag{9}$$

2.15. Sugars test

It is a set of tests conducted on the date syrup manufactured by the two methods of Ohmic heating and the traditional method after dilution to know the types of sugars present in it and to estimate the effect of the electric field strength on these sugars. A dilution was carried out by drawing (1 ml) of date syrup and dissolving it in (100 ml) of distilled water, and the following tests were carried out.

2.15.1. Molisch test, bendict test, barfoed test, seliwanoff test, bial test, and iodine test

It is aromatic (alpha-naphthol-α) when added to the sugary substance in an acidic medium of H_2SO_4 acid. The center forms a violet ring, a general carbohydrate detection. (1/2 ml) of date, syrup solution was added in a test tube (3 drops) of Molish's reagent shaken well, then (1/2 ml) of H_2SO_4 was carefully added to the tube walls [28].

Benedict's reagent is a blue solution of copper sulfate, sodium carbonate, and sodium esters. When added to the sugar solution, the copper ions are reduced to copper, and the color changes from yellow to reddish-brown in the presence of reducing sugars. In the absence of reducing sugars, the reagent retains its blue color. A 1/2 ml of diluted date syrup solution was added to a test tube, and then 1 ml of Benedict's reagent was added and placed in the water bath for 3–5 min [29].

This detection is done in an acidic medium and only in the presence of monosaccharides (because they are the most vital reducing properties of the dimers). A 1/2 ml of diluted date syrup solution was added in a test tube, 1 ml of Parfoid reagent, and then placed in the water bath for 3–5 min [30].

The seliwanoff test is used to distinguish between aldehyde and ketone monosaccharides. A 1/2 ml of diluted date syrup solution was added to a test tube, and 1 ml of Sulfa-Nof reagent was added and placed in the water bath for 3–5 min [30].

It is a unique detection for pentoses, and the basis of its action is the reaction of Furfural compounds with orcinol in the presence of ferric ions in this reagent. A 1/2 ml of diluted date syrup solution, five drops of concentrated HCL acid, and 1 ml of Biel reagent were added to a test tube and placed in the water bath for 1–5 min [28].

The iodine test distinguishes between polysaccharides (starch-glycogen-dextrin-inulin). A 1/2 ml of diluted date syrup solution was added to a test tube, and two drops of iodine reagent were added [28].

2.16. Sensory assessment

According to Kwaw, Ma [31], a sensory assessment was conducted. 15 expert panelists (10 males and 5 females) were selected from the Department of Food Sciences, College of Agriculture at the University of Basrah to assess the sensory properties, which were color, flavor, taste, and overall acceptance of the date syrup using 9 points hedonic scale (1 = dislike externally, 2 = dislike very much, 3 = slightly dislike, 4 = dislike, 5 = neither like nor dislike, 6 = like, 7 = slightly like, 8 = like very much, 9 = like extremely) using protocol according to ISO8586-1 (1993). Table S1 illustrates the form of sensory evaluation of date syrup. At first, approval was obtained from all participants to conduct a sensory evaluation. Moreover, the sensory tests do not require ethical approval in our country.

Table 2
Statistical parameters to choose the best model.

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	0.1419	0.9998	0.9998	0.9997	0.2548	Suggested
Quadratic	0.1444	0.9998	0.9998	0.9997	0.2842	
Cubic					*	Aliased

2.17. Kinetic model for decreasing pH during storage

To determine the development kinetics of pH value during the storage period, two kinetic models were used: the zero-order and first-order models, which are represented by equations (10) and (11):

$$pH = pH_o - k_0 t \tag{10}$$

$$pH = pH_o \, exp.(-k_1 t) \tag{11}$$

Where pH is at any given processing time, pH_o is at zero-time, t is the time (s), k_0 is the constant rate for the zero-order model (1/day), and k_1 is the rate of constant for the first order model (1/day). Equation (12) was used to determine the half-life ($t_{1/2}$) for the development of pH in date syrup.

$$t_{1/2} = \frac{-\ln(0.5)}{k} \tag{12}$$

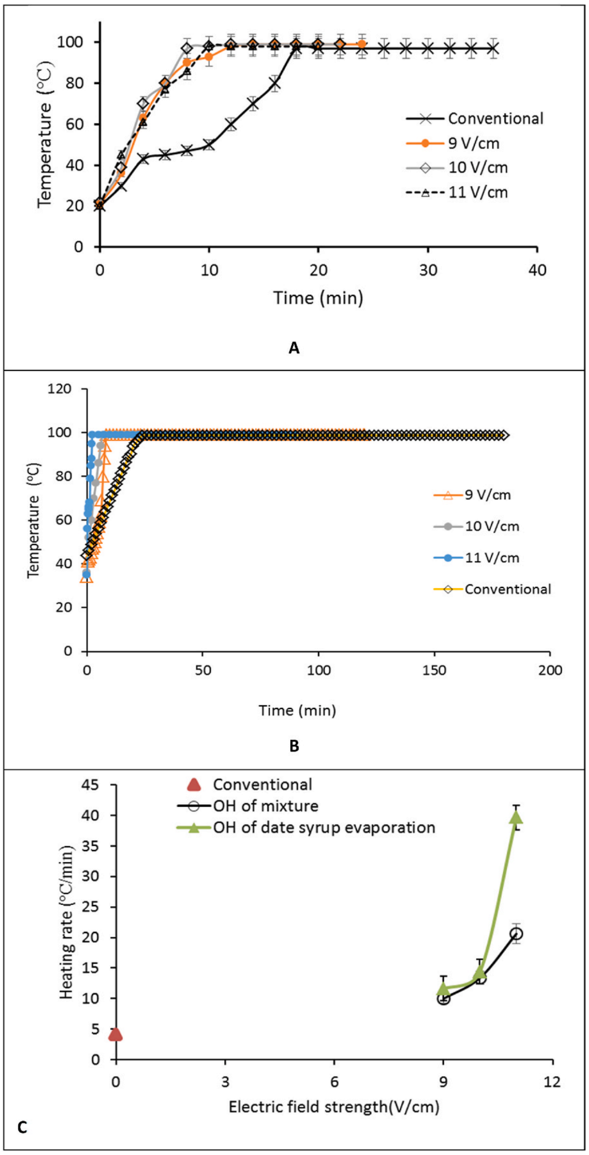

Fig. 2. The temperature of (A) mixture of dates and water, (B) date syrup extract, and heating rate (C) during CH and OH for mixture and date syrup.

2.18. Operation costs

The annual saving cost (ASC) was calculated from the following equation (13) [13];

$$ASC\left(\frac{\$}{year}\right) = total\ power\ saving\ (kW) \times annual\ hours\left(\frac{h}{year}\right) \times cost\left(\frac{\$}{kWh}\right) \tag{13}$$

2.19. Statistical analysis

The complete random design (one way) was applied in data analysis using the SPSS program version 25. The comparison between means was made using the least significant difference (LSD) at the level of significance $p < 0.05$. Three replicates were used for each experiment, and the standard deviation was also calculated.

3. Results and discussion

3.1. Temperature and heating rate

Fig. 2a shows the temperature of the date-water mixture during OH and CH. Significant differences ($p < 0.05$) appeared between the treatments of OH and CH, and the time required to reach boiling for OH was 12, 11, and 10 min, respectively. CH required a time of 18 min to reach the boiling point. From these results, it became clear that OH is faster than conventional heating. These results agreed with many studies that showed that OH is faster than CH, as it requires less time to reach the boiling point, and the increase in the EFS reduces the time needed to achieve the necessary temperature [21,32,33].

For the evaporation of date syrup, Fig. 2b shows the temperature change of date extract treated with OH and CH. The time required to reach the evaporating temperature using OH is less than CH. For example, the time needed to get the evaporating temperature of 99 °C was 2.3 and 23 min with OH and CH, respectively. The results also showed that the time required for evaporation decreased with the increase of the EFS. For example, when the EFS increased from 9 to 11 V/cm, the time needed for evaporating date syrup decreased from 120 to 90 min, respectively, and this is due to the increase in the input power, which led to an increase in the evaporation speed. The evaporation of date syrup required a time of 180 min, which is higher than the OH, and this is because the heating process takes place in the beginning through hot surfaces (conduction) to the date syrup, and then heat is transmitted through convection, and this requires a more significant time for heating.

The heating rate of the dates and water mixture, Fig. 2c, showed that the heating rate was more significant when using the EFS 11 V/cm, reached 20.61 °C/min, and was lower when using the CH, reached 5.00 C/min. For the evaporation of date syrup, the heating rate increased from 11.64 to 39.60 C/min when the EFS was increased from 9 to 11 V/cm. It is higher than the CH (4.11 C/min) due to energy losses occurring during CH as heat is transferred from outside to inside. During OH, most of the heat energy is converted into heat inside the extractor. Al-Hilphy [34] mentioned that the OH rate increases with the supply voltage of the water-eucalyptus mixture. They also found that the differences between OH and CH were significant ($p < 0.05$).

3.2. Chemical composition

The moisture, fat, protein, ash, fiber, and sugar of date fruits were 75.93 ± 2.11, 0.23 ± 0.01, 2.47 ± 0.04, 1.61 ± 0.02, 6.75 ± 0.12, and 13.01 ± 0.11%, respectively (Table 3). The titratable acidity and pH were both 0.05% and 6.10, respectively. Hussain, Farooq [35] revealed that the total sugar of Sukari variety date fruit was 78.5%. As Al-Hilphy, Al-Fekaiki [15] indicated, the moisture, fat, protein, ash, fiber, and sugar of the Sukari variety date were 12.598, 1.681, 2.520, 0.241, 6.86, and 78.01%, respectively.

3.3. Specific energy consumption and thermal energy efficiency

The results in Table 4 showed that the SEC decreased with the increase of the EFS. When the EFS increased from 9 to 11 V/cm, the SEC decreased from 4036.36 to 3073.63 kJ/kg. It may be due to the decrease in the evaporation time with the increase in the EFS and heating rate. The results also showed that the SEC using the CH amounted to 22470.54 kJ/kg, significantly higher than the OH parameters because the CH process requires more time. After all, the heat transfer to the extract is through conduction (hot surfaces) and convection. Cevik [36] found that the energy consumption for concentrating verjuice juice by OH decreased from 273.23 to 261.76 kJ/kg when the EFS was increased from 13 to 19 V/cm.

As for energy efficiency, the results showed that the thermal energy efficiency ranged from 75.43 to 99.67%. Cevik [36] stated that the thermal energy efficiency of concentrating verjuice juice by OH ranged between 71.27 and 75.22%, and they attributed the reason for this to the increase in heat generation in the sample and the decrease in energy lost during evaporation. Darvishi, Salami [37]

Table 3
Chemical composition of Sukari cultivar date fruits.

MC (%)	Fat (%)	Protein (%)	Ash (%)	Fibre (%)	Sugar (%)	pH	Titratable Acidity (%)
75.93 ± 2.11	0.23 ± 0.01	2.47 ± 0.04	1.61 ± 0.02	6.75 ± 0.12	13.01 ± 0.11	6.10 ± 0.00	0.05 ± 0.002

announced that the thermal energy efficiency of concentrated mulberry samples ranged between 66.61 and 74.27%. The thermal energy efficiency of traditional evaporation reached 8.17% due to increased heat loss, which increased energy consumption.

3.4. pH and physical properties

Table 4 shows the productivity, moisture, pH, and physical properties of date syrup extracted by OH and CH. The results showed that the productivity of OH of date syrup ranged between 0.206 and 0.268 kg/h and that the highest productivity was when using OH at an electric field strength of 11 V/cm, which is higher by 86.11% of CH. The time required for heating and evaporation was reduced when using OH. Increasing MC at EFS = 10 may be attributed to decreasing heat generation, which reduces the evaporation rate and increases processing time [38]. The results also showed that the change of date syrup moisture in all treatments ranged between 25 and 35% for date syrup samples treated with OH, while the moisture of date syrup treated with CH reached 27.5%. This change depends on factors such as the percentage of total solids, EC, EFS, and the number of ions in the food. Al Hilfi, Al-Fekaiki [12] found that the moisture content of thermally produced date syrup from Khadrawi dates was 31.082%. The results are close to those of Farahnaky, Mardani [39], who confirmed that the moisture content of date syrup was 24.07%. Al-Hilphy, Al-Fekaiki [15] found that the moisture content of date syrup extracted by heat (the traditional method) was 31.03%.

The pH values of date syrup extracted by OH and CH did not significantly affect ($p > 0.05$) with EFS and decreased as EFS increased. These results agreed with Assiry [16], who found that the pH of date syrup decreases after ohmic treatment, and the percentage of declined pH ranges from 2% up to 9%. It occurred because the EFS works to improve the pH, and the highest pH values appeared upon OH. Yousif, Morton [40] found the pH was 4.60 for date syrup produced in Libya and 4.14 for Iraqi date syrup. The reason for the low pH is the result of non-enzymatic structural reactions. Results in Table 4 showed that the refractive index was insignificant with the EFS ($p < 0.05$), and the highest refractive index of date syrup was 1.4755 at the EFS 10 V/cm, while the lowest refractive index of date syrup was at the EFS 11 V/cm which was 1.47. As for the density, the results showed no significant differences between CH and OH at the EFS 9 and 11 V/cm, while they differed significantly with the EFS 10 V/cm because of an increase of MC and a decrease of date syrup TSS. Density values ranged between 1.28 and 1.33 kg/m^3.

Regarding the total soluble solids of date syrup (TSS), the date syrup TSS ranged from 67 to 75%. TSS of date syrup evaporated by EFS of 10 V/cm reduced to 67.20% because of increasing MC. The highest TSS of date syrup upon conventional heating was 75%, and it did not differ significantly from the EFS of 11 V/cm, which amounted to 67%. Al Hilfi, Al-Fekaiki [12] clarified that the thermally produced date syrup concentration from Khadrawi variety dates reached 70%. The highest viscosity of date syrup was at the EFS of 9 V/cm, which was 6.38 pa. s, while the lowest viscosity was at 5.71 pa. s at the EFS of 10 V/cm. It is because of decreasing TSS and increasing MC. No significant differences existed between the electric field strengths 9 and 11 and the CH.

3.5. Modeling date syrup yield

The linear model was chosen according to statistical parameters (higher R^2, no significant lack of fit compared with other models). The model F-value of 40750.48 implies that the linear model is significant (Table 5). There is only a 0.01% chance that an F-value this large could occur due to noise [41]. *P*-values less than 0.0500 indicate that linear model terms are significant. In this case, EFS is a significant model term. The Lack of Fit F-value of 0.75 implies that the Lack of Fit is insignificant relative to the pure error. There is a 41.91% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good; it wants the model to fit. The Predicted R^2 of 0.9997 is in reasonable agreement with the Adjusted R^2 of 0.9998; i.e., the difference is less than 0.2. Adeq Precision measures the signal-to-noise ratio. A ratio greater than 4 is desirable. As illustrated in Table 5, the ratio of 363.361 indicates an adequate signal. This linear model can navigate the design space as given in equation (14). The model can be used to predict the response (syrup yield) for given levels of EFS.

$$Y = -74.3828 + 12.15\,E \tag{14}$$

Table 4
SEC, η, pH, and physical properties of date syrup extracted by OH and CH.

Properties	OH			CH
	Electrical field strength (V/cm)			
	9	10	11	
SEC (kJ/kg)	4036.36 ± 12.13^b	3847.87 ± 15.78^c	3073.63 ± 13.11^d	22470.54 ± 19.02^a
η (%)	75.43 ± 4.25^c	79.53 ± 2.23^b	99.67 ± 4.50^a	8.17 ± 4.67^d
Productivity (kg/h)	0.206 ± 0.06^b	0.241 ± 0.03^c	0.268 ± 0.01^d	0.144 ± 0.04^a
MC (%)	25.01 ± 1.50^c	33.00 ± 1.64^a	27.02 ± 1.78^b	27.50 ± 0.92^b
pH	4.65 ± 0.34^b	4.60 ± 0.13^b	4.80 ± 0.71^b	5.01 ± 0.56^a
Refractive Index	1.475 ± 0.15^a	1.470 ± 0.30^a	1.474 ± 0.32^a	1.473 ± 0.22^a
Density (g/cm^3)	1.33 ± 0.05^a	1.28 ± 0.21^b	1.32 ± 0.40^a	1.31 ± 0.44^a
TSS (%)	75.04 ± 2.10^a	67.20 ± 1.96^c	73.22 ± 2.13^b	72.50 ± 1.95^b
Viscosity (pa.s)	6.38 ± 0.12^a	5.71 ± 0.22^b	6.23 ± 0.34^a	6.17 ± 0.56^a

OH: Ohmic heating, CH: conventional heating, SEC: specific energy consumption, η: thermal energy efficiency, MC: moisture content, TSS: total sold soluble. Different letters in the column indicate significant differences between the parameters.

Y is the syrup yield (%), and E is the EFS (V/cm).

Fig. 3a shows the effect of EFS on the predicted syrup yield. The results showed that the predicted syrup yield increased as EFS increased. i.e., when EFS increased from 9 to 11 V/cm, the predicted syrup yield increased from 35 to 59.27%. It is because of an increase in water evaporation and extraction with EFS. Fig. 3b illustrates the linear relationship between predicted and actual syrup yield.

3.6. Optimization of process and validation of a model

Table 6 shows the optimization process results at optimum conditions of date syrup yield extracted by using OH. The optimum process condition was an EFS of 11.00 V/cm. These conditions provide date syrup with a predicted yield of 59.27 ± 0.114%. To check the veracity of date syrup yield by a linear model at optimized conditions, validation experiments were achieved based on the optimal (Custom) design. There are no significant ($p > 0.05$) differences between actual and predicted data using optimum conditions, and the desirability reached 0.991, which verified the response regression model validity. The experimental data of date syrup yield was higher than the conventional by 83.25%.

3.7. Color components and browning index

As for the color components, the results in Table 7 showed that the highest value of L^* was 21.47 when using the EFS 9 V/cm, followed by 11 V/cm (L = 18.627), which is less dark for the color of date syrup than the CH (L = 10.098). In contrast, the color of date syrup was darker at the EFS 10 V/cm (L = 6.471). The a^* and b^* values indicate color intensity or hue. The highest value for a^* was 0.471, b^* 4.235, and a/b 0.544 for 11 V/cm. It means that the color was a trend to be red/yellow. The results indicated that varied treatments significantly influenced the color component values. Al-Hooti, Sidhu [42] found that the L^*, a^*, and b^* of Birhi date syrup extracted by pectinase and cellulose enzymes and autoclaving methods were 10.93, 3.80, 5.30, and 7.02, 0.29, 0.77, respectively. Bahrami, Honarvar [43] depicted that the extracted date syrup's color components L^*, a^*, and b^* were 32.03, 0.006, and −0.08, respectively. The results showed that the BI was low for all samples and ranged from 15.63 to 32.99. The browning index can be used to determine the purity of the brown color (BI). Both enzymatic and nonenzymatic browning reactions can be found using this parameter. The lowest value of BI was when Ohmic heating was used with an electric field strength of 9 V/cm; it was 15.63. It is because no overheating happened.

3.8. Sensory assessment

The results in Fig. 4 showed that increasing the intensity of the electric field significantly affected all sensory traits, as the values of sensory attributes increased with the intensity of the electric field. For example, when the electric field strength increased from 9 to 11 V/cm, the color, flavor, taste, and overall acceptance increased by 21.43, 28.57, 21.21, and 32.81%, respectively. The reason for improving the sensory evaluation scores by increasing the electric field strength was to reduce the thermal treatment time by ohmic heating, and this prevents color breakdown and maintains the quality of the product. It can be concluded that the electrical field strength influenced organoleptic quality. Eltawil, Algonaian [5] found that the general acceptance characteristic of date syrup made by heating using a water bath was 9, which is higher than date syrup made by air heating and conventional heating. The score of OH at 11 V/cm was higher than CH treatment by 31.25, 12.50, and 14.28, 266%, respectively, because conventional heating causes local overheating, which affects the sensory attributes. The obtained data revealed that extraction and evaporation of date syrup using ohmic heating gained the highest scores of sensory attributes.

3.9. Storage time of date syrup and kinetic models for decreasing pH

Fig. 5 shows the pH of date syrup extracted by OH and CH vs. storage period. pH was reduced as storage time increased. When

Table 5
ANOVA for Linear model.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	820.18	1	820.18	40750.48	<0.0001	significant
EFS	820.18	1	820.18	40750.48	<0.0001	
Residual	0.1409	7	0.0201			
Lack of Fit	0.0157	1	0.0157	0.7523	0.4191	not significant
Pure Error	0.1252	6	0.0209			
Cor Total	820.32	8				
Std. Dev.	0.1419					
C.V. %	0.3194					
R^2	0.9998					
Adjusted R^2	0.9998					
Predicted R^2	0.9997					
Adeq Precision	363.3614					

EFS: electric field strength.

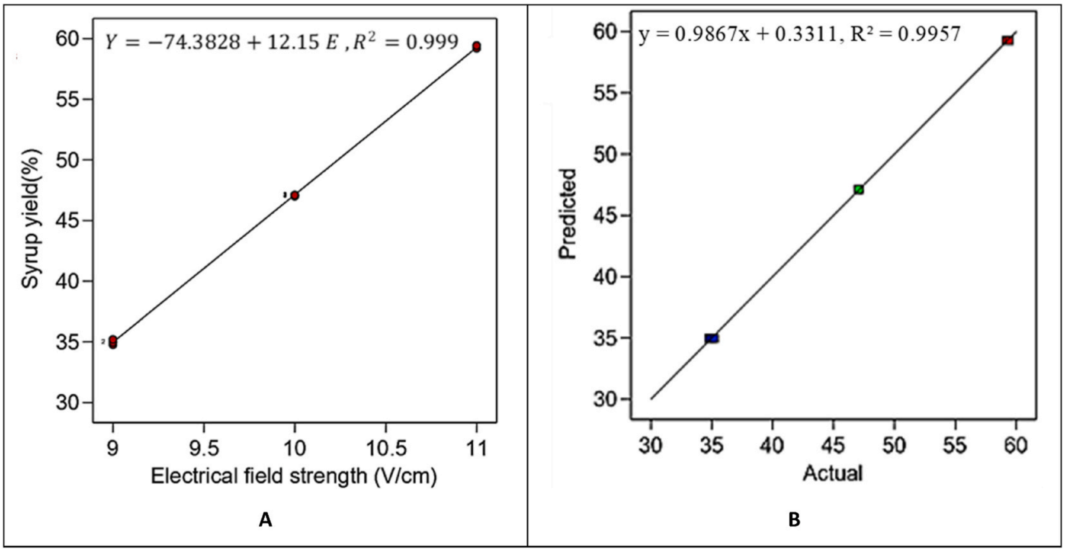

Fig. 3. Syrup yield versus EFS (A), and actual syrup yield versus predicted (B).

Table 6
Results of optimization process at optimum conditions for date palm syrup yield using OH and CH.

Independent variable	Optimum level	Predicted yield (OH) (%)	Experimental yield (OH) (%)	Conventional Heating	Desirability
Electrical field strength (V/cm)	11.00	59.27 ± 0.114[a]	60.93 ± 3.762[a]	35.4350 ± 2.991[b]	0.991

Table 7
Color Compounds and Color Index for date syrup treated by OH and CH.

Treatments	L*	a*	b*	a*/b*	BI
OH 9 V/cm	21.471 ± 1.12[a]	−0.235 ± 0.03[b]	3.294 ± 0.12[c]	−0.786 ± 0.01[d]	15.630 ± 0.99[a]
OH 10 V/cm	6.471 ± 0.34[d]	−0.471 ± 0.01[c]	2.118 ± 0.15[b]	−0.431 ± 0.03[c]	32.997 ± 1.23[c]
OH 11 V/cm	18.627 ± 1.89[b]	0.471 ± 0.06[a]	4.235 ± 0.25[a]	0.544 ± 0.02[a]	27.322 ± 2.12[b]
CH	10.098 ± 1.09[c]	−0.235 ± 0.08[b]	1.647 ± 0.98[d]	−0.186 ± 0.03[b]	15.817 ± .89[a]

OH: Ohmic heating, CH: conventional heating. Different letters in the column indicate significant differences between the parameters.

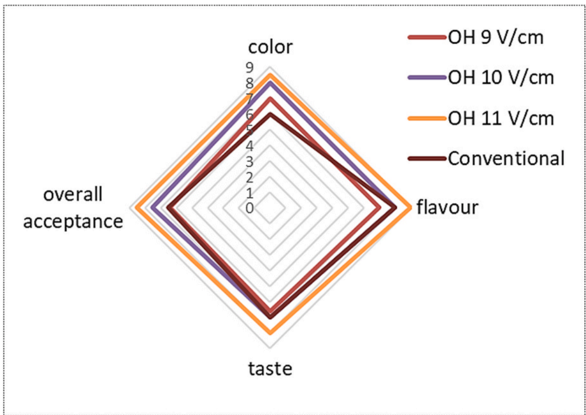

Fig. 4. Sensory assessment of date syrup extracted by OH and CH.

storage time increased from 0 to 60 days, the pH decreased from 5.13 to 5.02 using OH, respectively, and decreased from 4.4 to 3.60 using CH, respectively. It is clear from the results that the pH of date syrup extracted by OH was higher than CH because the OH did not cusses overheating for the date syrup, but in the case of CH, overheating for the date syrup occurs mainly at the walls of the container where the heat transfer to the product via heated surfaces (walls) which leads to reduce the quality. According to some studies, the chemical and biological reactions in some food products may be reflected in the change in pH. Rustom, López-Leiva [44] demonstrated that strawberry- and chocolate-flavored peanut beverages that had been aseptically filled and stored for up to six months at 5, 20, or 35 °C. Their findings showed that the beverages' pH decreased over time at all temperatures. Assiry [16] found that the pH of date juice was reduced from 5.5 to 3.5 as the storage time increased from 0 to 60 days. Saxena, Hussain [45] depicted that pH decreased with the increase in the storage period. They found that when the storage period increased from 0 to 15 days, pH decreased from 6.75–6.38.

Table 8 illustrates the constant of reaction, half-life, and statistical parameters for zero and first-order models. The findings demonstrated that the first-order model was suitable for representing OH data and CH techniques. It is because the R^2 was higher than in the zero-order model, and the RMSE and x^2 values were at their lowest levels. In the first-order model, OH and CH methods have k values of 0.003028 and 0.0035451/day, respectively, where RMSE and x^2 values were 0.008472, and 7.97E-05, and 0.061568 and 0.004738, respectively. The results revealed that the half-life for date syrup treated by OH and CH was 228.8949 with RMSE = 0.008472 and 195.5381 days, respectively. It concluded that the OH increases the shelf life of date syrup because no overheating occurs, and the heating is volumetrically, but the CH causes local overheating.

3.10. Operation cost of ohmic and conventional heating for date syrup

The maximum power of OH and CH added with the vacuum pump power (0.06 kW) was assessed in the current study to be 1.067 and 2.00 kW, respectively (Table 9). The power of OH is lower than CH because of reducing required time, current, and applied voltage for heating (Table 10), i.e., The required time using OH ranged from 45 to 120 min, but the CH required 180 min. Also, the current ranged from 5.5 to 9.7 A using OH and reached 9.09 A using CH. Moreover, the voltage ranged from 90 to 110 V using OH and reached 220 V using CH. Total Power consumption (kWh) for OH reached 0.85 kW h (Table 10). The total saved power by OH was 0.933 kW. The consumed power using OH was lower than the CH by 85.78%. The annual cost reached 1728.60 $/year and 12160.50 $/year for OH and CH heating, respectively. Therefore, the annual saving cost was 10431.75 $/year. It means that the OH can reduce the cost by 85.78%.

3.11. FT-IR spectroscopy

We measured FTIR (Fourier Transform Infrared Spectroscopy) to analyze the molecular composition of the sample. FTIR is a powerful technique that provides valuable information about the functional groups present in the material, allowing us to identify chemical bonds and gain insights into the structure and properties of the substance under investigation. Fig. 6a shows the infrared spectroscopy of a sample of date syrup treated using the OH technique, as the wavelength was obtained from 3594.22 to 3924.43 cm^{-1}. For the date syrup produced by conventional heating (Fig. 6b), the two wavelengths 3149.19 and 3553.2 cm^{-1} appeared, indicating the presence of the functional group alcohol and phenol group (*O*–H stretch). Ochida, Itodo [46] indicated that the wavelength of this functional group ranges from 3100 to 3600 cm^{-1}. Significant differences exist between the functional groups *O*–H (hydroxyl group) and *C*–H (alkyl group) regarding their chemical properties and reactivity. *O*–H and *C*–H groups have different chemical characteristics, with *O*–H groups being polar, reactive, and often involved in hydrogen bonding, while *C*–H groups are nonpolar, less reactive, and contribute to the hydrophobic nature of molecules. These differences are crucial in determining the behavior and properties of organic compounds containing these functional groups.

The wavelength of 2116.49 cm^{-1} was obtained for the OH method. Coates [47] showed that the wavelength range of this group ranged from 1990 to 2150 cm^{-1}. Ahmed, Manzoor [48] indicated that the 2100-2250 cm^{-1} wavelength represents alkynes, while the wavelength of the CH method was 2778.92 cm^{-1}. The wavelength from 2500 to 3300 represents (broad) alkene representing *O*–H stretching. The wavelength of 476.311 cm^{-1} was also obtained, which indicates the presence of the functional group Aryl disulfides. Coates [47] indicated that the wavelength range of this group ranges from 430 to 500 cm^{-1}. Wavelengths appeared in the CH method from 2075.03 to 2669, Nikalje, Kumar [49] indicated that wavelengths from 2426.98 to 2361.41 refer to *P*–H phosphine.

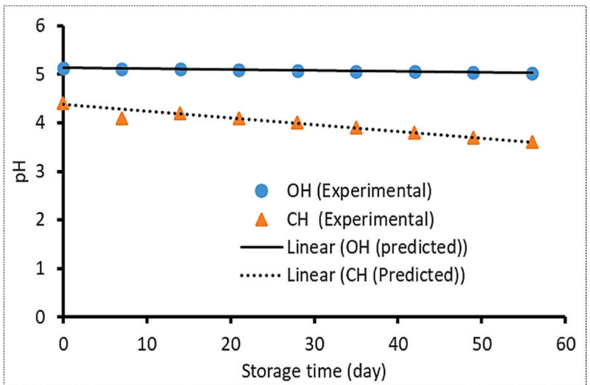

Fig. 5. pH of date syrup extracted by OH and CH vs. storage period.

Table 8
The constant of reaction, half-life, and statistical parameters.

Parameters	OH		CH	
	zero order model	first-order model	zero order model	first-order model
RMSE	0.052393683	0.008472	0.066503067	0.061568
x^2	0.003050109	7.97E-05	0.00497549	0.004738
R^2	0.984233247	0.999712	0.970913186	0.969522
K (1/day)	0.015406162	0.003028	0.0144258	0.003545
$t_{1/2}$ (day)	48.52030437	228.8949	48.04923207	195.5381

Table 9
Operation cost (in Iraq) of OH and CH for date syrup.

Characteristics	OH	CH
Power (kW) at 9 V/cm	0.495[a]	2.00[d]
Power (kW) at 10 V/cm	0.847[b]	
Power (kW) at 11 V/cm	1.067[c]	
Consumed power (kWh)	0.860[a]	6.05[b]
Total power saving (kW)	0.933	–
Annual cost ($/year)	1728.60[a]	12160.50[b]
Annual saving cost ($/year)	10431.75	–

OH: Ohmic heating, CH: Conventional heating.

Table 10
Mean of current, voltage, total Power consumption, and time for OH and CH treatments.

Treatments	Current (A)	Voltage (V)	Time (min)	Power of vacuum pump (kW)	Total Power consumption (kWh)
OH-9 V/cm	5.5	90	120	0.06	1.05
OH-10 V/cm	8.47	100	70	0.06	1.04
OH-11 V/cm	9.7	110	45	0.06	0.86
CH	9.09	220	180	0.06	6.05

Benabderrahmane, Atmani [50] indicated that the *S*–H, *O*–H, *C*–H, and *N*–H functional groups fall within the range of 2500–4000 cm^{-1}, while the C=C and C=O groups fall within the range of 1500–2000 cm^{-1}. In general, the principal results found to be *O*–H stretch functional group (alcohol) at wave number 3594.66 cm^{-1}, N=C=S (Isothiocyanate) at wave number 2116.49 cm^{-1}, *S*–*S* (Aryl disulfides) at wave number 476.331 cm^{-1} for date syrup treated by OH. As for CH, the functional groups, wave numbers, and compound classes were (N=C=S, 2075.03 cm^{-1}, isothiocyanate); (Triple bond, 2145.42 cm^{-1}, isothiocyanate); (*C*–H and H–C=O, 2669 cm^{-1}, Aldhyde); (*C*–H stretch, 3149.16 cm^{-1}, Aromatic ring); (*O*–H stretch, 3553 cm^{-1}, Carboxylic acid), respectively.

3.12. Detection of sugars in date syrup

Table 11 shows the detection of sugars in date syrup manufactured by OH and CH. The results showed a purple ring, which is an indication of the presence of total sugars, as well as the presence of reducing sugars, monosaccharides, ketone monosaccharides, and the absence of both pentoses and polysaccharides, and this is because these sugars are found only during the early stages of fruit growth. Al Hilfi, Al-Fekaiki [12] found all the total sugars, reducing and disaccharides sugar in thermally produced date syrup from Khadrawi variety dates.

4. Conclusions

The heating time decreased with the increase of the EFS. Moisture changed with the change of OH and CH treatments. The yield of date syrup using OH is higher than in the case of CH by 71.97%. The SEC of OH was lower than CH by 88.30%. The extraction efficiency of OH reached 99.67%, and for CH was 8.17%. The refractive index was variable as the parameters changed. No significant ($p < 0.05$) differences exist between the density of date syrup treated by OH and CH. The pH of date syrup treated with OH and CH was reduced as the storage period increased, and the pH of date syrup treated with OH was higher than CH. The sensory properties of date syrup treated by OH were higher than those of CH. The refractive index of date syrup was close between the treatments—an absence of pentose and polysaccharides in molasses extracted by OH and the CH. OH's annual costs and power consumption were lower than CH's by 57.65% and 72.65%, respectively. The linear model can predict the date syrup yield with a meager error rate.

The optimization results revealed that the optimal treatment for the EFS was 11 V/cm, which gives the highest yield of date syrup. The color and BI compounds were improved using OH compared with CH, and the half-life of date syrup produced by OH was higher than CH by 17.06%. As one of the Sustainable Development Goals (SDGs), it can also help farmers and the food industry by allowing

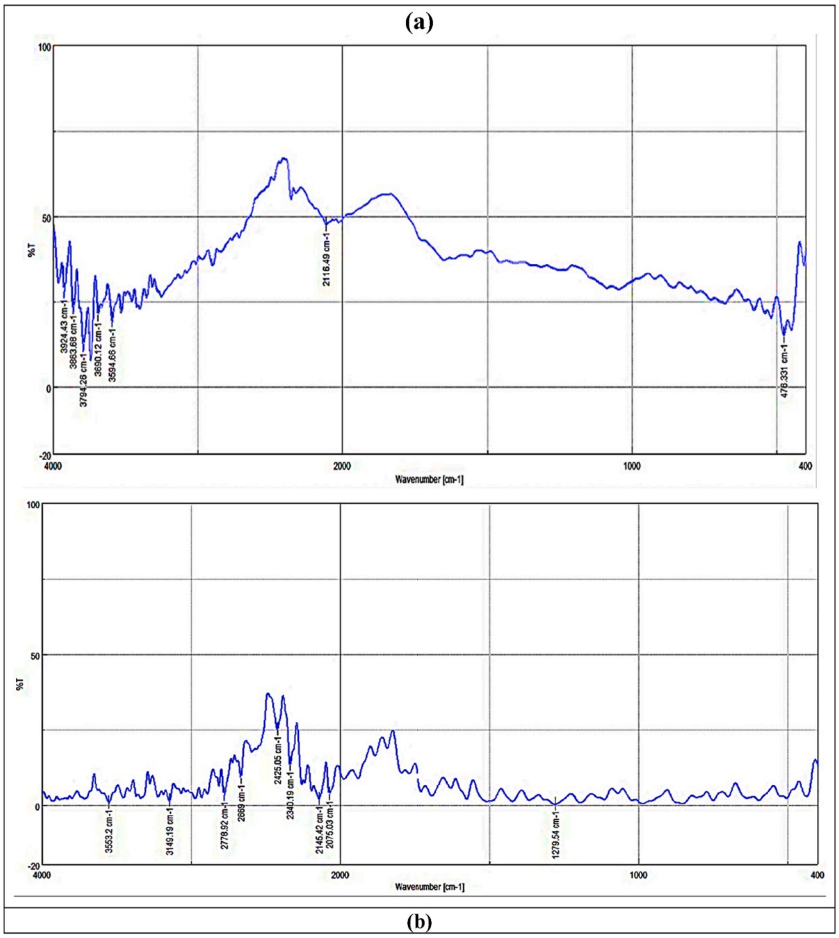

Fig. 6. FTIR spectrum of date syrup extracted by a: OH, and b: CH.

Table 11
Detection of sugars in date syrup manufactured by OH and the CH.

Treatments	total sugars	reducing sugars	monosaccharides	ketone monosaccharides	pentoses	polysaccharides
OH 9 V/cm	+	+	+	+	–	–
OH 10 V/cm	+	+	+	+	–	–
OH 11 V/cm	+	+	+	+	–	–
CH	+	+	+	+	–	–

OH: Ohmic heating, CH: conventional heating.

them to process the underutilized date fruit and create a high-quality, value-added product to improve resource efficiency.

Ethical concern

The sensory analysis was done per established ethical guidelines, and informed consent was obtained from the participants.

Author contribution statement

Asaad R. Al-Hilphy, Thamer-K.M. Al-Behadl, Atheer A. Al-Mtury, Arzaq A. Abd Al-Razzaq, Ayoub S. Shaish: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Lan Liao, Xin-An Zeng, Muhammad Faisal Manzoor: Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of interest's statement

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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Appendix A. Supplementary data

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