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Influence of infrared radiation drying on the Physicochemical Attributes of Date Powder

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Abstract

This study investigated the effect of different infrared radiation (IR) intensities (0.076, 0.14, and 0.223 Wcm^{-2}), airflow velocities (0.5, 1, and 1.5 ms^{-1}), and maltodextrin concentrations (0%, 20%, and 40%) on the physicochemical quality attributes of Sukkari date powder. Results revealed that the treatment conditions affected the quality attributes of date powder at different magnitudes ($P < 0.05$). Increasing the IR intensity and maltodextrin concentration reduced the drying time of date paste from 670 min to 25 min, whereas increasing airflow velocity increased the drying time of the paste ($P < 0.05$) from 70 to 265, 140 to 480, and 245 to 670 min at radiation intensity of 0.228, 0.152, and 0.076 Wcm^{-2} respectively at 0% maltodextrin. Increasing IR intensity increased the total color change (ΔE), moisture content, total phenolic content (TPC), DPPH antiradical activity, and glucose content but reduced the drying time, pH, and sucrose and fructose contents ($P < 0.05$). Increasing maltodextrin concentration in the powder increased the pH and glucose contents and reduced the drying time, ΔE, acidity, TPC, DPPH antiradical activity, and fructose and sucrose contents ($P < 0.05$). Increasing airflow velocity increased the drying time, pH, TPC, DPPH antiradical activity, and fructose content but reduced ΔE, acidity, and glucose and sucrose contents of date powder ($P < 0.05$). Overall, incorporation of maltodextrin into date powder together with the application of air velocity resulted in the production of date powder with good physicochemical quality and removed the negative impacts of IR radiation and temperature on the quality attributes of Sukkari date powder at the optimal condition of 40% maltodextrin, radiation intensity of 0.228 Wcm^{-2}, and airflow velocities of 1.5 ms^{-1}.

Keywords: Bioactive properties; DPPH antiradical activity; maltodextrin; Sukkari.

1. Introduction

The cultivation of date palm (*Phoenix dactylifera L.*) has expanded in recent decades to areas beyond its traditional growing desert and semi-desert regions in Middle East and North Africa; it is regarded as an important economically efficient crop for the production of highly nutritious fruits [1]. Global date fruit production reached 9.7 million tons in 2021, and Saudi Arabia ranks second globally in date production, with a total output of 1.6 million metric tons in 2021 [2]. The large production of date fruits in Saudi Arabia necessitates the need for the development of proper preservation and beneficial utilization techniques. As date fruit contains several essential nutrients such sugars, protein, vitamins, and minerals, it is highly perishable in its fresh form; thus, it needs special handling, storage, and processing treatments [3, 4]. The surplus of date fruits produced in Saudi Arabia is not fully utilized, and some are lost if not

processed into value-added products or more stable forms such as date powder.

The production of powder from date fruits can add economic value and increase the technological applicability of dates in various products [5]. Date

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powder is generally obtained by drying date paste or syrup, followed by grinding into fine powder [6]. Date paste and syrup are very sticky due to the presence of substantial amounts of reducing sugars, mainly glucose and fructose, which make the production of date powder challenging [6]. Low-molecular-weight anticaking agent such as maltodextrin and gum arabic can be used during date powder production to decrease stickiness and improve the glass transition of date powder [6, 7]. Maltodextrin is a low-molecular-weight partially hydrolyzed starch that is used in food application for the encapsulation of essential nutrients and as anticaking agent due to its low cost, low viscosity, high water solubility, and acceptable taste and aroma [8].

Drying processes such as spray drying [5, 10, 6], vacuum drying [3], solar drying [11], foam-mat freeze-drying [12, 7], microwave drying [13], hot air drying [14], and cabinet dryer [15] have been used for production of date powder using different drying aid agents. Infrared (IR) is a form of electromagnetic radiation in which heat transfer does not occur through a medium. In comparison to conventional heating, IR heating improves nutritional value and sensory properties rapidly and affordably, with the added benefits of rapid production and simple installation. Infrared radiation (IR) drying is a powerful technique that is used individually or in combination with other techniques for drying of various fruits and vegetables [16]. However, the application of IR for drying of date fruits and powder production is scarce. Therefore, this study was conducted to utilize IR for the production of date powder from the Sukkari date cultivar. The effects of different IR radiation intensities, airflow velocities, and different concentrations of maltodextrin on the physicochemical properties of date powder were assessed.

2. Materials and methods

2.1. Materials

Mature Sukkari date fruits at Tamar stage (moisture content 20–23.5 (%w.b.)) were purchased from date markets in Hail and Qassim districts, Saudi Arabia, during the harvesting season (June 2021). The samples were manually sorted, packed in carton boxes (capacity of 50 kg) internally lined with polyethylene bags, transported under cool conditions to the laboratory, and stored at 5 °C for further use.

2.2. Preparation of date paste

The dates were washed with water, and the excess water was removed with tissues. The kernels were then removed. The date fleshes were minced by using a laboratory-scale mincer (Al Halees Center, Jeddah, KSA) containing asynchronous motor (1320 W, 60 Hz single phase, 220–240 V, Italy) to make a smooth paste. Thereafter, different amounts of maltodextrin (0%, 20%, and 40% w/w) were added to the date paste, and the mixture was homogenized for 5 min using a laboratory-scale mixer (KM070, 1100 W, Kenwood, China). The mixture was then formed into sheets (2 × 2 cm dimensions, 3 mm thicknesses), sealed in plastic containers, and stored in the freezer until used for drying experiments (Figure 1. Prior to the drying process, the paste was defrosted, and placed at room temperature for 2 h.

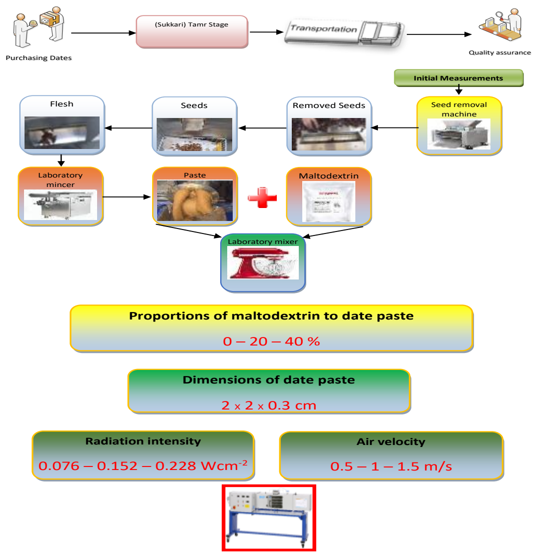

Fig. 1: Preparation of date paste and powder production

2.3. Infrared (IR) drying process

In this study, we utilized an IR dryer consisting of a 2340 mm drying channel length with internal dimensions of 350 × 350 mm, 0–3 kW electric heaters, a 0.033 kW air circulating fan, a balance (0–40000 g range), a drying chamber made of 1.5 mm sheet of galvanized metal, and 12 IR halogen lamps (0.5 kW; Figure 2). The drying chamber was shielded from inside with aluminum foil sheets for the reflection of IR over the date paste. The IR halogen lamps were installed inside the chamber facing the samples, and a pyrometer sensor (model H-201) was used to measure radiation intensity. For the drying process, date paste samples were uniformly spread on holding trays in the chamber facing the IR lamps. The samples were adjusted by height-adjusting screws, and the required radiation intensity was achieved by adjusting the height and voltage of lamps by using a voltage regulator. The drying experiments were carried out at an inlet air temperature of 40 °C [17], three radiation intensities (0.076, 0.14, and 0.223 W cm^{-2}), and three air velocities (0.5, 1, and 1.5 ms^{-1}).

Changes in the samples' mass were noted per minute for the first 5 min, every 5 min during the first hour, every 10 min during the second hour, every 15 min during the third hour, and every 20 min until the samples' moisture content reached about 2–2.5 (% b.w.). Dried samples were cooled in desiccators containing silica gel at room temperature for 5 min. About 100 g of dried samples was subjected to 10 s of grinding (General Electric Co., Fairfield, CN, USA), and the fine powder was immediately sealed in plastic bags to avoid moisture from the air.

2.4. Total color change (ΔE)

A colorimeter (Nix Sensor Ltd. 175, Hamilton, Ontario, Canada) was used for the analysis of the surface color attributes (L*, lightness; a*, redness; b*, yellowness) of date powder in triplicates. The Δ was calculated using the following equation:

$$\Delta E = \sqrt{(L_0 - L_f)^2 + (a_0 - a_f)^2 + (b_0 - b_f)^2}$$

2.5. Determination of moisture content, pH, and acidity

The moisture content of date powder was assessed by air oven drying of 2 g of samples at 105 °C for 24 h until achieving a constant weight (method No. 940.09, AOAC, 2007), and the results were expressed as a percentage of the weight loss of the samples. For the determination of pH and acidity, 10 g of date powder was suspended in 100 mL of distilled water and filtered (Whatman No. 42), and the filtrate was used to measure the pH and acidity. The pH of the filtrate was assessed using a digital pH meter model 3510 (Jenway, the UK). The acidity was measured by titration of 10 mL of filtrate against 0.1 N NaOH using phenolphthalein as an indicator and expressed as % lactic acid (method No. 962.19, [18]).

2.6. Determination of bioactive properties

The bioactive properties (total phenolic content [TPC] and DPPH antiradical activity) of date powder were determined using previously described methods [19]. Prior to the analysis of bioactive properties, date powder extract was prepared by extracting 5 g of date powder in 100 mL of 80% methanol at 60 °C for 3 h, followed by filtration and preservation of the extract at 4 °C for further use. For the determination of TPC, 200 µL of extract was mixed with 400 µL of diluted Folin–Ciocalteu (FC) reagent and 1000 µL of Na2CO3 solution (20%), and the mixture was vortexed and kept at room temperature for 2 h. The absorbance was measured at 765 nm (PD-303UV, Apel, Saitama, Japan), and the results were expressed as mg GAE/g. DPPH antiradical activity was assessed by mixing 500 µL of extract with 1000 µL of methanolic DPPH solution (250 mM), followed by incubation of the reaction mixture at room temperature in the dark for 10 min and measuring the absorbance at 517 nm. The antiradical activity was expressed as a percentage of DPPH reduction.

2.7. Determination of sugars

The sugar (sucrose, glucose, and fructose) content of date powder was assessed by HPLC [20]. In brief, sugar extract was prepared by adding 5 g of date powder and 1 g of calcium carbonate to 300 mL of distilled water. The mixture was boiled in a water bath for 30 min and combined with 3 mL of concentrated lead acetate. We then added 500 mL of distilled water. After stirring the mixture until it was clear, it was filtered using a Buchner funnel, followed by the addition of small amounts of potassium oxalate crystals and then leaving the solution alone for another 30 min. The mixture was filtered using Whatman No. 42 filter paper, followed by filtration with 0.22 µm Millipore filter membranes prior to injecting the samples (20 µL) into a Supelcosil LC-NH2 column (25 cm × 4.6 mm × 5 µm) attached to a LC10 AD HPLC

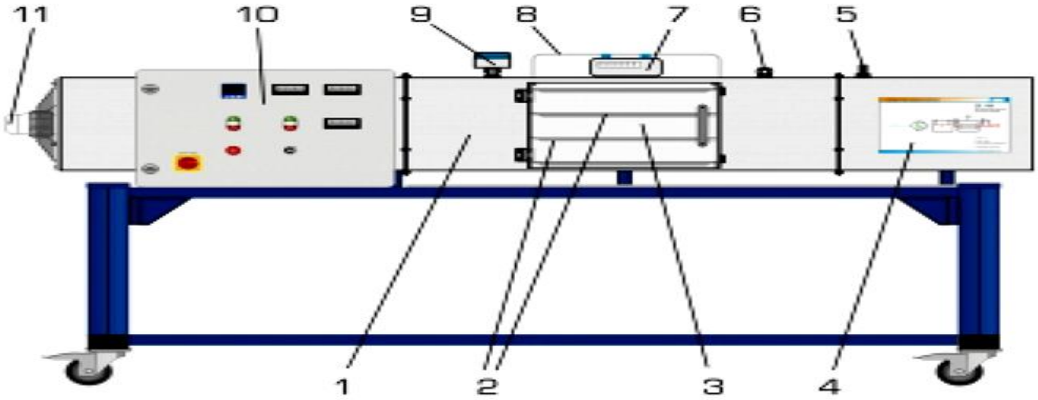

Fig. 2. Schematic of the convection infrared drying system

[1] drying channel, [2] drying plates, [3] transparent door, [4] process schematic, [5] air velocity sensor, [6] measuring point for humidity and temperature, [7] digital balance, [8] bracket for drying plates, [9] measuring point with humidity and temperature sensor, [10] switch cabinet with digital displays, [11] fan.

system (Shimadzu Corporation, Kyoto, Japan). The mobile phase was acetonitrile: water (75: 25, v/v), and the flow rate was 1 mL/min. The sugars were identified and quantified using authentic standards of sucrose, glucose, and fructose treated in the same manner.

2.8. Statistical analysis

The data of triplicate samples was collected and statistically analyzed using unidirectional analysis of variance (ANOVA) using a Minitab software version 21.2 and means were compared using Tukey Pairwise comparisons and significance was accepted at $P < 0.05$.

3. Results and discussion

3.1. Effect IR radiation intensity, airflow velocity, and maltodextrin on the drying time of date paste

The results of the changes in drying time of date paste due to variations in the IR intensity, airflow velocity, and maltodextrin concentrations are shown in Figure 3. Increasing the IR intensity significantly reduced ($P < 0.05$) the drying time of date paste, which was likely due to the increase in the temperature of date paste as the IR intensity was elevated. Similarly, previous studies have shown that increasing heat flux by IR source causes a rapid rise of the product temperature, resulting in the reduction of drying time [21, 22, 23, 24]. In addition, increasing the maltodextrin concentration from 0% to 40% significantly ($P < 0.05$) reduced the drying time. This effect was likely due to the absorption of moisture from the product by maltodextrin, which could be easily removed during drying, resulting in a reduction in drying time. High levels of maltodextrin also reduced the viscosity of product, which loosened the structure of the product, thereby increasing the rate of water evaporation and reducing the drying time [25, 26]. However, increasing the airflow velocity from 0.5 ms^{-1} to 1.5 ms^{-1} resulted in a concurrent ($P < 0.05$) increase in the drying time, probably due to the reduction of the surrounding and surface temperatures of the product. Several reports demonstrated that increasing the airflow velocity increases the drying time, and this phenomenon is attributed to the cooling effect of air at a constant inlet temperature [21, 22, 23, 24].

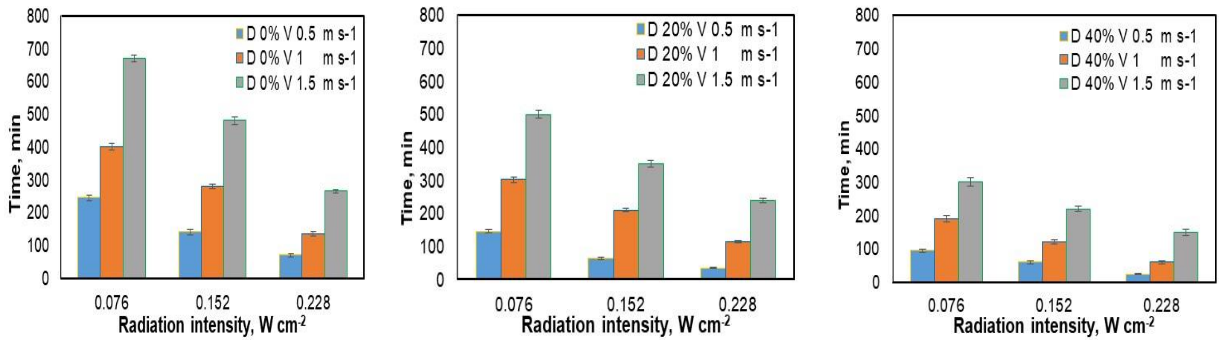

Fig. 3. Changes in drying time of the date paste at different radiation intensities, air flow velocities, and maltodextrin ratios.

3.2. Effect of IR intensity, airflow velocity, and maltodextrin on total color change (ΔE) of date powder

The results on the total color changes (ΔE) of date powder following changes in the IR intensity, airflow velocity, and maltodextrin concentration are depicted in Figure 4. Increasing the IR gradually increased ΔE to the maximum values at the highest intensity, which was likely due to increased temperature at high IR intensity, leading to increasing darkness (brown color) and total color changes [27]. Increasing IR powder was also reported to increase total color changes during drying of various food products [16] such as soybeans [28], pumpkin [29], and mushroom [27]. Increasing the maltodextrin concentration ($P < 0.05$) reduced ΔE of date powder to minimum levels at 40% maltodextrin due to minimal changes in color attributes of maltodextrin-containing powder [30], and probably due to the white color effect from maltodextrin which resulted in whiteness of the powder [31]. Increasing airflow velocity reduced ΔE to the minimum value at 1.5 ms^{-1}, which could be due to the cooling effects of airflow on the surface of the products, thereby reducing the color changes [32].]. Similar reports showed a reduction in ΔE as the airflow velocity increased during IR drying of okra powder [32] and hot air drying of garlic [33].

3.3. Effect of IR intensity, airflow velocity, and maltodextrin on moisture content of date powder

The results on the changes in the moisture content of date powder due to changes in the IR intensity, airflow velocity, and maltodextrin concentration are depicted in Figure 5. Increasing IR intensity generally increased the moisture content of date powder, with the highest increase being observed in the sample without maltodextrin. The incorporation of maltodextrin greatly diminished the effect of IR intensity on the moisture content as the changes in the moisture content were low at the highest levels of maltodextrin. Increasing airflow velocity to 1.5 ms^{-1} date powder without maltodextrin showed the least moisture content compared with that of maltodextrin containing samples. At the highest maltodextrin concentration (40%), the lowest moisture was evident in samples dried under the lowest airflow velocity (0.5 ms^{-1}). The increase in the moisture content following the increase in the IR intensity was probably due to the increased temperature on the surface of the paste, leading to the formation of a firm and solid surface that inhibited moisture evaporation and facilitated the retention of water inside the samples. This result was also confirmed by the reduction of moisture content as the airflow velocity increased, which reduced the negative impact of temperature on the surface of the date paste. The high moisture content in the 40% maltodextrin-containing date powder was likely due to the ability of maltodextrin to absorb water from the paste. This resulted in the product retaining a high moisture content, because the diffusion of water molecules through large maltodextrin molecules is difficult [34]. Similar changing trends of moisture content following the changes in drying temperature, power, air flow velocity, and maltodextrin ratio were previously reported [34, 27].

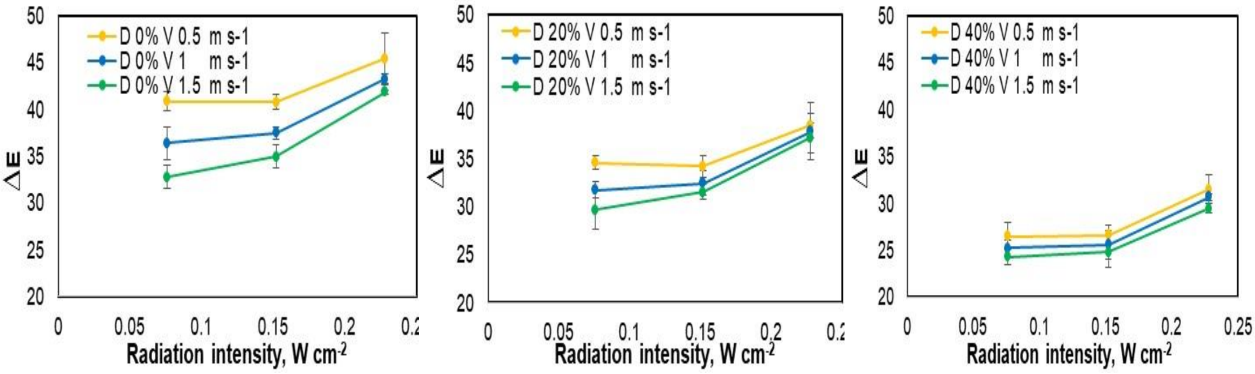

Fig. 4. Changes in total color difference (ΔE) color of the date powder at different radiation intensities, air flow velocities, and maltodextrin ratios.

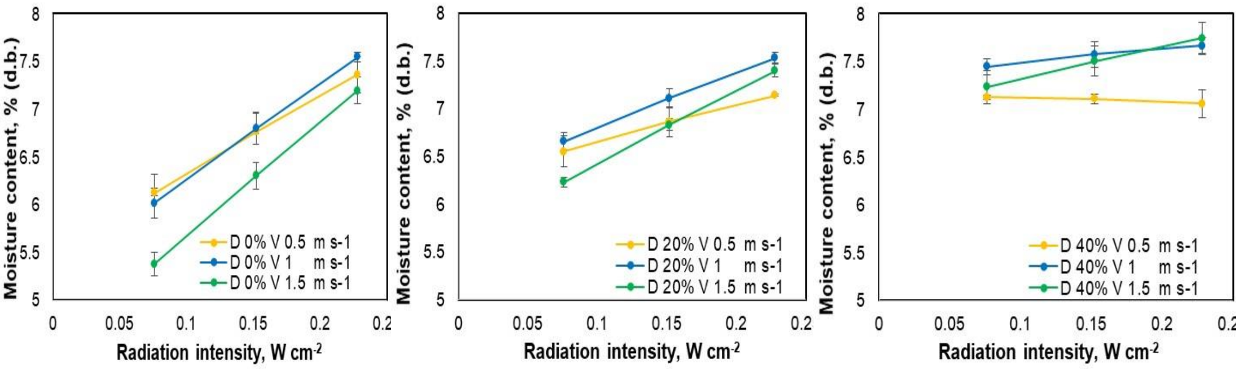

Fig. 5. Changes in moisture content of the date powder at different radiation intensities, air flow velocities, and maltodextrin ratios.

3.4. Effect IR radiation intensity, airflow velocity, and maltodextrin on pH and acidity of date powder

The results on the changes in pH and acidity of date powder due to differences in the IR intensity, airflow velocity, and maltodextrin levels are shown in Figure 6. The pH was not affected by the changes in the IR radiation velocity; however, it showed a slight reduction in the date powder at the highest airflow velocity. Increasing maltodextrin slightly increased the pH of the date powder to the highest values at 40% maltodextrin. Increasing the airflow velocity greatly increased the pH of the powder, with the highest changes in pH being observed in the samples treated at low IR intensity. Acidity was also affected by changes in the drying conditions and maltodextrin at variable magnitudes. Increasing the IR intensity exerted different effects on the acidity, with a general reduction in the samples treated at low airflow velocity. Increasing the maltodextrin concentration in the date powder resulted in a general reduction in the acidity of the product. Increasing the airflow velocity reduced the acidity of the powder, with the highest reduction rate observed in the sample without maltodextrin. The changes in pH and acidity of date powder following the variations in the drying conditions (IR intensity and airflow velocity) and maltodextrin ratio were attributed to the effects of these conditions on the Millard reaction between acids and protein, leading to a reduction in acidity and increase in pH [35]. The change in pH is closely related to the acid content. It was reported that heat treatment under high temperature over a long period of time accelerates the decrease in the acid content, thus increasing the pH values. A similar result was observed, with some acids lost due to evaporation during drying and the pH increasing as the concentration of carrier agents increased [36].

3.5. Effect IR intensity, airflow velocity, and maltodextrin on bioactive properties of date powder

The effects of IR intensity, airflow velocity, and maltodextrin levels on the bioactive properties (TPC and DPPH antiradical activity) are shown in Figure 7. Increasing the IR intensity gradually increased the TPC of date powder, which was likely due to the release of bound phenolic compounds and the free and extractable phenolic

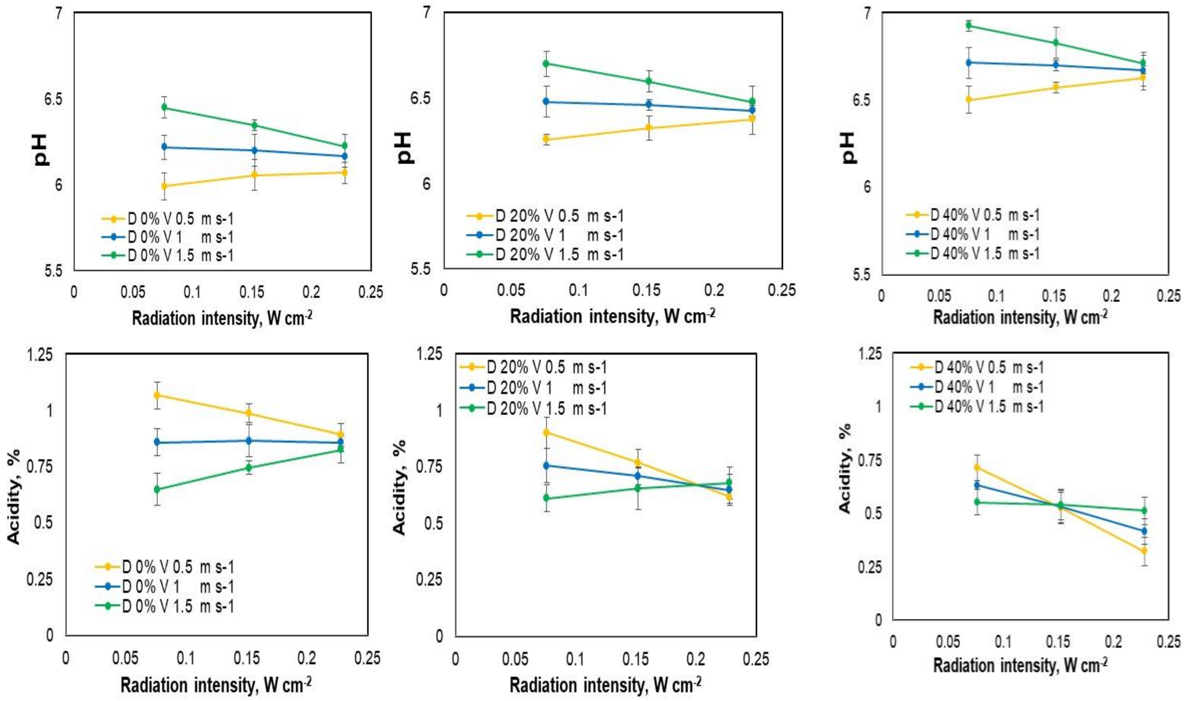

Fig. 6. Changes in pH and acidity of the date powder at different radiation intensities, air flow velocities, and maltodextrin ratios.

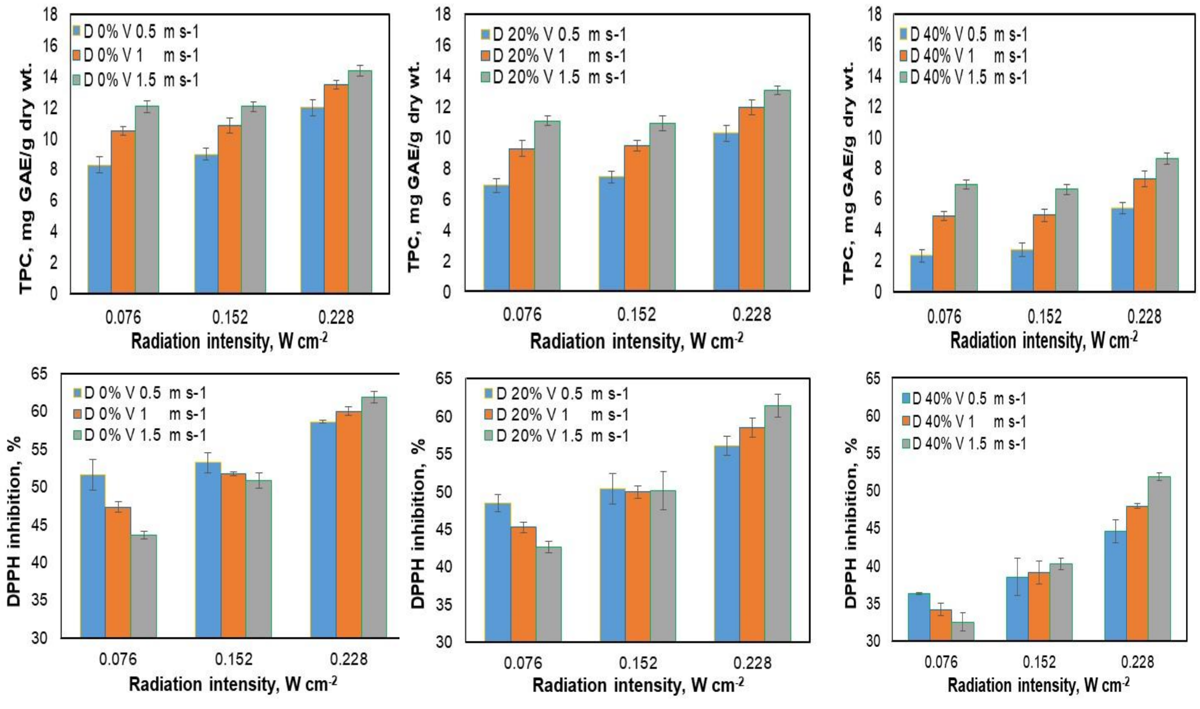

Fig. 7. Changes in TPC, and DPPH inhibition of the date powder at different radiation intensities, air flow velocities, and maltodextrin ratios.

compounds [37]. Increasing the maltodextrin concentration in date powder generally reduced the TPC of the product, with the minimum values being observed in powder with 40% maltodextrin, which could be due to the concentration effect of maltodextrin [37]. Increasing airflow velocity increased the TPC of date powder to the highest values at 1.5 ms^{-1}; where increasing the air speed may reduce the harmful effects of excessive temperature increase and create a balance between temperature and air speed. Shahdadi et al. [37] found that phenolic concentration decreased as temperature increased. Depending on the nature and sensitivity of the phenolic components, dehydration may cause an increase or decrease in phenolic concentration. This may happen when the air speed decreases and thus the temperature increases very significantly.

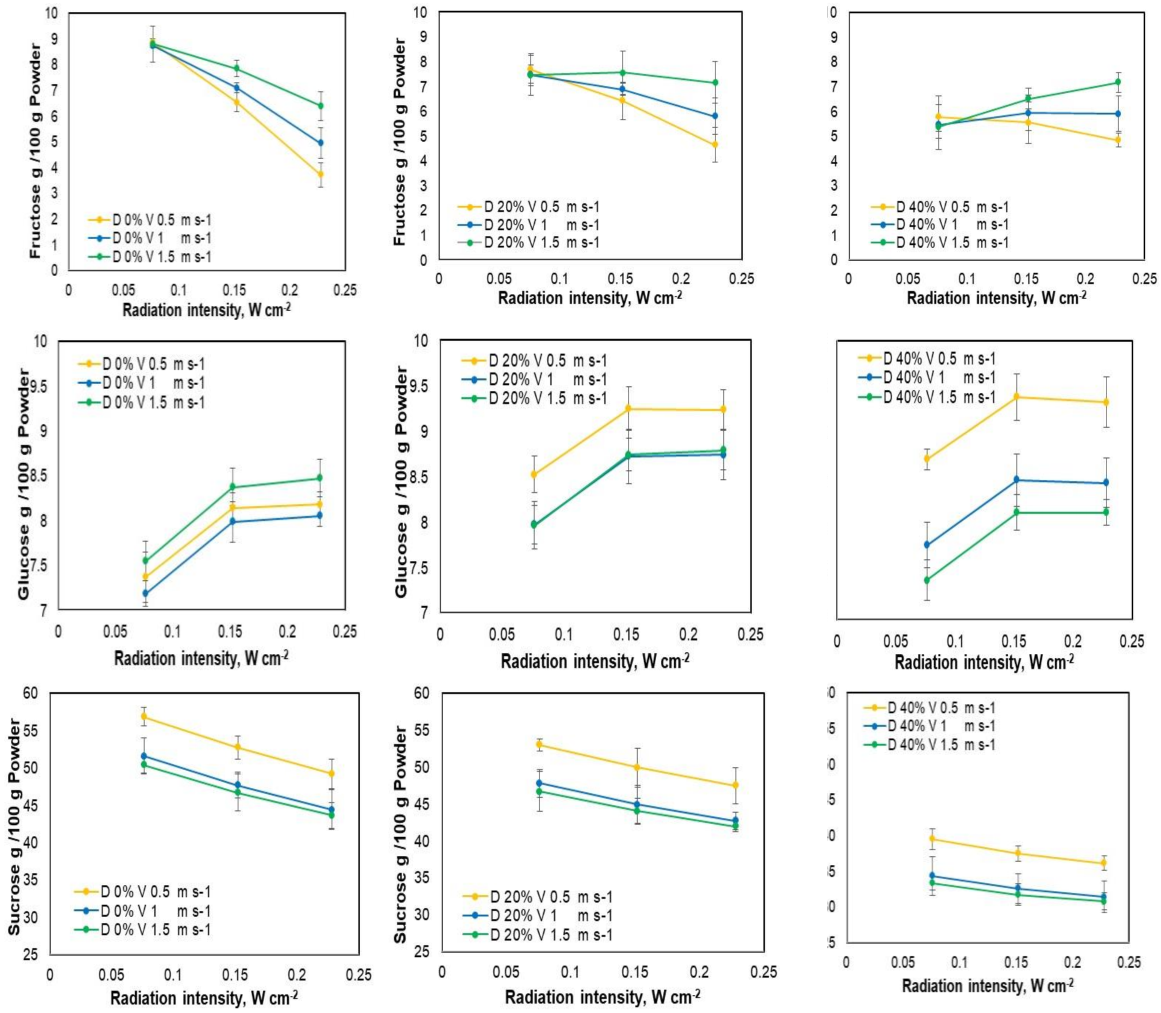

Fig. 8 Changes in fructose, glucose, and sucrose of the date powder at different radiation intensities, air flow velocities, and maltodextrin ratios.

The DPPH antiradical activity showed a similar trend to TPC. Increasing IR intensity increased the DPPH antiradical activity of date powder, possibly due to the increase in the release of phenolic compounds and synthesis of antioxidant compounds by the Millard reaction at increasing temperatures [39]. Increasing maltodextrin concentration significantly reduced the DPPH antiradical activity of date powder, reaching minimum values at 40% maltodextrin; this finding was likely due to encapsulation of phenolic compounds by maltodextrin and reduction of Millard reaction processes, resulting in reduced antioxidant activity of the product [39]. Increasing the airflow velocity reduced the DPPH antioxidant activity of the sample treated at low IR intensity, but it increased the DPPH at high IR intensity regardless of the incorporation of maltodextrin in the samples. Various researchers have reported similar observations on the changes in total phenolic compounds during drying processes and maltodextrin concentration [38, 37, 30]. Overall, IR drying improved the bioactive properties of date powder.

3.5. Effect IR intensity, airflow velocity, and maltodextrin on sugar content of date powder

Increasing the IR intensity generally reduced the levels of fructose and sucrose and increased the amounts of glucose. The fructose content of date powder without maltodextrin was high at the lowest IR intensity and then reduced to the minimum values at the highest IR intensity, whereas that of date powder with 40% maltodextrin showed a slight increase as the IR intensity increased, especially at the highest airflow velocity. Increasing maltodextrin levels in date powder gradually reduced the fructose content of the product. Increasing the airflow velocity increased the fructose content of date powder. Glucose content generally increased following an increase in the IR intensity. The incorporation of maltodextrin in the powder greatly affected the glucose content, and the effect was pronounced at the highest levels of maltodextrin (40%). Increasing the airflow velocity showed variable effects on the glucose content of date powder. In date powder without maltodextrin, the glucose content decreased at a velocity of 1 ms^{-1} and then increased again as the velocity rose to 1.5 ms^{-1}. In date powder with 40% maltodextrin, the glucose content was reduced as the airflow velocity increased. The sucrose content decreased with the increase in the IR intensity, airflow velocity, and maltodextrin levels. The changes in sugar contents during changes in drying processes (IR intensity and airflow velocity) and maltodextrin could be attributed to various reasons. The reduction in sucrose and increase in glucose and fructose were likely due to the enzymatic inversion into fructose and glucose by invertase enzymes, whereas the reduction in glucose and fructose at increased IR intensity and airflow velocity was probably due to the Millard reaction [40, 41]. The increase in the glucose content with increasing concentration of maltodextrin was probably due to the partial hydrolysis of maltodextrin during drying processes, leading to the release of glucose molecules, as glucose is the main component of maltodextrin.

4. Conclusion

IR is an innovative technique used in drying foods with high moisture content, producing powder with good quality under controlled and low temperature conditions. However, an increase in the drying temperature negatively influences the quality attributes of products. This study aimed to utilize IR for the production of Sukkari date powder and assess the impact of IR intensity, airflow velocity, and maltodextrin ratio at a constant inlet temperature of 40°C on the physicochemical quality attributes of Sukkari date powder. Increasing the IR intensity and maltodextrin concentration reduced the drying time of date paste, whereas increasing airflow velocity increased the drying time of the paste. Increasing IR intensity and airflow velocity enhanced the bioactive properties (TPC and DPPH antiradical activity) and reduced the sucrose content. The addition of maltodextrin at different concentrations enhanced the drying properties of date powder by reducing the drying time, total color change, and acidity. Thus, IR drying is effective in the production of good quality date powder when up to 40% maltodextrin is added, and airflow velocity of up to 1.5 ms^{-1} was applied to elevate the negative impact of temperature increases during IR drying.

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