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# Intermittent microwave drying and heated air drying of fresh and isomaltulose (Palatinose) impregnated strawberry

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## ABSTRACT

Fresh and osmotically pretreated (using a 35% isomaltulose solution) strawberries are highly perishable. This work aimed to dry them by intermittent microwave drying (IMD) and heated air drying (HAD) and evaluate their qualitative parameters. The sample temperature was monitored during IMD, adopting a setpoint temperature of 60 °C and continuous airflow, at room temperature. The HAD was performed by exposing the samples to air at 60 °C. IMD stood out for being faster (up to 64.91%) and consuming less energy (up to 73.16%) than HAD. During IMD, the magnetron was off for most of the time (up to 74.13%). The isomaltulose impregnation reduced drying rates in both methods, increasing drying time. Dried samples showed water activity ( $a_w$ ) within the safe range ( $a_w < 0.6$ ). The impregnation process was carried out to a reduced shrinkage product besides the enrichment with isomaltulose. Non-pretreated strawberries had lower  $a_w$ , hardness, and total color difference, and higher levels of bioactive compounds and antioxidants, especially with the IMD method. Retentions of up to 47.46%, 70.26%, and 81.18% of anthocyanins, phenolic compounds, and antioxidant capacity were obtained by IMD, respectively, concerning fresh strawberries. Therefore, IMD was an interesting alternative for fresh and impregnated with isomaltulose strawberries drying.

## 1. Introduction

The increase in concern and care for health and well-being has made consumers increasingly seek healthier foods nowadays (Tylewicz et al., 2020). Among healthy foods, fruits stand out due to the richness of nutrients, such as fiber, vitamins, minerals, and antioxidant compounds (Basu, Nguyen, Betts, & Lyons, 2014). The strawberry is one of the most consumed fruits because, besides its nutritional composition, it has desirable sensory characteristics. However, it is a highly perishable and fragile fruit. Therefore, strawberry processing is an essential and interesting strategy to add value, produce products, increase shelf life, and reduce post-harvest losses (Bhat & Stamminger, 2015).

Osmotic dehydration (OD) is a unit operation performed by immersing the food in a hypertonic solution. Mass transfers occur between the osmotic solution and the food due to the osmotic pressure gradient (González-Pérez, Ramírez-Corona, & López-Malo, 2021; Junqueira, Corrêa, & Ernesto, 2017). During OD, solute impregnation has made this process widely used to promote fruit enrichment with

beneficial health solutes (Macedo, da Silva Araújo, Vimercati, Saraiva, & Teixeira, 2021). Among the various solutes that can be used in OD, isomaltulose, also known as palatinose, is a carbohydrate that has aroused much interest due to the low cariogenic index, contributing to dental health, and the low glycemic index, minimizing glycemic peaks and insulin production, being an attractive feature for athletes and diabetics (Sawale, Shendurse, Mohan, & Patil, 2017).

The reduction of the moisture content during OD is insufficient to guarantee the stability of the osmo-dehydrated product for long periods. Several drying methods can be applied after OD (Ramya & Jain, 2017), being heated air drying (HAD) the most used one. It consists of exposing the wet material to heated air (Araújo et al., 2020). However, HAD has some limitations that led to the implementation of new drying technologies, such as microwave drying (Junqueira et al., 2017).

Microwave drying consists of wet material absorbing microwave energy and converting it to heat. The heat generated in food is mainly due to dipolar and ionic mechanisms. These tend to be oriented by the oscillating electric field generated by microwaves, resulting in the

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volumetric heating of the material (Kumar & Karim, 2019). This is an interesting method for drying fruits due to its high drying rate, low energy consumption, and preservation of heat-sensitive compounds. However, continuous exposure of the product to microwaves can generate overheating (Huang, Men, Tang, Li, & Sherif, 2021).

Intermittent microwave drying (IMD) is a discontinuous process in which the magnetron is turned on and off periodically. This allows moisture and temperature to be evenly distributed during the process, preventing overheating of the food. The IMD has lower energy consumption than HAD, and its use is associated with the production of dried foods of suitable physical, nutritional and chemical qualities (Huang et al., 2021; Junqueira et al., 2017; Keser et al., 2020; Mounir, Amami, Allaf, Mujumdar, & Allaf, 2020; Tepe & Tepe, 2020). In this context, this study aimed to evaluate the drying kinetic, energy consumption, and quality parameters of fresh and isomaltulose enriched strawberry dried by intermittent microwave drying and heated air drying.

## 2. Material and methods

### 2.1. Raw material

Fresh strawberries (*Fragaria x ananassa* cv. Camino Real) were purchased from the local market (Lavras, MG, Brazil) and selected for color, integrity, and maturation stage. The fruits were washed in running water, sanitized with chlorinated water (200 ppm for 10 min), rinsed, drained with absorbent paper, and stored at 4 °C for up to 2 days. The fruit skin was removed. Then, the inside of the strawberries was cut into 10 mm cubes (Macedo et al., 2021).

The fresh cubes had a moisture content of  $90.31 \pm 0.85\%_{w.b.}$ . The moisture content was determined by the gravimetric method established by method 934.06 of AOAC (2010), wherein the samples were placed in an oven at 70 °C, under vacuum.

### 2.2. Osmotic pretreatment

The strawberry cubes were immersed in an osmotic solution of 35% (w w<sup>-1</sup>) of isomaltulose (Beneo-Palatinit, Germany), in the proportion of 1:20 (w w<sup>-1</sup>, fruit:osmotic solution), at 25 °C, for 300 min. The osmotic process was carried out at 160 mbar for the first 20 min, followed by atmospheric pressure until completing the total time (Macedo et al., 2021). This process is called pulsed vacuum osmotic dehydration and is based on removing occluded gases in the interior of the samples (Junqueira et al., 2017). Then, the samples were removed from the osmotic solution and immersed in an ice bath for 10 s to interrupt the mass flow. The sample surfaces were drained with absorbent paper.

The conditions under which the osmotic process was carried out were determined in previous tests to obtain the maximum mass transfer rates. In the chosen condition, the isomaltulose impregnation was  $8.00 \pm 0.16\%$ . After the osmotic pretreatment, the strawberries showed a moisture content of  $76.56 \pm 1.02\%_{w.b.}$

### 2.3. Drying procedures

Fresh (non-osmotically pretreated) and osmotically pretreated strawberries were subjected to intermittent microwave drying (IMD) and heated air drying (HAD). Each drying was performed using  $60.02 \pm 0.69$  g of sample. During drying, the sample masses were measured at 5 min intervals. Drying processes were completed when the samples had a moisture content of  $10.28 \pm 0.12\%_{w.b.}$ . This value was established so that the samples of all treatments had water activity below 0.6 (Macedo et al., 2021).

#### 2.3.1. Intermittent microwave drying (IMD)

The IMD was performed in a hexagonal microwave drying cavity, 12 cm wide, 24.5 cm high. The equipment had a 12 cm long WR340

waveguide centered on one of the walls, magnetron 2M319J, perforated cover to allow the passage of drying air through the cavity (Costa, Alvarenga, Mesquita, & Petri Júnior, 2021). A fan was attached to the cavity base to promote continuous air circulation at  $0.5 \text{ m s}^{-1}$  at room temperature ( $22.89 \pm 1.17$  °C). After passing through the silica gel layer, the air presented a relative humidity of  $16.29 \pm 2.74\%$ .

The samples were placed in an 18.5 cm diameter perforated circular sample holder, positioned 3.0 cm high and in the center of the cavity. The cavity was closed. The sample holder was attached to a digital scale (Ohaus Adventurer, ARC 120, USA) to monitor the sample mass during the process.

The sample temperature was continuously measured with a type K thermocouple inserted in a strawberry cube. The microwave magnetron was triggered to heat the samples to the setpoint temperature (60 °C). Upon reaching the setpoint temperature, the magnetron was automatically turned off. With air circulation at room temperature, the sample temperature decreased below the setpoint, causing the magnetron to fire again. The on/off system allowed keeping the sample temperature close to the setpoint temperature throughout the process (Costa et al., 2021). Operating parameters were controlled by a system developed using a NI-USB6009 board and LabView software.

#### 2.3.2. Heated air drying (HAD)

HAD was performed in a tunnel dryer (Eco Engenharia Educacional, MD018 model, Brazil), with the airflow at 60 °C and  $0.5 \text{ m s}^{-1}$ . The relative humidity of the heated air was  $8.64 \pm 1.88\%$ . The samples were placed in an 18.5 cm diameter perforated circular sample holder. A digital scale (Ohaus Adventurer, ARC 120, USA) coupled to the sample holder monitored the mass of the samples during drying.

### 2.4. Drying rate (DR)

The DR was determined according to the moisture content<sub>d.b.</sub> according to Eq. (1) (Macedo, Vimercati, Araújo, Saraiva, & Teixeira, 2020; Macedo et al., 2021):

$$DR = \frac{X_t - X_{t+\Delta t}}{\Delta t} \quad (1)$$

where DR is the drying rate ( $\text{kg water kg dry solid}^{-1} \text{ min}^{-1}$ ),  $X_t$  and  $X_{t+\Delta t}$  are the moisture content ( $\text{kg of water kg of dry sample}^{-1}$ ) at  $t$  and  $t+\Delta t$ , respectively,  $t$  is the time (min) and  $\Delta t$  is the time difference (min).

### 2.5. Energy consumption

The electrical energy consumed during drying was measured with an ammeter (Hikari, HA-266 model, Shenzhen, China).

The total energy consumption was calculated according to Eq. (2).

$$EC_t = V \times I \times t \quad (2)$$

where  $EC_t$  is the total energy consumption (kWh),  $V$  is the voltage (V),  $I$  is the current (A),  $t$  is the time on (h).

The energy consumption required to remove 1 kg of water was calculated according to Eq. (3).

$$EC = \frac{EC_t}{m_0 - m_f} \quad (3)$$

where  $EC$  is the energy consumption per kg of water,  $EC_t$  is the total energy consumption (kWh) of each drying,  $m_0$  and  $m_f$  are the sample mass (kg) at the beginning and end of drying, respectively.

### 2.6. Quality analysis

The fresh and dried samples were characterized in terms of water activity, shrinkage, hardness, color, total anthocyanins, total phenolics, and antioxidant capacity.

### 2.6.1. Water activity ( $a_w$ )

The  $a_w$  of the samples was determined on an electronic hygrometer (Aqualab, series 3 TE, Washington, USA) at 25 °C.

### 2.6.2. Shrinkage

The shrinkage of the dried samples was determined by the toluene displacement method (Dehghannya, Hosseinlar, & Heshmati, 2018) and calculated according to Eq. (4):

$$\text{Shrinkage (\%)} = \left(1 - \frac{V}{V_0}\right) \times 100 \quad (4)$$

where  $V$  and  $V_0$  are the volumes ( $\text{m}^3$ ) of dried and fresh samples, respectively.

### 2.6.3. Hardness

The hardness was measured using a texture analyzer (Stable Micro Systems, TA-X2T, Surrey, England), equipped with a 50 kg load cell, a 6 mm diameter probe, test speed of  $2 \text{ mm s}^{-1}$ , and penetration distance of 3 mm. The response was expressed in Newton (N).

### 2.6.4. Color

The colorimetric parameters of the samples were obtained with the aid of a colorimeter (Konica Minolta, model CR-300, Osaka, Japan), with illuminant D65 and  $10^\circ$  viewing angle, using color scale CIE Lab. The  $L^*$  parameter represents the lightness, ranging from 0 (black) to 100 (white).  $C^*$  indicates chromaticity or color saturation. The  $h$  represents the hue of the sample, where the angles of  $0^\circ$  (or  $360^\circ$ ),  $90^\circ$ ,  $180^\circ$ , and  $270^\circ$  represent red, yellow, green, and blue angles, respectively. The total color difference ( $\Delta E$ ) of the samples concerning the fresh sample whose parameter is represented by the sub-index "0" was calculated according to Eq. (5).

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (5)$$

### 2.6.5. Total anthocyanins content (TAC)

The extract was prepared by mixing 2 g in 20 mL of acidified ethanol, using HCl (0.1%). The mixture was centrifuged at  $25400 \times g$  for 15 min. TAC was quantified by the differential pH method, according to Eq. (6) (Giusti & Wrolstad, 2001). The result was expressed in mg of cyanidin 3-glycoside per g sample<sub>d.b.</sub>.

$$\text{TAC} \left(\frac{\text{mg}}{100\text{g}}\right) = \left(\frac{(A_{510 \text{ nm}} - A_{700 \text{ nm}})_{\text{pH1}} - (A_{510 \text{ nm}} - A_{700 \text{ nm}})_{\text{pH4.5}}}{\epsilon} \times \text{MW} \times \text{DF}\right) \quad (6)$$

where MW is the molecular weight of cyanidin 3-glycoside (433.0); DF is the dilution factor;  $\epsilon$  is the molar absorptivity (22400).

### 2.6.6. Total phenolics content (TPC)

The extract for quantification of TPC was prepared by mixing 5 g in 40 mL of 50% methanol ( $v v^{-1}$ ). The homogenized mixture was left to stand for 1 h, protected from light, at room temperature. The mixture was centrifuged at  $25400 \times g$  for 15 min, and the supernatant was collected. The residue from the centrifugation was mixed with 40 mL of 70% acetone ( $v v^{-1}$ ) and left to stand for 1 h, protected from light, at room temperature. The mixture was centrifuged at  $25400 \times g$  for 15 min. The supernatant was collected and mixed with the first. The final volume was completed with deionized water up to 100 mL (Rufino et al., 2010). The extracts were kept at  $-20^\circ \text{C}$  until the analysis was carried out.

TPC was quantified using the Folin-Ciocalteu method (Waterhouse,

2003), and the result was expressed in mg of gallic acid per 100 g sample<sub>d.b.</sub>.

### 2.6.7. Antioxidant capacity (AC)

The same extract prepared for the TPC analysis was used for the AC analysis (Rufino et al., 2010; Vimercati et al., 2020). AC was quantified by the ferric reducing antioxidant power capacity (FRAP) and 2,2-diphenyl-1-picryl-hydrazyl (DPPH) methods. The results were expressed in  $\mu\text{mol}$  of ferrous sulfate per g of sample<sub>d.b.</sub>, and g sample<sub>d.b.</sub> per g of DPPH (Rufino et al., 2010).

## 2.7. Statistical analysis

The experiments were conducted in a completely randomized design, in a  $2 \times 2$  complete factorial scheme (Table 1). Data were evaluated by ANOVA. In the case of significant effects, the means were compared using the Tukey test. Each treatment was compared individually with the control (fresh) sample by the Dunnett test.

Statistical analyses were performed using the 5% probability level, using the Statistica software (Statsoft, Tulsa, USA).

## 3. Results and discussion

Dried strawberry samples, non- or osmotically pretreated, by IMD or HAD, are shown in Fig. 1S.

### 3.1. Drying

#### 3.1.1. Drying kinetic

Reductions in strawberry moisture content during the drying processes are shown in Fig. 2a. Initially, non-osmotically pretreated (fresh) and osmotically pretreated strawberries had a moisture content of 90.31%<sub>w.b.</sub> and 76.56%<sub>w.b.</sub>, respectively. Similar results were obtained by Macedo et al. (2021). Moisture contents reduced exponentially throughout the drying (Fig. 2a), as characteristic of fruit drying (Dehghannya et al., 2018; Junqueira et al., 2017; Macedo et al., 2020; Macedo et al., 2021; Macedo, da Silva; Araújo et al., 2020; Tepe & Tepe, 2020).

A relevant reduction of moisture content was observed in the first minutes of drying of non-pretreated strawberries, especially by the IMD method (Fig. 2a). This is due to the high moisture content of the fruit at

the beginning of the process, presenting a large amount of free water that can be easily removed (Huang et al., 2021). Concerning the pretreated samples, the rate of reduction of moisture content with time was more slightly. It is due to the water loss and the interaction of moisture with the incorporated solid.

**Table 1**  
Experimental conditions.

Code	Osmotic pretreatment	Drying method
Fresh	No	None
IMD	No	IMD
HAD	No	HAD
OP-IMD	Yes	IMD
OP-HAD	Yes	HAD

IMD: intermittent microwave drying; HAD: heated air drying; OP: osmotic pretreatment.

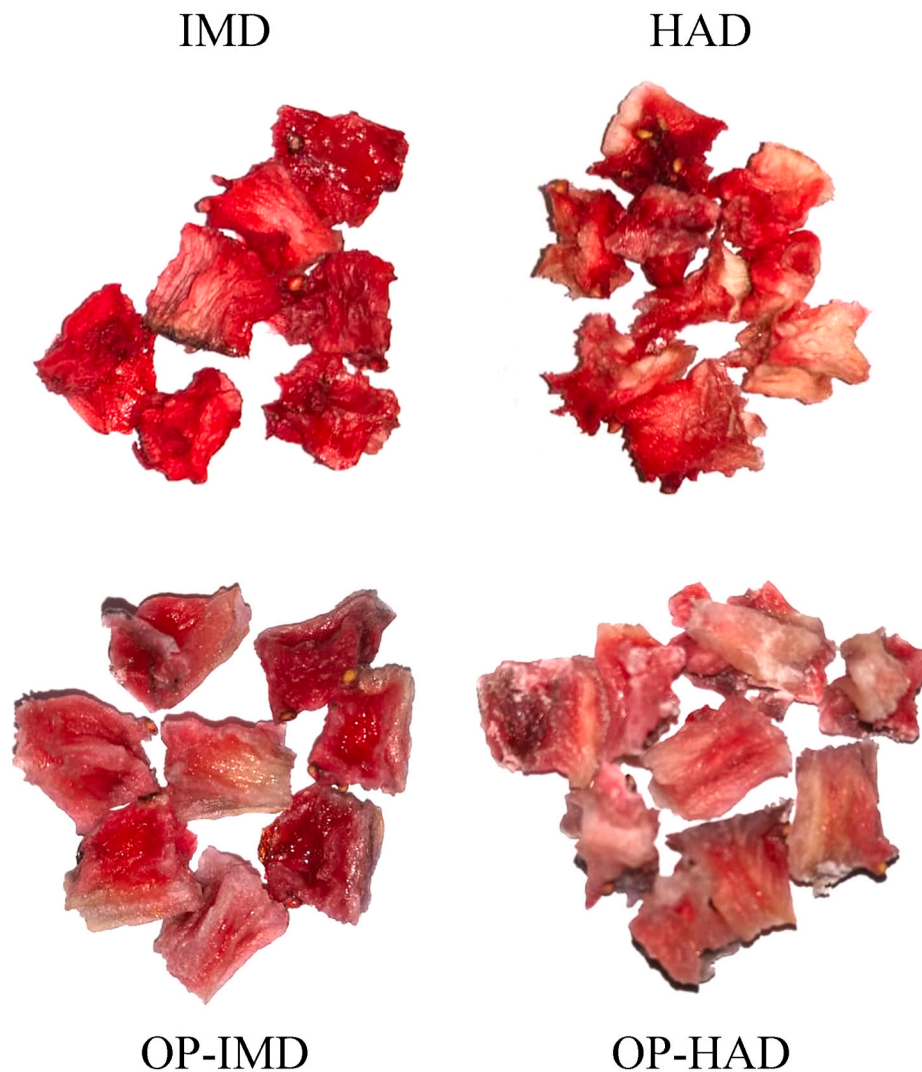


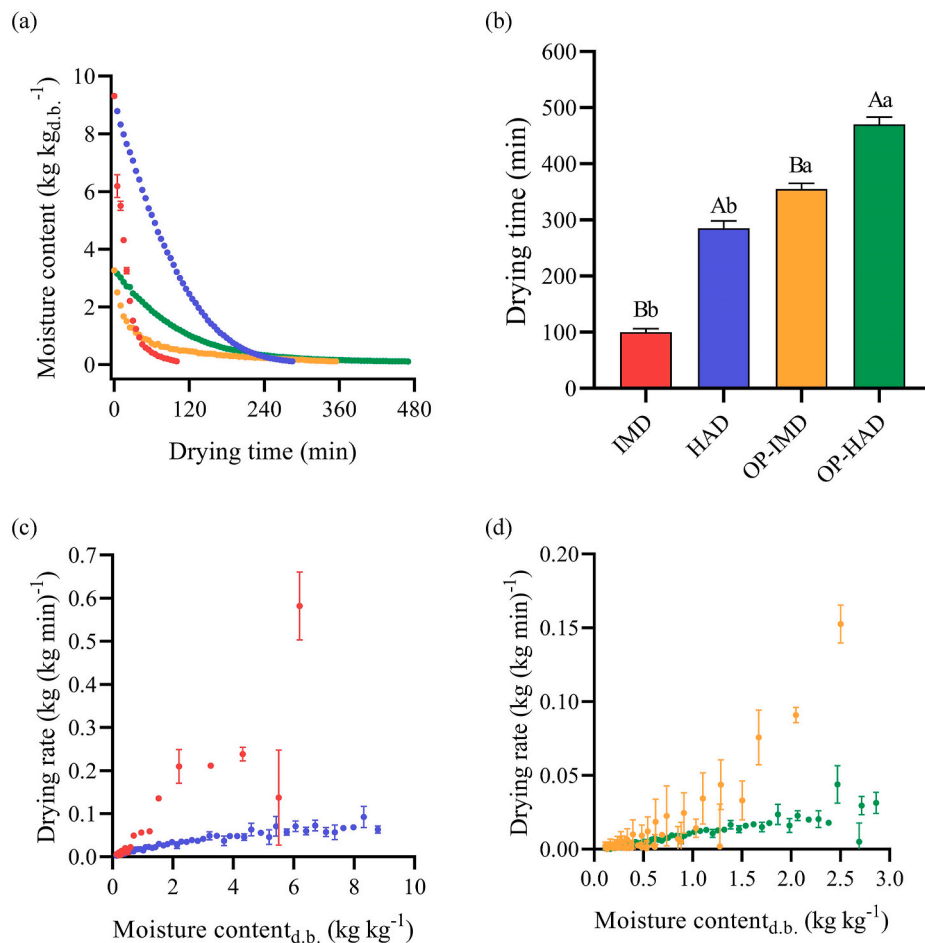
Fig. 1. S – Non- and osmotically pretreated (OP) dried strawberries using IMD and HAD methods.

In just 50 min, IMD managed to reduce the moisture content of the non-pretreated strawberry by 90.31%<sub>w.b.</sub> to 37.19%<sub>w.b.</sub>, whereas, at the same drying time, the sample had 85.23%<sub>w.b.</sub>. When dried by HAD (Fig. 2a). This highlights the IMD method is due to the volumetric heating generated mainly by the agitation of water molecules (bipolar rotation) due to the electric magnetic field, leading to a high water vapor pressure gradient between the internal and surface of the wet material, accelerating the transfer of moisture (Huang et al., 2021; Junqueira et al., 2017; Kumar & Karim, 2019; Zielinska, Ropelewska, Xiao, Mujumdar, & Law, 2020). In addition to resulting in a large water evaporation capacity, the intermittent system (power on/power off mode) minimizes the risk of sample overheating, which would result in the degradation of fruit compounds or even burning (Deghannya et al., 2018; Zielinska et al., 2020).

The drying processes required from 100 min to 470 min to reduce the moisture content of the samples to 10.28%<sub>w.b.</sub> (Fig. 2a and b). Similar drying times were found in other studies when drying strawberries (Changrue, Orsat, & Raghavan, 2008; Gamboa-Santos, Montilla, Cárcel, Villamiel, & Garcia-Perez, 2014; Gamboa-Santos & Campañone, 2019; Macedo et al., 2021; Méndez-Lagunas, Rodríguez-Ramírez, Cruz-Gracida, Sandoval-Torres, & Barriada-Bernal, 2017). For non- and osmotically pretreated strawberry drying, IMD was the method that required less time to complete the process. IMD was faster than HAD by 64.91% and 24.47% for drying non- and osmotically pretreated

strawberries, respectively (Fig. 2b). The same was observed in other studies (Huang et al., 2021; Tepe & Tepe, 2020). As discussed earlier, IMD results in volumetric heating of the material. On the other hand, drying by the HAD method is slow, as, initially, the surface of the material is heated by receiving heat from the heated air, by convection, starting the evaporation of surface water. Furthermore, there is also the conduction of heat from the surface to the interior of the material, but it is a slow mechanism, which contributes to the delay in drying. Subsequently, moisture moves from the interior to the surface of the material by mainly diffusion mechanisms due to a concentration and temperature gradient between the surface and the interior (Deghannya et al., 2018; Huang et al., 2021; Omolola, Jideani, & Kapila, 2017).

The application of osmotic pretreatment increased the drying time for both drying methods, as shown in Fig. 2b. The IMD method, including osmotic dehydration as a pretreatment, prolonged the drying time by 3.55 times and 1.65 times by the HAD method. Osmotic dehydration promoted a partial reduction in moisture content, as observed in the present study (90.31%<sub>w.b.</sub> to 76.56%<sub>w.b.</sub>). Reducing the volume of moisture in a material to be removed by complementary drying would facilitate the completion of this process. However, during the osmotic process, the solute is incorporated from the solution to the material, increasing the interaction of water with the material and decreasing the diffusivity of water, resulting in increased drying time. This same effect of osmotic dehydration on convective drying time was also observed in



**Fig. 2.** Kinetic of moisture content, on a dry basis (a), drying time (b), and drying rate of non-osmotically pretreated (c) and osmotically pretreated (d) samples.

Red: IMD; blue: HAD; orange: OP-IMD; green: OP-HAD. Values are mean  $\pm$  standard deviation,  $n = 3$ . The same uppercase letter indicates no significant difference between IMD and HAD samples. The same lowercase letter indicates no significant difference between non- and osmotically pretreated samples by the Tukey test ( $p < 0.05$ ).

other studies (An et al., 2019; Lyu et al., 2017; Macedo et al., 2021).

### 3.1.2. Drying rate (DR)

The DR of non- and osmotically pretreated strawberries are shown in Fig. 2c and d, respectively. At the beginning of the drying, the DR was higher than the end of the processes due to the large volume of water present in the samples initially (Macedo et al., 2021).

The DR showed decreasing behavior during most of the drying, with short periods of DR close to constant. Periods of constant rate were more frequent in HAD, where the evaporation rate of water from the surface of the sample was similar to diffusion within the material to the surface (Bhandari, 2006).

Among the four drying treatments, the DR of non-pretreated strawberry by IMD stood out, presenting the highest values during the process. In both drying methods, the DR of osmotically pretreated strawberries was lower than that of non-pretreated strawberries due to the higher volume of water in the non-pretreated samples. The DR by the IMD method was higher than by the HAD, mainly at the beginning of the drying. This is due to the volumetric heating capacity carried out by the electromagnetic field, causing higher water evaporation.

### 3.1.3. Sample temperature during IMD

The temperature records of the non- and osmotically pretreated strawberry during the IMD drying are presented in Fig. 3Sa and 3Sb, respectively.

Sample temperatures oscillated within a small range, as commonly occurs in IMD (Khan, Welsh, Gu, Karim, & Bhandari, 2020; Pham, Khan, & Karim, 2020), in which non- and osmotically pretreated strawberries had mean values very close to the setpoint temperature (60 °C), as shown in Table 2.

There were high peaks in sample temperature for a short period, between times 4.8 and 6.5 min during drying of the non-pretreated sample (Fig. 3Sa). This may be due to non-pretreated strawberries initially presenting high free water content, causing increased agitation of water molecules by microwaves, resulting in rapid heating of the sample. On the other hand, high peaks did not occur in the drying of the pretreated sample (Fig. 3Sb), as initially, the pretreated sample had a lower free water content due to water loss during the osmotic process and the interactions of the water with the incorporated solids.

Sample temperature fluctuated during IMD is due to the on/off system. When drying starts, the magnetron is turned on, causing the material to heat rapidly (Fig. 3Sa and 3Sb), as reported in other studies (Khan et al., 2020; Pham et al., 2020). In addition to the fact that the waves generate volumetric heating, the small initial size of the cubes (10 mm) favors the rapid heating of the material. As soon as the material reaches the setpoint temperature, the magnetron is automatically turned off. The strawberries cool down due to air circulation at room temperature ( $22.89 \pm 1.17$  °C) and water evaporation. When the sample has a temperature lower than the setpoint, the magnetron is switched on again.

The peak and base points reflect the heating times and the tempering times (Fig. 3Sa and 3Sb), respectively. They indicate the times when the microwave is turned on and off, respectively (Pham et al., 2020). Table 2 shows the percentage of time the magnetron was on and off for both IMD. For both the non- and osmotically pretreated strawberry, the magnetron remained off for most of the drying time, especially when drying the pretreated strawberry, where the magnetron remained off for approximately  $\frac{3}{4}$  of the time. Furthermore, the on and off cycles lasted  $10.45 \pm 3.33$  s and  $12.26 \pm 4.15$  s for non-osmotically pretreated strawberries, respectively. For osmotically pretreated strawberries, the

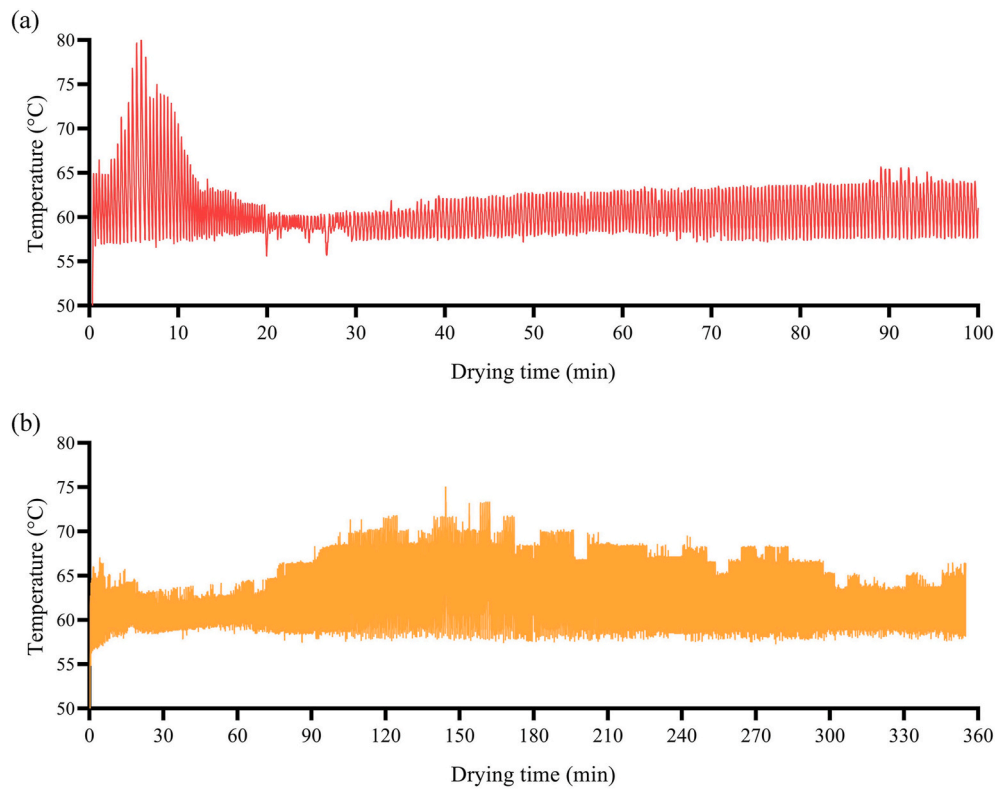


Fig. 3. S – Temperature of non-osmotically pretreated (a) and osmotically pretreated (b) samples during IMD.

Table 2

Sample temperature, percentage of magnetron on and off time during IMD and OP-IMD.

Code	Sample temperature (°C)	On (%)	Off (%)
IMD	60.542 ± 3.312 a	46.11 ± 1.80 a	53.89 ± 1.80 b
OP-IMD	61.685 ± 3.153 a	25.87 ± 0.61 b	74.13 ± 0.61 a

Values are mean ± standard deviation, n = 3. The same lowercase letter indicates no significant difference between non- and osmotically pretreated samples by the Tukey test ( $p < 0.05$ ).

on and off cycles lasted  $7.71 \pm 4.36$  s and  $22.11 \pm 6.62$  s, respectively.

### 3.1.4. Energy consumption

Drying is a unit operation known as an energy-intensive process, especially methods that use heated air (Khan et al., 2020). Therefore, the evaluation of this response becomes very important, aiming to minimize it. The energy consumption for each drying is shown in Fig. 4. To complete the drying, 155.45 to 1203.64 kWh kg of water<sup>-1</sup> removed were required. Similar results were found in other studies (Huang et al., 2021).

Microwave drying had lower energy consumption than HAD (Figs. 4), 73.16% and 68.99% lower in drying non- and pretreated strawberries, respectively. This is due to the intermittent system (on/off), in which the magnetron was off for most of the drying time, as discussed above. Other studies also reported that the on/off system favors the reduction of energy consumption (Cao, Chen, Islam, Xu, & Zhong, 2019; Huang et al., 2021). Furthermore, the convective method requires heating a large amount of air, resulting in high energy demand. Comparing the drying of non- and pretreated strawberries, the second required a higher amount of energy, linked to a longer drying time due to higher difficulty in eliminating the bounded water.

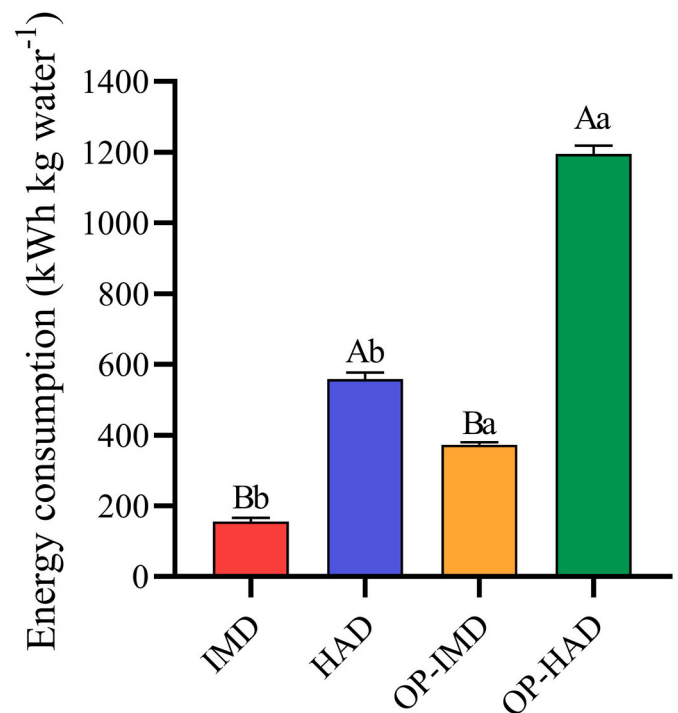
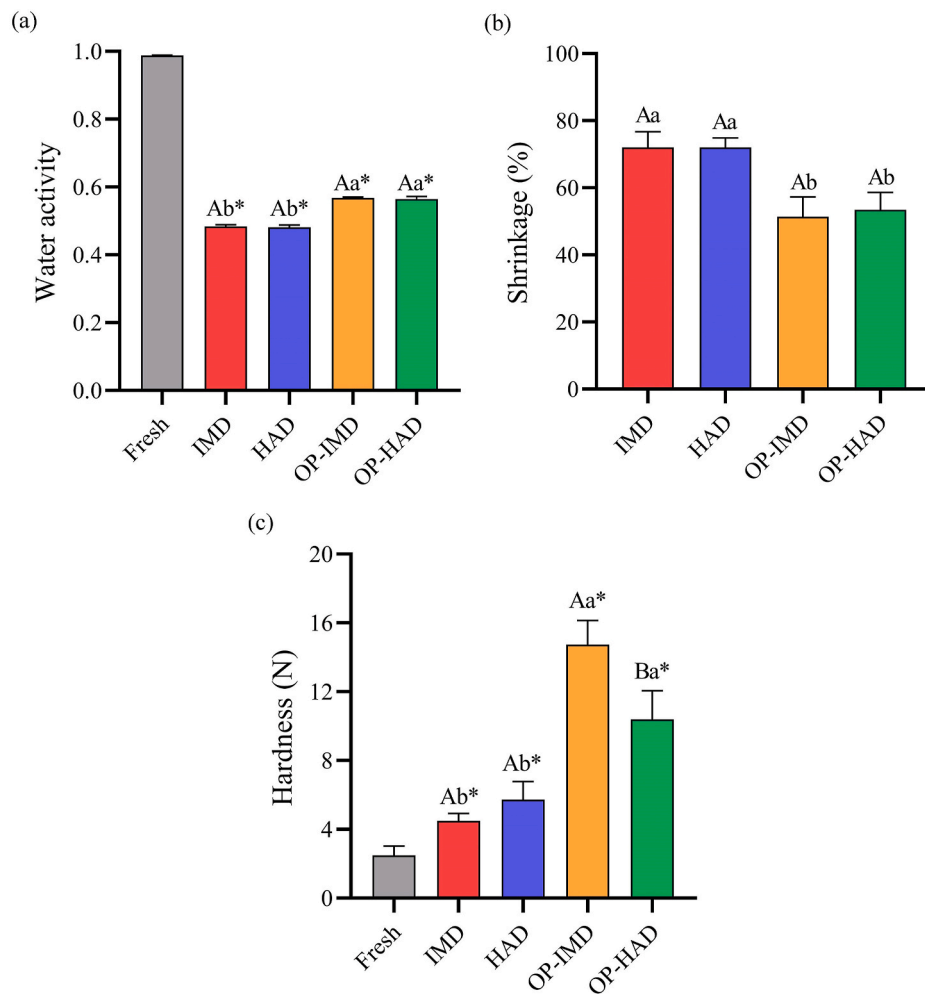


Fig. 4. Energy consumption at different drying conditions. Values are mean ± standard deviation, n = 3. The same uppercase letter indicates no significant difference between IMD and HAD samples. The same lowercase letter indicates no significant difference between non- and osmotically pretreated samples by the Tukey test ( $p < 0.05$ ).



**Fig. 5.** Water activity (a), shrinkage (b), and hardness (c) of the samples.

Values are mean  $\pm$  standard deviation,  $n = 3$ . The same uppercase letter indicates no significant difference between IMD and HAD samples. The same lowercase letter indicates no significant difference between non- and osmotically pretreated samples by the Tukey test ( $p < 0.05$ ). The asterisk indicates a significant difference between each treatment and the fresh sample by the Dunnett test ( $p < 0.05$ ).

## 3.2. Quality properties

### 3.2.1. Water activity ( $a_w$ )

The  $a_w$  of fresh and dried strawberries is shown in Fig. 5a. The fresh strawberry had a high  $a_w$ , characteristic of the fruit (Amami et al., 2017), indicating the high susceptibility to the growth of spoilage microorganisms, making a fruit highly perishable, which justifies the study of processing and preservation methods of fruit.

A significant difference was not observed between the drying methods. However, non-pretreated strawberries had  $a_w$  statistically lower than that of osmotically pretreated strawberries (Fig. a).

Dried strawberries had  $a_w$  less than 0.60, which is generally the minimum value for microorganisms to grow. Therefore, at this value or below, the viability of the growth of microorganisms is minimal. The occurrence of microbial deterioration in the dried food is unlikely for up to 2 years (Jay, Loessner, & Golden, 2005), provided that the drying process, storage, transport, and transportation until the sale are carried out under hygienic conditions. Otherwise, some pathogens, yeast, and molds can continue to grow in the dried food. In addition to extending shelf life, drying fruit reduces packaging requirements and transport weight (Alp & Bulantekin, 2021).

### 3.2.2. Shrinkage

Shrinkage is an inherent physical alteration in drying processes. However, it is undesirable and represents an important quality parameter in dried fruit. In addition to the negative aspect of product appearance, shrinkage prejudices moisture removal during drying and heat transfer (Dehghannya et al., 2018).

As shown in Fig. 5b, strawberries shrank from  $51.72 \pm 7.90$  to  $72.41 \pm 5.97\%$ . Between the drying methods, there was no significant difference. Some studies reported that the use of microwaves could minimize shrinkage when drying fruits (Raghavan & Silveira, 2001; Tepe & Tepe, 2020), but this effect was not observed in the present study. However, osmotic pretreatment minimized strawberry shrinkage (Fig. 5b), as also reported by other authors (Changrue et al., 2008; Raghavan & Silveira, 2001). This is due to the isomaltulose impregnation, contributing to the maintenance of the physical structure of the material (Changrue et al., 2008).

The reduction in material volume is due to the removal of water during drying, especially in materials such as strawberries, in which water represents a significant portion of its composition. According to Raghavan and Silveira (2001), strawberry shrinkage during drying has a linear relationship with moisture ratio.

For all dried samples, it was observed that the shrinkage was anisotropic due to deformations caused in the microstructure of the food, distorting the strawberry.

### 3.2.3. Hardness

The hardness of fresh and dried strawberries is shown in Fig. 5c. Fresh strawberries had a low hardness value, being one of the indicators of strawberry fragility. Dried strawberries had higher hardness than fresh strawberries, contributing to greater physical resistance of the material. However, the increase in material hardness due to drying must be controlled as products with high hardness may not be well accepted by consumers (Lyu et al., 2017).

Non-pretreated dried strawberries (IMD and HAD) showed no

significant difference between both drying methods. Between osmotically pretreated strawberries, IMD resulted in dried strawberries with higher hardness than those dried by HAD (Fig. 5c). According to Kumar and Karim (2019), one of the advantages of microwave drying is the minimization of case hardening compared to the process using heated air, due to the pumping of liquid to the surface of the material, where moisture is accumulated (Kumar & Karim, 2019; Zielinska et al., 2020). However, minimization of hardening may not have occurred in this study due to the airflow of the IMD system reducing surface moisture, leaving a hard and dry skin (Lin, Durance, & Scaman, 1998). This phenomenon may have made the hardening of samples submitted to IMD equal to or higher than those submitted to HAD.

According to Fig. 5c, pretreated strawberries had higher hardness than non-pretreated strawberries, regardless of the drying method. Similar behavior was observed in other studies (Lyu et al., 2017; Macedo, Corrêa, da Silva; Araújo et al., 2020; Wang, Zhang, & Mujumdar, 2010). This may be due to the impregnation of solids reducing the porosity of the material, making the cell structure more compact (Wang et al., 2010).

### 3.2.4. Color

The colorimetric parameters of fresh and dried strawberries are shown in Fig. 6.

The  $L^*$  parameter of fresh strawberry was equal to that of dried strawberries, except the IMD-non-pretreated dried strawberry (Fig. 6a), which presented a lower  $L^*$  value than fresh strawberry. According to Pathare, Opara, and Al-Said (2013), the decrease in  $L^*$  values can be a result of brown pigment formation during the drying process. Between

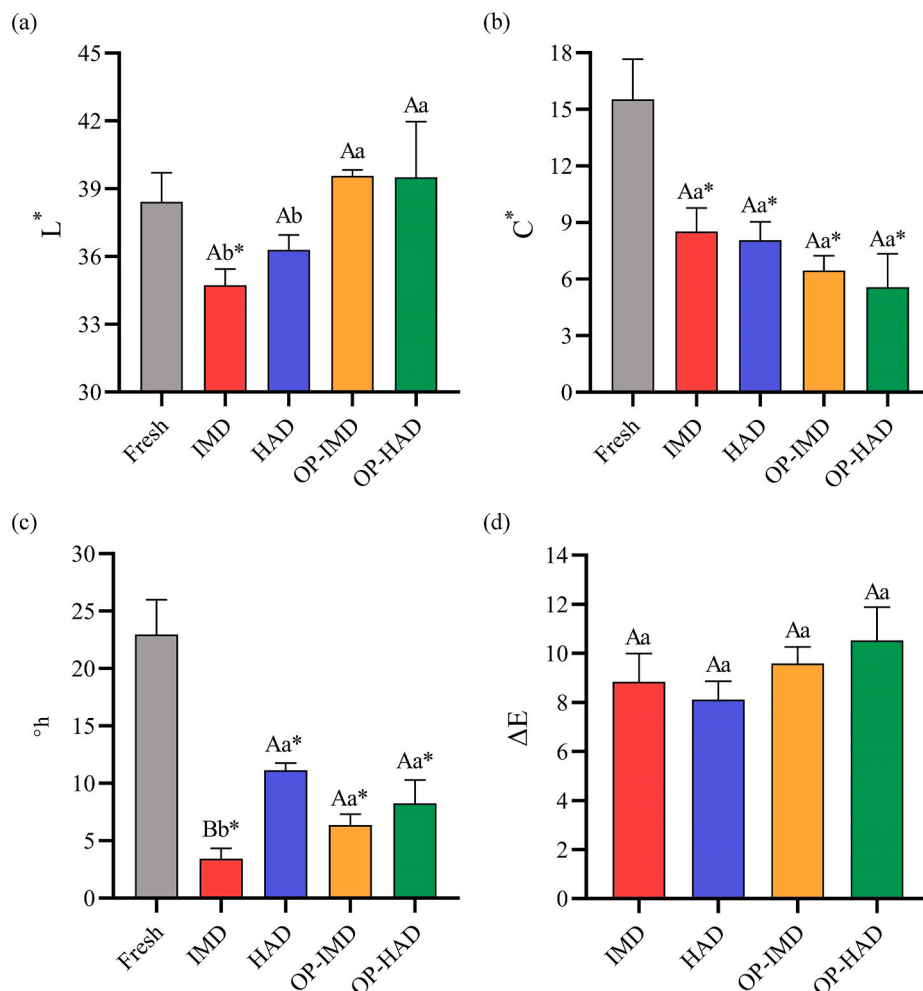
the drying method, there was no difference in  $L^*$  value. However, the osmotic pretreatment resulted in strawberries with higher  $L^*$ , indicating that these samples were lighter than the non-pretreated ones, as shown in Fig. 1S. This is due to the leaching of pigments during the osmotic process and isomaltulose impregnation.

The  $C^*$  of fresh and dried strawberries is shown in Fig. 6b. According to Pathare et al. (2013), high values of  $C^*$  represent the high color intensity of samples perceived by humans. Fresh strawberries had a higher  $C^*$  value than dried strawberries. This is the result of various chemical reactions including pigment destruction (Omolola et al., 2017). Furthermore, no statistical difference was observed among dried strawberries.

Fig. 6c shows the  $h^\circ$  values for the samples. Dried strawberries had lower  $h^\circ$  values than fresh strawberries, indicating a higher red hue ( $0^\circ$  or  $360^\circ$ ). This is due to the higher concentration of pigments in the dried strawberry, making them redder than the fresh strawberry cube. Among the dried strawberries, the non-pretreated dried by IMD had the lowest  $h^\circ$  value, indicating a higher red hue. This can also be seen in Fig. 1S.

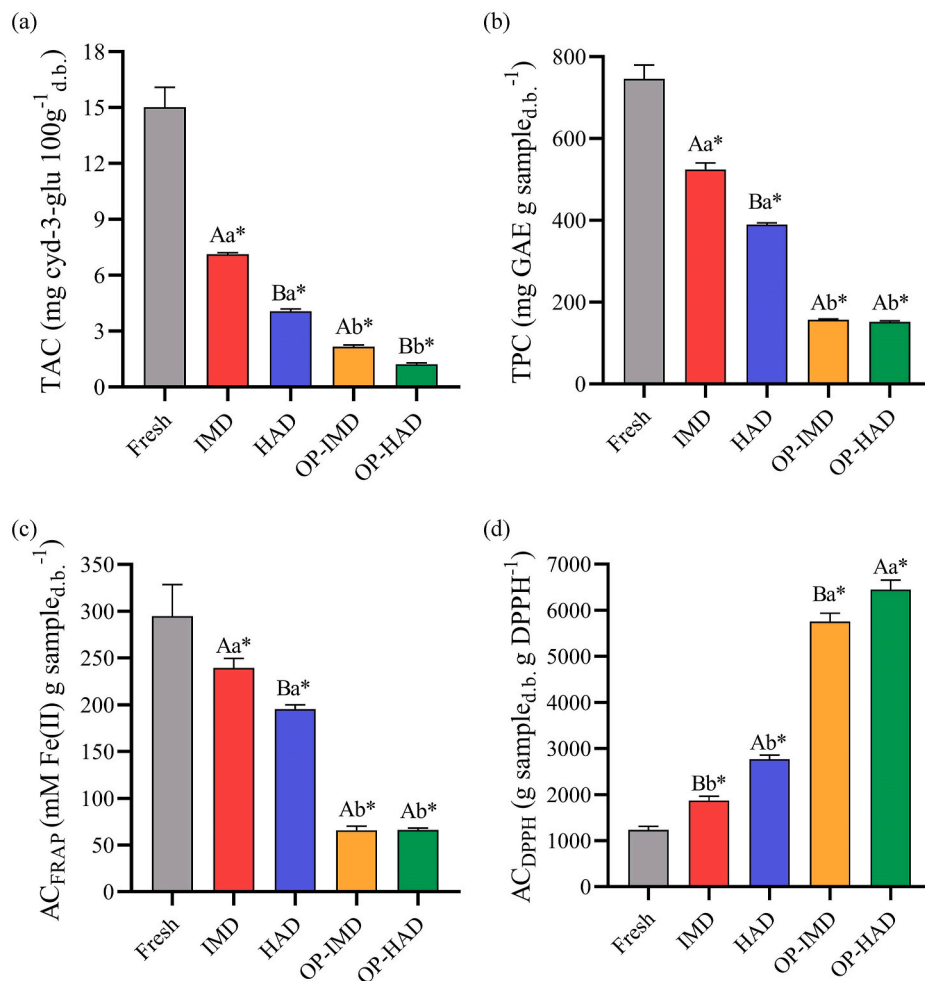
The  $\Delta E$  was not significantly influenced by the drying method or the osmotic process. The  $\Delta E$  values were between  $8.11 \pm 0.74$  and  $10.53 \pm 1.35$ , that is,  $\Delta E > 3.0$ , which indicates that the dried strawberries showed a high color difference from the fresh strawberry (Pathare et al., 2013). This high distinction between the colors of dried and fresh samples is due to a series of changes caused by drying, which include both the concentration and degradation of natural fruit pigments, in addition to the formation of other pigments. Similar results were observed by Amami et al. (2017).

Color is the most important attribute of food appearance because it is



**Fig. 6.** Colorimetric parameters of fresh and dried strawberries.

Values are mean  $\pm$  standard deviation,  $n = 3$ . The same uppercase letter indicates no significant difference between IMD and HAD samples. The same lowercase letter indicates no significant difference between non- and osmotically pretreated samples by the Tukey test ( $p < 0.05$ ). The asterisk indicates a significant difference between each treatment and the fresh sample by the Dunnett test ( $p < 0.05$ ).



**Fig. 7.** Total anthocyanins content (a), total phenolics content (b), and antioxidant capacity by FRAP (c) and DPPH (d) methods of fresh and dried strawberries.

Values are mean  $\pm$  standard deviation,  $n = 3$ . The same uppercase letter indicates no significant difference between IMD and HAD samples. The same lowercase letter indicates no significant difference between non- and osmotically pretreated samples by the Tukey test ( $p < 0.05$ ). The asterisk indicates a significant difference between each treatment and the fresh sample by the Dunnett test ( $p < 0.05$ ).

the first quality attribute that the consumer evaluates, attracting or not the consumer to purchase the product. Therefore, it is a characteristic that must be monitored in dried foods (Pathare et al., 2013).

### 3.2.5. Total anthocyanins content (TAC)

The TAC of fresh and dried strawberries is shown in Fig. 7a. Fresh strawberry proved to be a good source of anthocyanins, with  $15.02 \pm 1.07$  mg of cyanidin 3-glycoside per 100 g, on a dry basis, being one of the fruits with the highest TAC, along with others, such as berry fruits (such as chokeberry, blackberry, blueberry), grape and currant (Tsuda, 2012).

Fresh strawberries had a higher TAC than dried ones, as both osmotic dehydration and drying processes are responsible for causing some losses of these important compounds (González-Pérez et al., 2021).

IMD produced dried strawberries with higher TAC than the HAD method for non- and pretreated samples (Fig. 7a). As seen in Fig. 2b, the IMD required shorter drying times, which reduces the exposure time of the strawberry to high temperatures, reducing the degradation of anthocyanins.

The non-pretreated dried strawberry had a higher TAC than the osmotically pretreated one (Fig. 7a). In addition to the degradation of anthocyanins during drying, compounds from the food were leached to the osmotic solution during osmotic dehydration (González-Pérez et al., 2021), mainly water-soluble compounds such as anthocyanins.

Strawberry processing, transforming them into other more stable products, is necessary to ensure supply in all seasons of the year and several regions, including non-strawberry producers, and making different available products, according to the consumer preference.

However, quality losses inevitably occur during strawberry processing, especially bioactive compounds such as anthocyanins (Basu et al., 2014; Bhat & Stamminger, 2015).

Anthocyanins are the most prominent bioactive compounds in strawberries. They confer the attractive red color of strawberries and are associated with several beneficial health effects, such as preventing cancer, inflammation, and cardiovascular and neurodegenerative diseases. However, they are susceptible compounds easily degraded by oxidative processes, especially when exposed to high temperatures, such as in drying (Méndez-Lagunas et al., 2017). Retentions of up to 47.46% were obtained in the present study. Although nutritional losses have occurred, dried fruits can be considered essential sources of vitamins, minerals, fiber, and bioactive components or phytochemicals, due to the concentration of compounds concerning fresh fruit (Omolola et al., 2017).

### 3.2.6. Total phenolics content (TPC)

The TPC of fresh and dried strawberries is shown in Fig. 7b. Fresh strawberries had an important TPC ( $745.88 \pm 33.67$  mg of gallic acid equivalent per g of strawberry, on a dry basis), as also reported in other studies (Aaby, Mazur, Nes, & Skrede, 2012; Macedo et al., 2021). Fresh strawberries had higher TPC than dried ones. Osmotically pretreated strawberries had lower TPC than non-pretreated dried strawberries. Furthermore, a difference in TPC of pretreated strawberries was not observed between drying methods (Fig. 7b).

The osmotic and drying processes cause losses of phenolic compounds. Phenolics are water-soluble compounds, facilitating leaching loss during osmotic dehydration (Abrahão & Corrêa, 2021).

Furthermore, these compounds are thermosensitive, and therefore are easily degraded when the material is heated (Macedo et al., 2021). However, good TPC retention capacities were obtained in dried strawberries. Dried strawberry, non-pretreated, showed retention of 70.26% by the IMD method. Retention of 52.23% was obtained by the HAD method. A similar result was observed by Amami et al. (2017).

The group of phenolics present in strawberry is rich, formed by several compounds; there are anthocyanins, tannins, esters of hydroxycinnamic acids, especially p-coumaric acid, and ellagic acid and ellagic acid glycosides (Aaby et al., 2012). These compounds perform several beneficial functions to the organism. Therefore, the preservation of these compounds must be sought.

### 3.2.7. Antioxidant capacity (AC)

AC by FRAP and DPPH methods are shown in Fig. 7c and d, respectively. The FRAP method expresses AC per sample mass. However, the determination of AC by the DPPH method expresses the sample mass required to reduce the DPPH mass. Therefore, low response values by the DPPH method indicate high sample AC (Vimercati et al., 2020).

Fresh strawberries showed high antioxidant capacity by both methods (FRAP and DPPH), with higher values than dried strawberries.

Strawberry dried by the IMD method, non-pretreated, presented the highest AC, having an AC, by the FRAP method, of 81.18% concerning fresh strawberry, showing that this drying method is quite efficient in preserving antioxidant compounds. A possible explanation for this occurrence is the short drying time, which reduces the time the material is exposed to heating. Keser et al. (2020) also observed a good ability to preserve the antioxidant capacity of carrots when performing the IMD.

By the FRAP method, the AC of pretreated dried strawberries by IMD and HAD were statistically equal. On the other hand, the AC by the DPPH method showed a higher value by the HAD; that is, the IMD resulted in dried strawberries with higher AC.

The AC of the osmotically pretreated dried strawberries was lower than that of the non-pretreated ones by both methods of AC determination. This may be associated with compound leaching during the osmotic process, as discussed above.

## 4. Conclusion

IMD and HAD were efficient methods for producing non- and osmotically pretreated dried strawberries with good nutritional quality and low moisture and water activity, providing stability to the dried product. The principal component analysis efficiently helped the distinction of treatments and association of the evaluated responses.

IMD required less drying time than HAD, with reductions of up to 64.91%. The magnetron was off for a good percentage of time during IMD, resulting in low energy consumption, about 70% less. In addition, IMD contributed to the preservation of anthocyanin, phenolic and antioxidant compounds, showing retentions of up to 47.46%, 70.26%, and 81.18% compared to fresh strawberry, respectively.

The osmotic process could be used for impregnation in strawberries with significant values. It also leads to low shrinkage. However, increased drying time, some nutritional losses, hardness, and color change in dried strawberries were attributed to osmotic dehydration.

### CRedit authorship contribution statement

**Leandro Levate Macedo:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jefferson Luiz Gomes Corrêa:** Funding acquisition, Conceptualization, Project administration, Supervision, Resources, Writing – original draft, Writing – review & editing. **Irineu Petri Júnior:** Conceptualization, Data curation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – review & editing. **Cintia da Silva Araújo:** Data curation, Formal analysis,

Investigation, Methodology, Writing – review & editing. **Wallaf Costa Vimercati:** Data curation, Formal analysis, Investigation, Methodology, Writing – review & editing.

### Declaration of competing interest

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

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