Original paper

Effect of Microwave and Hot Air Drying on the Physicochemical Characteristics and Quality of Jelly Palm Pulp

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The drying of jelly palm pulp with hot air (HA) or microwave (MW) radiation was evaluated at three temperatures (50, 60 and 70°C), and the physicochemical and sensory properties of the dried pulp were considered. Drying using MW increased the drying rate and a reduction in the drying time compared with HA. Infrared thermography showed heterogeneous heating using MW. The water activity of the dried pulp ranged from 0.43 to 0.51. The colour of the dried pulps at 50 and 60°C after using both techniques suffered less thermal degradation than drying at 70°C, which generated darker pulp. The best results were obtained using MW at 60°C, because this presented no significant sensory differences and required a shorter drying time than MW at 50°C.

Keywords: dried fruit, *Butia odorata*, microwave drying time, sensory analysis, infrared thermography

Introduction

Inadequate processing is responsible for the loss of one-third of the food produced around the world, of which fruits account for a reasonable part (Kumar *et al.*, 2014). Besides reducing the effects of the perishability of fruits and vegetables, processing is also important given the excess production of fruits and vegetables at harvest time (Karam *et al.*, 2016; Raak *et al.*, 2016). Among the numerous forms of processing used to preserve fruit, drying has been widely used. Drying reduces water activity/chemical reactions, inhibits the growth of microorganisms, reduces transportation costs and facilitates the use of new products (Karam *et al.*, 2016; Zhang *et al.*, 2010).

The drying process can be performed using several techniques or a combination of them (Karam *et al.*, 2016; Kumar *et al.*, 2014). Drying techniques should be carefully optimized to assure the nutritional, microbiological and sensory qualities of fruit in an attempt to preserve the characteristic attributes of fresh fruit (Karam *et al.*, 2016). Drying of

fruits by conventional thermal techniques (sun- or hot air-dried) is wide spread due to the feasibility of implementation, but low drying rates and high time and energy expenditures are drawbacks of these methods (Vadivambal and Jayas, 2007). For temperatures above 70°C, these techniques result in changes to sensory characteristics of foods, such as colour, texture, aroma and taste (Kumar *et al.*, 2014; Zhang *et al.*, 2010). To reduce thermal degradation caused by the drying process, new techniques have been studied, such as those assisted by microwave (MW) radiation. These are promising alternatives for the drying of fruits and vegetables, reducing time and energy consumption and improving sensory and technological quality in the dried pulp (Arikan *et al.*, 2012; Orsat *et al.*, 2007; Vadivambal and Jayas, 2007; Zhang *et al.*, 2010). In this respect, Cuccurullo *et al.* (2012) dried apple pieces in convective dryer and in a microwave oven using temperature control with infrared at three temperatures (55, 65 and 75°C). Drying kinetics showed that microwave drying significantly increased drying rates,

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Fig. 1. Equipment of drying. (A) Microwave. (I) sample; (II) infrared pyrometer; (III) programming system of variables time, temperature, temperature variation, emissivity, heating ramp and cooling time; (IV) fan to remove moisture during drying located on the left side of the equipment; (V) magnetron. (B) Air circulation oven. (I) sample; (II) air circulation; (III) temperature control.

reducing drying time up to three times at 75°C. Motevali *et al.* (2014) evaluated the drying of Roman chamomile, identifying an energy efficiency of drying by microwave of 49.99% at 300 W power, while convective drying by hot air presented energy efficiency of 6.76%. Koyuncu and Lüle (2015) dried sorbus fruit in a microwave oven and convective dryer. The drying kinetics showed that MW significantly increased the drying rate, reducing the convective drying time of 22 h to 2.75 h in oven microwave. No papers report the drying of jelly palm fruit by any technique.

Jelly palm fruit (*Butia odorata*) are not well known outside their natural cultivation areas, but studies have shown that they have antioxidant, antiproliferative and antimicrobial actions beneficial to health (Ammar *et al.*, 2014; Hoffmann *et al.*, 2014). In addition, these fruits also contain high levels of carotenoids, mainly beta-carotene, beta-cryptoxanthin, 9-cis-beta-carotene and lutein; fibre (Ferrão *et al.*, 2013; Pereira *et al.*, 2013) and phenolic compounds, such as gallic acid, ferric acid and epicatechin (Beskow *et al.*, 2015; Denardin *et al.*, 2015; Hoffmann *et al.*, 2014; Pereira *et al.*, 2013).

To extend the shelf life of the jelly palm fruit, the fruit could be conserved through a drying method using modern technology, such as MW radiation, which would guarantee the quality of the final product. Therefore, this study aimed to evaluate the drying of the jelly palm fruit using hot air (HA) circulation and MW radiation at different temperatures in terms of the physicochemical (e.g., moisture, water activity, rehydration ratio, colour) and sensory quality of the *B. odorata* pulp. In addition, the drying kinetics and distribution of temperature within the product were studied using infrared thermography.

Materials and Methods

Harvesting and storage Fresh, healthy and ripe jelly palm (*B.*

odorata) fruits were harvested in the city of Tuparendi (Rio Grande do Sul State, Brazil; latitude $-27^{\circ} 45' 8.52''$ S, longitude $-54^{\circ} 29' 17.04''$ W) from January to March 2014. The point of ripening for harvest was established, according to Ferrão *et al.* (2013), when fruit naturally loosens from the bunch. All fruits were stored in sealed plastic bags and frozen at -20°C . Before all drying processes, the fruit from different bunches were homogenized and divided into experimental units. For drying, the fruits were defrosted for 1 h at room temperature inside the packages. The fruits were cleaned with tap water and then separated into peel, pits and pulp.

Drying The jelly palm fruit pulp (100 g) was weighed in a perforated polypropylene container (20 cm²) typically used in a domestic MW oven. Filling the bottom of the container, the pulp was then dried within to MW and HA equipment. MW drying was performed in household equipment (model Perfect, Panasonic, Brazil, 32 L, 800 W, 2450 MHz) modified using a fan to remove moisture during drying and an infrared pyrometer (Raytek) to control the heating by programmed temperatures (Fig. 1A). The infrared pyrometer was placed centrally at the top of the oven, 20 cm from the sample. The power delivered inside the cavity was experimentally determined according to Bizzi *et al.* (2011) and reached 604 W. An air circulation oven (Deo Leo, Brazil) was used for HA drying (Fig. 1B). Three drying temperatures were studied in both systems: 50, 60 and 70°C. Final drying time was determined when the pulp reached its final moisture content of $5 \pm 1\%$. After drying, the pulp was ground in a knife mill (Marconi MA-630, Brazil) for two minutes to obtain a dry jelly palm powder, which was stored in 50 mL polypropylene tubes at 5°C until analysis.

Drying evaluation Moisture loss on drying was measured by reduction in weight and calculated according to Equation 1 (Wang

et al., 2010). Samples were weighed on a digital scale balance (± 0.01 g) every five minutes during the first hour and subsequently every 10 minutes until they reached a final moisture content of $5 \pm 1\%$. Experiments were performed in triplicate.

$$X_t = \frac{mt - md}{md} \quad \dots\dots \text{Eq. 1}$$

In Equation 1, X_t is the moisture content at drying time t (min) on a dry basis (g/g); mt is the weight of material at time t ; and md is the dry matter weight of the material.

The drying rate (DR) of the pulp samples was calculated according to Equation 2 (Seremet *et al.*, 2016):

$$DR = \frac{X_{t+dt} - X_t}{dt} \quad \dots\dots \text{Eq. 2}$$

where dt is the time interval between the weighings and X_{t+dt} is the moisture content after the time interval between the weighings (dt).

Moisture analysis The moisture contents of the fresh and dried pulps were determined in a vacuum oven (Quimis, Brazil), according to the AOAC (1995; method 925.09/17) and measured in triplicate.

Infrared thermography The temperatures of the fresh and dried samples were monitored using a long-wave infrared camera (7.5 – 13.0 μm , FLIR E60 model, FLIR, Wilsonville, OR, USA), which provided images of 320×240 pixels at a frame rate of 30 Hz. Each container with pulp was removed from the drying equipment and positioned in the camera's focus (at 40 cm distance) to take pictures with a delay time lower than 5 s. This procedure was performed to minimize errors caused by interference of hot air from the drying equipment, as reported by Llave *et al.* (2017). Images were processed using ResearchIR software (FLIR), and the temperatures were corrected for ambient temperature and relative humidity. The mean and amplitude values of the temperatures were determined for each sample by monitoring an 8,000-pixel ellipse from an image with 14,000 pixels. The emissivity value ($\varepsilon = 0.88$) of the surface of the pulp was measured by adjusting the camera according to its surface temperature. The emissivity values during the drying process varied by 0.880 in the fresh pulp and 0.800 in the dry sample, representing maximum variation of target temperature of 2.6, 3.3 and 3.9°C at 50, 60, and 70°C, respectively.

Water activity Water activity was measured in triplicate using a thermohygrometer (Testo 650, Brazil), according to the manufacturer's instructions.

Rehydration capacity The rehydration capacity of the dried jelly palm pulp was measured, according to Megías-Pérez *et al.* (2014) method, as the rehydration ratio calculated from the mass of the rehydrated sample (g) and dry weight (g). The procedure was carried out in triplicate.

Colour The colours of the samples (fresh and dry) were measured with a CR-300 Konica Minolta colorimeter (Minolta Corp, Osaka, Japan) using the CIE Lab (L^* , a^* and b^*) colour system and a 2° observation angle. Each pulp sample was evaluated in a 40 mL Petri plate (1 cm thickness) on a standard white

background. All determinations were performed in triplicate. The colour indicators chroma (C^*_{ab}) and relative colour difference (ΔE_{ab}) were calculated using Equations 3 and 4, respectively:

$$C^*_{ab} = \sqrt{(a^*)^2 + (b^*)^2} \quad \dots\dots \text{Eq. 3}$$

$$\Delta E_{ab} = \sqrt{(L^{*0} - L^*)^2 + (a^{*0} - a^*)^2 + (b^{*0} - b^*)^2} \quad \dots\dots \text{Eq. 4}$$

where 0 indicates parameters of the fresh pulp.

Sensory evaluation The ethical aspects of this study were approved by the Research Ethics Committee of the Federal University of Santa Maria under protocol No. 39902414.4.0000.5346. The dried pulps were submitted to eight sensory evaluations: four using an untrained panel of 50 assessors to evaluate colour and overall appearance and four using 10 previously selected and trained judges to evaluate the characteristic odour of the jelly palm fruit. For all evaluations, discriminatory ranking tests were performed to investigate the influence of the three temperatures (50, 60 and 70°C). Subsequently, the samples obtained at the same temperatures but different drying techniques were subjected to two paired comparison tests. In this way, the dried pulp at 50°C by MW was compared with dried pulp at 50°C by HA, same procedure was performed to compare the dried pulps at 60°C. In the paired comparison and ranking tests, samples (10 g) were offered to assessors in 50 mL polypropylene containers encoded with random three-digit numbers. Samples were evaluated at room temperature in individual booths, acclimatized and illuminated with fluorescent lamp. Samples were served simultaneously, three for the ranking tests and two for the paired comparison tests.

The same tests were performed to evaluate the characteristic odour of the dried jelly palm fruit pulp. To evaluate this parameter, the samples were served in 50 mL polypropylene containers covered with perforated aluminium foil and closed with a watch glass. The assessors were instructed to remove the watch glass only when the sample was near their noses so that they could smell the odour without seeing the sample. The 10 previously selected assessors were trained using different concentrations of the jelly palm fruit pulp diluted in water and ethyl hexanoate as a reference standard, since this is the main volatile compound in the fruit (Bernardi *et al.*, 2014).

Statistical analysis Experimental data were evaluated by analysis of variance (ANOVA) and Tukey's test ($p < 0.05$) using Statistica 7.0 software (Tulsa, USA, 2004). Statistical analysis of the data obtained from the sensory analysis was performed using Friedman's test and Newell and MacFarlane's (1987) table.

Results and Discussion

Drying evaluation The drying curves (Fig. 2) and drying rate (Fig. 3) of the jelly palm fruit pulp showed different behaviour for the two drying treatments (HA and MW) at the three temperatures (50, 60 and 70°C). The use of the MW oven reduced drying time

Table 1. Influence of drying on the physical and chemical characteristics of the jelly palm fruit (*B. odorata*).

Treatments	T (°C)	Time (h)	Moisture (%)	Water activity	Rehydration ratio
Fresh pulp	-	-	80.02 ± 0.31	0.99 ± 0.01	-
Hot air	50	14.0	5.66 ± 0.20 ^{a*}	0.43 ± 0.01 ^d	2.4 ± 0.3 ^a
	60	8.0	5.21 ± 0.45 ^a	0.47 ± 0.00 ^b	2.6 ± 0.5 ^a
	70	6.0	4.76 ± 0.77 ^a	0.44 ± 0.01 ^{cd}	2.4 ± 0.2 ^a
Microwave	50	6.5	5.41 ± 0.49 ^a	0.51 ± 0.01 ^a	2.6 ± 0.4 ^a
	60	4.5	4.57 ± 0.57 ^a	0.49 ± 0.01 ^b	2.4 ± 0.2 ^a
	70	2.0	4.34 ± 0.33 ^a	0.47 ± 0.01 ^{bc}	2.6 ± 0.4 ^a

* The same letters in the same column indicate that the data do not differ statistically between each other (Tukey's test; $p < 0.05$). Results are the mean of triplicates. T: temperature; Time: drying time.

Fig. 2. Drying behaviour of the jelly palm fruit (*B. odorata*) using hot air (HA) and microwave (MW) heating at 50, 60 and 70°C. Results are the mean of triplicates.

by up to three times compared to HA drying at 70°C (Table 1). This significant reduction in drying time is due to the different heating phenomena involved in the two techniques, which influenced drying rates. In HA drying, heat transfer mainly takes place by conduction, with the surface of the food heated by hot air in the oven; this absorbed energy is then transferred into the food (Vadivambal and Jayas, 2007). In MW heating, there is also heat distribution by conduction inside the food, but the heat generated is due to the absorption of the MW radiation. The interaction of this energy with food promotes heating by both the rotation of dipoles and ionic migration phenomena (Chandrasekaran *et al.*, 2013). For fruit, the main absorptive dipole molecule is water itself, the heating of which increases the internal pressure of the food, thereby facilitating the diffusion of water vapours (Vadivambal and Jayas, 2007; Zhang *et al.*, 2010). Thus, MW drying more efficiently removes water from food compared to conventional systems, considerably increasing the drying rate and consequently reducing

processing time (Arslan and Özcan, 2011; Cuccurullo *et al.*, 2012; Seremet *et al.*, 2016).

The observed drying rate behaviour of the jelly palm pulp (Fig. 3) shows four distinct periods during drying, as described by Bilbao-Sáinz *et al.* (2006). At first, high water content (80%) is responsible for the increase in the internal temperature of the pulp, with increasing diffusion of water generating the first maximum in the drying rate curve (at 53–55% moisture). At the highest temperature (70°C) and under MW drying, this maximum is more prominent due to the higher heating of the pulp. From here, in MW drying, increasing transfer of water vapour from the interior to the surface causes condensation of water on the surface of the sample, possibly due to insufficient airflow to remove this surface moisture, reducing the drying rate. In HA drying, the movement of water vapour from the centre to the surface of the sample is resisted by the formation of a hard skin caused by contact of hot air with the surface of the pulp (Chayjan *et al.*, 2014). In the second period, the

Fig. 3. Drying rate of the jelly palm fruit (*B. odorata*) using microwave (B) and hot air (A) heating at 50, 60 and 70°C. Results are the mean of triplicates. MW = microwave; HA = Hot air.

sample temperature and the drying rate reduces. After free water evaporates in a third period, the drying rate reaches a second maximum (at 27–28% moisture) driven by different vapour pressures between the centre and the surface of the product. With decreasing pulp moisture, the drying rate reaches its last period of decline. In drying by MW, this period is marked by decreasing absorption of the MW radiation caused by reduced water content. In drying by HA, the dry matter yields a lower pressure gradient between the centre and the surface, making it more difficult to remove water and thus reducing the drying rate (Bilbao-Sáinz *et al.*, 2006; Chayjan *et al.*, 2014). Additionally, the standard deviations of drying rate in the MW processes were higher than for HA, mainly in the first interval of moisture-content reduction. For both techniques, increasing temperature triggers increasing standard deviation of drying rates, with mean values of 0.012 and 0.029 at 50°C, 0.021 and 0.047 at 60°C and 0.034 and 0.149 at 70°C for HA and MW, respectively. This drying behaviour is typical of fruits and vegetables, as demonstrated in the drying of

Fig. 4. Infrared thermography of the jelly palm fruit (*B. odorata*) during drying by hot air and microwave heating at temperatures (T) of 50, 60 and 70°C. Results are the mean of triplicates.

apples (Cuccurullo *et al.*, 2012) and pumpkins (Seremet *et al.*, 2016) using HA and MW heating.

Increasing temperature, regardless of drying system, led to higher removal of moisture and shorter drying time (Table 1). In HA the drying time was reduced using 60°C in comparison to 50°C by more than 40%. In drying by MW, increasing temperature from 60 to 70°C also reduced the drying time (by 55%). In other studies involving the drying of fruits and vegetables, such as pumpkins (hot air: 540 min at 50°C to 330 min at 70°C; Seremet *et al.*, 2016), apples (hot air: $\approx$ 270 min at 50°C to $\approx$ 170 min at 70°C; microwave: $\approx$ 120 min at 50°C to $\approx$ 50 min at 70°C; Cuccurullo *et al.*, 2012) and red bell peppers (hot air: 25 h at 50°C to 9 h at 70°C; Arslan and Özcan, 2011), the authors reported similar effects of drying temperature.

Thermographic analysis Infrared thermal images allowed visualization of the heat distribution surface of the pulp during the HA and MW drying processes (Fig. 4). These images showed several points of higher temperature (hot spots) under MW, with a more heterogeneous temperature distribution than the convection oven. This is due to the non-uniform distribution of the electromagnetic field inside the cavity of a MW oven, which generates cold and hot spots; by contrast, in the convection oven, the air circulates at a constant temperature (Bizzi *et al.*, 2011; Cuccurullo *et al.*, 2012; Vollmer, 2004). This high variation of temperature within samples dried by MW can be explained by this inhomogeneous distribution of radiation inside the cavity, but various technical changes might improve homogeneity, including the use of different vessels, microwave applicators and combination with other methods of drying (such as ohmic heating, convection or jet impingement; Choi *et al.*, 2011; Geedipalli *et al.*, 2008; Zhang *et al.*, 2006). Another factor is the temperature of the container, which was lower for MW heating because the pulp

Fig. 5. Temperature variation of the jelly palm fruit (*B. odorata*) during drying by hot air (HA) and microwave (MW) heating at 50, 60 and 70°C determined by infrared thermography.

directly absorbs microwave radiation, as described before. The ability to absorb microwave radiation and thus heat is represented by material dissipation factor ($\tan \delta$). The drying container used here was made of a plastic material (polypropylene) which has insignificant absorption of microwave radiation due to its very low dissipation factor around 2.0×10^{-4} (Kingston and Haswell, 1997). Thus, heating of the container in the process of MW drying mainly occurred through contact of the container with the heated pulp, which heated the container significantly less than in the HA technique, where the container heated to temperatures close to those of the pulp (Zhang *et al.*, 2006). The thermographic images showed a higher variation in temperature occurring in drying by MW at 70°C, increasing the hot spots. This phenomenon, closely related to drying by MW (Bhattacharya and Basak, 2017), may lead to the greater darkening of the pulp at this temperature, as reflected in the instrumental and sensory colour analyses discussed below.

Infrared thermography was also used to monitor temperatures during drying. The mean temperature of the surface of the pulp (MTP) over drying time is shown in Figure 5. The pulp was heated less by HA than by MW for all evaluated temperatures. When drying at 50°C, the HA treatment needed eight hours for at least one portion of the pulp to reach 50°C, but 50°C MTP was only reached at the end of the drying time (14 hours). On the other hand, when drying was performed at the same temperature using MW, a portion of pulp reached 50°C in five minutes and MTP of 50°C was reached after only two hours of drying. For MW drying at 60 and 70°C, the MTP reached the desired value in the first five minutes of drying; after reaching 70°C, the MTP decreased, possibly due to high temperature variation in drying by MW at 70°C at the end of drying (35.9°C at 74.5°C). By contrast, with the HA technique, reaching one portion at the drying temperatures required six hours of drying at 60°C and 4 hours of drying at 70°C. However, at these

two drying temperatures, the MTP did not reach the desired temperature in the oven until the end of drying. These data demonstrate the high efficiency of MW drying and could explain the differences in processing time compared to HA drying. These results are directly related to the behaviour, observed in Figures 2 and 3, of higher drying rates and more efficient reduction in moisture content in MW samples compared to HA samples, independent of temperature (though most accentuated at 70°C). This reported efficiency of MW is due to the direct interaction of the MW radiation with the pulp, while the conventional system is limited to heat transfer that occurs slowly due to the low thermal conductivity of the food (Bhattacharya and Basak, 2017).

Physicochemical characteristics The physicochemical properties of the fresh and dried jelly palm pulps are presented in Table 1. The moisture content of the dried pulps did not show significant differences among treatments, ranging from 4.34% (for MW 70°C) to 5.41% (for MW 50°C).

Concerning water activity, the dried pulps showed results within the range of 0.43 to 0.51 (Table 1). According to Orsat *et al.* (2007), these values are below the maximum allowed for stored fruit and vegetables ($A_w < 0.7$). This range of water activity is considered optimal for the conservation of food products, because, at these values, biochemical reactions are reduced and/or inhibited due to the low availability of free water (Orsat *et al.*, 2007; Zhang *et al.*, 2010). The rehydration ratio of the crushed dry pulp showed no significant differences between the two drying techniques tested (Table 1); the use of MW did not influence this parameter.

Colour analysis Differences in colour parameters were observed among all the treatments of the dried pulp compared to the fresh pulp (Table 2). During the drying process, enzymatic and non-enzymatic browning reactions and pigment degradation occur in the pulp, all of which are strongly influenced by increasing drying temperature (Kumar *et al.*, 2014; Vadivambal and Jayas,

Table 2. Colour of the jelly palm fruit (*B. odorata*) before (FP) and after drying by hot air (HA) and microwave heating (MW) at 50, 60 and 70°C.

Treatment	T (°C)	L*	a*	b*	C* _{ab}	H	ΔE _{ab}
FP		71.70 ± 0.61	3.38 ± 0.22	66.05 ± 1.22	66.13 ± 1.21	87.13 ± 0.25	
HA	50	56.02 ± 0.38 ^{a**}	10.17 ± 0.03 ^c	52.61 ± 0.22 ^a	53.58 ± 0.21 ^a	79.13 ± 0.06 ^a	21.74
	60	52.04 ± 0.06 ^{cd}	9.27 ± 0.13 ^d	43.88 ± 0.17 ^e	44.84 ± 0.19 ^e	78.17 ± 0.15 ^b	30.22
	70	51.58 ± 0.12 ^d	10.47 ± 0.33 ^{bc}	46.27 ± 0.57 ^d	47.45 ± 0.63 ^d	77.33 ± 0.23 ^c	29.09
MW	50	52.94 ± 0.10 ^b	10.77 ± 0.13 ^b	50.35 ± 0.23 ^b	51.49 ± 0.25 ^a	77.97 ± 0.12 ^b	25.56
	60	52.19 ± 0.06 ^c	10.38 ± 0.12 ^{bc}	48.54 ± 0.08 ^c	49.64 ± 0.09 ^c	78.00 ± 0.17 ^b	27.13
	70	40.65 ± 0.08 ^e	11.92 ± 0.07 ^a	31.51 ± 0.32 ^f	33.68 ± 0.33 ^f	69.37 ± 0.06 ^d	47.23

** The same letters in the same column indicate that the data do not differ statistically (Tukey's test; $p < 0.05$). Results are the mean of triplicates. The fresh pulp (FP) was not compared with the treatments. T = temperature; L* = lightness; a* and b* = colour scales; C*_{ab} = chroma; H = hue angle and ΔE = relative colour difference index.

Table 3. Results of the ranking test for the jelly palm fruit (*B. odorata*) dried by hot air and microwave at 50, 60 and 70°C.

Treatments	T (°C)	Appearance			Colour			Odour		
		50	60	70	50	60	70	50	60	70
Hot air	50	-	17ns	52*	-	35*	58*	-	1ns	13*
	60		-	35*		-	23ns		-	14*
	70			-			-		-	-
Microwave	50	-	16ns	53*	-	22ns	71*	-	10ns	20*
	60		-	37*		-	49*		-	10ns
	70			-			-		-	-

* Significant critical difference (5%) = for the three samples, minimum of 24 for the 50 untrained assessors (colour and appearance); minimum of 11 for the 11 trained assessors (odour), according to the Newell and MacFarlane tables. NS = Not significant. T = temperature.

2007). Regarding lightness, the pulp dried by HA at 50°C presented the highest L* value, differing significantly ($p < 0.05$) from the other samples. However, browning was more evident at higher temperatures (70°C) and with drying by the MW technique. In the latter treatment, the lower L* values can be attributed to the formation of hot spots, which occurred at 70°C when getting close to final humidity. On the other hand, the ΔE_{ab} values demonstrate that drying at 70°C caused higher colour variation of the dried pulp compared with fresh especially for MW drying. Carotenoids are the main pigments found in fresh pulp (Pereira *et al.*, 2013), and these results indicate less degradation of these pigments in dried pulps at 50 and 60°C with both techniques, as shown by the lower ΔE_{ab} values for these samples. Cuccurullo *et al.* (2012) also used MW and HA techniques to dry apples, reporting reduced a* parameters and increased b* values with use of MW. However, the colour parameters L*, a* and b* did not suffer significant alterations with temperature increase. On the other hand, Arıkan *et al.* (2012) reported significant changes in the colour of carrots with increasing air temperature of drying by the microwave-convective technique.

Sensory analysis For their colour evaluation, the assessors were instructed to consider the browning aspect of the sample as the pulp with the highest colour intensity. Thus, in the ranking test comparing the three drying temperatures (50, 60 and 70°C) using

the HA technique, the assessors indicated that 50°C resulted in a lighter colour than the other temperatures (Tabled value ≥ 24 assessors; Newell and MacFarlane, 1987; see Table 3). In the ranking test for the MW technique, the pulps dried by MW at 70°C resulted in greater browning, while the results for 50 and 60°C samples did not differ. These results agree with those observed in the instrumental colour analysis. The pulps dried at 50 and 60°C presented better overall appearance in both drying systems according to the ranking test; however, no significant differences were observed between these two temperatures in this test (Table 3). In the ranking test comparing the odour of the samples resulting from the three drying temperatures using the HA technique, the pulps dried at 60 and 70°C by HA presented an odour more characteristic of the jelly palm fruit than those dried at 50°C. Quite different results were found for the MW technique: the pulps dried at 50 and 60°C have better odour than 70°C (Table 3). The assessors reported that the sample dried by MW at 70°C had an unpleasant odour, a burnt note described as 'caramel' or 'burnt fruit'.

The paired comparison tests judged two samples dried at the same temperature using different techniques (Table 4). There were no significant differences ($p < 0.05$) found between the samples dried by HA and MW at 60°C for all the analysed parameters (colour, odour and overall appearance). For the samples dried at

Table 4. Results of the paired comparison test for the jelly palm fruit (*B. odorata*) dried by hot air and microwave at 50 and 60°C.

Temperature	Colour		Odour		Overall appearance	
	MW	HA	MW	HA	MW	HA
60°C	29ns	21ns	7ns	3ns	19ns	31ns
50°C	44*	6*	9*	1*	7*	43*

* Significant critical difference (5%) between the two techniques in the same temperature (50 or 60°C). NS = Not significant. MW = microwave. HA = hot air.

50°C, the assessors indicated MW samples as having an odour more characteristic of the fresh fruit (Table 4); however, they chose the pulps dried by HA as having better colour and overall appearance. Thus, drying using MW at 60°C can be considered to maintain the pulp's sensory characteristics, because there were no differences found between the drying methods at lower temperatures (50 and 60°C) in terms of the three evaluated sensory attributes. In addition, this treatment resulted in less browning and an odour more characteristic of the jelly palm fruit compared to the other treatments performed at higher temperatures.

Conclusion

Using MW radiation to dry jelly palm pulp led to an observed increase in the drying rate and consequent reduction in the processing time compared to the conventional HA drying technique. Increasing drying temperature improved water removal from the samples, with reduced drying time for both techniques. However, the use of a high temperature (70°C) resulted in sensory changes to the food product. The results presented here suggest that drying the pulp from the jelly palm fruit (*B. odorata*) using MW at 60°C is the most efficient of the tested treatments, despite the higher alteration of colour compared to either MW or HA drying at 50°C. However, these colour differences, determined by instrumental analysis, were not observed in the sensory analysis, and drying at this temperature requires less time. Thus, this work reported the potential use of MW radiation to obtain dried jelly palm pulp with desirable physical, chemical and sensorial characteristics.

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