

Convective drying of *Butia Capitata* pulp: effect of air temperature on kinetic and quality parameters

Secagem convectiva de polpa de *Butia capitata*: efeito da temperatura do ar nos parâmetros cinéticos e de qualidade

Secado por convección de la pulpa de *Butia capitata*: efecto de la temperatura del aire sobre los parámetros cinéticos y de calidad

Received: 11/24/2020 | Reviewed: 11/26/2020 | Accept: 11/27/2020 | Published: 12/02/2020

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Abstract

Butiá (*Butia capitata*) is a typical Brazilian Cerrado fruit, rich in several bioactive compounds. This work aimed to study the influence of air temperature on drying kinetics and quality parameters of butiá pulp. The pulps were dried at 50 and 70 °C. Mathematical models were fitted to the moisture ratio data. The effective moisture diffusivity (D_{eff}) and the drying rate (DR) were calculated. The fresh and dried pulps were characterized in terms of moisture content (MC), water activity (a_w), total carotenoids content (TCC), yellow flavonoids, total phenolic content (TPC), antioxidant capacity and color. The Page model was the one that best fitted to the moisture ratio data. Drying reduced MC, a_w and the bioactive compounds content and altered colorimetric parameters. The higher temperature resulted in lower TCC and higher total color difference. However, it reduced the drying time (from 300 to 180 min), with higher D_{eff} and DR and resulted in samples with higher retention of yellow flavonoids, TPC and total antioxidants and a lower browning index. Therefore, 70 °C was the most suitable temperature for drying butiá pulp.

Keywords: *Butia capitata*; Fruit dehydration; Drying kinetic; Diffusion; Bioactive compound.

Resumo

Butiá (*Butia capitata*) é uma fruta típica do Cerrado brasileiro, rica em diversos compostos bioativos. Este trabalho teve como objetivo estudar a influência da temperatura do ar na cinética de secagem e nos parâmetros de qualidade da polpa de butiá. As polpas foram secas a 50 e 70 °C. Modelos matemáticos foram ajustados aos dados de razão de umidade. A difusividade efetiva da umidade (D_{eff}) e a taxa de secagem (DR) foram calculadas. As polpas frescas e secas foram caracterizadas quanto ao teor de umidade (MC), atividade de água (a_w), teor de carotenoides totais (TCC), flavonoides amarelos, teor de fenólicos totais (TPC), capacidade antioxidante e cor. O modelo de Page foi o que melhor se ajustou aos dados de taxa de umidade. A secagem reduziu o MC, a_w e o conteúdo de compostos bioativos e alterou os parâmetros colorimétricos. A temperatura mais alta resultou em menor TCC e maior diferença de cor total. Porém, reduziu o tempo de secagem (de 300 para 180 min), com maiores D_{eff} e DR e resultou em amostras com maior retenção de flavonoides amarelos, TPC e antioxidantes totais e menor índice de escurecimento. Portanto, 70 °C foi a temperatura mais adequada para a secagem da polpa de butiá.

Palavras-chave: *Butia capitata*; Desidratação de frutas; Cinética de secagem; Difusão; Composto bioativo.

Resumen

Butiá (*Butia capitata*) es una fruta típica del Cerrado brasileño, rica en varios compuestos bioactivos. Este trabajo tuvo como objetivo estudiar la influencia de la temperatura del aire en la cinética de secado y los parámetros de calidad de la pulpa de butiá. Las pulpas se secaron a 50 y 70 °C. Los modelos matemáticos se ajustaron a los datos de la proporción de humedad. Se calcularon la difusividad de humedad efectiva (D_{eff}) y la velocidad de secado (DR). Las pulpas frescas y secas se caracterizaron en términos de contenido de humedad (MC), actividad de agua (a_w), contenido total de carotenoides (TCC), flavonoides amarillos, contenido fenólico total (TPC), capacidad antioxidante y color. El modelo de Page fue el que mejor se ajustó a los datos del índice de humedad. El secado redujo el contenido de MC, a_w y compuestos bioactivos y modificó los parámetros colorimétricos. La temperatura más alta resultó en un TCC más bajo y una diferencia de color total más alta. Sin embargo, redujo el tiempo de secado (de 300 a 180 min), con mayor D_{eff} y DR y resultó en muestras con mayor retención de flavonoides amarillos, TPC y antioxidantes totales y un menor índice de pardeamiento. Por tanto, 70 °C era la temperatura más adecuada para secar la pulpa de butiá.

Palabras clave: *Butia capitata*; Deshidratación de frutas; Secado cinético; Difusión; Compuesto bioactivo.

1. Introduction

Fruits are good sources of various nutrients, essential for the proper human organism operation. Several species of exotic fruits have received attention in recent years (Curi et al., 2019, Junqueira et al., 2017, Mendonça et al., 2017). These fruits have several beneficial effects on the human body, due to the rich composition of compounds such as fiber, minerals, vitamin C, carotenoids, phenolic compounds and antioxidants (Pereira et al., 2013). In this context, fruits of the genus *Butia*, deserve to be highlighted.

Butiá fruits are native from South America and consist of about 18 different species that present yellow pulp, highly aromatic and fibrous, in addition to a composition rich in bioactive compounds (Aguiar et al., 2014; Hoffmann, Barbieri, Rombaldi, & Chaves, 2014; Hoffmann et al., 2017). However, the fruits have high biochemical reaction rates, which make them highly perishable. Thus, the processing of fresh fruits is a crucial step to increase their shelf life (Chong, Law, Figiel, Wojdyło, & Oziembłowski, 2013).

Drying is a technique widely applied to the processing of fresh fruit, since it acts in the transfer of the moisture content of the food to the heated air, reducing the moisture content and

water activity and, resulting in a decrease in the rates of enzymatic chemical and microbiological deteriorations. In addition to a stable product, maintaining the quality of the dried product has been desired, so that it presents attractive characteristics for commercialization. In this context, the conditions used during the drying process, such as air temperature, have a direct effect on the physical properties and composition of bioactive substances presented by the product (Chong et al., 2013; Macedo, Vimercati, Araújo, Saraiva, & Teixeira, 2020). Bioactive compounds are heat sensitive, easily degraded during the drying process. Therefore, the retention of these compounds is an important quality parameter evaluated in dried products (Karam, Petit, Zimmer, Baudelaire Djantou, & Scher, 2016; Omolola, Jideani, & Kapila, 2017).

This study aimed to evaluate the effects of air temperature during convective drying on the drying kinetics and the content of bioactive compounds in the butiá pulp. Use o parágrafo como modelo

2. Material and Methods

The butiá (*Butia capitata*) pulp was obtained from Cooperativa Grande Sertão (Montes Claros, MG, Brazil). The pulp was stored at -20 °C until the beginning of the experiments.

2.1 Drying kinetic

The pulp (120g) was dispersed in Petri dishes (60 mm diameter), forming a 5 mm layer. The plates were inserted in a tunnel dryer (Eco Engenharia Educacional, MD018, Brazil), with air velocity of 1.5 m/s and dried at 50 and 70 °C. During drying, their mass was measured on an analytical scale (Marte Científica, AD33000, Brazil), coupled to the dryer. Drying was interrupted when the samples presented moisture content of 6 kg water/100kg samples.

The moisture ratio (MR) was calculated according to Equation 1 (Macedo et al., 2020).

$$MR = \frac{X_t}{X_0} \quad (1)$$

Where, MR is the moisture ratio; X_0 and X_t are the moisture, on a dry basis, of the sample; at the initial stage and at time t, respectively.

Lewis, Henderson and Pabis, Page, Midilli and Wang and Singh models (Table 1) were fitted to the MR data. The values of the model parameters were obtained by minimizing the sum of the squares of the deviations using non-linear regression.

Table 1. Mathematical models fitted to moisture ratio data.

Model	Equation
Henderson & Pabis	$MR = a \cdot \exp^{-k \cdot t}$
Lewis	$MR = \exp^{-k \cdot t}$
Midilli	$MR = \exp^{-k \cdot t^n} + b \cdot t$
Page	$MR = \exp^{-k \cdot t^n}$
Wang & Singh	$MR = 1 + a \cdot t + b \cdot t^2$

MR: moisture ratio; t: time (min); k, a, n and b are parameters of the models. Source: Authors.

The determination coefficient (R^2), adjusted coefficient of determination (R^2_{adj}) and the standard error of the regression (SE) of the models fitted to MR were calculated according to Equations 2 to 4, respectively.

$$R^2 = 1 - \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pred,i})^2}{\sum_{i=1}^N (MR_{exp,i} - \overline{MR})^2} \quad (2)$$

$$R^2_{adj} = 1 - \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pred,i})^2}{\sum_{i=1}^N (MR_{exp,i} - \overline{MR})^2} \cdot \frac{N-1}{N-p} \quad (3)$$

$$SE = \sqrt{\left(\frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pred,i})^2}{N-p} \right)} \quad (4)$$

Where, $MR_{exp,i}$ and $MR_{pred,i}$ are experimental and predicted values of the moisture ratio for the i-th observation, respectively; \overline{MR} is the mean value of the experimental moisture ratio; N is the number of observations; p is the number of constants in the model.

Fick's second law was used to calculate the effective moisture diffusivity (D_{eff}), according to Equation 5 (Crank, 1975), considering D_{eff} as constant, the sample as an infinite flat plate, moisture content equally distributed in the sample and the internal mass flow as unidirectional.

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} e^{[-(2n+1)^2 \pi^2 D_{\text{eff}} \frac{t}{4L^2}]} \quad (5)$$

Where, D_{eff} the effective moisture diffusivity (m^2/s); L is the thickness of the sample (m); t is the drying time (s); n is the number of terms in the model.

2.2 Moisture content and water activity

The moisture content of the samples was determined by the gravimetric method, at 70 °C under vacuum (AOAC, 2010).

Water activity was measured with the help of a water activity meter (Aqualab, series 3TE, Washington, USA), a 25 °C.

2.3 Bioactive compounds

The fresh and dried pulps were evaluated for the content of yellow flavonoids, total carotenoids, total phenolics and antioxidant capacity by FRAP methods (Ferric Reducing Antioxidant Power) and DPPH (2,2-diphenyl-1-picrylhydrazyl).

The retention index of bioactive compounds was calculated by the ratio of the dried sample response to the fresh sample response.

2.3.1 Total carotenoids content (TCC)

The TCC was performed as described by De Souza et al. (2012) and Carbonell-Capella et al. (2015), with some modifications. Briefly, 1.0 g of the sample was added to 5 mL of acetone and ethanol in a 1:1 ratio, and the resulting mixtures were shaken for 1 h at 200 rpm. Then, 5 mL of hexane was added to samples, homogenized and centrifuged for 5 min at 4000 rpm at 5°C. The supernatant was collected and the final volume was completed up to 25 ml with hexane. The absorbance measurement was performed on a spectrophotometer at 450 nm. The β -carotene extinction coefficient (2505) was used to calculate the total carotenoid content.

2.3.2 Yellow flavonoids

Yellow flavonoids determination was carried out as described by Silva et al. (2014), with some modifications. A sample (1.0 g) received 20 mL of an 85:15 (v/v) solution of ethanol (95%) and HCl (1.5 N), respectively, and vortexed. The samples were kept refrigerated, in the dark for 16 h. Sequentially, the samples were filtered (Whatman No. 1) and the absorbance was read on a spectrophotometer at 374 nm. Equation 6 was used to determine the content of yellow flavonoids. Results were expressed as mg of yellow flavonoids per 100 g of sample dry basis (mg/100 g db).

$$\text{Yellow flavonoids content } \left(\frac{\text{mg}}{100\text{g}} \right) = \frac{\text{ABS} \times \text{DF} \times 1000}{\text{sample weight} \times \epsilon_{1\text{cm},374}^{1\%}} \quad (6)$$

Where, ABS is absorbance; DF is the dilution factor and $\epsilon_{1\text{cm},374}^{1\%}$ is the absorption coefficient for yellow flavonoids (76.6 mol/cm).

2.3.3 Total phenolic content (TPC)

Fresh and dried pulp extracts were prepared as described by De Souza et al. (2012), with minor modifications. Initially, 1.5 g of sample was homogenized with 40 mL of 50% methanol (v/v). The mixture was kept at rest for 1 h, followed by centrifugation at 3500 rpm for 15 min. The supernatant was collected and 40 mL of 70% (v/v) acetone was added to the residue, followed by rest and centrifugation, as previously described. The supernatant from the two extractions was mixed and the volume completed up to 100 mL with distilled water.

The TPC was determined by the Folin-Ciocalteu method, as described by Silva et al. (2014), with some modifications. Briefly, 0.5 mL of each filtered and properly diluted extract was mixed with 2.5 mL of the 10% (v/v) Folin-Ciocalteu reagent and 2 mL of the 4% (w/v) sodium carbonate solution. After 1 h of reaction in the dark at room temperature, absorbance at 750 nm was measured using a spectrophotometer. Results were expressed as mg of gallic acid equivalent per g of sample dry basis (mg GAE/g db).

2.3.4 Antioxidant capacity

The extract for antioxidant capacity was obtained as described previously for total phenolics.

The antioxidant capacity by the ferric reducing antioxidant power (FRAP) assay was determined as by Rufino et al. (2010). Initially, the FRAP reagent was prepared immediately before use by mixing 10 mM TPTZ (2,4,6-tris (1-pyridyl)-5-triazine solution) with a 20 mM FeCl₃ solution, previously prepared with 40 mM HCl, and 0.3 acetate buffer, pH 3.6, in the proportion of 1:1:10 (v/v/v). For the determination of antioxidant capacity, a 90 µL aliquot of the duly diluted extract was mixed with 270 µL of deionized water and 2.7 mL of FRAP reagent. The mixture was homogenized and incubated at 37°C for 30 min. Sequentially, the absorbance was determined at 595 nm and FRAP reagent was used as blank. A calibration curve was constructed using an aqueous solution of ferrous sulfate (Fe₂SO₄.7H₂O at 500-2000 µM). Results were expressed as micromoles of ferrous sulfate per g of sample dry basis (µM ferrous sulfate/g of sample db).

The antioxidant capacity by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) decolorization assay was determined as by Ballesteros et al. (2014), with minor modifications. For the reactions, 100 µL of the extract was mixed with 2.9 mL of DPPH ethanolic solution (0.6 mM, with absorbance adjusted to 0.700 at 517 nm with ethanol) and kept protected from light for 30 min at room temperature. Subsequently, the absorbance was determined at 517 nm in a spectrophotometric and ethanol was used as blank. A calibration curve was constructed using Trolox solution. Results were expressed as micromoles of Trolox per g of sample dry basis (µmol Trolox/g of sample db).

2.4 Color

The color of fresh and dried pulps was determined on colorimeter (Konica Minolta, Spectrophotometer model CM-5), with illuminant D65 and 10° viewing angle. The parameters were obtained L*, a*, b*. L* indicates lightness, a* redness and greenness, and b* yellowness and blueness. Chroma (C*) and hue (°h) were calculated, according to Equations 7 and 8, respectively (Vimercati, Araújo, et al., 2020).

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (7)$$

$$\theta_h = \tan^{-1} \left(\frac{b^*}{a^*} \right) \quad (8)$$

The total color difference (ΔE) in relation to fresh pulp (subscript “0”), and the browning index (BI) were determined according to Equations 9 and 10, respectively (Pathare, Opara, & Al-Said, 2013).

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (9)$$

$$BI = \frac{100(x-0.31)}{0.17} \quad (10)$$

$$\text{Where, } x = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.021b^*}$$

2.5 Statistical analysis

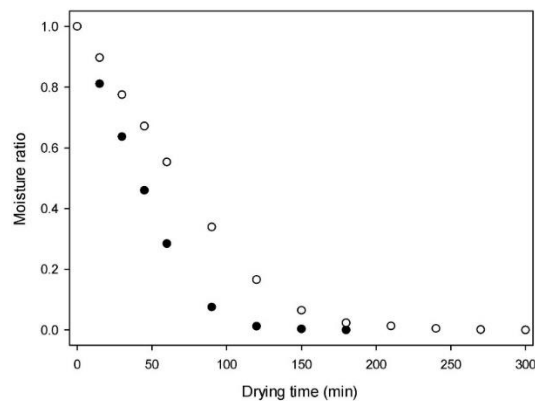
A completely randomized design was used. The experiments were carried out in three repetitions. The data were submitted to analysis of variance (ANOVA), followed by the Tukey test. All analyzes were performed at the 5% level of significance, with the help of the Statistica software (StatSoft Inc., Tulsa).

3. Results and Discussion

3.1 Drying kinetic

The evolution of the moisture ratio (MR) data is shown in Figure 1.

Figure 1. Drying kinetics curves of the butiá pulps at different temperatures.

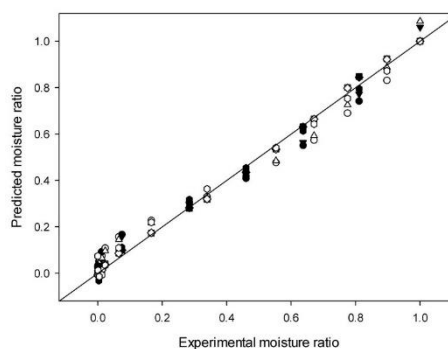


White circles: 50 °C; Black circles: 70 °C. Source: Authors.

Drying at the highest temperature (70 °C) took 180 min to complete, while at the lowest temperature, 300 min were required. It can be seen that the increase in the drying air temperature reduced the drying time by 40%. Macedo et al. (2020), Song et al. (2019) and Muliterno et al. (2017) also observed that drying time was reduced at higher temperatures on drying of banana, lotus pollen and okara, respectively.

The mathematical models (Table 1) fitted satisfactorily to the MR data, with R^2 and SE between 0.968 and 0.998, 0.016 and 0.067, respectively. Figure 2 shows the dispersion of the MR data predicted by the models as a function of the MR data obtained experimentally. The dispersion was close to the 45° line, indicating the proximity between predicted and experimental values (Macedo et al., 2020).

Figure 2. Dispersion of predicted versus experimental moisture ratio values.



White symbols: 50 °C; Black symbols: 70 °C; Circles: Lewis model; Triangles: Henderson & Pabis model; Squares: Page model; Diamonds: Midilli model; Hexagons: Wang & Singh model. Source: Authors.

For both drying air temperatures, the Page model was the one with the best fit, with the highest and lowest values of R^2_{adj} and SE, respectively (Table 2).

Table 2. Parameter, coefficient of determination (R^2), adjusted coefficient of determination (R^2_{adj}), standard error of the regression (SE) of mathematical models.

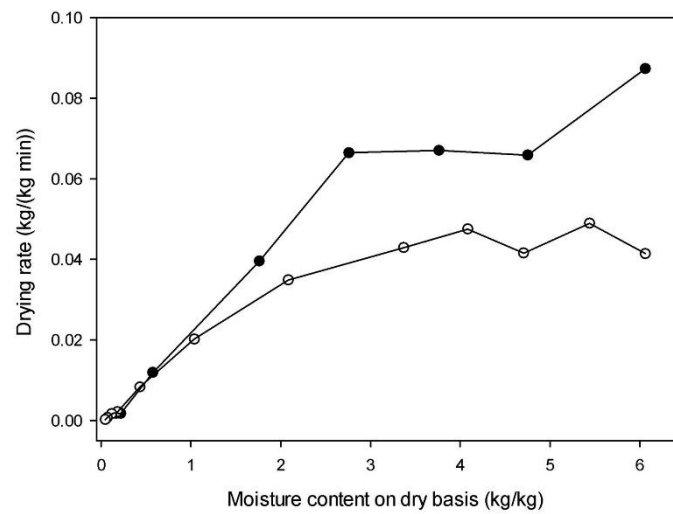
T (°C)	Model	k	a or n	b	R^2	R^2_{adj}	SE
50	Lewis	0.012346	-	-	0.968874	0.968874	0.067297
	HP	0.013445	1.085887	-	0.976764	0.974651	0.060731
	Page	0.001403	1.490056	-	0.998286	0.998130	0.016493
	Midilli	0.001491	1.473699	-0.000030	0.998410	0.998092	0.016661
	WS	-	-0.008787	0.000019	0.993667	0.993091	0.031706
70	Lewis	0.019866	-	-	0.971664	0.971664	0.064214
	HP	0.021079	1.060723	-	0.976195	0.972794	0.062921
	Page	0.003046	1.474348	-	0.997512	0.997157	0.020341
	Midilli	0.003293	1.450631	-0.000071	0.997753	0.997004	0.020880
	WS	-	-0.014380	0.000050	0.995144	0.994451	0.028417

Note: k, a, n and b: model parameters; HP: Henderson & Pabis; WS: Wang & Singh. Source: Authors.

The parameter k of mathematical models represents the effect of external drying factors (Santos, Figueirêdo, Queiroz, & Santos, 2017). As expected, the k value increased with increasing drying air temperature (Table 2). This same trend was observed by Macedo et al. (2020) and Santos et al. (2017). In addition, parameter b of the WS model also increased with temperature (Table 2). On the other hand, the parameters a of the HP and WS models, b of the Midilli model and n of the Page and Midilli models decreased with increasing temperature (Table 2).

The drying rate (DR) of the samples was higher using the highest drying temperature (Figure 3). At the beginning of the process, the drying rate was higher, for both temperatures. This is due to the higher moisture content available for removal. During the process, this content reduces, decreasing the DR. The same was observed by Macedo et al. (2020) and Kumar et al. (2019).

Figure 3. Pulp drying rate as a function of moisture content on a dry basis.



Source: Authors.

The butiá D_{eff} values (Table 3) are in the food drying interval (Thuwapanichayanan, Prachayawarakorn, Kunwisawa, & Soponronnarit, 2011).

Table 3. Effective moisture coefficient (D_{eff}) at different temperatures.

Temperature (°C)	$D_{eff} \times 10^9$ (m ² /s)	R^2	SE
50	2.70	0.9037	0.1184
70	3.943496	0.9068	0.1164

Source: Authors.

D_{eff} increased with temperature (Table 3), due to the easiness of water to migrate from the interior to the surface of the food due to the increase in the driving force caused by the higher temperature, increasing the velocity of the drying process.

3.2 Moisture content (MC) and water activity (a_w)

The fresh butiá pulp showed high MC and a_w values (Table 4), indicating high product perishability and the need to use conservation methods to extend its useful life. The MC of the fruits is close to that reported by other authors.

Table 4. Values and percentage of retention (between parenthesis) of moisture content, water activity and bioactive compounds of fresh and dried pulps.

Response	Fresh pulp	50 °C	70 °C
MC (kg/100 kg sample)	85.84±0.05 ^a	6.02±0.28 ^b	6.18±0.18 ^b
Water activity	0.990±0.001 ^a	0.553±0.001 ^b	0.555±0.002 ^b
YF (µg/g sample db)	500.44±35.30 ^a	362.08±13.91 (72.35%) ^c	427.63±14.88 (85.45%) ^b
TCC (µg/g sample db)	719.727±5.410 ^a	617.486±7.061 (85.80%) ^b	396.760±21.059 (55.13%) ^c
TPC (mg GAE/g sample db)	4.809±0.010 ^a	3.982±0.054 (84.78%) ^c	4.282±0.109 (85.98%) ^b
AC (µM Trolox/g sample db)	2.731±0.083 ^a	0.385±0.012 (14.10%) ^c	0.587±0.003 (21.49%) ^b
AC (µM ferrous sulphate/g sample db)	808.128±4.876 ^a	312.679±7.012 (38.69%) ^c	338.385±2.534 (41.87%) ^b

Means with different letters horizontally are statistically different by Tukey's test ($p < 0.05$).

MC: moisture content; YF: yellow flavonoids; TCC: total carotenoids content; TPC: total phenolic content; AC: antioxidant capacity.

Source: Authors.

The MC and a_w values decreased with drying, but did not differ between the dried pulps. The a_w value found is below 0.60, ensuring the stability of the dried product for a longer storage period. According to Samoticha et al. (2016), fruits submitted to drying must present a_w values between 0.60 and 0.80 and, preferably, this value must be below 0.60. The a_w values reported for butiá drying are close to those found for other dried fruits (Jangam, Joshi, Mujumdar, & Thorat, 2008; Samoticha et al., 2016).

3.3 Bioactive compounds

The drying temperature influenced the bioactive compounds and antioxidant activity of butiá (Table 4). The highest values found for flavonoids, total phenolics and antioxidant activity were for the highest drying temperature (70 °C).

3.3.1 Total carotenoids content (TCC)

The values obtained for TCC ranged from 396.760 to 719.727 ($\mu\text{g/g}$ sample db). According to Rufino et al. (2010), fruits with a TCC of 47 $\mu\text{g/g}$ can be considered rich sources of TCC, an important precursor of vitamin A. Thus, even with the reduction of the content of these compounds with drying, butiá pulps have been shown to have a high content of these compounds. Faria et al. (2011) found that the main carotenoid found in the pulp of these fruits is β -carotene. The TCC in the pulp found by these authors was lower than that of the present study, with a maximum value of 43.9 $\mu\text{g/g}$. According to Table 4, the lowest TCC was found for 70 °C and 50 °C showed a higher TCC retention. The reduction in TCC at elevated temperatures has also been observed by other authors. Song et al. (2019) observed a significant reduction in the TCC of dried pollen 60 and 70 °C, compared to lower temperatures (40 and 50 °C) along the drying time. Multari et al. (2018) found that the TCC of quinoa reduced significantly when 70 °C was used. According to these authors, the drying temperature, as well as light, oxygen and the presence of some catalysts, have a deleterious effect on the retention of carotenoids, given their unsaturated nature of easy oxidation and isomerization.

3.3.2 Yellow flavonoids

The fresh pulp presented 500.435 $\mu\text{g/g}$ sample db of yellow flavonoids (Table 4). This value is close to that found by Silva et al. (2014) for monbin pulp (542.2 $\mu\text{g/g}$ sample db) and passion fruit (603.7 $\mu\text{g/g}$ sample db). As described by Schneider et al. (2017), the importance of maintaining these compounds in food is related to their action as antioxidant and anti-inflammatory agents.

According to Table 4, the yellow flavonoids content decreased with drying. This reduction is greater for drying at 50 °C and in accordance with the reductions occurred with the content of total phenolic compounds. At this temperature, the retention index of these compounds was 72.35%. For 70 °C, this index was 85.45%. According to Mounir et al. (2020), the phytochemical properties of flavonoids can be altered during food processing, especially when thermal processes are used. Thus, the evaluation of the change in the content of flavonoids in high temperature processes, such as drying, is extremely relevant.

3.3.3 Total phenolic content (TPC)

The TPC found for the pulp was 4.809 ± 0.01 mg GAE/g sample db (Table 4). This value is higher than that reported by Almeida et al. (2011) for other fruits, such as papaya (4.45 mg GAE/g db), pineapple (2.98 mg GAE/g db) and tamarind (1.22 mg GAE/g db). On the other hand, the value is lower than those reported by Silva et al. (2014) for the acerola pulp (290.93 mg GAE/g db), cashew apple (52.86 mg GAE/g db), surinam cherry (39.57 mg GAE/g db) and soursop (28.86 mg GAE/g db). Although the TPC decreased with drying, the higher temperature used in the process (70 °C) allowed to preserve the highest amounts of TPC (85.98%). Samoticha et al. (2016) verified a 9 to 38% reduction in the TPC during the drying of chokeberries. In addition, as in the present study, these authors also observed that the convective drying carried out at 70 °C resulted in less TPC loss in relation to the lower temperature (50 °C). This difference is attributed to the longer drying time required at lower temperatures. López et al. (2010) also found that there was a reduction in the TPC of dried blueberries at different temperatures. However, these authors found the smallest reductions in TPC for temperatures above 70 °C. According to Fabisiak et al. (2005) when fruits go through the drying process at lower temperatures, the product is exposed for a long period of time to a temperature close to the ideal temperature of the polyphenoloxidase enzyme, 40 °C, contributing to its higher activity, which can lead to a reduction in the TPC of the samples.

3.3.4 Antioxidant capacity

The antioxidant activity of the pulp was 808.128 ± 4.876 (μ M ferrous sulphate/g sample db) by the FRAP method and 2.731 ± 0.083 (μ M Trolox/g sample db) when determined by the DPPH method. The drying process had a significant influence in reducing the antioxidant activity of the dry product. As with the content of phenolic compounds, the antioxidant activity (FRAP and DPPH) showed the highest values for the highest drying temperature used (70 °C), as presented in Table 4. López et al. (2010) also found higher antioxidant activity at the highest drying temperature (90 °C) and Samoticha et al. (2016) found less antioxidant activity during convective drying at 50 °C. The higher antioxidant activity at higher temperatures may be related to the formation of products from the Maillard reaction and caramelization, favored at higher temperatures, both of which also have an effect on the elimination of free radicals (Bober & Oszmianski, 2004).

3.4 Color

Color is an important physical attribute of dehydrated products, being one of the first parameters evaluated by consumers and which can lead to product rejection (Chong et al., 2013). The effect of drying conditions on the color parameters of butiá are shown in Table 5.

Table 5. Colorimetric parameters of fresh pulp and pulps dried at 50 and 70 °C.

Parameter	Fresh pulp	50 °C	70 °C
L*	50.77±2.19 ^a	34.92±0.53 ^b	33.88±0.62 ^b
a*	13.13±0.46 ^b	16.73±0.42 ^a	16.72±0.51 ^a
b*	47.33±1.87 ^a	29.22±0.40 ^b	26.51±0.92 ^c
C*	47.30±3.24 ^a	33.57±0.44 ^b	31.58±1.04 ^b
°h	73.84±0.77 ^a	60.10±0.75 ^b	58.01±1.06 ^c
ΔE	-	23.05±0.54 ^b	25.42±1.16 ^a
BI	-	180.59±5.16 ^a	168.85±5.64 ^b

Means with different letters horizontally are statistically different by Tukey's test ($p < 0.05$). Source: Authors.

The results showed that the fresh pulp had the highest values of L*, b*, C* and °h and the lowest value of a* in relation to dried pulps. The lower L* values of the dried pulps demonstrate the product's browning process. The drying temperature did not influence the parameters L*, a*, and C* of the dry pulps. However, the parameter b* was higher in the treatment at 50 °C, indicating that this sample was more yellow. This behavior may be associated with the higher TCC observed in this sample (Table 4). The °h values were found between 58.01 and 73.84, indicating that the fresh and dry pulps showed coloration between red (0°) and yellow (90°). The pulp dried at 70 °C and the fresh pulp showed the lowest and highest °h value, showing shades closer to orange and yellow, respectively.

The pulp dried at 70 °C showed a higher value of ΔE. According to Pathare et al. (2013), variations of ΔE greater than 3, indicate a very distinct color difference. Color changes in products subjected to high temperatures can occur due to several factors, such as oxidative processes, Maillard reaction and pigment degradation. Therefore, ΔE values are useful for indicating color variations resulting from food processing (Romdhane, Bonazzi, Kechaou, & Mihoubi, 2015; Macedo, Silva Araújo, Vimercati, Saraiva, & Teixeira, 2019; Vimercati, Macedo, et al., 2020).

The higher BI value presented by the pulp dried at 50 °C may indicate that there was a greater development of browning reactions at this temperature. This is especially true for the Maillard reaction, due to the presence of reducing compounds and free amino groups, naturally present in the fruits, giving rise to dark colored compounds. In addition, the production of o-quinones from the oxidation of phenolic compounds also results in product darkening (Chong et al., 2013; Pathare et al., 2013). These reactions occur mainly at the end of the drying process (Shaari, Sulaiman, Rahman, & Bakar, 2018). The longer drying time required for drying using the lower temperature contributed to the longer product exposure to the high temperature condition, which may result in more product darkening.

4. Conclusion

The higher temperature resulted in shorter drying time, presenting greater effective moisture diffusivity and drying rate. The mathematical models studied were adequate to represent the drying process, in which the Page model stood out, presenting the best fit to the experimental data.

Butiá proved to be a good source of bioactive compounds. The drying air temperature significantly influenced the bioactive compounds analyzed. The higher drying temperature led to a color difference compared to that of fresh pulp. However, in general, the highest quality indicators were associated with a higher drying temperature, probably due to the shorter exposure time of the product to the process conditions. Therefore, 70 °C was the most suitable temperature for convective drying of butiá pulp. The results of this study can be used to optimize the butiá drying process in later studies.

Future work can be developed by studying other methods of drying the butiá pulp and evaluating the stability of the dried pulps over time.

Funding details

This work was supported by CAPES Finance Code 001; CNPq; and FAPEMIG.

Conflicts of interest

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

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