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# INFLUENCE OF DRYING TEMPERATURE AND PULP LAYER THICKNESS ON THE PHYSICAL AND PHYSICOCHEMICAL QUALITY OF PEQUI POWDER[1]

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**ABSTRACT** - The objective of this work was to characterize the physical and physicochemical parameters of pequi powders obtained by means of convective drying at different temperatures (50, 60, 70 and 80 °C) and pulp layer thicknesses (0.5, 1.0 and 1.5 cm). Initially, the physicochemical characterization of fresh pulp was carried out, followed by convective drying under the conditions mentioned, until the equilibrium moisture content and subsequent disintegration to obtain the powders. Subsequently, the physical and physicochemical properties of the obtained powders were analyzed and the best powder was selected based on reduced moisture content and water activity and lower peroxide index. Pequi pulp showed a high fat content and a yellowish color; with the increase in drying temperature, there were reductions in the moisture content, water activity and protein content of the powders. As for the color parameters, the powder showed a darkening with the increase in drying time; the water adsorption isotherms of the selected pequi powder were classified as Type II, and the GAB model showed the best fits. The pequi powders showed good solubility and low cohesiveness. The powder that showed good flowability was produced at a drying temperature of 60 ºC and with pequi pulp layer thickness of 0.5 cm.

**Keywords**: *Caryocar coriaceum* Wittm. Physical properties. Adsorption isotherms.

## INFLUÊNCIA DA TEMPERATURA DE SECAGEM E ESPESSURA DA CAMADA NA QUALIDADE FÍSICA E FÍSICO-QUÍMICA DE PÓS DE PEQUI

**RESUMO** - Objetivou-se neste trabalho, caracterizar quanto a parâmetros físicos e físico-químicos pós de pequi obtidos por meio da secagem convectiva em diferentes temperaturas (50, 60, 70 e 80 °C) e espessuras da camada de polpa (0,5, 1,0 e 1,5 cm). Inicialmente foi realizada a caracterização físico-química da polpa *in natura*, seguindo-se a secagem convectiva nas condições citadas, até o teor de água de equilíbrio e posterior desintegração para obtenção dos pós. Posteriormente, foram analisadas as propriedades físicas e físico-químicas dos pós obtidos e fez-se a seleção do melhor pó com base em reduzido teor de água e atividade de água e menor índice de peróxido. A polpa de pequi apresentou elevado teor de gordura e coloração amarelada; com o aumento da temperatura de secagem houve uma redução do teor de água, a atividade de água e o teor de proteínas dos pós. Quanto aos parâmetros de cor, o pó apresentou um escurecimento com o aumento do tempo de secagem; as isotermas de adsorção de água do pó de pequi selecionado foram classificadas como Tipo II e o modelo de GAB apresentou os melhores ajustes. Os pós de pequi apresentaram boa solubilidade e baixa coesividade O pó que apresentou boa fluidez foi o produzido na condição de 60 ºC e 0,5 cm de espessura.

**Palavras-chave**: *Caryocar coriaceum* Wittm. Propriedades físicas. Isotermas de adsorção.

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# INTRODUCTION

The exploitation of Cerrado fruits has potential in the Brazilian agroindustrial scenario. Processing and application are able to add commercial and nutritional value, besides conferring remarkable characteristics such as aroma, flavor and color. Among the fruits of this biome is pequi, which is found mainly in the states of Goiás, Mato Grosso, Piauí, Pará, Minas Gerais, Tocantins and Maranhão, with incidence also in the states of Ceará, Pernambuco and Piauí (REIS; SCHMIELE, 2019; MOURA; CHAVES; NAVES, 2013).

Pequi stands out for its high biological potential and concentration of bioactive compounds present in the pulp due to the strong correlation between color and carotenoids, percentage of lipids and minerals (SILVA; SILVA; MENDES, 2020). The chemical and physicochemical composition of pequi pulp may vary according to difference of species and fruit harvest site. Specific techniques and equipment are required for obtaining pequi pulp, which may explain the low dissemination of pequi pulp in places far from the producing regions. An alternative to provide pequi pulp for several locations is through drying, since it adds commercial value and expands the possibilities of use.

Pulp drying contributes decisively to expanding the market of regional fruits. Dried, fractionated or powdered fruit pulps can be stored at room temperature without the costs required for freezing, transport and cold storage. The benefits of the drying process are several, including: ease in product preservation; stability of aromatic components at room temperature for long periods; protection against enzymatic and oxidative degradation; weight reduction; and energy saving by dispensing with the cold chain. Drying is used in order to facilitate the storage and marketing of pulp and of various agricultural products, for being a process capable of prolonging their useful life and for ensuring stability during storage (SANTOS et al., 2013).

After transforming the dried fruit pulp into a powder, through the disintegration process, it is important to know the hygroscopic characteristics of the product in order to establish safe levels of temperature and relative humidity combinations for the best conservation of the product (OLIVEIRA et al., 2011).

In the literature, there are some studies highlighting the characterization of pulp of the pequi species *Caryocar coriaceum* Wittm. and *Caryocar brasiliense* Camb. Sousa et al. (2016) evaluated the thermophysical properties of pequi (*C. coriaceum* Wittm.) pulp. Sousa et al. (2017) studied the modeling and effective diffusivity of pequi (*C. coriaceum* Wittm.) pulp. Paz et al. (2014) analyzed the nutritional and physicochemical composition of pequi (*C. brasiliense* Camb.). Justi et al. (2017) studied the technological aspects in the production of pequi (*C. brasiliense* Camb.) pulp flour. However, there are no reports about the influence of temperature on the physical and physicochemical quality of powders of the pequi species *C. coriaceum* Wittm. In view of the above, the objective was to analyze the influence of drying temperature and pulp layer thickness on the physical and physicochemical quality of pequi (*Caryocar coriaceum* Wittm.) powders.

# MATERIAL AND METHODS

### Obtaining and characterizing pequi pulp

The raw material used was pequi fruits (*C. coriaceum* Wittm.) harvested at the Araripe Plateau, geographic coordinates 07º 14’ 05.0” S and 039º 37’ 30.4” W, located in the south of the Ceará state, Brazil. The fruits were acquired from residents who sell them in the local market of the municipality of Crato, Ceará.

The pequi fruits were selected, keeping only those that were ripe and without physical damage. The ripe maturity stage was identified by the softened peel and easy removal of the peduncle remnant. The fruits were then washed under running water, sanitized in sodium hypochlorite solution (mg/100 g) for 15 min and rinsed. The pequi fruits were cut to separate the external mesocarp from the internal mesocarp (yellow pulp), and the internal mesocarp was washed with drinking water. In order to facilitate pulp extraction, the internal mesocarp was cooked in drinking water at 100 °C for 30 minutes; then, the cooked internal mesocarps were cooled and pulped using a stainless steel pulper (Max Machine®), which works with circular movements and whose inner part, which is in contact with the fruit, has an abrasive surface, which assists in pulp extraction. The pulps were packed in low-density polyethylene plastic bags, which were sealed and stored in a freezer (-20 °C) until the study was conducted, one month after obtaining the pulps.

The whole pequi pulps were analyzed for: moisture content, ash, lipids, proteins, total soluble solids, total titratable acidity, pH, total, reducing and non-reducing sugars, and ascorbic acid, according to the methodologies of the Adolfo Lutz Institute (IAL, 2008). Total carotenoids were determined according to the methodology described by Lichtenthaler (1987); water activity ($a_w$) at 25 °C was determined using the Aqualab 3TE hygrometer from Decagon Devices. Color was determined using a Hunter Lab Mini Scan XE Plus portable spectrophotometer, model 4500 L, obtaining the parameters L* (lightness), +a* (redness) and +b* (yellowness).

**Drying of pequi pulp**

The whole pequi pulp was dried convectively in a forced air circulation oven, at temperatures of 50, 60, 70 and 80 °C, with pulp layer thicknesses of 0.5, 1.0 and 1.5 cm and air velocity of 1.0 m/s. The pulp was spread evenly on rectangular stainless-steel trays (24.5 x 16.5 cm), which were weighed during drying at regular intervals until reaching constant weight. Temperature and thickness influenced the drying time; with the increase in thickness the drying time increased and with the increase in temperature the drying time decreased. The drying times ranged from 520 to 1,360 minutes for the pulp layer thickness of 0.5 cm, from 1,300 to 2,620 minutes for pulp layer thickness of 1 cm and from 1,900 to 2,860 minutes for the largest thickness (1.5 cm). After drying, the samples were removed from the trays with stainless steel spatula and crushed in an Arno® domestic multiprocessor for 2 minutes of spraying to obtain the powders.

The pequi powders obtained under the different conditions of drying air temperature and pulp layer thickness were evaluated according to the following analyses: moisture content, water activity, lipids, proteins, color (lightness, yellowness and redness), according to the methodologies mentioned above, and peroxide index, according to the methodology of the Adolfo Lutz Institute (IAL, 2008).

Physical analyses were performed to assess the quality of the powders obtained: bulk density, tapped density, Hausner ratio (HR), compressibility index (CI), angle of repose and solubility.

Bulk and tapped densities were determined by the relationship between mass and volume. Tapped density was determined using the methodology of Tonon, Brabet and Hubinger (2013), by weighing a mass of powder until completing the volume of 10 mL in a graduated cylinder and then compacting the material by tapping the graduated cylinder 50 times on the workbench. Tapped density was calculated by the relationship between the mass and the compacted volume.

Hausner ratio (HR) consists of the ratio between tapped density and bulk density, according to methodology of Hausner (1967), and is correlated with the flowability of a powder or granular material. The Hausner ratio of the powder was calculated according to Equation (1).

$$HR = \frac{\rho_{tapped}}{\rho_{bulk}} \quad (1)$$

Where:

HR - Hausner ratio (dimensionless);
$\rho_{tapped}$ - tapped density (g/cm³);
$\rho_{bulk}$ - bulk density (g/cm³).

Carr index (CI) or compressibility index was determined according to the methodology of Bhusari, Muzaffar and Kumar et al. (2014), as show in Equation 2.

$$CI = \frac{\rho_{tapped} - \rho_{bulk}}{\rho_{tapped}} X\ 100 \quad (2)$$

Where:

CI - Carr index (%);
$\rho_{tapped}$ - tapped density (g/cm³);
$\rho_{bulk}$ - bulk density (g/cm³).

The static angle of repose was determined based on the fixed height of a funnel to assist in the flow of pequi powders, considering the ratio between the height of the flowed powder and its diameter according to Bhandari et al. (1998), and calculated using Equation 3.

$$\Theta = \frac{\text{arctg}\ 2h}{D} \quad (3)$$

Where:

Θ - angle of repose (°);
h - height of the formed pile (cm);
D - pile diameter (cm).

Solubility was determined according to Cano-Chauca et al. (2005), with modifications: 1.0 g of powder was weighed in a beaker containing 100 mL of distilled water (25 °C), the material was homogenized with a magnetic stirrer for 5 min and then centrifuged at rotation speed of 2600 rpm for 5 min; subsequently, a 25-mL aliquot was collected, filtered on filter paper with the aid of a vacuum pump and subsequently dried in the oven at 105 °C for 24 h. Solubility was calculated by the ratio of masses according to Equation 4.

$$\text{Solubility (\%)} = \frac{\text{powder mass in supernatant}}{\text{total powder mass}} \text{X}\ 100 \quad (4)$$

**Selection of the best powder**

The best powder was selected based on the results obtained, by choosing the sample with lower values of water activity, moisture content and peroxide index.

**Water adsorption isotherms of the selected powder**

The water adsorption isotherms of the selected powder were determined, in triplicate, at temperatures of 20, 30 and 40 °C, using the static-indirect method, according to Crapiste and Rotstein (1982). The water activity measurements of the selected powder were taken using the Aqualab

hygrometer (3TE - Decagon Devices). Equilibrium moisture content on dry basis was determined by the relationship between the mass of water and the dry mass of the sample.

Table 1 shows the mathematical models of GAB (Equation 5), Oswin (Equation 6) and Peleg (Equation 7) were fitted to the experimental data of the water adsorption isotherms of the powders by nonlinear regression, using the Quasi-Newton method, in Statistica 5.0 software. The fitting criteria were the coefficients of determination ($R^2$) and the mean percentage deviations (P).

**Table 1**. Mathematical models for representing the water adsorption isotherms of the selected powder.

| Model designation | Model | Equation |
|---|---|---|
| Gab | $X_e = \frac{X_m\, CKa_w}{(1-Ka_w)(1-Ka_w+CKa_w)}$ | 5 |
| Oswin | $X_e = a\left(\frac{a_w}{(1-a_w)}\right)^b$ | 6 |
| Peleg | $X_e = K_1(a_w)^{n1} + K_2(a_w)^{n2}$ | 7 |

Where: $X_e$ - equilibrium moisture content (% d.b.); $a_w$ - water activity; $X_m$ - moisture content in molecular monolayer (% d.b.); C - BET constant related to the sorption heat of the molecular layer; a, b, K, $K_1$, $K_2$, $n_1$ and $n_2$ - fitting parameters of the models.

Equation 8 was used to determine the mean percentage deviation:

$$P = \frac{100}{n}\sum_{i=1}^{n}\frac{|X_{exp} - X_{pred}|}{X_{exp}} \qquad (8)$$

Where: P - mean percentage deviation (%); $X_{exp}$ - values obtained experimentally; $X_{pred}$ - values predicted by the model; n - number of experimental data.

**Statistical analysis**

Powder characterization data were subjected to a completely randomized design, in a 4 x 3 factorial scheme, corresponding to 4 drying temperatures (50, 60, 70 and 80 °C) x 3 thicknesses (0.5, 1.0 and 1.5 cm), and 3 replicates, using the software program Assistat 7.6 Beta (SILVA; AZEVEDO, 2016), and the means were compared by Tukey test at 5% probability level.

## RESULTS AND DISCUSSION

Chemical, physical and physicochemical characterization of whole pequi pulp

Table 2 shows the mean results and standard deviations found in the chemical, physical and physicochemical characterization of the whole pequi pulp.

**Table 2**. Chemical, physical and physicochemical characterization of whole pequi pulp.

| Analyzed parameters | Mean and standard deviation |
|---|---|
| Moisture content (% w.b.) | 77.14 ± 0.22 |
| pH | 5.50 ± 0.01 |
| Total titratable acidity –TTA (% citric acid) | 0.19 ± 0.00 |
| Ascorbic acid (mg/100 g) | 13.90 ± 0.35 |
| Water activity (25 °C) | 0.99 ± 0.01 |
| Ash (%) | 0.21 ± 0.07 |
| Lipids (%) | 14.59 ± 0.71 |
| Proteins (%) | 1.41 ± 0.03 |
| Total carotenoids (µg/g) | 0.26 ± 0.38 |
| Lightness (L*) | 68.25 ± 0.03 |
| Coordinate +a * | 3.81 ± 0.09 |
| Coordinate +b* | 33.28 ± 0.10 |

The mean moisture content found (Table 2) for pequi pulp can be considered low in comparison to most fruits, but still indicates a highly perishable pulp. The moisture content can vary according to several factors: chemical composition, species and fruit ripening stage. A similar result was reported by Sousa et al. (2014) in *C. coriaceum* Wittm. pequi pulp, which had moisture content of 80.73%. Sousa et al. (2012) recorded a moisture content of 82.58% for the pulp of pequi of the same species.

The pH of pequi pulp, of 5.50, within the range of low acidity, is close to that found by Sousa et al. (2012) in the pulp of pequi (*C. coriaceum* Wittm.), 5.21. Pequi differs from most tropical fruits for having a pH that classifies it as a food of low acidity, that is, above 4.5.

The total titratable acidity of pequi pulp of 0.19% citric acid is lower than the value reported by Paz et al. (2014) for fresh pequi (*C. brasiliense* Camb), which averaged at 0.7% citric acid.

The ascorbic acid content found, 13.90 mg/100 g, is close to that observed by Oliveira, Pinto and Rezende (2017) when studying the pulp of pequi of the species *C. brasiliense* Camp., from the region of Goiás, which was 16.43 mg/100 g. Such variations may be due to the process of obtaining, storage time and packaging of the pulp. In the present study, the pulp was extracted from the seeds after the cooking process, which causes degradation of ascorbic acid.

The water activity of pequi pulp, with a mean value of 0.99, indicates great susceptibility of the sample to deterioration reactions. The value reported by Barros, Lima and Rocha (2013) for *C. coriaceum* Wittm. pequi pulp was 0.97.

The ash content determined in the pulp, equal to 0.21%, is lower than those reported by Sousa et al. (2012) for the pulp of *C. coriaceum*, of the same species and originating from the same locality, which was 0.39%, and by Oliveira et al. (2010) for the pulp of pequi (*C. coriaceum*) fruits native to the Araripe Plateau, CE, with a mean value of around 0.6%. This parameter may vary according to soil, harvest period and locality, conservation status and pulp obtaining.

The mean values of lipid and protein contents of 14.59 and 1.41%, respectively, are lower than those found by Paz et al. (2014), who observed 31.5% and 2.4%, respectively, also in the pulp of pequi (*C. brasiliense* Camb).

The amount of total carotenoids present in pequi pulp of 0.26 mg/100 g may have been reduced by the cooking process to obtain the pulp. Similar results were reported by Souza et al. (2013), who quantified the total carotenoids of *C. coriaceum* pequi pulp and obtained values between 0.68 and 0.73 mg/100 g. Higher result was reported by Cordeiro et al. (2013) in a study on the physicochemical composition of pequi (*C. brasiliense* Camb) pulp from the state of Mato Grosso; pequi pulps from the municipality of Acorizal showed total carotenoids of 15.52 mg/100 g and those from Santo Antônio do Leverger showed 18.70 mg/100 g.

The values found for the +a* and +b* color parameters are probably related to the presence of carotenoids. In general, the pequi pulp showed light color (lightness above 50) and with predominance of yellowish pigments. Sousa et al. (2012) obtained for *C. coriaceum* pequi pulp values of 69.82 for lightness (L*), 3.02 for a* and 33.49 for b*. Oliveira et al. (2011) determined L* of 62.50, -a* of -1.24 and +b* of +16.16 in *C. coriaceum* pequi pulp. Cordeiro et al. (2013) reported values from 37.27 to 41.86 (+a*) and from 83.63 to 98.96 (+b) in *C. brasiliense* Camb. pequi pulp. The color of pequi pulp may vary according to species, maturity stage, processing and storage conditions.

**Physicochemical characterization of pequi powders**

Table 3 shows the mean values of the physicochemical characterization of pequi powders, obtained by convective drying at temperatures of 50, 60, 70 and 80 °C and pulp layer thicknesses of 0.5, 1.0 and 1.5 cm.

The moisture content of pequi powder, with variation from 1.38 to 4.33%, was reduced with the increase in temperature for all layer thicknesses. There was no statistical difference under the following drying conditions: 60 °C and thicknesses of 0.5 and 1.0 cm, drying times of 940 and 1900 minutes, respectively; 70 °C and thicknesses of 0.5 and 1.0 cm, drying times of 820 and 1720 minutes, respectively; at temperature of 80 °C the moisture content showed no statistical differences between the thicknesses. The reduction of moisture content between the smallest and the largest thickness may have occurred because, in the larger thicknesses, the material kept losing water for longer periods of time, resulting in samples with lower moisture content.

Botrel et al. (2016) produced araticum (*Annona crassiflora*) powders by convective drying at temperatures of 70, 80 and 90 °C and thickness of 0.2 cm and obtained final moisture contents of 14.14, 13.30 and 11.11%, respectively. The moisture content of pequi powders was low and consistent with those reported in other studies for powdered fruit pulp. Dieb et al. (2015) found values between 4.38 and 6.61% for soursop powders obtained by foam-mat drying at temperatures of 50, 60 and 70 °C and with layer thicknesses of 0.30, 0.45 and 0.60 cm. According to Breda, Sanjinez-Argandoña and Correia (2012) powdered products generally have low moisture content and one can find values within the range from 4 to 6%.

**Table 3**. Mean values of the physicochemical parameters of the pequi powders obtained at different drying temperatures and pulp layer thicknesses.

| Parameter | Thickness (cm) | Temperature (°C) | | | |
|---|---|---|---|---|---|
| | | 50 | 60 | 70 | 80 |
| Moisture content (% w.b.) | 0.5 | 4.33 aA | 2.18 aB | 1.77 aC | 1.57 aC |
| | 1.0 | 3.31 cA | 2.33 aB | 1.88 aC | 1.38 aD |
| | 1.5 | 3.64 bA | 1.81 bB | 1.57 bC | 1.45 aC |
| $a_w$ (25 °C) | 0.5 | 0.57 aA | 0.36 bB | 0.28 aC | 0.19 aD |
| | 1.0 | 0.43 cA | 0.37a B | 0.18 bC | 0.16 bD |
| | 1.5 | 0.47 bA | 0.20 cB | 0.17 cC | 0.12 cD |
| Lipids (% d.b.) | 0.5 | 62.34 aA | 61.44 aA | 60.44 aA | 60.55 aA |
| | 1.0 | 59.94 aB | 58.08 aB | 58.95 aB | 61.60 aA |
| | 1.5 | 60.30 aA | 59.55 aA | 60.40 aA | 59.83 aA |
| Proteins (% d.b.) | 0.5 | 7.97 bA | 7.35bB | 6.98cC | 6.06 cD |
| | 1.0 | 8.27aA | 7.52abB | 7.20 bC | 6.33bD |
| | 1.5 | 8.47aA | 7.64aB | 7.39aC | 6.59aD |
| Coordinate +a* | 0.5 | 8.37 aAB | 7.89 cC | 8.20 cB | 8.39 cA |
| | 1.0 | 8.29 aC | 8.34 bC | 10.46 aA | 10.09 bB |
| | 1.5 | 8.35 aD | 8.93 aC | 9.69 bB | 10.50 aA |
| Coordinate +b* | 0.5 | 35.18 aA | 32.62 aC | 31.17 aD | 34.36 aB |
| | 1.0 | 34.40 aB | 31.55 bB | 29.80 bC | 31.25 bB |
| | 1.5 | 33.60 aC | 32.72 aB | 29.85 bC | 29.36 cC |
| Lightness (L*) | 0.5 | 46.42 aB | 46.68 aB | 41.05 aC | 48.58 aA |
| | 1.0 | 45.88 aA | 45.48 aA | 36.45 bC | 38.10 bB |
| | 1.5 | 45.75 aA | 44.14 bB | 36.78 bC | 35.86 cC |
| Peroxide index (meq/kg) | 0.5 | 8.02 aA | 7.99 bA | 7.95 aA | 8.00 bA |
| | 1.0 | 8.04 aA | 7.66 cB | 8.03 aA | 8.03abA |
| | 1.5 | 7.87 bC | 8.28 aA | 8.04 aB | 8.13 aB |

Means followed by the same uppercase letter in the rows and lowercase letter in the columns do not differ from each other by Tukey test at 5% significance level.

For all thicknesses, water activity gradually decreased with the increase in temperature, and the lowest water activities were observed at temperatures of 60, 70 and 80 ºC and thickness of 1.5 cm, so the lowest water activity was observed at temperature of 80 °C and thickness of 1.5 cm.

The water activities of pequi powders, ranging from 0.12 to 0.57, fall within the class of microbiologically stable products, as powders with water activity below 0.6 are considered (SOUZA et al., 2015).

In general, there was no influence of temperature or layer thickness on lipid contents. Regarding thicknesses, no significant difference was observed. At temperatures of 50, 60 and 70 ºC, in thickness 1.0 cm, there was also no statistical difference.

The lipid content found for pequi powders was high compared to the fresh pulp, whose value is more than 40% lower than in powdered pulps, which results from the concentration of this constituent caused by the reduction of moisture content. Lipid values close to that of this study were reported by Yuyama et al. (2008) for tucumã pulp dehydrated in a forced air circulation even at a temperature of 60 °C, which had lipid content of 61.60%. The tucumã fruit, despite not being from the same family of pequi, has similar characteristics, as it contains an almond with white mass, rich in oil, quite hard and covered by an orangish yellow pulp, of soft consistency and oily.

The protein contents of pequi powders ranged from 5.97 to 8.17%, with the highest value under the condition of drying at 50 °C and with pulp layer thickness of 1.5 cm. Similar results were found by Yuyama et al. (2008) for the tucumã dehydrated in an oven at 65 °C with a mean value of 6.70%.

It is observed, for all thicknesses, that increasing temperature caused a decrease in protein content, and the increase in layer thickness resulted in higher protein contents, which shows that the thickness of the material favors protein denaturation; therefore, smaller pulp thickness tends to have greater ease of dehydration, and, consequently,

greater degradation of chemical constituents (proteins).

Regarding color, the red intensity in pequi powders was higher than that of pequi pulp before drying, exceeding it by more than 100%. This behavior was due to darkening of the pulp caused by the drying conditions. The mean value of the coordinate +a* of pequi powder in general increased with drying temperature and was also higher with the increase in layer thickness.

The coordinate +b* is related to yellowish pigments. In general, there was a trend of decrease in +b* with the increase in temperature, mainly between 50 ºC and the others, as well as reduction with the increase in thickness, with higher values for the thickness of 0.5 cm, indicating that, with increased temperature, the pequi pulp became darker and the yellowish color decreased.

The mean values of lightness of the pequi powders were reduced with the increase of drying temperature for the layer thicknesses of 1.0 and 1.5 cm, with no defined trend in the thickness of 0.5 cm. Among the thicknesses, there is no effect on lightness. The reduction of lightness can be attributed to the degradation of pigments caused by the effect of heating and exposure time, which may explain the greater change in thicker samples, which can cause greater degradation of the chemical compounds of pequi and, as a consequence, greater darkening.

According to Yuyama et al. (2008), the peroxide index indicates the degree of oxidation of the product or oxidative rancidity. The mean values of peroxide indices of pequi powders found in the present study, ranging from 7.66 to 8.28 meq/kg, complies with the limit established by FAO/WHO (2003), according to which the maximum peroxide value in crude oils should not exceed 15 meq/kg. From the set of values obtained for the pequi powders, there is no influence of drying temperature or foam layer thickness on peroxide indices.

**Physical characterization of pequi powders**

Table 4 shows the results of the physical parameters analyzed in the pequi powders obtained in the drying at different temperatures and pulp layer thicknesses.

**Table 4**. Physical characterization of pequi powders obtained at drying temperatures from 50 to 80 °C and layer thicknesses of 0.5, 1.0 and 1.5 cm.

| Parameter | Thickness (cm) | Temperature (°C) | | | |
|---|---|---|---|---|---|
| | | 50 | 60 | 70 | 80 |
| Bulk density (g/cm³) | 0.5 | 0.43bB | 0.47aA | 0.43aB | 0.44bB |
| | 1.0 | 0.45aAB | 0.43bC | 0.44aBC | 0.47aA |
| | 1.5 | 0.46aAB | 0.46aAB | 0.45aB | 0.47aA |
| Tapped density (g/cm³) | 0.5 | 0.63bB | 0.58cC | 0.70bA | 0.56bD |
| | 1.0 | 0.67bB | 0.61cB | 0.72aA | 0.68bB |
| | 1.5 | 0.68aBC | 0.66aC | 0.73aA | 0.69aB |
| Hausner ratio | 0.5 | 0.63bB | 0.59cC | 0.70bA | 0.56bD |
| | 1.0 | 0.68aB | 0.62bC | 0.73aA | 0.70aB |
| | 1.5 | 0.68aBC | 0.66aC | 0.74aA | 0.70aB |
| Carr index (%) | 0.5 | 32.33aB | 29.58aC | 38.67aA | 31.67aB |
| | 1.0 | 32.33aB | 30.67aC | 40.00aA | 32.33aB |
| | 1.5 | 31.67aB | 29.67aC | 39.00aA | 31.67aB |
| Angle of repose (°) | 0.5 | 13.68aB | 12.59cC | 14.33bA | 13.39bA |
| | 1.0 | 13.47aB | 13.02bC | 14.80aA | 13.52aB |
| | 1.5 | 13.43aBC | 13.60aB | 14.61abA | 13.22aC |
| Solubility (%) | 0.5 | 87.97aA | 83.79cB | 88.37aA | 81.21cC |
| | 1.0 | 85.87bAB | 86.58bA | 84.60bBC | 84.25bC |
| | 1.5 | 86.59bB | 89.79aA | 82.77cC | 89.21aA |

Means followed by the same uppercase letter in the rows and lowercase letter in the columns do not differ from each other by Tukey test at 5% significance level.

For bulk density, the highest values were found with the thickness of 1.5 cm, but without configuring, in view of the other layers, a trend of increase with the increase in layer thickness. Increasing temperature caused no effect on the bulk density. Knowledge on the density of fruit pulp powders makes it possible to determine the amount of powder that can be stored in a package and how it can be transported to be marketed; however, the density may vary with the process temperature, particle geometry and powder granulometry (FINNEY; BUFFO; REINECCIUS, 2002).

Likewise, the tapped density was also not influenced by the drying temperature, but tended to increase with the increase in layer thickness, with the highest values in the thickness of 1.5 cm. Similar results of tapped density were found by Fernandes et al. (2014) in tomato powder obtained from foam-mat drying at two temperatures (60 and 80 °C), with different concentrations of albumin (0 and 4.5%) and foam thickness of 0.5 cm, with values from 0.180 to 0.454 g/cm$^3$; these authors observed that there was an increase in tapped density as temperature increased.

With increase in temperature, there was no defined trend for the Hausner ratio (HR), but the increase in thickness led to increments in the values for all temperatures, indicating that the powder became more cohesive. According to Santhalakshmy et al. (2015), powders with HR below 1.2 are classified as of low cohesiveness, those with HR between 1.2 and 1.4 are of intermediate cohesiveness and those with HR > 1.4 are considered to have high cohesiveness.

According to this classification, all pequi powders showed low cohesiveness, that is, low attraction among particles, demonstrating ease of flow. Therefore, what may have contributed to the flow of the powders was the standardization in the obtaining process, which was through grinding (2 minutes of grinding in a processor); it is important to emphasize that no drying adjuvant was added to obtain the powders. Pequi powders showed a high percentage of lipids but, according to Saifullah et al. (2016), the determining factors for flowability are the size and shape of particles.

In general, Hausner ratio results were lower than those reported for powders obtained from other fruits. For instance, Santhalakshmy et al. (2015) found mean values from 1.57 to 1.72 for jambolão powders produced by atomization drying, at temperatures of 140, 145, 150, 155 and 160 °C, added of 25% maltodextrin, and observed a trend of reduction with increasing temperature. Bhusari et al. (2014) obtained HR within the range from 1.3 to 1.5 when studying tamarind powder produced by spray drying at 180 °C, with the addition of maltodextrin, gum arabic and whey protein concentrate.

It is observed that the values of compressibility index or Carr index (CI) varied between 29.58 and 40.00%, with the highest means observed at the temperature of 70 °C and with no trend with the increments in temperature or thickness.

The Carr index (CI) measures the flowability property of powders. CI values between 15-20% indicate good flowability, between 20-35% fair flowability, between 35-45% bad flowability and CI > 45%, very bad flowability (SANTHALAKSHMY et al., 2015). According to this classification, the pequi powder with good flowability was produced at 60 °C with 0.5 cm thickness, and the powders with the worst flowability were those produced at 70 °C, with bad flowability in samples dried with the three layer thicknesses. Therefore, there was no directly proportional relationship between HR and CI, a behavior that may be related to the initial composition of the pulp, type of drying process and non-use of drying adjuvant, in addition to the size of the particles, which interferes in bulk and tapped densities.

Goyal et al. (2015) analyzed microencapsulated flaxseed oil powder, obtained by atomization drying at 177 °C, with the addition of serum protein concentrate and sodium caseinate, and observed CI within the range from 33.82 to 34.57%. These values were close to those found in the pequi powders and are justified by the fact that both are lipid-rich materials.

The angles of repose of the pequi powders varied between 12.59 and 14.80°. Adekunle et al. (2013) found angles of repose from 37.28 to 40.6° for baobab (*Adansonia digitata* L.) powder. According to Medeiros et al. (2001), it refers to the angle of the powder pile formed with the horizontal line at which the material will remain when poured on the flat surface, and the smaller the angle of repose, the greater the flowability of the powder. However, some factors can influence this parameter, such as moisture content, particle size and powder agglomeration. There was no defined behavior of the angle of repose with the increase in drying temperature. The highest results were found at 70 °C, coinciding with the highest values of CI.

It is observed that the increase in drying temperature did not influence the solubility of the powders, and there was no defined behavior as a function of thickness, with an increase in solubility at temperatures of 60 and 80 °C as thickness increased and a trend of reduction at temperatures of 50 and 70 °C.

Fruit pulp powders, convenient for use as ingredients in the food industry, should have good solubility, and the capacity of the powder to dissolve in water is a relevant factor for its quality. The solubility of powdered products is the safest criterion to evaluate their behavior in aqueous solution (FERNANDES et al., 2014). Powder solubility is also associated with factors such as drying conditions (drying temperature) and moisture content, and

powders with low moisture content have good solubility.

**Adsorption isotherms of the selected pequi powder**

The water adsorption isotherms were determined in the selected pequi powder produced at the drying temperature of 70 °C and with a pulp layer thickness of 0.5 cm, whose results indicated lower values of water activity, moisture content and peroxide index.

Table 5 shows the fitting parameters of the GAB, Peleg and Oswin models fitted to the water adsorption data of the selected pequi powder, at temperatures of 20, 30 and 40 °C, as well as the coefficients of determination ($R^2$) and the mean percentage deviations (P).

**Table 5**. Parameters of GAB, Peleg and Oswin models fitted to the water adsorption isotherms of the selected pequi powder.

| Model | Temperature | Parameters | | | | $R^2$ | P (%) |
|---|---|---|---|---|---|---|---|
| | (°C) | $X_m$ | C | K | | | |
| GAB | 20 | 1.1846 | 127.8250 | 1.0383 | | 0.9942 | 5.39 |
| | 30 | 2.0150 | 3.1879 | 0.9719 | | 0.9979 | 2.77 |
| | 40 | 1.9418 | 13.6860 | 0.9762 | | 0.9980 | 3.10 |
| | Temperature | Parameters | | | | $R^2$ | P (%) |
| | (°C) | $K_1$ | $n_1$ | $K_2$ | $n_2$ | | |
| Peleg | 20 | 0.1702 | 0.3696 | 0.1702 | 0.3696 | 0.8774 | 9.05 |
| | 30 | 0.1787 | 0.3414 | 0.1787 | 0.3414 | 0.7568 | 3.61 |
| | 40 | 0.1851 | 0.3164 | 0.1851 | 0.3164 | 0.7700 | 6.23 |
| | Temperature | Parameters | | | | $R^2$ | P (%) |
| | (°C) | A | | B | | | |
| Oswin | 20 | 3.2614 | | 0.6682 | | 0.9851 | 18.80 |
| | 30 | 3.0518 | | 0.7297 | | 0.9963 | 15.18 |
| | 40 | 3.2611 | | 0.7153 | | 0.9960 | 14.81 |

Among the models tested, GAB was the one which best fitted to the water adsorption data of pequi powder at temperatures of 20, 30 and 40 °C, having the highest coefficients of determination ($R^2 > 0.98$) and the lowest mean percentage deviations ($P < 6\%$); Peleg model showed $P < 10\%$ and $R^2 > 0.74$, while Oswin model showed $P > 10\%$ and $R^2 > 0.97$, so that Peleg and Oswin models had low values of either $R^2$ or P.

The $X_m$ of GAB model did not show a defined behavior with the increment in temperature, increasing between 20 and 30 ºC and decreasing between 30 and 40 ºC. $X_m$ corresponds to the amount of water strongly adsorbed to specific sites on food surface and is considered as an excellent indicator to ensure food stability (GABAS et al., 2007), so that powders with high $X_m$ may have their stability compromised.

The values of constant C of the GAB model for pequi powder did not follow any trend, with results between 3.1879 and 127.8250 at the evaluated temperatures. According to Gabas et al. (2007), what favors the increase in the values of the constant C is low temperatures, because they favor the force of interaction between adsorbate and adsorbent.

The K values of the GAB model did not show a defined trend with the increase in temperature, ranging from 0.9719 to 1.0383. From the parameters C and K of the GAB model, it is possible to observe at all temperatures $K \leq 1$ and $C > 2$, which, according to Blahovec (2004), allows classifying the adsorption isotherms of pequi powder as type II, with sigmoidal shape and inflection point in the curves.

In the Peleg model, the fitting parameters $K_1$ and $K_2$ ranged from 0.1702 to 0.1851, increasing with the increase in temperature, while the parameters $n_1$ and $n_2$ had values between 0.3696 and 0.3164, decreasing with the increase in temperature.

In the Oswin model, the parameter a showed values from 3.0518 to 3.2614 and the results for the parameter b remained within the range from 0.6682 to 0.7297. According to Blahovec (2004), in the Oswin model the values must be within the following: $a > 0$ and $1 > b > 0$.

Figure 1 shows the water adsorption isotherms at temperatures 20, 30 and 40 °C with fits by the GAB model, the model with the best fitting parameters among the ones tested. The shape of the isotherms depends on the physicochemical composition of foods (fat, starch, sugar and proteins) (PARK et al., 2008).

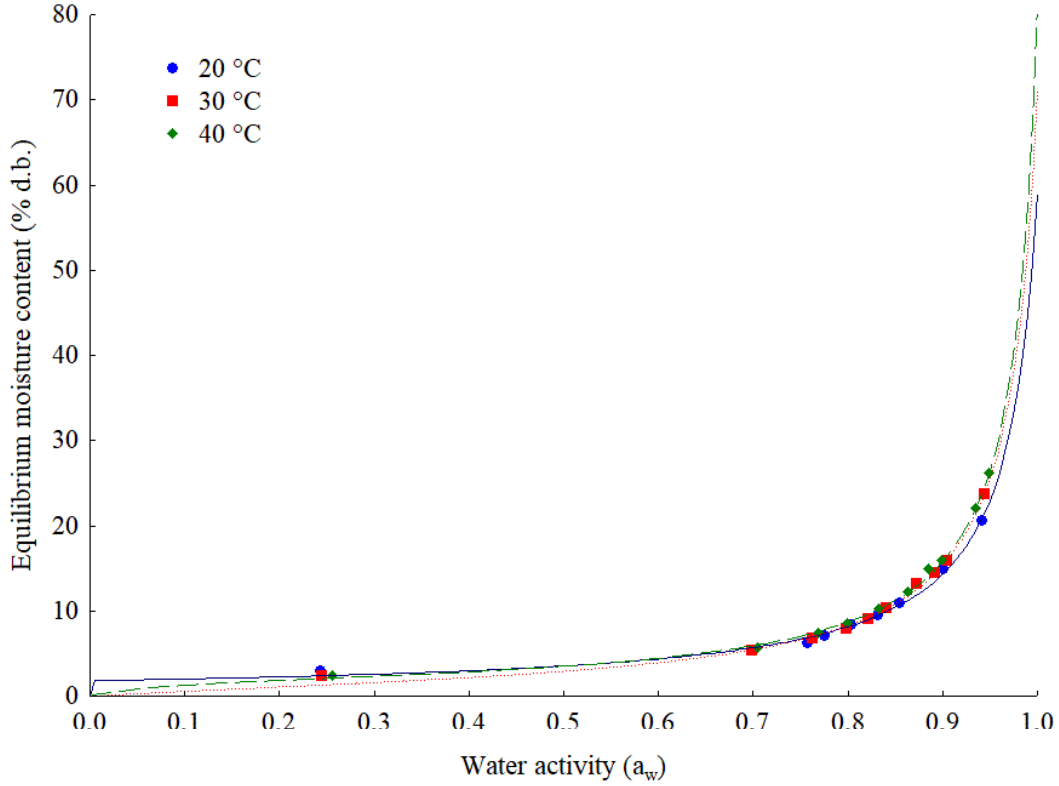


**Figure 1**. Water adsorption isotherms at temperatures of 20, 30 and 40 ºC of the selected pequi powder, with fits by the GAB model.

It is observed that, at the three temperatures, the isotherms of the pequi powder were very close to one another, with a small distance of the isotherm at 20 °C at $a_w$ greater than 0.9.

It was verified that the equilibrium moisture content gradually increased with the increase of water activity, whose values ranged between 0.243 and 0.941. The highest equilibrium moisture content was observed at 40 °C, being equal to 22.01% (d.b.).

## CONCLUSIONS

The pulp of whole pequi presented high moisture content, considerable percentage of lipids and proteins, low acidity and predominance of yellow color.

Powders produced in higher layer thicknesses had higher protein contents, and these contents were reduced with the expansion of the thermal condition.

The percentage of lipids from the powders was not affected by temperature or thickness of the pulp layer; the peroxide index showed a tendency of lipid oxidation at the highest temperatures.

The powders presented high solubility, little cohesiveness, free flow and flowability ranging from fair to bad.

The isotherms (20, 30 and 40 ºC) of pequi water adsorption obtained in the powder produced in the best drying condition (70 °C- 0.5 cm) were classified as Type II. Gab model was the model that best fit the experimental data, presenting the highest coefficients of determination ($R^2$) and the lowest mean percentage deviations (P).

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