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Stability of vacuum-packed peach palm (*Bactris gasipaes* Kunth) flours obtained by dehydration and freeze-drying during accelerated storage

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ABSTRACT: This paper evaluated the stability of vacuum-packed peach palm flours obtained by dehydration and freeze-drying during accelerated storage. For the elaboration of the flours, peach palm fruits (*Bactris gasipaes* Kunth var. *gasipaes*), harvested in the Eastern region of Ecuador, were used. The *in natura* fruits were washed with running water and disinfected. Before treatment, the fruits were scalded and cooled in an ice-water bath. Then, they were peeled, seeded and chopped. The dehydrated and lyophilized materials were pulverized in a blade mill and vibrated sieved for 10 min. Moisture content, ash, crude fiber, fat, carbohydrates, proteins and rheological parameters were determined for the flours. The flours were vacuum packed and stored at 30, 40 and 50 ºC. During accelerated storage, the peroxide value (POV) was determined. The results of this determination were subjected to linear regression analysis as a function of time. The parameters of the Arrhenius model (k and Ea) for the variation of the POV and the temperature acceleration factor (Q_{10}) were also determined. The variation of the POV in both flours showed a similar behavior during accelerated storage, without there being, in general, differences ($p \leq 0.05$) regarding the increase of the POV. In all cases, this POV increase during accelerated storage was adjusted to a zero-order reaction and linear models were obtained to estimate the variation of this parameter for each combination of flour and temperature. The Q_{10} values for the POV variation ranged between 1.05 and 1.29, regardless of the type of flour.
Keywords: peach palm; flour; accelerated storage; peroxide value.

Estabilidade de farinhas de pupunha (*Bactris gasipaes* Kunth) embaladas a vácuo obtidas por desidratação e liofilização durante armazenamento acelerado

RESUMO: Este trabalho teve como objetivo avaliar a estabilidade de farinhas de pupunheira embaladas a vácuo obtidas por desidratação e liofilização durante armazenamento acelerado. Para a elaboração das farinhas foram utilizados frutos de pupunheira (*Bactris gasipaes* Kunth var. *gasipaes*), colhidos na região Leste do Equador. Os frutos in natura foram lavados com água corrente e desinfetados. Antes do tratamento, os frutos foram escaldados e resfriados em banho de água gelada. Em seguida, foram descascados, semeados e picados. Os materiais desidratados e liofilizados foram pulverizados em moinho de lâminas e peneirados vibratórios por 10 min. Foram determinados o teor de umidade, cinzas, fibra bruta, gordura, carboidratos, proteínas e parâmetros reológicos das farinhas. As farinhas foram embaladas a vácuo e armazenadas a 30, 40 e 50 ºC. Durante o armazenamento acelerado, o valor de peróxido (POV) foi determinado. Os resultados desta determinação foram submetidos à análise de regressão linear em função do tempo. Também foram determinados os parâmetros do modelo de Arrhenius (k e Ea) para a variação do POV e o fator de aceleração da temperatura (Q_{10}). A variação do POV em ambas as farinhas apresentou comportamento semelhante durante o armazenamento acelerado, sem haver, em geral, diferenças ($p \leq 0{,}05$) quanto ao aumento do POV. Este aumento do POV durante o armazenamento acelerado foi ajustado, em todos os casos, para uma reação de ordem zero e foram obtidos modelos lineares para estimar a variação deste parâmetro para cada combinação de farinha e temperatura. Os valores de Q_{10} para a variação do POV variaram entre 1,05 e 1,29, independente do tipo de farinha.
Palavras-chave: pupunha; farinha; armazenamento acelerado; valor de peróxido.

1. INTRODUCTION

The Amazon region has fruits with high nutritional, functional and economic potential. Among these fruits is the peach palm (*Bactris gasipaes* Kunth), with nutritional and phytochemical compounds that allow it to be exploited by the food industry as food and to obtain compounds for food, cosmetic and pharmaceutical applications (PEIXOTO et al., 2021). Peach palm is a plant native to the hot, humid tropics of Latin America, belonging to the *Arecaceae* family

(GONZÁLEZ-JARAMILLO et al., 2022). Its origin is unclear, but it is presumed to be the Bolivian Amazon (VARGAS et al., 2020). Due to its chemical composition, the content of carbohydrates, proteins, fats, dietary fiber, carotenes and minerals, it has various applications, including peach palm flour (COSTA et al., 2022). However, one limitation is that data on the stability of the flours have not been reported.

The stability of food products is a fundamental aspect to guarantee their quality and safety during storage and marketing. The flour obtained from peach palm fruits has a high nutritional value and is potentially usable in the food industry; however, the lipid content of peach palm characterizes it as an oleaginous fruit (Santos et al., 2020) sensitive to oxidation, which can compromise the stability and useful life of these flours.

Among the methods commonly used to produce flour from fruits are dehydration and freeze-drying. The selection of the drying process depends on the suitability of the product, since while hot air drying is more economical than freeze-drying; it also affects the surface and changes the interior cellular structure of starches (AHMED et al., 2020). On the other hand, despite the high cost and length of freeze-drying, it allows the obtaining of high-value food products due to the maximum retention of food quality compared to other drying techniques (BHATTA et al., 2020). Therefore, it is necessary to compare these drying techniques in terms of the quality of the final product.

However, no specific studies have been found on the stability of vacuum-packed peach palm flours obtained by dehydration and freeze-drying. In this context, this paper aimed to evaluate the stability of vacuum-packed peach palm (*Bactris gasipaes* Kunth var. *gasipaes*) flours obtained by dehydration and freeze-drying during accelerated storage.

2. MATERIALS AND METHODS

2.1. Plant material

Peach palm fruits (*B. gasipaes* var. *gasipaes*) were harvested from the eastern region of Ecuador in the city of Puyo, Pastaza province. This variety presents larger fruits, higher starch content and lower lipid content than the wild variety *Bactris gasipaes* var. *chichagui* (Clement et al., 2017). The fruits were selected considering the absence of visible defects, uniform maturity state and similar size characteristics.

Before making the flour, the fresh fruits were washed with running water and disinfected with a sodium hypochlorite solution at a concentration of 1.0 mL L^{-1}. They were then scalded and immediately placed in an ice-water bath for 5 s, then removed and allowed to cool to ambient conditions. Once cooled, the fruits were peeled, seeded and cut into four parts.

2.2. Production of dehydrated and freeze-dried flour

For flour production, the cut fruits were dehydrated in an oven with forced air circulation (MA 035, Marconi, Piracicaba, Brazil) at 50 °C for 24 h. Moisture was determined at the beginning and during the drying period, taking samples from different areas of the tray and subjecting the material to occasional movement to obtain homogeneity in moisture content. This was determined through indirect gravimetry by volatilization by drying in a thermobalance (Sartorius Mod. MA-40, Germany) at 105 ºC until constant mass was obtained.

For lyophilization by manifold method, the cut fruits were placed in flasks and individually attached to the ports of the drying chamber. Previously, the product was frozen by immersion in liquid nitrogen, after which it was lyophilized on a laboratory scale at 10^{-2} Pa and -40 ºC in a ModulyoD Freeze Dryer (Thermo Fisher Scientific Inc., Waltham, Massachusetts) for 48 h.

The dehydrated and lyophilized materials were pulverized in a hammer mill until fine flour was obtained (Pires et al., 2019). The flours were vacuum packed (Tecnotrip EV086154, Spain) and later stored in chambers at controlled temperatures of 30, 40 and 50 ºC.

2.3. Fruits and flours analysis

Moisture, lipids, ashes, proteins and crude fiber were determined per the AOAC (2002) in the peach fruits and the recently obtained dehydrated and freeze-dried flours. In addition, the angle of repose (Silva-Espinoza et al., 2021) was determined in triplicate for the flours as the angle between the horizontal surface and the slope of the cone formed by dropping the flour into a glass funnel made from borosilicate with a short stem with an angle of 60º, suspended at a height of 20 cm.

The bulk density of the freeze-dried and dehydrated meals was calculated as the ratio between their mass and the volume they occupied in a graduated cylinder. The compacted density was determined by subjecting the graduated cylinder with 10 mL of powder to vibration (1200 min^{-1}, 10 s) in a vortex. The bulk and compacted density values were used to calculate the Carr and Hausner indices (CAMACHO et al., 2022). The hygroscopicity was determined according to the methodology described by Tonon et al. (2009).

The particle size distribution was carried out using the sieving method of a set of sieves (DIN 4188, Germany). The sieves were placed in order of decreasing opening size, from top to bottom, and previously weighed. Then, the flour samples (100 g) were added to the upper sieve and shaken using a mechanical vibrator (Retsch Model Vibro VM1, Haan, Germany) for 10 min to obtain a uniform granulometry. The samples retained on each sieve and the bottom were weighed to determine the relative frequency (Silva-Espinosa et al., 2021). Mold and yeast counts (NTE INEN 1529-11, 2013) and *Escherichia coli* counts (NTE INEN 1529-8, 2015) were also performed.

For the sensory evaluation of peach palm flour through quantitative descriptive analysis (Sidel et al., 2018), the descriptor generation process was carried out with 10 tasters trained in this type of product, who proposed sensory descriptors through the controlled association method (DAMASIO; COSTELL, 1991). The subsequent elimination of descriptors was conducted in open discussion with the judges, according to the criteria reported in NC-ISO 11035 (2015). The final descriptors were evaluated on a structured scale of 10 cm in length with increasing intensity of the descriptor from left to right. The evaluations used a balanced complete block design with three replicates in different sessions (ISO 13299, 2016).

2.4. Evaluation during the accelerated storage

During accelerated storage, periodic flour samples were taken to determine the peroxide value (POV) using the method of Gadani et al. (2017). The results were subjected to a linear regression analysis as a function of time (Cuevas-García, 2020) to evaluate the variation of the POV during accelerated storage. The best fit kinetic model was chosen using the R^2 and the Anova lack of fit test with a significance level of 5%. In addition, the parameters of the Arrhenius model (k and Ea) for the variation of the POV and the temperature acceleration factor (Q_{10}) were determined using statistical methods (GAIBOR et al., 2022). The Anova to detect significant differences ($p \leq 0.05$) and Duncan's multiple range test were performed using the Statistica program (v. 7, 2004, StatSoft. Inc., Tulsa, USA).

3. RESULTS

3.1. Evaluation of peach palm fruit

This study analyzed the chemical composition of peach palm fruits (Table 1). The results indicated that the fruits presented an average moisture content of 55.4% (± 2.1), which suggests that they contain a significant amount of water. This finding is consistent with ripe peach fruits' juicy and succulent nature.

Table 1. Chemical composition of peach palm fruits (*B. gasipaes* K.); n= 3
Tabela 1. Composição química dos frutos da pupunheira (*B. gasipaes* K.); n = 3

Component (%)	Mean (Standard deviation)
Humidity	55.4 (2.1)
Ashes	2.7 (0.4)
Proteins	4.2 (0.3)
Crude fiber	2.8 (1.3)
Fat	12.5 (3.2)

3.2. Dehydration kinetics of peach palm fruits

Figure 1 shows the decrease in humidity and rate of water loss during the dehydration of peeled and cut peach fruits. The kinetics of the process allowed the estimation of the optimal drying time of the material so that it was obtained with the lowest possible moisture content. In this case, it can be seen that after 25 h of the process, the moisture content stabilized, with values of 6 and 7 % (dry base) until 27 h.

The decrease in moisture content (H) and speed of water loss (WL) during dehydration were fitted to polynomial models of order 4 and 2, respectively, with high values of coefficients of determination:

$$H = -0.0009x^4 + 0.0538x^3 - 0.9619x^2 + 2.2757x + 52.953$$
$$R^2 = 0.9888$$

$$WL = -0.0942x^2 + 4.6588x - 8.2133$$
$$R^2 = 0.9571$$

where: H: moisture content (% m/m dry base); WL: water loss (g/h); and x: time (h).

3.3. Evaluation of peach palm flour obtained by dehydration and lyophilization

As observed in Table 2, the moisture content of the freeze-dried flour was significantly lower ($p \leq 0.05$) compared to that of the dehydrated flour, while the ash value was higher ($p \leq 0.05$). No differences were obtained in protein, fiber, and fat content. Likewise, Correa et al. (2011) found no differences in the proximal composition of dehydrated and freeze-dried marolo (*Annona crassiflora*) flour.

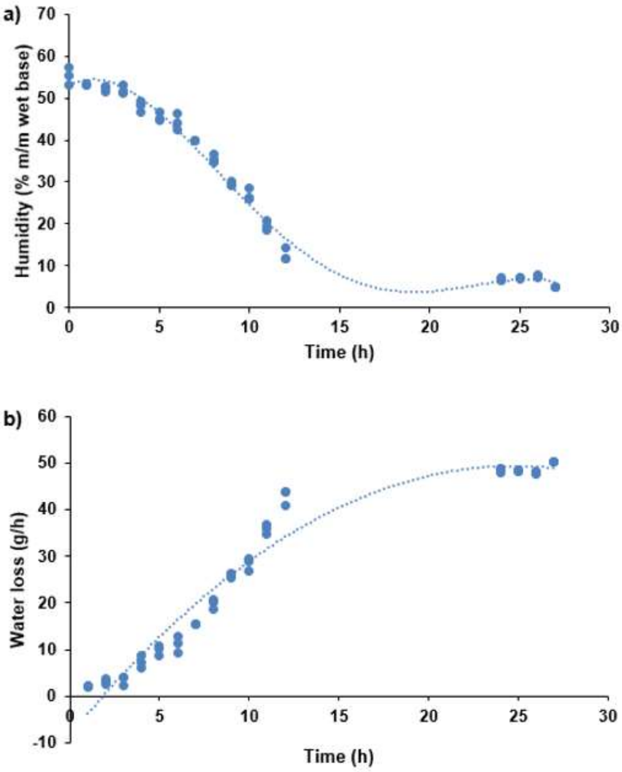

Figure 1. Kinetics of the dehydration process of peeled and cut peach palm fruits.
Figura 1. Cinética do processo de desidratação de frutos de pupunheira descascados e cortados.

Table 2. Chemical properties of flours obtained by dehydration and freeze-drying of peach palm fruits (*B. gasipaes*)
Tabela 2. Propriedades químicas das farinhas obtidas por desidratação e liofilização de frutos de pupunheira (*B. gasipaes*)

Component (%)	Peach palm flour	
	Dehydrated	Lyophilized
Humidity	6.52 (0.05) a	5.95 (0.17) b
Ashes	1.20 (0.05) b	1.59 (0.02) a
Proteins	2.15 (0.09)	2.16 (0.09)
Crude fiber	3.82 (0.05)	3.77 (0.11)
Fat	15.44 (0.95)	14.43 (0.18)

Mean (Standard deviation); n= 3.
Different letters in the same row indicate significant differences ($p \leq 0.05$).

Table 3 shows that the flow properties of dehydrated and freeze-dried meals, specifically bulk density, fluidity, Hausner index and angle of repose, showed significant differences. According to the hygroscopicity values, the freeze-dried flour exhibited a greater capacity to retain moisture than the dehydrated flour; however, there were no significant differences between them. On the other hand, the compacted and particle density did not show significant differences between both types of flour; instead, the apparent density showed differences.

The bulk density values of dehydrated and freeze-dried meals showed significant differences; however, both values were low. In the case of freeze-dried flour, this low apparent density could be related to the increase in volume (Buzera et al., 2022) and the affectation of its solubility. Regarding fluidity, the freeze-dried flour showed a significantly higher value than the dehydrated flour.

Table 3. Flow properties of flours obtained by dehydration and freeze-drying of peach palm fruits (*B. gasipaes*)
Tabela 3. Propriedades de fluidez das farinhas obtidas por desidratação e liofilização de frutos de pupunheira (*B. gasipaes*)

Parameter	Peach palm flour	
	Dehydrated	Lyophilized
Hygroscopicity (g/100 g d.s.)	7.6 (0.2)	8.3 (0.4)
Bulk density (g/mL)	0.419 (0.003) a	0.331 (0.008) b
Compacted density (g/mL)	0.55 (0.01)	0.52 (0.01)
Fluency (%)	24 (2) b	36.2 (0.7) a
Hausner ratio	1.32 (0.04) b	1.57 (0.01) a
Carr index (%)	23.81 (0.02) b	36.3 (0.01) a
Angle of repose (º)	29.6 (0.2) a	26.1 (0.4) b

Mean (Standard deviation); n= 3.
Different letters in the same row indicate significant differences ($p \leq 0.05$).

The compacted density is used to correct the fluctuation of the total volume of voids between particles during the transport, drying and packaging processes. The freeze-dried flour presented the lowest compacted density, making it more porous. According to Hasmadi (2021), this behavior is because freeze-dried powder granules have small particles that can agglomerate to form a lumpy powder, which produces more voids between them. These flours take up little space, which reduces packaging costs (BUZERA et al., 2022).

Another important flow property is the Hausner ratio, which is an indirect measure of the property of a bulk material to reduce its volume under mechanical influence and is a measure of compressibility and particle interaction. A low Hausner ratio means that the material flows more easily. In less fluid substances, greater cohesive forces exist between the particles, and the Hausner ratio is higher (KALMAN, 2021). In this investigation, the freeze-dried flour presented values significantly higher than the dehydrated flour, so the latter was classified as passable. In contrast, the freeze-dried flour had very poor flow.

The Carr or compressibility index directly measures the tendency to form arches or bridging and its strength. It is also an indirect measure of the flow properties of the powder. Free-flowing dust would have a value of this index less than 15, while low-flowing dust would have a value greater than 32 (AULTON; TAYLOR, 2013). Accordingly, dehydrated and freeze-dried flours were classified as passable and very poor flow, respectively.

Significant differences were observed between the angle of repose of dehydrated and freeze-dried flour. It has been suggested that the greater the angle of repose, the greater the cohesion of a bulk solid; therefore, the smaller the angle of repose, the more fluid the bulk solid will be (CAIN, 2002).

The particle size distribution is an important aspect to consider when evaluating the physical and functional properties of the flours obtained. Figure 2 shows the particle size distribution results for dehydrated and freeze-dried peach palm flours.

It is observed that the dehydrated flour retained the highest percentage (60%) at a mesh opening of 300 μm, while the freeze-dried flour had the highest retention percentage (40%) at a mesh opening of 150 μm. These results are consistent with what was reported by Buzera et al. (2022), where the particle size distributions of flours obtained by different drying methods were compared. It was found that freeze-drying resulted in a reduction in particle size, an increase in the fraction of finer particles and a higher retention of finer particles compared to conventional dehydration.

Table 4 presents the results of the microbiological analysis carried out on the dehydrated and freeze-dried flours. The microbiological counts on each flour met the requirements for solid food mixtures established in NTE INEN 3084 (2015).

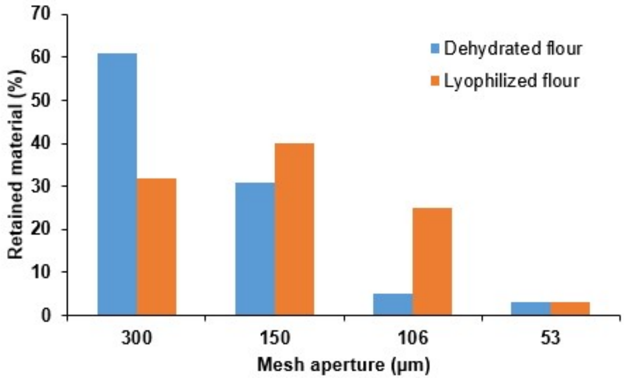

Figure 2. Particle size distribution of peach palm flours obtained by dehydration and freeze-drying.
Figura 2. Distribuição granulométrica de farinhas de pupunha obtidas por desidratação e liofilização.

Table 4. Microbiological analysis of dehydrated and freeze-dried flours
Tabela 4. Análise microbiológica de farinhas desidratadas e liofilizadas

Indicator	Peach palm flour	
	Dehydrated	Lyophilized
Molds and yeasts (CFU/g)	3.0×10^3	2.3×10^3
Escherichia coli (NMP/g)	< 3	< 3

Figure 3 presents the quantitative descriptive profiles of dehydrated and lyophilized peach palm flours. Different differences can be observed in some descriptors when comparing dehydrated and lyophilized peach flours. Regarding color, the dehydrated peach flour showed a moderate yellow-orange intensity, with some variations due to the dehydration process. In contrast, the lyophilized peach flour retained a brighter color close to that of the fresh product, and the lyophilization process minimizes the loss of pigments and the occurrence of browning reactions favored by the temperatures used in the dehydration processes. The presence of strange colors was not evidenced, and the color appeared uniform throughout the mass of the product. However, whitish particles related to the anatomical structure of the peach palm were detected.

Regarding the odor, both flours maintained the characteristic odor of peach palm. Still, according to the tasters' considerations, lyophilization preserved the fruit notes more intensely than dehydration, which slightly attenuated this characteristic. Strange odors were not detected in any of the flours.

In the case of taste, although both flours retained the characteristic peach flavor, lyophilization better maintained the nutty notes of the fresh fruit, unlike dehydration, which resulted in a product with a less intense flavor and cooked product notes due to the action of the drying temperature. The judges did not provide evidence of a strange taste, and the undesirable bitter taste was barely perceptible.

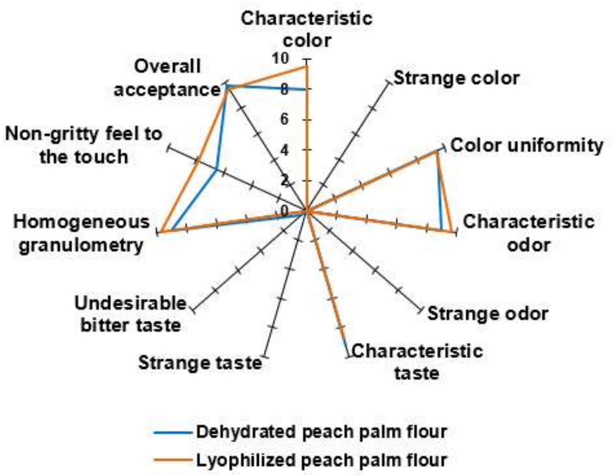

Figure 3. Quantitative descriptive profiles of dehydrated and lyophilized peach palm flours.
Figura 3. Perfis descritivos quantitativos das farinhas de pupunha desidratadas e liofilizadas.

The texture of the dehydrated flour was related to grinding, which generated a greater presence of coarse particles, typical of dehydrated, powdered products. Lyophilization, which could facilitate its mixing and dispersion in liquids, minimized the formation of lumps and obtained a finer and more uniform texture. This corresponded with the non-gritty feel to the touch perceived by the judges in the lyophilized peach palm flour.

3.4. Stability of vacuum-packed flours during accelerated storage

The stability of the dehydrated and lyophilized meals was evaluated by determining the POV during accelerated storage at 30, 40 and 50 ºC (Figure 4). The initial POV of the dehydrated and freeze-dried flours were 0.28 and 0.23 meq O_2 kg^{-1}, respectively.

At 30 ºC, no significant differences were observed between the dehydrated and freeze-dried flours up to 14 days, while between 14 and 28 days, the freeze-dried flour had a lower POV than the dehydrated flour. This behavior may be related to a lower moisture value or the low water activity achieved during lyophilization, which could damage the quality of lipid-based biocomposites (GUTIÉRREZ et al., 2008).

On the other hand, the flours stored at 40 ºC presented differences in the POV after 7 days. Although the freeze-dried flour maintained a lower POV than the dehydrated flour, at 28 days, the value of this parameter in the freeze-dried flour was higher than that of the dehydrated flour. At 50 ºC, the behavior of both flours was the same, and the POV did not differ in each measurement.

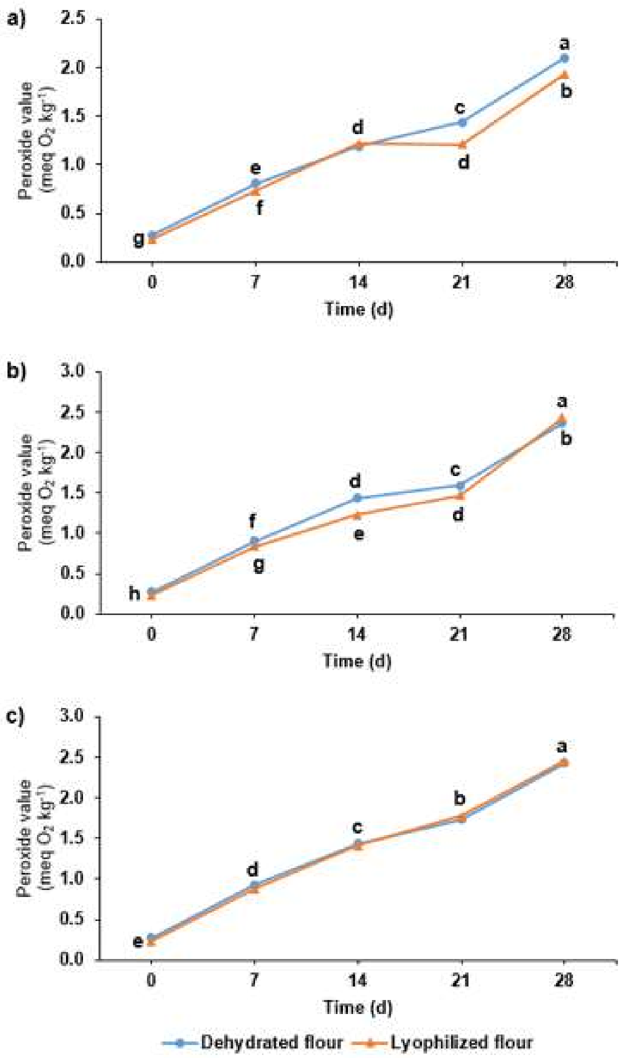

Figure 4. Variation of the peroxide value of dehydrated and lyophilized peach palm flours during accelerated storage: a) 30 ºC; b) 40 ºC and c) 50 ºC. Different letters indicate significant differences for $p \leq 0.05$.
Figura 4. Variação do índice de peróxidos das farinhas de pupunha desidratadas e liofilizadas, durante seu armazenamento acelerado: a) 30 ºC; b) 40 ºC e c) 50 ºC. Letras diferentes indicam diferenças significativas para p ≤ 0,05.

Table 5 shows that the POV variation was adjusted to zero-order kinetics for all temperatures. This behavior differs from the first-order kinetics reported by Pereira (2017) and Valenzuela; Rojas (2006) for extruded wheat flour and walnut flour, respectively. On the other hand, Calligaris (2007) also obtained zero-order kinetics for the POV variation in baked goods, which was associated with the addition of fat in the formulation.

Table 5. Zero-order adjusted peroxide value kinetic parameters.
Tabela 5. Parâmetros cinéticos do valor de peróxido ajustado de ordem zero.

Temperature (ºC)	Flour	Model	R	R^2	R^2 adjusted	p	k (meq O_2 kg^{-1} d^{-1})
30	Dehydrated	POV= 0.0611t+0.3054	0.9900	0.9388	0.9184	0.001201	0.0611
	Lyophilized	POV= 0.0554t+0.2898	0.9689	0.9440	0.9393	0.006549	0.0554
40	Dehydrated	POV= 0.0695t+0.3403	0.9851	0.9704	0.9605	0.002182	0.0695
	Lyophilized	POV= 0.0717t+0.2343	0.9776	0.9556	0.9408	0.004022	0.0717
50	Dehydrated	POV= 0.0728t+0.3383	0.9930	0.9860	0.9813	0.000709	0.0728
	Lyophilized	POV= 0.0762t+0.2809	0.996	0.9921	0.9894	0.000301	0.0762

In addition, the coefficients of determination (R^2) oscillate between 0.9388 and 0.9921; high values confirm the data's good fit to the model and indicate that the adjusted models explain more than 90.0 % of the POV variation. In an experimental design, R^2 indicates the variation around the mean explained by the model. This coefficient increases whenever significant factors are added to the model, while the adjusted R^2 value does not. Hence, estimation is needed for these kinetic models.

Table 6 presents the linearized Arrhenius equations for the POV variation and the Q_{10} values for dehydrated and freeze-dried meals. These parameters are important to understand oxidation's kinetics and the products' oxidative stability.

Table 6. Arrhenius equations for the variation of the peroxide value and the Q_{10} values
Tabela 6. Equações de Arrhenius para variação do valor de peróxido e dos valores de Q_{10}

Parameter	Peach palm flour	
	Dehydrated	Lyophilized
Linearized Arrhenius equation	ln k= -862.18 (1/T) + 0.0612	ln k= -1571.2 (1/T) + 2.3198
R	0.9697	0.9478
R^2	0.9403	0.8984
R^2 adjusted	0.8806	0.7969
Q_{10} (30-40 ºC)	1.14	1.29
Q_{10} (40-50 ºC)	1.05	1.06

As can be seen, the value of the R^2 demonstrates the good fit of the POV *versus* the temperature for estimating the rate constant. The R^2 value for the dehydrated flour was 0.9403, and the R^2 adjusted was 0.8806, while for the freeze-dried flour, the R^2 and R^2 adjusted were lower. In this sense, it can be argued that the model for dehydrated flour better explains the variation of the POV compared to the model for freeze-dried flour.

For the temperature range from 30 to 40 °C, the Q_{10} value for dehydrated flour was 1.14, while for freeze-dried flour, it was 1.29. These results indicate that the oxidation rate is slightly more sensitive to temperature changes in freeze-dried flour than in dehydrated flour; therefore, dehydrated flour could be considered more stable.

The results of this study indicate that the linearized Arrhenius equations adequately describe the POV variation as a function of temperature for both types of flour. In addition, the Q_{10} values showed differences in sensitivity to temperature changes between freeze-dried and dehydrated meals. These findings support the importance of considering temperature and oxidation kinetics when evaluating the stability of these products.

4. DISCUSSION

The analysis of the chemical composition of the peach palm fruits revealed a high content of moisture, ash, protein, crude fiber and fat. These results provide valuable information about the fruit's nutritional composition and may be useful for evaluating its nutritional value and potential use in different food applications. However, additional studies with a larger sample size are required to confirm these results and better understand the variability in the chemical composition of peach fruit.

The results of this paper differ from those reported by Martínez-Girón et al. (2017), who obtained higher moisture, ash and protein contents and lower fat content. These differences can be related to using a different variety in this research and the fact that the flour was obtained from the peach palm epicarp (shell) residues. On the other hand, Martínez (2019) reported higher moisture and protein values, while the fat content was lower in the case of dehydrated flour.

There are different reports regarding the moisture content of freeze-dried and dehydrated products. Umuhozariho et al. (2020) showed that the pumpkin flour obtained by dehydration presented lower moisture values than the flour obtained by freeze-drying, and Bao et al. (2021) obtained lower values of this indicator for freeze-dried potato flour.

The fluidity of the powders is affected by several factors resulting from the interaction between the shape, size and properties of the surface of the particles (Saker et al., 2019). The characterization of the flow properties of a powder is required for a reliable design and proper operation of industrial processes. The effect of the state of compaction and bed porosity on the fluency of bulk solids is probably the most critical area of understanding (LETURA et al., 2014). The apparent and compacted densities inform about the packing and arrangement of the particles, as well as the compaction profile of the material (MIRHOSSEINI; AMID, 2013). These characteristics are influenced by particle size distribution, attractive forces between particles, and particle shape (SINGH et al., 2010).

According to Carr (1965) classification, both flours have an excellent flow, although the freeze-dried flour presented a lower angle of repose. The dependence of the angle of repose on the moisture content has also been demonstrated (Kalman, 2021); in this case, it is confirmed that the freeze-dried flour, with lower moisture content, had the lowest angle of repose.

Buzera et al. (2022) reported that, according to the Carr index values and repose angle, dehydrated and freeze-dried potato flours had poor flow and very poor flow, respectively, and were characterized as cohesive powders. This behavior was similar to that of the present research.

The differences in the classification according to the nature of the flour flow can be based on the fact that although the angle of repose is one of the most important parameters for the characterization of bulk materials, it is not an intrinsic property of bulk solids, it depends on other characteristics, such as density, pour height, moisture content, and actual pile formation.

Lyophilization more effectively maintained the original sensory characteristics of peach palms compared to dehydration. It retained both the characteristic aroma and the flavor, in addition to maintaining a finer and more homogeneous texture. Despite these differences, the choice between both options will depend on production costs and the specific needs and preferences of consumers and the food industry.

In the initial phase of lipid oxidation, lipid radicals react with oxygen and generate lipid hydroperoxides as primary oxidation products (WEI et al., 2021).

Vanhanen and Savage (2006) reported increased POV in walnut flour up to 26 weeks of storage at 23 ºC. After this time, they recorded a decrease in this value, associated with decomposing primary oxidation products, such as hydroperoxides, into secondary oxidation products, such as aldehydes (GULKIRPIK et al., 2021). Also, Gadani et al. (2017) found that POV increases during storage time.

The behavior of the flour's POV in the present investigation was similar to that reported by Hurtado-Ribeira et al. (2023). These authors evaluated the oxidative quality of the fat obtained from the larva of the black soldier fly (*Hermetia illucens*) by different methods of sacrifice, drying, and fat extraction, reporting that the lyophilized samples were more stable regardless of the storage time. In general, the samples obtained by lyophilization and dehydration underwent lipid oxidation, reflected as an increase in POV during storage.

The Arrhenius equation describes the effect of temperature on the rate of chemical reactions. This equation is widely used in food research, technology and engineering. Kinetics plays a fundamental role in choosing storage conditions and establishing products' commercial shelf lives, maintaining their quality while minimizing nutritional losses.

Rate constants can be used to estimate the value of Q_{10}, a coefficient used to measure the sensitivity of reactions to temperature. This coefficient informs the increase in the speed of a reaction when the temperature is varied by 10 °C. In all cases, the POV during accelerated storage was adjusted to a reaction of zero-order and linear models were obtained to estimate the variation of this parameter.

5. CONCLUSIONS

The variation of the POV in both flours showed a similar behavior during accelerated storage, without there being, in general, differences ($p \leq 0.05$) regarding the increase of the POV. In all cases, this POV increase during accelerated storage was adjusted to a zero-order reaction and linear models were obtained to estimate the variation of this parameter for each combination of flour and temperature. The Q_{10} values for the POV variation ranged between 1.05 and 1.29, regardless of the type of flour.

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