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Production and characterization of a carotenoid-rich peach palm flour

Produção e caracterização de farinha de pupunha rica em carotenoides

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Resumo

A pupunha é um fruto da região amazônica ainda pouco aproveitado pela indústria de alimentos. Nesse sentido, no presente estudo foi realizada a otimização dos parâmetros de produção de farinha de pupunha para a obtenção de um produto com alto conteúdo de carotenóides. Para alcançarmos esse objetivo foram realizados testes de produção de farinha variando-se a composição do fruto (com casca e sem casca), uso de pré-tratamento térmico (com cocção e sem cocção), e a temperatura de secagem (50,60 e 70 °C). Após a otimização dos parâmetros de produção, a farinha de pupunha foi avaliada quanto às características físico-químicas e tecnológicas. Em geral, a presença da casca e o uso de temperaturas mais elevadas (70 ºC) durante a secagem contribuíram para uma maior retenção de carotenoides nas farinhas, enquanto que o pré-tratamento por cocção reduziu o teor de carotenoides no produto final. Os resultados evidenciaram que uma farinha produzida sem cozimento, com casca e seca a uma temperatura de 70 °C apresentou maior retenção de carotenoides. A farinha obtida da pupunha com casca e sem cocção à 70 °C apresentou valores elevados para carotenoides totais (160 µg/g), fibra total alimentar (11,1%), vitamina C (18 mg/100 g), lipídeos (13%) e carboidratos totais (72,04%). A farinha apresentou elevada acidez titulável (34,79 mg/100 g), baixo pH (3,99), índice de absorção de água de 3,12 g/g e índice de solubilidade em água de 7,98%. Os parâmetros de cor instrumental L (67,4), a* (8,6) e b* (71,2), indicaram uma farinha mais escura e alaranjada. Em conclusão, os resultados deste trabalho demonstram que a farinha de pupunha é um produto rico nutricionalmente e que apresenta características funcionais melhoradas, constituindo um promissor ingrediente para inclusão em formulações alimentícias, como bolos, pães e biscoitos.

Palavras-chave: *Bactris gasipaes* Kunth. Fibra alimentar. Carotenoides. Vitamina C.

Abstract

In this work a carotenoid-enriched peach palm flour was produced and characterized aiming to value-add to peach palm fruit, a still commercial neglected Amazon fruit. The production of peach palm flour allows the best use of the fruit as well as the supply of the product to the industry throughout the year. Firstly, the process parameters for peach palm flour production were optimized aiming to obtain a final product with high level of carotenoids. The optimization was carried out varying the composition of the fruit (with or without peel), the pre-treatment (with or without cooking), and the drying temperature (50, 60 and 70 °C). In general, the presence of peel and the use of higher temperatures (70ºC) during drying was able to provide a higher retention of carotenoids in the flour. Nevertheless, the pre-treatment by cooking reduced the content of total carotenoids in the produced flour. Thus, a flour obtained from fruits will preserved peel, without pre-treatment and dried at 70 °C, showed greater retention of carotenoids. At these conditions, the produced peach palm flour showed high content of total carotenoids (160 µg/g), total dietary fiber (11.1%), vitamin C (18 mg/100 g), lipids (13%) and total carbohydrates (72.04%). The flour also showed a high titratable acidity (34.79 mg/100 g), low pH (3.99), water absorption index of 3.12 g/g and water solubility index of 7,98%. Additionally, the instrumental color parameters L (67.4), a* (8.6) and b* (71.2) indicated a darker and orange flour. In summary, the results evidenced that peach palm flour is a promising healthy food product that can be used for the elaboration of foods with improved nutritional and functional properties, with especial potentiality to be included in gluten free products.

Keywords: *Bactris gasipaes* Kunth. Dietary fiber. Carotenoids. Vitamin C.

1. Introduction

The demand for food products with high nutritional value have been growing in the last years, and the changing in the consumer preferences stimulate the food industry to search for nutrients with improved nutritional and functional properties. In this scenario, the use of raw non-conventional food sources is an alternative to obtain ingredients with improved nutritious and healthy potential to be used in food industry. The peach palm tree (*Bactris gasipaes* Kunth) is native from the North region of Brazil, and is frequently industrially exploited with focus in the processing of canned palm hearts (Divino; Pinto, 2013; Pimenta, 2011). However, the peach palm fruits are still a neglected agro-industrial product, being considered an agricultural byproduct from the palm heart production (Pires et al., 2021; Santamarina et al., 2022).

The peach palm fruits can present peel and pulp color varying from yellow to red as function of the genetic variability of the specie. The diversity of colors observed in the fruits are a result of a varied content of carotenoids, which are pigments found in plant foods with orange, yellow and red color. Carotenoids are also considered precursor agents of vitamin A, which act as antioxidants, and have the ability to neutralize free radicals in the human body, being capable of preventing or even reducing the damage that these free radicals can cause to cells (Mezzomo, Ferreira 2016; Santos et al., 2022).

The peach palm fruit is divided into three parts: the epicarp, which is a fibrous shell that protects the inside of the fruit; the mesocarp, which is a pulp rich in starch and oil; and the endocarp, which involves a fibrous and oily almond (seed) (Carvalho et al., 2013). Its pulp is a rich source of lipids, proteins, starch, fibers, vitamin C, thiamine and carotenoids, having a pleasant flavor (Menezes et al. 2019; Pires et al., 2021). For these reasons, peach palm pulp has the consumer's preference and it is considered a raw material with high potential to be used for the development of functional foods, as it provides high content of bioactive compounds which can improve the nutritional and healthy properties of the produced foodstuff (Ferreira, 2021; Silva et al., 2010).

Furthermore, the peach palm pulp has also as advantage to be gluten free, which allows its use in bakery, for the development of cakes, cookies, breads and pasta, which can be consumed by many people, including those with gluten intolerance or celiac disease or those who personally choose gluten-free products (Reck; Miranda, 2016; Oliveira; Souza , Polesi, 2020). Many products marketed today without the presence of gluten are formulated with other types of refined flours or starches, presenting a low content of fiber and other micronutrients (Dias, 2021). In this scenario, the use of peach palm flour is also advantageous since it presents higher content of nutrients and fibers, contributing to increase the final quality of the produced foodstuff.

Despite its promising potential to be used in food industry, the seasonality of the fruit (fructifying from December to April) is a drawback associated to a better exploitation of peach palm fruit (Flores et al. 2019). To overcome the limitations associated to the seasonal fructifying period of these fruits, technological processes involving drying and flour production can be employed aiming to guarantee the availability of this material during whole year.

In this context, this work aimed to optimize the production process of peach palm flour, evaluating the effect of the presence of peel, heat pre-treatment and drying temperature on the content of carotenoids of the produced flour. Additionally, the optimized flour was characterized regarding its physicochemical characteristics.

2. Material and Methods

2.1 Preparation of the raw material and production the flour

The peach palm fruits used in this work were acquired in march 2021 from rural producers in the city of Ariquemes – Rondônia.

The fruits were selected in order to eliminate the deteriorated ones, being discharged the fruits with visible cracks, pulp crushing or even the presence of mold. Subsequently, they were cleaned and sanitized (200 ppm of active chlorine) for 15 minutes and rinsed in running water to remove excess chlorine. Aiming to obtain a peach palm flour with improved functional properties it was evaluated the effect of (1) presence/absence of peel; (2) cooking procedure; (3) drying temperature on the total content of carotenoids (Figure 1). The production of the flour and its characterization were carried out at the Food Engineering Laboratory, at the Federal University of Rondônia, Campus of Ariquemes, RO.

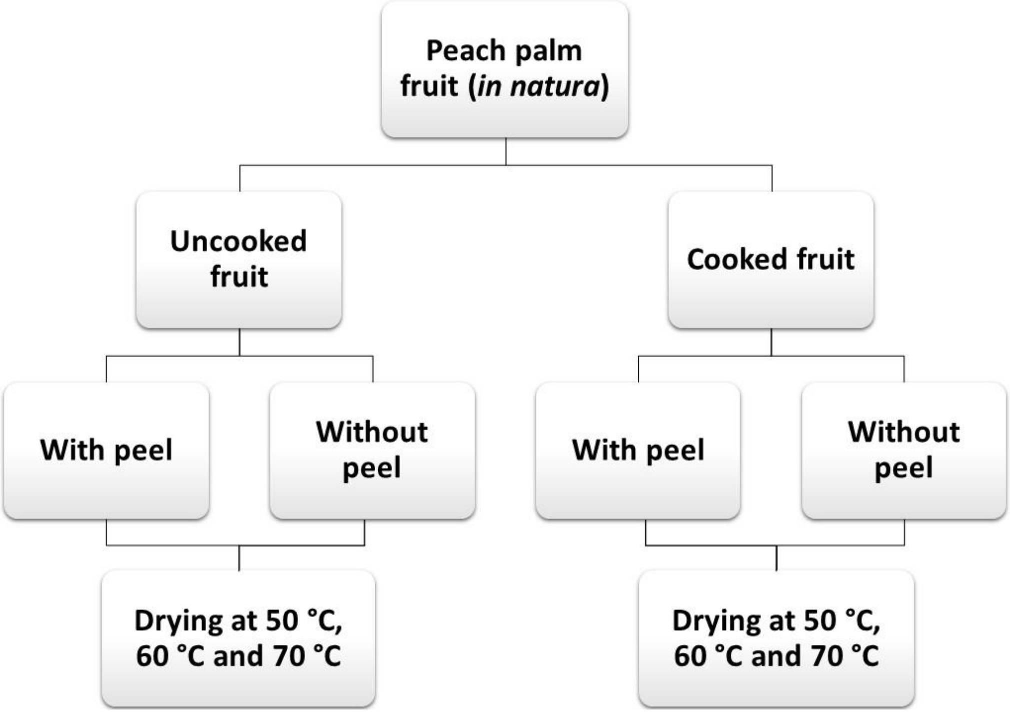

Figure 1 – Flowchart of the treatments used for the production of the peach palm flour.

For the flour production, the peach palm fruits were firstly divided according to the pre-treatment condition: (a) uncooked; and (b) cooked (Figure 1). The peach palm fruits submitted to the pre-treatment by cooking were put in a pan, covered with filtered water and left to boil for 20 min. After cooking, the fruits were cooled at room temperature, had their seeds removed and were sliced into pieces with thickness of approximately 0.5 cm (Figure 2B). For the peach palm fruits from the uncooked group, the seeds were removed and the pulp was sliced as described above. After that, the fruits were divided into two more groups: (a) with peel (Figure 2A); and (b) without peel (Figure 1). The peel of the fruit slices were manually removed using a bistoury. The sliced peach palm pulps were dehydrated (Figure 1) in an oven with air circulation (temperatures of 50ºC, 60ºC or 70ºC) to obtain a dry material with moisture lower than 12% (Figure 2C). The dehydrated pulps were grounded in a blender until to be reached a granulometry lower than 1.18 mm. The obtained peach palm flour (Figure 2C) was packed in transparent polyethylene bags, covered with aluminum foil and placed in a freezer at -18 °C, for further analysis.

Figure 2 – Photographs of the (a) whole i*n natura* fruits; (b) sliced palm peach fruits, with thickness standardized to 0.5 cm; (c) sliced palm peach fruits after drying; and (d) peach palm flour.

The flour production parameters that achieved the maximal retention of carotenoids at the end of the drying process were selected to produced peach palm flour to be characterized regarding its yield, proximate composition, titratable acidity, pH, vitamin C, granulometry, water absorption index, water solubility index and instrumental color.

2.2 Content of total carotenoids

The content of total carotenoid was determined according to Rodriguez-Amaya (2001), with modifications. Carotenoids extraction was performed by mixing 200 mg of sample with 100 mg of celite and 5 mL of acetone. The mixture was kept under stirring in a thermal bath at 20 °C for 10 minutes and the final solution was filtered through a separatory funnel with filter paper. The material retained on the filter paper was washed with ice-cold acetone until complete discoloration of the sample.

To the filtrate it was added 5 ml of petroleum ether and homogenized manually and slowly. Then, 60 mL of distilled water was slowly added, avoiding the formation of an emulsion. With the addition of water, the phases were separated, one containing petroleum ether and carotenoids and the other consisting of water and acetone. The clear liquid (water + acetone) was carefully discarded to avoid loss of carotenoids. The phase containing carotenoids was transferred to a volumetric flask and had its volume adjusted to 10 mL with petroleum ether.

The absorbance readings were performed in a UV-Vis spectrophotometer at 450 nm, using petroleum ether as a blank. For the calculations, it was used an absorption coefficient of β-carotene in petroleum ether equal to 2592. The total content of carotenoids was calculated using the Equation 1.

$$TC\ (\mu g.g^{-1}) = \frac{10^4.A.V}{2592.m} \qquad (1)$$

where TC is the concentration of total carotenoids (µg.g^{-1}), A is absorbance at 450 nm, V is the volume of the flask used in the dilution (mL), and m is the mass of the sample (g).

2.3 Yield

The total yield was calculated as the ratio of the weight of the produced flour and the *in natura* peach palm fruit. The fruit pulp yield was also calculated as the ratio between the weight of the pulp that was dried and the *in natura* fruit. Finally, the percentage of flour in function of the pulp content was calculate as the ratio between the weight of the produced flour and the fresh pulp.

2.4 Proximate composition

Moisture, protein, lipid, ash and dietary fiber contents were determined according to the methodologies of AOAC (2006). Moisture content was determined by drying the sample in an oven at 105 °C until constant weight. Nitrogen content was determined by the micro Kjeldahl method, with a conversion factor for proteins of 6.25. The lipid content was determined in a Soxleth extractor using hexane as a solvent. Ash content was determined after calcination in a muffle at 550 °C for 5 hours. Dietary fiber content was determined using the AOAC enzymatic-gravimetric method 985.29. Total and available carbohydrates were calculated by difference.

2.5 Titratable acidity and pH

The titratable acidity and pH were evaluated according to the methodologies of the Instituto Adolfo Lutz (IAL, 2008). For the pH determination, 10 grams of sample were diluted with 100 mL of distilled water in a beaker and the was pH measured in a pHmeter. Titratable acidity was performed on 10 grams of sample diluted in 100 mL of water. Titration was carried out with a 0.01 M sodium hydroxide solution up to pH 8.3 using a pHmeter. The result was expressed in mg of NaOH/100g.

2.6 Vitamin C content

The content of vitamin C was determined by the Tillmans titrimetric method, which is based on the reduction of 2-6-dichlorophenol-indophenol (DCPIP) by ascorbic acid in the sample (IAL, 2008). The standardization of the Tillmans solution was performed with 1 mL of the standard ascorbic acid solution (1mg.mL^{-1}) and 40 mL of 2% oxalic acid, titrated until reaching a slightly pink color for 15 seconds. For the sample analysis, one gram of peach palm flour was added to 40 mL of 2% oxalic acid and titrated with Tillmans solution until the color changed. Results were expressed as mg of ascorbic acid per 100 g of sample.

2.7 Granulometry

The granulometry was determined using a series of four analytical sieves (1.18, 0.500, 0.250, and 0.125 mm). To perform the evaluation, the empty sieves were weighed and 100 g of flour was added and stirred in a sieve shaker for 10 min. The content of peach palm flour retained on each sieve are weighed and expressed as percentages.

2.8 Water absorption index (WAI) and water solubility index (WSI)

WAI and WSI were determined according to the methodology of Anderson, Conway and Griffin (1969), with some modifications. For the determination WAI and WSI, 500 mg of each sample was weighed in tared centrifuge tubes and mixture with 6 mL of distilled water. The mixture was shaken every 5 min at room temperature for 30 min, then centrifuged at 1800 × g for 10 min. The supernatant liquid was carefully drained into tared Petri dishes and left to dry in an oven at 105 °C until constant weight. The remaining wet sediment from centrifugation process was also weighed to the determination of WAI. WAI and WSI were determined using equations 2 and 3, respectively:

$$WAI = \frac{WS}{DS-DSS} \tag{2}$$

where WAI is the water absorption index (g.g^{-1}) WS is weight of wet sediment (g), DS is the weight of dry sample (g), and DSS is the weight of dry solids in supernatant (g).

$$WSI = \frac{DSS}{DS} * 100 \tag{3}$$

where WSI is the water solubility index (%), DSS is the weight of dry solids in supernatant (g), and DS is the weight of dry sample (g).

2.9 Instrumental color

To evaluate the instrumental color of the samples, the flour was placed in a Petri dish (Ø 100 mm) until it formed a 10 mm thick layer and the color was evaluated using the colorimeter application (Lab Tools) for smartphones, version 1.6.6.3, developed by Research Lab Tools.

2.10 Statistical analysis

All experiments were conducted in a completely randomized order, with three replicates. The results of total carotenoid content were submitted to analysis of variance (ANOVA) and Tukey's test ($p<0.05$) to compare means.

3. Results and Discussion

3.1 Optimization of the parameters for obtaining peach palm flour

The time required to obtain a dried peach palm pulp with moisture lower than 12% is shown in Table 1. As can be observed, the drying time reduced with the increase of the temperature. This occurs because increasing temperature provides a greater amount of energy in the form of heat, which makes the sample adjust more quickly to the temperature around it, reaching the equilibrium water content in a shorter time than using lower temperatures (Araújo et al., 2021).

To obtain a peach palm flour with maximal carotenoids retention, all produced flours were evaluated regarding their content of total carotenoids (Table 1). For the peach palm fruits (raw material) it was observed a variation between 219 and 299 µg of carotenoids/g of dry matter, while in the produced flours it was found values between 114 and 205 µg of carotenoids/g of dry matter. Carvalho et al. (2013) found total carotenoids contents ranging from 19.9 to 339 µg/g of dry matter in 21 different peach palm matrices. With regard to flour, the levels of total carotenoids found in the literature range from 4.26 to 137.98 µg/g of dry matter (Carvalho et al., 2009; Ribeiro et al., 2021; Sakurai et al., 2020). In addition, Silva, Furtado and Rodrigues (2020) evaluated the nutritional quality of whole red peach palm fruits dehydrated at different temperatures and observed a decrease in the content of total carotenoids after drying, being reported values of 47.64 µg/g (dry basis) for *in natura* fruit and 30.42, 27.81 and 23.27 µg/g (dry basis) for dehydrated pulps at 45, 55 and 65 °C, respectively. The authors also observed that the higher the temperature used for drying, the lower the content of total carotenoids of the dehydrated fruits.

Table 1 – Drying time at different temperatures to obtain the peach palm flour and the content of total carotenoids of the flours obtained in the different treatments.

Treatment	Temperature (°C)	Drying time (h)	Total carotenoids content (µg /g of dry matter)	
			Fruit	Flour
Uncooked, with peel	50	7	299 ± 3.03 ^{aA}	205 ± 2.99 ^{aB}
Uncooked, without peel			240 ± 1.25 ^{cdA}	122 ± 2.19 ^{efB}
Cooked, with peel			250 ± 0.53 ^{cA}	153 ± 7.05 ^{dB}
Cooked, without peel			253 ± 0.88 ^{cA}	132 ± 5.21 ^{eB}
Uncooked, with peel	60	5,5	276 ± 4.65 ^{bA}	128 ± 6.78 ^{efB}
Uncooked, without peel			226 ± 7.78 ^{deA}	114 ± 3.57 ^{fB}
Cooked, with peel			254 ± 0.43 ^{cA}	126 ± 1.33 ^{efB}
Cooked, without peel			277 ± 2.33 ^{bA}	148 ± 4.96 ^{dB}
Uncooked, with peel	70	4	282 ± 3.65 ^{bA}	188 ± 4.52 ^{bB}
Uncooked, without peel			282 ± 4.09 ^{bA}	160 ± 3.47 ^{cdB}
Cooked, with peel			219 ± 3.28 ^{eA}	172 ± 2.10 ^{bcB}
Cooked, without peel			219 ± 2.68 ^{eA}	113 ± 2.72 ^{fB}

Values reported as mean ± standard deviation. Values followed by the same uppercase letter within a line and the same lowercase letter within a column are not statistically significant according to Tukey's test ($p < 0.05$).

Drying is a simple, easy and low-cost process, most used in the food preservation process. However, the chemical characteristics of the food that will be subjected to this process must be evaluated in order to stablish the appropriate drying temperature, aiming to avoid reactions such as browning, protein denaturation and starch gelatinization, factors that can negatively influence the quality of the dehydrated product (Pimenta, 2011).

The peach palm flours had a lower content of total carotenoids than the raw material. The drying temperature may have been responsible for this reduction in carotenoids. Degradation of carotenoids is common when food undergoes heat treatments because carotenoids are very prone to oxidation as they are highly unsaturated. Heat treatment can cause different losses, depending on its intensity and duration. In addition, other factors such as the food matrix, structure and food composition might interfere with the degradation of carotenoids during heat treatments (Carvalho et al., 2010; Fratianni et al., 2017; Rojas-Garbanzo et al., 2012).

On the other hand, it was observed an increase in the content of detectable carotenoids in the peach palm fruits that had their peel remove, cooked and dried at 60ºC, being observed values of carotenoids 22.6% higher for the dried fruits and 29.88% for the produced flour. This increase can be explained by the softening the cell walls and by the breakdown of carotenoid complexes with proteins and fatty acids, which increases the availability of carotenoids (Carvalho et al., 2009; Costa; Rodrigues; Silva, 2022; Rojas-Garbanzo et al., 2012).

For better understanding, the results were grouped according to cooking, presence of peel and temperature (Table 2). In general, cooking prior to drying negatively affected the content of total carotenoids in both fruits and flours. The presence of the peel during drying was responsible by a higher retention of carotenoids in the flours, when compared to the flour from decorticated fruits. The drying at 70 °C was more efficient to retain carotenoids from the raw material in the produced peach palm flours. Thus, a flour produced with peach palm fruits without cooking, with the peel and dried at a temperature of 70 °C should present the highest retention of carotenoids. According to Matos et al. (2019), the peach palm peel has about ten times more carotenoids than the pulp, which justifies the higher content of total carotenoids found in the treatments that kept the peel in the fruit.

Table 2 – Total carotenoid content and reduction of carotenoid content with drying by grouping the parameters.

Parameter	Total carotenoid content (μg /g of dry matter)		Reduction (%)
	Fruit	Flour	
Uncooked	268 ^{a}	153 ^{a}	42.9
Cooked	246 ^{b}	141 ^{b}	42.7
With peel	263 ^{a}	162 ^{a}	38.4
Without peel	249 ^{a}	131 ^{b}	47.4
Drying at 50 °C	261 ^{a}	153 ^{b}	41.4
Drying at 60 °C	258 ^{a}	129 ^{c}	50.0
Drying at 70 °C	251 ^{b}	158 ^{a}	37.1

Values followed by the same lowercase letter within a column for the same parameter do not differ significantly according to Tukey's test ($p < 0.05$).

Considering these results, the optimized parameter processes to produce peach palm flour were stablished as the use of peach palm pulp with peel, without a previous cooking and using a drying temperature of 70 ºC. The flour produced using these conditions was further characterized regarding its physicochemical and functional characteristics.

3.2 Yield

The yield of peach palm flour production using the fruit with peel, without cooking and drying at 70 °C is shown in Table 3. The yield of the whole fruit in pulp is related to the losses due to the removal of small injured parts and the removal of seeds (large percentage of losses). Compared to other values of pulp yield, the result found in our work are higher than those reported by Souza (2010) and Santos (2012), which obtained pulp yield of 76.1 and 76.32%, respectively.

Table 3 – Yield of production of the peach palm flour.

Yield	%
Whole fruit in pulp	83.0
Pulp in flour	45.6
Whole fruit in flour - total	39.2

The yield of flour from the pulp was 45.6%, this reduction is mainly due to the pulp drying process, in addition to small losses that can occur during milling and sieving processes. This value was very close to that found by Souza (2010) who reported a yield of 44.1%. Finally, considering the total process yield, which refers to the conversion of the whole fruit in flour, the yield obtained in this work (39.2%) was higher than those observed by Souza (2010) and Divino and Pinto (2013) that reported total yield of 33.6 and 35.32%, respectively.

3.3 Proximate composition

Table 4 shows the characteristics of the proximate composition obtained for the peach palm flour. As can be observed, the moisture content found in this work is in agreement with the literature data, being observed moisture content ranging from 2.83 to 11.16% in peach palm flours, depending on the peach palm fruit variety and the process parameters used to produce the flour (Carvalho et al., 2009; Sakurai et al., 2020; Silva; Furtado; Rodrigues, 2020; Souza et al., 2022). If we consider the feasibility of application of peach palm flour as food ingredient, we must to evaluate if their moisture fits to the regulatory recommendations for flour production. According to the Brazilian legislation (Brasil, 2005), the moisture of wheat flour must be a maximum of 15%. Thus, the moisture content of peach palm flour (8.52%) is within the standard established for wheat flour.

In addition, the low moisture content of the peach palm flour facilitates its storage and transport, in addition to prolonging its shelf-life by hindering the development of spoilage microorganisms and the spread of pests such as insects (Souza et al., 2022). According to Ferreira and Pena (2003), the final moisture content of a product is extremely important, as the higher water content favors the development of microorganisms and accelerates chemical or enzymatic reactions, reducing the shelf life of the food.

Table 4 – Proximal composition of peach palm flour.

Parameter	Peach palm flour
Moisture (%)	8.52 ± 0.26
Ash (%)	1.52 ± 0.06
Proteins (%)	4.92 ± 0.18
Lipid (%)	13.00 ± 0.03
Total dietary fiber (%)	11.10 ± 0.50
Total carbohydrates (%)	72.04
Available carbohydrates (%)	60.94
Energetic value (Kcal/100g)	380.44

Values reported as mean ± standard deviation.

The ash content obtained in this study for the peach palm flour (1.52%) was similar to that 1.4% reported by Ferreira (2021) and lower than those reported by Ribeiro et al. (2021) and Pimenta (2011). These differences in the ash content may be ascribed to the variety of the fruit used and to the methodology used to process the raw material (Pimenta, 2011). The ash content also complies with the Brazilian legislation (Brasil, 2005), which establishes the ash content between 0.8 and 2.5% for wheat flour.

The protein content of the peach palm flour (Table 4) was lower than those from Ribeiro et al. (2011), which found protein content of 7.3%, and similar to that found by Carvalho et al. (2009), Sakurai et al. (2020) and Souza et al. (2022), that reported values varying from 4.15 to 4.89%. Although the content of protein in peach palm flour don't meet the regulatory criteria stablish in the Brazilian legislation to be used as a substitute of wheat flour (at least 7.5% protein in the composition), protein content found in peach palm flour is higher than in cassava and potato flour (Ferreira, 2021), which makes it an alternative to increase the nutritional value of bakery products.

Considering the lipid content (Table 4), the peach palm flour obtained in this work showed similar values to that of 12.92% reported by Souza et al. (2022), and higher lipid values when compared to the data found by Sakurai et al. (2020), which reported a lipid percentage of 7.89%. In general, the differences observed in proximate composition of peach palm flour are a result of the process parameters during the flour production and the variety of the fruit used in it. Additionally, as carotenoids had a lipophilic nature, they are currently dissolved in the lipid molecules, which make the content of lipids important to maintain the functional properties of carotenoids-containing foods matrices (Rodriguez-Amaya, 2001). Lipids also contribute to the sensory properties of the food, interfering with the color, flavor and texture of the final product. Furthermore, they are important molecules to provide and store energy for human metabolism, are precursors of hormone synthesis, and help in the absorption of fat-soluble vitamins (Damodaran; Parkin, 2018).

The peach palm flour presented 11.1% of total dietary fiber (Table 4), value similar to that reported by Carvalho et al. (2009) and higher than that found by Sakurai et al. (2020). Moreover, the fiber content reported in this work was higher than those found for other types of flour, such as wheat (2.75%) and quinoa (5.52%) (Vieira et al., 2015). Bernaud and Rodrigues (2013) emphasize that dietary fiber has functional properties, and a regular consumption of foods with high content of fibers can offer health benefits, such as reduced risk of developing coronary heart disease, hypertension, obesity, diabetes and colon cancer. Therefore, our results evidenced that peach palm flour could be a promising alternative for the elaboration of food products with improved functional properties, especially due to the high dietary fiber content.

The total carbohydrate content (Table 4) corroborates the values between 65 and 72% found in the literature (Sakurai et al., 2020; Silva; Furtado; Rodrigues, 2020; Souza et al., 2022). Besides that, the available carbohydrate content in the peach palm flour was around 61% (Table 4), and the caloric value was found to be 308.44 kcal/100 g. These results evidenced that peach palm flour can be considered a product with a high energy value, and, therefore, could be an excellent alternative of food ingredient to be used for the development of products targeted to children and elderly, as long as it meets the different nutritional recommendations.

3.4 Titratable acidity and pH

The titratable acidity for peach palm flour was high, being found values of 34.79 ± 2.0 mg NaOH/100 g. Comparing our data with those from literature we found that the peach palm flour produced in this work have higher titratable acidity values than those reported by Almeida et al. (2011) and Pimenta (2011), which obtained peach palm flour with, respectively, 14.1 and 17.96 mg NaoH/100g. This high value of acidity could be associated to the presence of a high content of oxalic acid crystals commonly found in vegetal cells (Silva, 2013). Additionally, the high content of lipids found in the peach palm fruit could contribute to increase the titratable acidity of the produced flour, since the higher the lipid content, the higher the acidity values (Melo, 1941).

The peach palm flour also showed a pH value of 3.99 ± 0.2, value lower than those found by Souza et al. (2022), Sakurai et al. (2020) and Carvalho et al. (2009), who reported peach palm flour with pH values ranging from 5.74 to 6.16. The pH is an important factor in foods products since it is an indicator of the deterioration that can be caused by microorganisms and enzymatic activity, also interfering with the sensory properties and shelf-life of the products.

3.5 Vitamin C content

Ascorbic acid (vitamin C) is a water-soluble and unstable compound found in fruits and vegetables. It is considered a potent antioxidant agent and has important biochemical functions, such as facilitating the absorption of iron and assisting in the production of collagen. However, it is highly susceptible to degradation through oxidation, dehydration and polymerization to other non-nutritional compounds in the presence of oxygen, high temperature and long-time light exposition (Cardoso, 2021).

The vitamin C content found in peach palm flour was 18.6 mg/100 g, which was similar to those values commonly observed in the peach palm pulp (Matos et al., 2010; Santos et al., 2015; Spaki et al., 2021), which evidences the promising healthy potential of the peach palm flour.

3.6 Granulometry

The granulometry of peach palm flour is shown in Table 5. As can be observed, only 6% of the peach palm flour particles passed through the 250 µm mesh sieve, with the most of the particles (66%) being retained in the 500 µm mesh sieve. It is possible that the granulometry of the flour was influenced by the lipid content, which could be responsible to the particle aggregation. The Brazilian legislation (Brasil, 2005) for wheat flour establishes that 95% of the particles must pass through a 250 µm mesh sieve to be considered type 1 and 2, and for whole-wheat flour there is no specification. In this case, the peach palm flour should be considered a whole-meal flour, since it was produced using the whole peach palm pulp.

Table 5 – Granulometry of peach palm flour.

Sieve opening (µm)	Retained flour (%)
1180	2
500	66
250	26
125	6
Bottom pan	0

3.8 Water absorption index and water solubility index

The technological properties of the peach palm flour were evaluated with respect to its water absorption index (WAI) and water solubility index (WSI). The flour showed WAI of 3.12 g/g (±0.08) and WSI of 7.98% (±0.18). In general, WAI is related to the availability of hydrophilic groups to bind to water molecules, indicating the amount of water absorbed by the swollen and/or water-soaked flour (Carvalho et al., 2010; Rigon et al., 2022). On the other hand, the WSI is a parameter that quantifies water-soluble molecules at room temperature (Rigon et al., 2022), indicating the degree of severity of the heat treatment and the consequent debranching of the structure of the molecules of lower molecular weight (Carvalho et al., 2010; Rigon et al., 2022). In addition, the WAI and WSI values are also associated with the size of the flour particles, in which the smaller particles proportionally absorb more water and faster than the larger particles.

3.9 Instrumental color

The results regarding the colorimetry parameters of the peach palm flour are shown in Table 6. As can be observed, the produced flour showed a high luminosity (L) value, indicating that the structural organization of the components in peach palm flour had just a slight interference on the absorption of light. However, as reported by Pires et al (2015), the presence of peel can cause some reduction in the luminosity of peach palm flour, since its present high content of cellulose and hemicellulose, which can increase the properties of light absorption in final product.

With respect to the color parameters a* and b*, results have shown that the color of peach palm flour ranges from yellow to orange, with positive values for both parameters a* and b*. In addition, the values of chroma and Hue are also in agreement with the visual aspect observed for the produced flour showed in Figure 2D.

Table 6 – Instrumental color of the peach palm flour.

Parameters	Peach palm flour
L	67.4 ± 1.4
a*	8.6 ± 1.0
b*	71.2 ± 1.1
Chroma	71.7 ± 1.2
Hue	44.8 ± 0.4

4. Conclusion

In conclusion, peach palm fruit can be successfully used for flour production without the necessity of peel removal or pre-treatment by cooking. Indeed, the presence of peel improved the healthy quality of the produced flour by increasing the content of total carotenoids. Furthermore, those flours produced using the fruit without cooking also showed a higher content of carotenoids. Our results also demonstrated that the best drying temperature was 70ºC, being observed the lowest processing time and the higher retention of carotenoids in the flour. Altogether with the high content of carotenoids, the produced flour showed high content of carbohydrate, lipids, dietary fibers and vitamin C, which suggest that the peach palm flour is a product of high nutritional and functional value. In summary, the results evidenced that peach palm flour is a promising healthy food product that can be used for the elaboration of foods with improved nutritional and functional properties, with especial potentiality to be included in gluten free products.

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