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Bioactive, technological-functional potential and morphological structures of passion fruit albedo (*Passiflora edulis*)

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Abstract

Agroindustrial disposal generates tons of passion fruit albedo during pulp and juice processing. The reduction of this environmental pollution potential and its use involves research such as this one, which aims to determine the bioactive compounds in the passion fruit albedo (*Passiflora edulis*), its technological, functional potential and its morphological structures, aiming at food application. The methodologies applied followed internationally accepted and recommended guidelines. The results showed that the albedo flour obtained a yield of 9.76%, and from this, a semifine powder flour was prepared (75.8%), with 4.95% moisture, 40.72% reducing sugars, water activity of 0.37, pH of 5.29, total titratable acidity of 0.99 and total soluble solids of 1.5 °Brix. In addition, the presence of bioactive compounds such as polyphenols (18.88 mg AGE/100 g), flavonoids (13.51 mg/100 g), anthocyanins (1.74 mg/100 g) and chlorophyll b (69.65 mg/100 g) was evidenced, highlighting a considerable amount of vitamin C (377.36 mg/100 g) and pectin concentration (40.5%). In addition, the presence of bioactive compounds such as polyphenols (18.88 mg AGE/100 g), flavonoids (13.51 mg/100 g), anthocyanins (1.74 mg/100 g) and chlorophyll b (69.65 mg/100 g) was evidenced, highlighting a considerable amount of vitamin C (377.36 mg/100 g) and pectin concentration (40.5%).

Keywords: *Passiflora edulis*; albedo; bioactive compounds.

Practical Application: Research with new ingredients applicable to different industrial segments promotes the search for new products and by-products derived from passion fruit albedo (*Passiflora edulis*). This power as high bioactives content and functional terms, which is active in the prevention of cardiovascular diseases, with potential for application in several industrial segments.

1 Introduction

Originating in tropical America, passion fruit belongs to the *Passifloraceae* family and the *Passiflora* genus. It is estimated that this genus is composed of more than 500 species, of which more than 150 are native to Brazil, considered one of the largest centers of diversity. However, only three species are more produced in Brazil and in the world: yellow passion fruit (*Passiflora edulis f.* flavicarpa), purple passion fruit (*Passiflora edulis sims*.) and sweet passion fruit (*Passiflora alata*). Yellow passion fruit, also known as sour or acid passion fruit, is the most cultivated fruit worldwide and is responsible for more than 90% of the production of Brazilian orchards.

The advance in production and processing in the fruit sector in Brazil for the extraction of juices, pulps and oils generates a high surplus of materials, which are considered byproducts. The passion fruit for obtaining pulp produces approximately 54 thousand tons of residues per year, such as seeds and rinds (Albuquerque et al., 2019); however, the increase in consumption increases the generation of residues, which can increase the cost of the adequate destination of the byproducts, in addition to causing negative environmental impacts (Santos et al., 2021).

In this context, research has been carried out to use byproducts (passion fruit peel albedo) as functional ingredients in the processing of bread products associated with cereal flours (corn, wheat and rice) (Nascimento et al., 2020; Maia et al., 2018; Souza et al., 2020a), development of vegetal probiotic beverage of passion fruit (Guedes et al., 2021), development of cookies (Lima et al., 2022), development of biscuit (Weng et al., 2021). The enrichment of these products with passion fruit residue flour in the research by Souza et al. (2020b) showed important minerals (calcium, sodium and potassium) in the bark composition, as well as a viable alternative for application in bakery products intended for consumption by patients with celiac disease.

In addition, passion fruit peel represents 40% to 60% of the fruit's weight and is composed of flavedo and albedo. Flavedo contains large amounts of bioactive compounds, such as flavonoid luteolin and fibers, which have the ability to reduce

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LDL and increase HDL levels, which are important fractions in supporting the treatment of diseases such as diabetes and obesity (Ribeiro et al., 2018a; Santos et al., 2021). The albedo (white part) contains a high content of niacin (vitamin B3), iron, calcium and high content of dietary fiber, mainly pectin (Ribeiro et al., 2018b; Faleiro & Junqueira, 2016; Santos et al., 2021).

Research has been carried out with the use of food products made from the introduction of these byproducts to add positive effects on metabolic parameters (blood glucose control, lipid profiles and antioxidant status of human tissues) (Sousa et al., 2021; Marques et al., 2016; Lima et al., 2016; Panelli et al., 2018). Thus, in view of the above, this research aimed to determine the bioactive compounds, functional-technological potential and morphological albedo structures of passion fruit (*Passiflora edulis*) for food applications.

2 Materials and methods

2.1 Raw material

The passion fruit (*Passiflora edulis*) used in this research was purchased at the Pará Supply Center, located in the metropolitan region of the city of Belém (Pará, Brazil). The sample was transported in low-density polyethylene plastic bags to the Food Science Laboratory of the Federal University of Pará (Belém, Pará, Brazil). All samples were stored at 7 °C until used for analysis.

2.2 Passion fruit albedo flour obtention

Passion fruits were selected, washed in running water, sanitized with sodium hypochlorite solution (20 ppm for 15 min) and washed again to remove excess solution. Then, the albedos were separated, crushed and subjected to the drying process in an air circulation oven (TH-520, Thoth) at 55 °C and an air velocity of 1.0 m/s for 12 h. The flour was obtained by grinding the dehydrated albedo in a knife mill (Start FT 50, Fortinox) for 5 minutes. The sanitized fruits, peel, pulp, albedo and flour obtained were weighed for yield calculation, which was determined by gravimetry.

2.3 Flour granulometric analysis

The granulometry analysis was performed in a magnetic round sieve shaker (VP-01, Bertel, Italy). For the granulometric classification, a set of six sieves with mesh openings of 9 (2.00 mm), 20 (850 µm), 28 (600 µm), 60 (250 µm), 80 (180 µm) and 100 mesh was used. (150 µm) and a base. Then, the contents retained on each sieve were weighed on a semianalytical balance (L303i, Bel, Italy) and expressed as retention percentages. The granulometric classification was performed in duplicate.

2.4 Physico-chemical analysis

The recommended methods of the Association of Official Analytical Chemists (Association of Official Analytical Chemists, 2010) were adopted to determine the moisture content, water activity (a_w), reducing sugars (RS), hydrogenic potential (pH), titratable total acidity (TTA) and total soluble solids (TSS) of fresh albedo and passion fruit albedo flour. The moisture content was determined gravimetrically by sample drying at 105 °C. A_w, pH and TTS were determined by direct measurement on a digital thermohygrometer (neo Series 3TE Novasina, Labmaster–aw), benchtop potentiometer (mPA210, MS Tecnopon) and benchtop digital refractometer (1809001, Guimis), respectively. TTA was determined by the titrimetric method, while the RA content was determined by the Lane-Eynon method. All of the experiments were performed in triplicate.

2.5 Determination of the concentration of bioactive compounds

To determine the concentration of bioactive compounds, an aqueous extract was prepared according to the methodology proposed by Vieira (2011). The extract was prepared in a 1 : 20 ratio (sample: solvent) using distilled water as a solvent, homogenized for 30 min and filtered in a vacuum filtration system.

Flavonoids and anthocyanins

These compounds were determined according to the methodology described by Lees & Francis (1972) with a UV–Vis spectrophotometer (IL-592, KASUAKI) at a wavelength of 374 nm for flavonoids and 535 nm for anthocyanins.

Total polyphenols

The total polyphenol content was determined according to the Folin Ciocalteu assay, as described by Aliakbarian et al. (2011), using a UV–Vis spectrophotometer (IL-592, KASUAKI) at a wavelength of 725 nm. The results were calculated using the standard curve of gallic acid with the equation of the straight line y = 0.0017x (R^2 = 0.9966).

Chlorophylls

Chlorophylls were quantified according to the methodology proposed by Vinha et al. (2014), with readings at wavelengths of 453, 505, 645 and 663 nm in a UV–Vis spectrophotometer (IL-592, KASUAKI). Chlorophyll a and chlorophyll b were calculated using Equations 1 and 2, respectively.

$$\text{Chlorophyll a } (mg/g) = -0{,}999\,A_{663} + 0{,}0989\,A_{645} \quad (1)$$

$$\text{Chlorophyll b } (mg/g) = -0{,}328\,A_{663} + 1{,}77\,A_{645} \quad (2)$$

2.6 Technological functional properties

The main technological functional properties of passion fruit albedo flour were evaluated based on the following analyses: water absorption capacity (WAC): determined by the methods described by Sosulski et al. (1976) and Ramos & Bora (2004, 2005). Water Solubility Index (WSI): determined according to the methodology proposed by Anderson et al. (1970) with adaptations. Oil absorption capacity (OAC): determined by a combination of the methods described by Ramos & Bora (2004, 2005) and Gong et al. (2016). Emulsifying capacity (EMC) and foam stability (FS): determined according to the methods described by Ramos & Bora (2004, 2005) and Coffmann & Garciaj (1977). Gelling property (GP): determination according to the methodology of Lawal & Adebowale (2005).

2.7 Flour morphology

The morphological surface analysis of the partially defatted granules of the *Passion fruit albedo flour* was performed using scanning electron microscopy (SEM). The granules were coated with a 20-nm thick Au/Pd layer for 150 s under an 85-90 µA current using a sputter coater (SC7620; Quorum Technologies Ltd, Ontario, Canada). The electron micrographs were obtained using a scanning electron microscope (model VEGA3; TESCAN USA, Inc., Warrendale, PA).

2.8 Absorption spectroscopy in the infrared region

The absorption spectra were obtained by infrared absorption spectroscopy with Fourier transformation in a spectrometer (IRPrestige-21, Shimadzu, Japan) with records in the absorption spectral frequency range from 4000 to 500 cm^{-1}. Sample incorporation was performed in potassium bromide (KBr) pellets with Scan 100 and resolution 4 cm^{-1}. All bands were analyzed using the Origin 8.0 software program.

3 Results and discussion

3.1 Passion fruit albedo flour yields

The passion fruit albedo flour (PFAF) yield was 9.76% and considered relatively low due to the high albedo moisture content (89.06%) lost during the drying process. This result is superior to that found by Talma et al. (2019) for mature mesocarp flour (4.6%).

In the granulometric analysis, the data show a semifine structure with 47.5% of the mass retained in the 60 mesh sieve and 75.8% between two sieves (60 and 80 mesh) of 250 and 180 µm. Thus, PFAF is classified as a semifine powder, with particles that pass through a sieve with a mesh opening of 355 µm and, at most, 40% through a sieve with a mesh opening of 180 µm, according to the powder classification of the Farmacopeia Brasileira (Agência Nacional de Vigilância Sanitária, 2010).

Regardless of the particle size, it will have technological and functional applicability, as smaller particles allow the formation of a softer texture, that is, less hardness, while larger granules provide an increase in crispness and greater hardness (Souza et al., 2020a). However, this last characteristic can be controlled by homogenizing the size of the particles, as it occurs more in the larger particles that will be less hydrated than the smaller ones, resulting in different degrees of cooking of the product.

3.2 Physicochemical characteristics

The physical-chemical data of fresh passion fruit albedo and its flour prepared in this study are described in Table 1.

The drying process caused the loss of water and, consequently, a reduction in the moisture content (from 89 to 5%) and water activity (from 0.983 to 0.374). A higher value compared to this study was presented by Silva et al. (2019) when evaluating the water activity of the albedo of the same species *in natura* (0.995), but the flour dried at 70 °C of this residue presented a lower value (0.285), confirming that the increase in temperature influences the level of water reduction in this product.

Table 1. Physical-chemical characteristics of fresh passion fruit albedo and its oven-dried flour.

Physical-chemical characteristics	*In natura*	Flour
Water activity (a_w)	0.98 ± ≤ 0.01	0.37 ± ≤ 0.01
Moisture content (%)	89.05 ± 0.90	4.95 ± 0.60
Hydrogen potential (pH)	6.27 ± 0.06	5.29 ± 0.77
Total titratable acidity (% Citric acid)	0.06 ± ≤ 0.01	0.99 ± 0.03
Total soluble solids (°Brix)	0.25 ± ≤ 0.01	1.50 ± ≤ 0.01
Reducing sugars (%)	4.68 ± 0.23	40.72 ± 0.95
Pectin (%)	-	40.50 ± 1.13

According to Silva et al. (2019), the dehydration of passion fruit byproducts is extremely important for their conservation, since most of the water is free and can be used in chemical, enzymatic and microorganism growth reactions. Thus, the drying of the albedo was effective for the production of a low-perishable flour with a longer shelf life, preventing the proliferation of microorganisms in this raw material and thus ensuring against the production of toxins in the albedo pulp (Miranda et al., 2017).

The moisture content of albedo was reduced 18 times compared to fresh albedo (89.05%). This reduction was also reported in the study by Miranda et al. (2017) for the same byproduct of yellow passion fruit with 95.77% moisture, resulting in flour with 4.33% moisture. Considering the dehydrated flours of fruit byproducts in an oven, higher moisture contents were obtained in the albedo of dried yellow passion fruit at 70 °C (5.13%) (Silva et al., 2019), dried orange passion fruit peel at 60 °C (14.56%) (Reis et al., 2018), dried açaí residue at 60 °C (9.06%) (Borges et al., 2021) and dried mango peel at 60 °C (14.14%) (Chagas et al., 2020).

The moisture content in the flour (5%) is within the levels allowed for flour (15%) (m/m) according to current Brazilian legislation (Brasil, 2005). In addition, considering the humidity reached after the drying process, flour is considered a good alternative for the elaboration of food products, as it does not tend to form lumps with other ingredients, which would impair homogenization (Fernandes et al., 2008).

The passion fruit albedo flour had an average pH value of 5.293, characterizing it as a weakly acidic product; however, it retained the neutrality (pH of 6.273) of the albedo *in natura*. Nempeque et al. (2021) obtained inverse pH values for Tahiti lemon peel (4.26) and its flour (9.80) compared to the study. This significant difference provides the flour with greater stability by hindering the development of microorganisms, such as bacteria that generally prefer a pH close to neutrality (6.5-7.0). However, even with this change in pH, the flour is still susceptible to the development of fungi adapted to acidic pH (4.5-5.0) (Abud & Narain, 2010).

Albedo flour showed a total titratable acidity (0.99% citric acid) higher than *in natura* albedo (0.06% citric acid), so the application of heat was able to increase the acidity of the flour. In studies by Miranda et al. (2017) and Coelho et al. (2018), the total titratable acidity was higher than in this study for flour of yellow passion fruit byproducts, such as albedo (1.74 g/100 g of citric acid) and peel (4.65 g/100 g of citric acid). In addition to influencing the rate of microbial growth, depending on the presence and nature of acids in foods (Ribeiro et al., 2018a), pH variations also affect stability, color and flavor and allow the detection of certain acids of a nutritional nature for the body. human, such as citric acid and ascorbic acid (Miranda et al., 2017).

A higher content of total soluble solids was obtained in the flour (1.5 °Brix) compared to the albedo *in natura* (0.25). Machado et al. (2017) found a much higher value in yellow passion fruit peel flour (28.73 °Brix). This difference in values may be related to the degradation of starch by time and temperature applied during the drying process, resulting in soluble molecules, especially sugars.

The flour showed a high percentage of reducing sugars (40.72%) compared to the value found in albedo *in natura* (4.68%). In the study developed by Miranda et al. (2017), the value was much lower (1.52%) than that found in the albedo flour of the same passion fruit species. The higher amount of sugars present in the albedo flour may come from the drying process, since the temperature also has the effect of causing hydrolysis in the reducing sugars.

The passion fruit albedo flour presented good yield and physicochemical characteristics that suggest good quality and conservation of this product according to Brazilian legislation. In addition, the presence of bioactive compounds was evidenced mainly in the flour, such as traces of polyphenols, flavonoids, anthocyanins and chlorophyll b, highlighting a considerable amount of vitamin C. FAM presented fiber bundles in its morphology and relevant concentration of pectin, which are essential for gastrointestinal health. Thus, passion fruit albedo flour presented relevant substances (pectin and bioactive compounds) that combined with healthy habits can prevent and treat various chronic diseases, highlighting cardiovascular diseases.

Furthermore, the processing used in this research was able to produce a flour with different properties, characteristics and aspects that allow its high technological potential in several applications of interest to the food industry. Thus, the use of passion fruit albedo for flour production showed potentially applicable results to human health and the food industry, in addition to enabling a reduction in environmental disposal.

The albedo flour presented 40.5% calcium pectate, a value much higher than the pectin contents in the yellow (37.67%), purple (32.85%) and orange (21.55%) passion fruit peel flours (Reis et al., 2018). Yellow passion fruit dry albedo powder (30.78%) (Inayati et al., 2018) and yellow passion fruit mesocarp flour (26.6%) (Lawal & Adebowale, 2005). The higher pectin content can be explained by the different extraction methods applied, considering in the present research the use of citric acid, while in the comparison studies, tartaric acid, hydrochloric acid (0.02 N) and nitric acid were used, respectively, as well as different times and temperature processes.

Pectin present in flour can have food applications, from traditional as a gelling agent in the preparation of jams, jellies and marmalades, as well as applications to a variety of products including fruit drinks, soft drinks, dairy products, confectionery, and bakery fillings (Picot-Allain et al., 2020), providing these products with a higher content of fibers and bioactive compounds. Pectin has also been used to nanoencapsulate bioactive compounds, thereby increasing their shelf life and stability (Rehman et al., 2019). The consumption of this flour with high levels of pectin can help in the prevention and reduction of diseases, such as gastric ulcers, by protecting the mucous membranes of the gastric wall; diabetes mellitus 2, by reducing fasting blood glucose and glycated hemoglobin; dyslipidemia, by decreasing the level of triglycerides and reducing the absorption of fat and cholesterol (Abboud et al., 2019).

According to Picot-Allain et al. (2020) and Sundarraj & Ranganathan (2017), the quality, physicochemical characteristics and extraction yield of pectin depend on the extraction method used and are influenced by the extraction time, the type of acid, pH, temperature of the medium and even the liquid–solid ratio.

3.3 Concentration of bioactive compounds

A diet is not limited to its nutrient content but also provides other compounds that protect against oxidative stress, such as bioactive compounds, which are mainly found in plant foods such as fruits and their byproducts. Table 2 presents the values of bioactive compounds in fresh passion fruit albedo and in its oven-dried flour.

The content of phenolic compounds was six times higher in the flour (18.88 mg AGE/100 g) than in the in natura albedo (2.99 mg AGE/100 g), which suggests that dehydration caused the concentration of phenolic compounds in the albedo of yellow passion fruit, with the temperature submitted for the elaboration of this product being adequate. Bakar et al. (2018) and Sulaiman et al. (2011) explained that this increase in concentration may be related to the drying process, as the oxidative enzymes and phenolic compounds separate, causing a collapse in the vacuoles and thus increasing the availability of these compounds. In addition, hydrolytic and oxidative enzymes can be denatured by oven drying at 60 °C, allowing the preservation of phenolic compounds.

Phenolic compounds are secondary metabolites produced in fruits and are not evenly distributed in tissues (Miller et al., 2020). In yellow passion fruit, the concentrations in the peel (1061.87 mg AGE/100 g) were much higher than those in the seed (346.69 mg AGE/100 g) (Reis et al., 2018). Different values when compared to our study can be attributed to the analysis method used in our research (spectrophotometry), which differed from the method used by Reis et al. (2018) (high-performance liquid chromatography). In addition, other fruits present higher amounts in their byproducts and flours than in

Table 2. Bioactive compounds from fresh passion fruit albedo and its oven-dried flour.

Bioactive compounds	*In natura*	Flour
Anthocyanins (mg/100 g)	0.08 ± 0.05	1.74 ± 0.01
Flavonoids (mg/100 g)	0.75 ± 0.04	13.51 ± 0.01
Phenolic compounds (mg AGE/100 g)	2.99 ± 0.77	18.88 ± 5.38
Vitamin C (mg/100 g)	94.34 ± 0.0	377.36 ± 0.00
Chlorophyll a (mg/100 g)	1.35 ± 0.001	Nd
Chlorophyll b (mg/100 g)	2.16 ± 0.003	69.65 ± 0.07

ND – Note Detected.

this study, as in the skins melon (364.01 μg g^{-1}) (Miller et al., 2020) and pomelo (241 mg AGE/100 g) (Rodrigues et al., 2021) as well as in the peel flours yellow passion fruit albedo (0.64 mg GAE/g) (López-Vargas et al., 2013), Tanduk banana (54.60 mg GAE/g) (Bakar et al., 2018), and mango (83.72 mg AGE/g) (Chagas et al., 2020).

In the concentration of flavonoids in albedo flour (13.51 mg/100 g), there was an increase of 14% in relation to albedo in natura in relation to albedo in natura (0.75 mg/100 g) after treatment at 55 °C for 24 h. This behavior is already expected due to the loss of moisture, even if part of the compounds is lost during drying by the action of temperature. In research on passion fruit byproducts, flavonoids were present in all parts of different species (Reis et al., 2018), as well as in yellow passion fruit albedo flour (3.18 mg RE/g) (López-Vargas et al., 2013). This lower amount than the flour in our study may be associated with losses in flavonoid content during the process, by the equipment used, during extraction, processing or storage of food, as well as influencing pH, temperature, enzymes and metal ions (Havsteen, 2002).

The anthocyanin content found was low both in fresh passion fruit (0.08 mg/100 g) and in flour (1.74 mg/100 g). This pigment was not detected by Reis et al. (2018) in fruits of the same species, while the purple passion fruit peel revealed a large amount of anthocyanins (103,686.48 mg/100 g) as well as the orange passion fruit pulp, while in the other parts, it showed an insignificant amount of these compounds.

Vitamin C (ascorbic acid) is the most abundant vitamin in citrus fruits, located mainly in the peel, so these fruits are the main natural source of vitamin C. Significant values are also found in other fruit byproducts, as observed in this research. The flour presented a much higher amount (377.36 mg/100 g) than that found in fresh albedo (94.34 mg/100 g). These results were higher compared to the research by Miller et al. (2020) with melon rinds that obtained in the flour (29.3 mg/100 g) content four times higher than that found in the flavedo/albedo (18 mg/100 g). Therefore, the flour had a significant content of vitamin C, and when considering its importance as an essential nutrient for human health, it can be used as an indicator of food quality, with its antioxidant properties and protection of the organism from oxidative stress.

Although flour has low values for some bioactive compounds (anthocyanins and flavonoids) compared to other flours derived from fruit byproducts, it can still have beneficial effects on the health of consumers. Research with another genotype is necessary, as is evaluating effects such as geographic, crop year, maturation and storage conditions. There are some characteristics that can influence the content of phenolic compounds, anthocyanins, flavonoids, carotenoids and other bioactive compounds in all fruits (Cardeñosa et al., 2016).

Chlorophyll is the pigment responsible for flavedo (fruit peel) green color, represented mainly by chlorophyll a and chlorophyll b. The content of this pigment tends to be high during the fruit development period and to decrease with ripening. The mean value of the total amount of chlorophyll a (1.35 mg/100 g) is approximately twice as low as the mean value of chlorophyll b (2.16 mg/100 g) in albedo *in natura*. These values are opposite to those reported in the literature for fruits and vegetables, which are generally found in a 3 : 1 ratio (chlorophyll a:chlorophyll b) (Rodriguez-Jimenez, 2018). In the flour, the chlorophyll b content increased more than thirty times in relation to the *in natura* albedo, while chlorophyll a was not detected. This behaviour in the flour may be associated with the temperature to which this product was subjected to dehydration, since chlorophyll a is thermally more unstable than chlorophyll b (Pareek et al., 2017). In the study by Miller et al. (2020), the melon rind showed higher values than this research. The content of chlorophyll a (57.50 ± 6.27 μg/g) was almost twice as high as that of chlorophyll b (30.36 ± 4.32 μg/g).

3.4 Functional and technological properties of passion fruit albedo flour

Passion fruit albedo flour showed a water absorption capacity (WAC) of 862.4% (8.6 g H_2O/g flour). This result is higher than that verified by Miranda et al. (2017) for passion fruit albedo flour (501.56%), by Oliveira et al. (2016) for purple passion fruit albedo flour (549.84%) and by Chagas et al. (2020) for mango peel flour (717.19%). These differences between albedo flours from the same fruit in different studies may be related to the processes (such as milling, drying, heating or extrusion cooking) to which they were submitted. These processes can modify the physical properties of the fiber matrix, also affecting the hydration properties (Elleuch et al., 2011).

In addition, the high WAC of passion fruit albedo flour is due to the high amount of soluble fiber (common in fruits such as bananas, passion fruit and grapes and their skins), mainly due to the higher pectin content (Table 1). Pectin is a potent hydrocolloid with high porosity and the ability to trap a large amount of water in its structure (Santana et al., 2017). This is a relevant feature, as it can help retain moisture, allowing the addition of more water to the dough and improving material handling, for flour applicability in products such as meat, bakery and confectionery (Silva et al., 2021).

The WSI of yellow passion fruit albedo flour was 12.5%, which is much lower than that obtained by Weng et al. (2021) for yellow (35.09%) and purple (31.73%) passion fruit peel flours. This result indicates that the soluble molecular content of the flour is lower than that of the flours from the peels of both purple and yellow passion fruit. Solubility is a characteristic related to the amount of soluble solids in the dry sample and plays a critical role in the texture, color and sensory and nutritional characteristics of the product (Yuliana et al., 2014).

The passion fruit albedo flour had an average oil absorption capacity (OAC) of 252.7%, which corresponds to 2.53 g oil per g of flour. The value found was lower than the value found in passion fruit peel flour (298%) by Duarte et al. (2017) and higher than that found for mango peel flour (86.47%) studied by Chagas et al. (2020). However, a similar value was found in studies by Miranda et al. (2017) and Borges et al. (2021) for passion fruit albedo flour (262.62%) and açaí residue flour (2.47 g/g), respectively.

Albedo flour presented a considerable OAC, possibly associated with a considerable amount of fiber. Bau et al. (2012) observed that fibers have hydration properties and the ability to retain oil. According to Mozafarpour et al. (2019), a higher ORC can be caused by an increased protein concentration caused by reduced moisture. This concentration forms smaller protein aggregates that improve the functionality of the protein, conferring binding of protein parts of the flour to the oil molecules (Santana et al., 2017).

The elaborated flour absorbs a relevant amount of oil, which acts to retain flavor and enhance the texture of foods (Santana et al., 2017). Thus, flour can be a good flavor retainer and play a role in industrialized foods, such as meat products and emulsified products (cake doughs, mayonnaise or salad dressings, soups and processed cheeses) (Porte et al., 2011).

The passion fruit albedo flour presented an emulsifying capacity (EMC) of 22.87%, and during this analysis, it was possible to verify that the FAMDE retains a large amount of water, providing a smaller amount for the formation of the emulsion. This occurrence may explain the higher value found in yellow passion fruit peel flour (35.56%) (Sohaimy et al., 2018) and defatted castanets almond flour (30.50%) (Santos et al., 2020).

The EMC and emulsion stability (ES) are properties dependent on the proteins (quality and solubility) present in the studied food. According to Shi et al. (2022), EMC and ES are determined by the ability of proteins to undergo changes in their composition and rearrangement at the air-water interface, causing the formation of a cohesive viscoelastic film by intermolecular interactions. For Damoraran & Parkin (2010), a concentration of 2 to 8% of proteins is required to form foams. However, the concentration of protein alone is not enough to form foams, as other factors can compromise these results, such as pH, temperature, particle size, and oil-to-protein ratio.

The flour produced in this research was not able to foam in a significant volume (0.068%), and consequently, it was not possible to evaluate the foam stability. Similar behavior was observed by Chagas et al. (2020) in mango peel flour. In the studies of Santana et al. (2017) and Santos et al. (2020), good foaming was observed in passion fruit peel flour (35.56%) and in defatted castanets almond flour (52.3%), respectively. This result suggests the impossibility of using passion fruit albedo flour as an ingredient in food products, such as sparkling drinks, ice cream, meringues and mice (Silva et al., 2021).

Gelation is an extremely important functional property in the application of a particular ingredient in food production. This occurrence results in the formation of a three-dimensional network of carbohydrates modified or not by thermal processes, together with partially denatured protein and lipid molecules (Adebowale & Lawal, 2003). The results of the qualitative test for the gelling capacity of the oven-dried yellow passion fruit albedo flour are shown in Figure 1.

Figure 1 shows the formation of a fragile gel in the presence of 12% flour and a resistant gel at a concentration of 14%. Therefore, this is the minimum concentration necessary to be used in the manufacture of products that depend on the formation of gel.

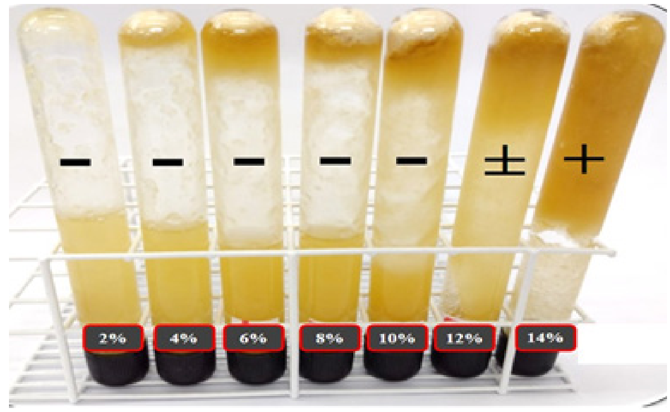

Figure 1. Qualitative test for the gelling capacity of oven-dried yellow passion fruit albedo flour ([-] indicates no gel formation, water and material flow occurs; [±] indicates weak gel formation, viscous material flow occurs; [+] indicates gel formation, material flow does not occur).

Santana et al. (2017) found a fragile gel at concentrations of 14 to 20% for commercial passion fruit flour. On the other hand, oat and white wheat flours showed good gel formation capacity at low concentrations, which demonstrates that these flours can be used in the formulation of porridges, creams and sauces.

3.5 Morphology of passion fruit albedo flour

Scanning electron microscopy (SEM) is an instrument used to detect the surface phenomena of solid materials. The results provide information on morphology, including shape and size. The micrographs shown in Figures 2a-2b reveal the structure of the passion fruit albedo flour granules. The structural morphology of the flour (Figure 2a) reveals the presence of residual structures from the processes of grinding, drying and releasing the lipid portion, resulting in a material that looks like fibrous bundles. In general, processing was responsible for creating amorphous and fibrous structures in which it is not possible to clearly distinguish other structures in the sample.

In Figure 2b, the preservation of structuring plant parenchyma is observed, keeping the fibrillar networks in their natural state. The plant cell wall constituents with elongated structures and thin thickness perceived in micrographs are related to dietary fibers (Costa, 2004). The flour has a high content of dietary fiber; therefore, this suggests that the structures observed in the micrographs are characteristic of the existing fibers.

The structural conformations shown in these micrographs can be related to some aspects that guided the responses obtained in the functional technological potential of flour, such as CAA, CAO and gelling capacity. Miranda et al. (2017) visualized the surface of passion fruit albedo flour, with a fibrous structure in the form of overlapping cross-linked material bundles and a compacted membrane. Thus, the observed behavior confirmed that the high fiber contents potentiated the technological applications of the studied flour in CAA and CAO.

The application of SEM and the functional and technological properties made it possible to determine the structure and its respective functions. In addition, this knowledge allows a glimpse of

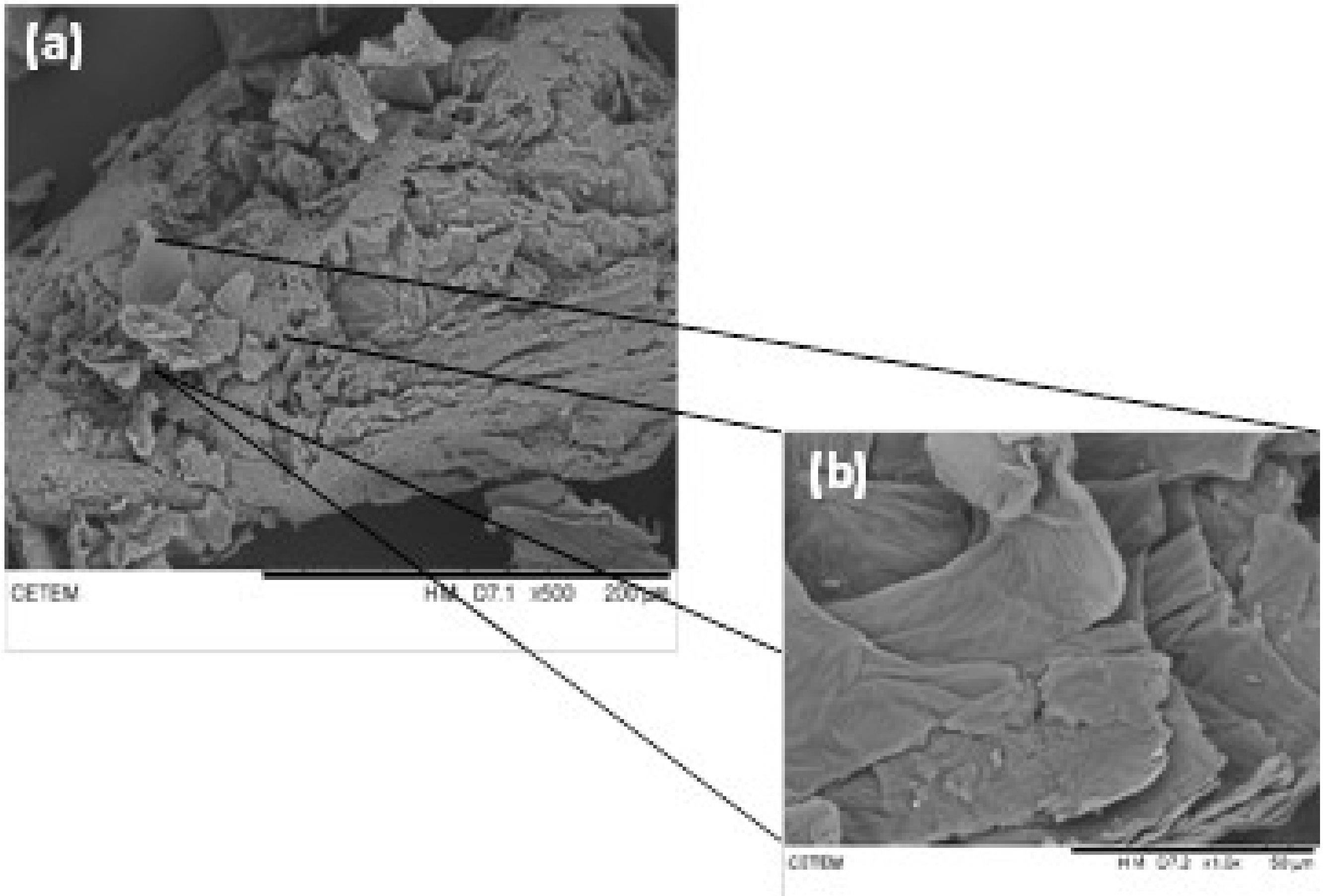

Figure 2. Micrographs of the surface structure of yellow passion fruit albedo flour. (a) Overview of structures and (b) highlighted view of fibers.

its application possibilities in the various food industrial segments with greater efficiency, time and cost reduction. Furthermore, the nutritional and functional importance associated with pectin yield highlights the quantitative emphasis on fibers, one of the most important aids in the prevention of cardiovascular diseases, acting on cholesterol metabolism among other functions, which make it a functional ingredient.

3.6 Absorption spectroscopy in the infrared region

Other data of considerable relevance are the chemical groups present in this raw material. Figure 3 shows the Fourier transform infrared spectroscopy of passion fruit albedo flour.

The greatest highlight is located in the spectral peak in the range of 3350 cm^{-1}, which is characteristic of hydrogen bonds with the presence of OH compounds of hydroxyl groups frequent in D-glucose units, a reducing sugar of great energetic importance in human food (Valencia et al., 2015; Melo et al., 2015). This fact confirms the high levels found in this flour, as shown in Table 2.

A frequency range of approximately 1637 cm^{-1} to 1055 cm^{-1} is present, which is characteristic of carbonyl functional groups (C=O), methyl esters, ketones, frequent aldehydes in long-chain fatty acids and elongation (NH) of amide groups present in proteins (Araujo et al., 2021; Martinez et al., 2021).

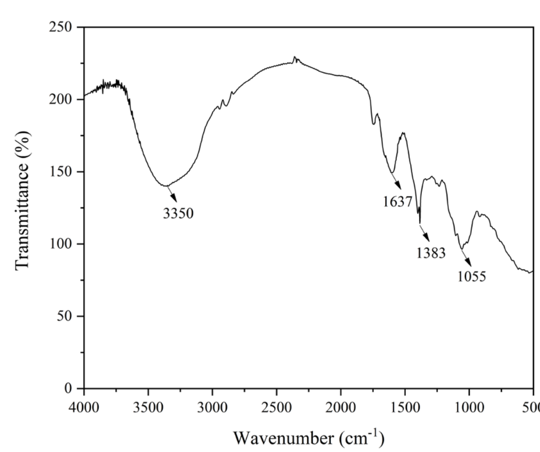

Figure 3. Fourier transform infrared spectroscopy of passion fruit albedo flour.

4 Conclusions

The passion fruit albedo flour presented good yield and physicochemical characteristics that suggest good quality and conservation of this product according to Brazilian legislation.

In addition, the presence of bioactive compounds was evidenced mainly in the flour, such as traces of polyphenols, flavonoids, anthocyanins and chlorophyll b, highlighting a considerable amount of vitamin C. The flour presented fiber bundles in its morphology and relevant concentration of pectin, which are essential for gastrointestinal health. Thus, passion fruit albedo flour presented relevant substances (pectin and bioactive compounds) that combined with healthy habits can prevent and treat various chronic diseases, highlighting cardiovascular diseases.

Furthermore, the processing used in this research was able to produce flour with different properties, characteristics and aspects that allow its high technological potential in several applications of interest to the food industry. Thus, the use of passion fruit albedo for flour production showed potentially applicable results to human health and the food industry, in addition to enabling a reduction in environmental disposal.

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References

Abboud, K. Y., Luz, B. B., Dallazen, J. L., Werner, M. F. P., Cazarin, C. B. B., Maróstica, M. R. Jr., Iacomini, M., & Cordeiro, L. M. C. (2019). Gastroprotective effect of soluble dietary fibers from yellow passion fruit (*Passiflora edulis* f. *flavicarpa*) peel against ethanol-induced ulcer in rats. *Journal of Functional Foods*, 54, 552-558. http://dx.doi.org/10.1016/j.jff.2019.02.003.

Abud, A. K. S., & Narain, N. (2010). Incorporação da farinha de resíduo do processamento de polpa de fruta em biscoitos: uma alternativa de combate ao desperdício. *Brazilian Journal of Food Technology*, 12(4), 257-265. http://dx.doi.org/10.4260/BJFT2009800900020.

Adebowale, K. O., & Lawal, O. S. (2003). Foaming, gelation and electrophoretic characteristics of mucuna bean (*Mucuna pruriens*) protein concentrates. *Food Chemistry*, 83(2), 237-246. http://dx.doi.org/10.1016/S0308-8146(03)00086-4.

Agência Nacional de Vigilância Sanitária – ANVISA. (2010). *Farmacopeia brasileira* (5th ed., Vol. 1). Brasília: ANVISA.

Albuquerque, M. A. C., Levit, R., Beres, C., Bedani, R., LeBlanc, A. M., Saad, S. M. I., & LeBlanc, J. G. (2019). Tropical fruit byproducts water extracts as sources of soluble fibers and phenolic compounds with potential antioxidant, anti-inflammatory, and functional properties. *Journal of Functional Foods*, 52, 724-733. http://dx.doi.org/10.1016/j.jff.2018.12.002.

Aliakbarian, B., Casazza, A. A., & Perego, P. (2011). Valorization of olive oil solid waste using high pressure-high temperature reactor. *Food Chemistry*, 128(3), 704-710. http://dx.doi.org/10.1016/j.foodchem.2011.03.092.

Anderson, R. A., Conway, H. F., & Peplinski, A. J. (1970). Gelatinization of corn grits by roll cooking, extrusion cooking and steaming. *Stärke*, 22(4), 130-135. http://dx.doi.org/10.1002/star.19700220408.

Araujo, N. M. P., Arruda, H. S., Marques, D. R. P., Oliveira, W. Q., Pereira, G. A., & Pastore, G. M. (2021). Functional and nutritional properties of selected Amazon fruits: a review. *Food Research International*, 147, 110520. http://dx.doi.org/10.1016/j.foodres.2021.110520. PMid:34399498.

Association of Official Analytical Chemists – AOAC. (2010). *Official methods of analysis of the Association of Official Analytical Chemistry* (18th ed.). Washington DC: AOAC.

Bakar, S. K. S. A., Ahmad, N., & Jailani, F. (2018). Chemical and functional properties of local banana peel flour. *Journal of Food and Nutrition Research*, 26(8), 492-496.

Bau, T. R., Silva, L. C., Garcia, S., & Ida, E. I. (2012). Propriedades funcionais tecnológicas das fibras de soja, aveia e trigo e produtos de soja com adição de fibras e fermentados com cultura de kefir. *Semina: Ciências Agrárias*, 33(Suppl. 2), 3093-3102. http://dx.doi.org/10.5433/1679-0359.2012v33Supl2p3093.

Borges, M. V., Sousa, E. B., Silveira, M. F. A., Souza, A. R. M., Alves, V. M., Nunes, L. B. M., & Barros, S. K. A. (2021). Propriedades físico-químicas e tecnológicas da farinha do resíduo de açaí e sua utilização. *Research, Society and Development*, 10(5), e17810514517. http://dx.doi.org/10.33448/rsd-v10i5.14517.

Brasil, Ministério da Saúde, Agência Nacional de Vigilância Sanitária – ANVISA. (2005, September 23). Regulamento técnico para produtos de cereais, amidos, farinhas e farelos (Resolução-RDC n° 263, de 22 de setembro de 2005). *Diário Oficial da República Federativa do Brasil*, seção 1.

Cardeñosa, V., Girones-Vilaplana, A., Muriel, J. L., Moreno, D. A., & Moreno-Rojas, J. M. (2016). Influence of genotype, cultivation system and irrigation regime on antioxidant capacity and selected phenolics of blueberries (Vaccinium corymbosum L.). *Food Chemistry*, 202, 276-283. http://dx.doi.org/10.1016/j.foodchem.2016.01.118. PMid:26920295.

Chagas, E. G. L., Garcia, V. A. S., Silva, L. C. B., Vanin, F. M., & Carvalho, R. A. (2020). Farinha de casca de manga: propriedades tecnológicas e perfil de compostos fenólicos. In C. A. M. Cordeiro (Ed.), *Tecnologia de alimentos: tópicos físicos, químicos e biológicos* (Vol. 2, pp. 360-379). Guarujá: Editora Científica Digital. http://dx.doi.org/10.37885/200800935.

Coelho, E. M., Azevêdo, L. C., Viana, A. C., Ramos, I. G., Gomes, R. G., Lima, M. S., & Umsza-Guez, M. A. (2018). Physico-chemical properties, rheology and degree of esterification of passion fruit (Passiflora edulisf.flavicarpa) peel flour. *Journal of the Science of Food and Agriculture*, 98(1), 166-173. http://dx.doi.org/10.1002/jsfa.8451. PMid:28556245.

Coffmann, C. W., & Garciaj, V. V. (1977). Functional properties and amino acid content of a protein isolate from mung bean flour. *International Journal of Food Science & Technology*, 12(5), 473-484. http://dx.doi.org/10.1111/j.1365-2621.1977.tb00132.x.

Costa, L. A. (2004). *Caracterização do resíduo da fabricação de farinha de mandioca e seu aproveitamento no desenvolvimento de alimento em barra* (Master's thesis). Universidade Federal de Santa Catarina, Florianópolis.

Damodaran, S., & Parkin, K. L. (2010). *Química de alimentos de Fennema* (5th ed.). Porto Alegre: Artmed.

Duarte, Y., Chaux, A., Lopez, N., Largo, E., Ramírez, C., Nuñez, H., Simpson, R., & Vega, O. (2017). Effects of Blanching and Hot Air Drying Conditions on the Physicochemical and Technological Properties of Yellow Passion Fruit (Passiflora edulis Var. Flavicarpa) by-Products. *Journal of Food Process Engineering*, 40(3), 158-164. https://doi.org/10.1111/jfpe.12425.

Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: characterization, technological functionality and commercial applications: a review. *Food Chemistry*, 124(2), 411-421. http://dx.doi.org/10.1016/j.foodchem.2010.06.077.

Faleiro, F. G., & Junqueira, N. T. V. (2016). *Maracujá: o produtor pergunta, a Embrapa responde*. (500 perguntas, 500 respostas). Brasília: Embrapa.

Fernandes, A. F., Pereira, J., Germani, R., & Oiano, J. No. (2008). Efeito da substituição parcial da farinha de trigo por farinha de casca de batata (Solanum Tuberosum Lineu). *Food Science and Technology*, 28, 56-65. http://dx.doi.org/10.1590/S0101-20612008000500010.

Gong, K.-J., Shi, A.-M., Liu, H.-Z., Liu, L., Hu, H., Adhikari, B., & Wang, Q. (2016). Emulsifying properties and structure changes of spray and freeze-dried peanut protein isolate. *Journal of Food Engineering*, 170, 33-40. http://dx.doi.org/10.1016/j.jfoodeng.2015.09.011.

Guedes, C. K. R. M., Guedes, A. F. L. M., Silva, J. R., Silva, E. B. B., Santos, E. C. M., Stamford, T. C. M., & Stamford, T. L. M. (2021). Development of vegetal probiotic beverage of passion fruit (*Passiflora edulis Sims*), yam (*Dioscorea cayenensis*) and *Lacticaseibacillus casei*. *Food Science and Technology*, 41(Suppl. 2), 619-626. http://dx.doi.org/10.1590/fst.66120.

Havsteen, B. H. (2002). The biochemistry and medical significance of the flavonoids. *Pharmacology & Therapeutics*, 96(2-3), 67-202. http://dx.doi.org/10.1016/S0163-7258(02)00298-X. PMid:12453566.

Inayati, Puspita, R. I., & Fajrin, V. L. (2018). Extraction of pectin from passion fruit rind (*Passiflora edulis var. flavicarpa Degener*) for edible coating. *AIP Conference Proceedings*, 1931, 030002. http://dx.doi.org/10.1063/1.5024061.

Lawal, O. S., & Adebowale, K. O. (2005). Physicochemical characteristics and thermal properties of chemically modified jack bean (*Canavalia ensiformis*) starch. *Carbohydrate Polymers*, 60(3), 331-341. http://dx.doi.org/10.1016/j.carbpol.2005.01.011.

Lees, D. H., & Francis, F. J. (1972). Standardization of pigment analyses in cranberries. *HortScience*, 7(1), 83-84.

Lima, E. R., Matos, T. B., Sousa, T. R., Pereira, I. O., Pereira, R., Paula, S. A., & Milagres, M. P. (2022). Development and characterization of cookies using passion fruit from the caatinga (*Passiflora cincinnata* Mast.). *Food Science and Technology*, 42, e56220. http://dx.doi.org/10.1590/fst.56220.

Lima, G. C., Vuolo, M. M., Batista, Â., Dragano, N. R. V., Solon, C., & Maróstica, M. R. Jr. (2016). *Passiflora edulis* peel intake improves insulin sensitivity, increasing incretins and hypothalamic satietogenic neuropeptide in rats on a high-fat diet. *Nutrition*, 32(7-8), 863-870. http://dx.doi.org/10.1016/j.nut.2016.01.014. PMid:27138107.

López-Vargas, J. H., Fernández-López, J., Pérez-Álvarez, J. A., & Viuda-Martos, M. (2013). Chemical, physico-chemical, technological, antibacterial and antioxidant properties of dietary fiber powder obtained from yellow passion fruit (Passiflora edulis var. flavicarpa) coproducts. *Food Research International*, 51(2), 756-763. http://dx.doi.org/10.1016/j.foodres.2013.01.055.

Machado, A. V., Barbosa, L. S., Souza, J. A., Medeiros, A. C., Almeida, J. C., Silva, E. V., Ugulino, A. L. N., Alexandre, F. B. A., & Maracajá, P. B. (2017). Convective drying and physicochemical evaluation of passion fruit peel flour. *International Journal of Development Research*, 7(11), 11242.

Maia, S. M. P. C., Pontes, D. F., Garruti, D. D. S., Oliveira, M. N., Arcanjo, S. R. S., & Chinelate, G. C. B. (2018). Farinha de maracujá na elaboração de bolo de milho. *Revista Verde de Agroecologia e Desenvolvimento Sustentável*, 13(3), 328-336. http://dx.doi.org/10.18378/rvads.v13i3.5678.

Marques, S. S. F., Libonati, R., Sabaa-Srur, A. U. O., Luo, R., Shejwalkar, P., Hara, K., Dobbs, T., & Smith, R. E. (2016). Evaluation of the effects of passion fruit peel flour (*Passiflora edulis* fo. *flavicarpa*) on metabolic changes in HIV patients with lipodystrophy syndrome secondary to antiretroviral therapy. *Revista Brasileira de Farmacognosia*, 26(4), 420-426. http://dx.doi.org/10.1016/j.bjp.2016.03.002.

Martinez, J. M., Moreno-Caicedo, L. P., & Loaiza-Loaiza, A. O. (2021). Dimensiones sensoriales del chontaduro (*Bactris gasipaes*) e implicaciones para su futura investigación genética. *Scientific Article*, 32, 77-92.

Melo, B. A. No., Barbosa, A. A., Leite, C. X. S., Almeida, P. F., Bonomo, R. C. F., & Pontes, K. V. (2015). Chemical composition and functional properties of starch extracted from the pejibaye fruit (*Bactris Gasepaes* Kunth.). *Acta Scientiarum. Technology*, 37(1), 105-110. http://dx.doi.org/10.4025/actascitechnol.v37i1.20740.

Miller, F. A., Fundo, J. F., Garcia, E., Santos, J. R., Silva, C. L. M., & Brandão, T. R. S. (2020). Physicochemical and bioactive characterization of edible and waste parts of "piel de sapo" melon. *Horticulturae*, 6(60), 4-10.

Miranda, L. R., Souza, A. L. G., Silva, G. C. T., & Santos, O. V. (2017). Aplicação da microscopia eletrônica de varredura aos grânulos do albedo de maracujá: qualidade nutricional-funcional e potencial tecnológico. *Revista Brasileira de Produtos Agroindustriais*, 19(2), 217-230.

Mozafarpour, R., Koocheki, A., Milani, E., & Varidi, M. (2019). Extruded soy protein as a novel emulsifier: structure, interfacial activity and emulsifying property. *Food Hydrocolloids*, 93, 361-373. http://dx.doi.org/10.1016/j.foodhyd.2019.02.036.

Nascimento, N. C., Medeiros, H. I. R., Pereira, I. C., Oliveira, R. E. S., Medeiros, I. L., & Medeiros, F. C. Jr. (2020). Elaboração de biscoito com a farinha da casca do maracujá (*Passiflora edulis*). *Research, Society and Development*, 9(7), e501974333. http://dx.doi.org/10.33448/rsd-v9i7.4333.

Nempeque, L. V. J., Cabrera, Á. P. G., & Moncayo, J. Y. C. (2021). Evaluation of Tahiti lemon shell flour (Citrus latifolia Tanaka) as a fat mimetic. *Journal of Food Science and Technology*, 58(2), 720-730. http://dx.doi.org/10.1007/s13197-020-04588-y. PMid:33568866.

Oliveira, D. A., Angonese, M., Gomes, C., & Ferreira, S. R. S. (2016). Valorization of passion fruit (Passiflora edulis sp.) by-products: Sustainable recovery and biological activities. *The Journal of Supercritical Fluids*, 111, 55-62. https://doi.org/10.1016/j.supflu.2016.01.010.

Panelli, M. F., Pierine, D. T., Souza, S. L. B., Ferron, A. J. T., Garcia, J. L., Santos, K. C., Belin, M. A. F., Lima, G. P. P., Borguini, M. G., & Minatel, I. O. (2018). Bark of Passiflora edulis treatment stimulates antioxidant capacity, and reduces dyslipidemia and body fat in db/db mice. *Antioxidants*, 7(9), 120. http://dx.doi.org/10.3390/antiox7090120. PMid:30205562.

Pareek, S., Sagar, N. A., Sharma, S., Kumar, V., Agarwal, T., González-Aguilar, G. A., & Yahia, E. M. (2017). Chlorophylls: chemistry and biological functions. In E. M. Yahia (Ed.), *Fruit and vegetable phytochemicals: chemistry and human health* (Vol. 1, pp. 269-284). New York: John Wiley & Sons. http://dx.doi.org/10.1002/9781119158042.ch14.

Picot-Allain, M. C. N., Ramasawmy, B., & Emmambux, M. N. (2020). Extraction, characterization, and application of pectin from tropical and sub-tropical fruits: a review. *Food Reviews International*, 4, 1-31.

Porte, A., Silva, E. F., Almeida, V. D. S., Silva, T. X., & Porte, L. H. M. (2011). Propriedades funcionais tecnológicas das farinhas de sementes de mamão (carica papaya) e de abóbora (Cucurbita sp). *Revista Brasileira de Produtos Agroindustriais*, 13(1), 91-96. http://dx.doi.org/10.15871/1517-8595/rbpa.v13n1p91-96.

Ramos, C. M. P., & Bora, P. S. (2004). Functional characterization of acetylated Brazil nut (*Bertholletia excelsa* HBK) kernel globulin. *Food Science and Technology*, 24(1), 134-138. http://dx.doi.org/10.1590/S0101-20612004000100024.

Ramos, C. M. P., & Bora, P. S. (2005). Functionality of succinylated Brazil nut (*Bertholletia excelsa* HBK) kernel globulin. *Plant Foods for Human Nutrition*, 60(1), 1-6. http://dx.doi.org/10.1007/s11130-005-2533-0. PMid:15898352.

Rehman, A., Ahmad, T., Aadil, R. M., Spotti, M. J., Bakry, A. M., Khan, I. M., Zhao, L., Riaz, T., & Tong, Q. (2019). Pectin polymers as wall materials for the nanoencapsulation of bioactive compounds. *Trends in Food Science & Technology*, 90, 35-46. http://dx.doi.org/10.1016/j.tifs.2019.05.015.

Reis, L. C. R., Facco, E. M. P., Salvador, M., Flôres, S. H., & Rios, A. O. (2018). Antioxidant potential and physicochemical characterization of yellow, purple and orange passion fruit. *Journal of Food Science and Technology*, 55(7), 2679-2691. http://dx.doi.org/10.1007/s13197-018-3190-2. PMid:30042584.

Ribeiro, B. D., Pereira, K. S., Nascimento, R. P., & Coelho, M. A. Z. (2018a). *Microbiologia industrial*. Rio de Janeiro: Elsevier.

Ribeiro, T. H. S., Bolanho, B. C., Montanuci, F. D., & Ruiz, S. P. (2018b). Physicochemical and sensory characterization of gluten-free fresh pasta with addition of passion fruit peel flour. *Ciência Rural*, 48(12), e20180508. http://dx.doi.org/10.1590/0103-8478cr20180508.

Rodrigues, D. O. B., Guimarães, R. C. A., & Bogo, D. (2021). Extração de compostos bioativos do flavedo/albedo e da farinha do pomelo submetida a diferentes processamentos. *Multitemas*, 30, 117-131. http://dx.doi.org/10.20435/multi.v25i61.1937.

Rodriguez-Amaya, D. B. (2016). Natural food pigments and colorants. *Current Opinion in Food Science*, 7, 20-26. http://dx.doi.org/10.1016/j.cofs.2015.08.004.

Rodriguez-Jimenez, J. R., Amaya-Guerra, C., Baez-Gonzalez, J., Aguilera-Gonzalez, C., Urias-Orona, V., & Nino-Medina, G. (2018). Physicochemical, functional, and nutraceutical properties of eggplant flours obtained by different drying methods. *Molecules*, 23(12), 3210. http://dx.doi.org/10.3390/molecules23123210. PMid:30563127.

Santana, G. S., Oliveira, J. G. Fo., & Egea, M. B. (2017). Características tecnológicas de farinhas vegetais comerciais. *Revista de Agricultura Neotropical*, 4(2), 88-95. http://dx.doi.org/10.32404/rean.v4i2.1549.

Santos, E. N., Santos, E. N., Medeiros, I. F., Feitoza, J. V. F., Vieira, F. J. A., & Dantas, T. N. P. (2020). Propriedades funcionais da farinha desengordurada da amêndoa da castanhola. *Revista Brasileira de Gestão Ambiental*, 14(1), 1-5.

Santos, O. V., Vieira, E. L. S., Soares, S. D., Conceição, L. R. V., Nascimento, F. C. A., & Teixeira-Costa, B. E. (2021). Utilization of agroindustrial residue from passion fruit (*Passiflora edulis*) seeds as a source of fatty acids and bioactive substances. *Food Science and Technology*, 41(Suppl. 1), 218-225. http://dx.doi.org/10.1590/fst.16220.

Shi, L., Ma, H., Zhao, H., Ma, M., Wang, J., Kong, R., Li, Z., Ma, R., Wang, J. H., Wu, S., Dong, M. Q., & Li, Z. (2022). The endoplasmic reticulum membrane protein complex (EMC) negatively regulates intestinal homeostasis through the Hippo signaling pathway. *bioRxiv preprint*. https://doi.org/10.1101/2022.01.25.477727.

Silva, E. C. O., Silva, W. P., Gomes, J. P., Silva, C. D. P. S., Souto, L. M., & Costa, Z. R. T. (2019). Physico-chemical characteristics of passion fruit flour under removal of flavedo and of maceration. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 23(11), 869-875. http://dx.doi.org/10.1590/1807-1929/agriambi.v23n11p869-875.

Silva, F. C., Silva, F. E. S. No., Silva, M. M., Souza, B. D. A., Araújo, D. S., Souza, L. C., Lemos, T. O., Pereira, A., & Abreu, V. (2021). Propriedades físico-químicas e funcionais tecnológicas da farinha de *Talinum paniculatum* para aplicações alimentares. *Revista Geintec-Gestão, Inovacão e Tecnologias*, 11(1), 5849-5864.

Sohaimy, S., Mohamed, S., Shehata, M., Mehany, T., & Zaitoun, M. (2018). Compositional analysis and functional characteristics of quinoa flour. *Annual Research & Review in Biology*, 22(1), 1-11. http://dx.doi.org/10.9734/ARRB/2018/38435.

Sosulski, F., Humbert, E. S., Bui, K., & Jones, J. D. (1976). Functional properties of rapeseed flours, concentrates and isolate. *Journal of Food Science*, 41(6), 1349-1352. http://dx.doi.org/10.1111/j.1365-2621.1976.tb01168.x.

Sousa, D. F., Araújo, M. F. M., Mello, V. D., Damasceno, M. M. C., & Freitas, R. W. J. F. (2021). Cost-effectiveness of passion fruit albedo versus turmeric in the glycemic and lipaemic control of people with type 2 diabetes: randomized clinical trial. *Journal of the American College of Nutrition*, 40(8), 679-688. http://dx.doi.org/10.1080/07315724.2020.1823909. PMid:33141635.

Souza, V. F., Ascheri, J. L. R., Oliveira, N. G. M., Oliveira, A. C. S., & Ferreira, R. H. A. (2020a). Efeito da granulometria na expansão de extrusados de cascas e albedo de maracujá (*Passiflora edulis flavicarpa* Degener) e arroz (*Oryza sativa* L.). *Brazilian Journal of Development*, 6(7), 43214-43228. http://dx.doi.org/10.34117/bjdv6n7-076.

Souza, V. F., Oliveira, N. G. M., Ferreira, R. H. A., Oliveira, A. A. N., & Ascheri, J. L. R. (2020b, September 25-27). Perfil sensorial e avaliação física de cookies com farinha mista extrudada de cascas e albedo de maracujá e arroz. In Universidade Federal do Agreste de Pernambuco (Ed.), *I Congresso Internacional da Agroindústria* (pp. 1-18). Garanhuns, Brazil: Editora IIDV.

Sulaiman, S. F., Yusoff, N. A., Eldeen, I. M., Seow, E. M., Sajak, A. A. B., Supriatno, & Ooi, K. L. (2011). Correlation between total phenolic and mineral contents with antioxidant activity of eight Malaysian bananas (Musa sp.). *Journal of Food Composition and Analysis*, 24(1), 1-10. http://dx.doi.org/10.1016/j.jfca.2010.04.005.

Sundarraj, A., & Ranganathan, T. A. (2017). Review-pectin from agro and industrial waste. *International Journal of Applied Environmental Sciences.*, 12(10), 1777-1801.

Talma, S. V., Regis, S. A., Ferreira, P. R., Mellinger-Silva, C., & Resende, E. D. (2019). Characterization of pericarp fractions of yellow passion fruit: density, yield of flour, color, pectin content and degree of esterification. *Food Science and Technology*, 39(Suppl. 2), 683-689. http://dx.doi.org/10.1590/fst.30818.

Valencia, G. A., Moraes, I. C. F., Lourenço, R. V., Bittante, A. M. Q. B., & Sobral, P. J. D. A. (2015). Physicochemical, morphological, and functional properties of flour and starch from peach palm (*Bactris Gasipaes* K.) fruit. *Stärke*, 67(1-2), 163-173. http://dx.doi.org/10.1002/star.201400097.

Vieira, L. M. (2011). *Caracterização química e capacidade antioxidante in vitro do coco babaçu (Orbignya speciosa)* (Master's thesis). Universidade Federal do Piauí, Teresina.

Vinha, A. F., Alves, R. C., Barreira, S. V. P., Castro, A., Costa, A. S. G., & Oliveira, M. B. P. P. (2014). Effect of peel and seed removal on the nutritional value and antioxidant activity of tomato (*Lycopersicon esculentum* L.) fruits. *Lebensmittel-Wissenschaft + Technologie*, 55(1), 197-202. http://dx.doi.org/10.1016/j.lwt.2013.07.016.

Weng, M., Li, Y., Wu, L., Zheng, H., Lai, P., Tang, B., & Luo, X. (2021). Effects of passion fruit peel flour as a dietary fiber resource on biscuit quality. *Food Science and Technology*, 41(1), 65-73. http://dx.doi.org/10.1590/fst.33419.

Yuliana, M., Truong, C. T., Huynh, L. H., Ho, Q. P., & Ju, Y.-H. (2014). Isolation and characterization of protein isolated from defatted cashew nut shell: influence of pH and NaCl on solubility and functional properties. *Lebensmittel-Wissenschaft + Technologie*, 55(2), 621-626. http://dx.doi.org/10.1016/j.lwt.2013.10.022.