Characterization of flours made from peach palm (*Bactris gasipaes* Kunth) by-products as a new food ingredient

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Summary

Flours production from unused parts of peach palm rods harvested for heart-of-palm is an alternative to add value to the canning industry. The aim of this work was to evaluate the composition, physicochemical and antioxidant properties, as well as water sorption isotherms of flours produced from median sheath (MSF) and unused stem part (SF) of peach palm. The main component of the flours was dietary fibre, especially insoluble fibre. SF had higher content of ashes (50.61 $g\cdot kg^{-1}$), proteins (98.40 $g\cdot kg^{-1}$), lipids (23.22 $g\cdot kg^{-1}$) and saccharides (157.07 $g\cdot kg^{-1}$) than MSF. There was higher carotenoid content in MSF and higher content of phenolic compounds in SF. This flour also had the highest antioxidant activity as measured by ABTS, DPPH and FRAP methods. SF standed out due to the physicochemical properties: water solubility, water absorption, swelling and viscosity. The isotherm indicated that MSF was more hygroscopic than SF for relative humidity of equilibrium lower than 50% and the contrary is valid for values higher than 50% with final moisture content of 268 $g\cdot kg^{-1}$ and 325 $g\cdot kg^{-1}$ of water, respectively.

Keywords

chemical composition; flour; dietary fibre; minerals; antioxidant activity; physicochemical properties

The peach palm (*Bactris gasipaes* Kunth) is a multistemmed Amazonian tropical palm that has economic potential related to its fruits and heart-of-palm production. The heart-of-palm (locally known as palmito) is appreciated by many consumers and can be obtained from various species of palms. Among the cultivated palms, peach palm, known in Brazil as pupunha, stands out as an alternative crop for heart-of-palm production. Currently, the sustainable production is increasing due to the depletion of extractive material, intense supervision of the remaining plants in nature and the high value of the product. This palm has all the desirable characteristics when compared to those of predatory exploitation and advantages such as rapid growth, early maturity for cutting (2 years) and growth of stems from offshoots [1].

The palm stem has three layers (sheaths): external, middle and heart-of-palm. The outer layer that surrounds the palm stem is fibrous, of green or brown colour, while the second layer called median or semi-sheath is lighter in colour. The central core, known as heart-of-palm, is attached to a slightly more fibrous cylindrical base with a larger diameter (both are edible; Fig. 1).

The heart-of-palm is the main product of peach palm and its harvest generates a large volume of waste from unused parts such as sheaths (external and median) and a stem part, which is cut together with the heart-of-palm but not used for canning because of its toughness. These by-products of peach palm represent approximately 84% of the harvested plant weight. To minimize the impact of the discarded parts of the peach palm in the environment, an alternative is to produce flours from the median sheaths and the unused stem part. By-products, obtained specially from fruit and vegetable processing, are gaining attention as novel and economic sources of healthy functional ingredients. They can be used in products that contain value-added materials, such as dietary fibre or bioactive compounds. The production of such ingredients and their addition to foods may be costly for the producer but may have a positive

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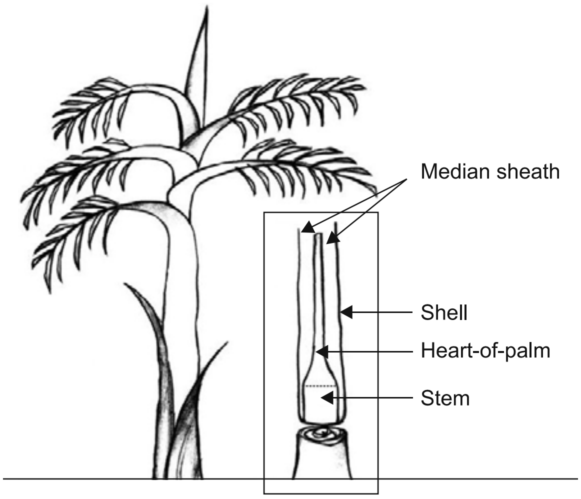

Fig. 1. Peach palm (*Bactris gasipaes* Kunth) and identification of its parts.

impact on the health of consumers and on the environment [2].

By-products having high dietary fibre content could be used in bakery products, dairy products, jams, processed meats, canned or dried soups, where they can alter textural properties, avoid syneresis and improve the shelf-life, while benefiting the consumer. Fibre intake has a positive impact on human health by slowing down the hydrolysis, digestion and absorption in the small intestine, increasing the volume of stools, and reducing the levels of glucose and cholesterol absorbed from the lumen [3]. Among the associated phytochemicals, the antioxidant compounds are important due the ability to scavenge free radicals, which are involved in oxidation of biomolecules, damaging cells and causing tissue alterations [4]. Besides the nutritional characteristics, it is important to evaluate the functional properties of the flours to direct their application in food products, as well as to study their water absorption ability, which may limit their shelf life.

The aim of this work was to characterize the flours produced from peach palm by-products as a possible new source of dietary fibre, evaluating composition, physicochemical and antioxidant properties and water sorption isotherms.

MATERIAL AND METHODS

Production of flour from peach palm by-products

Peach palm flours were produced from median sheaths and parts of the unused stem, harvested in heart-of-palm farm in Mariluz (Paraná, Brazil). These were subjected to washing, cleansing, cutting and drying in an oven with forced air circulation (MA 035, Marconi, Piracicaba, Brazil) at 60 °C for 36 h. The dried material was ground in a knife mill (type Willye SL-031; Solab, Piracicaba, Brazil) and passed through a set of sieves with particle separation from 150 μm to 600 μm, subjected to vibration for 10 min. The flours from median sheath (MSF) and stem part (SF) of peach palm with particle size of 150 μm were used in the study.

Proximate and mineral composition

MSF and SF were analysed for chemical composition by AOAC methods: moisture (method 925.09), ash (method 923.03), protein (method 920.87), crude fibre (method 978.10) and fat (method 920.85) [5]. Glucose, fructose and saccharose were extracted with hot water and the content was estimated using Enzytec (E1247; R-Biopharm, Darmstadt, Germany).

Uronic acids were analysed following the recommendations of Simas et al. [6]. The samples were dissolved in water ($0.5\ mg\cdot ml^{-1}$) and hydrolysed with sulphuric acid and then the reaction was carried out with 0.1% m-hydroxydiphenyl dissolved in 0.5% sodium hydroxide. The absorbance was read in spectrophotometer (700 Plus; Femto, São Paulo, Brazil) at 520 nm. A standard curve with different concentrations of galacturonic acid ($10–60\ \mu g\cdot ml^{-1}$) was used for the calculation of uronic acid content.

Minerals were analysed in atomic absorption spectrophotometer (AAnalyst 200; PerkinElmer, Waltham, Massachusetts, USA) after nitro perchloric acid digestion ($HNO_3:HClO_4$, 3 : 1) and appropriate dilution.

Dietary fibre and its components

The determination of soluble and insoluble dietary fibre was done by the gravimetric enzymatic AOAC method 991.43 [5]. The total dietary fibre was obtained by summing soluble and insoluble dietary fibre contents. Resistant starch was determined according to AOAC method 2002.02 [7] and, after enzymatic hydrolysis, the glucose content was determined with a glucose oxidase kit, supplied by Bioclin (Belo Horizonte, Brazil).

Contents of acid detergent fibre and neutral detergent fibre were determined according to the Van Soest system [8] and the lignin content was determined after hydrolysis with 72% sulphuric acid [9]. The contents of lignin, cellulose and hemicellulose were calculated from the contents of acid detergent fibre and neutral detergent fibre.

Total carotenoid, total phenolic compounds and antioxidant activity

The carotenoid content was determined according to the methodology described by RODRIGUEZ-AMAYA and KUMIRA [10]. Extraction of antioxidants was carried out using 80% ethanol [11] and the ethanol extract was used for the determination of total phenolic content using Folin-Ciocalteu method [12]. The content of phenolic compounds was determined using a standard curve prepared with gallic acid (Sigma, New Orleans, Louisiana, USA) and expressed in milligrams of gallic acid equivalent (GAE) per kilogram.

The scavenging activity of 2,2-diphenyl-1-picrylhydrazyl radicals (DPPH•; Sigma-Aldrich Chemical, St. Louis, Missouri, USA) was determined according to BRAND-WILLIAMS [13] and the ferric reduction power (FRAP) of the extracts was assessed following the methodology described by BENZIE and STRAIN [14]. The calibration curves were linear between 100 μmol·l^{-1} and 1000 μmol·l^{-1} of Trolox (6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid; Sigma-Aldrich Chemical). The antioxidant capability of the extracts with 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid free radical (ABTS$^{\bullet+}$; Sigma-Aldrich Chemical) was carried out according to THAIPONG et al. [15]. A standard curve with different concentrations of Trolox (from 100 μmol·l^{-1} to 2000 μmol·l^{-1}) was used for the calibration. All results were expressed as Trolox equivalent (in millimoles of Trolox per kilogram).

Physicochemical properties

The pH was measured with a potentiometer (PG 2000; Gehaka, São Paulo, Brazil) using 10 g of sample suspended in 100 ml of water. The bulk density was measured through the relation between weight and volume using a graduated cylinder [16].

To determine the swelling volume of the particles (*SVP*), 1 g of sample was mixed with excess of distilled water and stirred for 2 h. After complete decantation, the volume occupied by the sample in the beaker was named swelling volume, expressed in millilitres per gram of dry matter [17].

The water solubility index (*WSI*) of flours was evaluated according to AZIZ et al. [18] and the results were expressed in grams of soluble solids per kilogram.

The water absorption index (*WAI*) was measured weighing 2 g of sample in centrifuge tubes, adding 20 ml of water and stirred continuously in a shaker. The mixture was centrifuged at 3 000 ×*g* for 10 min, the supernatant was discarded and the residue weighed. *WAI* was obtained by the weight ratio between the wet sediment and the dry matter. The result was expressed in grams of water absorbed per gram of dry matter.

The oil absorption index (*OAI*) was determined in the same way as the water absorption, but using commercial soybean oil [17].

To measure the viscosity, three percentages of the flours suspensions (4%, 5% and 6%) was analysed using the Viscometer Model DVII (Brookfield; Middleboro, Massachusetts, USA) with spindle number 1 (0.05 Hz to 1.00 Hz) at a constant rotational frequency of 0.05 Hz and 0.10 Hz.

Water sorption isotherm

The water sorption isotherm of SF and MSF was determined using Aquasorp (Decagon Devices; Pullman, Washington, USA) at 25 °C with relative humidity of equilibrium (*RHE*) between 10% and 85%, which corresponds to water activity between 0.10 and 0.85. The water content was expressed in grams of water per kilogram on dry basis.

Statistical analysis

Analyses were done in three replicates and the results were expressed as mean ± standard derivation. The variance analysis ($p < 0.05$) and correlations tests ($p < 0.05$) were performed using the software Statistica version 6.0 (StatSoft, Tulsa, Oklahoma, USA).

RESULTS AND DISCUSSION

Proximate and mineral composition

SF had higher ash content than MSF (Tab. 1), but lower than that reported by HELM et al. [19] for flour produced from the uvarana palm (*Cordyline spectabilis*) by-products (84.6 g·kg^{-1} of ash). Protein, lipid and crude fibre contents were higher in SF than in MSF, the values of protein were higher than that found by SIMAS et al. [6] in the leaf sheath flour of king palm (35 g·kg^{-1}). The lipid content in SF and MSF was similar to that found in field pea flours (19 g·kg^{-1}) [20].

Glucose was the most abundant saccharide in the flours from SF and MSF, followed by fructose, both being reducing saccharides that may participate in browning reactions, like Maillard reaction, during cooking in dehydration conditions or during drying of the material. ABOUBAKAR et al. [21] found in taro (*Colocasia esculenta*) flours values ranging from 135 g·kg^{-1} to 267 g·kg^{-1} of reducing saccharides. SF had higher content of saccharose than MSF. The total of glucose, fructose and saccharose in SF and MSF corresponded to

Tab. 1. Chemical composition of flours obtained from peach palm by-products (wet basis).

Component	Stem flour	Median sheath flour
Moisture and volatiles* [g·kg-1]	61.62 ± 2.51 a	53.20 ± 3.40 b
Ash [g·kg-1]	50.61 ± 0.90 a	43.82 ± 0.83 b
Proteins** [g·kg-1]	98.40 ± 1.12 a	68.62 ± 2.81 b
Crude fat [g·kg-1]	23.22 ± 0.53 a	20.10 ± 1.02 b
Crude fibre [g·kg-1]	219.55 ± 6.40 b	301.51 ± 7.03 a
Glucose [g·kg-1]	64.41 ± 4.49 a	47.82 ± 3.60 b
Fructose [g·kg-1]	46.76 ± 1.74 a	41.53 ± 1.70 b
Saccharose [g·kg-1]	45.90 ± 2.72 a	30.10 ± 1.04 b
Uronic acid [g·kg-1]	15.92 ± 0.96 a	12.20 ± 0.82 b
Mg [g·kg-1]	3.90 ± 0.02 a	2.62 ± 0.06 b
Ca [g·kg-1]	4.32 ± 0.10 b	7.30 ± 0.08 a
K [g·kg-1]	14.77 ± 0.10 a	11.76 ± 0.09 b
P [g·kg-1]	2.95 ± 0.08 a	2.44 ± 0.05 b
Fe [mg·kg-1]	3.75 ± 0.07 a	0.97 ± 0.06 b
Cu [mg·kg-1]	2.67 ± 0.06 b	2.83 ± 0.06 a
Mn [mg·kg-1]	3.75 ± 0.30 b	12.75 ± 0.90 a
Zn [mg·kg-1]	12.50 ± 0.70 a	4.07 ± 0.11 b

Means values in the same line followed by the same letter are not significantly different ($p \leq 0.05$).
* – dried at 105 °C, ** – conversion factor 6.25.

157 g·kg-1 and 119 g·kg-1, respectively. These saccharides are probably present in tissues conducting nutrients to the apical meristem of peach palm (SF) with a higher content in flour from the younger tissue of the stem.

Saccharides and uronic acids are the most abundant soluble components of plant cells. The uronic acid content was higher in SF than in MSF, which was lower than in oat straw (16.7 g·kg-1), barley (18.2 g·kg-1), canola (68.5 g·kg-1) and mustard (82.1 g·kg-1) [22]. The uronic acid content in the flours is consistent with the occurrence of pectin, a component from the primary cell wall and middle lamella.

SF with higher ash content than MSF had higher content of minerals with exception of calcium, copper and manganese (Tab. 1). Mg, Fe, Mn and Cu contents in the flours were lower than those found by Simas et al. [6] in king palm flour, and the contents of Ca and Zn in MSF were close to the values reported ibid. Major macro elements in the flours were potassium and calcium. Calcium is important to protein structuring of RNA and DNA and its deficiency may lead to osteoporosis [23].

Among the microelements, manganese and zinc were found in high levels. These minerals are components of a number of enzymes acting as essential activators in metabolic reactions, and they are very important elements for reproduction and growth [24]. The availability of minerals present in the flours depends on the presence of antinutrients and digestibility.

Dietary fibre and its components

In the flours total dietary fibre content was higher than the crude fibre content, or the residue remaining after the chemical decomposition by sulphuric acid and/or sodium hydroxide, which does not include water-soluble fibre.

The flour obtained from the median sheath of peach palm showed higher dietary fibre content than the flour produced from the stem (Tab. 2). There was a higher content of soluble fibre in SF, since it is a younger tissue, and a higher content of insoluble fibre in MSF, since it is an older, protective tissue. The contents of soluble and insoluble dietary fibre were similar to those reported by Aziz et al. [18] for banana pseudo-stem flour (25.8 g·kg-1 and 545 g·kg-1). SF also had total dietary fibre content similar to that reported by Helm et al. [19] for the uvarana palm flour.

SF and MSF can be considered sources of dietary fibre, a class of compounds that include a mixture of saccharides such as cellulose, hemicellulose, pectin, gum, resistant starch, inulin, which are associated with lignin and other compounds not classified as saccharides (polyphenols, saponins, cutin, phytate and resistant proteins). This group is important not only to help to slow down the hydrolysis, digestion and absorption in the small intestine, but also by increasing the volume of the stools, stimulate the fermentation process and reduce the levels of glucose and cholesterol absorbed from the lumen [3]. Food and Drug Administration recommended for adults the consumption of 25 g of dietary fibre per day [25]. Thus, to reach the demand of the daily consumption of dietary fibre, an intake of approximately 40.4 g of SF or 35.1 g of MSF would be necessary.

Because dietary fibre was the main component of the flours, it means that they can participate in the development of a potential large market of fibre-rich products. By-products have traditionally been undervalued; however there is a trend to find new sources of dietary fibre that can be used as ingredients in the food industry. Fibres provide many functional properties that alter the technological function of foods, like consistency, texture, rheological behaviour and sensory characteristics. Moreover, the by-products rich in fibres can be used for economical and technological purposes, for example, as bulking agents or fat substitutes [2, 3, 26].

Fibres are nowadays becoming very visible ingredients in the marketplace. They can be incorporated in dairy products, breakfast cereals, baked goods, pasta, cereal bars, snacks, nutritional supplements and other food products. Manufacturers are finding incorporating fibre into their products a good way to make them healthier and subsequently more appealing to health-conscious consumers. Besides the nutritional aspect, the addition of fibres should not adversely affect the sensory characteristics of the product and, for this reason, these should be light in colour, tasteless, and not perceived in the mouth when added to products [26].

The percentage of resistant starch did not differ between the flours. Resistant starch represents a portion of starch that is not digested in the small intestine of healthy human, in other words, it is not subject to the action of amylase enzymes, but is fermented by the colonic microflora, with similar health benefits as the dietary fibre [27].

MSF had higher percentage of acid detergent fibre and neutral detergent fibre than SF. AZIZ et al. [18] observed levels of acid detergent fibre and neutral detergent fibre similar to those found in SF in flour from banana pseudo-stem and in tender core flour. The acid detergent solution dissolves the cellular content, hemicellulose and soluble minerals, leaving a residue consisting of fibrous cellulose, lignin, and also a percentage of insoluble proteins and minerals, while the neutral detergent solution does not dissolve hemicellulose. Thus, determination of acid detergent fibre is related to the cellulose content and neutral detergent fibre is associated with the content of hemicellulose in the sample.

Tab. 2. Content of dietary fibre components of flours obtained from peach palm by-products (wet basis).

Component [g·kg^{-1}]	Stem flour	Median sheath flour
Total dietary fibre	619.42	711.84
Insoluble dietary fibre	587.21 ± 9.50 ^{b}	686.70 ± 6.94 ^{a}
Soluble dietary fibre	32.20 ± 2.82 ^{a}	25.14 ± 2.86 ^{b}
Resistant starch	9.23 ± 0.44 ^{a}	8.15 ± 0.70 ^{a}
Acid detergent fibre	229.30 ± 10.27 ^{b}	332.94 ± 12.60 ^{a}
Neutral detergent fibre	345.74 ± 8.44 ^{b}	492.05 ± 11.41 ^{a}
Hemicellulose	116.43 ± 6.30 ^{b}	159.12 ± 10.42 ^{a}
Cellulose	223.61 ± 9.05 ^{b}	326.04 ± 7.41 ^{a}
Lignin	10.40 ± 1.16 ^{a}	15.92 ± 2.41 ^{a}

Means values in the same line followed by the same letter are not significantly different ($p \leq 0.05$).

The content of cellulose, hemicellulose and lignin were higher in MSF than in SF, in agreement with previously determined values for insoluble dietary fibre. According to AZIZ et al. [18], banana pseudo-stem flour contained 274 g·kg^{-1} of cellulose and 119 g·kg^{-1} of hemicellulose, which are values similar to those found in SF.

The major components of dietary fibre in the studied flours were cellulose and hemicellulose, with contents of 340 g·kg^{-1} in SF and 485 g·kg^{-1} in MSF, which together with pectin and lignin form the cell wall of plants. SF is produced from a younger tissue with more saccharides and lower content of fibres and non-lignified tissues than MSF, which is more related to structuring and protection of the rod. Lignin was the minor component of the dietary fibres in SF and MSF. This can be explained by the fact that lignification occurs only in specialized cells, increasing the resistance of the cell wall against mechanical, chemical and enzymatic degradation [28].

Total carotenoids, total phenolic compounds and antioxidant activity

MSF had higher content of carotenoids, but lower content of phenolic compounds than SF (Tab. 3). SIMAS et al. [6] found lower content of phenolic compounds in the king palm flour obtained from leaf sheath (1270 mg·kg^{-1}). RODRIGUEZ-AMAYA et al. [29] found 900 μg·kg^{-1} of α-carotene and 160 μg·kg^{-1} of β-carotene in heart-of-palm (*B. gasipaes*) after boiling. Carotenoids are pigments widely distributed in nature being important for its pro-vitamin A activity. However, recent studies showed that carotenoids also exhibit antioxidant activity, through their interaction with free radicals, providing protection against oxidation in vitro and in vivo [29].

The antioxidant activity measured by DPPH, ABTS and FRAP methods (Tab. 3) indicated that the mechanisms involved in these in vitro reactions can be performed by the components of the flours. SF had higher antioxidant potential (1.36–15.27 mmol·kg^{-1}, expressed as Trolox equivalents) than MSF (0.88–14.98 mmol·kg^{-1}), which is probably related to the higher content of phenolic compounds. The antioxidant activity demonstrated by the flours in DPPH assay was close to that reported by RAGAEE et al. [30] for rye whole flour (12.17 mmol·kg^{-1}).

The phenolic content of the flours has a positive correlation with the antioxidant activity ($r \geq 0.93$, $p < 0.05$). Free radicals are unstable molecules that are formed during the use of oxy-

Tab. 3. Total phenolic compounds, total carotenoids and antioxidant activity in the flours produced from peach palm by-products (wet basis).

	Stem flour	Median sheath flour
Total phenolic compounds [mg·kg^{-1}]	2698.60 ± 62.60^{a}	2332.82 ± 56.22^{b}
Carotenoids [μg·kg^{-1}]	349.63 ± 3.04^{b}	966.50 ± 5.02^{a}
Antioxidant activity		
DPPH• [mmol·kg^{-1}]	15.27 ± 0.12^{a}	14.98 ± 0.06^{b}
ABTS•+ [mmol·kg^{-1}]	1.36 ± 0.05^{a}	0.88 ± 0.07^{b}
FRAP [mmol·kg^{-1}]	10.97 ± 0.30^{a}	8.59 ± 0.39^{b}

Means values in the same line followed by the same letter are not significantly different ($p \leq 0.05$).
Total phenolic compounds are expressed as gallic acid equivalents. Antioxidant activity is expressed in Trolox equivalents.

gen by the body. Antioxidants, such as phenolic compounds, interact with these reactive species, making it possible to prevent some damage to human cells. The role of antioxidants involves donation of electrons or the transfer of hydrogen atoms to free radicals, without compromising the stability of their molecules. Moreover, they are capable to inhibit lipid peroxidation in vitro through the capacity to sequester free radicals or chelate metals [4].

Therefore, the antioxidant activity demonstrated by in vitro methods indicates that the compounds present in MSF and SF can interact with free radicals and help in human diseases prevention. However, the in vivo efficacy and the dilution or re-processing of such products at the moment of consumption may influence the real content and the antioxidant potential of the compounds present in these flours.

Physicochemical properties

Suspensions of SF and MSF had pH of 6.02 and 5.76, respectively, and bulk density of 0.39 g·ml^{-1} and 0.40 g·ml^{-1}, respectively. Benítez et al. [16] found similar values of bulk density in onion by-products (0.3–0.4 g·ml^{-1}). According to these authors, the bulk density depends on the structural characteristics, the particle size and its distribution.

WSI associated with saccharides and some proteins, ranged from 135.13 g·kg^{-1} to 173.31 g·kg^{-1} in MSF and SF, respectively. These values were similar to those found in field pea flour (137 g·kg^{-1}) and pigeon pea flour (206 g·kg^{-1}) [20].

Water and oil absorption of SF and MSF were higher than the values found in field pea and pigeon pea flours [20], bean flours [31] and cowpea, horse gram and chickpea flours [32]. *WAI* is related to the ability of a substance to associate with water under specific conditions, with saccharides and proteins being the main components responsible for such property, due to the presence of polar or charged groups in the molecules. In food processing, this property influences functional and sensory properties [32]. The oil absorption is also an important functional property of flours, retaining the flavour and aroma compounds, and can be used in many food applications, like emulsion-type meat products. Proteins have in their molecules lipophilic and hydrophilic portions and so are the most responsible for this property, because non-polar amino acids may form interactions with the lipid hydrocarbon chains [33].

The values of *WAI* and *OAI* of the flours can be related to the content of dietary fibres and indicate that the flours can probably be used in many food applications. Dietary fibre has an important role in the hydration properties of flours, which is associated with the chemical structure of its components, porosity, particle size, pH and ionic strength, among others. Similarly the oil absorption capacity can be defined as the amount of oil retained by the fibres after stirring, incubation with oil and centrifugation. This property is related to surface characteristics of the particles that form the sample and is associated with the charge density and the hydrophobic nature of the constituents [3].

Furthermore, the values of *WAI* and *WSI* suggest that these flours can act as hypoglycemic agents and can be used in weight loss diets because, after consumption, they likely form a tridimensional network with water, that prolongs the satiety sensation and delay the nutrient absorption [27].

The swelling volume of flours was 17.21 ml·g^{-1} and 20.79 ml·g^{-1} dry matter for MSF and SF, respectively. *SVP* was positively correlated ($p < 0.05$) with viscosity in all conditions tested. The viscosity of the suspensions increased with the increase of flour concentrations, and the values were higher for SF than for MSF, ranging for SF from

26.85 mPA·s to 96.41 mPA·s at 0.10 Hz and from 32.8 mPA·s to 173.35 mPA·s at 0.05 Hz, and for MSF from 13.04 mPA·s to 26.76 mPA·s at 0.10 Hz and from 23.20 mPA·s to 41.82 mPA·s at 0.05 Hz (Tab. 4). Siddiq et al. [31] found apparent viscosity to range between 10 mPA·s and 60 mPA·s in selected dry been flours (0.10 $g \cdot ml^{-1}$), reaching the maximum value of 462 mPA·s for small red kidney bean flour dispersion at 0.30 $g \cdot ml^{-1}$. According to these authors, the particle size distribution can influence the viscosity of dispersion, since small particles tend to be more uniform and offer higher resistance due to the inter-particle friction, resulting in high viscosity of dispersion. Solubility is another critical factor, which also influences the viscosity of the dispersion, especially in case of soluble fibre. The low solubility of the flours produced from peach palm by-products led to the deposition of particles over time, in spite of their small size. Therefore, viscosity was determined immediately after homogenization.

In this study the correlations between protein content with *WAI*, *SVP* and viscosity varied from 0.86 to 0.99 ($p < 0.05$). Among saccharides, saccharose, fructose and glucose had positive correlations ($r \geq 0.84$) for all physicochemical properties and viscosity ($p < 0.05$), with the exception of no significant correlation between saccharose and *OAI*. The contents of crude fibre, total dietary fibre, insoluble dietary fibre, acid detergent fibre, neutral detergent fibre, hemicellulose and cellulose in the flours were significantly correlated with *WAI* and *SVP*, with r values from –0.82 to –0.88 and from –0.89 to –0.93, respectively, with the exception of acid detergent fibre for *WAI*, and of hemicellulose for *SVP*. Viscosity was also negatively correlated with these variables ($-0.91 \leq r \leq -0.99$; $p < 0.05$). On the other hand, soluble dietary fibre content had significant positive correlations with *WAI* ($r = 0.94$), *SVP* ($r = 0.84$), viscosity ($r = 0.87$–0.92) and *WSI* ($r = 0.93$). This indicated that the high levels of soluble dietary fibre, proteins, lipids and saccharides improved the physicochemical properties, contrary to what occurs with the increasing values of crude or dietary fibre and its insoluble components. Overall, SF was superior in its physicochemical properties.

Water sorption isotherms

The experimental sorption isotherms (Fig. 2) indicated that MSF was more hygroscopic than SF for *RHE* lower than 50%, but the opposite was valid for *RHE* higher than 50%. The water absorption of SF and MSF reached 325 $g \cdot kg^{-1}$ and 268 $g \cdot kg^{-1}$ of water on dry basis, respectively, at *RHE* of 85%, which was the maximum *RHE* at which the measurements were done. Similar values were determined by Rao et al. [34] for quamachil aril powders.

Water absorption occurs due to the presence of macromolecules like saccharides and proteins that contain polar groups and can form hydrogen bonds with water. Probably the high fibre content of MSF promoted the high water absorption up to 50% of *RHE*. Above this value of *RHE*, the higher content of saccharides contributed to the hygroscopic behaviour of SF, which reached higher final humidity than MSF. Among the insoluble compo-

Tab. 4. Physicochemical properties, technological properties and viscosity.

Property	Stem flour	Median sheath flour
pH	6.02 ± 0.01 a	5.76 ± 0.01 b
Bulk density [$g \cdot ml^{-1}$]	0.39 ± 0.01 a	0.40 ± 0.01 a
Water solubility index [$g \cdot kg^{-1}$]	173.31 ± 17.87 a	135.13 ± 13.03 b
Water absorption index [$g \cdot g^{-1}$]	7.36 ± 0.28 a	6.60 ± 0.20 b
Oil absorption index [$g \cdot g^{-1}$]	3.58 ± 0.09 a	3.46 ± 0.10 a
Swelling volume [$ml \cdot g^{-1}$]	20.79 ± 0.91 a	17.21 ± 0.75 b
Viscosity 4% / 0.05 Hz [mPA·s]	32.8 ± 1.15 a	23.2 ± 2.13 b
Viscosity 4% / 0.10 Hz [mPA·s]	26.85 ± 0.84 a	13.04 ± 0.91 b
Viscosity 5% / 0.05 Hz [mPA·s]	126.09 ± 6.93 a	31.64 ± 1.27 b
Viscosity 5% / 0.10 Hz [mPA·s]	91.28 ± 5.64 a	22.80 ± 1.05 b
Viscosity 6% / 0.05 Hz [mPA·s]	173.35 ± 8.65 a	41.82 ± 3.56 b
Viscosity 6% / 0.10 Hz [mPA·s]	96.41 ± 4.14 a	26.76 ± 1.47 b

Means values in the same line followed by the same letter are not significantly different ($p \leq 0.05$).
Water solubility index, water absorption index, oil absorption index and swelling volume are expressed per gram of dry matter.

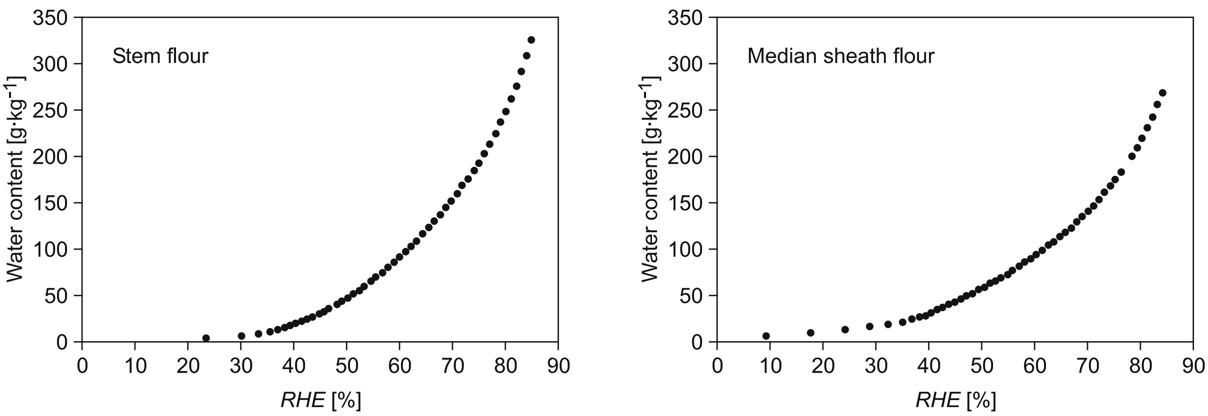

Fig. 2. Absorption isotherms.

Content is expressed per kilogram on dry basis.

nents of fibres, the hemicellulose content seemed to have a positive effect on water absorption, while cellulose and lignin content affected it negatively [35]. Although MSF had the highest content of hemicellulose, this flour also had the highest content of other insoluble compounds.

Although there is no mathematical model adjusted to the experimental data, it is possible to note that the flours tend to gain moisture at *RHE* above 10% and values above 60% led to moisture content of the flours above 100 $g \cdot kg^{-1}$ of water on dry basis, which is the limit value for storage of flours in general. Therefore, the packaging system used to store these flours must maintain *RHE* bellow 60%.

CONCLUSIONS

SF had higher content of moisture, ash, proteins, lipids and saccharides than MSF. On the other hand, MSF had higher content of dietary fibre than SF, which is the most abundant component of the flours, basically formed by cellulose and hemicellulose. There was higher carotenoid content in MSF and higher content of phenolic compounds and antioxidant activity in SF. As a consequence of its composition, SF had better physicochemical properties than MSF, especially *WAI*, *SVP* and viscosity. Above 60% of *RHE*, the flours absorbed water at more than 100 $g \cdot kg^{-1}$ on dry basis, which can limit their shelf life. Therefore, it is indicated that a package system is necessary to protect the flours from the environmental humidity.

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