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Evaluation of physicochemical, technological and morphological characteristics of powdered yellow passion fruit peel

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Abstract

The aims of this study were to ascertain the physicochemical properties, technological properties, phytochemical compounds and morphology of powdered yellow passion fruit products to determine their suitability for use as natural food ingredients. Passion fruit peel powder was obtained by convective hot air-drying at 60°C, freeze-drying and compared with a commercial sample. The passion fruit peel (dried at 60°C and freeze-dried powders) could be used as an intermediate food ingredient in the development of functional foods because of its good levels of phenolic compounds and the high total dietary fiber (63.98-72.62%) content as pectin (6.98-19.6%). In addition, these fiber-rich co-products have potential applications as ingredients in products requiring hydration and viscosity development due to their high total dietary fiber content and good technological proprieties, especially their water holding (6.30-14.9 g H_2O/g) and oil holding capacities (2.6–6.5 g oil/g), especially for the freeze-dried samples.

Introduction

The term 'passion fruit' comprises several species from the genus *Passiflora* L., family Passifloraceae; the genus *Passiflora* consists of approximately 400 species, with over 150 being native from Brazil (Bruckner and Picanço, 2001). The most important variety cultivated in Brazil for commercial purposes is the yellow passion fruit, *Passiflora edulis Sims f. flavicarpa Degener* (Teixeira *et al*.,1994), which is used for pulp and juice processing. The *P. edulis* var. *flavicarpa* fruits are round in shape, with a diameter between 8 and 10 cm and a green peel at maturity. The edible part of the passion fruit (40%) consists of pulp with seeds, and 60% of the peel consists of mesocarp and epicarp. They contain many seeds (as do the other Passifloraceae species) surrounded by a gelatinous yellow pulp that has an intense aroma and a sweet-acid taste (López-Vargas *et al*., 2013).

Pulp, seeds, peel and pericarp from passion fruit peel play an important role in human nutrition and health because of their nutritional and bioactive properties (e.g., pectin, fibers, phenolic compounds, and carotenoids) (Chankvetadze *et al.*, 2011). The valorization of agricultural residues is receiving more attention nowadays, and many researchers have been evaluating the conversion of by-products into food ingredients and other value-added materials (Arnous *et al*., 2001; Viuda-Martos *et al*., 2011; López-Vargas *et al*., 2013). These by-products may still contain many valuable substances, such as pigments, sugars, organic acids, flavors and bioactive compounds with antioxidant and antimicrobial activities, as well as being valuable sources of dietary fiber (Fernández-López *et al.*, 2009). Hypocholesterolemic and blood glucose reduction properties, among others, have been attributed to the passion fruit peel (Chau and Huang, 2005; Zibadi *et al*., 2007; Janebro *et al*., 2008; Salgado *et al*., 2010).

Dietary fiber from the passion fruit peel can be added to a variety of foods, including meat products (Viuda-Martos, Ruiz-Navajas, Fernández-López and Pérez-Álvarez, 2010), breakfast cereals, bakery products (Vergara-Valencia *et al*., 2007) and dairy products (Sendra *et al.*, 2008) for different functions. Galanakis *et al.* (2010) observed good gelling properties of dietary fibers from olive mill wastewater and Jiménez *et al.* (2000) showed the water holding capacity and cation exchange capacity of the dietary fibers from olives. Galanakis *et al.* (2010) observed

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good gelling properties of dietary fibers from olive mill wastewater and Jiménez *et al*. (2000) showed the water holding capacity and cation exchange capacity of the dietary fibers from olives. In addition, studies showed different applications for fibers such as, to improve the sensorial characteristics of biscuit (Serial *et al*., 2016), to control the stability of oils (Iwata *et al.*, 2014) and to increase the properties, proteolytic digestibility of lactoferrin nano-particles (David-Birman *et al.*, 2013) and to modify the characteristics of pasta (Foschia *et al*., 2015).

Normally, by-products from vegetable materials are composed by complex ingredients, which normally are discharged in the environment. The wastes originated by various branches of the food industry can be used to add value in different products. Normally, the extraction, fractionation and isolation of high added-value compounds from food wastes have ultimate goal of: maximizing the yield of the target compounds; suiting the demands of industrial processing; clarifying the high added-value ingredients from impurities and toxic compounds; avoiding deterioration and loss of functionality during processing and ensuring the food grade nature of the final product (Galanakis *et al.*, 2012).

Therefore, the mesocarp and epicarp of passion fruit should not be considered just as industrial residue because it can be used for the development of new functional and technological products. The aim of this study was characterize the physicochemical properties, technological and morphological characteristics of powdered passion fruit peel obtained by hot-air convection drying, freeze drying and compare with a commercial sample.

Material and Methods

Plant material

Two batches of 10 kg of yellow *Passiflora edulis* Sims f. flavicarpa Degener were purchased from a local market (Porto Alegre, RS, Brazil). The fruits were washed and sliced to remove the pulp with seeds. The peels (composed with mesocarp and epicarp) were blanched in water (100°C for 3 min) followed by cooling in an ice bath. After, they were ground in a domestic blender (according to the manufacturer's instructions). The peels were dried in an oven with air circulation (60°C for 48h) or freeze-dried (25°C for 72h). After drying, the samples were milled again in the domestic blender until pass through mesh 60#. A sample of passion fruit powder (drying by convection hot-air) purchased from a local market (Porto Alegre, RS, Brazil) was also were milled in the domestic blender until pass through mesh 60#.

Physicochemical analysis and technological properties

Moisture, ash, protein, and fat content were determined by AOAC methods (AOAC, 1997). Moisture (g/100 g) was determined by drying at 105 °C to constant weight. Ash (g/100 g) was performed by heating in an oven at 550°C for 6 h. Protein (g/100 g) was analyzed according to the Kjeldahl method using a nitrogen conversion factor of 5.75 (BRASIL, 2003). Fat (g/100 g) was determined by weight loss after a 6-cycle extraction with petroleum ether in a Soxhlet apparatus. Total dietary fiber (TDF) (g/100 g) was determined following the 991.43 AOAC method (AOAC, 1997). All analyses above were expressed in dry weight (d.w.). Available carbohydrate was calculated by difference; the amount of dietary fiber is analyzed and subtracted from total carbohydrate, thus: 100 - (weight in grams [protein + fat + water + ash + dietary fiber] in 100 g of sample).

Pectin was extracted by traditional heating extraction based on the method of Kratchanova *et al.* (Kratchanova *et al*., 2004) with slight modifications. The sample (4 g) was mixed with acidified 100 mL hot water (HNO_3 50 mM). After that, the mixture was heated to 80–82°C using a heating magnetic stirrer, and the extraction was carried out with continuous stirring for 20 min. The hot mixture was cooled and filtered by vacuum filtration, and the filtrate was collected and stored in a refrigerator at 4°C for subsequent purification. The extracted pectin was precipitated with two volumes of 95% ethanol (v/v) and allowed to stand for 30 min. Thereafter, the pectin was immersed in 70% ethanol for 12h for the removal of impurities and then washed with acetone and immediately dried at 40°C for 12h in an oven with air circulation. All values were expressed in g/100 g of d.w. The pH was measured in a suspension resulting from blending 3 g sample with 30 mL of deionized water using a pH meter (model pH/Ion 510, Eutech Instruments Pte Ltd., Singapore). The acidity was determined by titration with 0.01N NaOH as described in AOAC methods (AOAC, 1997). The water activity (a_w) was determined in a TH-500 Sprint Novasina Thermoconstanter (Pfäffikon, Switzerland) at 25°C.

The color was studied in CIELAB color space using a Minolta CM-2600d (Minolta Camera Co., Osaka, Japan) with D65 as an illuminant and an observer angle of 10° (Recommendations on uniform color spaces, color-difference equations, 1978). All analyses were performed in triplicate, and the results are expressed as the mean ± standard deviation.

The water holding capacity (WHC) and oil holding capacity (OHC) were determined according

to Robertson *et al*. (2000). The WHC is expressed as g water held/ g sample; the OHC is expressed as g of oil held/g sample. Each assay was carried out in quintuplicate, and the results are expressed as mean ± standard deviation.

Quantitative analysis of phenolic compounds and total carotenoids

The phenolic compounds were determined by the procedure developed by (Larrauri *et al*., 1997) with minor modifications; phenolic compounds were extracted by weighing approximately 2 g of sample and adding 10 mL of 80% methanol followed by ultrasonic mixing in a vortex mixer for 10 min followed by a 10 min centrifugation (5200 g). This procedure was repeated 5 times. After this step, the sample was extracted again with 70% acetone repeating the same procedure described above. The total phenol content (TPC) was determined using Folin–Ciocalteu reagent (Singleton and Rossi, 1965). The results were expressed as g gallic acid equivalents (GAE)/kg sample. The total flavonoid content was determined by the method based on (Zhishen *et al.*, 1999) with minor modifications. A sample of 250 µL of passion fruit peel extract was mixed with 75 mL $NaNO_2$ (5%), and 150 µL $AlCl_3$ (10%) was added after 5 min. The samples were mixed in a vortex for 2 min, and after 6 min they were neutralized with 0.5 mL NaOH (1 M). The absorbance was read at 510 nm, and correlated to a calibration curve. Different concentrations of catechin were used for calibration and the results were expressed in g catechin/kg sample. The total flavan-3-ols content was determined according to (Arnous *et al*., 2001) and (Poudel *et al*., 2008) and expressed as g epicatechin/kg sample. The carotenoids were exhaustively extracted with cold acetone, partitioned into petroleum ether and washed with distilled water. The total content of carotenoids was determined by spectrophotometry at 450 nm in petroleum ether, and the result is expressed in terms of β-carotene using an absorptivity coefficient of 2592 (Rodriguez-Amaya, 2001). All polyphenols and carotenoids are expressed in d.w.

Particle size distribution and scanning electron microscopy

Particle size distribution (PSD) was determined using a MasterSizer Laser Diffraction Particle Size Analyzer (Malvern Instrument Ltd, Malvern, England). Size distribution was quantified as relative volume of particles in size bands presented as size distribution curves (Malvern MasterSizer Micro software v 5.40). The PSD parameters recorded included specific surface area, largest particle size (D_{90}), mean particle volume (D_{50}), smallest particle size (D_{10}), Sauter mean diameter (D[3,2]) and mean particle diameter (D[4,3]) (Afoakwa *et al*., 2007). The microstructure of the passion fruit peel was analyzed by scanning electron microscopy (SEM). Powders were mounted on aluminum stubs with sticky double-side conductive metal tape without special treatment. Examination was performed with a TM3000 table-top scanning electron microscope (Hitachi High-Technologies Corporation, Tokyo, Japan) at 10 kV accelerating voltage. The image acquisition was performed by TM300 Microscope software, version 02-01(Hitachi High-Tech, Tokyo, Japan).

Statistical analysis

All reported values represent the average value of the analysis of at least three separate replicates. An ANOVA was performed followed by Tukey's test ($p<0.05$) for mean comparison. To explore de data, principal component analysis (PCA) was also performed. PCA is a multivariate statistical method that entails data reconstruction and reduction. It generates a set of a new orthogonal axes know as principal components (PCs) from the original variables (Shin *et al*.,, 2010). The Statistica 8.0 software for Windows (Statsoft, Tulsa, OK, USA) was employed.

Results and Discussion

Physicochemical analysis and technological properties

Table 1 shows the chemical compositions of passion fruit peel dried at hot-air convection (60°C), freeze-dried and the commercial sample, with the results expressed on dry weight. For the samples freeze-dried and dried at 60°C two batches were analyzed. The total dietary fiber was very high (>60 % d.w.). López-Vargas *et al.* (López-Vargas *et al*., 2013) found a total dietary fiber content of 71.8 g/100 g d.w. for the passion fruit mesocarp. In the present study, under the same conditions (passion fruit peel dried at 60°C), the level of dietary fiber was 72.7 g/100 g d.w. for the first batch and 64.0 g/100 g d.w. for the second. The high fiber content associated with the flavor and aroma makes the dehydrated passion fruit peel products potentially usable in some food preparations with the purpose of increasing fiber content. These co-products can be incorporated in several foods due to their capacity to retain water and increase satisfaction after eating, as well as its ability to decrease the time of nutrient absorption. In addition, these co-products can have technological

Table 1. Physicochemical composition of powdered passion fruit peel

Sample	Passion fruit peel - dried at 60 °C		Passion fruit peel - freeze dried		Commercially
	batch 01	batch 02	batch 01	batch 02	produced
Moisture (%)[1]	6.72±0.45	4.75±0,86[b]	9.46±0.48[c]	6.36±0.53[d,a,b]	7.56±0.91[a,c,d]
Ash (%)[1]	8.42±0.11[a]	7.24±0.09[b,c]	9.47±0.46[a]	8.76±0.07[a,d]	8.17±0.03[c,d]
Protein (%)[1]	7.89±0.42[a]	7.88±0.52[a]	8.64±0,19[a]	8.48±0.14[a]	7.77±0.19[a]
Fat (%)[1]	1.16±0.07[a]	0.98±0.15[a,b]	0.91±0.16[a,d]	0.86±0.21[b,d]	2.87±0,06[c]
Dietary fiber (%)[1]	72.67±0.27[a]	63.98±0.11[b]	67.40±0,12[c]	65.91±0.86[c]	72.68±0.19[a]
Available carbohydrate[2]	3.14	15,17	4.12	9.63	0.95
Pectin (%)[1]	6.98±0.32[a]	13.54±1.01[b]	15.91±0.29[c,b]	19.60±1.62[c]	8.38±0.35[a]
Water activity	0.398±0.001[a]	0.415±0.001[b]	0.455±0.001[c]	0.474±0.001[d]	0.437±0.001[e]
Acidity (g $C_6H_8O_7$/100 g sample)	1.22±0.02[a]	1.85±0.03[b]	3.32±0.04[c]	2.05±0.03[d]	1.97±0.00[d]
pH	5.28	4.83	4.53	4.91	4.56

The results represent the average of triplicate ± standard deviation followed by different small letters in line indicate significant difference ($p<0.05$) by the Tukey test. [1] Values are expressed as g/100 g d.w. [2]Calculated by difference.

applications as important thickening agents, gelling and stabilizers of foams and emulsions (Fito *et al.*, 2012). Passion fruit peel has been reported to contain significant amount of pectin (Kulkarni and Vijayanand, 2010). In this study, there was significant difference in the amount of pectin between the two batches of peel dried at 60°C. This difference is most likely due to the differences in the degree of maturity, storage time and harvest time. It is worth noting that, as expected, the amount of pectin of the powdered obtained by freeze-dried is greater than that dried with hot air convection, for the same batches (15.91 and 6.98% d.w. for batch 1 and 19.60 and 13.54 for batch 2). Moreover, the commercial sample (that was dried according to the information of the label) shows a significantly lower level when compared with the peel dried at 60°C (second batch) and peel freeze-dried. Freeze-drying is used and restricted primarily to industry because it requires qualified personnel and higher investment costs. In contrast, convective hot-air drying demands a small investment for crop producers and small industries. The utilization of passion fruit peel for commercial pectin production will not only solve waste disposal problems but can enhance the availability of pectin in the marketplace. The pectin extracted from the peels of passion fruit can be used to enhance the functional properties of different food products (Kulkarni and Vijayanand, 2010).

The proximate composition analysis showed higher fat contents in the commercial sample compared to the other samples ($p<0.05$). The average fat content found in the samples that were freeze-dried and dried at 60°C (0.88% and 1.07% d.w., respectively) are very close to those found by López-Vargas *et al.* (2013) (1.00% d.w.). The ashes content of the samples varied between 7.24 and 9.47% d.w., which are higher than the values obtained by Martínez *et al.* (2012) for different fruit peels, such as mango and pineapple. According to the same authors, the high ash content could be a problem in the potential application of these co-products in food since the amounts of metal ions would increase considerably and might facilitate the oxidation of the product in which they are incorporated. The ashes are made up mainly of potassium (4.49 g/100 g d.w.), sodium (0.136 g/100 g d.w) and magnesium (0.109 g/100 g of d.w.) (data not shown). It can also be observed that there is a difference ($p<0.05$) in ash between lots of passion fruit peel dried at 60°C that is probably due to the degree of ripeness of the fruit. Regarding the proteins, the passion fruit peel that was dried at 60°C had a protein content of approximately 8% d.w., which was higher than that reported by (Martínez *et al*., 2012) and (López-Vargas *et al.*, 2013) in passion fruit extracts obtained from pulp, peel and seeds (6.2% and 0.35%).

The pH ranged from 4.53±0.01 to 5.28± 0.03; the pH of passion fruit peel dried at 60°C were similar to that found by (López-Vargas *et al*., 2013) (4.36). However, the pH values of passion fruit peel were higher than the co-product fiber of lemon albedo (3.96) obtained by (Lario *et al*., 2004). The acidity results obtained for the passion fruit peel powder showed variation between the fruit peel dried at 60°C and freeze-dried. The decrease in acidity in fruit peel dried at 60°C may be due to the loss of volatile acid compounds during the thermal process. For the freeze-dried samples, the acidity was higher, most likely because they were not subjected to heat and the dehydration process occurs in the absence of oxygen. The low water activity and pH values (both parameters highly related to product deterioration) of the samples indicate that the risk of deterioration (by microorganisms or enzymes) is minimal. Almost all deterioration processes that occur in food are

Table 2. Technological properties, particle size distribution and phytochemical compounds of powdered passion fruit peel

Sample	Passion fruit peel - dried at 60°C		Passion fruit peel – freeze-dried		Commercially
	batch 01	batch 02	batch 01	batch 02	produced
L^*	41.45±0.14[a]	40.46±0.12[b]	84.36±0.03[c]	85.48±0.09[d]	35.02±0.51[e]
a^*	3.60±0.03[a]	3.78±0.02[b]	0.27±0.01[c]	0.21±0.01[c]	3.56±0.05[a]
b^*	16.69±0.14[a]	15.88±0.02[b]	24.37±0.06[c]	23.16±0.04[d]	15.28±0.14[e]
C_{ab}^*	17.07±0.14[a]	16.33±0.01[b]	24.37±0.06[c]	23.16±0.04[d]	15.69±0.15[e]
h_{ab}	1,36±0,00[a]	1,34±0,00[b]	1,56±0,00[c]	1,56±0,00[c]	1,34±0,00[b]
WHC[1]	9.82±0.57[a]	6.30±0.04[b]	14.99±0.67[c]	14.91±0.41[c]	8.02±0.31d
OHC[2]	2.65±0.25[a]	3.16±0.18[a]	6.36±0.23[b]	6.55±0.40[b]	3.06±0.14a
D_{10} (µm)	31.61	34.81	38.46	41.15	23.67
D_{50} (µm)	246.31	307.33	186.43	247.45	111.51
D_{90} (µm)	837.50	751.31	588.4	502.21	386.96
D[3,2] (µm)	3.27	2.33	2.95	1.86	3.26
D[4,3] (µm)	345.06	345.54	259.64	250.39	163.87
Phenolic compounds[3]	6.39±0.33[a]	5.02±0.33[b]	9.04±0.12[c]	6.47±0.21[a]	5.79±1.58[a,b]
Flavonoid[4]	1.02±0.01[a]	0.95±0.03[a]	0.68±0.02[b]	0.59±0.05[b]	1.42±0.02[c]
Flavan-3-ols[5]	0.009±0.001[a]	0.012±0.001[b]	0.023±0.001[c]	0.019±0.01[d]	0.025±0.001[c]
Total carotenoids[6]	2.55±0.18[a]	9.41±0.66[b]	5.29±0.19[c]	8.03±0.51[d]	5.96±0.55[c]

The results represent the average of triplicate ± standard deviation followed by different small letters in line indicate significant difference ($p< .05$) by the Tukey test. [1] WHC (Water Holding Capacity), g of H_2O/g. [2] OHC (Oil Holding Capacity), g oil/g. [3] g gallic acid equivalents (GAE/Kg d.w.). [4] g catechin/Kg d.w. [5] g epicatechin/kg d.w. 6 µg all-trans-β-carotene/g d.w.

influenced by the mobility and concentration of water, so it is necessary to control the moisture and the aw of food to increase its shelf life. In this study, the dehydrated products had aw values lower than 0.60, which can prevent microorganisms, xerophilic molds and osmophilic yeasts from growing because they typically grow between aw of 0.60 and 0.65.

Regarding the color parameters (L^*, a^*, b^*, C_{ab}^* and h_{ab}) present in the Table 2, all the powdered passion fruit peel were located on the 2nd quadrant of the CIELAB a^*b^* plane (values of a^* ranging from 0.21 to 3.78 and values of b^* ranging from 15.28 to 24.37), so were classified as yellowish. The difference in lightness (L^*) between the samples was statistically significant ($p<0.05$). In regard to the red-green coordinate, (a^*), differences occurred between the samples dried at 60°C and freeze-dried. The yellow–blue coordinate (b^*) of the freeze-dried sample had a value of approximately 24, while the sample dried at 60°C had a value of approximately 16, with a statistically significant difference ($p<0.05$). The differences in chroma (C_{ab}^*) values and hue angle (h_{ab}) between the samples dried at 60°C, freeze-dried and commercially produced were also statistically significant ($p<0.05$). There was some browning in the hot-air convection drying samples, whereas the freeze-dried samples had a lighter coloring compared to the fresh fruit. In general, all the dehydrated products presented a variation in yellowish coloring (Chua *et al*., 2001). The dark yellow observed in samples dried at 60°C is most likely due to enzyme activity which resulted in the oxidation of phenolic compounds to o-quinones due to the polyphenol oxidase (PPO) activity. During the freeze-drying process the enzymatic browning reaction did not occur, leaving the samples lighter. Finally, it can be observed that the coordinates L^*, chroma and hue angle values indicated that the convective hot-air dried sample presented a darker color (orange) when compared to the freeze-dried sample (light yellow).

The results for the water holding capacity (WHC) and oil holding capacity (OHC) of passion fruit peel dried at 60°C, freeze-dried and commercially produced are shown in Table 2. The hydration properties of dietary fiber are related to the chemical structure of the polysaccharide component and other factors such as porosity, particle size, ionic form, extraction condition pH, temperature, ionic strength, type of ions in solution, vegetable source and stresses on fibers (Elleuch *et al*., 2011). The water-holding capacity is an important property of dietary fiber from both physiological and technological standpoints. This property shows the ability of a moist material to retain water when subjected to an external centrifugal gravity force or compression. Processes such as grinding, drying, heating or extrusion cooking, for example, may modify the physical properties of the fiber matrix, also affect the hydration properties (Elleuch *et al*., 2011). According to Table 2, the WHC values of the peel that was dried at 60°C were significantly different between the two batches; for the lyophilized powder, the values did not differ significantly. There was a significant difference ($p<0.05$) between the WHC of the peel dried at 60°C (9.82±0.57 and 6.30±0.04) and the higher values of the freeze-dried peel (14.99±0.67 and 14.91±0.41).

Exposure to 60°C for an extended period could have altered the polysaccharide structure and, consequently, created a decrease in water-holding capability. The commercial sample showed values similar to those of peel dried at 60°C. Fito *et al*. (Fito *et al.*, 2012) found values for water-holding capacity of 6.40 and 13.50 g/g for mango and passion fruit concentrates, respectively. López-Vargas *et al.* (López-Vargas *et al.*, 2013) found similar values of WHC (13.00 g H_2O/g) for passion fruit albedo with those found in the present study for freeze-dried peel.

The oil holding capacity (OHC) is also a technological property related to the chemical structure of plant polysaccharides and depends on their chemical and physical structure (Martínez *et al.*, 2012). As noted in Table 2, OHC values were shown to be within the range of 2.65–6.55 g oil/g, with statistically significant differences ($p<0.05$) for the freeze-dried samples compared with the others; The freeze-dried sample showed a higher OHC when compared to the other samples, indicating that exposure of passion fruit peel to a temperature of 60°C for a long period altered the physicochemical structure of plant polysaccharides and the hydrophobic nature of the particle (Fernández-López *et al*., 2009). López-Vargas *et al*. (2013) found an OHC of passion fruit albedo of 2.03 g oil/g, a value similar to that found in this work for the passion fruit peel dried at 60°C. Other studies have reported the OHC of fibrous residues, such as coconut fiber (5.30 g oil/g) (Raghavendra *et al*., 2006) or fiber-rich banana powder (2.20 g oil/g) (Rodríguez-Ambriz *et al.*, 2008).

Phytochemical compounds

Phenolic content can be used as an important indicator of antioxidant capacity and as a preliminary screen for any product intended to be used as a natural source of antioxidants in functional foods (Viuda-Martos *et al.*, 2011). The total phenol content of dried at 60°C samples ranged from 5.02±0.33 g/kg d.w. (second batch) to 6.39±0.33 g/kg d.w. (first batch) with statistically significant differences ($p<0.05$) between the two batches (Table 2). López-Vargas *et al.* (López-Vargas *et al.*, 2013) found the TPC of passion fruit albedo to be 0.64 g/kg d.w. when the conditions were the same used in this study. Martínez *et al*. (2012) obtained TPC of the fiber concentrates from pineapple equal to 1.29 g/kg d.w. Others sources of phenolic compounds were studied by different authors. Medouni-Adrar *et al.* (2015) investigated the TPC in grape by-products and found 36.06 g/kg d.w. (skin) and 92.06 g/kg d.w. (seeds). Leite-Legatti *et al.* (2012) studied the content of phenolic in powder of jaboticaba peels and observed a content of 556.3 g GAE/kg. Antonini *et al*. (2015) evaluated the profile of carotenoids in extra-virgin olive oils and obtained a content of lignans, ranged from 0.024 to 0.045 g/kg d.w. Freeze-dried samples showed the highest TPC, ranging from 6.47±0.21 (second batch) to 9.04±0.12 g/kg d.w. (first batch), with a statistically significant difference ($p<0.05$) between the two batches. For the same batch, the freeze-dried samples presented a higher TPC values when compared with samples dried at 60°C. These data suggest that phenolic compounds were retained in the process of lyophilization because enzymatic activity was inhibited during the drying time. The lighter coloration observed in these samples indicates the absence of brown compounds such as o-quinones. Prolonged exposure to 60°C and oxygen was most likely the cause of the degradation of phenolic compounds observed in the dried passion fruit peel. With regard to the commercial sample, the TPC was 5.8±1.58 g GAE/kg d.w., which was not significantly different ($p<0.05$) from the dried samples. These values are within the broad range reported in the literature for the peels of exotic fruit such as banana passion fruit *(Passiflora mollissima)* (2.46 g GAE/kg d.w.), cocona *(Solanum sessiliflorum)* (0.87 GAE/kg d.w.), and cupuaçu *(Theobroma grandiflorum)* (2.52 g GAE/kg d.w.) (Contreras-Calderón *et al.*, 2011).

The total flavonoid (TFC) content in the commercial sample was the highest (1.42±0.02 g catechin /kg d.w.), which was statistically significantly different ($p<0.05$) from the others samples. Surprisingly, the dried samples had higher TFC when compared to the freeze-dried samples. The flavan-3-ols contents ranged from 0.009±0.001 to 0.025±0.001 g epicatechin/kg d.w. The commercial sample showed the highest flavan-3-ols content, differing significantly from the dried at 60°C samples (first and second batch) and the second batch of the freeze-dried sample. The concentration and type of phytochemical compounds in fruit and fruit co-products depend on several factors: differences in varieties, ripeness and season; environmental factors (such as soil type and climate); genetic factors, processing and extraction methods.

In addition to their colorant properties, carotenoids are known to have several other biological functions, such as vitamin A activity, cancer-preventing effects, protective effects against cardiovascular disease and reduction of the risk of cataracts and age-related macular degeneration (Rodriguez-Amaya, 2001). According to Souza *et al*. (2012), β-carotene is the majority carotenoid found in passion fruit. The carotenoid levels are also shown in Table 2 and

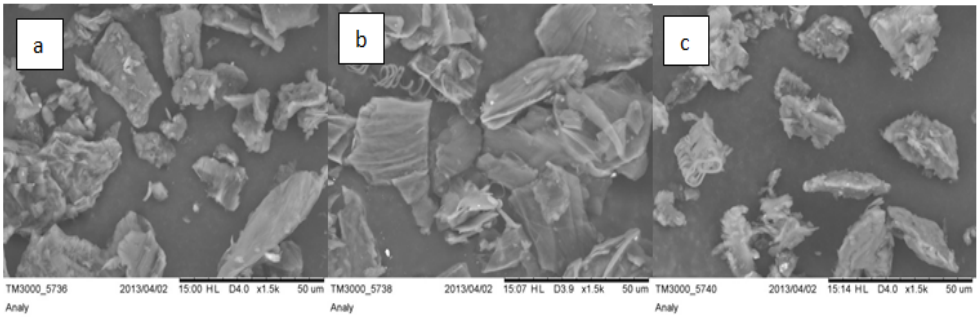

Figure 1. Scanning electron micrographs (x1500 magnification) of passion fruit peel. a) commercial sample, b) freeze-dried sample, c) dried at 60°C sample

ranged from 2.55±0.18 to 9.41±0.66 µg all-trans-β-carotene/g. Souza *et al*. (2012) found 13.10 µg β-carotene/g d.w. for the sweet passion fruit pulp and 12.10 µg β-carotene/g d.w. for soursop. Leong *et al.* (2012) investigated some bioactive compounds in summer fruit and vegetable and found a content of β-carotene in carrots of the 440 µg/g, 30 µg/g in peaches and 40 µg/g in plums. All these studies were analyzed by spectrophotometer at wavelengths of 450 nm for β-carotene.

Particle size distribution and microstructure

The particle size distribution is of major importance because it determines both the technological functionality of the fiber and its role in the digestive tract (transit time, fermentation, fecal excretion). The shape and consequently the size of the fibers depend on the degree of processing and may also vary during transit in the intestine tract as a result of digestion processes (Rosell *et al*., 2009). Researchers have shown that the co-products of passion fruit are rich in fiber (López-Vargas *et al.*, 2013), so the study of the structure and the particle size is of great importance. The particle size distribution (PSD) of the different sample powders is presented in Table 2. The commercial sample showed the lowest mean particle diameter (D[4,3]) and the largest particle size was observed for the dried peel. The average diameter and particle size distribution showed similar values for the two batches (sample hot-dried and freeze-dried), which would be expected since the two batches were prepared by the same milling processes (even though the process for the hot-dried samples took more time). A reduction in particle size has typically been associated with lower ability to retain water and oil holding capacity. Certainly, particle size is not the only determinant parameter of hydration; chemical structure and shape also play essential roles. Therefore, the effect of particle size on water and oil holding cannot be generalized and must be assessed for each type of fiber (Shin *et al*., 2010). In this study, the average particle size of the

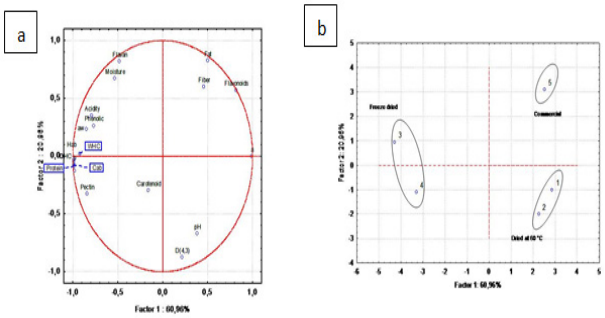

Figure 2. Results of the principal component analysis: a) loading plot of PC1-PC2. b) score plots for samples

lyophilized powder was smaller than hot-dry powder while its capacity for holding water and oil was the greatest of all.

In order to investigate the change in the microstructure caused by the drying process, Figure 1 shows the scanning electron micrograhs of the samples. As can be seen, the structure of the lyophilized powder was more conserved when compared to the hot-dry and commercial sample. The microstructures were similar to others samples from plant sources that have a high fiber content (Rosell *et al*., 2009).

Multivariate analysis

The results of multivariate analysis are showed in Figure 2. The first principal component (i.e., PC1) accounted for 60.96% of the variability in the data set, and the second (i.e., PC2) accounted for 20.96% of the variance in the data (Figure 2a). The PC1 has high and positive contributions from chromatic coordinate a^* (0.989) and flavonoids (0.816) and presented high and negative contributions from colour: L^* (-0.965), chromatic coordinate b^*(-0.987), $C_{ab}{}^*$ (-0.987) and hab (-0.987); from technological properties: OHC (-0.990) and WHC (-0.925); and some physicochemical properties: protein content (-0.989), pectin (-0.845) and water activity (-0.849). The PC2 has high and positive contribution from fat (0.826), flavan-3-ols (0.819), moisture (0.676) and fiber (0.603) and high and negative contributions from D(4,3) (-0.875) and pH (-0.667). The score

plots of the five powders of passion fruit peel generated from comparisons of the two PC (PC1 and PC2) are depicted in Figure 2b. Three distinct groups of samples can be seen (freeze-dried, convective dried at 60°C and commercial sample). The freeze-dried powders were separated from the others by PC1 (being well differentiated by color and by technological variables). The difference between the commercial and freeze-dried powders can be explained mainly by the difference in the values of fat, D[4,3] and flavonoids. Multivariate analysis allowed the grouping of samples that were subjected to the same treatments despite differences obtained in the analyzes of different batches.

Conclusion

In the present work, two different methods of dehydration – freeze-drying and convective drying at 60°C – were used to produce a powdered passion fruit peel, which is a co-product of the production of passion fruit juice. This powder is reach in dietary fiber and bioactive compounds, so researches concerning its reuse in the food industry are of great importance.

It was observed that the freeze-dried powder presented a less dark color, a higher ability to absorb water and oil and a higher phenolic compounds and pectin content when compared with the others samples. The drying process a 60°C, which is a much less expensive process, produced a powder with a more intense color but preserved the amount of the total dietary fiber.

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