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Study of the drying process of the purple-fleshed sweet potato (*Ipomoea batatas* (L.) *Lam*) in spouted bed

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Abstract

This study aimed to study the drying of purple-fleshed sweet potato (PFSP) in a spouted bed and define the best drying conditions, producing flour and analyzing it using physical, chemical, and technological analyses. The best condition of the drying process was a feed load of 300 g PFSP and a drying temperature of 70°C. Flour with a moisture content of 3.95% and a low water activity was obtained, which had high carbohydrates, low fats, and a considerable amount of ashes and proteins. The sweet potato flour presented good solubility in water and milk and good absorption in water, oil, and milk, forming gel but not foam. PFSP flour is a good alternative for the use of its residues, avoiding the waste of raw material that has no commercial value and can be useful to incorporate in products such as porridges, creams, and sauces.

Keywords: agroindustrial optimization; flour; sweet potatoes; use of residues.

Practical Application: Purple-fleshed sweet potato flour can be a promising alternative in food formulations.

1 INTRODUCTION

Sweet potato is a tuberous root and has predominantly carbohydrates, low proteins and fats, high dietary fiber and vitamin A, and a relevant amount of minerals (Histifarina et al., 2023; Sánchez et al., 2019). Besides phenolic compounds (e.g., phenolic acids, flavonoids, and anthocyanins), carotenoids and anti-nutritional are present (Histifarina et al., 2023; Laveriano-Santos et al., 2022). Sweet potato has varieties in terms of flesh and skin colors. The purple-fleshed variety is nutritious, rich in anthocyanins, and has antioxidant properties (Laveriano-Santos et al., 2022; Rodrigues et al., 2016). This type of sweet potato serves as a potential source of natural colorant and can be used to develop functional foods such as juices, powders, and industrialized drinks (Liu et al., 2017).

Because it has a high moisture content, sweet potatoes do not have an extensive shelf life, and they are easily susceptible to microbiological, enzymatic, and chemical deterioration. Therefore, one of the alternatives used to extend the shelf life would be to reduce the moisture content by drying, also aiming to add value to the raw material (Silva et al., 2019).

The processing of this raw material into flour, through drying, is an effective way to increase the shelf life of this root, as it allows to take advantage of those outside the commercial standards as an ingredient of many food products, contributing to the reduction of losses within the supply chain. Flour processing facilitates its incorporation into various products such as cakes, bread, cookies, and others, with purple sweet potato flour being able to replace wheat flour (Rashid et al., 2022; Rodriguez-Amaya et al., 2011) partially.

One way to obtain flour is by drying in a spouted bed dryer, which stands out for providing high-quality and low-cost products in a shorter drying time, offering advantages over other methods due to the excellent heat transfer coefficients and greater uniform distribution of drying temperature (Castro et al., 2017; Chada et al., 2022).

Given the above, the objective was to study the drying process of the purple-fleshed sweet potato (PFSP) in a spouted bed and evaluate the resulting flour's technological characteristics for its application in food products.

2 MATERIALS AND METHODS

2.1 Raw material

PFSPs were obtained from a farm in the region of Cezarina, Goiás. Sweet potatoes were placed in trays at room temperature and stored at the Vegetable Laboratory of the Food Engineering sector, at the School of Agronomy of the Universidade Federal de Goiás (UFG), Samambaia Campus, Goiânia, GO, until they were sprouting, wilted, and without commercial value, to obtain flour to use their residues.

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2.2 Obtaining purple-fleshed sweet potato flour

2.2.1 Spouted bed drying

Sweet potato drying tests were done by using a conical geometry spouted bed dryer, made of stainless steel with the following components: electric heat exchanger with two 1000-W resistors; 2-in. and 5-in. stainless steel tubing; 2-in. orifice plate; radial blower of 7.5 Cv; type K thermocouple; data logger; U-tube manometer with methylene blue as gauge fluid; two ball valves; and cyclone and cylindrical spouted bed with a conical base.

2.2.2 Processing

Sweet potatoes were first selected according to undesirable marketing patterns (withered and sprouting). They were washed in running water to remove dirt, peeled and cut into small cubicles of 0.1 cm^2, and dried in a spouted bed. For all tests, inert (low-density polyethylene) was used to obtain a more uniform particle circulation rate within the bed due to the geometry of the particles, which makes it difficult for air to pass evenly throughout the load. After drying, the sweet potatoes were separated from the inert and immediately subjected to grinding in a hammer mill of the Marconi brand (model Ma 600). Drying time was standardized at 1 h and 30 min for all tests.

The flour obtained in the drying process was stored in polypropylene jars wrapped in aluminum foil and left in the cold room for further physical, chemical, and technological analysis.

2.3 Study of the drying process of purple-fleshed sweet potato flour

For the study of the drying process, a 2^2 factorial design with a central point was used, which evaluated the effects of quantitative factors: load of PFSP (g) and drying temperature (°C), as shown in Table 1. In the dependent variables, moisture parameters and color index of the flour were evaluated.

Drying tests of sweet potato in a spouted bed included four mains (± 1), a duplicate was made, and a central point (to improve the linearity of the statistical model) was applied with four repetitions, totaling 13 tests to define the better load and temperature parameters in the process, as shown in Table 1. The data obtained after carrying out the 2^2 factorial design were analyzed to calculate the main effects and the interaction of the variables on the responses, determining which were the significant factors ($p < 0.5$). The significant coefficients of the model were evaluated using the t-test. They were also submitted to analysis of variance (ANOVA).

2.4 Flour processing under operating conditions

From the data obtained with the drying of the sweet potato, further dryings were made following the experimental planning, based on the optimum parameters of the process, to obtain the purple sweet potato flour.

Table 1. Levels of the factors of the study variables, load, and temperature in the study of the drying of purple-fleshed sweet potato in the spouted bed and matrix of factorial design 2^2 with coded variables (+ and -) and real variables (mass and temperature).

Factors	Levels		
	-1	**0**	**1**
Load (g)	150	225	300
Temperature (°C)	50	60	70

Test	Coded variables (Levels)		Real variables: Mass (g)	Real variables: Temperature (°C)
1	-	-	150	50
2	+	-	300	50
3	-	+	150	70
4	+	+	300	70
5	0	0	225	60
6	0	0	225	60
7	0	0	225	60
8	0	0	225	60
9	0	0	225	60
10	-	-	150	50
11	+	-	300	50
12	-	+	150	70
13	+	+	300	70

2.5 Characterization of dry purple-fleshed sweet potato flour in the best drying conditions

2.5.1 Physical and chemical composition of flour

Water activity (aw) was determined using the AquaLab device through a direct reading of the sample. Total titratable acidity, pH, moisture content, ash, protein, fats, and total carbohydrates were determined according to the methodology described by AOAC (2012). Total protein content was determined using the Kjeldahl method, with a nitrogen-protein factor of 5.75 for vegetables, established by FAO/73, and expressed as a percentage. Total carbohydrate content was determined by the difference between 100 and the addition of the protein, moisture, lipid, and ash content and expressed as a percentage. Total fat content was determined according to the Soxhlet method (AOAC, 2012), with modifications.

For fat determination, 5 g of the sample was weighed and placed in cartridges made with paper filters placed in a reboiler with 100 mL of petroleum ether. The extraction was carried out with the sample immersed in ether for 4 h. Then, the cartridges were suspended, and the petroleum ether dripped on them for 30 min, followed by the recovery of the petroleum ether. The reboiler containing all the fat extracted from the sample was taken to the oven at 105°C to evaporate the residual ether and remove humidity. Afterward, the reboiler was placed in a desiccator for 30 min and weighed. The percentage of lipids was obtained by the Equation 1:

$$\text{L\%} = \frac{(Wb - Wa)}{w} x100 \quad (1)$$

where:

L%: lipids;

Wa: weigh in gram of the reboiler;

Wb: weigh in gram of the reboiler with lipids;

W: weight in gram of the sample.

The conversion factors for protein of 4 kcal/g, lipids 9 kcal/g, and carbohydrates 4 kcal/g were used to calculate the energy value, following Equation 2 (Brasil, 2003):

$$Px\ 4{,}0\ + L\ X\ 9{,}0\ +\ C\ X\ 4{,}0\ = Energy\ value\ (Kcal\ 100\ g) \quad (2)$$

2.5.2 Color determination

The color was determined at three different points of the sweet potato flour by reading three parameters with the determination in the CIE L * a * b * mode provided by the colorimeter (Hunterlab, ColorQuest II). The color was determined by direct reading on the samples, using a Konica Minolta colorimeter (model Chroma Meter CR-40). The results were expressed in L *, a *, b *, chroma, and hue values (Bible & Sigha, 1997). The result was expressed by the color index (CI), proposed by Camelo and Gómez (2004), which is expressed by Equation 3:

$$CI = \frac{2000a*}{L*\sqrt{(a*)^2+(b*)^2}} \quad (3)$$

2.5.3 Granulometry

The size of the flour particles was determined by using a vibratory sieve shaker of the Produtest brand, composed of five sieves, whose openings varied from 0.106 to 1.00 mm, where 100 g of flour was stirred for 10 min, weighing the amount of sample retained in each sieve (Cereda & Cataneo, 1986).

2.5.4 Technological properties

2.5.4.1 Water absorption index and milk absorption index

WAI and MAI were determined by the methodology described by Santana (2005), with modifications. A quantity of 2 g of flour was added in 25 mL of distilled water at 50°C and placed in previously weighed 45-mL centrifuge tubes, which were stirred for 30 min. After that, the tubes were centrifuged at 2,500 rpm for 10 min. The supernatant was transferred to a Petri dish, and the tube containing the final sample with water was weighed. The absorption index, in grams of the hydrated sample per gram of the dry sample, was obtained by Equation 4:

$$WAI = MAI = \frac{mass\ of\ the\ hydrated\ sample}{mass\ of\ the\ dehydrated\ sample} \quad (4)$$

2.5.4.2 Oil absorption index

OAI was determined by the methodology described by Santana (2005), with modifications. An amount of 1 g of flour was added to 10 mL of soybean oil at 25°C and placed in previously weighed 45-mL centrifuge tubes, which were stirred for 30 min. After that, the tubes were centrifuged at 2,500 rpm for 10 min. The supernatant was placed in a Petri dish, and the tube containing the final sample with oil was weighed. The oil absorption index (OAI), in grams of the hydrated sample per gram of the dry sample, was obtained by Equation 5:

$$OAI = \frac{mass\ of\ the\ insoluble\ residue}{mass\ of\ the\ dehydrated\ sample} \quad (5)$$

2.5.4.3 Water solubility index, milk solubility index, and oil solubility index

WSI, MSI, and OSI were determined by the methodology described by Santana (2005), with modifications. The water solubility index (WSI) was obtained using the same methodology as WAI and MAI. Petri dishes with supernatant were placed in an oven at 60°C for approximately 15 h until the sample was dehydrated. The solubility index was calculated as a percentage, using Equation 6:

$$WSI = MSI = \frac{mass\ of\ the\ dry\ sample}{mass\ of\ the\ sample} x100 \quad (6)$$

2.5.4.4 Emulsifying activity

EA of PFSP flour was determined by the methodology of Yasumatsu et al. (1972). One gram of the sample was added to 10 mL of water and 10 mL of soybean oil in 15-mL graduated tubes and centrifuged at 3,000 rpm for 5 min.

The emulsifying activity was calculated according to Equation 7:

$$emulsifying\ activity = \frac{emulsifying\ layer\ (ml)}{total\ volume\ in\ the\ tube\ (ml)} x\ 100 \quad (7)$$

2.5.4.5 Emulsion stability

To determine the ES, the tubes were heated in a water bath at 80°C for 30 min, then cooled for 20 min in running water, and centrifuged at 3,000 rpm for 5 min. The emulsion stability (ES) was calculated by Equation 8 (Yasumatsu et al., 1972):

$$Emulsion\ stability = \frac{remaining\ emulsified\ layer\ (ml)}{emulsified\ layer\ in\ the\ tube\ (ml)} x\ 100 \quad (8)$$

2.5.4.6 Foaming capacity

The foaming capacity was determined by the methodology of Coffmann and Garciaj (1977). One gram of flour and 50 mL of distilled water were stirred for 5 min in a shaker. The volume was transferred to a 100-mL graduated cylinder and observed for foaming.

2.5.4.7 Gel-forming ability

The gel-forming capacity of the flour was determined according to Coffmann and Garciaj (1977). Dispersions of sample concentrations (2, 4, 6, 8, 10, 12, 14, 16, 18, and 20%) were carried out in 20 mL of water and subjected to heating at 90°C for 30 min. Then, they were cooled to room temperature and refrigerated at 4°C for 2 h. The tubes were inverted and analyzed for gel formation.

2.6 Statistical analysis

To evaluate the results obtained from the drying process of the PFSP in the spouted bed, the STATISTICA® software was used to characterize the experimental design of factor 2^2 with a central point, with the load and temperature being dependent variables of the process.

From the data obtained by the physical, chemical, and technological analysis of sweet potato flour, the average and standard deviation were made using Excel to present the results.

3 RESULTS AND DISCUSSION

3.1 Effects of drying temperature and mass load on the moisture and color of purple-fleshed sweet potato flour

Table 2 presents the data from experimental planning 2^2 with the response variables, moisture, and color index. The color index indicates the degree of variation in the purple tones of the samples. Figure 1 shows the Pareto chart of significant factors for moisture and color and the contour plot for variable moisture of PFSP flour.

Through the Pareto chart in Figures 1A and 1B, statistically important effects can be observed quickly and clearly. The factors or interactions that go beyond the dotted line have a significant effect on the response variable. It is observed that the temperature and the interaction between the two factors (load and temperature) had a significant influence on the moisture, being inversely proportional, which means, that when increasing these parameters, the moisture of the sample was reduced. Regarding the color index, the Pareto chart points out that none of the factors, temperature, load, or the interaction between them had a significant influence, so there is no significant variation between the colors of the samples. According to Costa et al. (2015), with the use of the spouted bed, it is possible to perform the drying of thermosensitive materials because the average temperature of the particles is lower than the average temperature of the drying air.

Through the contour plot (Figure 1C), based on the moisture-dependent variable, it is observed that by increasing the temperature, less moisture is obtained, which was expected. However, by increasing the load, for the same temperature, moisture values did not change significantly. In the static bed height range (mass of sweet potato particles) applied, the charge effect was negligible for the same airflow due to the high degree of agitation of the particles in the spouted bed. This agitation provides an effective rate of heat and mass transfer, as well as uniformity (Brito et al., 2017; Pinto et al., 2023). When evaluating sweet potato powder in a spouted bed, Almeida et al. (2020) also observed a decrease in moisture as the temperature increased. The same pattern has also been observed in other food products (Du et al., 2023).

The application of higher temperatures promotes a greater temperature difference between the drying air and the product. This results in greater heat transfer, which increases the rate of migration of the water contained in the product to the surface, and, as a result, more water evaporates from the product, resulting in lower moisture (Zhao et al., 2022).

Table 3 presents the ANOVA for the variable moisture and color index. The information presented in Table 3 refers to the F-value test compared with the F-statistic. Although significant, analyzing Table 3, it was found that the model is not predictive for the moisture variable, which means that it does not allow making predictions because it covers a small range of variation of the factors studied. Regarding the color index, in addition to not being significant, the model is not predictive.

After analyzing the data, it is observed that the best drying parameters were obtained from drying 300 g at a temperature of 70°C as the temperature directly influenced the moisture content (3.5006%). In contrast, this parameter did not influence the load. Also, there was no effect of temperature and load on the color of the product.

Table 2. Data from the experimental design of factor 2^2 with real mass and temperature variables and response variables (moisture and color index).

Test	Coded variables		Real variables		Response variables	
	X	Y	m (g)	T (°C)	M* (%)	CI*
1	-	-	150	50	7.4387	32.2416
2	+	-	300	50	8.2648	32.2851
3	-	+	150	70	5.0617	32.6524
4	+	+	300	70	3.5006	33.6324
5	0	0	225	60	5.0400	31.7676
6	0	0	225	60	5.9292	32.5796
7	0	0	225	60	6.1450	31.1742
8	0	0	225	60	5.6611	31.8303
9	0	0	225	60	5.2507	32.4991
10	-	-	150	50	8.4864	32.3108
11	+	-	300	50	8.6683	32.0267
12	-	+	150	70	4.7440	32.4597
13	+	+	300	70	3.6485	33.1362

M*: moisture; CI*: color index.

3.2 Physical and chemical evaluation of PFSP flour

With the best drying parameters for the PFSP, obtained from drying 300 g at 70°C, the process was repeated to obtain the flour for physical, chemical, and technological analysis.

3.2.1 Chemical characterization of flour

The chemical composition of PFSP flour and recent findings from the sweet potato flour literature are shown in Table 4. As can

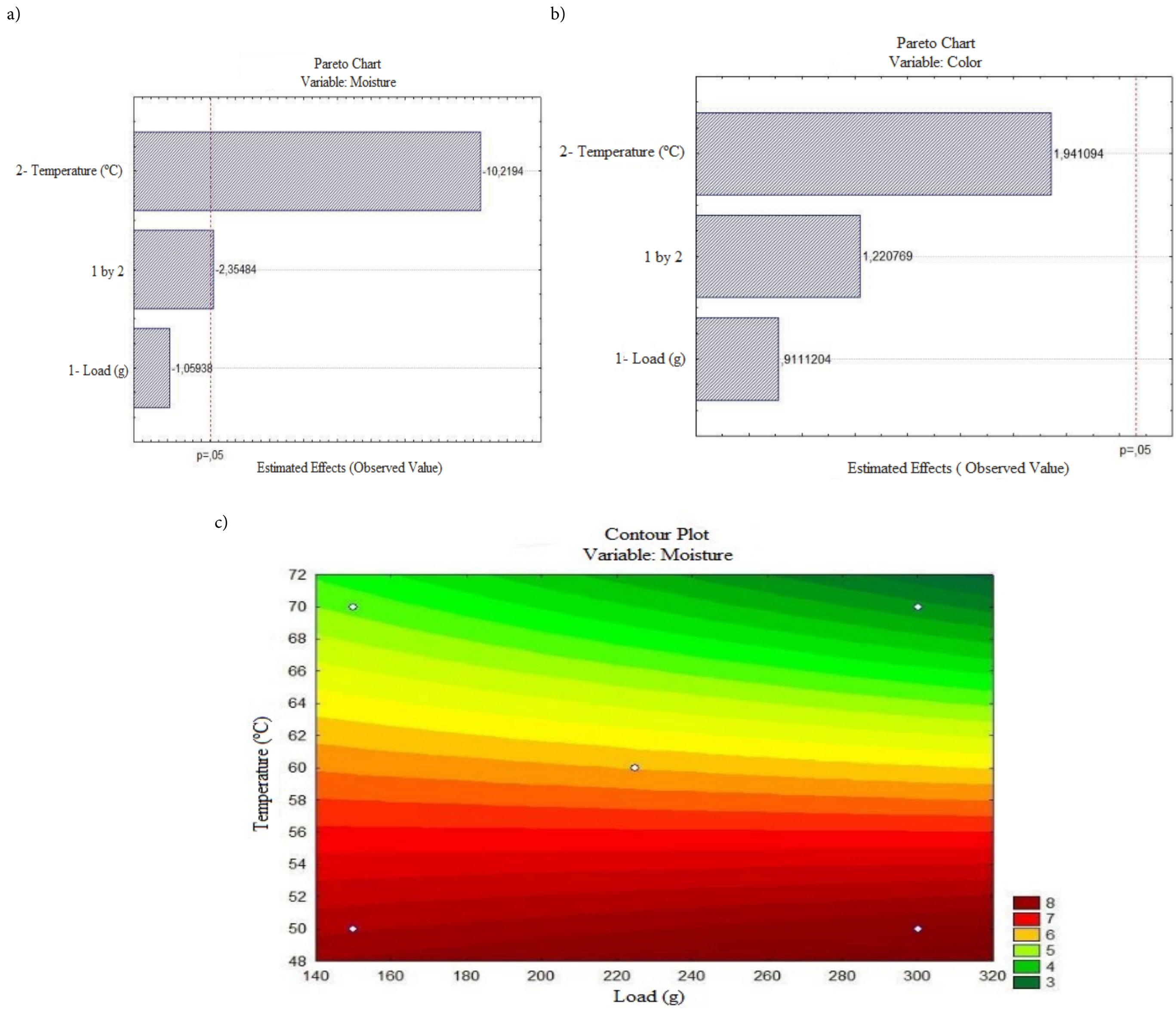

Figure 1. Pareto chart of the significant factors for (A) moisture, (B) color, and (C) contour plot for variable moisture of PFSP flour.

Table 3. ANOVA generated by the experimental design of type 2^2 with a central point for the moisture and color index of the PFSP flour.

Factors of variation	DF*	Moisture ($R^2 \rightarrow 0.92506$)				Color index $R^2 = 0.40351$			
		SS*	MS*	F-value*	F-statistic*	SS*	MS*	F-value*	F-statistic*
Regression	1	0.3397	0.3397	1.1223	161.450	0.25059	0.25059	0.83014	161.450
Residual	1	31.6147	31.6147			1.13741	1.13741		
Lack of fit	1	1.6786	1.6786	5.5453	5.1174	0.44987	0.44987	1.49027	5.1174
Pure error	9	2.7244	0.3027			2.71685	0.30187		
Total	12	36.3576	33.9360			4.55473			

be seen, PFSP flour is a food composed, for the most part, of carbohydrates, having considerable protein content and low lipid content.

PFSP flour had low moisture content, in compliance with Resolution RDC 263/2005 by the Brazilian National Health Surveillance Agency (ANVISA), of September 2005, which establishes 15% as the maximum moisture limit for flours, cereal starch, and bran (Brasil, 2005). Similar values were found by Silva et al. (2020), in white sweet potato flour (Ipomoea potatoes L.) (4.07%). It is known that the moisture, or water content of food, constitutes one of the most important and most evaluated indexes. Moisture outside the technical recommendations may cause loss of chemical stability, microbiological deterioration, or changes in the overall quality of the food (Instituto Adolfo Lutz, 2008), affecting the storage, processing, and packaging.

Table 4. Chemical composition of PFSP flour obtained by drying under desirable conditions and data from the literature on sweet potato flours.

Components	PFSP flour*	Mariano and Arruda (2016) Purple sweet potato flour	Silva et al. (2020) Dry white-fleshed sweet potato flour	Jaime et al. (2020) Orange-fleshed sweet potato flour	
				São Paulo	Minas Gerais
Moisture (%)	3.95 ± 0.07	5.68	4.07	9.76	9.95
Ash (%)	3.14 ± 0.05	2.88	3.01	3.66	6.95
Protein (%)	4.31 ± 0.15	3.32	2.78	7.38	9.85
Fats (%)	0.53 ± 0.06	0.86	1.19	0.76	1.39
Carbohydrates (%)	86.75	87.14	90.09	78.89	71.86
pH	5.97 ± 0.01	–	–	5.62	5.49
aw	0.15 ± 0.01	–	0.14	0.35	0.33
Titratable acidity	8.95 ± 0.09	–	–	1.91	1.91
Total energy value (kcal/100 g)	369.01	–	372.29	351.92	339.35

*Mean ± σ.

PFSP flour presented a low aw content, corroborating the findings by Silva et al. (2020) for white-fleshed sweet potato flour. According to Bolzan (2013), foods with water activity lower than 0.6 are considered safe because of their suppressed microbial growth; thus, an elaborated PFSP flour can be considered a safe product due to the low water activity and, consequently, less probability of microbial growth.

When comparing the contents of nutrients (e.g., ash, protein, fats, and carbohydrates) with other studies, some differences in the results can be justified by the variation in cultivation, maturation stage, fertilization conditions, climatic factors, and genetic conditions of the plant (Silva et al., 2020). The evaluated sample had an ash content of 3.14%, a value close to those found by Mariano and Arruda (2016) in purple sweet potato flour, by Silva et al. (2020) in white-fleshed sweet potato flour, and by Jaime et al. (2020) in flour made from orange-fleshed sweet potato grown in the state of Minas Gerais. For wheat flour, the legislation stipulates maximum ash of 0.8, 1.4, and 2.5% for type 1, type 2, and whole-wheat flour, respectively (Brasil, 2005).

Determination of fat content is essential because fats play an important role in food quality, contributing to flavor, texture, and caloric value (Almeida et al., 2018). In this study, an average of 0.53% fats was obtained, which is a value lower than those found in the literature for different cultivars of sweet potato flour. According to Brazilian Ordinance No. January 27, 2013, 1998 (Brasil, 1998), PFSP flour can be considered a product with low-fat content, which considers foods with 3 g of fat or less per 100 g of food as food with low-fat content.

A protein content of 4.31% was found, which is higher than that found by Mariano and Arruda (2016) in purple sweet potato flour and lower than that found in orange sweet potato flour (Jaime et al., 2020). There is no specific Brazilian legislation for sweet potato flour. When comparing with Brazilian legislation for wheat flour, it is observed that the values obtained from proteins do not meet the standards required by law because type 1 wheat flour must contain a minimum of 7.5% protein and 8.0% in both type 2 and integral (Brasil, 2005). The content of carbohydrates in PFSP flour was 86.75%, which is similar to that found by Mariano and Arruda (2016), and the energy value of 369.1 kcal, which is similar to those found by Silva et al. (2020) and by Jaime et al. (2020) in different cultivars of sweet potato.

It is observed that PFSP flour has a considerable energetic value, having carbohydrates as its main macronutrient, with low levels of proteins, and is practically fat-free. Among the sweet potato carbohydrates, about 30% are sugars. The remainder is starch, containing no saturated, polyunsaturated, or monounsaturated fats; the percentage of cholesterol is zero, and sweet potatoes are also very rich in dietary fiber (2.7 g/100 g) (Sánchez et al., 2019). It is worth mentioning that the sweet potato has a very low glycemic index; that is, the carbohydrates present in the sweet potato are absorbed more slowly and for a longer period, resulting in a lesser impact on the increase of blood glucose of those who consume it. In addition to the high fiber content, this property makes sweet potatoes a healthy food, highly recommended for sportspeople and people who practice intense physical activities (Sánchez et al., 2019).

The total titratable acidity content is related to the fermentation process or the type of rocesssing that the product went through (Chisté & Cohen, 2011), affecting the taste and odor of the food and relating to the amount of existing organic acids (Araújo et al., 2015). PFSP flour had a value of 8.95 for total titratable acidity, which is higher than that determined by Jaime et al. (2020) in orange-fleshed sweet potato flour. When evaluating different varieties of fresh sweet potato, Sánchez et al. (2019) also observed that the purple varieties had much higher acidity values than the rest, especially compared with the orange-fleshed varieties. The authors attribute this parameter as a distinctness, not only in terms of flavor but also in terms of preservation capacity and culinary properties. PFSP flour presented an average pH value of 5.97, which is similar to that of 5.9 and 6.0 found by Sánchez et al. (2019) in fresh purple sweet potatoes.

The great importance of PFSP flour In the human context becomes evident when considering nutritional needs. It can be used as a nutritional supplement to help populations that have problems related to malnutrition, as sweet potato is a food that can provide caloric deficiencies and certain nutritional compounds, such as B-complex vitamins and vitamin A, in addition to minerals such as iron, calcium, potassium, sulfur, and magnesium (Vizzotto et al., 2018).

3.2.2 Color

The need for standardization of the color scale is extremely important from an analytical point of view because a product can have different colors when viewed with the unaided eye and by different people. Therefore, a color determination needs to be expressed objectively through numbers to avoid possible problems and ensure that the product follows its specifications (Leite, 2017).

The mean L*(lightness), a* (red-green coordinate), and b* (yellow-blue coordinate) values for the color parameters found in this study were 50.88 ± 1.22, 18.19 ± 0.63, and 11.18 ± 0.27, respectively. In addition, the chroma, hue, and color index (CI) parameters were found to be 21.36 ± 0.66, 31.59 ± 0.44, and 33.50 ± 0.92, respectively. Leite (2017) evaluated the color parameters in samples of different sweet potato varieties; for two batches of sweet potato SCS370 Luiza, of lyophilized purple flesh, the values 43.75 and 43.38 were found for the L* coordinate, indicating that the evaluated samples had lower luminosity than those of this study. The value of a* (10.28 and 10.73) indicates that the evaluated PFSP flour tended to be redder than the evaluated by the author; for parameter b* (-4.7 and 3.41), it also showed a lower value, indicating that the studied PFSP flour tends to be more yellow. The hue values depend on the relative amount of red and yellow colors, while the chroma values indicate the color saturation or intensity, being more attractive to the purchaser (Monteiro & Pires, 2016). This study showed a chroma value of 21.36 and a hue value of 31.59. Compared with the one found by Leite (2017), the chroma (11.31 and 11.27) was higher. However, concerning the hue (335.37 and 342.33), the value was lower.

When studying native flours of four PFSP varieties, Phomkaivon et al. (2018) found significantly varied values, from L*, a*, and b*. In comparison with the flour in this study, the native flours of the four varieties showed lower values of a* (7.51, 11.66, 4.28, and 4.84) and b* (4.94, 1.58, 10.90, and 12.5) and higher L* (75.44, 66.85, 79.04, and 76.41), being lighter and less red flours. In this way, the variation of the color parameters is perceived according to the sweet potato variety, which may be related to the anthocyanin levels. According to Cesa et al. (2017), there is a correlation between the total anthocyanin content and the color parameters.

The consumer's first contact with a product is generally with the visual presentation, where the color and appearance stand out. Each product has an expected appearance and color that is associated with personal reactions of acceptance, indifference, or rejection (Tavares et al., 2022). The quality of dry products is assessed from the point of view of consumers through appearance, with color being the organoleptic characteristic that defines their acceptability and purchase intention. Therefore, PFSP flour presented a characteristic color close to the vegetable that originated it.

3.2.3 Granulometry

An insignificant amount of the flour was retained in the larger meshes (gap of 0.500 mm and 1,000 mm). About 76.66% was retained in meshes ranging from 0.250 to 0.106 mm, as shown in Table 5.

Granulometry, meaning the particle size of flour after grinding, establishes an important aspect in preparing pasta and other derivatives, interfering in quality parameters such as water absorption and viscosity. Greater uniformity of granulometry promotes the development of a product with better sensory quality, mainly texture, flavor, and visual aspects, as the product is cooked evenly, which is the result of homogeneous water absorption (Borges et al., 2013). In this study, 87.87% of PFSP flour passed through the 0.250-mm sieve. According to Brasil (2005), referring to the granulometry of types 1 and 2 wheat flours, 95% of the product must pass through the 250-μm mesh sieve, which means that the grain size of the PFSP flour obtained in this study is below that recommended for wheat flour. However, most of the grain size of the PFSP flour is the stipulated size, which allows part of the wheat flour to be replaced by the PFSP flour in the preparation of bakery products.

Although the granulometric characteristic of the raw material is an essential aspect in the bakery product formulation, it does not mean that flour with extremely fine granulometry presents more quality because high percentages of fine particles in the mixtures can harm the internal structure (core) of bakery products, which may have high moisture and gumminess (Silva et al., 2009). Thus, tests on the application of PFSP flour in bakery products are necessary.

3.3 Technological evaluation of PFSP flour

3.3.1 Absorption index, water, milk, and oil solubility index, emulsifying activity, and emulsion stability

Table 6 shows the absorption and solubility values in water, milk, and oil in PFSP flour, as well as emulsifying activity and ES of PFSP flour. The water absorption index (WAI) of a food product measures the water holding capacity by the starch after

Table 5. Granulometry of PFSP flour.

Sieve opening (mm)	Mean± σ
1.000	0.25 ± 0.01
0.500	1.74 ± 0.06
0.250	12.13 ± 0.07
0.150	18.61 ± 0.08
0.106	45.92 ± 1.24
Sieve bottom	21.57 ± 1.34

Table 6. Absorption and solubility index in water, milk, and oil in g/g, and emulsifying activity and emulsion stability in PFSP flour are expressed as percentages (%).

	Water	Milk	Oil
Absorption index	1.54 ± 0.08	1.53 ± 0.13	1.43 ± 0.01
C.V (%)	5.40	8.29	0.65
Solubility index	17.5 ± 0.003	14.63 ± 0.016	–
C.V (%)	1.714	1.094	–
Emulsifying activity	–	–	14.05 ± 0.58
C.V (%)	–	–	4.13
Emulsion stability	–	–	81.59 ± 7.15
C.V (%)	–	–	8.76

swelling in excess water, which corresponds to the weight of the gel formed, and thus it is an index of the degree of starch gelatinization (Godswill, 2019). In PFSP flour, the WAI was 1.54 g/g, with potential application in viscous foods. According to Aletor et al. (2002), products that have WAI ranging from 1.49 to 4.92 g/g are considered acceptable substances in foods such as soups and sauces. Santana et al. (2017) determined the WAI for oat flour (0.85% and 1.20%), white wheat (1.15%), and passion fruit (4.85%) and related the low WAI for white wheat flour due to the high starch content and low solubility in cold water. The low WAI in PFSP flour can be explained by the high starch content and the low solubility in cold water, as well as in wheat.

According to Becker et al. (2014), a high milk absorption index (MAI) is desirable when the elaborated product is dairy, which helps in homogenizing the components and decreasing the probability of syneresis. With a value very close to the WAI, it appears that there is a considerable interaction between components of flour and milk, suggesting the application of PFSP flour in milk-based products.

The OAI consists of the ability of non-polar sites in the protein chain to trap oil. Therefore, oil absorption capacity (OAC) is determined by the quantity and quality of proteins present in the flour (Ofori et al., 2020). The OAC of food determines the mouth-feel, flavor retention, as well as shelf-stability of baked or fried foods (Ofori et al., 2020). The PFSP flour analyzed in this study had an OAI value of 1.43%, which is similar to that found by Santana et al. (2017) for banana flour (3.02 g/g), passion fruit flour (2.35 g/g), and oat flour (1.7 g/g). Also, Castilho et al. (2010) found OAI for the sweet lupin flour of 1.2–1.3 g/g, suggesting that the flours provide satisfactory values to perform functionality in industrialized foods. According to the authors, the oil absorption characteristic improves the palatability of the food by assigning adequate properties of consistency, viscosity, and adhesion, improving the texture quality. Thus, it is suggested that PFSP flour, analyzed in this study, can be functional in industrialized oil-based foods.

WSI is a sample referring to the amount of soluble solids and is often an indication of the degradation of starch molecules. It is also a parameter for measuring the conversion rate of starch during processing and reflects amounts of released polysaccharides from starch granules (Hatamian et al., 2020). The WSI for PFSP flour (17.50%) was close to that of 18–20% reported by Gomes et al. (2012) in cowpea bean flour. The PFSP flour showed higher solubility in water than in milk, and there was no solubility in oil.

Emulsifying properties are established in two categories, emulsifying capacity (EC) and ES. In the EC, the volume of oil that is emulsified per gram of food is verified. The stability of the emulsion is determined through the percentage reduction in the volume of the initial emulsion. To obtain good emulsifying and foaming features, proteins must have good surface hydrophobicity and a high degree of flexibility, which will allow good diffusion of the protein in the air/water and oil/water phases, where the surface tension will decrease, which means that it will act as an agent active tense (Pereda et al., 2005). It should be noted that PFSP flour has low emulsifying activity because the percentage of proteins found was low. However, good ES was obtained.

The value found by Porte et al. (2011) for the emulsifying activity was 48.06% for pumpkin seed flour and 48.14% for papaya seed flour. When compared with the values found in the study of PFSP flour (14.05%), very low emulsifying activity is observed. According to Santana et al. (2017), flours with low emulsifying activity are not of commercial interest for products that require this property, as is the case with meat products.

3.3.2 Foaming properties and gel-forming ability

After analyzing the foaming capacity, neither foam expansion nor stability in PFSP flour was observed. This result was expected, considering that PFSP flour is not rich in proteins, and the foaming property is directly related to protein denaturation. According to Porte et al. (2011), the absence of this property suggests inadequacy as an ingredient for ice cream, mousses, meringues, and other products that require this property.

Gelation results from the formation of a three-dimensional network by protein denaturation and changes in the structure of the polysaccharides, such as starch, during the thermal process (Adebowale & Lawal, 2003). In all concentrations of PFSP flour, there was gel formation. The gelation was directly proportional to the concentration of PFSP flour; that is, the higher the sample concentration, ranging from 2 to 20%, the greater the amount of formed gel.

PFSP flour is a product rich in carbohydrates with a low lipid content, exhibits gel formation boasts good absorption capabilities for water, milk, and oil, and shows remarkable notable solubility in both water and milk, low emulsifying activity, and good stability, without showing foaming properties. Therefore, the results indicate that the flour of this study can be satisfactorily used in food products as a thickener or in partial replacement of wheat flour, in addition to being used as a food supplement, as it has good nutritional qualities. Its use is already a reality. For example, it has already been incorporated into boiled pork sausage (Jin et al. (2012), bread (Cui & Zhu, 2022; Mariano & Arruda, 2016), snacks (Phomkaivon et al., 2018), and noodles (Nurdjanah et al., 2022).

4 CONCLUSION

PFSP flour has characteristics that allow its use as an ingredient with technological functional properties for several applications of interest to the food industry, such as meat products and bakery, dairy products, sauces, baby food, porridges, and creams.

The spouted bed drying technique was then shown to be suitable for drying the PFSP and obtaining flour, as the drying time of the raw material was relatively short (1 h and 30 min) when compared with conventional dryers, such as tray dryers (70°C for 18 h). The drying of PFSP, and its transformation into flour, presents itself as a good alternative for its use, avoiding the waste of raw material that is of no commercial value.

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