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Transformation of fresh yams (*Dioscorea trifida*) into flours and starches: sustainable options for the food industry contributing to the development of this production chain

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ABSTRACT: Despite the significant socioeconomic impact of yam cultivation in developing countries, this field needs more scientific studies and incentives. In Brazil, the absence of a developed processing chain has resulted in a considerable production loss due to the predominant form of commercialization (*in natura*). This study aimed was to examine the physicochemical and technological composition of yams of the species *Dioscorea trifida* L., including both white and purple varieties. The aim was to contribute to an increase in food utilization and technological potential. The proximate composition of the flours indicated that the yam species investigated have the potential for human consumption and are good sources of energy (1,489 and 1,527 kJ), with considerable levels of total fiber (8.18 and 6.69 g 100 g^{-1}), potassium (1,325 and 981 mg 100 g^{-1}), and phenolic compounds (133 and 110 mg 100 g^{-1}) for white and purple yams, respectively. Additionally, the yams demonstrated distinct properties in water and oil, indicating their potential for use in breading applications. The viscoamylographic profiles of purple yam flour and yam starches were found suitable for use in quick-cooking foods that reach high viscosity when heated, whereas white yam flour was identified as a suitable thickening agent. The yams yielded flours and starches with favorable characteristics as food ingredients, offering greater added value and enhanced stability compared to the original raw materials. They present a sustainable alternative for reducing post-harvest losses and, as they are gluten-free, they cater to the celiac population.

Keywords: tuber, gluten free, ingredient, sustainability

Introduction

Some Amazonian yams, which remain relatively understudied, including *Dioscorea trifida* L., have the potential to act as agents of socioeconomic transformation through practical applications that respect family farming and can add value to local culture. Despite the status of the Amazon region as a major producer of yams and the favorable conditions for cultivation, the region needs a developed processing chain. Consequently, a significant portion of the production is lost due to how yam is sold (*in natura*) and the prevalence of logistical challenges, given the remote location of the fields. *Dioscorea trifida* belongs to the Dioscoreaceae family and is native to tropical regions, including the Amazon. It was first cultivated by European and African immigrants in this region (Nascimento et al., 2023; Pérez et al., 2011). Despite its significant socioeconomic implications, this plant has been largely neglected in scientific research. As few as 29 scientific articles have been identified to address this particular species of yam (Cereda and Vilpoux, 2023). A literature review reveals that, in addition to carbohydrates (the major compounds), the species has a good protein content, low fat content, and high levels of minerals (phosphorus, calcium and iron), vitamins A, C and from the B complex. Additionally, the species contains other beneficial compounds, including anthocyanins (dyes and antioxidants) and bioactive compounds such as mucins, diosgenins, and phenolic compounds (Adoméniené and Venskutonis, 2022; Pérez et al., 2011). Similar to most tubers, *D. trifida* contains approximately 70 % water, making it susceptible to microbial attack. Therefore, how it is sold, fresh and stored at room temperature, contributes to its rapid deterioration, reducing its useful life. In this case, the drying process is of interest, as it reduces costs of transportation, handling, distribution, and storage, in addition to increasing the shelf life of raw materials with high moisture content (Santos et al., 2022). The species is appreciated for its slightly sweet flavor and excellent texture. In Brazil, the utilization of yam in its natural state is also limited to its consumption in a cooked state in a limited number of recipe options (puree, salad, soup, porridge, etc.) exclusively during the harvest season.

Flour and starch represent viable alternatives that can be employed to enhance the yam culture, safely increase its consumption, and enable its use as an ingredient in countless applications. They can contribute to the sustainability of the production chain, generate income for small producers, reduce post-harvest losses, and add value to the product. This study aimed to examine the physicochemical and technological composition of yams of the species *D. trifida*, including both white and purple varieties, to increase food utilization and technological potential.

Materials and Methods

Materials

The municipality of Caapiranga, Amazonas state, Brazil (3°19′42″ S, 61°12′34″ W, altitude 34 m), provided samples of fresh yams of the species *D. trifida* (white and purple varieties) from the 2020 harvest.

The yam flour (white and purple) was obtained by the specifications outlined in Figure 1.

Sample preparation

The operations diagram utilized in this research to obtain yam flours is presented in Figure 1, based on Santos et al. (2010) with adaptations. The starches were isolated from yams (white and purple) according to the aqueous separation procedure described by Cruz and El Dash (1984). This involved separation in a blender (max speed, 2 min), crushing of 100 g of yam pulp with 400 mL of distilled water, passed through a sieve (mash size of 63 mm), then centrifugation at 1,008 g (15 min). The adjacent layer was resuspended in distilled water and subjected to two further centrifugations. The suspension was then dried at 50 °C for 24 h.

Characterization

The moisture content of the yam flour was determined using the AOAC (2022) method 925.10, while the protein content was assessed using method 979.09, with a conversion factor of 6.25. The ash content was evaluated using method 923.03, and the total dietary fiber was determined using the method 985.29. Additionally, the insoluble and soluble dietary fiber contents were quantified using the method 991.43. The total fat content was determined in accordance with the IAL (2005) method 034B. The methodology proposed by Diemair (1963) determined the starch content. The mercury content was determined by the method proposed by Morgano et al. (2015), while the arsenic, cadmium, and lead content was based on the approach outlined by Slavin et al. (1975). The quantities of the elements calcium, iron, phosphorus, and potassium were determined using the official methods of the AOAC

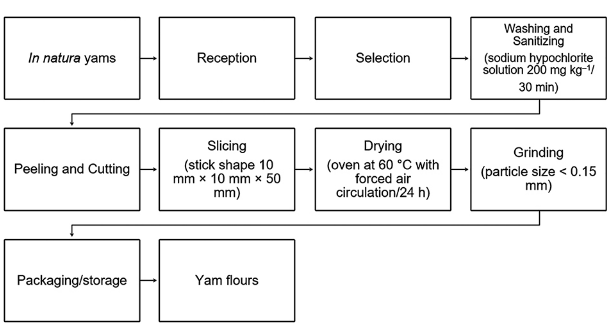

Figure 1 – Diagram of operations for obtaining yam flours.

(2022), specifically 985.35 and 984.2. The analysis of total phenolic compounds was based on the methodology described by Kim et al. (2003). The carbohydrate content was calculated by difference, and the energy value was obtained by considering the energy conversion factors: 9 kcal g^{-1} for lipids, 4 kcal g^{-1} for proteins, and 4 kcal g^{-1} for digestible carbohydrates. All analyses were performed in triplicate.

The color parameters of *in natura* yams (peel and pulp) and their flours (without peel) were evaluated using the CIELab system with a colorimeter (CR-10 - Konica Minolta). The yam flours were also evaluated using the RGB (Red, Green and Blue) system, as described by Ayustaningwarno et al. (2021), through images captured with a semi-professional camera, processed in the Adobe Photoshop Lightroom CC 2016 program, and subsequent color distribution analysis in the ImageJ program (Color Inspector plugin 3D, v. 2.3). Chroma is a quantitative attribute of color and was calculated as shown in Eq. (1).

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}} \tag{1}$$

where C^*_{ab} = Chroma; a^{*2} = color green - red; b^{*2} = color blue – yellow.

The pasting properties of *D. trifida* yams, comprising white and purple varieties, were evaluated using a Rapid Visco Analyzer (RVA) model RVA-4500 viscometer (Perten Instruments), according to the heating profile of method 76-21.01 AACCI (2012). The yam starch and flour were used 2.5 % and 3.0 %, respectively.

The parameters determined and subsequently evaluated were as follows: paste temperature, maximum viscosity, minimum hot viscosity, final viscosity, breakdown, tendency to retrogradation (setback), and peak time. The pastes obtained from RVA analysis were evaluated for their textural properties using texture profile analysis (TPA) with the TA (Texture Analyzer). The XT2i texture analyzer (Stable Micro Systems L), as Sandhu and Singh (2007) described, was utilized. For analysis, the cooked paste was placed in the RVA's aluminum container, covered with plastic film, allowed to cool, and stored in a refrigerator (5 ± 2 °C) for 16 h. Following this, the paste was equilibrated at room temperature for 2 h before analysis. The TPA was conducted using a 25 mm diameter acrylic cylindrical probe, a test speed of 0.0005 m s^{-1} at a distance of 10 mm, and a 50 kg load cell. All analyses were performed in duplicate or more.

The thermal properties of white and purple yam varieties (*Dioscorea trifida*), in both starch and flour forms, were analyzed using a Differential Scanning Calorimetry (DSC) instrument (Mettler Toledo model DSC1), with sample preparation and temperature range based on the method described by Felisberto et al. (2019). All analyses were performed in duplicate or more.

The water absorption index (WAI) is defined as the weight of gel obtained per gram of dry sample previously submerged in water and subsequently drained. The water solubility index (WSI) is defined as the amount of solids remaining after drying in the recovered water absorption analysis. Both methods were evaluated using the methodology proposed by Anderson (1982). All analyses were performed in duplicate or more.

The oil absorption capacity (OAC) was determined in accordance with the methodology delineated by Lin et al. (1974), with the calculation based on the supernatant layer, according to Eq. (2). A quantity of 0.5 g of the sample was added to 5 mL of soybean oil at a temperature of 25 °C. The mixture was subjected to alternating processes of homogenization (vortexing for 10 s) and rest (5 min), repeated over 30 min. It was then centrifuged at 595 g for 25 min and the supernatant was removed by inverting the tube, allowing the oil to drain for 2 min. All analyses were performed in duplicate or more.

$$OAC = \frac{oil\ absorbed\ by\ the\ sample\ (g)}{sample\ weight\ (g)} \quad (2)$$

Statistical analyses

The data from the analyses, which were performed in duplicate, were subjected to analysis of variance (ANOVA) using the SISVAR 5.6 program. When significant, the Scott-Knott test was employed to determine statistical differences between means ($p \leq 0.05$).

The data obtained from the analyses, performed in triplicate, were subjected to ANOVA using the SISVAR 5.6 program. When statistically significant, the F-test was employed to ascertain the existence of statistical differences between the means ($p \leq 0.05$) utilizing Excel software (Microsoft Office Mondo v. 2016).

Results

Physicochemical composition of yam flour

The proximate composition of the flours obtained *in natura* from *D. trifida* varieties white and purple, which were subjected to a drying process at 60 °C for 24 h, is presented in Table 1.

No significant difference was observed between the varieties with respect to the contents of ash, total fat, and soluble dietary fiber. In both varieties, carbohydrates constituted the majority of nutrients, primarily in the form of starch, indicating that yam flour could be a valuable source of energy. The total fat content in the flours of both varieties was practically identical. Analyses were conducted, and both yam flours were found to be safe with regard to heavy metals, specifically arsenic and mercury, which were not detected. Phenolic compounds were identified in both white yam flour and purple yam flour.

Visual aspects and instrumental color of yams

The visual characteristics of *D. trifida*, encompassing both the white and purple yam varieties, are depicted in Figure 2, in fresh and flour forms. The color parameters of the peels, pulps, and flours are presented in Table 2, while the graphs of the main shades that comprise he color of the flours are shown in Figure 3. The two varieties exhibited similar external appearances, characterized by

Table 1 – Physicochemical composition of *Dioscorea trifida*, white yam and purple yam varieties in flour form on a dry basis.

Composition	Yam Flour	
	White	Purple
Moisture (g 100 g^{-1})	10.46 ± 0.85^{b}	12.07 ± 1.22^{a}
Ash (g 100 g^{-1})	3.03 ± 0.04^{a}	2.49 ± 0.15^{a}
Proteín (g 100 g^{-1})	4.17 ± 0.09^{a}	3.14 ± 0.40^{b}
Total fats (g 100 g^{-1})	0.25 ± 0.02^{a}	0.26 ± 0.08^{a}
Total dietary fiber (g 100 g^{-1})	8.18 ± 0.21^{a}	6.69 ± 1.03^{b}
Soluble dietary fiber (g 100 g^{-1})	3.61 ± 0.10^{a}	3.02 ± 1.31^{a}
Insoluble dietary fiber (g 100 g^{-1})	4.57 ± 0.12^{a}	3.67 ± 0.28^{b}
Total carbohydrates (g 100 g^{-1})	84.37 ± 0.30^{b}	87.42 ± 0.57^{a}
Starch (g 100 g^{-1})	72.30 ± 1.00^{b}	80.64 ± 0.62^{a}
Energetic value (kcal 100 g^{-1})	356^{b}	365^{a}
Total phenolic compounds (mg 100 g^{-1})	133 ± 3^{a}	110 ± 4^{b}
Arsenic (mg kg^{-1})	< 0.1**	< 0.1**
Calcium (mg 100 g^{-1})	16.20 ± 0.40^{a}	6.26 ± 0.18^{a}
Cadmium (mg kg^{-1})	< 0.1**	< 0.1**
Lead (mg kg^{-1})	< 0.1**	< 0.1**
Iron (mg 100 g^{-1})	1.26 ± 0.03^{a}	1.03 ± 0.04^{a}
Mercury (mg kg^{-1})	< 0.1**	< 0.1**
Phosphorus (mg 100 g^{-1})	96 ± 3^{a}	59 ± 1^{a}
Potassium (mg 100 g^{-1})	1,323 ± 33^{a}	981 ± 19^{a}

The results are the means ± standard deviation of three determinations. Data in the same row with different letters indicate a significant difference using the Scott-Knott test ($p \leq 5$). **not detectable.

Table 2 – Color of the peel, pulp, flour and starch of *Dioscorea trifida*, white yam and purple yam varieties.

Parameters	Peels		Pulps		Flours		Starches	
	White Yam	Purple Yam	White Yam	Purple Yam	White Yam	Purple Yam	White Yam	Purple Yam
RGB[1]								
L	37.13 ± 0.58^{b}	38.71 ± 0.41^{a}	79.51 ± 1.48^{a}	45.16 ± 2.42^{b}	75.79 ± 0.24^{a}	61.85 ± 0.18^{b}	97.48 ± 0.62^{a}	98.07 ± 0.55^{a}
a*	6.73 ± 1.30^{a}	6.19 ± 0.09^{a}	4.63 ± 0.42^{b}	13.11 ± 1.06^{a}	5.16 ± 0.06^{b}	7.06 ± 0.10^{a}	117 ± 0.13^{a}	0.48 ± 0.10^{b}
b*	14.95 ± 1.71^{a}	15.38 ± 1.29^{a}	16.15 ± 1.71^{a}	–1.66 ± 0.71^{b}	14.11 ± 0.07^{a}	3.80 ± 0.03^{b}	–0.14 ± 0.08^{b}	1.78 ± 0.24^{a}
C^{*}_{ab}	16.39 ± 1.21^{a}	16.57 ± 1.09^{a}	16.80 ± 1.04^{a}	3.52 ± 0.05^{b}	15.02 ± 0.17^{a}	8.02 ± 0.09^{b}	117 ± 0.25^{b}	1.84 ± 0.20^{a}

The results are the means ± standard deviation of three determinations. Data in the same row with different letters indicate a significant difference using the Scott-Knott test ($p \leq 5$). 1Lab parameters were converted to RGB (Red, Green and Blue) scaling, resulting in the colors illustrated in the table. L = luminosity; a* and b* indicate the directions that the color can take (+a* = red and –a* = green; +b* = yellow and –b* = blue); C^{*}_{ab}= chroma.

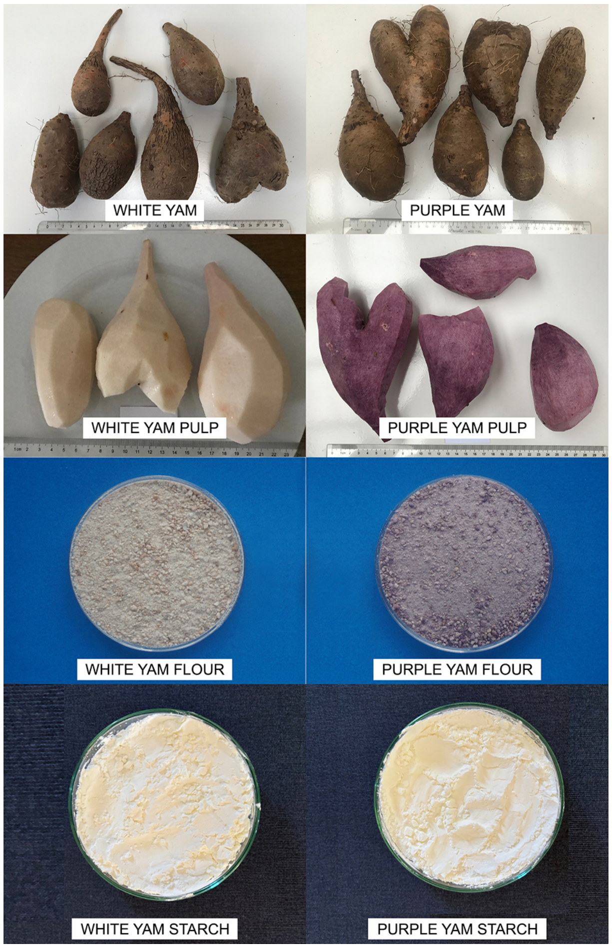

Figure 2 – Visual aspects of *Dioscorea trifida*, white and purple yam varieties, in whole, fresh without shell, flour and starch forms.

a brownish skin with lint and similar shapes ("heart" and "drop"). However, it was only possible to differentiate them visually after peeling when the colors of the "white" and "purple" pulps, characteristic of "white yams" and "purple yams", respectively, became evident.

The color was determined in the Commission Internationale de I'Eclairage (CIEL*a*b*) system employing the following parameters: L* (brightness), a* and b* (chromaticity coordinates). In this system, L* indicates the luminosity (0 = black and 100 = white) and a* and b* indicate the directions that the color can take (+a* = red and –a* = green; +b* = yellow and –b* = blue).

The results of the skin color analysis (Table 2) corroborated the visual impression, as both varieties exhibited similarities in chromaticity, with no statistically significant difference between the a* and b* values. With regard to luminosity, the L* values indicated that the purple yam skins exhibited a slight lightness compared to those of the white yam. The brownish hue of the peel was attributed to the positive a* and b* values, with the purple yam peel exhibiting a more pronounced orange tone. The results of pulp color analysis (Table 2) also corroborated the visual impression, as the analyzed varieties' luminosity and chromaticity exhibited notable discrepancies. The color of the white yam pulp can be attributed to the high incidence of luminosity, which prevailed over the positive chromaticity of the a* and b* parameters, resulting in a light pulp with color parameters situated within the yellow light region. The chromaticity parameter values of a* and b* considerably influenced the color of the purple yam pulp, which exhibited a hue indicative of a mixture of red and blue, with medium luminosity. Following grinding, the flours derived from *D. trifida*, white and purple varieties, retained the tones of their respective pulps, as illustrated in Table 2. The predominant colors and the proportion of each in the final composition of the flour shades are illustrated in Figure 3. In the case of white yam, the positive chromaticity of the a* and b* parameters resulted in a yellowish color for the flour, which is slightly darker than its pulp, due to the lower incidence of light. In contrast, the higher luminosity in the purple yam resulted in a lighter color (lilac or violet) of the flour compared to its pulp (purple). Additionally, both yam flours exhibited some darker particles, which stood out.

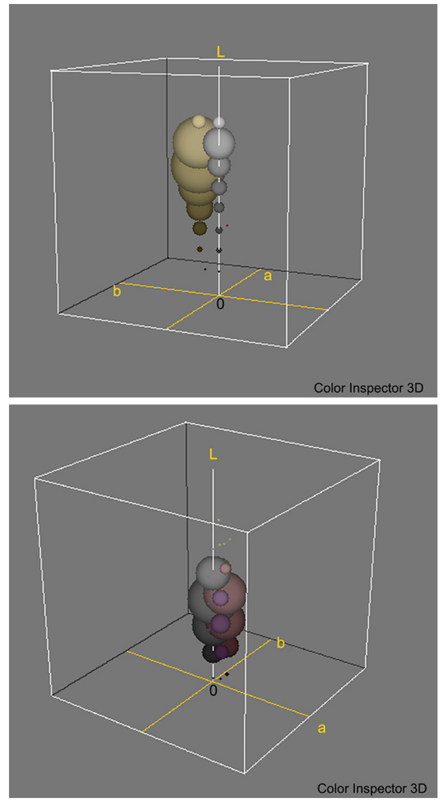

Figure 3 – Graphical representation of the color distribution of flours obtained from *Dioscorea trifida*, white and purple yam varieties, respectively.

Technological assessment

The mean values obtained from the evaluation of yam flours in relation to their characteristics in aqueous and lipophilic environments are presented in Table 3.

The WAI analysis revealed no significant difference between the white and purple yam flour samples. The OAC results for white and purple yam flour were found to be similar and did not show any statistically significant difference between the two.

The results of the pasting properties of yam starches (white and purple), in isolated forms and their flours, respectively, obtained by RVA, Texturometer, and DSC are presented in Table 4.

For comparative purposes, Figures 4 to 7 show the viscoamylograms obtained by RVA of yam starch pastes (white and purple), in isolated forms and their flours, respectively.

The viscoamylograms obtained from RVA demonstrated that the isolated starches (white yam and purple yam) exhibited similar profiles when isolated but markedly disparate profiles when formulated into flours. These findings are illustrated in Figures 4 to 7 and are summarized in Table 4.

With regard to the gelatinization phenomenon, the white and purple yams, in the form of flours, exhibited slightly higher temperatures than when they were in isolated form. A comparison of the RVA gelatinization temperature

Table 3 – Results of the evaluation of yam and cassava flours regarding their properties in water and oil.

Parameters	Flour	
	White Yam	Purple Yam
WAI (g g^{-1})	2.40 ± 0.04^{b}	2.17 ± 0.06^{b}
WSI (%)	18.76 ± 0.56^{a}	14.59 ± 0.91^{b}
OAC (g g^{-1})	1.11 ± 0.07^{a}	1.07 ± 0.02^{a}

WAI = water absorption index; WSI = water solubility index; OAC = oil absorption capacity. The results are the means ± standard deviation of three determinations. Data in the same row with different letters indicate a significant difference using the Scott-Knott test ($p \leq 5$).

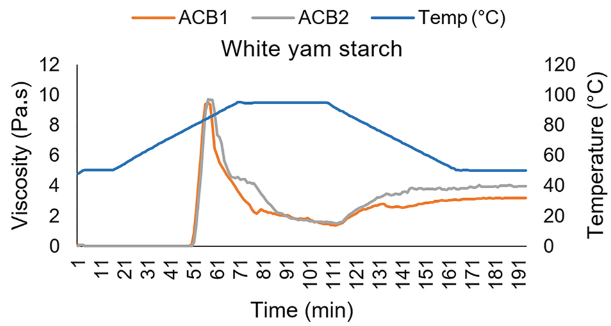

Figure 4 – Viscoamilogram of white yam starch (ACB) obtained by Rapid Visco Analyzer (RVA), in duplicate. Temp = temperature.

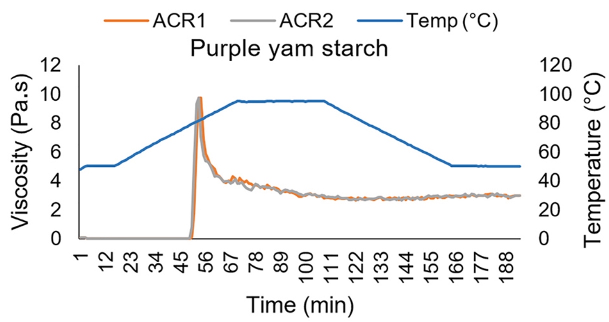

Figure 5 – Viscoamilogram of purple yam starch (ACR) obtained by Rapid Visco Analyzer (RVA), in duplicate. Temp = temperature.

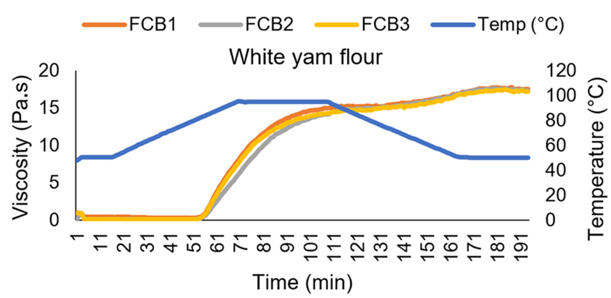

Figure 6 – Viscoamilogram of white yam flour (FCB) obtained by Rapid Visco Analyzer (RVA), in triplicate. Temp = temperature.

Table 4 – Properties of yam (white and purple) starch paste and flour past.

Equipment	Parameters	Starch		Flour	
		White Yam	Purple Yam	White Yam	Purple Yam
RVA	Peak viscosity (Pa·s)	9.514 ± 1.448^{a}	8.299 ± 2.004^{a}	1.429 ± 0.040^{c}	4.468 ± 0.132^{a}
	Breakdown (Pa·s)	8.066 ± 0.154^{a}	5.646 ± 2.004^{b}	0.149 ± 0.038^{c}	1.906 ± 0.120^{a}
	Setback (Pa·s)	2.135 ± 0.451^{a}	0.310 ± 0.004^{b}	0.450 ± 0.063^{b}	0.565 ± 0.097^{b}
	Final viscosity (Pa·s)	3.583 ± 0.544^{a}	2.963 ± 0.004^{b}	1.731 ± 0.016^{c}	3.128 ± 0.107^{b}
	Paste temperature (°C)	79 ± 0.04^{a}	79 ± 0.07^{a}	82 ± 0.08^{a}	81 ± 0.38^{b}
	Peak time (min)	3.87 ± 0.00^{a}	3.64 ± 0.05^{b}	7.00 ± 0.00^{a}	5.05 ± 0.24^{b}
Texture	Gel firmness (N)	6.34 ± 0.69^{a}	6.72 ± 0.12^{a}	0.34 ± 0.01^{c}	2.06 ± 0.11^{b}
DSC	H (mJ)	–39.37	–23.74	–20.18	–26.55
	ΔH (J g^{-1})	–3.58	–2.12	–1.98	–2.45
	T_0 (°C)	73.89	73.60	75.69	75.45
	T_p (°C)	76.23	75.50	79.00	78.15
	T_f (°C)	79.75	78.34	82.86	81.49

The results are the means ± standard deviation of at least two determinations. Data in the same row with different letters indicates a significant difference. RVA = Rapid Visco Analyzer; DSC = differential scanning calorimetry. T0 = past temperature; Tp = peak time; Tf = final temperature.

data with the DSC parameters revealed that the results fell within the gelatinization range as determined by the DSC analysis. The highest peak viscosities were observed for yams in isolated form. The peak viscosity parameters, paste temperature, and peak time exhibited significant variation between the varieties of yams studied when prepared as flours. Conversely, the highest breaking viscosities were observed for yams prepared in an isolated fo rm. When prepared as flour, the breaking viscosity results exhibited notable divergence between the varieties of yam studied. With regard to viscosity behavior during cooling, white yam starch demonstrated the highest setback value when compared to purple yam (starch and flour).

The highest final viscosity values were observed for white yam starch, followed by purple yam flour, purple yam starch, and white yam flour.

For comparison purposes, Figures 8 and 9 show images of gels after 24 h of refrigeration, obtained by RVA from yam starch pastes (white and purple) in isolated forms and from their flours.

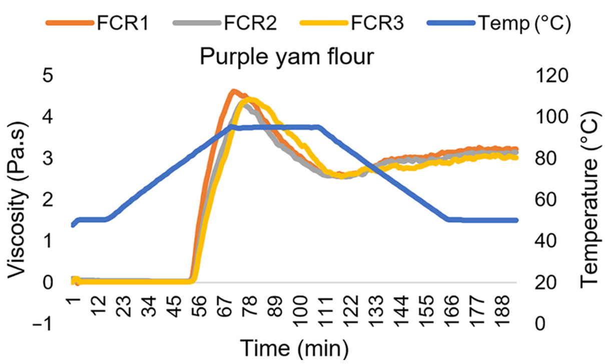

Figure 7 – Viscoamilogram of purple yam flour (FCR) obtained by Rapid Visco Analyzer (RVA), in triplicate. Temp = temperature.

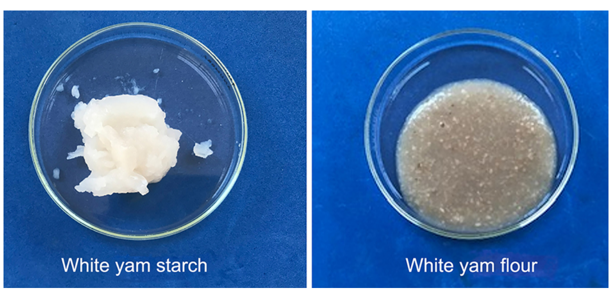

Figure 8 – Photographs of the white yam gels (starch and flour), after 24 h of refrigeration.

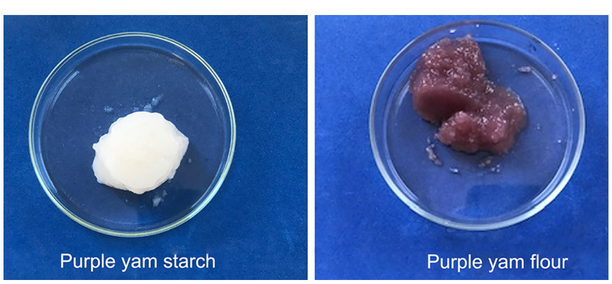

Figure 9 – Photographs of the purple yam gels (starch and flour), after 24 h of refrigeration.

Discussion

Physicochemical composition of yam flour

A literature review revealed a paucity of data regarding the characterization of yam flour. Except for fiber and moisture content, all other parameters of the nutritional composition of the yam flour in this study yielded results that were lower than those reported by Rached et al. (2006). In contrast, a comparison with another study revealed that all parameters were higher, except fat, moisture, and ash (Teixeira et al., 2016). The humidity of the yam flour falls within the range permitted by current Brazilian legislation, establishing a maximum value of 14 % (ANVISA, 2005). This is consistent with the findings reported in the literature (Rached et al., 2006; Teixeira et al., 2016). The high carbohydrate content, consisting mainly of starch, indicates that yam flour could serve as an excellent source of energy for humans. Starch contents of approximately 65 % have been documented in other root and tuber crops, including cassava, potatoes, and cereal grains. The carbohydrate content of purple yam flour was reported to be 89.90 %, while white yam flour was reported to be 90.50 % (Rached et al., 2006). In contrast, the carbohydrate content of white yam flour was reported to be 83.95 % by Teixeira et al. (2016).

The dietary fiber values reported in this research for the flour varieties *D. trifida*, white yam and purple yam, are significantly higher than those reported by Teixeira et al. (2016) and in comparison to other commercial flours listed on the Brazilian Food Composition Table (TACO), including rice (0.6 %), yellow corn flour (5.5 %), wheat flour (2.3 %), and cassava flour (6.4 %) (UNICAMP, 2011). Dietary fibers are essential for the optimal functioning of the digestive system in humans and animals. When ingested in adequate quantities, they enhance the water retention capacity, thereby regulating the intestine and conferring physiological benefits. These include the reduction of blood sugar and cholesterol levels, the elimination of toxic substances, and the promotion of intestinal flora growth.

The protein levels found in *D. trifida* flour, white yam, and purple yam varieties were similar to those reported in the literature for the same varieties and exhibited a higher concentration in relation to cassava flour (1.6 %) (Rached et al., 2006; Teixeira et al., 2016; UNICAMP, 2011). Protein is vital for the growth and development of organs in humans and animals. It plays a crucial role in the reconstruction of body tissues, the synthesis of hormones and enzymes, and other vital biological processes.

The total fat content of the flours from both varieties was practically identical, with levels significantly lower than those reported in the scientific literature (Rached et al., 2006; Teixeira et al., 2016). The presence of fat, even in minimal quantities, is crucial for the supply of energy and the functionality of the starch.

The ash contents of *D. trifida* flour, purple yam, and white yam varieties were found to be in close alignment of scientific reports from previous studies (Rached et al., 2006; Teixeira et al., 2016). Inorganic compounds encompass metals essential for the functioning of metabolism and others that are harmful to health and can be fatal and carcinogenic. Analyses demonstrated that both yam flours are free of arsenic and mercury, which were undetected.

In accordance with the current legislation on labeling in Brazil (ANVISA, 2020), each 100 g of yam flour (white and purple, respectively) described in this research would provide the following nutrient values: 18 % of the daily value (DV) for energy, 28 to 29 % DV for carbohydrates, 6 to 8 % DV for proteins, 0.4 % DV for total fat, and 27 to 33 % DV for total dietary fiber (ANVISA, 2020). Given the high fiber content, yam flour can be considered a natural source of this nutrient. Consequently, depending on the specific product and portion size, food formulations containing yam flour may be eligible as a "source" or "high fiber content" claim on the label.

The presence of phenolic compounds in both white yam flour and purple yam flour may account for the observed results regarding pigments, as evidenced visually and instrumentally in this investigation. A recent literature review has indicated the presence of phenolic compounds in the genus *Dioscorea*. Furthermore, the presence of total anthocyanin content (TAC), total phenol content (TPC), and antioxidant activity of pigments extracted from *D. trifida*, where the compounds were identified: pelargonidin, cyanidin, peonidin glycosides and other derivatives, have been described by Ramos-Escudero et al. (2010). A higher antioxidant capacity, as well as higher TPC and TAC values, were observed for freeze-dried purple yam powder in comparison to dried products, as reported by Santos et al. (2022). Bioactive compounds, such as phenolics, have the ability to act on cellular metabolic activities, thereby promoting a range of health benefits, including antioxidant, antihypertensive, anti-inflammatory, and antidiabetic effects, among others.

A wide variation in nutritional composition has been documented in studies on the genus *Dioscorea*, with variations influenced by several factors, including species, variety, edaphoclimatic conditions, agronomic practices, degree of maturity, and analytical methodology, among others. The same was observed in the varieties studied in this work, namely white and purple yam of *D. trifida*. However, further scientific studies are necessary to gain a deeper understanding of these species, to ensure their preservation, and to ascertain their value, thus contributing to the advancement of scientific knowledge and the development of the production chain.

Visual aspects and instrumental color of the yams

The two varieties exhibited morphological characteristics similar to those described in the literature by Pérez et al. (2011).

The results of the skin color analysis (Table 2) corroborated the visual impression, as both varieties exhibited similarities in chromaticity, with no statistically significant difference in the values of a* and b*. The chroma index (C^*_{ab}) provided information regarding the vibrancy of the color, whereas the L* values indicated that the peel of the purple yam is slightly lighter than that of the white yam in terms of luminosity. The brownish tone of the peel was attributed to the positive values of a* and b*, with the purple peel of the yam exhibiting a more pronounced orange tone. The results of the color analysis of the purple yam pulp differed from those reported by Santos et al. (2022), who analyzed the same sample and reported the following values: L* = 22.37, a* = 7.41, and b* = 1.41. The yam flours exhibited a prevalence of darker particles, which distinguished them from the others. This phenomenon may be attributed to the presence of sugars, which, during the drying process, may have initiated darkening reactions. The light shade may be conducive to using these flours in bakery products, including traditional or wholemeal items such as breads, cookies, and cakes.

The observed variation in the colors of the yam pulps analyzed in this research may have been influenced by natural pigments, including anthocyanins and carotenoids. Anthocyanins are known as purple, blue, and black hues, while carotenoids are responsible for yellow, orange, and red.

Assessment analyses of technological characteristics

The lower solubility (water solubility index - WSI) of purple yam flour may be attributed to its higher starch content in comparison to that observed in white yam flour, as illustrated in Table 3. Given their high starch content, all flours exhibited low water solubility, indicating a limited capacity for weight gain. This property may present a challenge in terms of their use in instant foods. The WAI results suggest that the starch absorption capacity of all flours in cold water is limited. The OAC results for white and purple yams indicate that the flours have low solubility in oil, which allows their use in breading products.

The utilization of Rapid Visco Analyzer (RVA) data facilitates the assessment of starches in relation to their behavior during heating in water, gelatinization, and retrogradation. This is crucial to ascertaining their potential as ingredients and potential applications.

Many studies have reported that the peak temperatures of roots and tubers typically range from 50 to 60 °C. In contrast, cereal and legume starches have been observed to reach temperatures above 60 °C (Schmiele et al., 2019). However, the present research findings suggests that peak temperatures for yams may be considerably higher, reaching approximately 80 °C.

A comparison of the gelatinization temperature data obtained by RVA with the DSC parameters (Table 4) revealed that the results fell within the gelatinization range as determined by the DSC. Similar temperatures were reported by Pérez et al. (2011) when studying starches from the same varieties, while markedly different values were reported by Santos et al. (2022) when studying purple yam starch. The following ranges were reported for starch from the *Dioscorea opposita* Thumb. variety: paste temperature (T_0 = 68.4 to 71.5 °C), peak time (T_p = 72.4 to 74.4 °C), and final temperature (T_f = 76.8 to 78.2 °C) (Tagliapietra et al., 2021).

The high temperatures observed in yam paste (isolated starches and flours) can be attributed to the formation of robust bonds inside the granule, making it resistant to rupture under heating conditions. This property presents an intriguing potential for utilization as thickeners in the food industry (Santos et al., 2022). Lower pasting temperatures (approximately 76 °C) were reported by Pérez et al. (2011) for starches from the same varieties (white and purple yams), the same used in this study. Similar values (approximately 80 °C) for purple yam starch were reported by Santos et al. (2022), while similar results in relation to flours from the same yam varieties were observed by Rincón et al. (2000). With regard to the starch derived from the *D. opposita* variety, the range of 72.13 to 73.95 °C has been documented (Tagliapietra et al., 2021). These inconsistencies can be attributed to several factors, including the amylose/amylopectin ratio, botanical origin, granule size and distribution, among others.

The results indicate that the degrees of association of yam starch granules (white and purple) in isolated form are more fragile than in flour form. This is due to lower paste temperatures and peak times, which suggest that the starch suspensions of both varieties are easier to cook than their flours.

The highest peak viscosities were observed for yams in isolated form, for white yam starch and purple yam starch. This indicates that these samples have a high-water retention capacity prior to breaking. A literature review revealed that the peak viscosity values reported for this yam species are significantly higher than those observed in our study. Some studies have reported the following values for peak viscosity: 4.178 Pa·s for purple yam starch found (Santos et al., 2022) and 1.667 Pa·s and 2.037 Pa·s for white and purple yam starch, respectively (Pérez et al., 2011). With regard to starch from the *D. opposita* variety, peak viscosity values within the range of 4.794 Pa·s to 8.590 Pa·s have been reported (Tagliapietra et al., 2021).

The peak viscosity, paste temperature, and peak time parameters of the yam varieties differed significantly when expressed in the form of flour. This suggests that purple yam flour exhibits a greater water retention capacity prior to breaking. The lower peak viscosity value of white yam flour may be related to its higher protein content (4.17 %) when compared to that of purple yam flour (3.14 %), as protein can hinder the swelling of the granule of starch, forming a physical barrier. A negative correlation between protein content and peak viscosity was reported by El Saied et al. (1979). Flours in suspension at 8.6 % were analyzed by Rincón et al. (2000) from the same varieties of yam in a Brabender viscometer. The author found significantly lower peak viscosity results, reporting values of 0.360 Pa·s and 0.180 Pa·s for white and purple yam, respectively.

The highest breaking viscosities were observed for yams in isolated form, exhibiting a markedly elevated viscosity compared to previously documented scientific reports for the same yam species. The value of 1.796 Pa·s for purple yam starch was found by Santos et al. (2022), while values of 0.375 Pa·s and 0.695 Pa·s were reported for white and purple yam starch, respectively, by Pérez et al. (2011).

The viscosity of yam flour samples differed significantly between the studied varieties, with white yam flour demonstrating greater stability than purple yam flour. When analyzed in their isolated form, the yams exhibited lower paste stability than flour, indicating they are more susceptible to mechanical forces and/or heating, as evidenced by their higher breaking viscosity values.

With regard to the viscosity behavior exhibited during the cooling process, the white yam starch demonstrated the highest setback value, indicating a greater propensity for retrogradation than the purple yam starch and flour.

The final viscosity is defined as the ability of starch to form a paste after undergoing a heating and cooling cycle. The findings suggest that products made with white yam flour exhibit reduced viscosity compared to those produced with other flours. A setback value of 0.591 Pa·s and a final viscosity of 3.002 Pa·s was found by Santos et al. (2022) for purple yam starch, whereas negative setback values (–0.397 Pa·s and –0.764 Pa·s) for yam starch white and purple, respectively, were reported by Pérez et al. (2011). The final viscosity range of 6.335 to 7.636 Pa·s has been reported for starch derived from the *D. opposita* variety (Tagliapietra et al., 2021).

A comparison of the texture results obtained after 24 h of refrigeration (Table 4) with the accompanying photographs (Figures 8 and 9) indicates that the gels derived from yam starches are significantly firmer than those produced from their flours. This is evidenced by the higher values of the gel firmness parameter observed in the gels derived from starches. All starch gels appeared white and opaque, including that of purple yam, which is a highly desirable commercial quality. In contrast, the appearance of the flour gels preserved the color of the pulp of the original tuber, a quality particularly evident in the case of purple yam flour. The white yam gel exhibited a notable lack of strength compared to the others.

This project demonstrated that *D. trifida*, which exhibits white and purple varieties, can be processed into yam flour suitable for human consumption. The results of the physicochemical and technological characterization indicated that the flour has the potential to be valuable for energy, as it contains over 80 % carbohydrates and high levels of fiber, potassium and phenolic compounds, which are beneficial for health.

Starches from yams (obtained by aqueous separation) were isolated and found to possess technological characteristics with potential for use in the food industry. Both yam flours exhibited low values in relation to water and oil properties, indicating that they could be utilized in breading products.

The yams studied in this work, specifically the *D. trifida*, including booth white and purple varieties, yielded starches and flours with favorable characteristics as potential ingredients for food applications. The paste profiles of the purple yam flour and starches were suitable for quick-cooking foods, such as soups, broths, and sauces, which reach viscosity when hot. The low tendency of purple yam starch to retrograde makes it suitable for use in products that require firmness during refrigeration, such as puddings and flans. The white yam flour exhibited a paste profile suitable for use as a thickener, demonstrating minimal viscosity behavior alteration due to heating, mechanical agitation, and cooling processes.

This scientific work facilitated the advancement of the production chain of this significant crop, indicating the pathways for socioeconomic transformation for the benefit of society. Both isolated starches and yam flour (white and purple) can be utilized as ingredients with a wide range of domestic and industrial applications in the production of other food products or culinary preparations. As gluten-free, they can be marketed as healthy products for the public and individuals with celiac disease. Moreover, they offer sustainable alternatives to reduce post-harvest losses, providing stability to the product and adding value. The range of potential preparations is no longer limited, allowing for the development of numerous practical and healthy food products, such as gluten-free or gluten-free bakery products, which align with consumer trends and sensory expectations.

However, further research is needed to gain a deeper understanding of the nutritional benefits of yam flour, particularly in relation to minerals, fiber, and phenolic compounds.

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Authors' Contributions

Conceptualization: Ferrari MC, Ferrari RA. **Data curation:** Ferrari MC, Ferrari RA. **Formal analysis:** Ferrari MC, Ferrari RA. **Funding acquisition:** Ferrari MC, Ferrari RA. **Investigation:** Ferrari MC, Ferrari RA. **Methodology:** Ferrari MC, Ferrari RA. **Project administration:** Ferrari MC. **Resources:** Ferrari MC. **Supervision:** Ferrari RA. **Writing-original draft:** Ferrari MC, Ferrari RA. **Writing-review & editing:** Ferrari MC, Ferrari RA.

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