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RESEARCH

Technological and Functional Potentialities of Mairá (*Casimirella rupestris*) and Ariá (*Goeppertia allouia*) Starches

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Abstract

The Amazon region holds untapped potential with its starch-rich tubers, which are not yet industrialized and face a risk of extinction due to competition from widely cultivated crops. Beyond their traditional subsistence use, Amazonian tubers such as Mairá and Ariá can be utilized as starch sources, offering an opportunity to support regional agriculture, preserve indigenous heritage, and provide sustainable income streams. This study aimed to characterize starches extracted from Mairá (MPS) and Ariá (ARS for rhizome and APS for potato), focusing on their technological and functional potential. Following extraction (maceration, filtration, decantation, and drying), their structure and size were analyzed using SEM and optical microscopy. Amylose content was determined spectrophotometrically, while pasting and thermal properties were assessed using RVA and DSC techniques. They exhibited axial diameters of 18.9, 22.6, and 26.7 µm, with MPS, ARS, and APS displaying spherical, elliptical, and polygonal shapes, respectively. According to RVA results, MPS showed lower viscosity and paste stability compared to others, making it more suitable for products requiring minimal thickening. Ariá starches demonstrated a rapid retrogradation and the formation of opaque pastes, indicating potential applications in products requiring these characteristics. Starches from these Amazonian tubers present significant potential as thickening and gelling agents for the food industry, standing out for their safety in consumption and their role in preserving endangered species.

Keywords Amazon food · Starchy tubers · Regionalism · Maintenance of local culture

Abbreviations

ANOVA	Statistical analysis of variance
APS	Ariá potato starch
ARS	Ariá rhizome starch
DSC	Differential scanning calorimetry
IFAM-CZL	Federal Institute of Education, Science, and Technology of Amazonas
MO	Optical microscope
MPS	Mairá potato starch
RVA	Rapid visco analyzer
SEM	Scanning election microscope
UNICAMP	University of Campinas

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Introduccion

The Amazon region is home to numerous underutilized starchy tubers that hold significant potential for industrial applications. They play a fundamental role in the economy and nutrition of small communities around the world, and are important for smallholder farmers. Grown in diverse regions and soils, tubers offer high resistance and productivity, providing a reliable source of essential nutrients such as carbohydrates, fiber, vitamins, and minerals in the local diet [1, 2].

In addition, these crops promote regional development by strengthening food security and generating direct income for farmers, who can market both fresh and processed products [3]. The cultivation of tubers, by supporting family farming and encouraging sustainable practices, also contributes to soil preservation and the reduction of rural exodus, consolidating the relevance of them for subsistence and socioeconomic development in producing regions [4, 5]. Mairá (*Casimirella rupestris*) and Ariá (*Goeppertia allouia*) stand out as promising sources of starch.

Mairá potato (MP) is a starch-rich crop that presents a significant historical use in the Amazon, but is still unknown to both science and society outside this region. This remarkable tuber can weigh over one hundred kilograms, making it an excellent option for biomolecule extraction and applications in the food industry [6, 7]. Despite its potential, the MP faces challenges, including the need to clarify its classification as a tuberous root or tuber and to determine the best methods for propagation. It could be used as a sustainable food source and alternative income for local populations while preserving an important aspect of indigenous agricultural heritage. Further research and development could unlock its full potential, benefiting both nutrition and health.

Ariá is a tuber, traditionally cultivated by indigenous communities and flourishing in tropical areas such as Puerto Rico, the West Indies, and Jamaica [8]. It has been gradually replaced in the diets of small rural producers by other foods, such as sweet potatoes or industrialized products [9]. However, increasing research efforts and exploring innovative technologies are crucial to harnessing its potential and revitalizing its use. The potato portion consists of 84.5% moisture, 0.75% protein, 0.77% fat, 0.84% ashes, and 13% carbohydrates [8], making it a promising raw material for starch production.

These plants are propagated using segments of the rhizomes, which are often reserved solely for this purpose. However, the portions not utilized commercially also possess a nutrient-rich composition with promising potential for applications in food industry products and processes [10, 11]. Starch yield from the MP have shown a variation in the extraction percentage from 5.70 to 11.90% [7], while in Ariá it was around 11% [8], these values are similar to the starch extraction of other tubers, such as sweet potato (*Ipomoea batatas* (L) Lam.) [12] and yam (*Dioscorea* spp) [13].

Investigating the properties of these tubers can promote regional agriculture and boost their market value. By doing so, we can discover innovative, sustainable food solutions that honor traditional knowledge and support local economies. So, our aim is to characterize starches from MP and Ariá, emphasizing their technological and functional potentialities.

Materials and Methods

Materials

Tubers were naturally found in the vegetation of the Federal Institute of Education, Science, and Technology of Amazonas, Zona Leste Campus - IFAM-CZL (3°4’45” S, 59°55’59” W, Manaus, Amazonas, Brazil), with the assistance of Professors V. Knupp and D.R. Barros. Starch extraction and evaluations were performed at the Cereals, Roots and Tubers Laboratory (FEA, UNICAMP, Campinas, SP, Brazil).

Methods

Starch Extraction

Samples of MP ($n=1$ unit) (Herb. INPA 278.724) and Ariá potato and rhizome ($n>10$ units) (Herb. INPA 64563) were washed, sanitized, peeled, cutted, and processed in a blender at a ratio of 1:3 (tuber: distilled water). This mixture was filtered (100 µm mesh) and placed in a bucket with 10 times the volume of distilled water for sedimentation for 12 h (under refrigeration). After this period, the supernatant liquid was removed, and successive washes followed by sedimentation were performed until clear water in the supernatant. The final sediment was dried in an oven with air circulation at 50 °C until the moisture content reached below 10%. The objective of the extraction was to obtain a pure starch without using chemical reagents and without worrying about the yield.

Starch Images

Starches were placed in a Petri dish and the image was captured using a scanner equipped with HP PrecisoScan version Pro 3.1 software (HP Scanjet 4400 C, Hewlett-Packard, USA). Images of starch granules were obtained using two pieces of equipment, the optical microscope (MO) (BX51, Olympos, Tokyo, Japan), with the samples placed on a glass

slide and images recorded with an attached camera (E-330-ADU1.2X, Olympus, Tokyo, Japan), in magnifications of 40x and 100x, including versions with polarized light; and the Leo 440i scanning electron microscope (SEM) with a 6070 energy-dispersive X-ray detector (Cambridge, England), in this case, the starches were placed on an aluminum stub with carbon tape and then gold-metallized using the Sputter Coater EMITECH K450 equipment (Kent, UK). The micrographs from SEM were made using magnifications of 1500x and 5000x.

Characterization of Starch Image

The SEM images were used on ImageJ software, determining shape, surface feature, particle size distribution, average axial diameter, and circularity [14].

Starch Characterization

Color measurements were performed in the CIELab color space using a colorimeter (CR-10 - Konica Minolta, Japan) to determine the white index (WI) according to Eq. 1. Samples (10 g) were weighed and placed in a Petri dish and read in five different places. Starches were purified by washing with acetone and dried in a vacuum oven to a constant weight (dry basis). Total starch was then measured, in triplicate, using the K-TSTA-100 A enzymatic kit and method from Neogen Corporation (Megazyme).

$$\text{White index} = \sqrt{(100 - L*)^2 + (a*)^2 + (b*)^2} \quad (1)$$

Apparent Amylose

The apparent amylose content was determined according to the ISO 6647-1 [15] methodology, in triplicate. A total of 150 mg of previously defatted sample was weighed. Subsequently, 1 mL of 95% ethanol and 9 mL of NaOH (1 M) were added, and the mixture was gently stirred, and placed in a boiling water bath for 10 min and cooled to 25 °C. The solution was transferred to a 100 mL volumetric flask, and the volume was completed with distilled water. Aliquots of 18 mL of this solution were transferred to 50 mL test tubes containing 2 mL of NaOH (0.09 N). After homogenization, a 5 mL aliquot was transferred to a 100 mL volumetric flask, and 1 mL of acetic acid (1 mol/L) and 2 mL of iodine solution (0.0157 N) were added, and the volume was completed with distilled water. The flasks were left to stand for 20 min, protected from light, and the absorbances were measured in a Beckman DU730 UV-Vis Spectrophotometer at 620 nm. Absorbance values were compared to a standard curve, and the results were expressed as a percentage of amylose. The amylopectin content was calculated by difference.

Paste Properties

The analysis was carried out using a Rapid Visco Analyzer (RVA) model RVA-4500 (Perten Instruments, Warriewood, Australia), employing the Standard 1 program for 13 min, as outlined in method 76-21.01 (AACCI, 2010). A sample of 2.5 g of starch, adjusted to a 14% moisture content (g/g), was mixed with 25 ± 1 mL of distilled water. It was conducted in duplicate.

Gel Firmness

Pasta samples were stored in the same aluminum container, sealed with PVC film, and refrigerated for 24 h. Subsequently, gel strength was assessed after a 1 h equilibration period at room temperature. Texture analysis was conducted, in duplicate, using a TAXT2i Texture Analyzer (Stable Micro Systems, Godalming, Surrey, England) with a 25 mm diameter acrylic probe. Firmness was determined at a test speed of 0.5 mm/s and a compression distance of 10 mm [16].

Thermal Properties

Thermal properties were determined using a Differential Scanning Calorimetry (DSC) equipment Mettler Toledo model DSC1 (Schwerzenbach, Switzerland), following the sample preparation and temperature interval described by Felisberto et al. [17] and the proportion 1:3 of sample and water. The analyses were performed in duplicate.

Statistical Analysis

The statistical analysis of variance (ANOVA) was performed using the STATISTICA 8.0 software (Statsoft, Tulsa, USA) with the Tukey test to determine statistical differences between means ($p \leq 0.05$).

Results and Discussion

Characterization of Starch Image

Figure 1 shows the images of the starches from Amazonian tubers by naked eyes (Fig. 1A, F, and K), MO (Fig. 1B, G and L) and through SEM (Fig. 1D, I, and N). It can be observed that all starches exhibit the Maltese cross (MO, Fig. 1C, H, and M), but visualization was difficult for MPS, due to its surface structure. The surface of MPS (Fig. 1E)

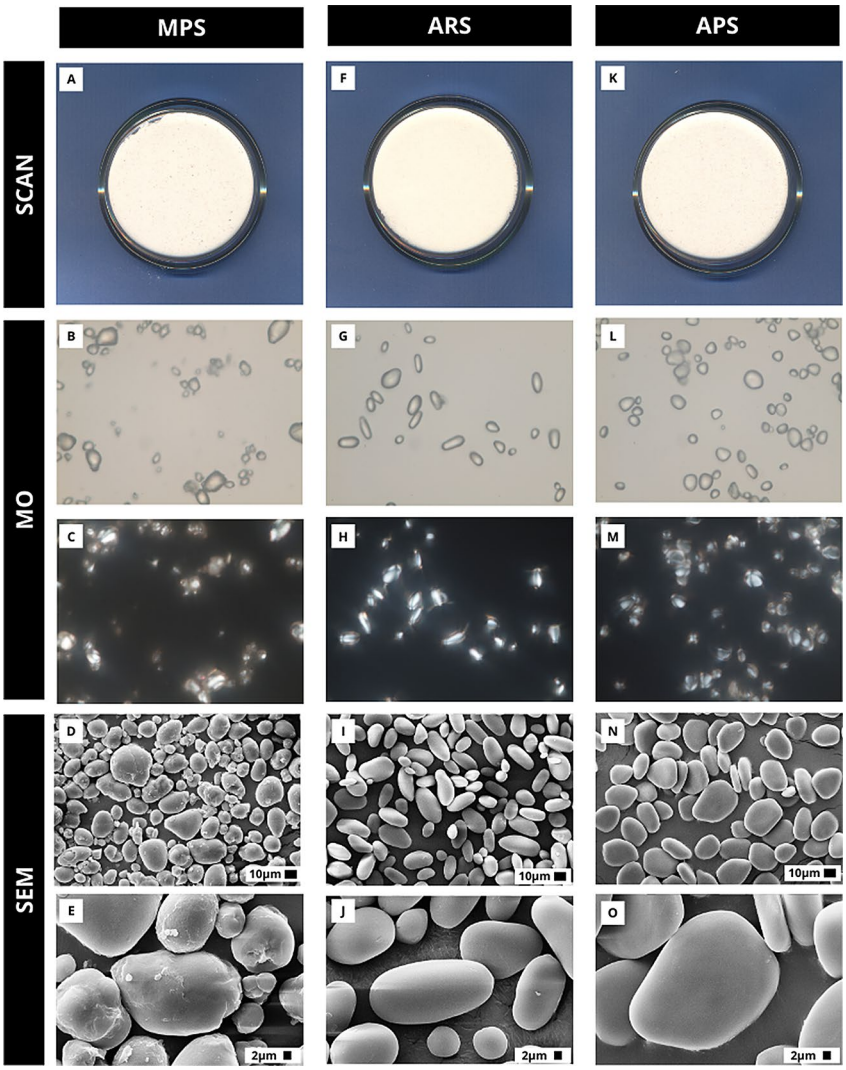

Fig. 1 Images of starch granules from Amazonian tubers: naked eye - SCAN, without and under polarized light at optical microscope - MO (40x magnification) and with 1500x and 5000x magnifications at scanning electron microscope - SEM, respectively, for MPS = mairá potato (**A** to **E**), ARS = ariá rhizome (**F** to **J**) and APS = ariá potato (**K** to **O**). Source: own authorship

Table 1 Physical characteristics of amazonian tuber starches, observed and measured through images captured by a scanning Electron microscope (SEM) at a 1500x magnification

Starch[1]	Shape	Surface	Circularity*	Axial diameter (µm)*
MPS	Spherical	Rough	0.9 ± 0.0 ^{a}	18.9 ± 7.0 ^{b}
ARS	Elliptical	Smooth	0.8 ± 0.1 ^{b}	22.6 ± 6.0 ^{ab}
APS	Polygonal	Smooth	0.9 ± 0.0 ^{a}	26.7 ± 5.0 ^{a}

[1]Where: MPS = mairá potato starch, ARS = ariá rhizome starch, APS = ariá potato starch. *Mean of at least ten determinations ± standard deviation, where different letters in the same column indicate significant differences by the Tukey test ($p < 0.05$)

has presented some irregularities, considering that this tuber has a very fibrous structure that intensifies friction during starch extraction.

This is the first research that reveals the characteristics of MPS (Table 1), with a spherical shape and circularity that is close to the other potato starches as presented by Singh et al. [18]. For the starch of ARS, there are no characterization studies available, and its shape and consequent circularity were different from those observed for the starch of its potato portion (APS) (Table 1). This differentiation shows that the location of starch in the plant (stem, rhizome, root, whether grouped or close to the bark) can naturally present starches with different shapes.

The characteristics of APS are like those described by Martins et al. [19], who describe starches with different shapes that include bell, elliptical, round, and polygonal-shape, and differ from the spherical shape found by Barros et al. [8]. These differences may be related to the different tuber harvest stages [20]. Polygonal shape is also found in other tubers such as sweet potato and taro [21]. The shape and size of granules can affect the technological properties of starch, such as swelling, solubility, paste properties, gelatinization, and crystallinity [22].

For the MPS, a wide distribution range was found for the size of starch granules (Fig. 1D), and because it is a tuber that can reach large sizes, a study can be performed of the use of different portions of the tuber, to direct the different sizes of starches found. According to Milanez [23],

the period of the plant cycle affects the size distribution of starch granules.

There was a significant difference between ARS and APS (Fig. 2A), showing that the different portions of tubers can be directed to different applications depending on the size of the starch granules. APS presents a distribution range of bigger starch granules than that found by Martins et al. [19], from 6.7 to 23.4 µm. For use as ingredient, granule size is a parameter that is related to mixing, formulation homogeneity and particle-particle interactions [24], as well as starch gelatinization and retrogradation characteristics.

Starch Characterization

Parameters of instrumental color, WI and total starch content are presented in Table 2. APS has the highest L* value (99.2), indicating that it is the lightest among the samples, while the ARS is a little darker (88.2) and the MPS has the lowest luminosity (86.0). These values suggest that the APS is the purest visually, considering the greatest clarity. Regarding the a* index, the ARS has the highest value (1.5), indicating a slight reddish tendency, followed by the MPS (1.1), and APS (0.4). In the b* parameter, the ARS also has the highest value (8.8), followed by the MPS (7.3), with the APS having the lowest value (2.7), indicating a less yellowish coloration. Silva et al. [25] have found values of 98.92, 0.04, and 4.89, for L*, a*, and b*, respectively, in white rice

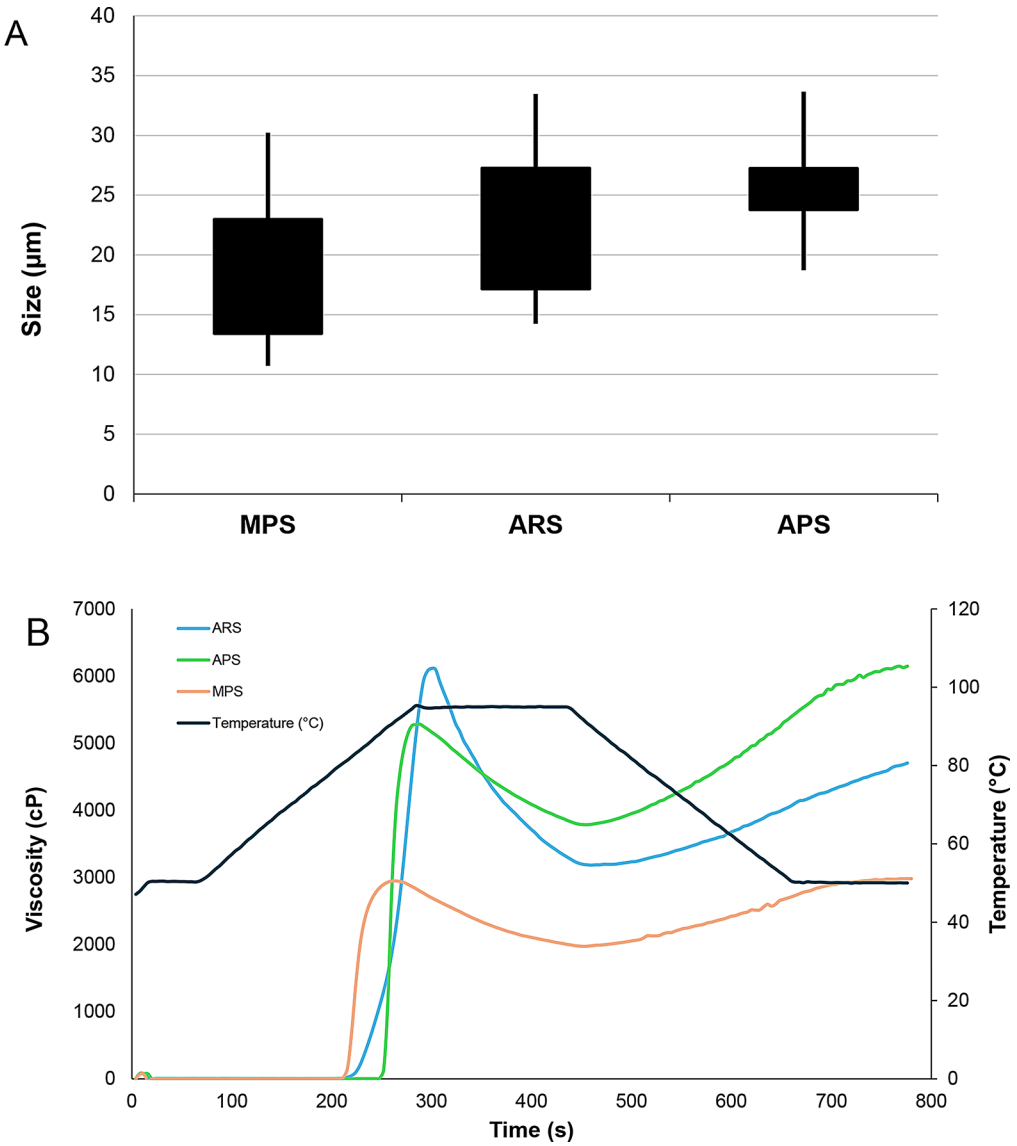

Fig. 2 Granule size distribution (**A**) and Rapid Visco Analyzer (RVA) curves (**B**) of Amazonian starches, where MPS = Mairá potato, ARS = Ariá rhizome, and APS = Ariá potato. Source: own authorship.

Table 2 Indicators of starch purity through instrumental color, with calculation of the white index and total starch analysis

Parameter (unit)[1]	Mairá potato starch	Ariá starch	
		Rhizome	Potato
Instrumental color			
*L**	86.0 ± 0.7[b]	88.2 ± 1.4[c]	99.2 ± 0.1[a]
*a**	1.1 ± 0.0[b]	1.5 ± 0.1[a]	0.4 ± 0.0[c]
*b**	7.3 ± 0.1[b]	8.8 ± 0.4[a]	2.7 ± 0.0[c]
White index	15.8 ± 0.6[a]	14.8 ± 0.9[a]	2.8 ± 0.1[b]
Total starch (%)	76.6 ± 1.0[a]	74.3 ± 2.1[a]	75.1 ± 1.6[a]

[1]Different letters in the same line indicate significant differences by the Tukey test ($p < 0.05$)

starch; while Kovac et al. [26] presented values between 93.67 and 94.85, -1.45 and −0.79, 2.27 and 2.93, for L*, a*, and b*, respectively, in starch from different potato cultivars grown in Croatia. Based on them, our results are close to those found in literature.

WI confirms the observations, with MPS having the highest WI (15.8), followed by ARS (14.8), while APS have a WI of 2.8. These results suggest that MPS and ARS have the potential to be used in products that require starch with high whiteness, while APS could be used in formulations where color is not a crucial factor.

For the total starch content, there are no significant differences between the samples ($p > 0.05$), with values ranging from 74.3 to 76.6%, suggesting that the purity in terms of starch content is relatively constant between the samples, despite the differences in color and WI. Further studies are essential to optimize extraction of starch from these tubers, with the aim of achieving a high-purity product.

Traditionally, Ariá potatoes are used for starch extraction, while the rhizome is often disregarded as a starchy source. However, this study identified that the rhizome also has great potential for this, representing a viable and promising alternative. Although MP and Ariá rhizomes are not yet widely used in food, the results of this study indicate great potential for their valorization, which can boost new applications and promote regional economic development.

Apparent Amylose

There are a significant variation between the samples ($p < 0.05$), in terms of amylose content. APS had the highest content (37.26 ± 0.32%), followed by the MPS with 34.07 ± 0.24%. ARS had a considerably lower amylose content, at 24.55 ± 0.21%, when compared with the APS. Barros et al. [8], Martins et al. [19], and Orjuela-Baquero et al. [27] also found a similar value on Ariá and MPS.

These results indicate that these starches may have functional characteristics that provide a firmer and more resilient structure, especially in applications that require greater gel formation and heat resistance. Starches with higher amylose content tend to form fewer sticky pastes, with a greater tendency to retrograde, which can be useful in products that require long-term stability or structural firmness, such as breads and cookies.

Nonetheless, ARS, which have higher amylopectin contents (75.45 ± 0.21%), may be more suitable for products that require higher viscosity and less formation of hard gels. Starches like that generally exhibit a greater tendency to form stickier and more malleable pastes, which can be advantageous in food formulations such as creams, sauces and products that require greater textural flexibility. The statistical variation between starches confirms that each source has distinct properties, directly influencing their industrial applications.

Table 3 Past and thermal properties of the amazonian tuber starches

Parameter (unit)	Ariá starch		Mairá potato starch
	Rhizome	Potato	
Past properties at RVA[1]			
Viscosity Pick (cP)	6,114 ± 4 [b]	5,282 ± 45 [b]	2,948 ± 36 [c]
Final viscosity (cP)	4,704 ± 1 [b]	6,147 ± 174 [a]	2,981 ± 99 [c]
Past temperature (°C)	83 ± 0 [b]	89 ± 0 [a]	80 ± 0 [c]
Pick time (min.)	5 ± 0 [a]	5 ± 0 [a]	4 ± 0 [a]
Thermal properties at DSC[2]			
To (°C)	73	73	69
Tp (°C)	79	78	74
Tc (°C)	86	83	80
R (°C)	14	10	11
ΔH (J.g^{-1})	14	13	12

[1]Analytical results of Rapid Viscosity Analyzer (RVA), correspond to the average of at least two determinations ± standard deviation and different letters in the same line indicate significant differences by the Tukey test ($p < 0.05$); [2]Differential Scanning Calorimetry (DSC) is sensitive equipment, requiring only one reading per sample, where: To = initial temperature (onset); Tp = peak temperature; Tc = final temperature (conclusion); R = gelatinization temperature range (To - Tc); ΔH = enthalpy of gelatinization

Paste Properties

MPS had the lowest viscosity of the three starches, peaking at approximately 2,948 ± 36 cP at 264 s (Fig. 2B; Table 3). After this point, the viscosity decreased to approximately 1973 cP at 453 s, indicating significantly lower stability under prolonged heating (Table 3). Due to this rapid viscosity breakdown, the MPS may be more suitable for formulations that require less initial thickening or that require rapid viscosity reduction during processing. This parameter refers to the level of disintegration of the starch granule or the ability of the paste to maintain its stability when subjected to shear forces and temperature variations [28].

The ARS showed a sharp increase in viscosity after 228 s, reaching its peak of approximately 6,114 ± 4 cP at

300 s (Table 3). This value is the highest among the tested starches, suggesting a high thickening capacity. For APS, the peak viscosity value corroborates with Barros et al. [8], who found 5402 ± 146 cP for Ariá starch. After the peak, there was a significant drop in viscosity (Fig. 2B). This behavior may be useful for applications that require high initial viscosity, but with less need for prolonged maintenance of this characteristic.

Nevertheless, APS showed a more moderate viscosity profile, with a peak of 5,282 ± 45 cP at 288 s, ending with 6,147 cP (700 s) (Table 3). This pattern suggests that this starch has superior stability compared to ARS, which may be advantageous for industrial processes that require constant viscosity over the heating time, without sharp drops. Among the Ariá portions, the highest temperature was for APS, which may be related to the difference in the shape and size of the starches (Table 1), which presented the highest paste temperature among the starches (Table 3).

Gel Firmness

There is a statistically significant difference in gel firmness between ARS and APS, according to the Tukey test ($p < 0.05$). ARS presented a gel firmness of 51.46 ± 3.73 N, indicating a more rigid structure compared to the APS (16.93 ± 0.04 N). In comparison, the MPS presented an intermediate firmness, with a value of 29.90 ± 1.60 N. These data highlight the structural differences between the starch sources, which may influence their industrial applications. Probably after 24 h of storage, realignment of the amylose and amylopectin chains in the gels occurred, demonstrating a greater occurrence of retrogradation, when compared with the results obtained by RVA, which show the viscosity of the sample in a short period of time.

Thermal Properties

The thermal properties, analyzed by DSC, reveal the gelatinization behavior of the starches (Table 3). The onset temperature of MPS was 69 °C, while APS and ARS has shown no variation between them. The gelatinization range was wider for ARS (14 °C), indicating a more gradual transition during the gelatinization process, while APS showed a lower range (10 °C), suggesting a faster transition.

The ΔH was higher in ARS (14 $J.g^{-1}$), indicating that it requires more energy to gelatinize completely, while MPS showed the lowest enthalpy (12 $J.g^{-1}$). The values of ΔH to ARS and APS are in accordance with the results reported in the literature [9, 19], being slightly higher than those obtained by Barros et al. [8], which was 12.3 ± 0.7 J/g.

These results indicate that ARS and APS have high viscosity and stability, making them suitable for applications that require greater thickening and durability in hot conditions. MPS, with lower viscosity and greater brittleness, may be more suitable for products that require less thickening and less resistance to prolonged heat. These data are essential for choosing the appropriate starch in different sectors of the industry, such as biodegradable films [29], Gluten-free pastas [30], 3D printing [31], and others.

Conclusions

This study highlighted the technological and functional potential of starches extracted from Mairá and Ariá, two Amazonian tubers. The characterization of these starches revealed significant properties that support their use in the food industry. They exhibited promising gelatinization and viscosity profiles, indicating their suitability as thickeners, gelling agents, and ingredients for beverages undergoing thermal processing. Additionally, the high gel firmness of Ariá starch suggests potential for applications requiring structural stability, while MPS, may be more appropriate for products with lighter textural demands. By exploring these underutilized tubers, this work contributes to the sustainable use of biodiversity, supports food security, and encourages further research on optimizing extraction methods and evaluating industrial applications.

Future studies on these species should be encouraged, aiming to understand their properties in the next years of cultivation, and could focus on long-term field studies on cultivation practices, the influence of these plants on biodiversity and local culture, considering their role in capturing CO_2 from the environment. Furthermore, knowledge of this species will help in its conservation, as well as in regional economic development.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Competing Interests The authors declare no competing interests.

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