



Physicochemical and functional properties of starch from red peach palm, yellow peach palm and babassu

Propriedades físico-químicas e funcionais de amido de pupunha vermelha, pupunha amarela e babaçu

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Starch is a complex polymer produced in large quantities by plants and it is the main source of energy in human food. Unconventional fruits can be potential sources of starch. Peach palm and babassu are fruits rich in starch, but little of them are used in the food industry. This work was therefore carried out with the aim of extracting and evaluating the native starches of red peach palm, yellow peach palm and babassu and comparing them with commercial corn and cassava starches. The babassu starch was extracted using the alkaline method, while the starch from the two varieties of peach palm was extracted by maceration in water. The starches were assessed for their centesimal composition, amylose content, water absorption index, water solubility index, syneresis, transparency and gel structuring capacity. Significant differences were observed between the extracted starches. Red peach palm starch differed from yellow peach palm starch for all the analyses except for the water solubility index. Babassu starch had a higher amylose and syneresis content, as well as showing water exudation during gel formation and good structure after unmolding. The starches evaluated showed low transparency, forming more opaque pastes and gels. The opacity of the starches may be associated with the granular structure of the starch chain and its behavior after cooling. Each starch has different characteristics, which allows them to be used in different types of food formulations.

Keywords: *Bactris gasipaes*. *Attalea speciosa*, amazon fruit.

O amido é um polímero complexo produzido em grande quantidade pelas plantas, sendo a principal fonte de energia na alimentação humana. Frutos não convencionais podem ser potenciais fontes de amido. A pupunha e o babaçu são frutos ricos em amido, porém pouco aproveitados na indústria de alimentos. Portanto, este trabalho foi realizado com o intuito de extrair e avaliar os amidos nativos de pupunha vermelha, pupunha amarela e babaçu e comparar com amidos comerciais de milho e mandioca. O amido de babaçu foi extraído pelo método alcalino enquanto que o amido das duas variedades de pupunha foi extraído por maceração em água. Os amidos foram avaliados quanto à composição centesimal, teor de amilose, índice de absorção de água, índice de solubilidade em água, sinérese, transparência e capacidade de estruturação do gel. Diferenças significativas foram observadas entre os amidos extraídos. O amido de pupunha vermelha diferiu do amido de pupunha amarela para todas as análises exceto para análise de índice de solubilidade de água. O amido de babaçu apresentou maior teor de amilose e sinérese, além de apresentar exsudação da água durante a formação do gel e apresentou boa estrutura após ser desenformado. Os amidos avaliados apresentaram baixa transparência, formando pastas e géis mais opacos. A opacidade dos amidos pode estar associada à estrutura granular da cadeia amilácea e do comportamento da mesma após o resfriamento. Cada amido apresentou características diferentes, o que permite que eles sejam utilizados em diferentes tipos de formulações alimentícias.

Palavras-chave: *Bactris gasipaes*. *Attalea speciosa*, frutas amazônicas.

1. INTRODUCTION

Starch is a complex polysaccharide produced in large quantities by plants and is the main source of energy in human food. This polymer is made up of two carbohydrate macromolecules, amylose and amylopectin. Amylose has a low degree of polymerization and branching, thus characterizing it as a linear homopolymer linked together by α -1,4 glycosidic bonds. While amylopectin has a highly branched structure combining linear chains with α -1,4 glycosidic bonds that are branched into other chains by α -1,6 bonds. The proportions of amylose and amylopectin vary according to the botanical source and can have technological influences on their use. Amylose accounts for around 30% of most native starches, while amylopectin makes up 65-95% of the starch in most plant tissues [1-3].

The widespread use of starch is associated with the fact that it is inexpensive, a renewable source, widely available in nature and easily biodegradable. Commercial starches are commonly obtained from cereals such as corn, wheat, rice and tubers such as potatoes and cassava. The food sector accounts for the largest percentage of starch use, around 60%, and its applicability is desirable for various purposes. It can be used as a thickener, stabilizer, gelling agent, encapsulant and edible coating for food preservation [4-8].

The search for new sources of starch is essential. Unconventional sources can contain significant amounts of starch, with unique technological characteristics, and can be potential sources for extraction and commercialization. The Amazon is rich in natural diversity, possessing a variety of fruits with high exploitation potential. The native fruits of the Amazon Rainforest are potential sources of starch. The fruits of peach palm (*Bactris gasipaes*) and babassu (*Attalea speciosa*) are excellent sources of starch, containing around 70-80 % and 60-90 % starch respectively [9-11]. This shows that they can be used as unconventional sources of starch.

Peach palm starch has low viscosity and low retrogradation and can be used in breads, soups and sauces. However, different varieties of peach palm may differ in their constitution and properties depending on the color of the peel at full ripeness (green, yellow, orange and red) [11, 12]. Starches extracted from peach palms exhibit a wide variation in amylose content (1.07-32.6%), which results in very distinct starch properties [11-14].

Babassu is one of the main products of Brazilian plant extraction, with economic potential to be harnessed [15]. The babassu mesocarp represents 20% of the fruit. The babassu starch granule is oval in shape with a flaky, fractured surface and no grooves. However, these properties can vary according to the method used for extraction, since the method used directly affects the chemical composition, degree of crystallinity, granule size and functional properties of the starch [8, 9].

Thus, this study was carried out with the aim of extracting and evaluating native starches from red peach palm, yellow peach palm and babassu and comparing them with commercial corn and cassava starches.

2. MATERIAL AND METHODS

The red peach palm, yellow peach palm and babassu fruits were purchased from rural producers in the city of Ariquemes - Rondônia. Approximately 3 kg of each raw material was acquired. The fruits were immediately taken to the laboratory, and only the ripe and healthy ones were selected. Subsequently, they were sanitized, the mesocarp was manually separated, and they were frozen until used. Commercial corn and cassava starches were purchased from local stores. The reagents used were of analytical grade.

2.1. Starch extraction

The starch extraction methodologies for both peach palm and babassu were developed in this research.

2.1.1 Extraction of babassu starch

The babassu mesocarp was ground in an industrial blender with a 0.25% NaOH solution, in a ratio of 1:2 (w/v), for 4 minutes. The crushed material was passed through stainless steel sieves of 60 mesh (250 μm) and then 170 mesh (90 μm). The residue retained on the sieves was reprocessed (beaten in a blender with distilled water in a 1:1 (v/v) ratio) and sieved again; this procedure was repeated twice. The residue was discarded, and the liquid fraction (starch milk) was placed in plastic trays for decanting for 2 hours. The supernatant was discarded and the decanted starch was suspended in distilled water and neutralized with 2M HCl to pH 7.0. Again, the starch milk was left to decant for 1 hour, the supernatant discarded and the decanted starch suspended in distilled water; this procedure was repeated twice. The decanted starch was taken to an oven with air circulation at 40 °C for 12 hours. The dried starch was ground in a mortar, sieved (250 μm) and stored in glass jars under refrigeration.

2.1.2. Extraction of peach palm starch

The peach palm mesocarp was ground in an industrial blender with distilled water in a ratio of 1:2 (w/v) for 4 minutes. The crushed material was passed through stainless steel sieves of 60 mesh (250 μm) and then 170 mesh (90 μm). The residue retained on the sieves was reprocessed (beaten in a blender with distilled water in a 1:1 (v/v) ratio) and sieved again; this procedure was repeated twice. The residue was discarded, and the liquid fraction (starch milk) was placed in plastic trays for decanting for 2 hours. The supernatant was discarded, the decanted starch was suspended in distilled water, and left to decant again for 2 hours. This procedure was repeated three times. The decanted starch was taken to an oven with air circulation at 40 °C for 12 hours. The dried starch was ground in a mortar, sieved (250 μm) and stored in glass jars under refrigeration.

2.2. Characterization of the extracted starch

The centesimal composition of the extracted starches was analyzed to check the efficiency of the extraction process. For comparison purposes, commercial corn and cassava starch was used for the analysis of amylose, absorption and solubility in water, syneresis and gel transparency.

2.2.1. Centesimal composition

Moisture, protein, lipid and ash content were assessed according to the AOAC methodology (2006) [16]. The moisture content was determined by drying the sample in an oven at 105 °C until constant weight. The nitrogen content was determined using the micro Kjeldahl method, with a conversion factor for proteins of 6.25. The ash content was determined after calcination in a muffle furnace at 550 °C. The lipid content was determined in a Soxhlet extractor using hexane as the solvent. Total carbohydrates were calculated by difference.

2.2.2 Amylose content

The amylose content of the defatted starches was determined according to the ISO methodology (1987) [17]. The starch granules were dispersed with ethanol and gelatinized with sodium hydroxide. An aliquot was acidified and, after reaction with iodine, the blue-colored complex formed was quantified by spectrophotometry at 620 nm.

2.2.3. Water absorption index (WAI) and water solubility index (WSI)

WAI and QSI were determined according to the methodology of Anderson et al. (1969) [18], with some modifications. In a pre-weighed centrifuge tube, 0.5 g of the sample was weighed

and 6 mL of distilled water was added. The tubes were shaken for 30 min at 30 °C and then centrifuged at 1800 x g for 15 min. The supernatant liquid was carefully drained into a pre-weighed Petri dish and the remaining material was weighed. The water in the Petri dish was evaporated in an oven at 105 °C and the evaporation residue was weighed.

The calculations were carried out as follows: WAI = weight of centrifugation residue / (weight of sample - weight of evaporation residue); WSI = (weight of evaporation residue / weight of sample) *100.

2.2.4. Syneresis

In a pre-weighed 15 mL centrifuge tube, 0.5 g of starch was weighed and 10 mL of distilled water was added. The starch was kept suspended by shaking the tube in a vortex and immediately placed in a boiling water bath for 20 minutes, shaking the vortex every minute for the first 5 minutes to prevent the starch from settling. The tubes were cooled and stored at 4 °C for 7 days. Syneresis was calculated as the percentage of water released after centrifugation at 1800 x g for 15 minutes.

2.2.5. Gel transparency

Gel transparency was analyzed according to Gani et al. (2013) [19] with adaptations. 0.5 g of the sample was weighed and 50 mL of distilled water was added to a glass beaker. The samples were heated on a hotplate, stirring constantly with a glass rod and then kept under heat for 2 minutes after boiling. After cooling, the starch gel was transferred to 50 mL falcon tubes and the transmittance was measured in a spectrophotometer at 650 nm using distilled water as a blank. The tubes were refrigerated at 4 °C and the transmittance measured at 650 nm at 24 hours (1 day), 96 hours (4 days) and 144 hours (6 days).

2.2.6. Ability to structure the gel

A suspension was made in a beaker with 10 g of starch and 200 mL of distilled water. The suspension was then heated on a hotplate until the first bubbles appeared, counted for 1 minute and removed from the heat. The paste, still warm, was poured into disposable cups and stored at 5 °C in the fridge for 24 hours. Afterwards, the formed gel was unmolded and the shape of the gel was recorded with photos.

2.3. Statistical analysis

The experimental design was completely randomized with 3 replications. The results were subjected to analysis of variance (ANOVA) and Tukey's test ($p < 0.05$) to compare means using the ASSISTAT statistical system version 7.7 beta [20].

3. RESULTS AND DISCUSSION

3.1. Yield and centesimal composition of extracted starches

The yield of extracted starch was 10.6% for red peach palm, 10.2% for yellow peach palm, and 9.6% for babassu. If the yield from the mesocarp of each fruit is considered, the yields increase to 14.8, 17.1, and 35.3% for red peach palm, yellow peach palm, and babassu, respectively. The extracted starches had a low content of non-starch constituents (Table 1), indicating that the method used for extraction was efficient. There were no significant differences in the protein, lipid and ash parameters, but they only differed in terms of carbohydrate and moisture content. This difference in the carbohydrate content of the red peach

palm starch may be associated with the moisture content, as it was the only sample with a higher moisture content than the others. In addition to the carbohydrate constituents (amylose and amylopectin), extracted starches can have up to 2% non-starch constituents bound to the starch [21]. The purity of starches depends on the botanical source and the extraction method, which can affect their composition, structure and functionality and, consequently, reflect the applications in which the starch will be used [22]. Starches should contain as little protein and lipid as possible. The presence of lipids can affect the functional properties of starches, affecting gelling, altering the rheological behavior of the paste, inhibiting the crystallization of molecules and delaying retrogradation [23].

Table 1 - Centesimal composition (%) of extracted starches.

Sample	Moisture	Proteins	Lipids	Ash	TC
RPS	12.34 ± 0.36 ^a	0.46 ± 0.09 ^a	0.35 ± 0.01 ^a	0.09 ± 0.02 ^a	86.77 ± 0.35 ^b
YPS	10.28 ± 0.04 ^b	0.51 ± 0.14 ^a	0.30 ± 0.03 ^a	0.11 ± 0.03 ^a	88.80 ± 0.24 ^a
BS	10.60 ± 0.49 ^b	0.39 ± 0.08 ^a	0.33 ± 0.07 ^a	0.11 ± 0.03 ^a	88.57 ± 0.49 ^a

Notes: RPS: red peach palm starch; YPS: yellow peach palm starch. BS: babassu starch; TC: total carbohydrates calculated by difference. Data reported as mean ± standard deviation. Means followed by the same letter (lowercase) in the column do not differ by Tukey's test ($p \geq 0.05\%$).

The highest percentage of non-starch constituents present in the extracted starches was observed in the protein content, results similar to those reported in work carried out by Ali et al. (2023) [24] and Carvalho et al. (2024) [25] which evaluated starches extracted from three potato varieties and sorghum starch, respectively. Barros et al. (2024) [11] quantified a high amount of lipids in peach palm starch (3.8 g/100g). The authors used the alkaline method to isolate the starch. Maniglia and Tapia-Blácido (2016) [9] evaluated the starch of babassu mesocarp extracted by two different methods, maceration in water and maceration at alkaline pH, both extraction methods showed a higher concentration of non-starch constituents when compared to the results of this work.

3.2. Amylose content, water absorption index, water solubility index and syneresis of starches

Amylose content ranged from 16 to 32% (Figure 1). In this work, the native starches extracted were compared with corn and cassava starches. According to Moore et al. (1984) [26] starch can be classified as normal starch, which contains between 18 and 30% amylose, waxy starch, consisting of 1% amylose and starch with a high amylose content of 50 to 70% or more. According to this classification, the starches evaluated can be considered normal starch.

Yellow peach palm starch showed the lowest amylose content, while babassu starch had the highest. Native starch can have similar chemical characteristics, but in different concentrations, and can vary from species to species [27]. Felisberto et al. (2020) [13] quantified 18.92% of amylose in peach palm starch, value close to those obtained in this study. Pires et al. (2021) [14] evaluated the starch of different peach palm genotypes (macrocarpa, mesocarpa, and microcarpa) extracted by aqueous and alkaline methods. The authors concluded that peach palm starch is a waxy starch, as it had an amylose content below 4%, regardless of the genotype and the method used for extraction. Barros et al. (2024) [11], who found 32.6% amylose in peach palm starch, suggest that this difference may be associated with the degree of ripeness of the fruit used. However, such a large variation (more than 30% amylose) is better explained by the genetic diversity of the species, which is directly related to starch biosynthesis. Furthermore, edaphoclimatic conditions can also interfere with starch composition.

The babassu starch sample showed an amylose content close to commercial starches, thus demonstrating that fruit starches can show some similarities to commercial starches. Maniglia and Tapia-Blácido (2016) [9] quantified 35.79 % amylose in babassu starch macerated in water and 24.38 % macerated in alkaline pH, indicating that the method of starch isolation can

influence the amylose content. However, the data for starch extracted in water was closer to that of this work than that extracted in NaOH.

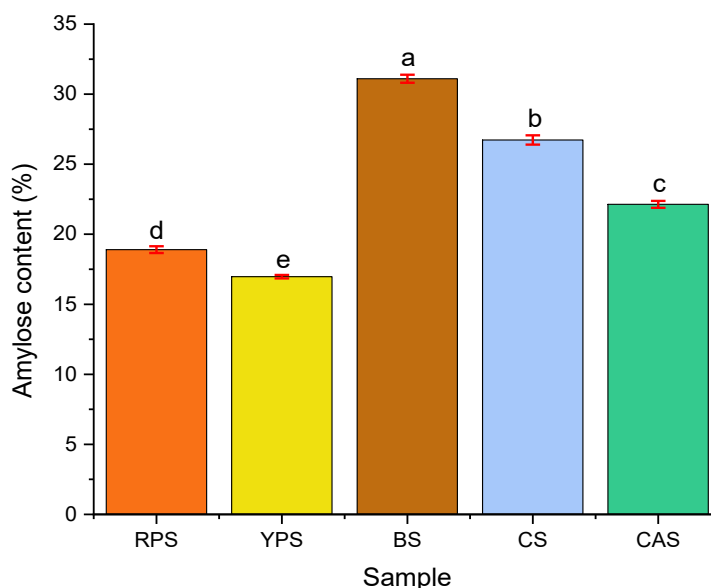


Figure 1 – Amylose content in different starch samples. RPS: red peach palm starch, YPS: yellow peach palm starch, BS: babassu starch, CS: corn starch; CAS: cassava starch.

The functional properties of the starches evaluated are shown in Table 2. The absorption index and water solubility reflect the interaction of starch with water and are influenced by several factors in addition to the structure and position of the granule. It was observed that there was no statistical difference in the analysis of WAI between the samples of red peach palm, babassu, corn starch and cassava. However, the yellow peach palm variety had the highest WAI among all the samples, while babassu starch differed only from yellow peach palm and corn starch.

Table 2 - Water absorption index (WAI), water solubility index (WSI) and syneresis.

Samples	WAI (g.g ⁻¹)	WSI (%)	Syneresis (%)
RPS	1.98 ± 0.06 ^{bc}	0.60 ± 0.16 ^{ab}	5.9 ± 0.37 ^d
YPS	2.22 ± 0.05 ^a	1.33 ± 0.25 ^a	24.27 ± 0.46 ^b
BS	2.05 ± 0.05 ^b	0.67 ± 0.25 ^{ab}	50.50 ± 1.39 ^a
CS	1.90 ± 0.01 ^c	0.40 ± 0.16 ^b	10.57 ± 1.22 ^c
CAS	1.93 ± 0.02 ^{bc}	1.13 ± 0.34 ^{ab}	0.20 ± 0.08 ^e

Note: RPS: red peach palm starch, APA: yellow peach palm starch, BS: babassu starch, CS: corn starch; CAS: cassava starch. Data reported as mean ± standard deviation. Means followed by the same letter (lowercase) in the column do not differ by Tukey's test ($p \geq 0.05\%$).

The yellow peach palm sample showed the highest WSI content, however, it did not differ from the others, except for cornstarch. This result was the opposite of that reported by Barros et al. (2024) [11], as the author observed that the WSI of peach palm starch was significantly equal to commercial corn starch and higher than cassava starch. De Melo Neto et al. (2015) [28] suggest that peach palm starch is compatible for use in the production of biodegradable packaging since the granules tend to be poorly soluble in water and have low resistance to high temperatures.

All the samples differed in their analysis of syneresis. The analysis of syneresis is characterized by the release of water from the starch gel during refrigeration. The amount of

syneresis is associated with the tendency of starch to retrograde and may also be associated with the ability of the hydrocolloid to retain or expel water [29]. Babassu starch showed the highest percentage of syneresis, followed by yellow peach palm starch. Red peach palm starch had a low level of syneresis, higher only than cassava starch.

Syneresis can be used as an indicator of starch retrogradation, since high syneresis can accelerate retrogradation [30]. In general, a starch with a high amylose content has a greater tendency to retrograde, forming a more rigid and organized crystalline network [11]. Peach palm starch did not show this behavior, especially yellow peach palm. This may have been influenced by the size of the amylose chains. According to Wang et al. (2015) [31] retrogradation is not favored when the amylose chain is too short or too long. The granules in peach palm starch show a bimodal distribution with a higher percentage of granules below 10 μm [13, 14, 28]. This leads to the inference that the amylose chain in peach palm starch is relatively short, which may have influenced the low syneresis content. Or perhaps this result could be related to the content of carboxyl groups in the starch molecules, since there is a strong correlation between the presence of carboxyl groups and reduced retrogradation, since carboxyl groups can interfere with the tendency of amylose to associate and retrograde [32].

3.3. Transparency

The transparency of the starch gels was determined by reading the transmittance over time, as described in Figure 2. The starch source influenced the gel transparency. The cassava starch gel showed greater transparency while the yellow peach palm gel showed greater opacity. The red peach palm, babassu and corn gels did not differ from each other on day zero, but showed a marked reduction in transparency in the first 4 days, and then showed a tendency towards stability up to 6 days of storage. The transparency of the cassava starch gel remained constant throughout the 6 days of analysis.

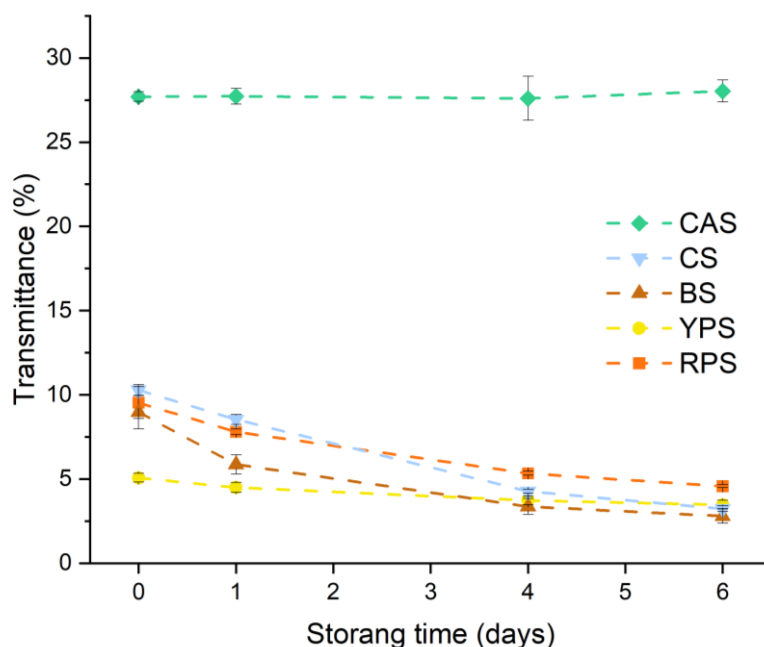


Figure 2 – Transparency of the paste and starch gels. RPS: red peach palm starch, YPS: yellow peach palm starch, BS: babassu starch, CS: corn starch; CAS: cassava starch.

Transparency is one of the most important analyses of starch. There are reports in the literature that the amylose content can influence the opacity of starch gels. When amylose is released into a solution, hydrogen bonds occur, forming rigid and opaque gels [26, 33].

However, this correlation was not observed in this study since the starch with the lowest amylose content (yellow peach palm starch) had the lowest transparency and the babassu starch with the highest amylose content did not differ from corn and red peach palm starch.

Transparency can be related to the granular characteristics of the starch and may be associated with retrogradation, where the molecules reorganize during cooling, giving the gels more opacity. The opacity of the starch paste may be associated with the more organized granular structure of the starch chain; the greater the interaction between the amylose and amylopectin chains, the greater the difficulty in the passage of light, which results in a more opaque paste. Other factors can also be associated with the opacity of starch gels, such as aggregates of leached amylose, aggregates of amylose and amylopectin, chain length, intramolecular bonding and swelling of the starch granules [34].

4.3. Gel structuring capacity

The pastes and gels of the starches are shown in Figure 3. The red and yellow peach palm starches showed the formation of air bubbles in the pastes that remained in the gels (cooled paste), however, these bubbles were more pronounced for yellow peach palm. This characteristic may be associated with the interaction with non-starch materials present in the starch after extraction or even with the morphological characteristics of the peach palm starch. The appearance of the gel formed shows that it did not resemble the other gels. This characteristic is associated with the strength of the starch gel, since peach palm starch has a low rate of retrogradation, resulting in a weak gel that can be used in products that require slow retrogradation, such as breads, soups and porridges [13].

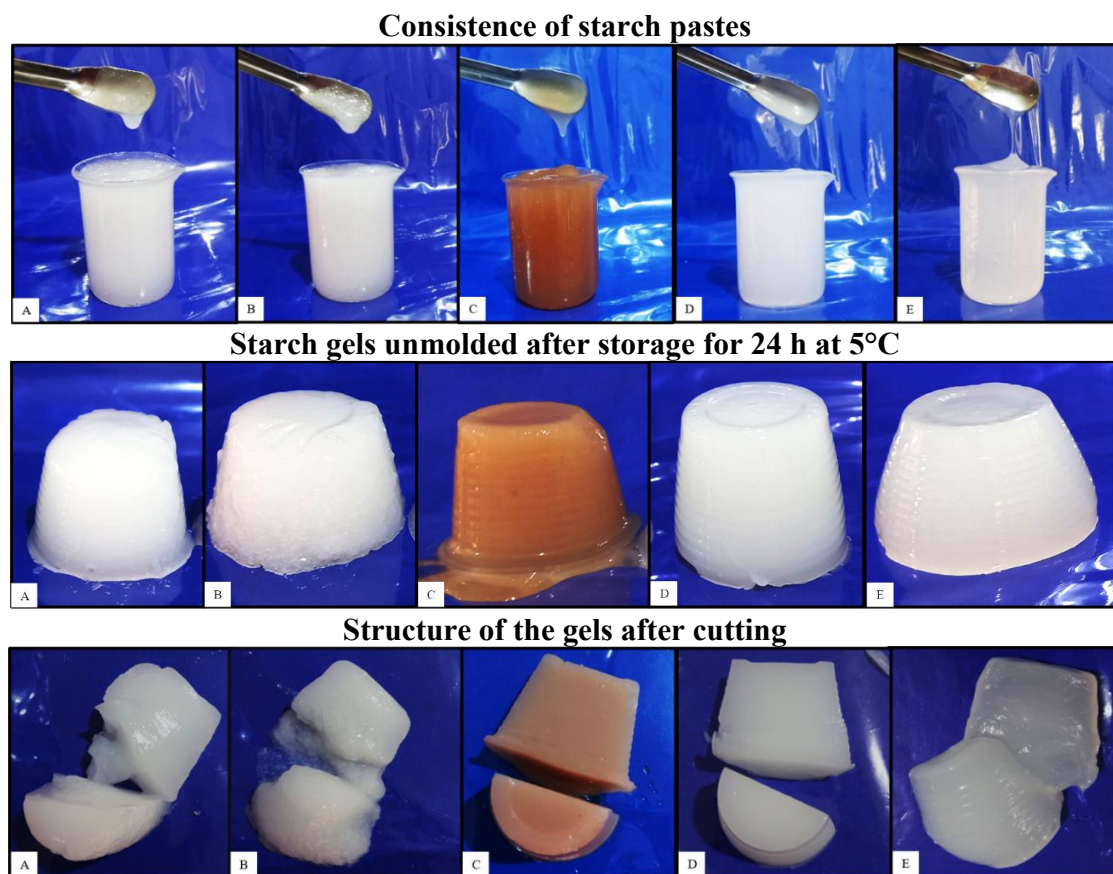


Figure 3 – Images of the paste, unmolded gels and gels after cutting of native and commercial corn and cassava starch. A: red peach palm starch, B: yellow peach palm starch, C: babassu starch, D: corn starch and cassava starch.

According to the literature, starch in its commercial form is a white powder, insoluble in cold water, odorless and tasteless. After cooking, its characteristics vary according to the botanical source [23]. However, it was observed that babassu starch does not have a white color. Although the babassu gels presented a similar transparency to corn starch and red peach palm, the babassu starch paste and gel presented a coloration with reddish yellow tones. According to Maniglia and Tapia-Blácido (2016) [9], the babassu starch presented a yellow-red coloration, regardless of the extraction method. This coloration is attributed to the phenolic compounds that remain in the starch after extraction. Babassu starch extracted by the aqueous, alkaline and acid methods showed 63.7, 8.2 and 77.0 mg of gallic acid / 100 g of sample and 66.8, 68.7 and 72.3% antioxidant activity by the DPPH method, respectively [10]. This shows that babassu starch can be used in food products not only for its functional properties, but also to increase color and nutritional value due to the presence of phenolics.

Babassu starch gel showed water exudation, which is related to starch retrogradation and syneresis. As previously reported, babassu starch has a high syneresis content (50.50%). No studies were found that evaluated the retrogradation content of babassu starch.

In general, the gels showed a good consistency and kept their shape after being removed from the mold. However, the babassu starch gel was the one that presented the firmest shape and maintained its structure even after cutting, closer to the behavior of the corn starch gel. While the peach palm starch gels presented a weaker structure, which did not resist cutting.

This cohesive and firm structure of babassu starch gel indicates that it can be used in 3D printing technologies. It is suggested that future work could evaluate the retrogradation and texture of the gels, to highlight their rheological behavior, in order to direct possible applications of these starches for the food industry.

4. CONCLUSION

The starches evaluated showed a low content of non-starch constituents, showing that the extraction method was efficient. In relation to the functional properties evaluated, red peach palm starch differed from yellow peach palm starch for all the analyses except for the water solubility index. Considering that both fruits were at a similar stage of ripeness, the main factor of variation is genetics, primarily related to starch biosynthesis. Babassu starch showed a good correlation when compared to corn starch and had a higher amylose and syneresis content, which corroborated the exudation of water during gel formation, resulting in a gel with a strong structure, maintaining the shape of the mold after being unmolded. The starches evaluated showed low transparency, forming more opaque pastes and gels. The gels showed good structures after being unmolded. The babassu starch paste and gel presented a reddish-yellow coloration, which allows it to be used in formulations with dual function (as a texture and color agent). Thus, peach palm and babassu can be considered unconventional sources of starch and can be used in different segments of industry.

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