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PHYSICOCHEMICAL CHARACTERIZATION OF THE SEED FLOUR AND THE PULP OF UNRIPE AND RIPE ARATICUM, A BRAZILIAN NATIVE FRUIT

CARACTERIZAÇÃO FÍSICO-QUÍMICA DA FARINHA DAS SEMENTES E DA POLPA DE ARATICUM VERDE E MADURO, UMA FRUTA NATIVA BRASILEIRA

CARACTERIZACIÓN FISICOQUÍMICA DE LA HARINA DE SEMILLAS Y DE PULPA DE ARATICUM VERDE Y MADURO, UNA FRUTA NATIVA BRASILEÑA

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ABSTRACT

Brazil plays an important role in the international fruit market; however, the native ones are still little explored. Araticum (*Rollinia sylvatica* or *R. sylvatica*) is native from Brazil, but studies on the characterization of the fruit and its seeds are still scarce. Thus, this study aimed to evaluate the physicochemical characteristics of the pulp and seed flour of *R. sylvatica* in two ripening stages: unripe and ripe. The centesimal composition of the araticum pulp and seed flour was determined according to the Association of Official Analytical Chemists (AOAC) methods (moisture: n. 925.10, ashes: n. 900.02A, proteins: n. 955.04C, lipids: n. 920.39C, crude fiber: n. 962.09E, and carbohydrates by difference), the total titratable acidity (TTA) by AOAC method n. 942.15, a_w with an analyzer (Novasina®), and total soluble solids (TSS) and instrumental color with, respectively, a digital refractometer (ABBE®) and digital colorimeter (Konica Minolta®). Pulp's ashes, lipids, proteins, TTA, and TSS increased with ripening, while moisture, a_w, carbohydrates, and pH decreased. For seed flour, moisture, proteins, carbohydrates, and pH were enhanced, while lipids and TTA were reduced during ripening. The instrumental color indicated no changes in the total color differences of the pulp as the araticum ripened, although the ripe seed flour became darker with ripening. When ripe, araticum's pulp presented important amounts of proteins (8.26%) and sugars, indicated by the 22.03ºBrix, while the seeds flour contained high amounts of fibers (35.63), lipids (22.91%), and proteins (11.65%). Therefore, the fruit may be a profitable alternative for farmers since it can be commercialized in natura, or processed in the form of pulp and the by-product flour.

KEYWORDS

Rollinia sylvatica; *R. sylvatica*; araticum-do-mato; by-product; functional food.

RESUMO

O Brasil desempenha um papel importante no mercado internacional de frutas, porém as nativas ainda são pouco exploradas. Araticum (*Rollinia sylvatica* ou *R. sylvatica*) é nativa do Brasil, mas estudos sobre a caracterização do fruto e de suas sementes ainda são escassos. Assim, esse estudo teve como objetivo avaliar as características físico-químicas da polpa e da farinha das sementes de *R. sylvatica* em dois estádios de maturação: verde e maduro. A composição centesimal da polpa e da farinha das sementes de araticum foi determinada segundo os métodos da Association of Official Analytical Chemists (AOAC) (umidade: n. 925.10, cinzas: n. 900.02A, proteínas: n. 955.04C, lipídios: n. 920,39C, fibra bruta: n. 962.09E e carboidratos por diferença), a acidez total titulável (ATT) pelo método AOAC n. 942.15, a_w com um analisador (Novasina®), e sólidos solúveis totais (SST) e cor instrumental com, respectivamente, um refratômetro digital (ABBE®) e um colorímetro digital (Konica Minolta®). Cinzas, lipídios, proteínas, ATT e SST da polpa aumentaram com o amadurecimento, enquanto que a umidade, a_w, carboidratos e pH diminuíram. Para a farinha das sementes, umidade, proteínas, carboidratos e pH foram aumentados, enquanto lipídios e ATT diminuíram durante o amadurecimento. A cor instrumental não indicou alterações nas diferenças de cor total da polpa à medida que o araticum amadureceu, embora a farinha das sementes maduras tenha se tornado mais escura com o amadurecimento. Quando madura, a polpa do araticum apresentou quantidades consideráveis de proteínas (8,26%) e açúcares, indicados pelo 22,03ºBrix, enquanto a farinha das sementes continha altos teores de fibras (35,63%), lipídios (22,91%) e proteínas (11,65%). Assim, o fruto pode ser uma alternativa rentável para os agricultores, pois pode ser comercializado in natura, ou processado na forma de polpa e farinha de subproduto.

PALAVRAS-CHAVE

Rollinia sylvatica; *R. sylvatica*; araticum-do-mato; subproduto; alimento funcional.

RESÚMEN

Brasil tiene un papel importante en el mercado internacional de frutas; sin embargo, las frutas nativas aún son poco exploradas. Araticum (*Rollinia sylvatica* o *R. sylvatica*) es originaria de Brasil, pero los estudios sobre la caracterización de la fruta y sus semillas aún son escasos. Por lo tanto, esta

investigación tuvo como objetivo evaluar las características fisicoquímicas de la pulpa y la harina de semillas de *R. sylvatica* en dos estados de maduración: verde y maduro. La composición centesimal de la pulpa y harina de semillas de araticum se determinó según los métodos de la Association of Official Analytical Chemists (AOAC) (humedad: n. 925.10, cenizas: n. 900.02A, proteínas: n. 955.04C, lípidos: n. 920.39C, fibra cruda: n. 962.09E y carbohidratos por diferencia), acidez titulable total (ATT) por el método AOAC n. 942.15, a_w con un analizador (Novasina®), y sólidos solubles totales (SST) y color instrumental con, respectivamente, un refractómetro digital (ABBE®) y un colorímetro digital (Konica Minolta®). Las cenizas, lípidos, proteínas, ATT y SST de la pulpa aumentaron con la maduración, mientras que humedad, a_w, carbohidratos y pH disminuyeron. En la harina de semillas, la humedad, proteínas, carbohidratos y pH aumentaron, mientras que lípidos y ATT disminuyeron durante la maduración. El color instrumental no indicó cambios en las diferencias de color total de la pulpa a medida que el araticum maduró, aunque la harina de la semilla madura se tornó más oscura con la maduración. En su madurez, la pulpa de araticum presentó cantidades considerables de proteínas (8,26%) y azúcares, estos indicados por 22,03ºBrix, mientras que la harina de semillas contenía altos niveles de fibras (35,63%), lípidos (22,91%) y proteínas (11,65%). Por lo tanto, la fruta puede ser una alternativa rentable para los agricultores, ya que puede comercializarse in natura o procesarse como pulpa y harina de subproducto.

PALABRAS CLAVE

Rollinia sylvatica; *R. sylvatica*; araticum-do-mato; subproducto; alimento funcional.

1 INTRODUCTION

Brazil has stood out in the international market as an important producer, consumer, and exporter of fruits, especially tropical fruits (FAO, 2023). Some are native to Brazil, others introduced, but many are unknown and still unexplored (KINUPP; LORENZI, 2021). Among the native Brazilian fruits that have not yet become major cultivars with significant production and consumption is araticum, also called ariticum or araticum-do-mato (*Rollinia sylvatica, R. sylvatica, Annona sylvatica* St.-Hil., or *Annona silvestris* Vell.) (CARVALHO, 2008; 2014). The collection and cultivation of araticum can be considered excellent options for expanding the sources of nutrients available to the population, promoting food sovereignty and security, besides adding value to the available natural resources, mainly because, to date, only a limited number of tropical fruit species from the *Annonaceae* family have economic value (KAZMAN *et al.*, 2022).

The economic exploitation of products and by-products from some specific fruits has increased (FIDELIS *et al.*, 2019), given the consumers' growing concern about diet and health (ITAL, 2020). In this sense, the physicochemical characterization of fruits and their corresponding by-products is important for understanding the nutritional, functional, and technological properties which, from a commercial point of view, add value and quality to the final product.

To produce natural or concentrated juices, jams, pulps, and extracts, industrial yield is not total, and a significant volume of fruit by-products is generated, which contains seeds that are often discarded instead of being used in full (FEITEN, 2023). Seeds contain significant amounts of oil that may have physicochemical characteristics similar to some edible oils potentially used for human consumption (ANDRADE *et al*., 2012; TIENCHEU *et al*., 2021).

In recent years, fruit seeds from the *Annonaceae* family have been studied as they contain different classes of substances with biological activities, such as antioxidant, antimicrobial, antiparasitic, and anti-carcinogen (BENITES *et al*., 2015; MENEZES *et al*., 2019; KAZMAN *et al*., 2022; RAMOS *et al*., 2023), with applications in the food, chemistry, and pharmaceutical industries, among others (MENEZES *et al*., 2019; RODRÍGUEZ *et al*., 2021). In this sense, araticum pulp falls apart easily when ripe, leading to easier separation of the seeds, which can be transformed into flour or functional ingredients for new products development. To this end, it is necessary to evaluate the most appropriate industrial operations and processing technologies to preserve their nutritional content.

Nevertheless, studies with araticum are scarce and little available in the literature, making it important to carry out the physicochemical characterization of its pulp and seed flour, which can contribute to the knowledge of their technological potential and nutritional value. The fruit can also become an additional income alternative for family farmers, who could use their rural properties for araticum production and processing. Thus, araticum seeds utilization is an excellent alternative for reducing food waste (MENEZES *et al*., 2019; RODRÍGUEZ *et al*., 2021), contributes to developing new functional products at a reduced cost, and may bring the food industry and the consumers into the habit of making the full utilization of food (FEITEN, 2023). In this sense, this study addresses issues of public interest framed in four Sustainable Development Goals (UN, 2015): 2 – Zero Hunger, 3 – Good health and well-being, 9 – Industries, Innovation, and Infrastructure, and 12 – responsible consumption and production. With that in mind, this study aimed to investigate the physicochemical characteristics of the seed flour and pulp of araticum (*R. sylvatica*) in the unripe and ripe stages.

2. METHODS

2.1. OBTAINING ARATICUM PULP AND SEED FLOUR

Maturation is indicative of the fruit being ready for harvest. At this point, the edible part of the fruit is fully developed in size, although it may not be ready for immediate consumption. Ripening follows maturation, rendering the product edible (BARBOSA-CÁNOVAS *et al*., 2003; ANWAR *et al*., 2019). Thus, araticum (*R. sylvatica*) fruits were collected in the rural area of Ipumirim, Santa Catarina, Brazil (27.0755º S, 52.1344º W), in April 2024, in two ripening stages: unripe and ripe. The ripening classification occurred visually, where the completely green and the completely yellow fruits were classified as unripe and ripe, respectively, as seen in Figure 1.

Figure 1 - Araticum ripening stages: unripe (left) and ripe (right).

Source: Authors

The fruits were cleaned in running and potable water, followed by sanitization with sodium hypochlorite at 100 ppm for 20 minutes. Subsequently, the peels were removed, and four batches were prepared: unripe or ripe pulp and unripe or ripe seeds. The products were stored in polyethylene packaging in a freezer at -14 ºC until further use.

The seeds were dried in a dehydration oven at 65ºC for 8 hours; and then crushed in a knife mill (Fortinox®, model STAR FT-50), which has a 10 mesh sieve (2.0 mm) installed at the bottom. The flour was stored in sealed food-grade polypropylene bags in a dry and dark place, until physicochemical analyses.

2.2. PHYSICOCHEMICAL CHARACTERIZATION OF ARATICUM PULP AND SEED FLOUR

The centesimal composition of araticum pulp and seed flour was determined according to the Association of Official Analytical Chemists methods (LATIMER, 2023). Moisture content was obtained by desiccating the samples in the oven at 105ºC (method n. 925.10). The muffle incineration method was applied to quantify the crude ash content at 550ºC (method n. 900.02A). Crude protein content was measured indirectly, by determining nitrogen content using Kjeldahl method (n. 955.04C). Total lipid content was extracted by Soxhlet method (n. 920.39C) after drying the samples in the oven. Crude fiber was quantified by digesting the samples with sulfuric acid and sodium hydroxide (method n. 962.09E). Finally, total carbohydrate content was estimated by subtracting the sum of crude protein, moisture, total lipids, crude fiber, and crude ash.

The water activity (aw) was obtained using the aw analyzer LabMaster (Novasina®). pH measurement was carried out through a bench digital pHmeter (Marconi®, model MA-522) previously calibrated with pH 10.0, 7.0, and 4.0 buffer solutions. Total titratable acidity (TTA) was measured according to method n. 942.15 (LATIMER, 2023) by titrating the properly diluted samples against sodium hydroxide (0.1 M) to the equivalence point (pH 8.0). To determine the total soluble solids (TSS) content, a solution was prepared with the pulp of the unripe and ripe fruit, by diluting 5 grams of each sample in 50 mL of distilled water. Then, the solutions were filtered, and the TSS content was measured directly, in ºBrix, using a digital refractometer (ABBE®).

The instrumental color was determined using the Konica Minolta® Colorimeter (model CR-400) previously calibrated with a white color calibration plate. The system adopted follows the coordinate parameters CIE L*, a*, and b*, where L* measures the luminosity, indicating brightness on a scale from white (L* = 0) to black (L* = 100), a* defines intensity, where -a = green and +a = red, and b* indicates the tone from -b = blue and +b = yellow (KONICA MINOLTA, 2022). The total color differences (E*) were calculated by Equation 1, where ∆L*, ∆a*, and ∆b* are color differences.

Equation 1 $$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{\frac{1}{2}}$$

2.3. STATISTICAL ANALYSIS

All measurements were conducted in triplicate. The data was statistically treated using analysis of variance (ANOVA) and Student's t-test at 5% significance level ($p<0.05$) using the Statistica® software, version 7.0 (StatSoft, Inc, Tulsa, USA), and the results were presented by the mean ± standard deviation.

3 RESULTS AND DISCUSSION

Ripening corresponds to physical and physicochemical changes that reflect in the sensory aspects of flavor, odor, color, and texture, which make the fruit more acceptable to the consumer (CHITARRA; CHITARRA, 2005; DUTCOSKY, 2019). With ripening, specific flavors and odors are developed along with increasing sweetness and acidity in the fruits, and the softening of the fruit usually follows a color change (BARBOSA-CÁNOVAS *et al*., 2003). Thus, Table 1 presents the results of the physical and physicochemical analyses conducted on the unripe and ripe araticum pulp and seed flour.

Table 1. Physical and physicochemical characterization of araticum pulp and seed flour.

Analyses	Unripe pulp	Ripe pulp	Unripe seed flour	Ripe seed flour
Moisture (%)	$84.99^a \pm 0.01$	$83.29^b \pm 0.01$	$21.74^a \pm 0.52$	$22.82^b \pm 0.29$
Ashes (%)	$1.18^a \pm 0.07$	$1.64^b \pm 0.36$	$1.72^a \pm 0.01$	$1.70^a \pm 0.02$
Lipids (%)	$3.37^a \pm 0.21$	$4.70^b \pm 0.14$	$24.65^a \pm 0.06$	$22.91^b \pm 0.67$
Proteins (%)	$6.66^a \pm 0.24$	$8.26^b \pm 0.07$	$10.89^a \pm 0.03$	$11.65^b \pm 0.12$
Fibers (%)	$1.34^a \pm 0.09$	$1.31^a \pm 0.12$	$36.03^a \pm 1.23$	$35.63^a \pm 0.61$
Carbohydrates (%)	$2.46^a \pm 0.16$	$0.80^b \pm 0.14$	$4.97^a \pm 0.31$	$5.29^a \pm 0.45$
a_w	$0.95^a \pm 0.00$	$0.94^b \pm 0.00$	$0.42^a \pm 0.00$	$0.41^b \pm 0.00$
TTA (%)	$1.18^a \pm 0.10$	$1.37^b \pm 0.00$	$1.96^a \pm 0.10$	$1.76^b \pm 0.00$
pH	$5.34^a \pm 0.01$	$4.82^b \pm 0.03$	$6.22^a \pm 0.01$	$6.34^b \pm 0.02$
TSS (ºBrix)	$11.37^a \pm 0.31$	$22.03^b \pm 0.67$	-	-

Analyses	Unripe pulp	Ripe pulp	Unripe seed flour	Ripe seed flour
		Instrumental color		
L*	60.23^{a} ±1.23	57.42^{b} ±1.09	26.94^{a} ±0.23	38.74^{b} ±0.90
a*	6.99^{a} ±0.87	10.78^{b} ±0.83	7.16^{a} ±0.36	7.31^{a} ±0.11
b*	19.52^{a} ±1.01	22.46^{b} ±0.96	16.25^{a} ±1.12	21.61^{b} ±1.06
ΔE*	63.70^{a} ±6.32	62.43^{a} ±6.68	32.27^{a} ±1.75	44.96^{b} ±2.23

- Not determined.
Means with different exponents in the same line indicate a difference according to the Student's t-test ($p \leq 0.05$).
Source: Research data

Unfortunately, araticum is a Brazilian native fruit still underexplored in the scientific field. There are no many studies in the current theme-related literature investigating the physicochemical properties of araticum, and only a few researches available were carried out on such topic within the last 5-10 years. Nevertheless, the results of the present study were somehow correlated and compared to those findings, as we consider them relevant to the areas of health and nutrition, besides science and technology of foods.

Fruits have high moisture levels, and are, therefore, subject to numerous changes since water is the main vehicle for chemical, biochemical, physiological, sensory, and microbiological alterations (DAMODARAN; PARKIN, 2019; FRANCO; LANDGRAF, 2023). In this study, it was observed a reduction in the moisture of the araticum pulp (84.99 to 83.29%) during fruit ripening, which may be related to the fruit's respiration and transpiration processes. Pereira *et al*. (2013) found lower moisture (78.61%) in the ripe *R. sylvatica* St.-Hil. pulp harvested in Pelotas-RS (31.7700º S, 52.3313º W).

Moisture content in fruits has effects on post-harvest quality and storage. The water loss increases whenever the ambient temperature also increases. Moreover, whenever there is a difference in moisture between the product and the environment, water will be lost by evaporation (BARBOSA-CÁNOVAS *et al*., 2003; ANWAR *et al*., 2019). Water loss leads to changes in appearance (wilting, wrinkling, accelerated development of damage), texture (loss of crispness and juiciness), and nutritional quality (loss of vitamins A and C). Some practical methods can be used to reduce moisture loss in fruits, such as rapid cooling or maintaining low temperatures and high relative humidity (90 - 95%) (ANWAR *et al*., 2019; DAMODARAN; PARKIN, 2019).

The water activity (a_w) indicates the intensity of the forces that favor non-aqueous compounds to bind to water, and therefore, the water available for several chemical and biochemical reactions and microbial growth (ORDÓÑEZ *et al*., 2005; DAMODARAN; PARKIN, 2019). The a_w values showed that during ripening there are significant changes, indicating that araticum's metabolism slightly alters a_w. Values between 0.94 and 0.95 characterize the pulp as a product with high a_w (ORDÓÑEZ *et al*., 2005; DAMODARAN; PARKIN, 2019), making it susceptible to microbiological deterioration (FRANCO; LANDGRAF, 2023).

The mineral content is influenced by several factors, such as characteristics of the cultivar, soil, and climate, and also agronomic practices. Nonetheless, it is expected to increase as the ripening process progresses (WATHARKAR *et al*., 2020), and that was observed for araticum pulp, in which ash content enhanced from 1.18 to 1.64% with ripening. On the other hand, 1.18% of ashes were quantified for ripe *R. sylvatica* St.-Hil (PEREIRA *et al*., 2013). Cruz *et al*. (2013) identified the order of macro and micronutrients in the pulp of atemoya (*A. squamosa* L. x *A. cherimola* Mill.) as K>P>Ca>Mg and Fe>Zn>Mn>Cu>S, respectively.

There was also an increase in the protein content of the araticum pulp as the fruit ripened (6.66 - 8.26%). The protein content increases with ripening because of the nitrogen (which was added in the form of ammonia, nitrate, dinitrogen, or amino acids) incorporation in the form of proteins and amino acids (LLÁCER *et al*., 2008). Pereira *et al*. (2013) found a lower protein content of 1.82% in the pulp of ripe *R. sylvatica* St.-Hil., while Mazepa (2014) quantified 1.22% protein in *Annona* x *atemoya Mabb* pulp. On the other hand, Cruz *et al*. (2013) observed 6.84% of proteins in the ripe atemoya (*A. squamosa* L. x *A. cherimola* Mill.) pulp, a value similar to that found in this study for the pulp of unripe araticum.

Lipids in most fruits constitute small portions. They are mostly polar, mainly phospholipids and glycolipids components of cell membranes and epidermis (DAMODARAN; PARKIN, 2019). In this research, there was an increase in the lipids content in the araticum pulp with ripening (3.37 to 4.70%), while Pereira *et al*. (2013) detected only 0.28% lipids in the pulp of ripe *R. sylvatica* St.-Hil. harvested in Pelotas-RS. Cruz *et al*. (2013) and Mazepa (2014) found lower lipid contents in the atemoya pulp, of 1.51% (*A. squamosa* L. x *A. cherimola* Mill.) and 0.03% (*Annona* x *atemoya Mabb*), respectively. Lipids are important constituents as they provide twice the energy provided by carbohydrates and proteins; are vehicles for fat-soluble vitamins (A, E, D, and K) and essential fatty acids; contribute to improving taste, and the feeling of satiety (ORDÓÑEZ *et al*., 2005). However, they are susceptible to deterioration and structural transformation by oxidation processes (DAMODARAN; PARKIN, 2019).

The crude fiber method quantifies the insoluble residue (cellulose and hemicellulose) that remains after a defatted plant-origin food has gone through the extraction process with sulfuric acid and sodium hydroxide (ANWAR *et al*., 2019). There was no major change in the crude fiber contents in the unripe and ripe araticum pulp (1.34 and 1.31%). In addition to cellulose and hemicellulose, substances such as lignin, gums, mucilages, algal polysaccharides, pectin, and modified starch can also be described as fiber (COULTATE, 2023). Nevertheless, Pereira *et al*. (2013) found that 91.42% of the total dietary fiber in *R. sylvatica* St.-Hil. pulp is composed of insoluble fibers. Also, the carbohydrates found for both unripe and ripe pulp were low (2.46 and 0.80, respectively), meaning that the fruit pulp is unlikely to present considerable soluble fiber.

The TSS is the sum of all solids dissolved in water (sugars, salts, proteins, acids, etc.) (COULTATE, 2023), and it is an essential parameter for fruit quality, due to its influence on the physical, chemical, sensorial, and biological properties (BARBOSA-CÁNOVAS *et al*., 2003; CHITARRA; CHITARRA, 2005). Hence, in the industry, the greater the TSS content in the fruit, the lower the amount of sugar added to formulations, reducing production costs and increasing the nutritional and sensorial quality of the product (ORDÓÑEZ *et al*., 2005; DUTCOSKY, 2019). In this study, TSS content almost doubled in the pulp (from 11.37 to 22.03 ºBrix) with the araticum ripening. This increase may be related to the hydrolysis of starch, which is converted into glucose and oxidized in subsequent reactions (CHITARRA; CHITARRA, 2005). A lower TSS (16.35 ºBrix) was found for ripe *R. sylvatica* St.-Hil (PEREIRA *et al*., 2013).

The common characteristic of fleshy fruits is their richness in sugars (glucose, sucrose, and fructose) and relatively high acidity (ANWAR *et al*., 2019). In this sense, TTA increased in the araticum pulp (1.18 to 1.37%) with ripening. The content of organic acids, with few exceptions, decreases with ripening as a result of their transformation into sugars (CHITARRA; CHITARRA, 2005). The organic acids influence the characteristics of color, flavor, odor, stability, and global quality maintenance (DAMODARAN; PARKIN, 2019; DUTCOSKY, 2019). Thus, the increase in araticum's pulp acidity can be attributed to the formation of galacturonic acid in the process of cell wall degradation that occurs during ripening (COULTATE, 2023).

The TSS content associated with TTA are properties that indicate fruit ripeness (ANWAR *et al*., 2019; PEREIRA *et al*., 2013). In many fruits, the TSS/TTA ratio is used as a criterion for evaluating "flavor" (CHITARRA; CHITARRA, 2005). In this study, TSS/TTA ratios were 9.64 and 16.08 for unripe and ripe araticum pulp, respectively. Pereira *et al*. (2013) measured a lower TTA (0.39%) in *R. sylvatica* St.-Hil, resulting in a TSS/TTA ratio of 41.92, while Mazepa (2014) found a TTA of 0.27% and a similar TSS (19.53 ºBrix) for the ripe pulp of *Annona* x *atemoya Mabb*, leading to a TSS/TTA ratio of 72.33.

The pH measurement is important for determining food deterioration due to microbial growth, enzymatic activity, and flavor and odor retention (DAMODARAN; PARKIN, 2019; FRANCO; LANDGRAF, 2023). There was a reduction in the pH values with the ripening of the araticum pulp (5.34 to 4.82). There is, usually, an increase in pH as the fruit ripens due to the transformations that occur with the organic acids, which are converted into sugars (CHITARRA; CHITARRA, 2005; ANWAR *et al*., 2019). However, for some fruits, there is a synthesis of organic acids with a consequent pH reduction (COULTATE, 2023), which seems to be the case of araticum. A pH of 4.90 was determined for the *Annona* x *atemoya Mabb* pulp (MAZEPA, 2014), similar to the value found in this study for the ripe fruit.

Color is an important aspect of appreciation of food. Since customers cannot try food before purchasing, color is the quality characteristic that can be analyzed (DUTCOSKY, 2019; COULTATE, 2023). Changes in fruit color with maturation are due to degradative and synthetic processes and are correlated with increased sweetness and the development of other desirable sensory attributes, such as flavor, texture, and acidity (CHITARRA; CHITARRA, 2005). However, there was no change in the total color differences of the pulp as the araticum ripened (ΔE of 63.70 and 62.43). Despite that, by analyzing the color coordinates individually, differences between the ripe and unripe pulp colors are observed. L^* parameter indicated that the unripe pulp is lighter (60.23 against 57.42), while b^* describes the ripe pulp as slightly yellower (22.46 against 19.52).

The importance of drying the seeds to reduce their moisture is that the flour presents a longer shelf life and greater added value, besides broadening its application in new product formulations (PATHANIA; TIWARI, 2021). In this sense, a moisture content of 6.80% was found for *A. squamosa* L. seed flour (ESHRA *et al*., 2019), although the authors did not state the conditions under which the flour was obtained. To reduce the moisture of flours obtained in this study (21.74 to 22.82%), longer drying times and/or higher temperatures could be tested. There was a significant reduction in the seeds a_w with the araticum ripening (0.42 and 0.41); nonetheless, both seed flours are microbiologically stable (DAMODARAN; PARKIN, 2019; FRANCO; LANDGRAF, 2023).

For ashes, there was no difference between the seed flour from the unripe and the ripe fruit (1.72 to 1.70%). Mazepa (2014) found 1.66% of ashes in *Annona* x *atemoya Mabb* fresh seeds, while Eshra *et al*. (2019) found an ash content of 1.89% in the *A. squamosa* L. seed flour, a value closer to those found for araticum seed flour in the present study. The authors identified the macro and micronutrient as, respectively, K>P>Ca>Mg>Na and Fe>Mn>Zn>Cu>Pb>Cd. Yet, Menezes *et al*. (2019) quantified macro and micronutrient order in the *A. muricata* seed flour as K>Mg>P>Ca>Zn>Fe>Cu>Mn.

There was an increase in the protein content of araticum seed flour (10.89 to 11.65%) with ripening. Nonetheless, both of them can be considered sources of protein, since according to the Brazilian legislation, the reference portion of 50 g of any flour (BRAZIL, 2003) must contain at least 5 g of protein to be a source of it (BRAZIL, 2020). In this sense, studies can be carried out to investigate the wheat flour substitution by araticum seed flour, as an alternative to offering products with higher nutritional value at affordable prices (CAZAGRANDA *et al*., 2022). Mazepa (2014) found a lower protein content (2.72%) in *Annona* x *atemoya Mabb* seeds. In Eshra *et al*. (2019) study, *A. squamosa* L. seed flour presented 20.01% protein, but the flour was less humid, i.e., more concentrated in total solids than the flour obtained in this study. The authors identified the predominant amino acids as glutamic (13.13), aspartic (9.03), alanine (7.84), leucine (7.15), arginine (6.29), and lysine (5.37) g/100g protein.

It was observed a reduction in the lipid content of the seed flour when araticum ripened (22.91%, compared to 24.65% of unripe seed flour). Eshra *et al*. (2019) found 31.22% of lipids for a more concentrated *A. squamosa* L. seed flour. Mazepa (2014) reported a lipid content of 25.31% in atemoya (*Annona* x *atemoya Mabb*) seeds, similar to that found in this study for unripe seeds. Such a result suggests that unripe seeds would provide a higher yield in oil extraction.

Andrade *et al*. (2012) found a lipid content of 12.11% in *Rollinia sylvatica* seed flour, and determined the saturated and unsaturated fatty acids (UFA) profile as 25.1% and 74.9%, respectively. Among the UFA, the total monounsaturated fatty acids were 72.64%, known for having a neutral effect on human cholesterol levels. The polyunsaturated fatty acids were 27.36%, composed of linoleic and -linolenic acids, which present anti-inflammatory, antithrombotic, and antiatherogenic effects (TIENCHEU *et al*., 2021).

There was no major change in the crude fiber value for araticum seed flour (36.03 and 35.63%) throughout the fruit's ripening. Fiber physiological effects are associated with the reduction of blood cholesterol and glucose control, which therefore contributes to the control of diabetes. Furthermore, they are responsible for the beneficial effect of fecal motility on the intestines (ORDÓÑEZ *et al*., 2005; COULTATE, 2023).

For the flour to be classified as a 'source of fiber' or that presents a 'high content', the reference portion of 50 g (BRAZIL, 2003) must contain at least 5 g or 10 g of fiber, respectively (BRAZIL, 2020). Therefore, the araticum seed flours can be considered products with a high content of fibers, which renders this by-product a potential use as a functional ingredient. Hence, formulations can be developed by adding araticum seed flour, in order to offer products with higher nutritional value (BRAZIL, 2020), besides reducing agro-industrial waste (MENEZES *et al*., 2019).

On the opposite of the pulp, there was a significant reduction in the seeds' TTA (1.96 to 1.76%) with ripening, and the pH enhanced from 6.22 to 6.34. That means the organic acid content in the seeds decreased throughout fruit ripening. Mazepa (2014) measured a pH of 6.01 for *Annona* x *atemoya Mabb* fresh seeds, lower than values found for araticum.

The total color differences of the seed flour ranged from 32.27 to 44.96 for unripe and ripe araticum, respectively. The L* values describe the darkness of both flours, while the b* parameter indicates they were yellowish. Thus, yellow and black lead to the characteristic brown color in both flours (Figure 2), although the ripe seed flour was darker (38.74 against 26.94).

Figure 2 - Unripe (left) and ripe (right) araticum seed flour.

Source: Research data

4 CONCLUSIONS

Araticum pulp and seed flour showed significant changes with ripening: pulp's ashes, lipids, proteins, TTA, and TSS increased, contrasting with moisture, a_w, carbohydrates, and pH; while moisture, proteins, carbohydrates, and pH were enhanced in the seed flour, opposing to lipids and TTA. The instrumental color indicated no major changes in the total color differences of the pulp as the araticum ripened, although the ripe seed flour became darker with ripening.

Physicochemical characterization of the araticum pulp and seed flour compared to the literature available indicated that *Annonaceae* family fruits have distinct composition, influenced by several factors, such as cultivar, soil, climate, and agronomic practices. Nevertheless, *R. sylvatica* may be promising for processing, as it contains important amounts of proteins, TSS, and lipids in the pulp, which can be used to produce juice, jams, and marmalade. The whole fruit can be used to produce liqueurs, where the pulp part is released under conditions in the presence of ethanol, for example.

For seed flour, some parameters stood out, such as fibers, lipids, and proteins. The processing and characterization of such a by-product, in addition to adding economic, functional, and nutritional value to formulations, has the character of disseminating sustainable development and environmental protection, given that local production is valued and post-harvest losses and waste production are reduced. Hence, this study shows the araticum potential and can be an incentive for cultivation, consumption, and processing by either family farmers or agroindustry.

REFERENCES

ANDRADE, J.M.M. *et al*. Comparison of the fatty acid profiles of edible native fruit seeds from Southern Brazil. **Int J Food Prop**, v. 15, n. 4, p. 815–822, 2012.

ANWAR, R. *et al*. Ripening and Senescence of Fleshy Fruits. In: Paliyath, G. *et al*. (ed.). **Postharvest Biology and Nanotechnology.** 1° Ed. Hoboken: Wiley-Blackwell, 2019.

BARBOSA-CÁNOVAS, G.V. *et al*. **Handling and Preservation of Fruits and Vegetables by Combined Methods for Rural Areas.** Rome: Food and Agriculture Organization of the United Nations, 2003.

BENITES, R.S.R. *et al*. Contents of constituents and antioxidant activity of seed and pulp extracts of *Annona coriacea* and *Annona sylvatica*. **Braz J Biol**, v. 75, n. 3, p. 685–691, 2015.

BRAZIL. Ministério da Saúde. Agência Nacional de Vigilância Sanitária. **Resolução RDC nº 359, de 23 de dezembro de 2003.** Brasília, 2003.

BRAZIL. Ministério da Saúde. Agência Nacional de Vigilância Sanitária. **Instrução Normativa nº 75, de 8 de outubro de 2020.** Brasília, 2020.

CARVALHO, P.E.R. **Ariticum-da-Mata:** *Rollinia sylvatica.* Brasília: Embrapa Florestas, 2008.

CARVALHO, P.E.R. **Espécies arbóreas brasileiras.** 5º ed. Brasília: Embrapa, 2014.

CAZAGRANDA, C. *et al*. Obtenção de farinha de ora-pro-nóbis (*Pereskia aculeata* Miller) e sua aplicação no desenvolvimento de biscoitos tipo cookie. **Cienc Cult Tecnol**, v. 39, n. 3, p. e27148, 2022.

CHITARRA, M.I.F.; CHITARRA, A.B. **Pós-colheita de frutos e hortaliças: fisiologia e manuseio.** 2º ed. Lavras: UFLA, 2005.

COULTATE, T.P. **Food: The Chemistry of its Components.** 7º ed. London: Royal Society of Chemistry, 2023.

CRUZ, L.S. *et al*. Caracterização física e química das frações do fruto atemoia Gefner. **Cienc Rural**, v. 43, n. 12, p. 2280–2284, 2013.

DAMODARAN, S.; PARKIN, K.L. **Química de alimentos de Fennema.** 5º ed. Porto Alegre: Artmed, 2019.

DUTCOSKY, S.D. **Análise Sensorial de Alimentos.** 5º ed. Curitiba: PucPress, 2019.

ESHRA, D.H. *et al*. Physicochemical properties of the seed kernels and the oil of custard apple (*Annona squamosa* L.). **Int J Food Sci Biotechnol**, v. 4, n. 4, p. 87–93, 2019.

FAO. Food and Agriculture Organization of the United Nations. **Major Tropical Fruits Market Review 2022.** 2023. Available at: https://openknowledge.fao.org/server/api/core/bitstreams/ec-c80c38-d519-4404-9a66-e36460358bd4/content Accessed on: 9 Jun. 2025.

FEITEN, M.C. Desenvolvimento de plano de aula prática na educação básica como forma de promover a redução da geração de resíduos alimentares. **Rev Bras Educ Ambient**, v. 18, n. 2, p. 29–37, 2023.

FIDELIS, M. *et al*. Fruit seeds as sources of bioactive compounds: sustainable production of high value-added ingredients from by-products within circular economy. **Molecules**, v. 24, n. 21, p. 1-54, 2019.

FRANCO, B.D.G.M.; LANDGRAF, M. **Microbiologia dos alimentos.** 2º ed. São Paulo: Atheneu, 2023.

ITAL. Instituto de Tecnologia de Alimentos. **Brasil Food Trends 2020.** São Paulo: ITAL/FIESP, 2020. Available at: https://ital.agricultura.sp.gov.br/brasilfoodtrends/8/ Accessed on: 10 Jun. 2025.

KAZMAN, B.S.M.A. *et al*. Traditional uses, phytochemistry and pharmacological activities of Annonaceae. **Molecules**, v. 27, p. 1-32, 2022.

KINUPP, V.F.; LORENZI, H. **Plantas alimentícias não convencionais (PANC) no Brasil.** 2º ed. São Paulo: Plantarum, 2021.

KONICA MINOLTA**. Identifying Color Differences Using L*a*b* or L*C*H* Coordinates.** 2022. Available at: https://sensing.konicaminolta.us/us/blog/identifying-color-differences-using-l-a-b-or-l-c-h-coordinates Accessed on: 9 Jun. 2025.

LATIMER, G.W Jr. **Official Methods of Analysis of AOAC INTERNATIONAL.** 22º ed. Nova Iorque: AOAC Publications. 2023.

LLÁCER, J.L. *et al*. Arginine and nitrogen storage. **Curr Opin Struct Biol**, v. 18, n. 6, p. 673–681, 2008.

MAZEPA, L. **Análise do perfil físico-químico, atividade antioxidante e atividades biológicas da espécie vegetal** *Annona x atemoya Mabb.* (Dissertation) Mestrado em Segurança Alimentar e Nutricional - Federal University of Paraná, Curitiba, 2014.

MENEZES, E.G.T. *et al*. Assessment of chemical, nutritional and bioactive properties of *Annona crassiflora* and *Annona muricata* wastes. **Food Sci Technol**, v. 39, n. 2, p. 662–672, 2019.

ORDÓÑEZ, J.A. *et al*. **Tecnologia de alimentos: Componentes dos alimentos e processos.** 1º ed. Porto Alegre: Artmed, 2005.

PATHANIA, S.; TIWARI, B.K. **Food Formulation: Novel Ingredients and Processing Techniques.** 1º ed. Hoboken: Wiley Blackwell, 2021.

PEREIRA, M.C. *et al*. Characterization, bioactive compounds and antioxidant potential of three Brazilian fruits. **J Food Compos Anal**, v. 29, p. 19–24, 2013.

RAMOS, A.L.C.C. *et al*. Evaluation of the total phenolic content, antioxidative capacity, and chemical fingerprint of *Annona crassiflora* Mart. bioaccessible molecules. **Food Res Int**, v. 165, p. 112514, 2023.

RODRÍGUEZ, B.S. *et al*. Food by-products and food wastes: are they safe enough for their valorization? **Trends Food Sci Technol**, v. 114, p. 133–147, 2021.

TIENCHEU, B. *et al*. Effect of oven and sun drying on the chemical properties, lipid profile of soursop (*Annona muricata*) seed oil, and the functional properties of the defatted flour. **Food Sci Nutr**, v. 9, p. 4156–4168, 2021.

UN. UNITED NATIONS. **Take Action for the Sustainable Development Goals.** 2015. Available at: https://www.un.org/sustainabledevelopment/sustainable-development-goals/. Accessed on: 10 Jun. 2025.

WATHARKAR, R.B. *et al*. Change in physicochemical characteristics and volatile compounds during different stage of banana (*Musa nana* Lour vs. Dwarf Cavendish) ripening. **J Food Meas Charact**, v. 14, p. 2040–2050, 2020.

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