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Article

Characterization and Stability Study of a Fluoride Toothpaste with Organic Abrasive from Acai (*Euterpe oleracea* Mart.) Seeds for Oral Hygiene Use

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Abstract: Açaí is a fruit common in the northern region of Brazil, and its consumption is primarily focused on culinary uses, resulting in the disposal of its seeds and contributing to environmental pollution. In this context, the objective of this study was to obtain, characterize, and perform a stability study of a toothpaste made from acai seeds as an organic abrasive for oral hygiene use. The depulped acai seeds were subjected to drying, grinding, and sieving to achieve the desired granulometry before being added to the other formulation components. Stability tests were conducted through centrifugation, density determination, acidity index, foam formation, FTIR, TG/DTG, rheological properties, and accelerated stability study. The formulation proved stable after the centrifugation test. The obtained density value was 1.36. The acidity value was 0.1720 mg/KOH, and the initial and final foam indices were 66.66%. TG/DTG analysis showed stability around 90°C. The acai toothpaste exhibited pseudoplastic fluid behavior. The pH ranged from 6.5 to 8.08, and it showed good stability under the study conditions. Thus, the acai seed powder was found to be an acceptable organic abrasive for incorporation into toothpastes, and it demonstrated favorable characteristics for daily use in oral hygiene.

Keywords: açaí; seed; residue; toothpaste

1. Introduction

Acai (*Euterpe oleracea* Mart.) is a popular fruit from the northern region of Brazil (Amazon region), and its pulp is widely consumed by the local population [1,2]. It is a dark-colored fruit, ranging from purple to black, grows in clusters, and is typically cultivated in areas with moist or flooded soil. This fruit contains anthocyanins, including: cyanidin-3-glucoside, cyanidin-3-rutinoside, and pelargonidin-3-glucoside. The anthocyanins, present in the seeds, are responsible for the dark coloration of the fruit and act as antioxidants against free radicals, along with flavonoids and phenols. However, the seeds are often discarded in inappropriate places, contributing to environmental pollution and waste. Therefore, their reuse is viable both environmentally and economically [3,4,5].

The reuse of seeds is extremely valid and has been explored in the cosmetics and dentistry industries due to their anti-inflammatory and healing properties [4,5]. Additionally, they are very rich in calcium and phosphorus, which are important elements in the dental remineralization process, as well as silicon, potassium, and other chemical elements [3].

Currently, toothpaste is a well-established product in the market, as it is extremely important for oral hygiene. Its formulations vary, but generally include mineral abrasives, with hydrated silica

being the most common, followed by titanium dioxide and calcium carbonate. Additionally, toothpaste formulations may contain humectants (glycerin and sorbitol), binders (carboxymethylcellulose), detergents or foaming agents (sodium lauryl sulfate), preservatives (formaldehyde and methylparaben), fluoride agents (sodium monofluorophosphate), and distilled water [6,7]. Moreover, natural products such as essential oils are commonly added to toothpastes; for example, peppermint oil, which has antimicrobial and anti-inflammatory activity, significantly reduces colonies of *S. mutans* bacteria [8].

Sodium Lauryl Ether Sulfate (SLES), an anionic surfactant with a negative charge, is generally used as a primary surfactant in cleaning systems. Products like shampoos and liquid soaps use SLES due to its high cleaning power and foaming ability. Additionally, it is a good thickener in the presence of electrolytes (NaCl and NH₄Cl) [9].

According to Araujo et al. [10], glycerol, commercially known as glycerin, is a very versatile substance. Chemically, it is a triol with 3 carbon atoms, systematically named (IUPAC) 1,2,3-propanetriol. It is a colorless, sweet-tasting, odorless, and highly viscous liquid derived from natural or petrochemical sources [10]. Additionally, carboxymethylcellulose (CMC) is widely used in the pharmaceutical and food industries, as well as in paints and adhesives, cosmetics, and as a stabilizing agent for colloids [11].

Another component commonly used in toothpaste is sodium bicarbonate, due to its ability to help neutralize pH and make the toothpaste neutral, with a pH between 7 and 8. It also has properties that aid in the removal of bacterial plaque and prevent potential periodontal diseases associated with tartar buildup or cavities. Although studies indicate that it may increase the roughness of the dental surface, the amount proposed in toothpaste is minimal, primarily aimed at helping balance pH [2].

Moreover, sodium fluoride, a naturally occurring mineral, plays an extremely important role in both the prevention and control of dental caries due to its biological activity against the virulence of cariogenic bacteria and its direct role in the remineralization of dental tissues [10]. This inorganic salt also has the advantage of being enzymatic and microbicidal [12], making it one of the main components in toothpastes.

The incorporation of new agents into toothpastes is the result of various research efforts. For example, Rodrigues et al. [8] evaluated the antimicrobial activity of rosemary oil in several articles. Batista et al. [13] assessed new toothpastes with natural products in their composition. The search identified formulations based on *Spilanthes acmella*, a common leaf from the northern region of the country known as jambu, as well as formulations with ginger and peppers such as Sancho pepper and Capsicum. These components were added to toothpastes due to their properties capable of reducing sensitivity to cold or heat, stimulating saliva production, and providing analgesic effects [13].

Peppermint (*Mentha piperita*), commonly used for its analgesic properties, has its essential oil, rich in menthol, as the primary product of interest. It is widely used in the food and pharmaceutical industries, with applications in oral hygiene products, flavorings, food and beverage aromatizers, perfumery, confectionery, and pharmaceuticals due to its antiseptic, antibacterial, and antifungal properties [14].

From this perspective, although açai has already been used in dentistry, the reuse of its seeds as an abrasive agent in the formulation of toothpaste has not yet been reported. Therefore, research that demonstrates that this residue, in addition to being repurposed and potentially reducing environmental pollution, can contribute to the development of a low-cost basic hygiene product, would be of great value. Thus, the objective of this work was to obtain, characterize, and conduct a stability study of a toothpaste using açai seeds as an organic abrasive for oral hygiene.

2. Materials and Methods

2.1. Materials

The acai seeds were obtained from a commercial establishment in the metropolitan area of Belém (Belém, Pará, Brazil). Sodium fluoride gel was purchased from Maquirá (Maringá, Paraná, Brazil). Sodium lauryl sulfate (P.A., M.W. 288.38) was purchased from Êxodo Científica Química (Sumaré, São Paulo, Brazil). Peppermint oil was purchased from P Amaro LTDA (Iguatu, Ceará, Brazil). Sodium bicarbonate (P.A., M.W. 84.019) was purchased from Êxodo Científica Química (Sumaré, São Paulo, Brazil). Ethylenediaminetetraacetic acid (P.A., A.C.S., M.W. 372.24) (EDTA) was purchased from Quimibrás Indústrias Químicas S.A (Rio de Janeiro, Rio de Janeiro, Brazil). Glycerin (P.A., A.C.S., M.W. 92.09) was purchased from Êxodo Científica Química (Sumaré, São Paulo, Brazil). Sodium carboxymethylcellulose (P.A.) was also purchased from Êxodo Científica Química (Sumaré, São Paulo, Brazil).

2.2. Methods

2.2.1. Drying, Grinding, Sieving, and Granulometric Classification of Acai Seeds

The acai seeds (*Euterpe oleracea* Mart.), with the pulp removed, were collected from a commercial establishment located in Belém/PA, Brazil, and taken to the research center of the School of Chemical Engineering at the Federal University of Pará (UFPA) for powder extraction. After collecting the acai seeds, they were subjected to a drying process to remove excess moisture. A convective oven (FANEM A-HT, São Paulo, Brazil) was used for this process, operating at 70°C for 48 hours. Following the drying process, the seeds were ground in three stages. In the first stage, a knife mill with hammers (TRAPP TRF 600, Santa Catarina, Brazil) was used, followed by a knife mill (MARCONI - MA 048, São Paulo, Brazil), and finally a ball mill (CIMAQ - Work Index 005, São Paulo, Brazil) in a batch process with a specific weight of 500 to 700 g of acai seeds for 3 hours to achieve the desired granulometry.

For the sieving or granulometric classification process, a sieve shaker (PRODUTEST RO-TAP, São Paulo, Brazil) with 5 amps was used, with cycles of 60 minutes for every 100 g of acai seed powder. Sieves with 80#, 115#, 200#, 270#, and 400# mesh were employed. Figure 1 shows the flowchart of the acai powder extraction processes [5].

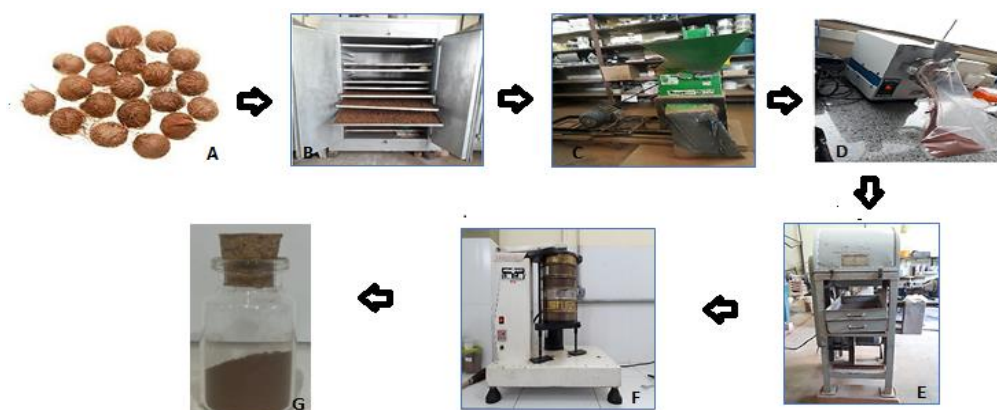


Figure 1. Flowchart of the Acai Powder Extraction Process. A: Depulped Seeds, B: Drying in Oven, C: Grinding in Hammer Knife Mill, D: Grinding in Knife Mill, E: Grinding in Ball Mill, F: Sieving, G: Acai Seed Powder.

2.2.2. Preparation and Characterization of the Toothpaste

The formulation of the toothpaste was defined based on the Brazilian Pharmacopoeia Formulary, 2nd Edition [15], according to the percentage parameters for each component. The concentrations of the components in the initial base formula were adjusted to achieve a formulation

with the desired characteristics for the toothpaste (Table 1). After sieving, the acai seed powder was added to the other components of the formulation (Table 1). Each powdered component was weighed using an analytical balance, added to a clean and sterile beaker, and gradually mixed with the liquid components to ensure the homogeneity of the toothpaste. This was done using a mechanical agitator (Silex, Belém, Pará) at a speed of 3000 rpm for 20 minutes.

Table 1. Composition of the Toothpaste Formulated from Acai Seed.

Components	%
Acai seed powder	20
Sodium fluoride gel (2%)	7
Sodium lauryl ether sulfate	1
Peppermint essential oil	2
Sodium bicarbonate	1
Ethylenediaminetetraacetic acid	0.1
Glycerin	1.5
Carboxymethylcellulose	0.9
Water qsf 100g	

2.2.3. Physicochemical Characterization of Acai Toothpaste

Centrifugation Test

In the centrifugation test, 5 g of the gel were weighed and placed in Falcon tubes. The test was performed in triplicate under the following experimental conditions: ambient temperature (25°C ± 2.0°C); rotation speed of 3.000 rpm; and test duration of 30 minutes [16].

Density Determination

For the density test, a 100 mL graduated cylinder was used, and 10 g of gel was placed in the cylinder. The cylinders were weighed empty, filled with distilled water at room temperature, and then with the 10 g sample of toothpaste [17]. The analysis was performed in triplicate. The apparent density was calculated according to Equation (1).

$$D = M \div V \quad (1)$$

where, D = apparent density; M = sample mass; v = occupied volume

Foam Formation

For the foam test, a small sample of toothpaste, 5 g in triplicate, was placed in a Falcon tube and filled with the same amount of distilled water. The tube was then shaken for 1 minute until foam was formed. The test was conducted at time 0 and repeated after 180 days [17]. The foam index (FI) was calculated according to Equation (2).

$$IE = 1000 \div A \quad (2)$$

where A is the volume, in milliliters, of the solvent used for the preparation of the dilution in the tube where the foam was observed.

Acidity Index Analysis

For the determination of the acidity index, 5 g of the sample were weighed and diluted with distilled water to a sufficient quantity in a 100 mL volumetric flask. Then, 10 mL of the sample solution was pipetted into a 125 mL Erlenmeyer flask. Next, 2 drops of 0.1% phenolphthalein indicator were added, and the solution was titrated with 0.1 N sodium hydroxide solution until a pink coloration appeared [18,19]. The percentage of total titratable acidity was calculated according to Equation (3).

$$IA = 5,16 \times N \div M \quad (3)$$

where: n = volume (in mL) of 0.1 M potassium hydroxide used in the titration, m = sample mass in grams.

Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR spectra of the toothpaste were obtained by infrared absorption spectroscopy using Fourier Transform Infrared Spectroscopy (FTIR) on an IR Prestige 21 spectrometer (Shimadzu®, Kyoto, Japan), using the Attenuated Total Reflection (ATR) technique with 32 scans in the absorption range of 4000-500 cm⁻¹ and a resolution of 4 cm⁻¹ [12].

Thermogravimetric Analysis (TG/DTG)

The TG/DTG curve was obtained using a TGA-50 thermal analyzer (Shimadzu®, Kyoto, Japan) in an aluminum crucible with 3.636 mg of sample, a flow rate of 50 mL/min under a nitrogen (N₂) atmosphere, a heating rate of 10 °C/min, and conducted over a temperature range of 25 to 600 °C. The data obtained were analyzed using the TA-508W Shimadzu software [21].

Rheological Properties

The viscosity of the samples was determined using a Brookfield RST+RHEOMETER (Brookfield, MA, USA), rotating at 600 rpm at a fixed temperature (25 °C) for a period of 120 seconds [19].

2.3. Formulation Stability Study

In the accelerated stability study, the samples in triplicate were stored in an incubator (± 40°C), refrigerator (± 5°C), or at room temperature for 180 days. Analyses were conducted at time T0 (immediately after preparation), T7 (7 days), T15 (15 days), T30 (30 days), T60 (60 days), T90 (90 days), and T180 (180 days). Immediately after each cycle, the samples were evaluated for the following parameters: pH value determination and organoleptic characteristics (emphasizing any changes in appearance, color, and odor). Homogeneity, shine, and the absence of lumps and precipitates were also analyzed. The pH determination for the stability test was carried out using a pH meter calibrated with pH 4.0 and 7.0 buffer solutions, with results representing the average of three independent determinations. Each measurement was conducted in triplicate according to the storage type: room temperature, incubator, and refrigerator. The test was performed by weighing 2 g of the toothpaste diluted in 20 mL of distilled water, followed by measurement with a digital pH meter calibrated with pH 4.0 and 7.0 buffer solutions, in triplicate [17].

3. Results

3.1. Centrifugation Test

After the preparation of the toothpaste, the centrifugation stability test (Figure 2) showed that there was no phase separation after the test. It is important that there is no separation of components to ensure that all components fulfill their intended function and that the final product remains stable [22].



Figure 2. Centrifugation test conducted on the toothpaste formulation 24 hours after its preparation.

3.2. Density Determination

In the characterization of the toothpaste, one important factor is density. The density test was performed in triplicate and the average value was $1.36 \pm 0.02 \text{ g/m}^3$ [17].

3.3. Foam Formation Test

When evaluating foam formation, a value of approximately $66.66 \pm 0\%$ was found, given that the Falcon tube had 15 mL. The foam height was greater than 1 cm in all measurement tubes (Figures 3). Therefore, the foam index is greater than 1000, and the result was similar for both the initial test and the final test after 180 days [17].

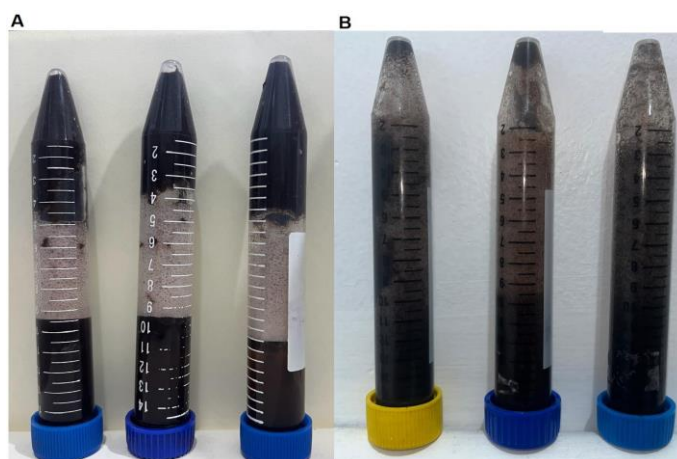


Figure 3. Foam Formation Test conducted on the toothpaste formulation. A. Test after 24 hours, B. Test after 180 days.

3.4. Acidity Index Evaluation

The acidity index (AI) is directly related to the amount of potassium hydroxide present in the formulation, necessary to neutralize the free fatty acids in 1 g of the sample. In this study, the obtained acidity index was $0.1720 \pm 0.08 \text{ mg/KOH}$.

3.5. Infrared Spectroscopy Analysis

Figure 4 shows the FTIR spectrum of the toothpaste made from açai seed. A band was observed around 3391 cm^{-1} corresponding to O-H stretching in hydrogen bonds, 1649 cm^{-1} attributed to C=O

stretching vibration, and around 650 cm^{-1} associated with out-of-plane angular deformation in hydrogen bonds [23].

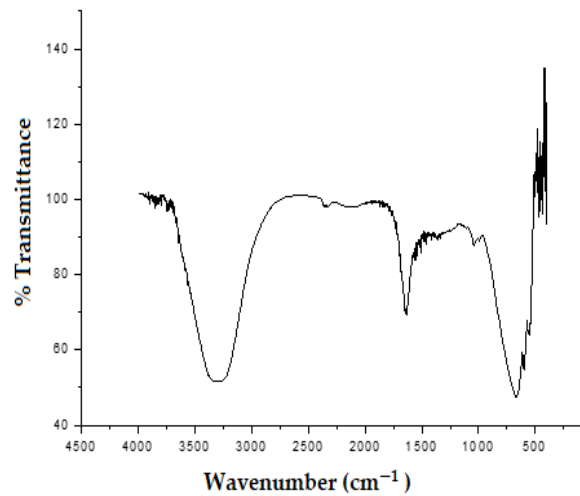


Figure 4. Infrared Spectra of Açai Seed Toothpaste.

3.6. Thermogravimetric and Derivative Thermogravimetric Analysis

The thermal behavior of the açai toothpaste was examined by thermogravimetry (TG/DTG) and revealed only one mass loss event. This event began at 47.65°C and ended at 71.96°C, with a 41.01% mass loss associated with the evaporation of water present in the formulation [21,24].

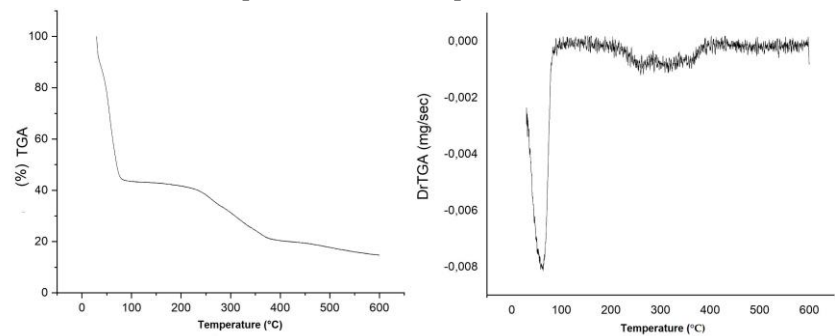


Figure 5. Thermogravimetric Analysis (TG) and its Derivative (DTG) performed on the açai toothpaste.

3.7. Rheological Properties Analysis

The analysis of rheology is related to understanding the flow and deformation of a material, where factors such as force, time, and deformation are investigated through the relationship between stress and strain of the substance, such as toothpaste [19]. Figure 6 shows the rheological behavior of the açai seed toothpaste. It exhibited the behavior of a non-Newtonian pseudoplastic fluid.

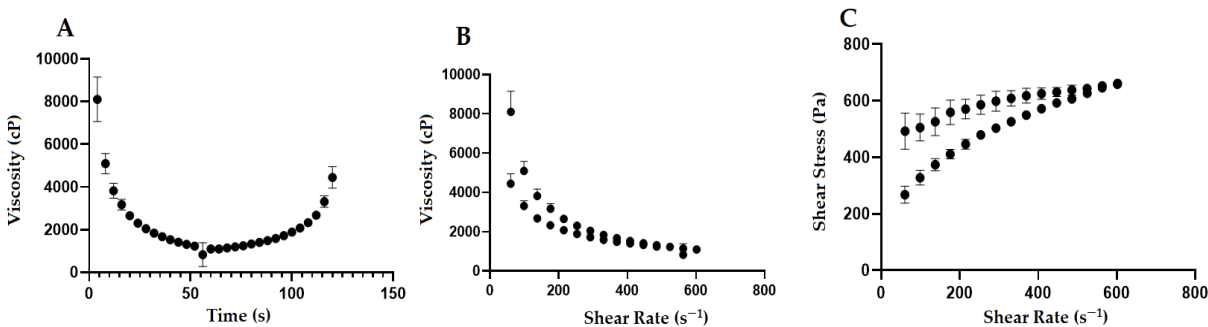


Figure 6. Rheological Behavior of Açai Toothpaste. A: Viscosity versus time; B: Viscosity versus shear rate; C: Shear stress versus shear rate.

3.8. Stability Analysis

Accelerated stability was evaluated in terms of pH and organoleptic characteristics. Table 2 shows the variation in pH, which is mainly influenced by the anthocyanins present in the açai seed [25].

Table 2. Data obtained from pH evaluations conducted on different days of the stability study under various temperature conditions.

Time (Days)	Room Temperature	Incubator	Refrigerator
0	8.08	-	-
1	7.41	7.21	7.1
7	7.49	7.56	7.50
14	7.56	7.12	7.45
21	7.92	7.07	7.88
30	7.0	6.8	7.8
45	6.84	6.51	7.71
60	6.80	6.50	7.60
90	7.55	6.53	7.56
180	6.49	6.50	6.69

Organoleptic characteristics can be defined as the properties perceived by human senses, related to taste, smell, and sight. They are extremely important as they are directly linked to the preservation state of a food or hygiene product [26]. Figure 7 shows the organoleptic characteristics of the açai seed toothpaste analyzed over the 180-day period of accelerated stability study in the refrigerator.

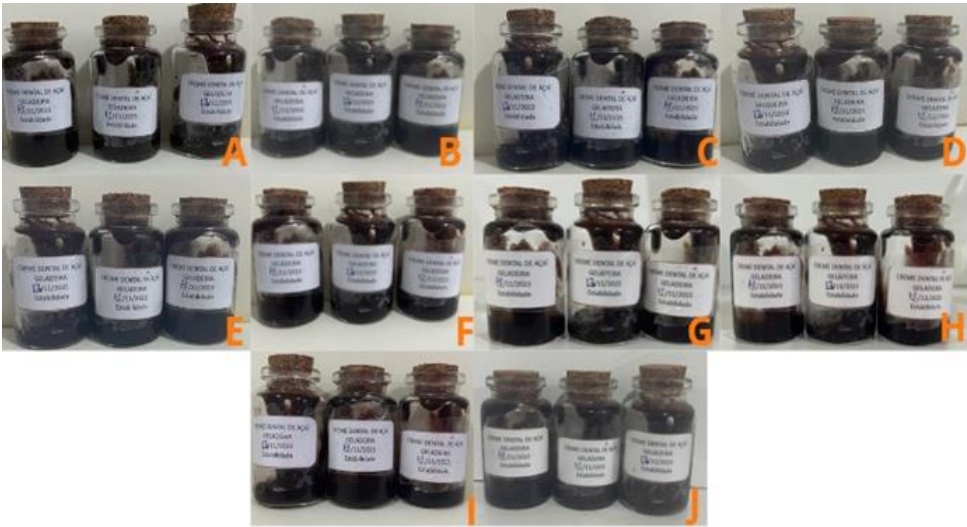


Figure 7. Stability in Refrigerator: A: Initial Stability; B: 24 hours; C: 7 days; D: 14 days; E: 21 days; F: 30 days; G: 45 days; H: 60 days; I: 90 days; J: 180 days.

Figure 8 reveals the organoleptic characteristics of the açai seed toothpaste analyzed over the 180-day period of accelerated stability study in the room temperature.



Figure 8. Stability at Room Temperature: A: Initial Stability; B: 24 hours; C: 7 days; D: 14 days; E: 21 days; F: 30 days; G: 45 days; H: 60 days; I: 90 days; J: 180 days.

Figure 9 shows the organoleptic characteristics of the açai seed toothpaste evaluated over the 180-day period of accelerated stability study at incubator.



Figure 9. Stability in Incubator: A: Initial Stability; B: 24 hours; C: 7 days; D: 14 days; E: 21 days; F: 30 days; G: 45 days; H: 60 days; I: 90 days; J: 180 days.

In this study, the final characteristics of color and appearance in the incubator varied slightly when compared to the initial ones or those from the refrigerator and room temperature conditions, indicating that the anthocyanins degraded with temperature (Table 3).

Table 3. Organoleptic Characteristics Observed in the Stability Study (1 to 180 days).

Characteristic		Refrigerator	Room Temperature	Incubator
Initial	Color	D	D	D
	Odor	C	C	C
	Appearance	Ho	Ho	Ho
Final	Color	D	D	W
	Odor	C	C	C
	Appearance	Ho	Ho	He

Legend: D - Dark / C - Characteristic / Ho - Homogeneous / W - Whitish / He – Heterogeneous.

Figure 10 shows the final appearance of the toothpaste, as well as its extrusion, i.e., the ease with which the formulation can be expelled from the tube, which is important for semi-solid formulations.

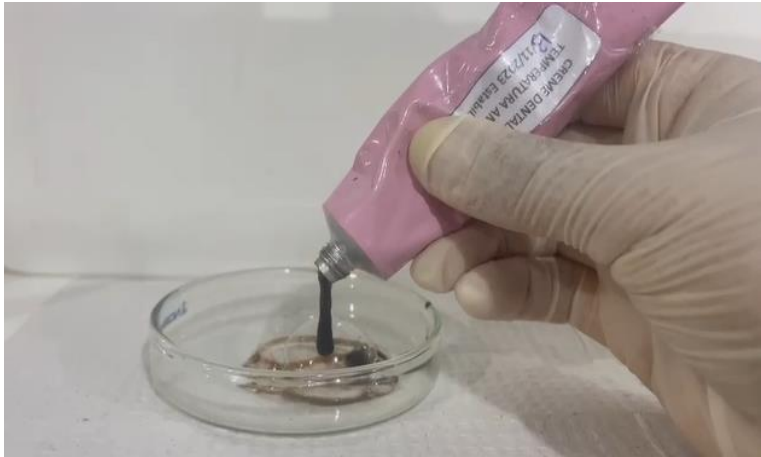


Figure 10. Final Appearance and Extrusion of the Toothpaste.

4. Discussion

Biotransformed and economically viable products are the focus of research, especially in dentistry [27,28]. In this context, açai, which has rounded and purplish seeds, is primarily used for food; however, its antioxidant properties have prompted investigations in the cosmetic field [5,29,30]. The açai seed contains calcium carbonate, an inorganic compound responsible for the abrasive effect in commercially available toothpaste. In this study, açai seed (waste) was used as an abrasive to create a toothpaste for oral hygiene. The obtained formulations were evaluated for physical and physicochemical parameters to ensure their quality [4], and the research is innovative, with some tests being conducted for the first time on açai seed toothpaste.

In terms of initial stability, centrifugation testing is necessary to prevent separation of homogenized compounds in the formulation [22]. The toothpaste proved stable after centrifugation testing. Azevedo, in his study, evaluated a toothpaste incorporated with propolis and assessed the product’s stability both preliminarily, with the centrifugation test, and accelerated, with shelf-life testing, to evaluate its commercial viability [28,31,32].

Another analysis required for semi-solid formulations is density, to understand why products with the same molecular weight occupy different volumes, which applies to personal care products like toothpaste [21]. The results obtained in this work were similar to those of Ponpeo [33] and Santos [34], who assessed the physicochemical properties of different toothpastes with sucupira, tea tree,

copaiba, eucalyptus, and white pine oils, and found their densities ranged from 1.05 to 1.57 g/m³, similar to the values obtained in this study. Santos [35] found that the density of açaí seeds had an average result of 1.27 g/cm³, corroborating the findings here [34,36].

In addition to appropriate density, it is important for toothpastes to have a high foam-forming capacity to aid in the mechanical removal of bacterial plaque. This is a stimulating factor in daily oral hygiene routines, as it promotes a feeling of cleanliness [37]. Surfactants are responsible for foam formation; for example, sodium lauryl sulfate, even in a minimal amount of 1% in this study's formulation, plays a crucial role in this regard [21]. The obtained data were similar to Souza's study [38], which evaluated a mouthwash with plant-based biosurfactants.

In this context, the acidity index is extremely important for assessing the degradation of triglycerides, which can cause sensory changes in odor and flavor of the toothpaste [2]. Elevated acidity is related to storage, bacterial activity, and moisture [17,19]. The findings of this article demonstrate the influence of sodium bicarbonate in lowering acidity [2,39].

Regarding chemical characterization, infrared spectroscopy is necessary to examine the preliminary chemical structure of substances present in a given sample, providing structural information about a molecule. Molecules may be similar, but they are never identical. Therefore, FTIR was used to preliminarily determine the chemical composition of açaí toothpaste, with the goal of identifying the functional groups of the compounds present in the formulation [40,41]. The functional groups found may be related to water, which is present in higher quantities in the formulation, as well as lignin and cellulose found in the açaí pulp and seed [40,41]. The study's findings corroborate those of Oliveira, Azevedo, and Barros 2021, who found the same functional groups such as lignin, cellulose, and water [24,40,41].

In terms of physical characterization, viscosity is highlighted as an essential characteristic in the analysis of materials, especially concerning rheological aspects, as it is closely related to the flow behavior of the material when subjected to shear stress or strain rate [6,44,45]. Additionally, fluids can be classified in different ways according to their behavior; pseudoplastic fluids, where viscosity increases as shear rate decreases [42,43,44], and thixotropic fluids, where viscosity decreases as the duration of applied strain rate increases [42]. The açaí toothpaste exhibited the behavior of a pseudoplastic fluid; as the shear rate increased, viscosity decreased, and these fluids can also be associated with nonlinear shear stress [5,42]. The same behavior was observed in a study evaluating 0.12% carbopol gel [42].

The açaí toothpaste exhibits characteristics of a non-Newtonian fluid, as there was a decrease in shear stress with an increase in shear rate, resulting in shear resistance and consequently more fluidity of the material [5,43-45]. Another observation regarding the rheological behavior of the toothpaste was that viscosity decreased with increased time. Thus, toothpastes need to have adequate viscosity to flow well, similar to gels. Metta [46] characterized dental gels as having non-Newtonian fluid characteristics, and Krishna's toothpaste viscosity results were similar to those found in this study [22].

One of the most important studies in pharmaceuticals and cosmetics is stability testing, as it provides data to predict shelf life and monitor organoleptic, physicochemical, and microbiological stability, generating information about product safety and reliability. In this study, accelerated stability was assessed by checking pH as well as organoleptic characteristics [22,46].

The oral cavity is an environment influenced by acids and bases; saliva plays a crucial role in maintaining oral balance, but toothpastes should remain neutral to basic to avoid demineralization and promote remineralization. This stability of pH over time is an important factor for product stability [44]. Srivastava et al. 2023 also evaluated the stability and pH of various toothpastes, yielding results similar to those of this study [7].

pH showed variations according to temperature changes, strongly associated with the anthocyanins present in açaí, where drastic changes lead to a decrease in pH, making the environment more acidic [47]. The color and structure of anthocyanins can vary with pH, and in the açaí toothpaste formulation, pH values ranged between 8 and 6.5, with greater variation at higher temperatures (oven). This is because anthocyanins tend to be unstable, especially during heating,

which is related to the breakdown of the heterocyclic ring of the chalcone present in the pigment [25]. Krishna reported similar results, with a pH value of 8.07 for the initial sample [22].

In addition to temperature and pH, anthocyanins can vary with light exposure. This is because these pigments absorb significant amounts of light and degrade in its presence [47]. It is important to note that, besides light, the presence of oxygen is necessary for more intense degradation. The greater the amount of available oxygen, the higher the degree of pigment degradation, with fluorescent light exacerbating pigment deterioration [45,48]. Monomeric anthocyanins and their color intensity tend to decrease with time and temperature, causing them to appear lighter or whitish, factors also observable in organoleptic characteristics [49].

The formulations exhibited a heterogeneous appearance at 40 °C and at room temperature due to the packaging being exposed to light, which degraded the anthocyanins present in açai. The formulation stored in the refrigerator remained stable without precipitation, and the odor remained consistent across all conditions. There were variations in the formulation with the different temperatures (refrigerator, oven, and room temperature) at time 0 and after 180 days. Organoleptic properties play a crucial role in quality control, making it essential to ensure their stability over time. Good stability is associated with storage in a refrigerator, where the packaging protects the product from light and temperature influences on the degradation of anthocyanins. At room temperature, even with exposure to light, the characteristics remained stable for approximately 150 days. However, in an oven, the formulation began to show losses around 60 days due to the instability of anthocyanins at high temperatures [25,47].

According to ANVISA Resolution 752 of September 2022 [61], toothpastes should have their primary and secondary packaging, where the primary packaging must be compatible with aluminum to protect the substance from light RDC 752/2022 [50]. Thus, stability tests were conducted in aluminum packaging under the same parameters as the pharmacopoeia to obtain results closer to the final product and packaging, where the organoleptic characteristics of color and odor remained stable after 180 days, unlike glass packaging [6,17].

In the toothpaste made with açai seeds, variations in organoleptic and physicochemical properties were noted. The most significant variation occurred in the group stored in the oven at 40 °C, followed by storage at room temperature under fluorescent light [25,47]. It is important to highlight that, in the thermal stability analysis by thermogravimetry, the açai toothpaste demonstrated stability close to 100 °C. The group that showed the best results was the one stored in the refrigerator, where both pH and color did not experience significant changes. Due to these changes, it is recommended that toothpastes be sold in aluminum packaging, which ensures the preservation of their physicochemical and organoleptic properties. Considering that this experimental formula contains açai, which is rich in anthocyanins that are sensitive to temperature, light, and pH, the use of packaging without protection against light may have influenced the results obtained [49].

5. Conclusions

Based on the evaluations conducted in the study, the toothpaste made from açai seeds as an organic abrasive has proven to be safe, with satisfactory quality, and could represent a promising and bioeconomic alternative for oral hygiene products. The preliminary and accelerated stability studies demonstrated favorable characteristics and good stability throughout the entire analyzed period.

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