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Sugarcane *Rapadura*: Characteristics of the Oldest Historical Energy Food and Its Native Production Method

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Abstract: *Rapadura* is a well-recognized sugar-cane-derived product with a sweet, characteristic flavor and hard texture. This product is a cultural Brazilian landmark, particularly in Ceará, Brazil, where it is usually produced by small family businesses and consumed locally. This feature contributes to the difficulties of *rapadura* production standardization, a requirement for the global market. Against this backdrop, this study focuses on analyzing the centesimal composition and mineral content of *rapadura*. Six samples from different cities in Ceará were analyzed for moisture, ash, lipids, proteins, carbohydrates, energy value, and minerals. The results ranged from 6.42–11.74% for moisture, 0.23–1.12% for ash, 0.49–0.92% for protein, 85.18–89.12% for lipids, and 352.00–391.19 Kcal for energy value. Significant variations were observed between the samples, showing a lack of standardization in the production process. The analysis of micronutrients revealed low levels, with copper and iron standing out in sample D. It can be concluded that the *rapadura* analyzed meets the physical-chemical parameters established by national legislation and is a food rich in carbohydrates and energy.

Keywords: *rapadura*; sugarcane; energy value

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1. Introduction

Rapadura is a food product developed from sugar cane (*Saccharum officinarum*) juice heating, presenting a sweet flavor and hard texture [1,2]. This product emerged in the XVI century in the Canary Islands, a Spanish territory. In Brazil, *rapadura* arose during the colonization period and was first used as food for slaves. Later, due to its flavor, nutritional capacity, and ease of transportation, this product became part of the Brazilian countryside diet. In this scenario, the population expansion in these regions leveraged sugar cane manufacturing [3].

Sugar-cane-derived products such as *rapadura*, brown sugar, and molasses were classified as non-refined sugar, defined as natural sugar sweeteners enriched with phytochemical molecules such as flavonoids and phenolic acids. Experimental evidence suggests that these products can benefit human health, including the reversal of hypoglycemic effects, improvement of insulin sensitivity, weight control, hypolipidemic effects, reduced inflammation and oxidative stress, and protection against neurodegenerative diseases [4]. These data provide relevant information that highlights the importance of nutritional education promotion regarding knowledge about food composition, classifications, and functions in the body, which improve and contribute to healthier dietary choices. Nevertheless, the consumption of natural and minimally processed foods is known for its beneficial effects and has become a primary choice for both young individuals and adults.

Sugar cane manufacturers grew and became notable mostly in the northwestern and midwestern regions of Brazil [5]. The abundance of this raw material facilitated the *rapadura*'s popularity and influenced the consolidation of this product as a cultural landmark in these regions; an example is Mato Grosso do Sul State Law No. 4.936, which recognizes this product as state cultural and historical patrimony [6,7]. The popularization of *rapadura* intake is part of regional cuisine, serving as raw material for a vast quantity of products, which boosts the consolidation of this product in the native's gastronomic identity, which connects people, and helps in the construction of affective memories [8].

In a population-based study in Brazil that evaluated food consumption based on the degree of food processing, behavioral variables, and sociodemographic factors, it was concluded that natural and minimally processed foods represent 61.36% of individuals' daily energy intake. Notably, *rapadura* contributes only 0.13% to daily energy intake. Furthermore, the results suggest that ultra-processed foods contribute more significantly to the daily energy intake of younger individuals, and the consumption of ultra-processed foods is positively associated with sedentary behavior and lower educational levels [9].

The northwestern Brazilian state of Ceará holds a special place for *rapadura* in its culinary heritage. Ceará's *rapadura* is produced through time-honored methods passed down through generations. The Ceará cities of Aquiraz, Cariri, and Pindoretama are regionally recognized for their "engenhos", which are local standard constructions recognized by yield products derived from sugar cane. Usually, these products are sold to the community at a local level in street markets or in small businesses in the region [10,11]. The manufacturing process of *rapadura* results in a solid form, presented in blocks or bricks. In Japan, it is known by the name Kokuto [12]. In the countries of South America, it is named "panela".

The *rapadura* production requires at least 80% of total sugars, and the soluble solids content should reach 70–73 °Brix when hot and 82–85 °Brix when cold, to be then beaten, molded, and naturally cooled to achieve a solid appearance [1]. Compared to refined sugar, *rapadura* has advantages, such as a high nutritional value and low caloric rates; however, it can show disadvantages with a short shelf life and a slow dissolution value [13].

The choice of sugarcane variety used in the production of *rapadura* plays a crucial role in achieving a final product of better quality [14]. In addition, the skillful execution of cutting techniques, traditionally performed by seasoned agriculturists, contributes significantly to preserving the final product's inherent sweetness and nuanced flavors. This discerning approach to sugarcane harvesting underscores the artistry inherent in producing exquisite *rapadura* [15].

Rapadura, a traditional sweetener derived from sugarcane in Brazil and Latin America, has profound social, cultural, and economic significance. It is deeply ingrained in the culinary heritage of the region, serving as a symbol of identity and legacy. The production of *rapadura* not only generates employment opportunities for local communities but also plays a pivotal role in sustainable agriculture through sugarcane cultivation. Therefore, this activity boosts local economic growth and contributes to poverty alleviation, influencing environmental conservation. Moreover, *rapadura* stands as a popular and versatile commodity, influencing domestic consumption and international trade, thereby bolstering economic development across the region. The preservation and promotion of *rapadura* culture safeguard a rich culinary legacy and catalyze social cohesion and economic prosperity in Brazil and throughout Latin America.

In this scenario, the present study investigated the composition of different *rapadura* types produced in regions of the Brazilian state of Ceará by several producers, where the centesimal composition and mineral rates were evaluated to characterize the products, highlight their similarities, and examine their nutritional aspects.

2. Materials and Methods

2.1. Sample Preparation

Six samples of *rapadura* from different *engenhos* localized in the Ceará cities of Ubajara (−3.879638 S/−40.922401 W), São Benedito (3°59′23″ S/40°51′25″ W), and Pindoretama (4°04′11″ S/38°17′37″ W) were acquired directly from the producers, choosing only products newly manufactured with their original packaging provided by the seller.

The *rapadura* samples were produced from sugarcane (Saccharum officinarum) cultivated around the mill region. The cultivation of samples A, B, and C was located at the

Moitinga farm in Ubajara; sample D was situated in the rural area at the São Miguel farm in São Benedito; and samples E and F were in the rural area of Pindoretama.

Sugarcane was harvested within 24 to 72 h until the juice was acquired for *rapadura* production. The manufacture occurs during daylight, starting with boiling in the early morning and culminating in concentration and molding into *rapadura* bars by late afternoon. *Rapadura* samples were collected at the end of the day, specifically in October 2022, and directed to the laboratories.

2.2. Proximal Composition and Minerals

The analyses of moisture, ash, and total lipids were conducted according to the Adolf Lutz Institute [16]. The analyses of proteins and minerals were performed following the methods outlined by the Association of Official Analytical Chemists (AOAC) [17]. The analyses of carbohydrates and energy values were carried out under the methods specified by the United States Department of Agriculture [18].

2.2.1. Moisture

The moisture content was measured after weighing approximately 7 g of each sample in tared porcelain capsules, and the measurements were performed in triplicate. The samples were placed in a drying oven at 105 °C for 24 h and weighed and calculated. The moisture percentage was calculated using the following formula:

$$\%\ \text{moisture} = \frac{100 - (\text{final capsule weight } - \text{ initial capsule weight})}{\text{Sample Weight } \times 100}$$

2.2.2. Ash

The ash content was obtained after weighing approximately 2 g of each sample in a porcelain crucible. All the content above was previously dehydrated in a drying oven at 105 °C for 24 h and subjected to a muffle furnace at 550 °C for 6 consecutive hours. The ash percentage was calculated using the following formula:

$$\%\ \text{ashes} = \frac{(\text{final weight of capsule } - \text{ initial weight of capsule})}{\text{Sample Weight (g)} \times 100}$$

2.2.3. Total Lipids

The total lipid content was obtained using the Soxhlet method. Flat-bottomed flasks with ground mouths were pre-tared and weighed. Subsequently, approximately 2 g of each dehydrated sample was weighed and placed on filter paper. Total lipid extraction took place using a PA-grade hexane reagent over 6 h through solvent evaporation in distillation. Later, the flasks were weighed, and the residual value was calculated. The lipid percentage was calculated using the following formula:

$$\%\ \text{Total lipid} = \frac{(\text{final weight of flask } - \text{ initial weight of flask})}{\text{Sample Weight (g)} \times 100}$$

2.2.4. Protein

The protein determination was carried out by weighing 0.2 g of each dehydrated sample in triplicate. Subsequently, 1.5 g of digestion mixture and 5 mL of sulfuric acid (H_2SO_4) were transferred to Kjeldahl-type test tubes. The sample digestion occurred in a digestion block at 400 °C for 3 h. Then, distillation occurred in a Kjeldahl distiller. To conclude, titration using a burette with 0.02 M chloride acid (HCl) was performed for each sample until the endpoint. The nitrogen-to-protein conversion factor of 6.25 was used for subsequent protein calculations. The protein percentage was calculated using the following formula:

$$\%\ \text{Protein} = \frac{(\text{Volume of HCl } \times 0.02 \times \text{ HCl Factor } \times 0.014 \times 6.25)}{\text{Sample Weight } \times 100}$$

2.3. Carbohydrates and Energy Value

The total carbohydrate content was determined by the difference between 100 and the sum of the percentages of moisture, protein, total lipids, and ash. The energy value was calculated based on the protein, and the total content of total lipids and total carbohydrates was calculated using the Atwater system, with values of 4 kcal/g, 9 kcal/g, and 4 kcal/g, respectively.

2.4. Minerals (Phosphorus, Potassium, Calcium, Magnesium, Sulfur, Sodium, Copper, Iron, and Manganese)

The samples were previously mineralized through a wet process. The ashes resulting from the sample digestion with concentrated hydrochloric acid (HCL) were dissolved so that the final concentration of HCl was 10% v/v. Subsequently, it was transferred with distilled and deionized water to a volumetric flask. The Inductively Coupled Plasma Optical Emission Spectrometer (ICP OES) was calibrated using a 10% HCl solution, and then the samples were read using linear standard curve solutions [17].

2.5. Statistics

The study data were expressed as the mean and standard deviation. Normality and homogeneity tests for the data were conducted using the Shapiro–Wilk and Levene tests, respectively. ANOVA was utilized to compare the means of parametric variables, followed by the Tukey test for multiple comparisons. Principal Component Analysis (PCA) was applied to the centesimal composition and mineral data to make it easier to visualize the results. GraphPad Prism 8 software was used for the mean comparison analyses, and Statistics Kingdom (http://www.statskingdom.com) (accessed on 12 January 2024) was used for the multivariate analyses. The significance level of $p < 0.05$ was considered.

3. Results

Rapadura Composition Analysis

The analyses of proximate composition (moisture, ash, total lipids, protein, and carbohydrates) and energy value are presented in Table 1.

Table 1. Proximate composition (mg/100 g) and energy value (Kcal) of *rapadura* samples (mean ± standard deviation).

Sample	Moisture	Ash	Total Lipid	Protein	Carbohydrate	Energy Value
A	10.24 ± 2.16 ^{a}	0.85 ± 0.00 ^{a}	0.40 ± 0.00 ^{a}	0.49 ± 0.00 ^{a}	88.02 ^{a}	357.60 ^{a}
B	11.74 ± 0.33 ^{b}	0.93 ± 0.04 ^{a}	0.54 ± 0.00 ^{a}	0.56 ± 0.01 ^{a}	86.22 ^{a}	352.00 ^{a}
C	9.34 ± 0.01 ^{a}	1.12 ± 0.01 ^{a}	3.44 ± 0.31 ^{b}	0.92 ± 0.05 ^{b}	85.18 ^{c}	375.35 ^{c}
D	7.31 ± 0.21 ^{c}	0.37 ± 0.00 ^{c}	4.13 ± 0.03 ^{c}	0.37 ± 0.01 ^{ac}	87.82 ^{a}	389.94 ^{d}
E	6.42 ± 0.04 ^{c}	0.23 ± 0.00 ^{c}	3.56 ± 0.90 ^{bc}	0.67 ± 0.00 ^{ab}	89.12 ^{a}	391.19 ^{d}
F	7.67 ± 0.02 ^{c}	0.56 ± 0.00 ^{c}	2.16 ± 0.21 ^{d}	0.64 ± 0.05 ^{a}	88.97 ^{a}	377.87 ^{c}

ANOVA test, followed by the Tukey test for multiple comparisons. Significance level of $p < 0.05$. $^{a-d}$ Comparative statistical mean significance between the samples.

In Figure 1, the multivariate analysis of the proximate composition tests of the analyzed *rapadura* samples is presented.

Table 2 presents the values of minerals (phosphorus, potassium, calcium, magnesium, sulfur, sodium, copper, iron, and manganese) in the *rapadura* samples.

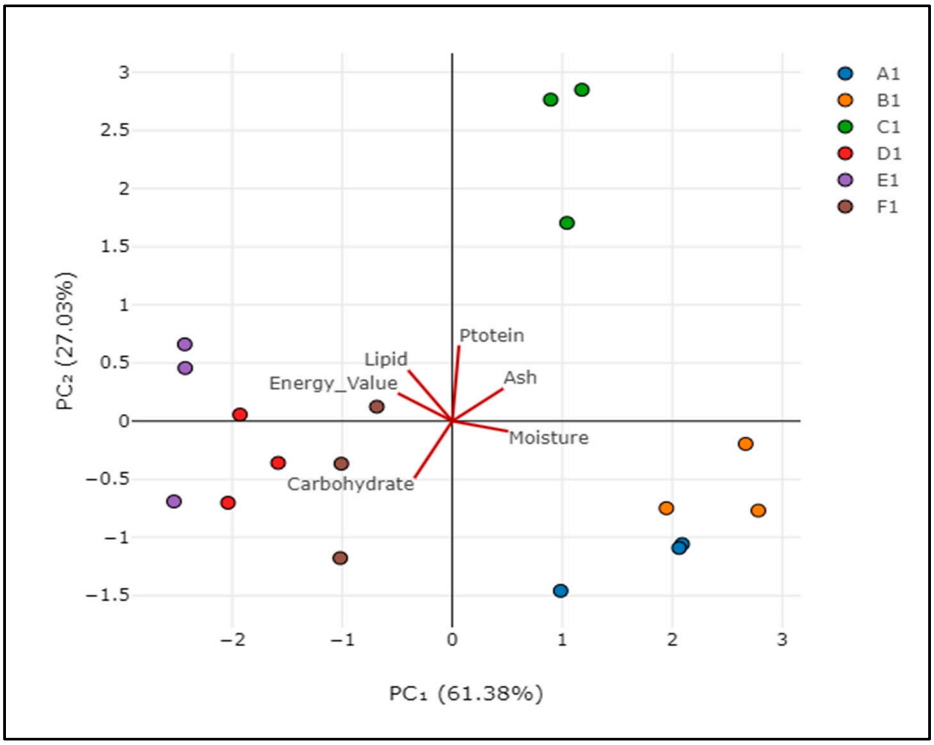

Figure 1. Multivariate analysis of the proximate composition using principal components PC1 and PC2. Biplot graph (scores and loadings).

Figure 2 shows the multivariate analysis of the mineral analysis tests of the analyzed *rapadura* samples.

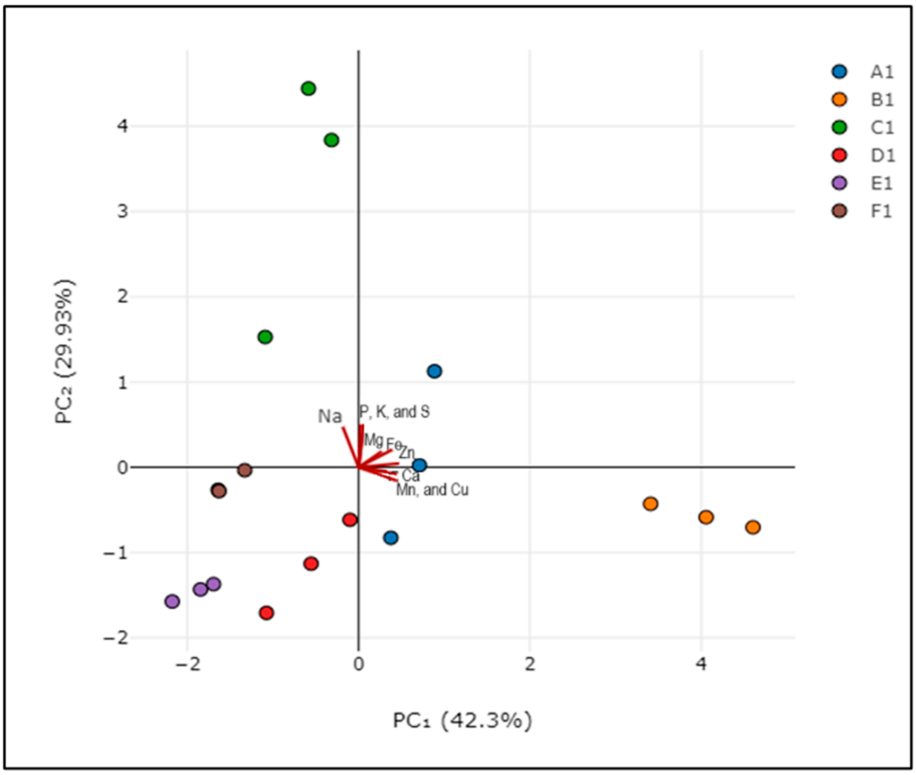

Figure 2. Multivariate analysis of the proximate composition by principal components PC1 and PC2. Biplot graph (scores and loadings).

Table 2. Minerals in mg/100 g of *rapadura* samples.

Samples	P	K	Ca	Mg	S	Na	Cu	Fe	Zn	Mn
A	0.44 ± 0.01^{a}	1.52 ± 0.09^{a}	0.38 ± 0.03^{a}	0.49 ± 0.03^{a}	0.24 ± 0^{a}	0.17 ± 0.01^{a}	1 ± 0^{a}	13.67 ± 3.79^{a}	0 ± 0^{a}	2 ± 2^{a}
B	0.13 ± 0.00^{b}	0.47 ± 0.15^{b}	0.49 ± 0.01^{b}	0.32 ± 0.01^{b}	0.22 ± 0^{a}	0.13 ± 0.01^{a}	0.33 ± 0.58^{a}	9.67 ± 2.08^{b}	0 ± 0^{a}	2 ± 2^{a}
C	0.86 ± 0.02^{c}	5.49 ± 0.26^{c}	0.37 ± 0.00^{a}	0.63 ± 0.02^{c}	0.78 ± 0.04^{b}	0.50 ± 0.06^{b}	1 ± 0^{a}	31.33 ± 3.21^{c}	1.67 ± 0.58^{a}	2 ± 2^{a}
D	0.37 ± 0.02^{d}	1.52 ± 0.11^{a}	1.32 ± 0.03^{c}	0.73 ± 0.02^{cd}	0.29 ± 0.02^{a}	0.04 ± 0.02^{c}	64.67 ± 2.52^{c}	42.33 ± 1.53^{d}	6 ± 1^{b}	12 ± 2^{b}
E	0.27 ± 0.01^{e}	4.36 ± 0.05^{e}	0.98 ± 0.02^{d}	1.03 ± 0.04^{e}	0.61 ± 0.01^{c}	0.17 ± 0.05^{a}	4.33 ± 0.58^{b}	16.67 ± 0.58^{e}	2 ± 0^{a}	6 ± 2^{c}
F	0.06 ± 0.01^{f}	0.53 ± 0.17^{b}	0.43 ± 0.03^{a}	0.56 ± 0.07^{c}	0.41 ± 0.06^{d}	0.13 ± 0.03^{a}	0 ± 0^{a}	21.33 ± 4.04^{f}	1 ± 0^{a}	6.33 ± 2^{c}

Legend: P—phosphorus, K—potassium, Ca—calcium, Mg—magnesium, S—sulfur, Na—sodium, Cu—copper, Fe—iron, Zn – Zinc and Mn—manganese. ANOVA test, followed by the Tukey test for multiple comparisons. Significance level of $p < 0.05$. $^{a–f}$ Comparative statistical mean significance between the samples.

4. Discussion

4.1. Historical and General Aspects

Sugarcane (*Saccharum officinarum*) is a species within the grass family [19]. Sugarcane juice has a variety of uses, such as the production of sugar and its derivatives, as well as the production of spirits and fuel alcohol [20,21].

Rapadura production occurs worldwide, with India as the main producer, while Brazil is only the seventh, where the northwestern region is responsible for most of the production. The commercialization of the product is strongly performed by the family-owned business using artisanal techniques, which can vary according to the producer, leading to difficulties in setting standard fabrication processes. Food products entering the market need to comply with various regulations imposed by the relevant regulatory bodies; the absence of standard production and informality in the sales promote difficulties for Brazilian *rapadura* exportation [3].

Sugar production depends on the tonnage, sugar content, and quality of sugarcane. Vegetative growth is reduced, and the sugar content of the cane increases significantly close to maturity. Concerning juice purity, it is positively influenced by low minimum temperatures several weeks before harvest. Sugarcane does not require a special type of soil, but it has high nitrogen and potassium requirements and relatively low phosphate needs [22].

As presented in Figure 3, recent data from IBGE (Brazilian Institute of Geography and Statistics) rank sugarcane as the third-highest in production, with significant financial representation, trailing only soybeans and corn [23].

Knowing the nutritional composition of *rapadura* is relevant and can provide greater security for its recommendation for consumption by the general public. Samples of *rapadura* from South American countries (Brazil, Colombia, Ecuador, and Peru) were evaluated in terms of their physical-chemical and mineral aspects, revealing significant differences between countries, which may be a result of the origin and quality of the sugarcane juice and the very artisanal production process of *rapadura* [24].

In addition, concrete data from the FAO shows that the production of *rapadura* can be a strong point to avoid wasting sugarcane agricultural production during the annual season so that the juice can be stored in the form of homemade jam [25].

This international visibility of *rapadura* is being looked at by government bodies such as the Brazilian Cooperation Agency of the Ministry of Foreign Affairs (ABC/MRE), the Brazilian Ministry of Agriculture, Livestock, and Supply (MAPA), the Colombian Ministry of Agriculture and Rural Development (MADR), and the Food and Agriculture Organization of the United Nations (FAO) to consciously encourage the consumption of *rapadura*.

In Brazil and Colombia, the experience of including *rapadura* in school meals is a success, as it promotes the reinforcement of the local economy, food and nutritional security, and poverty reduction [22].

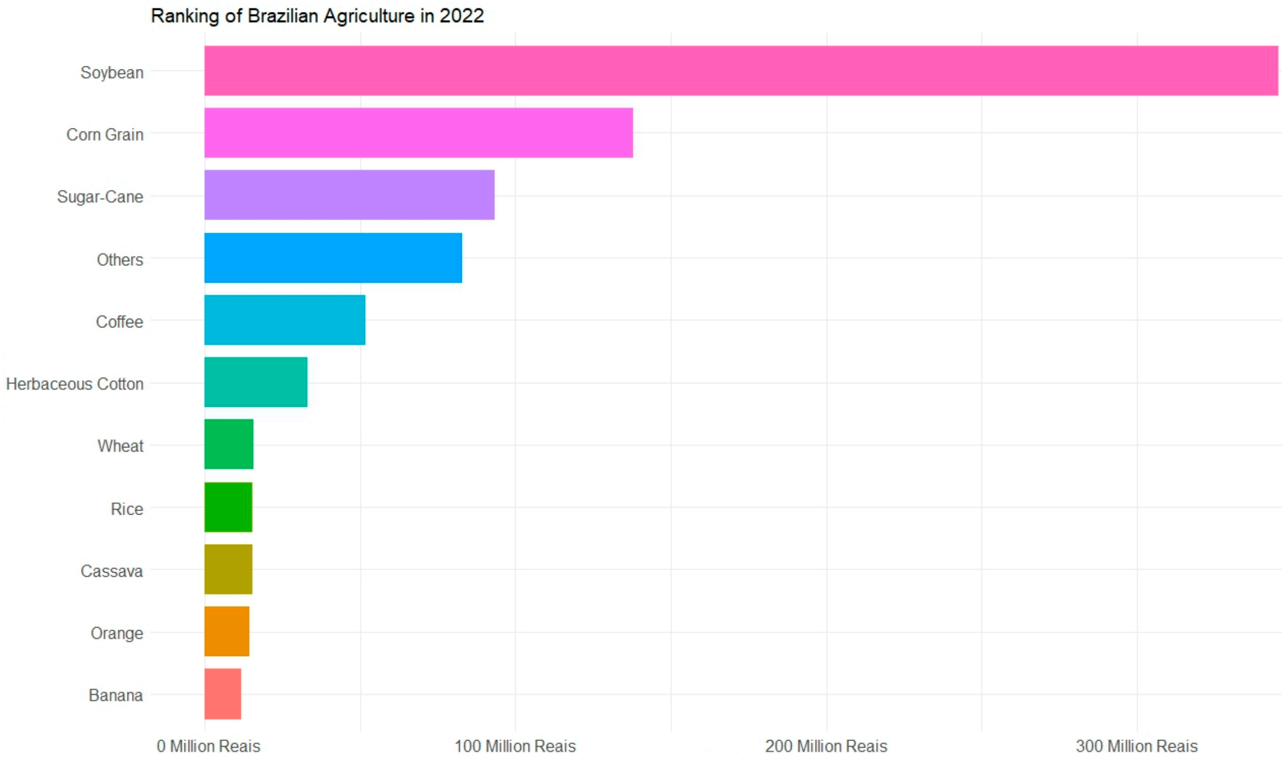

Figure 3. Ranking of Brazilian agriculture in 2022.

In the Acre region, located in Brazil's northeastern region, agribusiness sectors focused on the production of *rapadura*, murumuru, buriti, rubber, and chestnut play significant roles in the industry. These segments have the potential to drive investments in forest industrial complexes, thus contributing to the industrial expansion of the state and, consequently, the country. The richness and diversity of these natural resources not only strengthen the local economy but also provide opportunities for sustainable industrial development, aligning with broader initiatives for economic growth and environmental preservation [26].

4.2. Rapadura Manufacturing Process

Although the process of producing *rapadura* is simple, it is noteworthy that it consists of 10 distinct and interdependent stages (Figure 4). Cutting, transporting sugarcane, and decanting the juice must be carried out as quickly as possible; otherwise, there will be a loss of *rapadura* quality. At a controlled temperature, concentration is achieved by boiling the juice to the point of beating and molding the *rapadura*, which is then unmolded and packaged after cooling [3].

Additional ingredients can be incorporated into the original composition of *rapadura* to enhance the technological potential of the product, offering sensory and nutritional advantages. For instance, rice by-products and chestnuts, characterized by low microbiological risk and favorable sensorial acceptance, result in *rapadura* with distinct nutritional content and hardness values compared to the traditional product [26].

Although *rapadura* is an artisanal product, adopting Good Manufacturing Practices (GMP) for food products is essential to prevent microbiological contamination and potential impurities in the production environment. This control should be implemented by the producer through adherence to hygiene measures for both workers and the physical space [27].

The commercialization interest in the product will determine the molding phase of *rapadura*, which has highly varied characteristics, allowing it to be presented in different shapes and sizes.

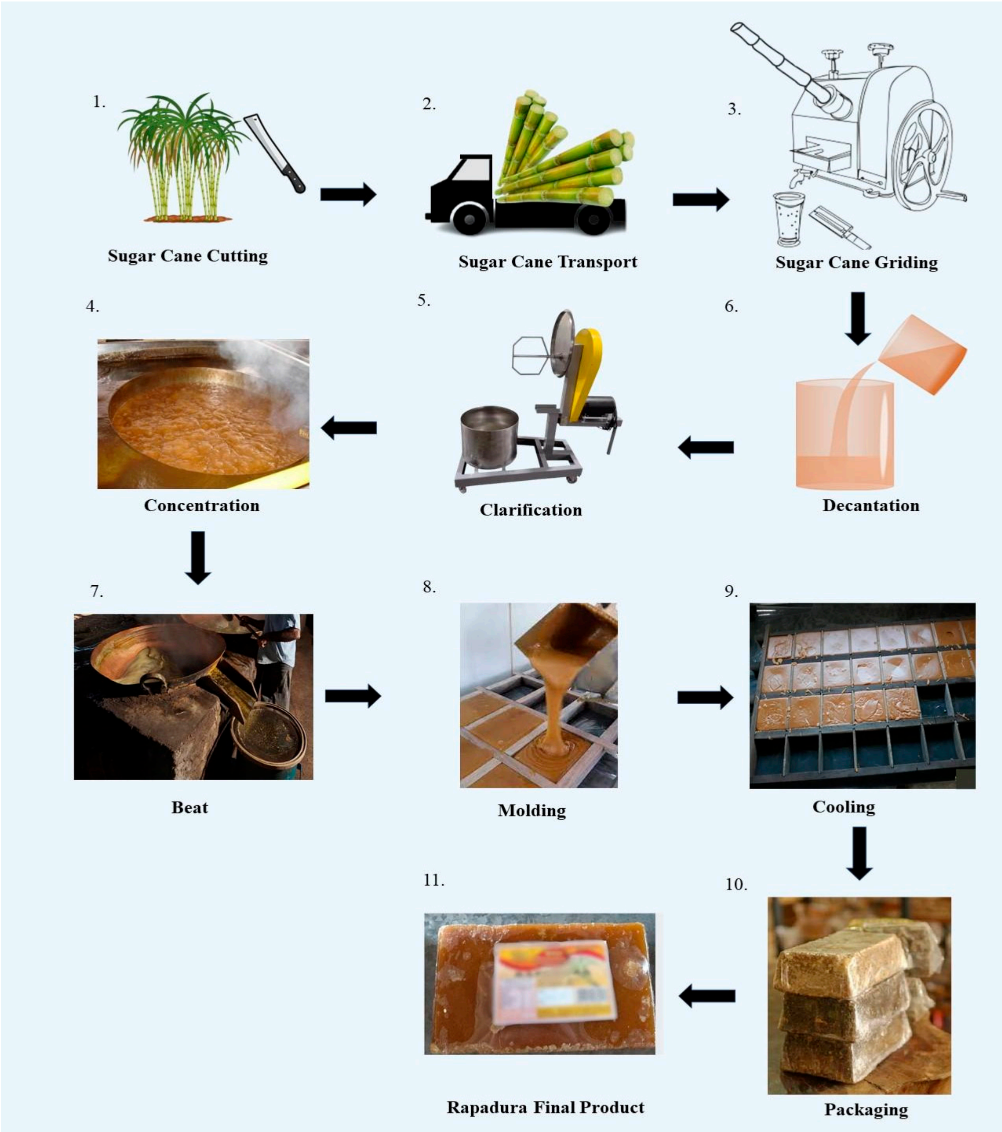

Figure 4. Simplified flowchart of the *rapadura* processing.

During the production of *rapadura*, we cannot overlook the routine of sugar cane mills and the physical, biological, chemical, and ergonomic risks to which workers are exposed. Furthermore, workers are hesitant to discuss their work schedules, the risks they are exposed to, the history of workplace accidents, and the use of Personal Protective Equipment (PPE). It becomes necessary to delve into studies on the work carried out in sugar cane mills, taking into account the daily risks to which these workers are subjected [28].

4.3. Rapadura Composition Analysis

Following the current legislation for *rapadura* production [1], the physicochemical characteristics of the analyzed samples fell within the established parameters but well below the maximum limits. Specifically, the moisture content should be at most 25%, and it reached a maximum of 11% in sample B, with a minimum nearly four times lower in sample E. With an average variation of 6.42–11.74%, high moisture content promotes crystal dissolution, microbial deterioration, and biochemical degradation reactions, thereby shortening the shelf life of sugars [29].

Studies indicate average moisture values of 10.4 percent [30,31] and variations of 3.21–4.17 percent [32]. Variation of 2.34–4.33 percent [29]. In a compilation of analytical data for sugarcane derivatives, moisture content ranges from a minimum of 1.5% to a maximum of 15.8% [12].

Regarding ash parameters (inorganic matter), the maximum allowed is 6%, but the data showed a variation of 0.23–1.51 mg/100 g, indicating that the product is not particularly rich in minerals [33]. The maximum content of 1.15 mg/100 g characterizes a product with good palatability, as a high amount of ashes can alter the taste, imparting a bitter or salty flavor, which hinders its acceptability [14].

A study indicates average ash values of 0.35% [31]. The variation ranges from 0.8% to 1.54%, and a separate range of 1.27% to 2.56% is also described [14,32]. In a compilation of analytical data for sugarcane derivatives, ash values range from 0.3% to 3.6%, with minimum and maximum values [12].

For total carbohydrate parameters, the minimum content should be 80%, a value considerably achieved in the samples analyzed across seven different geographical locations in Ceará. This confirms the significance of this food as an energy source, as it exhibits values above 85%. Regarding the preferred food consumption during pre-, intra-, and post-training among cyclists, it was observed that 18% of consumers chose *rapadura* instead of maltodextrin or fruit juices. It confirms that amateur athletes know the importance of carbohydrate consumption to enhance performance. However, the majority of participants are unaware of the ideal quantity and frequency of carbohydrate intake [34].

In a compilation of analytical data from sugarcane derivatives, total carbohydrate values range from a minimum of 83.9% to a maximum of 92.7% [12]. It is also noteworthy to have information on specific sugar content, with levels such as 86.65 mg/g of sucrose, 2.35 mg/g of glucose, and 2.70 mg/g of fructose [31].

There is a significant difference in all analyzed parameters among the samples, emphasizing the lack of standardization in *rapadura* production [4]. *Rapadura* is renowned for its high caloric value, making it suitable for energy replenishment in aerobic exercise enthusiasts [34]. It is also used in school meals in some states in northeastern Brazil [23] or simply as an ingredient in culinary preparations for diverse age group [35].

This confirms that the nutritional composition of kokuto samples in Japan predominantly includes simple sugars, and they are nutritionally differentiated by their content of amino acids, minerals, and phenolics. These nutritional components found in kokuto affected the flavor characteristics, contributing to sweetness, umami, astringency, and bitterness in potentiometric measurements of electronic tongue detection [36].

Evaluating total lipid content (with a minimum variation of 0.4% and a maximum variation of 4.13%) and protein content (with a minimum variation of 0.37% and a maximum variation of 0.92%), it is noticeable that these foods are low in these nutrients. Therefore, they cannot be used as total lipid or protein sources.

According to Figure 1, it can be observed that the data variability (moisture, ash, protein, total lipid, carbohydrate, energy value) is explained by PC1–PC2 (88.4%). There is a significant correlation between all compounds explained in PC1 (61.38%) and PC2 (27.3%). It is seen that samples D, E, and F have higher carbohydrate and energy value contents, while sample C is further away from this result, thus confirming the comparison of means shown in Table 1.

Among the twelve minerals studied, iron (9.67–42.33 mg/100 g) and copper (0.33–64.67 mg/100 g) stand out in terms of value variation, while the other evaluated micronutrients showed a range of 0.00–5.91 mg/100 g. Nitrogen and boron were not detected in any of the samples; data attributed to either their absence or minimum levels could not be accurately detected. This significant variation or the mere absence of detection may result from specific soil characteristics in which the sugarcane was harvested for *rapadura* production [37].

A study reveals that kokuto samples in Japan are rich in minerals, with potassium being predominant, representing approximately 63.41–74.39% of the total minerals, followed by calcium (11.20–21.27%) and magnesium (5.44–10.56%). Furthermore, these samples contain four essential minerals: iron (1.92–10.42 mg/100 g), manganese (0.06–4.25 mg/100 g), zinc (0.33–1.12 mg/100 g), and copper (0.06–0.26 mg/100 g). Moreover, numerous types of composition-flavor correlations were observed, including contributive and irrelevant or negative associations, where the main mineral elements and total phenolics positively influenced astringency and bitterness [36].

According to Figure 2, it is implied that the data variability (P—phosphorus, K—potassium, Ca—calcium, Mg—magnesium, S—sulfur, Na—sodium, Cu—copper, Fe—iron, and Mn—manganese) is explained by PC1–PC3 (72.2%). This shows a low correlation among all compounds explained in PC1 (42.3%) and PC2 (29.93%). The presentation of the samples distributed in the four quadrants shows that the average levels and their comparisons reinforce that the *rapadura* samples have low levels of the minerals studied, without any representative groupings.

4.4. Physiological Benefits of Sugarcane and Its Derivatives

Intervention studies based on in vitro and animal experiments, reviewed systematically in the past year, have provided robust evidence that the administration of unrefined sugarcane products, such as *rapadura* and brown sugar, positively contributes to inducing the inflammatory response when compared to other sweeteners, including dietary sucrose and artificial sweeteners, based on in vitro and animal experiments [38].

Although *rapadura* is effective in preventing atherosclerosis compared to sucrose in Japanese quails, further studies are still needed to clarify how this food prevents the development of atherosclerotic lesions and improves deteriorated lipid metabolism in different animal species [39]

Transitioning to the sports field, it has been observed that the development of specific sports products based on sugarcane can be conducted to assess their effects directly on humans. This is because carbohydrate supplementation with sugarcane before resistance exercise could maintain blood glucose levels in normal conditions and prevent muscle glycogen catabolism in experimental animals [40].

4.5. Limitations and Future Perspectives

While the research analyzing the nutritional and mineral composition of *rapadura* derived from sugarcane juice is not unprecedented, there were some limitations. Firstly, despite the methodology for making *rapadura* following some pre-established steps in the literature, there is a certain lack of standardization in the final product, as confirmed by the different nutrient characterizations presented in the study. Furthermore, the raw material originated from different locations in Ceará, thus lacking a faithful analysis of soil composition and sugarcane's lifespan. In light of the above, to try to mitigate the biases presented, it would be relevant to document the entire *rapadura* production process, as one of the strengths highlighted by the study was the use of robust methodologies in the scientific community.

5. Conclusions

In conclusion, the physicochemical analysis of *rapadura* samples confirms its suitability for consumption as a rich source of carbohydrates and energy. However, the observed variations among the six samples in terms of both macronutrients and micronutrients underscore a lack of standardization in the production process. Despite the generally low levels of micronutrients, sample D stands out with notable concentrations of copper and iron. To enhance the overall quality and nutritional consistency of *rapadura*, there is a need for improved standardization in its production, ensuring a more uniform composition across different batches. Therefore, it can ensure consumer satisfaction and promote a more reliable and competitive presence in domestic and international markets.

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