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Nutritional and biological attributes of *Spondias tuberosa* (Umbu) fruit: An integrative review with a systematic approach

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ABSTRACT

Spondias tuberosa is a tree fruit native to the *Caatinga* biome in Brazil whose fruits (umbu) are usually consumed fresh, in regional recipes or in the form of pulp. Grown in Brazilian low-income regions, *S. tuberosa* fruits present high sociocultural importance in the Semiarid region of Brazil, acting as a source of livelihood for various family groups in these regions. In this sense, the aim of this work was to develop an integrative review of the nutritional and biological attributes of *S. tuberosa* fruits using a systematic approach. We searched on four databases: CABI, Pubmed, Scopus, and Web of Science. Twenty-four studies were included after the review protocol was applied. The results showed that umbu exhibits low carbohydrate and protein content, varying according to the maturation stage and fruit part. Both the pulp and peel of umbu presented low lipid content whereas the highest lipid content was found in the seeds, which also presented the highest fiber content. The fruits presented considerable amounts of vitamin C and minerals. Bioactive phenolic compounds and carotenoids are concentrated mainly in the fruit peel and seeds. The studies presented promising findings, which reinforce the importance of considering the consumption of this fruit due to its potential for health benefits and increase of its socioeconomic value.

1. Introduction

Currently, studies highlight the relationship between the availability of regional plants and fruits and their presence in the food culture and market of the regions in which these foods grow (Gonçalves et al., 2016). In this sense, the number of plants used in food is generally influenced by the diversity of species and local food culture (Cunha, 2020).

The Brazilian semiarid biome extends across all states in the northeast region of the country, also comprising part of the southeast region, occupying 12% of the total Brazilian territory (Medeiros et al., 2012). Furthermore, this region is occupied by around 28 million inhabitants, distributed in 38% of rural areas, whose agriculture and extractivism are characterized as the main economic activity (Medeiros et al., 2012).

Climate projections predict longer droughts and higher temperatures (Torres et al., 2017), which will reduce the habitat of endemic species and consequently affect the ecosystem, compromising water availability (A. dos Santos et al., 2020). In this sense, the supply of plants and their use have been investigated for decades, providing evidence that human populations mainly consume plants that are most available in the landscape (Gonçalves et al., 2016).

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Umbu (*Spondias tuberosa*) is a fruit tree native to the Caatinga biome (semi-arid) in Brazil, which belongs to the Anacardiaceae family and is found in the Northeast region and the state of Minas Gerais in Brazil (Fig. 1) (Barreto and Castro, 2010).

This plant is used to low-rainfall environments and is widely explored for its fruits through extractivism in the semiarid region of the Northeast of Brazil; the processing of these fruits is an alternative source of income for small farmers in the dry season (Cavalcanti et al., 1996; Martins and Melo, 2017). Most umbu production is concentrated in the Northeast region of Brazil, which produced 7465 tons of this fruit in 2017 (Instituto Brasileiro de Geografia e Estatística, 2017).

The *S. tuberosa* fruit (umbu) is round, has smooth or hairy peel, and weighs between 5.5 and 130 g; the fruiting season is between November to March, summer in Brazil. Umbu is composed of approximately 68% pulp, 22% peel, and 10% seed, and presents higher weight, yield, and length when mature (Barreto and Castro, 2010; Costa et al., 2004; V. R. de Oliveira et al., 2018). The production of an adult tree reaches approximately 300 kg of fruits per crop season. Umbu is a very perishable fruit, which hinders its fresh marketing. Thus, besides being consumed fresh, it is processed to produce juices, ice creams, sweets, alcoholic drinks, and frozen pulps (Barreto and Castro, 2010; Lago et al., 2016).

Products from umbu are marketed in several regions of Brazil and market niches in Europe (Lima et al., 2018). Umbu stands up among the fruits of the semiarid region of Brazil because it is part of the culture and social and economic activities of family farmers (Castro and Rybka, 2015).

The literature shows that umbu fruits present vitamins riboflavin, nicotinamide, pantothenic acid, vitamin C (Assis et al., 2020), minerals, phosphorus, potassium, calcium, magnesium, iron, copper, sodium, zinc, selenium, cobalt, and nickel, macronutrients, and fiber (Almeida et al., 2009). In addition, the fruit pulp, peel, and seed show antioxidant activity; and the composition of fresh fruits presents bioactive components, such as anthocyanins, flavonoids, carotenoids, and chlorophyll (Ribeiro et al., 2019; Rufino et al., 2010).

In this sense, considering the umbu fruit's economic, sociocultural, nutritional, and biological importance, the objective of this work was to review the nutritional and biological potential of umbu fruits.

2. Materials and methods

To evaluate the nutritional and biological characteristics of umbu, an integrative review with a systematic approach was performed.

Fig. 1. *Spondias tuberosa* ripe fruits.

2.1. Inclusion and exclusion criteria

The criteria for inclusion of studies were fruit collection place, which was restricted to the Northeast region of Brazil because the fruit is native to this region; and edible parts of the fruit (pulp, peel, and seed). Studies regarding the analysis of non-edible parts such as branches, leaves, stems, and roots were excluded. Short communications, reviews, books, case reports and conference abstracts were also excluded. For a better understanding of the available literature and considering that the analyzed fruit is endemic only in the Brazilian region, no time limits were adopted concerning the publication of studies.

2.2. Information sources

Individual search strategies were developed for four electronic databases: Centre for Agriculture and Bioscience International (CABI), PubMed, Scopus, and Web of Science. The last search was performed on 1st December 2023. The reference lists of the included studies were also examined to retrieve more studies apart from the screening phase.

2.3. Search strategy

The first part of the research focused on the *S. tuberosa* nutritional and chemical composition. Thus, the keywords researched were "*Spondias tuberosa*" combined with "carbohydrates", "proteins", "amino acids", "minerals", "dietary fiber", "vitamins", "fatty acids", "carotenoids", "phenolic compounds", "polyphenols", "flavonoids", "proximate composition", or "nutritional composition". Patent research was also carried out utilizing Google patents.

A search was carried out for each term combination in the databases. Endnote Web® and Rayyan Web® software were used to manage bibliographic references.

2.4. Study selection

The selection of the studies was performed in two stages. In the first stage, two independent reviewers analyzed the title and abstracts of all studies identified in the databases. Studies that did not meet the inclusion criteria were discarded. In the subsequent phase, decisions were made by the first and second reviewers, while a third independent reviewer was available to solve possible disagreements.

In the second stage, the same first two reviewers applied the eligibility criteria to the full text of the selected studies. In addition, two experts were consulted for possible disagreements unsolved by the third reviewer and also for the inclusion of relevant studies. In the end, the sample consisted of the full texts included by the group of reviewers.

2.5. Data collection

The following data was collected from the included studies: authors and year of publication, fruit part analyzed, collection place and both nutritional and functional composition. Regarding the nutritional composition, the values for carbohydrates, starch, and sugars, dietary fiber, protein, lipids, vitamins, and mineral content was collected. Values were presented as proximate composition (%) or in g/100 g of the fruit/part of the fruit. For the functional composition, data regarding the presence and quantity of phenolic compounds and carotenoids were collected.

3. Results and discussion

3.1. Studies general characteristics

After applying the stipulated review protocol, 24 complete studies were chosen for data extraction. No patents were found. Fig. 2 below summarizes the studies included according to their publication date as

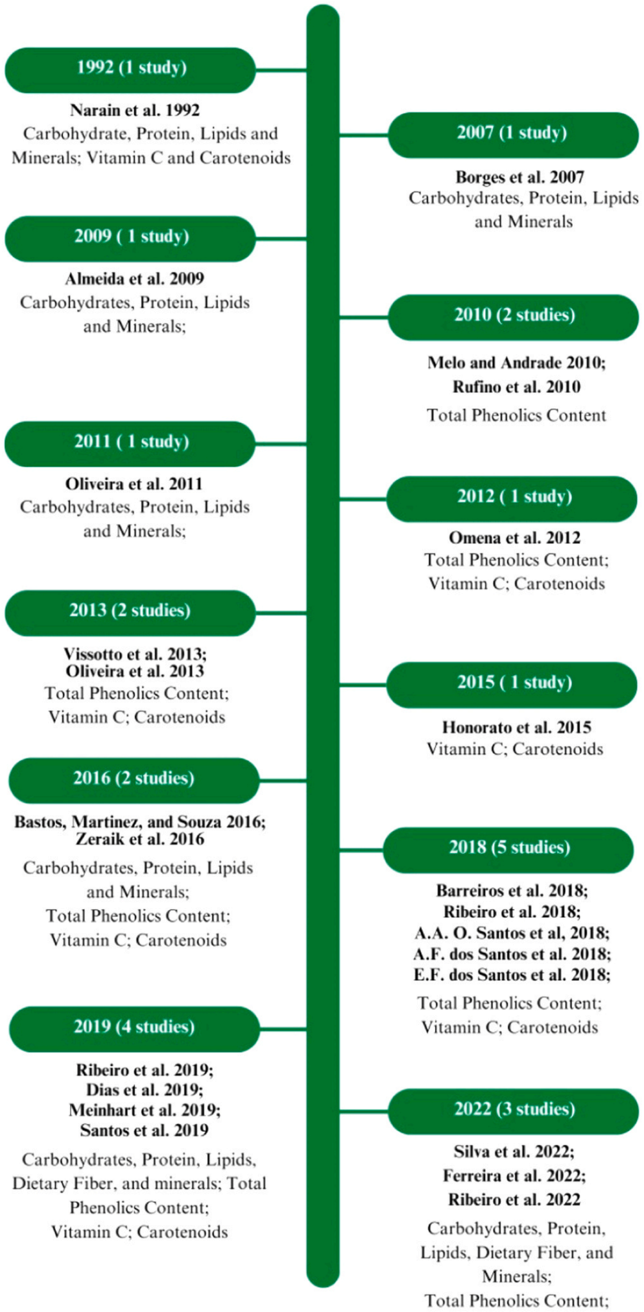

Fig. 2. Summary of complete studies included for data extraction arranged according to temporality and analyses performed.

well as the analyses carried out by them. Since umbu is a Brazilian regional fruit, 100% (n = 24) of the studies were performed in Brazil, between 1992 and 2022. Fig. 3 below illustrates the proportion of analyses carried out by the included studies.

From all included studies, three studies (12.5%) determined the carotenoid content of all parts of the umbu fruit (Melo and Andrade, 2010; Oliveira et al., 2011; Ribeiro et al., 2019). Eight studies quantified the ascorbic acid (vitamin C) content of umbu fruits; no other vitamins were quantified (Bastos et al., 2016; Gonçalves et al., 2016; Honorato et al., 2015; Narain et al., 1992; C.F.P. Oliveira et al., 2013; Omena et al., 2012; Ribeiro et al., 2018; L. O. Ribeiro, Viana et al., 2019; Vissotto et al., 2013).

Regarding the total phenolics content (TPC), 50% of the studies (n = 12) performed TPC analysis (Barreiros et al., 2018; Dias et al., 2019; Ferreira et al., 2022; Gonçalves et al., 2016; Meinhart et al., 2019; Melo and Andrade, 2010; Omena et al., 2012; Ribeiro et al., 2019; Rufino et al., 2010; A.F. Santos et al., 2018; E.F Santos et al., 2018; Vissotto et al., 2013).

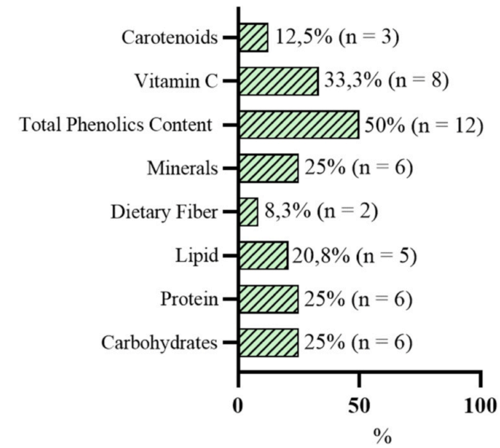

Fig. 3. Proportion of analyses carried out by the included studies.

As for the mineral content, six of the included studies (25%) presented data (Narain et al., 1992; S.L. Silva et al., 2022; Borges et al., 2007; Ribeiro et al., 2019; E.A. Oliveira., 2011; Almeida et al., 2009). Only two studies (8.3%) presented information regarding umbu fruit dietary fiber content (Ribeiro et al., 2019; Silva et al., 2022).

For the macronutrient content, six studies (25%) performed analyses regarding both carbohydrate content and protein (Borges et al., 2007; Narain et al., 1992; Oliveira et al., 2011; Ribeiro et al., 2019; Bastos et al., 2016; Silva et al., 2022). Five studies (20.8%) analyzed the total lipid content and fractions (Borges et al., 2007; Narain et al., 1992; Oliveira et al., 2011; Ribeiro et al., 2019; Silva et al., 2022).

3.2. *Nutritional characteristics*

3.2.1. *Carbohydrates*

Umbu (*Spondias tuberosa*) fruit usually has low carbohydrate content, and its composition varies according to the fruit maturation stage or part analyzed. Two studies analyzed the carbohydrate content of umbu seeds (Borges et al., 2007; Ribeiro et al., 2019). Results showed that immature seeds presented a lower content of carbohydrates (9.40 g/100 g fresh weight (FW)) compared to mature fruits (11.50 g/100 g FW) (Borges et al., 2007). In the other study (Ribeiro et al., 2019), umbu seeds presented 9.01 g/100 g FW of carbohydrates, however, the maturation stage was not described.

In the case of fruit seeds in general, the carbohydrate content refers to the energy reserve of the fruit, directed to the budding and growth of the fruit respectively, however, unlike fruit pulps which are mostly made up of carbohydrates and water, the seeds also concentrate most of the proteins and lipids in the fruit (Fidelis et al., 2019).

Five studies performed analysis regarding carbohydrate content of umbu pulp in different presentations (Bastos et al., 2016; Narain et al., 1992; Ribeiro et al., 2019; A. A. Santos et al., 2018; Silva et al., 2022).

In the study conducted by Narain et al. (1992), the results showed that the carbohydrate content increased as the fruit matured, with the total carbohydrate value being 3.37 g/100 g FW in the immature fruit and 6.14 g/100 g FW in the mature fruit, respectively (Narain et al., 1992).

This tendency, however, is inherent to the fruit ripening process. Due to ethylene, a hormone in gaseous form produced by the fruit itself, resistant starch chains and dietary fiber are converted into saccharides with a simpler molecular structure, such as fructose, thus becoming more bioavailable and detectable in carbohydrate analyses (Lin et al., 2009).

In the case of different processing techniques used in the pulps, different carbohydrate levels were found. In studies in which the total amount of carbohydrates in isolated umbu pulps were evaluated (Ribeiro et al., 2019; Silva et al., 2022), samples from fresh umbu pulps presented values between 5.67 g/100 g FW and 71.53 g/100 g dry weight (DW), thus highlighting a lot of variety in the nutritional value of these products. However, it is important to note that the results found in the study conducted by Silva et al. (2022) were expressed in wet weight (5.67 g/100 g), while the carbohydrate values found by Ribeiro et al. (2019) were expressed in dry weight.

However, in the context of fruit pulp manufacturing processing, there are several variables to be considered. The first refers to the fruit's state of maturity, given that more mature fruits tend to have a higher content of available carbohydrates (Zhao et al., 2015). Another point concerns the processing technique used in making pulps.

Pulps sold after the pasteurization process have a higher content of available carbohydrates, since the thermal process used favors the hydrolysis of carbohydrate chains present in the fruit, thus increasing their concentration (Subharaj et al., 2022). Furthermore, the water content of the pulps also influences the concentration of their nutrients, as a greater amount of water results in the dilution of their nutritional value (Guo et al., 2003).

However, one of the limitations presented by both studies is the lack of characterization of pulp processing, thus highlighting a knowledge gap (Ribeiro et al., 2019; Silva et al., 2022). Only one of the studies presented the concentration of carbohydrates in umbu peel, with average values of 40.42 g/100 g DW (Ribeiro et al., 2019).

Within the analyses carried out in the included studies, results were also found regarding the levels of reducing, non-reducing and total sugars present in different presentations of umbu (Bastos et al., 2016; Narain et al., 1992; A.A. Santos et al., 2018).

In the case of isolated pulps, differences in relation to the quantity of reducing and non-reducing sugars were found based on the state of ripeness of the fruits (Narain et al., 1992). Regarding immature fruit pulp, the reducing sugar content was around 2.79 g/100 g FW, while in ripe fruit pulp, this concentration rose to 4.14 g/100 g FW (Narain et al., 1992). In the context of non-reducing sugars, the value was 0.58 g/100 g FW for immature umbu pulp and 2 g/100 g FW for mature umbu (Narain et al., 1992). Total sugar values were higher in ripe fruit pulp, with average values of 6.14 g/100 g FW, while immature fruit pulp presented only 3.37 g/100 g FW (Narain et al., 1992).

When considering the processing variables, in non-concentrated commercial umbu pulps, the value of reducing sugars was lower compared to its concentrated commercial variation, being 4.96 g/100 g FW and 6.08 g/100 g FW respectively (A.A. Santos et al., 2016). This tendency was the same in relation to the non-reducing sugar content. While the non-concentrated commercial version presented 3.56 g/100 g FW, the concentrated version presented a higher content, 7.46 g/100 g FW (A.A. Santos et al., 2016).

The proportion of reducing and non-reducing sugars in a fruit is decisive in its industrial application. In the case of umbu, it is noted that it is a fruit with a higher proportion of reducing sugars, therefore, its use can be more efficient in the development of products that require more viscoelastic textures, fermented, or used in order to intensify the Maillard reaction, providing more sensorially desirable coloring in products (Mckenzie & Lee, 2022; Prasanna et al., 2007). In the same sense, the lower proportion of non-reducing sugars reduces the sweetness of the fruit, hindering its application in preparations that depend on the fruit to impart a sweet taste, except for the concentrated version of its pulp (Mckenzie & Lee, 2022; Prasanna et al., 2007).

Only one study carried out analysis of the starch content of umbu fruits, which decreased from 1.55 g/100 g FW in immature fruit to 1.39 g/100 g FW in mature fruit (Narain et al., 1992), being this reduction is an inherent process of fruit ripening, also due to the action of ethylene (Prasanna et al., 2007).

3.2.2. Protein

A total of six studies evaluated the total crude protein present in different parts of umbu fruits (Bastos et al., 2016; Borges et al., 2007; Narain et al., 1992; Oliveira et al., 2011; Ribeiro et al., 2019; Silva et al., 2022). All of them utilized the certified AOAC Kjedahl method based on nitrogen distillation (Helrich, 1990).

In the context of umbu pulps, samples were analyzed regarding different stages of maturation (Narain et al., 1992), commercial samples (Bastos et al., 2016; Ribeiro et al., 2019), concentrated commercial samples (Bastos et al., 2016) and fresh pulp (E.A. Oliveira et al., 2011; Ribeiro et al., 2019; Silva et al., 2022).

As in the case of the majority of fruits, umbu pulp did not present high concentrations of protein. Regarding the different stages of maturation, the immature fruit pulp presented 0.31 g/100 g FW of protein, while the mature fruit presented a lower concentration of 0.24 g/100 g FW, however, no significant differences were found in statistical analysis (Narain et al., 1992).

A higher variation was found between analyzed commercial pulps. One study presented an average value of 0.68 g/100 g FW (Bastos et al., 2016), while another analyzed sample presented 6.18 g/100 g DW (Ribeiro et al., 2019). However, similar to what was found in the analysis of carbohydrates, the study conducted by Ribeiro et al. (2019) expressed its data based on the dry weight of the samples, thus concentrating the constituents, and increasing their value in percentage (Ribeiro et al., 2019).

In the study in which a commercial sample of concentrated umbu pulp was analyzed, the protein value presented was 1.28 g/100 g FW, compared to the traditional version of the same brand, which presented only 0.68 g/100 g FW (Bastos et al., 2016), thus totaling a difference of 88.2% due to the process used. This variation is a consequence of the thermal concentration process used, given that part of the moisture content of the pulp is evaporated, thus concentrating the nutritional content of fruit pulps (Orrego et al., 2014).

Only one of the included studies evaluated the protein content of umbu seeds (Borges et al., 2007). Similar to other fruits, the highest protein percentage in umbu is concentrated in the seeds, with values between 24.20 and 25.10 g/100 g FW (Borges et al., 2007).

Fruit seeds are commonly not consumed fresh and are discarded during the preparation of these cultivars. However, recent studies point to the potential of using fruit seeds as an alternative to improve use and reduce costs, as their protein content can serve to enrich the nutritional value of pasta, bread, and cereal bars, in addition to being used as an ingredient in the manufacture of animal feed (Larrosa and Otero, 2021; Tuna Ağirbaş et al., 2022).

In this sense, more studies are needed to evaluate the suitability of using umbu seeds in this type of product, thus expanding its range of applications and increasing its financial and socioeconomic value.

3.2.3. Lipids and fatty acids

In general, umbu fruit presented a low concentration of lipids, with the highest percentage being concentrated in its seeds (Table 1). Narain et al. (1992) studied fruits at different maturation stages and found no significant variation in lipid contents. Ribeiro et al. (2019) evaluated lipid contents in different parts of the fruit and found higher content in the seed, followed by fresh pulp, commercial pulp, and peel.

In comparison, lipid content in pulps of *S. pinnata* (0.1 g/100 g FW), *Spondias lutea* L. (0.33 g/100 g FW), and *Spondias purpurea* L. (0.76 g/100 g FW) fruits were lower than that from fruits of *S. tuberosa* (Bramont et al., 2018; Judprasong et al., 2013).

The fatty acid profile showed the presence of palmitic acid, stearic acid, oleic acid, arachidonic acid, and fruits of the cultivars *S. tuberosa* Moraes Pires (immature and mature) and *S. tuberosa* Moraes Pires Peludo (mature) present similar saturated, monounsaturated, and polyunsaturated fat content (Borges et al., 2007).

A study evaluated different types of extraction and solvents, including supercritical fluid extraction (SFE) using CO_2 and different

Table 1
Lipid content (g/100 g fresh weight and %) in fruits and fruit parts at different maturation stages from different cultivars of umbu (*Spondias tuberosa*).

Study	Cultivar, fruit part, and/or fruit maturation stage	Total lipids	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid	Arachidonic acid	Saturated	Unsaturated	Mono-unsaturated	Poly-unsaturated
	Immature	0.81 g	-	-	-	-	-	-	-	-	-	-
(Narain et al., 1992)	Semi mature	0.82 g	-	-	-	-	-	-	-	-	-	-
	Mature	0.89 g	-	-	-	-	-	-	-	-	-	-
	Seed											
(Borges et al., 2007)	Morales Pires (immature)	55%	19%	10.57%	33.60%	-	-	0.55%	30.12%		33.60%	35.52%
	Morales Pires (mature)	58%	19.21%	1.31%	35.89%	-	-	0.56%	31.08%		36.89%	32.44%
	Morales Pires Peludo (mature)	56%	19.98%	12.08%	33.61%	-	-	0.56%	32.62%		33.61%	33.04%
	Fresh pulp	6 g	-	-	-	-	-	-	-	-	-	-
(Ribeiro et al., 2019)	Commercial pulp	4.12 g	-	-	-	-	-	-	-	-	-	-
	Seed	8.92 g	-	-	-	-	-	-	-	-	-	-
	Peel	0.78 g	-	-	-	-	-	-	-	-	-	-
	Seed	-										
	SFE 15	-	19.9%	9.6%	32.4%	35.5%	2.6%	-	29.5%	70.5%	32.3%	38.2%
(Dias et al., 2019)	SFE 30	-	19.5%	9.5%	32.4%	35.8%	2.5%	-	29.4%	70, 6%	32.4%	38.2%
	SFE 30	-	19.5%	9.5%	32.7%	35.6%	2.4%	-	29.3%	70.7%	32.7%	38%
	UAE Hex	-	19.6%	9.5%	32.8%	35.5%	2.1%	-	29.5%	70.5%	32.8%	37.7%
	UAE EtOH	-	19.6%	9.5%	32.2%	37.0%	2.7%	-	27%	73%	33.3%	37.7%
	UAE 30	-						-	29.8%			
	SOX Hex	-	19.9%	9.5%	32.4%	35.5%	2.3%	-	30%	70.2%	32.4%	37.8%
	SOX EtOH	-						-		70%	32.5%	37.5%
(Silva et al., 2022)	Fresh Pulp	0.04 g	-	-	-	-	-	-	-	-	-	-

pressures; ultrasound-assisted extraction (UAE) using ethanol, hexane, and ethanol-water; and Soxhlet extraction (SOX) using ethanol and hexane, and determined the lipid profile of umbu seeds; it showed the presence of saturated fatty acids (palmitic and stearic acid) and unsaturated fatty acids (oleic, linoleic, and linolenic acid), constituting most of the fat found in the seeds (Dias et al., 2019).

The dichloromethane extract of *S. mombin* seeds showed a fatty acid profile with higher saturated fatty acid content, palmitic (25.8%) and stearic (13.9%), than that of umbu seeds, whereas unsaturated fatty acids, palmitic (25.8%), linoleic (31.7%), and oleic (24.4%) were lower than those found in umbu seeds, and total saturated (43.9%) and unsaturated (56.1%) fatty acids were higher in umbu seeds (Rezende et al., 2018).

A comparison of results of umbu seeds to results of oils extracted from nine commercial oilseeds showed that saturated fatty acid content (palmitic and stearic acid) in umbu seeds were lower, unsaturated fatty acids (oleic acid) in umbu seeds were higher than those of six of the oilseeds studied, linolenic and arachidonic acid in umbu seeds were also higher than those of six of oilseeds analyzed (Tuberoso et al., 2007).

Umbu seeds presented an interesting fatty acid profile, which is more promising for the extraction of edible oil when compared to the other species of the *Spondias* genus and oils extracted from conventionally used seeds in human food.

3.2.4. Dietary fibers

Dietary fiber is the edible part of plants or analogue carbohydrates that are resistant to digestion and absorption in the human small intestine, with complete or partial fermentation in the large intestine (American Association of Cereal Chemists AACC, 2001). Dietary fiber include cellulose, hemicellulose, lignin, pectin, and β-glucans (Lattimer and Haub, 2010). Dietary fiber presents several beneficial effects on human health, such as the prevention of cardiovascular diseases and cancer, control of type II diabetes, glycemia, appetite, corporal weight, and abdominal adiposity, prebiotic effect, and short-chain fatty acid production (Barber et al., 2020; Ötles and Ozgoz, 2014; Slavin, 2013).

The number of studies on dietary fiber in umbu fruits that met the review criteria were low. Ribeiro et al. (2019) evaluated different fractions of fruits and found higher fiber contents in seeds (65 g/100 g FW) than in peels (49.34 g/100 g FW), fresh pulp (12.35 g/100 g FW), and commercial pulp (6.18 g/100 g FW). The maturation stages did not significantly alter dietary fiber content in umbu fruits (Narain et al., 1992). The fruit pulps of *S. pinnata* (7.5 g 100 g-1) and *S. mombin* presented lower fiber content (3.56 g/100 g FW) than the pulps of *S. tuberosa* (Judprasong et al., 2013; Satpathy et al., 2011).

In this sense, umbu fruit can contribute to the addition of dietary fiber in diets in which it is present, however, not in an overt way when compared to other fruits typical of Brazilian eating habits, such as plums, avocado and banana.

3.2.5. Minerals and vitamins

Minerals are essential for the functioning of the human body. They participate in the formation of bones, transmission of nerve impulses, production of hormones, heart rate regulation, and enzyme structures, and are important for nerve and erythrocyte cells. In addition, they participate in the regulation of glucose levels, activation of antioxidant enzymes, assist in the control of arterial pressure, and are involved in the immunological and cerebral systems (Gharibzahedi and Jafari, 2017).

Table 2 shows the mineral content in umbu fruits. Ribeiro et al. (2019) analyzed different parts of umbu fruits and found higher mineral content in the seeds, including phosphorus, calcium, magnesium, iron, and zinc. The highest potassium and sodium contents were found in the commercial pulp. Almeida et al. (2009) and Oliveira et al. (2011) found phosphorus, potassium, calcium, magnesium, iron, copper, sodium, zinc, selenium, cobalt, and nickel in frozen umbu pulps.

Schiassi et al. (2018) characterized pulps of fruits of the Cerrado biome in Brazil and umbu stood out, showing higher calcium, phosphorus, magnesium, and iron content than araçá (*Psidium guineense* Swartz; 42.29, 9.62, 15.28, and 0.18 mg/100 g FW, respectively), buriti (*Mauritia flexuosa* L.; 37.83, 6.85, 14.29, and 0.67 mg/100 g FW, respectively), cagaita (*Eugenia dysenterica* DC.; 22.50, 12.75, 5.78, and 0.33 mg/100 g FW, respectively), cajá (*S. mombin* L.; 40.31, 26.24, 10.31, and 0.37 mg/100 g FW, respectively), mangaba (*Hancornia speciosa* Gomes; 31.01, 9.16, 12.80, and 0.50 mg/100 g FW, respectively), and marolo (*Annona crassiflora* Mart.; 39.26, 22.24, 31.78, and 0.65 mg/100 g FW, respectively). Higher potassium content than that found in umbu were found in araçá (*Psidium guineense* Swartz) (295 mg/100 g FW) and marolo (*Annona crassiflora* Mart.) (379 mg/100 g FW) (Schiassi et al., 2018).

The highest mineral content were found in immature fruits (Narain et al., 1991). The same result was found in analyses of cajá fruits (*S. mombin*) (Bora et al., 1991). The fruits of *S. cytherea* at three different maturation stages presented a different trend regarding mineral contents: calcium was higher in mature fruits, whereas phosphorus, magnesium, and zinc were higher in immature fruits (Ishak et al., 2005).

Umbu seeds of different cultivars and maturation stages presented different phosphorus, potassium, calcium, magnesium, iron, copper, manganese, sodium, and aluminum contents (Borges et al., 2007). The seeds of *S. mombin* present higher calcium (802 mg/100 g FW), iron (9 mg/100 g FW), and phosphorus (708 mg/100 g FW) content and lower magnesium (243 mg/100 g FW) and potassium (128 mg/100 g

Table 2
Mineral content (mg/100 g fresh weight) in fruits and fruit parts at different maturation stages from different cultivars of umbu (*Spondias tuberosa*).

Reference	Cultivar, fruit part, and/or fruit maturation stage	P	K	Ca	Mg	Fe	Cu	Mn	Na	Al	Zn	Se	Co	Ni
(Narain et al., 1992)	Immature	32.7	-	16.2	-	1.5	-	-	-	-	-	-	-	-
	Semi mature	23.9	-	15.1	-	1.4	-	-	-	-	-	-	-	-
	Mature	29.9	-	15.8	-	1.4	-	-	-	-	-	-	-	-
(Borges et al., 2007)	Seed													
	Morales Pires (immature)	825	679	191	463	9.59	2.33	2.38	0.16	0.55	-	-	-	-
	Morales Pires (mature)	773	684	143	143	10.1	2.62	2.16	0.14	0.53	-	-	-	-
	Morales Pires Peludo (mature)	780	699	114	478	7.50	2.60	1.85	0.16	0.46	-	-	-	-
(Almeida et al., 2009)	Fruit	29.4	205	30.1	10.8	0.41	0.07	-	2.07	-	0.14	0.11	0.0085	12.1
	Fresh pulp	150	1.240	64	57	2	-	-	6	-	0.7	-	-	-
(Ribeiro et al., 2019)	Commercial pulp	114	2.164	171	87	4	-	-	26	-	1	-	-	-
	Seed	287	755	348	135	74	-	-	6	-	2	-	-	-
	Peel	154	1.49	1	88	1	-	-	12	-	0.7	-	-	-
(Oliveira et al., 2011)	Fresh pulp	14.3		17.9		0.25		-	-	-	-	-	-	-

FW) content than *S. tuberosa* seeds (Dike, 2010).

The studies showed that vitamin C (ascorbic acid) was the only vitamin found in the umbu pulp and is present in higher content in immature fruits (Narain et al., 1992). However, *S. cytherea* fruits presented higher vitamin C contents in mature fruits (Ishak et al., 2005); Melo and Andrade (2010) found higher vitamin C content in semi-mature fruits (11.07 mg/100 g FW) than in mature fruits (9.33 mg/100 g FW); C. F. P de Oliveira et al. (2013) found 16.73 mg/100 g FW of ascorbic acid content in umbu fruits; and A. F. Santos et al., (2018) found no difference in vitamin C contents in umbu pulps subjected to a heating process.

Bastos, Martinez, and Souza (2016) found differences in vitamin C content between commercial and concentrated umbu pulps (5.47 and 3.36 mg/100 g FW, respectively). Similar acid ascorbic content were found in umbu peels, pulps, and seeds (1.52, 1.60, 1.74 mg/100 g FW, respectively) (Omena et al., 2012). Rufino et al. (2009) analyzed fruits from the Northeast region of Brazil and found that umbu presented the lowest vitamin C content among the fruits evaluated (18.4 mg/100 g FW). Honorato et al. (2015) evaluated umbu pulps of two brands and found vitamin C content of 2.13 and 8.42 mg/100 g FW. Higher vitamin C content than that found in umbu pulp were found in fruit pulps from *Spondias bahienis* (8.94–16.69 mg/100 g FW), *Spondias dulcis* (53.5 mg/100 g FW), and *S. purpurea* (29.6 mg/100 g FW) (Almeida et al., 2009; Assis et al., 2020). Umbu pulps presented low acid ascorbic content than orange (*Citrus sinensis* L.) (68.1 mg/100 g FW) and Tahiti lime (*Citrus latifolia*) (41.4 mg/100 g FW) (Barros et al., 2012).

3.2.6. Phenolic compounds

Phenolic compounds are widely spread in nature and form one of the main classes of secondary metabolites in plants. They occur predominantly as polyphenols, whose structure is characterized by the presence of two or more aromatic rings, with at least one hydroxyl connected to each of them (Agostini-Costa et al., 2012; Robards et al., 1999). Phenolic compounds present a wide structural diversity, varying from simple phenols to polymers of intermediate molecular weight, long chain, or high molecular weight (Agostini-Costa et al., 2012; Hu et al., 2017). A widely used classification of phenolic compounds consists of dividing them into flavonoids and non-flavonoids (Crozier et al., 2009; Del Rio et al., 2013; Hu et al., 2017). Polyphenols are important for the prevention of several chronic non-transmissible diseases and have several biological properties, such as antioxidant, anti-inflammatory, anticancer, anti-obesity, antidiabetic, and anti-neurodegenerative activities (Koch, 2019).

Different polyphenols contents were found in umbu commercial pulps, whole fruit, peel, and seed, as well as quercetin, flavonoids, flavonones, anthraquinones, anthrones, coumarin, leucoanthocyanidins, anthocyanins, and tannins. The highest phenolic compound content is found in the peels and seeds of umbu fruits (Dias et al., 2019; Omena et al., 2012; Ribeiro et al., 2019; Rufino et al., 2010; Rufino et al., 2009; E. F. dos Santos et al., 2018; Vissotto et al., 2013).

Umbu fruits showed higher phenolic compound content in the umbu peel than in the pulp (Ribeiro et al., 2019). The umbu pulp also presented 5-caffeoylquinic acid (CQA) and 4-CQA (Meinhart et al., 2019). The highest phenolic compound content were found in extracts of peels and seeds of umbu fruits, which are parts that are not usually eaten. Ethanolic extracts from *S. pinnata* fruits have a higher total phenolic compound (50.7 gallic acid equivalents (GAE)/g FW) and flavonoid (17.8 mg rutin equivalents (RE)/g FW) content in the seeds than in the pulp (Maisuthisakul et al., 2007). Dichloromethane extracts from *S. purpurea* of seven different ecotypes collected in Mexico also present higher phenolic compound and flavonoid content in the epicarp than in the pulp (Villa-Hernández et al., 2017). Similar results were found for umbu fruits.

Differences in total phenolic content according to the maturation stage were found for *S. tuberosa* fruits; semi-mature umbu fruits presented higher phenolic compound content than those at other maturation stages (Melo and Andrade, 2010). Another study found higher phenolic compound content in mature fruits when compared to other maturation stages (E. F. dos Santos et al., 2018). Contrastingly, immature *S. cytherea* fruits present higher phenolic compound content (686 mg/100 g FW) than those in the other maturation stages (Ishak et al., 2005).

Acetone and ethanolic extracts of pulp and whole seriguela fruits (*S. purpurea*), despite belonging to the same genus of umbu, exhibited different phenolic profile, presenting protocatechuic acid, *p*-hydroxybenzoic acid, *p*-coumaric acid, salicylic acid, synaptic acid, syringic acid, *trans*-cinnamic acid, gentisic acid, vanillic acid, ferulic acid, ellagic acid, gallic acid, rutin, myricetin, quercetin, catechin, and phenolic compounds in the whole fruits (2276 mg/100 g FW) and in the pulp (989 mg/100 g FW) (Dutra et al., 2017). Some pulp extracts of fruits of the *Spondias* genus present lower total phenolic contents than umbu pulp, including methanolic extracts from pulps of *S. dulcis* fruits (33.5 mg GAE/100 g FW), methanolic extract from mature *S. pinnata* fruits (30.64 m GAE/g FW), and ethanoic extract from *S. purpurea* fruits (95.95 mg GAE/100 g FW) (Kubola and Siriamornpun, 2011; Silva and Sirasa, 2018; Zocoler de Mendonga et al., 2019).

Several factors affect secondary metabolite contents in plants, including genetic, ontogeny, morphogenetic, and environmental factors, which are divided into biotic and abiotic factors; abiotic factors include water, drought, salt, temperature, radiation, and chemical stresses, seasonal variations, and regional effects (Kubola and Siriamornpun, 2011). Variations in bioactive compound contents in *S. tuberosa* fruits can be explained by the action of these factors in the fruits.

3.2.7. Carotenoids

Carotenoids are natural pigments that contribute to the color of foods (Tapiero et al., 2004). They are widely used in the food industry, as supplements, dyes, and enhancements. Carotenoids have several positive functions on the human body, such as pro-vitamin A supply; eye, cardiovascular, and bone health; improvement of cognitive performance; protection against solar radiation; weight control; improvement of immune system; prevention of cancer; and child nutrition (Eggersdorfer and Wyss, 2018).

Carotenoids in umbu pulp vary according to the maturation degree. Mature fruits presented higher carotenoid content than immature fruits (Melo and Andrade, 2010). Disregarding differences between maturation stages, other works found carotenoid content varying between (0.76–3.02 mg/100 g FW) in the fruit (Melo and Andrade, 2010; E. A. de Oliveira et al., 2011; Rufino et al., 2010). Umbu fruit extracts exhibited higher carotenoid contents than *S. dulcis* fruits (0.44 mg/100 g FW) and lower carotenoid contents than *S. lutea* (18–23 μg/g FW) and *S. purpurea* (275 μg/g FW) fruits (Bobrich et al., 2014).

Ribeiro et al. (2019) found lutein, β-cryptoxanthin, α-carotene; β-carotene, 13-*cis*-β-carotene, 9-*cis*-β-carotene in fresh umbu pulp; lutein, zeaxanthin, zeinoxantin, β-cryptoxanthin, α-carotene, β-carotene, 13-*cis*-β-carotene, 9-*cis*-β-carotene in the frozen pulp; and lutein, zeaxanthin, zeinoxantin, β-cryptoxanthin, α-carotene, β-carotene, 13-*cis*-β-carotene, 9-*cis*-β-carotene in the fruit peel. Assis et al. (2020) determined the carotenoid profile of pulp and peel of tropical fruits in Brazil and found some carotenoids present in pulps of umbu, including umbu-cajá (*Spondias bahienses*), whose composition presented all--*trans*-lutein, all-*trans*-zeaxanthin, 13-*cis*-β-cryptoxanthin, all--*trans*-α-cryptoxanthin, all-*trans*-β-cryptoxanthin, all-*trans*-α-carotene, all-*trans*-β-carotene, 9-*cis*-β-carotene. Considering these results, the highest carotenoid content can be found in mature fruits.

4. Study limitations

Although the review protocol included the participation of three reviewers and four databases, a potential limitation of this study refers to the type of publication carried out in documenting the composition of umbu fruits. As it is a regional fruit, whose use is mainly concentrated in endemic growth areas, the scientific literature on umbu is scarce, and there is also the absence of a full systematic review protocol with a risk of bias assessment for better evaluation of studies' overall quality.

5. Conclusion

This review discussed the nutritional profile and potential of whole umbu fruit, and its pulp, peel, and seeds. Twenty-four articles were used for the analysis. Fruit parts that are not traditionally eaten, such as peel and seeds, mainly seeds, were highlighted regarding their protein, lipid, fatty acid, and mineral contents. The umbu seed fatty acid profile showed potential for extraction of edible oil, which requires further studies. The peels showed higher phenolic compound content than the pulp.

The results of this review indicate the promising nature of umbu fruits, suggesting their inclusion in healthy diets. Additionally, considering the potential health benefits, the utilization of peel and seeds as alternatives in the development of food products is recommended. It is noteworthy that the population residing in the endemic areas of these trees is economically disadvantaged, necessitating conservation efforts and the provision of native, culturally recognized, and nutrient-rich foods over the past few decades, either through governmental or other initiatives.

Ethics statement

No animal or human experimentation is conducted in this review manuscript.

CRediT authorship contribution statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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References

Agostini-Costa, T. da S., Vieira, R.F., Bizzo, H.R., Silveira, D., Gimenes, M.A., 2012. Secondary metabolites. Em. Chromatography and Its Applications. IntechOpen. https://doi.org/10.5772/35705.

Almeida, M.M.B., Sousa, P.H.M. de, Fonseca, M.L., Magalhães, C.E.C., Lopes, M. de F.G., Lemos, T.L.G. de, 2009. Avaliação de macro e microminerais em frutas tropicais cultivadas no nordeste brasileiro. Food Sci. Technol. *29*, 581–586. https://doi.org/10.1590/S0101-20612009000300020.

American Association of Cereal Chemists (AACC) (2001) The Definition of Dietary Fiber. Report of the Dietary Fiber Definition Committee to the Board of Directors of the AACC, 46 (3), 112-126.

Assis, R.C., Lima Gomes Soares, R., Siqueira, A.C.P., Rosso, V.V., Sousa, P.H.M., Mendes, A.E.P., Alencar Costa, E., Góes Carneiro, A.P., Maia, C.S.C., 2020. Determination of water-soluble vitamins and carotenoids in Brazilian tropical fruits by High Performance Liquid Chromatography. Heliyon *6* (10), e05307. https://doi.org/10.1016/j.heliyon.2020.e05307.

Barber, T.M., Kabisch, S., Pfeiffer, A.F.H., Weickert, M.O., 2020. The health benefits of dietary fibre. Nutrients *12* (10), 3209. https://doi.org/10.3390/nu12103209.

Barreto, L.S., Castro, M.S. de, 2010. Boas práticas de manejo para o extrativismo sustentável do umbu. Embrapa Recur. Gen. éticos e Biotecnol., Bras. ília 64.

Barros, H.R. de M., Ferreira, T.A.P. de C., Genovese, M.I., 2012. Antioxidant capacity and mineral content of pulp and peel from commercial cultivars of citrus from Brazil. Food Chem. *134* (4), 1892–1898. https://doi.org/10.1016/j.foodchem.2012.03.090.

Bastos, J.S., Acosta Martinez, E., Almeida De Souza, S.M., 2016. Características físico-químicas da polpa de umbu (Spondias tuberosa Arruda Câmara) comercial: Efeito da concentração. J. Bioen. Food Sci. *03* (1), 11–16. https://doi.org/10.18067/jbfs.v3i1.48.

Bobrich, A., Fanning, K.J., Rychlik, M., Russell, D., Topp, B., Netzel, M., 2014. Phytochemicals in Japanese plums: Impact of maturity and bioaccessibility. Food Res. Int. *65* (*Part A*), 20–26. https://doi.org/10.1016/j.foodres.2014.06.030.

Bora, P.S., Narain, N., Holschuh, H.J., da S. Vasconcelos, M.A., 1991. Changes in physical and chemical composition during maturation of yellow mombin (*Spondias mombin*) fruits. Food Chem. *41* (3), 341–348. https://doi.org/10.1016/0308-8146(91)90058-V.

Borges, S.V., Maia, M.C.A., Gomes, R. de C.M., Cavalcanti, N.B., 2007. Chemical composition of umbu (Spondias tuberosa arr. Cam) seeds. Química Nova *30*, 49–52. https://doi.org/10.1590/S0100-40422007000100011.

Bramont, W.B., Leal, I.L., Umsza-Guez, M.A., Guedes, A.S., Alves, S.C.O., Reis, J.H.O., Barbosa, J.D.V., Machado, B.A.S., 2018. Comparação da Composição Centesimal, Mineral e Fitoquímica de Polpas e Cascas de Dez Diferentes Frutas. Rev. Virtual Quim. *10* (4), 811–823. https://doi.org/10.21577/1984-6835.20180059.

Castro, C.D.P. da C., & Rybka, A. cecília P. (2015). Potencialidades do Fruto do Umbuzeiro para a Agroindústria de Alimentos. *Embrapa Semiárido, Petrolina, PE* .

Cavalcanti, N., de, B., Resende, G.M., Brito, L.T. de L., Lima, J.B., 1996. Extrativismo do imbuzeiro (Spondias tuberosa Arr. Cam.) como fonte alternativa de renda para pequenos produtores no semi-árido nordestino: um estudo de caso. Ciência Agrotecnologia - Embrapa Semiárido *20* (4), 525–528.

Costa, N.P. da, Luz, T.L.B., Gonçalves, E.P., Bruno, R. de L.A., 2004. Caracterização Físico-Química de Frutos de Umbuzeiro (Spondias tuberosa Arr. Cam), colhidos em quatro estádios de maturação. Bioscience *20* (2), 65–71. Retrieved from. https://seer.ufu.br/index.php/biosciencejournal/article/view/6515.

Crozier, A., Jaganath, I.B., Clifford, M.N., 2009. Dietary phenolics: Chemistry, bioavailability and effects on health. Nat. Prod. Rep. *26* (8), 1001–1043. https://doi.org/10.1039/b802662a.

Cunha, S.S. da (2020). *Recursos forrageiros em florestas secas: como o conhecimento ecológico local pode influenciar a dinâmica de uso frente a sazonalidade*. Universidade Estadual da Paraíba.

Dias, J.L., Mazzutti, S., de Souza, J.A.L., Ferreira, S.R.S., Soares, L.A.L., Stragevitch, L., Danielski, L., 2019. Extraction of umbu (*Spondias tuberosa)* seed oil using CO2, ultrasound and conventional methods: Evaluations of composition profiles and antioxidant activities. J. Supercrit. Fluids *145*, 10–18. https://doi.org/10.1016/j.supflu.2018.11.011.

Dike, M.C., 2010. Proximate, phytochemical and nutrient compositions of some fruits, seeds and leaves of some plant species at Umudike, Nigeria. ARPN J. Agric. Biol. Sci. *5* (1). 〈http://www.arpnjournals.com/jabs/research_papers/rp_2010/jabs_0110_167.pdf〉.

Dutra, R.L.T., Dantas, A.M., Marques, D., de, A., Batista, J.D.F., Meireles, B.R.L., de, A., de Magalhães Cordeiro, Â.M.T., Magnani, M., Borges, G. da S.C., 2017. Bioaccessibility and antioxidant activity of phenolic compounds in frozen pulps of Brazilian exotic fruits exposed to simulated gastrointestinal conditions. Food Res. Int. *100*, 650–657. https://doi.org/10.1016/j.foodres.2017.07.047.

Eggersdorfer, M., Wyss, A., 2018. Carotenoids in human nutrition and health. Arch. Biochem. Biophys. *652*, 18–26. https://doi.org/10.1016/j.abb.2018.06.001.

Fidelis, M., de, Moura, C., Kabbas Junior, T., Pap, N., Mattila, P., Mäkinen, S., Putnik, P., Bursać Kovačević, D., Tian, Y., Yang, B., Granato, D., 2019. Fruit seeds as sources of bioactive compounds: Sustainable production of high value-added ingredients from by-products within circular economy. Molecules *24* (21), 3854. https://doi.org/10.3390/molecules24213854.

Gharibzahedi, S.M.T., Jafari, S.M., 2017. The importance of minerals in human nutrition: Bioavailability, food fortification, processing effects and nanoencapsulation. Trends Food Sci. Technol. *62*, 119–132. https://doi.org/10.1016/j.tifs.2017.02.017.

Gonçalves, P.H.S., Albuquerque, U.P., Medeiros, P.M.D., 2016. The most commonly available woody plant species are the most useful for human populations: A meta-analysis. Ecol. Appl. *26* (7), 2238–2253. https://doi.org/10.1002/eap.1364.

Guo, C., Yang, J., Wei, J., Li, Y., Xu, J., Jiang, Y., 2003. Antioxidant activities of peel, pulp and seed fractions of common fruits as determined by FRAP assay. Nutr. Res. *23* (12), 1719–1726. https://doi.org/10.1016/j.nutres.2003.08.005.

Helrich, K.C., Ed Official methods of Analysis of the AOAC, Association of Official Analytical Chemists Inc., Arlington, 1298. Volume 2. No. Ed. 15. 1990..

Honorato, A.C., Dias, C.B.R., Souza, E.B. de, Carvalho, I.R.B. de, Sousa, K. dos S.M. de, 2015. Parâmetros físico-químicos de polpas de fruta produzidas na cidade de Petrolina – PE. Rev. Verde De. Agroecol. e Desenvolv. Sustent. áVel. *10* (4), 01–05. https://doi.org/10.18378/RVADS.V10I4.3415.

Instituto Brasileiro de Geografia e Estatística. (2017). *Produção da Extração Vegetal e da Silvicultura*. Internet. 〈https://sidra.ibge.gov.br/pesquisa/pevs/tabelas〉.

Ishak, S.A., Ismail, N., Mohd Noor, M.A., Ahmad, H., 2005. Some physical and chemical properties of ambarella (Spondias cytherea Sonn.) at three different stages of maturity. J. Food Compos. Anal. *18* (8), 819–827. https://doi.org/10.1016/J.JFCA.2004.11.007.

Judprasong, K., Charoenkiatkul, S., Thiyajai, P., Sukprasansap, M., 2013. Nutrients and bioactive compounds of Thai indigenous fruits. Food Chem. *140* (3), 507–512. https://doi.org/10.1016/j.foodchem.2013.01.057.

Koch, W., 2019. Dietary polyphenols—Important non-nutrients in the prevention of chronic noncommunicable diseases. A systematic review. Nutrients *11* (5), 1039. https://doi.org/10.3390/nu11051039.

Kubola, J., Siriamornpun, S., 2011. Phytochemicals and antioxidant activity of different fruit fractions (Peel, pulp, aril and seed) of Thai gac (*Momordica cochinchinensis* spreng). Food Chem. *127* (3), 1138–1145. https://doi.org/10.1016/j.foodchem.2011.01.115.

Lago, R.C.A., Maia, M.L.L., Matta, V.M. da, 2016. O Sabor das Frutas Tropicais no Brasil. Embrapa.

Larrosa, A.P.Q., Otero, D.M., 2021. Flour made from fruit by-products: Characteristics, processing conditions, and applications. J. Food Process. Preserv. *45* (5) https://doi.org/10.1111/jfpp.15398.

Lattimer, J.M., Haub, M.D., 2010. Effects of dietary fiber and its components on metabolic health. Nutrients *2* (12), 1266–1289. https://doi.org/10.3390/nu2121266.

Lima, M.A.C., Silva, S. de M., Oliveira, V.R., 2018. Umbu— Spondias tuberosa. Exotic Fruits. Elsevier, pp. 427–433. https://doi.org/10.1016/B978-0-12-803138-4.00057-5.

Lin, Z., Zhong, S., Grierson, D., 2009. Recent advances in ethylene research. J. Exp. Bot. *60* (12), 3311–3336. https://doi.org/10.1093/jxb/erp204.

Maisuthisakul, P., Suttajit, M., Pongsawatmanit, R., 2007. Assessment of phenolic content and free radical-scavenging capacity of some Thai indigenous plants. Food Chem. *100* (4), 1409–1418. https://doi.org/10.1016/j.foodchem.2005.11.032.

Martins, S.T., & Melo, B. (2017). *SPONDIAS (Cajá e outras)*. Universidade Federal de Uberlândia, Instituto de Ciências Agrárias.

Medeiros, S., de, S., Cavalcante, A., de, M.B.C., Marin, A.M.P., Tinôco, L.B., de, M., Salcedo, I.H., Pinto, T.F., 2012. Sinopse do Censo Demográfico para o Semiárido Brasileiro. Instituto Nacional do Semiárido (INSA).

Meinhart, A.D., Damin, F.M., Caldeirão, L., de Jesus Filho, M., da Silva, L.C., da Silva Constant, L., Filho, J.T., Wagner, R., Godoy, H.T., 2019. Chlorogenic and caffeic acids in 64 fruits consumed in Brazil. Food Chem. *286*, 51–63. https://doi.org/10.1016/j.foodchem.2019.02.004.

Melo, E. de A., Andrade, R.A.M. de S., 2010. Compostos bioativos e potencial antioxidante de frutos do umbuzeiro. Braz. J. Food Nutr. /Aliment. e Nutr. ção *21* (3), 453–457.

Narain, N., Bora, P.S., Holschuh, H.J., Vasconcelos, M.A. da S., 1992. Variation in physical and chemical composition during maturation of umbu (*Spondias tuberosa*) fruits. Food Chem. *44* (4), 255–259. https://doi.org/10.1016/0308-8146(92)90047-6.

Oliveira, E.A. de, Borges, S.V., Furtado, Â.A.L., Modesta, R.C.D., Godoy, R. de O., 2011. Heat processing (Htst) of umbu (Spondias tuberosa Arruda Câmara) pulp. Food Sci. Technol. *31*, 923–928. https://doi.org/10.1590/S0101-20612011000400015.

Oliveira, V.R. de, Drumond, M.A., Santos, C.A.F. dos, & Nascimento, C.E. de S. (2018). Spondias tuberosa Umbu. In L. Coradin, J. Camilo, & F.G. Pareyn (Eds.), *Espécies nativas da flora brasileira de valor econômico atual ou potencial. Plantas para o futuro: região Nordeste* (Série Biodiversidade, pp. 304–315). Ministério do Meio Ambiente.

Oliveira, C.F.P. de, Souza, S.M.A. de, Martinez, E.A., Guanais, A.L. da S.R., Silva, C.M.R. da, 2013. Estudio del proceso de deshidratación osmótica de umbu (Spondias tuberosa Arruda Câmara). Semin. Ciências Agr. árias *34* (2), 729–740.

Omena, C.M.B., Valentim, I.B., Guedes, G. da S., Rabelo, L.A., Mano, C.M., Bechara, E.J. H., Sawaya, A.C.H.F., Trevisan, M.T.S., da Costa, J.G., Ferreira, R.C.S., Sant'Ana, A. E.G., Goulart, M.O.F., 2012. Antioxidant, anti-acetylcholinesterase and cytotoxic activities of ethanol extracts of peel, pulp and seeds of exotic Brazilian fruits: Antioxidant, anti-acetylcholinesterase and cytotoxic activities in fruits. Food Res. Int. *49* (1), 334–344. https://doi.org/10.1016/j.foodres.2012.07.010.

Orrego, C.E., Salgado, N., Botero, C.A., 2014. Developments and trends in fruit bar production and characterization. Crit. Rev. Food Sci. Nutr. *54* (1), 84–97. https://doi.org/10.1080/10408398.2011.571798.

Ötles, S., Ozgoz, S., 2014. Health effects of dietary fiber. Acta Sci. Pol., Technol. Aliment. *13* (2), 191–202. https://doi.org/10.17306/J.AFS.2014.2.8.

Prasanna, V., Prabha, T.N., Tharanathan, R.N., 2007. Fruit ripening phenomena–an overview. Crit. Rev. Food Sci. Nutr. *47* (1), 1–19. https://doi.org/10.1080/10408390600976841.

Rezende, L.C. de, Santos, P. de A., Riatto, V.B., David, J.M., David, J.P., 2018. New alkyl phenols and fatty acid profile from oils of pulped *Spondias mombin* l. Seed wastes. Química Nova *41*, 540–543. https://doi.org/10.21577/0100-4042.20170203.

Ribeiro, L. de O., Viana, E. de S., Godoy, R.L. de O., Freitas, S.C. de, Freitas, S.P., Matta, V.M. da, 2019. Nutrients and bioactive compounds of pulp, peel and seed from umbu fruit. Ciência Rural *49*, e20180806. https://doi.org/10.1590/0103-8478cr20180806.

Del Rio, D., Rodriguez-Mateos, A., Spencer, J.P.E., Tognolini, M., Borges, G., Crozier, A., 2013. Dietary (Poly)phenolics in human health: Structures, bioavailability, and evidence of protective effects against chronic diseases. Antioxid. Redox Signal. *18* (14), 1818–1892. https://doi.org/10.1089/ars.2012.4581.

Robards, K., Prenzler, P.D., Tucker, G., Swatsitang, P., Glover, W., 1999. Phenolic compounds and their role in oxidative processes in fruits. Food Chem. *66* (4), 401–436. https://doi.org/10.1016/S0308-8146(99)00093-X.

Rufino, M.S.M., Alves, R.E., de Brito, E.S., Pérez-Jiménez, J., Saura-Calixto, F., Mancini-Filho, J., 2010. Bioactive compounds and antioxidant capacities of 18 non-traditional tropical fruits from Brazil. Food Chem. *121* (4), 996–1002. https://doi.org/10.1016/j.foodchem.2010.01.037.

Rufino, M.S.M., Fernandes, F.A.N., Alves, R.E., de Brito, E.S., 2009. Free radical-scavenging behaviour of some north-east Brazilian fruits in a DPPH system. Food Chem. *114* (2), 693–695. https://doi.org/10.1016/j.foodchem.2008.09.098.

Santos, A.A.O., Abud, A.K.S., De Araujo, A.G.T., Santos, R.C.A., Santos, P.L., Narain, N., 2018a. Effect of thermal treatment of must on quality of fermented beverage elaborated by using umbu (*Spondias tuberosa* arruda camara) fruit pulp. Acta Hortic. (*1198*), 163–176. https://doi.org/10.17660/ActaHortic.2018.1198.27.

Santos, A.F., Lopes, M.F., Medeiros, J.B., Farias, E.T.R., Silva, F.V.G., 2018b. Quantification of total polyphenols in fruits of genus *Spondias* stored at different temperatures. Acta Hortic. (*1198*), 255–258. https://doi.org/10.17660/ActaHortic.2018.1198.42.

Santos, A. dos, Oliveira Lopes, P.M., Silva, M.V. da, Maniçoba da Rosa Ferraz Jardim, A., Barbosa de Albuquerque Moura, G., Siqueira Tavares Fernandes, G., Oliveira Silva, D.A. de, Bezerra da Silva, J.L., de Moraes Rodrigues, J.A., Araújo Silva, E., Oliveira-Júnior, J.F. de, 2020. Causes and consequences of seasonal changes in the water flow of the São Francisco river in the semiarid of Brazil. Environ. Sustain. Indic. *8*, 100084 https://doi.org/10.1016/j.indic.2020.100084.

Satpathy, G., Tyagi, Y.K., Gupta, R.K., 2011. Preliminary evaluation of nutraceutical and therapeutic potential of raw Spondias pinnata K., an exotic fruit of India. Food Res. Int. 44 (*7*), 2076–2087. https://doi.org/10.1016/j.foodres.2011.01.040.

Schiassi, M.C.E.V., Souza, V.R. de, Lago, A.M.T., Campos, L.G., Queiroz, F., 2018. Fruits from the Brazilian Cerrado region: Physico-chemical characterization, bioactive compounds, antioxidant activities, and sensory evaluation. Food Chem. *245*, 305–311. https://doi.org/10.1016/J.FOODCHEM.2017.10.104.

Silva, K.D.R.R., Sirasa, M.S.F., 2018. Antioxidant properties of selected fruit cultivars grown in Sri Lanka. Food Chem. *238*, 203–208. https://doi.org/10.1016/J.FOODCHEM.2016.08.102.

Silva, S.L. da, Souza, E.V.N. de, Couto, L.A., Moreira, E. de S., Landim, L.B., Rusciolelli, L. B., Cafieiro, C.S.P., 2022. Parâmetros proximais da polpa de umbu (Spondias tuberosa Arr. Cam.) comercializada no município de Guanambi, Bahia, Brasil. Braz. J. Sci. *1* (12), 76–82.

Slavin, J., 2013. Fiber and Prebiotics: Mechanisms and Health Benefits. Nutrients *5* (4), 1417. https://doi.org/10.3390/NU5041417.

Subharaj, C., Logesh, K., Joe Patrick Gnanaraj, S., Appadurai, M., Maria Antony Sebastin Vimalan, P., 2022. Design and development of Palmyra fruit pulp production equipment through sustainable approach. Mater. Today.: Proc. *68*, 1762–1768. https://doi.org/10.1016/j.matpr.2022.09.456.

Tapiero, H., Townsend, D.M., Tew, K.D., 2004. The role of carotenoids in the prevention of human pathologies. Biomed. Pharmacother. = Biomedecine Pharmacother. *58* (2), 100–110. https://doi.org/10.1016/J.BIOPHA.2003.12.006.

Torres, R.R., Lapola, D.M., Gamarra, N.L.R., 2017. Future Climate Change in the Caatinga. Caatinga: Larg. Trop. Dry. For. Reg. South Am. 383–410. https://doi.org/10.1007/978-3-319-68339-3_15.

Tuberoso, C.I.G., Kowalczyk, A., Sarritzu, E., Cabras, P., 2007. Determination of antioxidant compounds and antioxidant activity in commercial oilseeds for food use. Food Chem. *103* (4), 1494–1501. https://doi.org/10.1016/J.FOODCHEM.2006.08.014.

Tuna Ağirbaş, H.E., Yavuz-Düzgün, M., Özçelik, B., 2022. Valorization of fruit seed flours: Rheological characteristics of composite dough and cake quality. J. Food Meas. Charact. *16* (4), 3117–3129. https://doi.org/10.1007/s11694-022-01423-0.

Villa-Hernández, J.M., Mendoza-Cardoso, G., Mendoza-Espinoza, J.A., Vela-Hinojosa, C., Díaz de León-Sánchez, F., Rivera-Cabrera, F., Alia-Tejacal, I., Pérez-Flores, L.J., 2017. Antioxidant Capacity In Vitro and In Vivo of Various Ecotypes of Mexican Plum (Spondias purpurea L.). J. Food Sci. *82* (11), 2576–2582. https://doi.org/10.1111/1750-3841.13862.

Vissotto, L.C., Rodrigues, E., Chisté, R.C., Benassi, M. de T., Mercadante, A.Z., 2013. Correlation, by multivariate statistical analysis, between the scavenging capacity against reactive oxygen species and the bioactive compounds from frozen fruit pulps. Food Sci. Technol. *33* (1)), 57–65. https://doi.org/10.1590/S0101-20612013000500010.

Zhao, J., Li, H., Xi, W., An, W., Niu, L., Cao, Y., Wang, H., Wang, Y., Yin, Y., 2015. Changes in sugars and organic acids in wolfberry (*Lycium barbarum* l.) fruit during development and maturation. Food Chem. *173*, 718–724. https://doi.org/10.1016/j.foodchem.2014.10.082.

Zocoler de Mendonga, V., Lopes Vieites, R., Zocoler de Mendonga, V., Lopes Vieites, R., 2019. Physical-chemical properties of exotic and native Brazilian fruits. Acta Agron. ómica *68* (3), 175–181. https://doi.org/10.15446/ACAG.V68N3.55934.