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Physico-chemical characterization of Tamarind residues (*Tamarindus indica* L.): nutritional and anti-nutritional potential

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Abstract

The purpose of this study was to characterize tamarind residues in terms of physico-chemical aspects, phenolic proportion, and antioxidant activity, exploring its nutritional and anti-nutritional potential for human consumption. The selected fruits were weighed, and the pods were manually broken, separated from the pulps, seeds, and husks. The products were dried in an oven with air circulation (6h). The husks were crushed and submitted to granulometric sieving (250 μm) to form tamarind husk powder (THP). Regarding the seeds, a fraction was submitted to roasting (115ºC for 15 min) and another one kept in natura. Subsequently, they were crushed and subjected to granulometric sieving (250 μm) to form fresh seed powder (FSP) without roasting, and toasted seed powder (RSP). The analytical measurements were taken for the attributes: pH, titratable acidity, water activity, humidity, ash, proteins, lipids, total fiber. The antioxidant potential was determined using the free radical 2,2-diphenyl-1-picrilhidrazil, in addition to the total phenolic composition and tannins. All powders had low moisture values. THP (24.6g/100g) and RSP (15.31g/100g) showed high fiber content. In terms of protein, the RSP had a higher content (14.56g/100g). As for the phenolic compounds, these were higher in the seed powder. The tannin content was similar between powders. Powders showed high antioxidative capacity. Tamarind residues are promising, in terms of added nutritional value, and are able to supplement human diets, especially in relation to fiber, protein, energy, and antioxidant content.

Palavras-chave: Food waste; Integral feeding; Nutrients; Powders.

INTRODUCTION

The need to explore alternative ingredients gained notoriety due to the current increase in the conventional cost of food and the deficit supply[1]. Thus, the inclusion of unconventional foods, such as agro-industrial waste, can reduce the effective cost of nutrients, decrease the increased demand for food and reduce waste and organic waste[2], which are urgent problems in the current scenario of socio-environmental sustainability. On the other hand, a large amount of agro-industrial by-products is produced annually and wasted by the lack of knowledge about the nutritional value and methods of processing them[1].

Therefore, fruits and vegetables have been studied in a more comprehensive way, seeking to highlight the benefits that their residues can offer to the population. This is because, for the most part, they have nutritional values (sources of proteins, carbohydrates, fibers and bioactive compounds) that can be reused by the pharmaceutical, chemical, and especially

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food industries[2].

Tamarind (*Tamarindus indica* L.) stands out for its nutritional qualities. The seed of this fruit shows great richness in sulfur amino acids, allowing the population to take advantage of it as a component of a cereal-based protein regime[3].

Traditionally, tamarind is used in herbal medicine to heal wounds, also for the treatment of abdominal pain, diarrhea, dysentery, parasitic infestation, fever, malaria, and respiratory disorders. It is also commonly used in tropical countries due to its laxative and aphrodisiac characteristics[4].

Although it is not native to the Northeast region, tamarind trees are considered a typical fruit plant in this region due to their ability to adapt, making them an ideal food crop for the semiarid region[5].

Tamarind fruits provide two important products - pulp, most of which is consumed directly or used to make local food and drinks, which are sold for domestic income. On the other hand, seeds and husks, originated from the consumption and processing of fruits in a significant volume, are discarded annually; meanwhile seeds, obtained after pulping the pod, are usually thrown away[6].

According to Akajiaku *et al*. (2014)[7], the fruit pulp contains tartaric acid, responsible for providing typical fruit acidity, while seeds are good sources of protein, crude fiber, carbohydrates, and phytochemicals[8].

Due to the scarce technological use, there is little evidence in the literature, information, or studies aimed at physico-chemical characterization and human consumption of tamarind husks and seeds, especially in a semiarid region.

Due to the great search for nutritional improvements, as well as the incentive to use food residues, it is clear that tamarind has a huge potential to be explored. However, the scarcity of studies of its properties limits its use, in addition, the growth conditions (soil, climate, rainfall) differentiate the studies regarding the physico-chemical properties, making it impossible to estimate a real nutritional and nutraceutical value.

Thus, the proximate composition is one of the ways to show the nutritional importance and the possibility of using residues, which until now were considered inedible, in the Brazilian diet. This study aims to contribute to the improvement of the nutritional status of the population and to reduce the problems caused by deficient and non-nutritious food, in addition to reducing the accumulation of organic waste produced in the country[9].

According to Zanatta, Schlabitz, Ethur (2010)[21], the preparation of powders from fruit residues corresponds to a viable alternative for reuse, since these can be used as ingredients in the preparation of the most diverse products (cookies, cakes, breads, sweets, among others). In addition, they can act as an enriching source of nutrients.

In terms of food stability, it is hoped that the elaborated powders present parameters that maintain their sensory conservation and a state that avoids microbiological contamination. Among the quality parameters, the water content, the acidity, and the pH, as well as the ash content are worth mentioning[22].

In question, it is emphasized that the culture of tamarind assumes economic importance in the Northeast region - generating income; however, its waste still has a lot of potential to be exploited. Therefore, this physico-chemical study is a way to clarify the potential of these residues.

Based on the exhibitions carried out and considering that there is a lack in the scientific field of chemical identification of tamarind seeds and husks in the *Sub-Middle* region of São Francisco, this test aimed to manufacture powders from the residues of the tamarind fruit (*Tamarindus indica* L.), from the region and characterize them physically and chemically, in addition to checking their antioxidant and phenolic activity. Therefore, exploring its nutritional and anti-nutritional potential for human consumption.

METHODOLOGY

Tamarind fruits: obtaining, selecting, and separating waste

Tamarind fruits were purchased at street markets in the São Francisco valley region, in the cities of Petrolina, Pernambuco (latitude 09º23'55"S; longitude 40º30'03"W) and Juazeiro, Bahia (latitude: 09º24'42"S, longitude: 40º29'55"W), in their full maturity stage for human consumption, between the months of September to December 2018. They were then transported immediately to the Nutrition I (Bromatology) and Nutrition II (Dietary Technique) laboratories of Universidade de Pernambuco – Petrolina Campus, in plastic bags at room temperature, in which the inspection/search for signs of damage, injury, insects, or signs of rotting occurred. Then, the selected fruits were weighed, and the pods were manually broken, separated from the pulps, seeds, and husks.

Preparation of seed powders (fresh and roasted) and husks

The seed pulps were soaked for 12 hours in clean water (1: 3m/v) to allow complete removal of the pulp and fiber threads. To prepare the powders, the seeds were later washed with distilled water and dried in an oven with air circulation (60ºC) for 6 hours. Soon after, the grinding was carried out into fine powders using the appropriate commercial blender, and a granulometric sieve was used for sieving (250 μm), which was stored in an airtight container protected from light and at room temperature (28ºC) until later use. The roasting took place at 150ºC for 15 minutes in a conventional oven and were subsequently crushed and sieved under the same conditions as fresh powder. Finally, the tamarind husks followed the same processes, however without roasting.

Physico-chemical analysis

The physico-chemical characterization of the powders was carried out in the Nutrition Laboratory I (Bromatology) of the University of Pernambuco – Petrolina Campus and in the laboratories of the National Service for Industrial Learning (SENAI). The powders were analyzed in triplicates for the following attributes: pH, titratable acidity, moisture, crude protein, crude lipid, crude fiber, and ash, according to the recommendations proposed by the Adolf Lutz Institute (2008)[12]. Quantification of carbohydrates occurred by difference, following the schematic formula: [100 - (lipids + crude protein + ash + crude fiber)][13]. The measurement of water activity was verified by the Standard Methods for the Examination of Water and Wastewater. Conversion values were used to determine the calorific value: 4 kcal/g for carbohydrates, 4 kcal/g for proteins, and 9 kcal/g for lipids.

Elaboration of extracts and phenolic quantification, tannins, and determination of antioxidant activity

Powder samples were extracted with methanol at room temperature for 24 hours with a volumetric mass in the proportion of 1:20 (g/ml). This solvent was determined based on the study by Razali et al. (2015)14, which found the best extraction for tamarind residues. The methanol extract was then evaporated under reduced pressure. Then, they were dissolved in 10% dimethyl sulfoxide (DMSO). Both solvents, methanol and DMSO are non-toxic in these concentrations. The extracts were preserved at -20°C until the analysis of phenolic compounds and antioxidant activity[14].

For the quantification of phenolic compounds, the Folin-Ciocalteau (FC) method (Sigma®, USA) modified by Roesler et al. (2007)15 was used with extracts in a proportion of 1:10 (w/v). In summary, 500µl of the extract was pipetted in a test tube (10ml), completed with 0.5µl of Folin-Ciocalteau (1:10). Subsequently, 0.5µl of a sodium carbonate solution (20%) was added, followed by 3.5µl of distilled water and the mixture was homogenized using a vortex. The mixture was then incubated at room temperature for 2 hours to allow the color to develop. Absorbance was measured at 725 nm. To express the results, a calibration curve was drawn up with the following concentrations: 0.01µl, 0.015µl, 0.02µl, 0.025µl, 0.050µl, 0.075µl, and 0.1µl and expressed in mg of gallic acid equivalents (GAE) per gram of extract (mg GAE.g^{-1}).

As for tannins, they were determined by the method of Magalhães, Rodrigues and Durães (1997)[16], using the Folin-Denis' reagent (FD) (Sigma®, USA). For the measurement, initially, the tannin extraction process was carried out. For this, 0.5g of each powder was transferred to a test tube, 10 ml of a solution of hydrochloric acid (1%) in methanol was added and closed. Then, the samples were vortexed for 20 minutes and centrifuged at 1000 rpm for 8 minutes (with a gradual speed from 200 to 1000 rpm). After extraction, the measurement gear was performed. Briefly, 1000µl of the extract was added to a test tube, then 8.4ml of distilled water, 1µl of saturated sodium carbonate solution, and 0.5µl of the Follin-Denis reagent were added. Then, the tubes were shaken for 30 minutes and measured at 760nm. To express the results, a calibration curve was drawn up with the following concentrations: 100µl, 200µl, 300µl, 400µl, 500µl, 600µl, 700µl, 800 µl. The results were expressed in mg of tannic acid g^{-1} sample.

The evaluation of the antioxidant activity of the extracts occurred by deactivating the free radical DPPH (2,2-diphenyl-1-picrilhidrazil), which were evaluated for their ability to donate hydrogen to DPPH, according to the methodology of Yamaguchi et al. (1988)17. The reading was carried out in the UV-VIS spectrum at a wavelength of 517 nm. The percentage of DPPH radical sequestration was calculated using Equation 1:

$$\% \text{ Sequestration: } \frac{(\text{Absorbance of the control} - \text{Absorbance of the sample}) \times 100}{\text{Absorbance of the control}}$$

Statistical design

Statistical analyzes were performed using the SPSS version 23.0 data package (SPSS Inc., Chicago, IL, USA). Data were compiled in Microsoft Excel 2013. The discrete quantitative variables were tested for normal distribution by the Shapiro Wilk test and homogeneity of variances by the Levenne test. As they assumed normal distribution, a parametric analysis was performed using the Analysis of Variance test (ANOVA one way) with Tukey's post-hoc. A significance level of 5.0% was established for rejection of the null hypothesis.

RESULTS

The yield of tamarind residues (husks and seeds) is presented in relation to the pulp, a popular part of the fruit and considered noble in table 1. Thus, it appears that for each kg of fruit, the residues account for approximately half (48.6%) of the weight of the whole fruit, with emphasis, in terms of proportion, on the tamarind husks.

Quadro 1 – Estimation of the proportions of the parts of the Tamarindo fruit (*Tamarindus indica* L.) from the Sub-Middle Region of São Francisco for each 1kg of pods (2020).

	Tamarind		
	Pulp	Seed	Husks
Part of the fruit for each 1kg of pods	514g	221g	265g
Yield (%)	51.4	22.1	26.5

Source: Author (2020).

The physico-chemical components of the husk and seed powders (fresh and roasted) of tamarind can be seen in Table 1. The analyses revealed in wet (WB) and dry (DB) bases that the fiber content and the glycosidic fraction are predominant in THP. In relation to fresh and roasted seed powders, in addition to the dominance of fibers and carbohydrates, the protein content was also relevant.

The comparative analysis between the powders studied in table 2 is summarized. It is observed that in relation to pH, the powders showed values considered acidic, with an emphasis on the THP, differing significantly from the other powders ($p<0.05$). Regarding the titratable acidity, THP presented higher values ($p<0.05$) in relation to the other powders.

As for moisture, the seed powder in natura showed higher and statistically significant content ($p <0.05$). Regarding the nitrogen or protein content, it is possible to verify that the seeds are concentrated. The RSP demonstrated content that significantly ($p<0.05$) surpassed in natura content (Table 2).

Regarding the lipid content, it is observed that the powders showed reduced values (Table 1), in which the main part fell significantly ($p <0.05$) for the roasted seed powder (Table 2), surpassing the fresh powder, and the husk powder significantly ($p <0.05$). The latter had minimal content (0.6g 100g-1).

While, in relation to carbohydrates, these were significantly higher in the husk powder. All powders can be considered foods with a high fiber content. The THP showed significant values ($p <0.05$) that exceed the seed powder (Table 2).

The ash content was higher in THP, followed by RSP. As for the caloric value, the roasted seed powder had a higher content when compared to the husk powder, differing significantly ($p<0.05$) (Table 2).

Regarding the results of phenolic quantification, tannins, and antioxidative activity, the results can be seen in table 3. In view of the content of phenolic compounds, it is noted that this was higher in seed powders, notably in RSP, differing significantly from FSP and THP, the latter with less quantified content. Regarding the tannin values, it is noted that there was no difference in the averages found for the three types of powder. Finally, when evaluating the DPPH radical scavenging activity, all powders had a high percentage of inhibition, above 97%, and were without statistical differences.

Table 1 – Physico-chemical parameters of powders of in natura husks and seeds and roasted tamarind seeds (*Tamarindus indica* L.) from the São Francisco Sub-Middle Region (2020).

Physico-chemical variables	Powders					
	THP		FSP		RSP	
	WB	DB	WB	DB	WB	DB
pH	2.9±0.35	-	6.1±0.04	-	5.8±0.09	-
Titratable Acidity	3.8±0.12	-	1.9±0.17	-	1.3±0.17	-
Water activity (Aw)	0.43±00	-	0.48±0.0	-	0.47±0.0	-
Humidity (g.100g^{-1})	6.3±0.28	6.7±0.32	9.6±0.43	10.6±0.53	6.2±0.21	6.6±0.24
Protein (g.100g $^{-1}$)	3.4±0.01	3.63±0.01	10.3±0.09	11.4±0.11	13.7±0.10	14.6±0.09
Total fat (g.100g^{-1})	0.6±0.01	0.6±0.01	3.2±0.04	3.5±0.05	4.3±0.16	4.6±0.16
Total Dietary Fiber (g.100g $^{-1}$)	23.04±0.0	24.6±0.08	16.5±0.38	18.3±0.43	14.3±0.02	15.31±0.0
Glycosidic fraction (g.100g – 1) *	62.2±0.43	59.5±0.41	58.7±0.50	54.3±0.74	59.3±0.25	56.6±0.3
Ashes (g.100g $^{-1}$)	4.7±0.02	5.0±0.02	1.8±0.01	2.0±0.01	2.1±0.02	2.3±0.08
Total caloric value	267±1.14	237±1,65	304.5±2.4	294.4±3.0	330.7±1.3	326.1±1.5

Source: Author (2020). Schematic values in mean and standard deviation. *Obtained by the difference. THP: Tamarind husk powder; FSP: Fresh tamarind seed powder; RSP: Roasted tamarind seed powder; WB: wet base; DB: dry base.

Table 2 – Comparison between the physico-chemical components of the powders in the husks, fresh seeds, and roasted tamarind seeds (*Tamarindus indica* L.) from the Sub-Middle Region of São Francisco (2020).

Physico-chemical variables	Husk powder	Fresh seed powder	Roasted seed powder
pH *	2.9±0.35^{B}	6.1±0.04^{A}	5.8±0.09^{A}
Titratable Acidity *	3.8±0.12^{A}	1.9±0.17^{B}	1.3±0.17^{C}
Water activity (WA) *	0.43±0.0^{C}	0.48±0.0^{A}	0.47±0.0^{B}
Humidity (g.100g–1)	6.7±0.32^{B}	10.6±0.53^{A}	6.6±0.24^{B}
Protein (g.100g–1)	3.63±0.01^{C}	11.4±0.11^{B}	14.56±0.09^{A}
Total fat (g.100g–1)	0.6±0.01^{C}	3.5±0.05^{B}	4.6±0.16^{A}
Total Dietary Fiber (g.100g–1)	24.6±0.08^{A}	18.3±0.43^{B}	15.31±0.03^{C}
Glycidic fraction (g.100g–1)	59.45±0.41^{A}	54.3±0.74^{C}	56.6±0.3^{B}
Ashes (g.100g–1)	5.0±0.02^{A}	2.0±0.01^{C}	2.3±0.08^{B}
Total caloric value	237.0±1.65^{A}	294.4±3.01^{B}	326.1±1.52^{A}

Source: Author (2019). Schematic values in mean and standard deviation; *Values on a wet base; Means followed by different capital letters on the lines differ significantly by the one-way analysis of variance (ANOVA) followed by the *a posteriori* Tukey test at a 0.05 significance level.

Table 3 – Comparative analysis of total phenols, tannins, and antioxidant activity of powders from tamarind residues, Petrolina - Pernambuco, 2020.

Powders	Phenolic compounds (mg GAE.g^{-1})	Tannins (mg TAE.g^{-1})	Kidnapping of the radical DPPH (%)
THP	8.9±0.16^{C}	2.9±0.17^{A}	97.4±0.28^{A}
FSP	15.5±0.21^{B}	3.1±0.07^{A}	99.9±0.00^{A}
RSP	16.5±0.15^{A}	3.1±0.02^{A}	97.7±2.05^{A}

Source: Author (2020). THP: Tamarind husk powder; FSP: Fresh tamarind seed powder; RSP: Roasted tamarind seed powder; DPPH: 2,2-diphenyl-1-picrylhydrazyl; GAE: Gallic acid equivalent; TAE: Tannic acid equivalent; Averages followed by different capital letters in the columns differ significantly by the one-way analysis of variance (ANOVA) followed by the *a posteriori* Tukey test at the significance level of 0.05.

DISCUSSION

In this study, disproportionate relationships of plant residues were found in relation to the parts considered to be desirable in the fruits. Disagreeing with the findings of the present study, the assay by Pereira et al. (2010)18 the parts consisting of tamarind husk, pulp, and seeds contributed respectively with 30%, 30%, and 40% of the weight of the whole fruit. In addition to this, research by the Brazilian Agricultural Research Corporation Semi-arid (EMBRAPA) found a volume of waste generated in the processing of between 50 to 65% 19. Although there may be percentage divergences in relation to the residues yields due to the manual or instrumental processes (mechanized industrial process) used and due to the composition, it is understood that the residues account for important parts of the fruits, largely overcoming the desirability of the pulps (part stigmatized as noble).

Regarding the total water content (humidity), it is observed that the powders showed values within the normal standards, which according to the National Health Surveillance Agency (ANVISA)[20] is at most 15g.1001 or 15%. Similarly, these findings are confirmed by the approximate values observed in the study by Mohamed, Mohamed, and Ahmed (2015)[21], in which the tamarind seed powders showed values of 11.21g $100g^{-1}$ of moisture. Also, in the article by El-Gindy, Youssif, and Youssif (2015)[22], studying the chemical properties and technological application of tamarind seeds, found values of 11.5±0.5. Moreover, in the work of Kumar Shanta and Bhattacharya Sila (2008)[23], the humidity values for the seeds ranged from 9.4 to 11.3%.

As for husks, limited and scarce tests restrict comparisons. However, the values of husk moisture were shown to be lower in relation to seeds. Comparing these data with non-conventional powders, the powder from the tamarind husk has lower values. Just look, in the study by Cazarin *et al.* (2014)[24], evaluating the proximate composition of passion fruit husk powder (Passiflora edulis), with reported values of 9.48±0.26. Similarly, Lima et al. (2015)25, working with watermelon (Citrulus lanatus) powder in the formulation of biscuits, found moisture standards of 9.55±0.29.

In addition, the free water content represented by the water activity (aw), as Melo Filho and Vasconcelos Silva (2011)[26], classify the powdered foods as having low water content, since all presented an aw below 0.6. Naturally, as the water content, specifically the free water, is the reason for most of the deteriorating manifestations, the observed values predicted a commercial stability of these products.

In addition to the context of microbiological and sensory stability, the pH and acidity variants are also decisive. In this work, depending on the pH, the husk powder can be considered a very acidic food (pH<4.5), while seed powders are a low acid food (pH>4.5), according to the criteria of Krolow (2006)[27]. On the other hand, in terms of total acidity, the powders of the seeds showed higher values in relation to the husk, which was already expected due to the pH of the seeds being higher. It is worth mentioning that even though the seed powders have low acidity according to the pH, the values do not reach alkalinity, guaranteeing protection added to the low availability of water.

The high protein content of tamarind seeds has also been observed in other studies. El-Gindy, Youssif and Youssif (2015)22, found an average protein content of 13.1±1.1 in seeds from Cairo, Egypt, similarly to our study. Rana Mahima and Sharma Paul (2018)28 measured values of 14.1±1.6 in seeds from Jaipur, India, also confirming our analyses. Still, in Sudan, Mohamed, Mohamed, and Ahmed (2015)[21], working with light and dark colored tamarind seeds, found nitrogen values of 20.23±0.5658 and 23.75±0.0839, respectively, exceeding our results, but maintaining the seeds as a food with high protein content.

According to ANVISA29, FSP is considered a protein source since it presented a minimum of 6g/100g of food, while RSP is a high-content food, as it presented a minimum of 12g/100g of food. Therefore, the values recorded in this study suggest that the seed powder can be classified as a potential source of vegetable protein and, therefore, could be used as a protein supplement.

Allied to the fact, it is mentioned that according to the study by Kumar Shanta and Bhattacharya Sila (2008)[23], the index of essential amino acids for tamarind seed protein is 71.5% in relation to the Food and Agriculture Organization (FAO) standard (1973)[30]. On the other hand, the protein content of tamarind THP, in this study, did not stand out, demonstrating reduced values. One explanation for the low protein content in THP is the evidence by Costa et al. (2015)[31] explaining that the storage of a concentrated form of protein occurs in the seeds, which are storage organs. When husks and pulps are compared to seeds, their protein content is lower.

Regarding the fat content, in the follow-up scenario, the average estimates of lipid values found are 3.90±0.05 and 3.17±0.04, respectively, for light and dark colored Sudanese tamarind seed powders observed in the work of Mohamed, Mohamed, and Ahmed (2015)[21]. The study by El-Gindy, Youssif, and Youssif (2015)[22] reached lipid averages of 5.3±1.0 in Egyptian tamarind seeds. In both studies, the results came close to our work, confirming it. However, as a contrast, there is the research of Rana Mahima and Sharma Paul (2018)[28], evaluating the physico-chemical composition of Indian tamarind seeds, in which they obtained values of 7.84±0.64 of lipid content, the which considerably surpasses the results of the research herein. It is theorized that agroecological variations, such as climate, vegetation, temperature, and soil, imply differences in the chemical composition of the fruit.

As for fibers, all powders assumed values greater than 3g/100g can be considered sources, and values greater than 6g/100g may be considered sources of high content, as regulated by ANVISA29. Regarding the husk, there are no physico-chemical composition studies in the scientific field, however, the values found centralize its importance as a main or alternative ingredient in food formulations. As for seeds, several studies share these results. Shlini Purushothaman and Murthy Siddalinga (2015)[32] reported values of 14.9 g of fibers in a control tamarind seed sample. Likewise, El-Gindy, Youssif, and Youssif (2015)22 reported numbers of 21.6±0.05g. Also endorsed by Rana Mahima and Sharma Paul (2018)[28] measuring averages of 14.75±2.1g. For this reason, it appears that seeds are potential sources of fiber in diets. Moreover, traditional consumer powders (wheat, corn, and cassava) do not add fiber content suitable to the nutritional needs of individuals and populations. Still, the potential and interest of the powders of the husks is verified in this context, due to the high content observed. Fiber is an important part of the diet, which lowers serum cholesterol levels, the risk of coronary heart disease, hypertension, diabetes, colon, and breast cancer8. Eventually, in the studied segments it is necessary to trace the profile (soluble and insoluble) of the fibers, in order to guarantee a basis for specialized indication. However, based on the assumption that the fiber recommendation is in the range of 20-30g/day[33], based on this study, the consumption of 100g of husk powder would reach 100% of the recommendations, while fresh and roasted seed powders would cover 90 and 70%, respectively, considering the minimum recommendation of 20g/day.

The carbohydrate content found was also highlighted for the THP that presented higher (Table 1) and significant ($p<0.05$) (Table 2) values in relation to the roasted and fresh seed powders (Table 2). Analyzing the findings on the proximate composition of tamarind seeds, it is possible to observe analogies regarding the glycolytic fraction in several studies[21,22,28] which are close to those found in this study. Regarding THP, it is observed that the values were lower when compared to non-traditional powders, such as powder from the passion fruit husk according to the study by Cazarin et al. (2014)[24], which obtained 79.39g.100g^{-1}. Likewise, the values of 83.31g.100g^{-1} seen by Medeiros *et al.* (2010)[34] with green banana powder. Relating the values analyzed with habitual and traditional powders, such as wheat, corn, and manioc, which presented 75.1g, 79.1g, and 81g of carbohydrates, respectively, according to the Brazilian Food Composition Table[35], husk and seed powder have comparatively less content.

Thus, in dietary regimes with low glycolytic content, the powders studied appear as alternatives. On the other hand, the high energy percentage observed in the seeds is mainly due to the higher protein and lipid content in the seeds compared to the husk, which is fundamentally a source of carbohydrates, as well as due the thermal process that possibly concentrated the nutrients.

The ash content represents the mineral mass, and it is possible to assign some indication. However, this study did not propose to evaluate these elements individually, which is the reason for more trials. As for seeds, similarly, the study by Mohamed, Mohamed, and Ahmed (2015)21, working with light and dark seeds, found values of 2.5 and 2.17g, respectively, of mineral material, approaching the results of this study. However, most studies[22,28,32] with the same proposal for centesimal composition analysis, found values that exceeded the total inorganic mass observed in this work.

According to Okello *et al.* (2017)[6], one of the factors that contributes to the retention of minerals is the high rainfall. The Northeast region where the study was carried out, comprises the Caatinga, a biome with low rainfall, an explanation for the low ash content compared to other studies, and, furthermore, the genetic variability of the studied variety.

Regarding the phenolic compounds, it is evident that the seed powders have a higher content compared to the husk powder. An additional fact is that the thermal processing of the seed powder does not decrease the phenol content, on the contrary, it promoted a significant increase in comparison to the others. One explanation may lie in the fact that the phenolic compounds present in the seed powder have considerable thermostability. Another arguable point that is sustained would be due to the loss of water and the consequent concentration of the compounds, as explained by Dutra et al. (2012)[36].

In terms of quantity, the phenolic values found are different from Ferreira's study (2018)[37], who found values of 7.4 (mg EGAg^{-1}) for powder from tamarind husk and 40.36 (mg EGAg^{-1}) for seed powder. Another Brazilian study, carried out in the southeastern region, found values of 49.3

(mg EGA g^{-1}) for tamarind seeds, however, it worked with an ethanol extract. In Malaysia, Razali *et al.* (2015)[14] found a much higher value in tamarind seed powder compared to Brazilian studies, with values of 271.23 (mg EGAg^{-1}). Notably, there are divergences in the studies, making it difficult to suggest phenolic values in tamarind residues. It remains, therefore, to consider phenolic compounds as components highly influenced by factors such as fruit variety, climatic conditions, genetic factors, among others, as explained by Sartori, Costa, and Ribeiro (2014)[38], and which could justify the variations between this and other studies. It is reiterated that regardless of the variations observed and the extraction methods, the presence of phenolic compounds in the husks and seeds is verified, which adds nutritional value and the possibility of biological activity for human consumption.

With regards to tannins, these components were similar for the three types of powder. Quantitatively, these data are similar with the study by Ferreira (2018)[37] for husk powder that obtained values of 3.3 (g 100g^{-1}), a value close to that of this study. However, for seed powder, Ferreira (2018)[37] found higher values. Other studies have also found high values in seed powder[39,40].

On the other hand, the use of tannins as adjuvants in the treatment of cardiovascular diseases, cancer, and diseases such as Alzheimer's and Parkinson's disease has been ruled[44]. In view of the differences in therapeutic considerations in virtue of the studies, further research is necessary in order to determine the nutritional value, such as the therapeutic quantity and dose. In addition, for food purposes, reducing the content to less astringent or acceptable levels is also worth mentioning. According to the studies, the powders still have content, suggesting adjustments in the formulation. However, it appears that the content found is inferior to that of other foods, such as wines, foods with pronounced tannin content and therefore bringing a margin of safety to the powders.

Regarding antioxidant activity, the data reveal that all powders had a high inhibitory capacity, suggesting protection against free radicals. These results agree with Ferreira's study (2018)[37], who found antioxidant capacity values greater than 90% and, like this study, found no significant differences between different types of powder. On the other hand, Luzia and Jorge (2011)[42], working with tamarind seeds from southeastern Brazil, found an antioxidant capacity of 75.93%, which was less than the findings of this study.

It is important to mention that the inhibition time must be considered for antioxidant activity. As it was noted, for THP the maximum inhibitory capacity occurred in 50 min, in comparison the seed powder had a shorter time, especially FSP. One explanation may be the presence of phenolic compounds in greater quantity in seed powders since they have antioxidant activity[38]. According to what was observed, it is possible to incorporate tamarind residues as foods with nutritional value and protective capacity, which corroborates the research by Natukunda, Muyonga, and Mukisa (2016)[43], incorporating powder from the tamarind seed in enriched biscuits and mango juice increasing the antioxidant capacity of these foods.

CONCLUSION

Tamarind residues in the form of powder concentrate an important content of nutrients, especially proteins and fibers as constituents of seeds, and fibers as constituents of husks. In addition, phenolic compounds were found, and a high antioxidant capacity of the powders studied was observed.

For the Northeast region, particularly the semiarid region, this study, in addition to clarifying and supporting the indication of tamarind residues, opens space for a socioeconomic issue aimed at the full utilization of residues in the context of population income and material for industries.

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