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Chemical composition and ruminal degradability of tucumã (*Astrocaryum aculeatum* Meyer) peel as a by-product in ruminant feeding

[*Composição química e degradabilidade ruminal da casca de tucumã* (Astrocaryum aculeatum *Meyer) como subproduto na alimentação de ruminantes*]

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ABSTRACT

This study evaluated the chemical composition and ruminal degradability of tucumã peel (*Astrocaryum* aculeatum), aiming at its use in ruminant feeding. Bromatological analyses revealed a high content of neutral detergent fiber (70.4%) and ether extract (10.5%), along with a low level of non-fibrous carbohydrates (3.2%), characteristics typical of forage-type feedstuffs. The indigestible carbohydrate fraction (C) was predominant (81.6%), while the potentially degradable fraction (B2) was very low (0.4%). Regarding protein, a high proportion of non-protein nitrogen (81.4%) was observed, which is important for microbial fermentation. Ruminal degradability parameters of dry matter, crude protein, and NDF indicated low potential degradability, reinforcing the limited digestibility of the residue. Nonetheless, tucumã peel shows potential as an alternative fiber source, especially during forage shortage periods or in systems focused on sustainability and the valorization of regional co-products. Its inclusion must be technically supported, considering its nutritional constraints. Further studies are recommended to evaluate its impact on voluntary intake, performance, and ruminal fermentation in different ruminant categories.

Keywords: Amazon, *Astrocaryum aculeatum*, digestibility, fiber, ruminant nutrition

RESUMO

Este estudo avaliou a composição química e a degradabilidade ruminal da casca de tucumã (Astrocaryum aculeatum), *visando a seu aproveitamento na alimentação de ruminantes. As análises bromatológicas revelaram alto teor de fibra em detergente neutro (70,4%) e extrato etéreo (10,5%), além de baixo conteúdo de carboidratos não fibrosos (3,2%), características compatíveis com alimentos do tipo volumoso. A fração C (indigestível) foi predominante (81,6%) nos carboidratos, enquanto a fração B2 (potencialmente degradável) foi muito baixa (0,4%). Quanto às proteínas, observou-se elevada proporção de nitrogênio não proteico (81,4%), relevante para a fermentação microbiana. Os parâmetros de degradabilidade ruminal da matéria seca, proteína bruta e FDN indicaram baixos valores de degradabilidade potencial, reforçando a limitada digestibilidade do resíduo. Ainda assim, a casca de tucumã apresenta potencial como fonte alternativa de fibra, especialmente em épocas de escassez de forragem ou em sistemas que priorizam sustentabilidade e valorização de coprodutos regionais. O uso deve ser tecnicamente planejado, respeitando seus limites nutricionais. Estudos complementares são recomendados para avaliar o impacto sobre consumo voluntário, desempenho e fermentação ruminal em diferentes categorias de ruminantes.*

Palavras-chave: Amazônia, Astrocaryum aculeatum, *digestibilidade, fibra, nutrição de ruminantes*

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INTRODUCTION

The Amazon region is globally renowned for its extraordinary biodiversity, harboring a flora that includes approximately 200 to 250 species traditionally used by local populations for food and other purposes (Nascimento, 2010). Within this vast diversity, native Amazonian palms are particularly noteworthy, as they possess high potential for applications in the cosmetics, essential oils, pharmaceuticals, and food industries (Clement *et al*., 2005; Silva *et al*., 2023; Chaves *et al*., 2024).

Among these palms, tucumã stands out as a tropical species of the Arecaceae family, widely distributed throughout the Amazon rainforest, with the fruit being its most valuable resource (Clement *et al*., 2005; Miller *et al*., 2013). Two main species are recognized: *Astrocaryum aculeatum* Meyer, found mainly in Rondônia, Roraima, Acre, and Amazonas, often in dense forests and floodplains; and *Astrocaryum vulgare* Mart, common in Pará, Maranhão, and Amapá, better adapted to anthropized and savanna-like environments (Nascimento, 2010).

The nutritional profile of tucumã highlights its potential for innovative uses. The fruit is rich in calories, fiber, provitamin A (carotene), and lipids, making it a promising energy source for domestic animal feed (Yuyama *et al*., 2008; Miller *et al*., 2013). Its composition includes high levels of ether extract (12.66% DM) and crude protein (10% DM) (Silva *et al*., 2023; Chaves *et al*., 2024). The lipid fraction is dominated by polyunsaturated fatty acids, such as oleic acid (46–58%), linoleic acid (3–26%), and linolenic acid (0.9–5%), alongside saturated fatty acids like palmitic (13–29%) and stearic (3–9%) (Ferreira *et al*., 2008). These characteristics make tucumã-derived oils not only valuable for human consumption but also for animal nutrition, where they can help reduce enteric methane emissions and improve the fatty acid profile of animal products (Silva *et al*., 2023; Chaves *et al*., 2024; Inô *et al*., 2025).

In addition to the fruit itself, tucumã by-products, such as kernels and agro-industrial residues, represent strategic resources in the context of sustainable livestock production. Their use can reduce dependence on conventional inputs, lower production costs, and add value to regional resources (Inô *et al*., 2025). Importantly, investigating their application in ruminant feeding is innovative, as it combines nutritional potential with environmental and economic benefits, offering an unprecedented alternative for integrating regional biodiversity into animal production systems (Rufino *et al*., 2015; Inô *et al*., 2025). Therefore, the objective of this study was to evaluate the chemical composition and ruminal degradability of tucumã residue as a by-product for use in ruminant nutrition.

ETHICAL ASPECTS

The research was submitted to the *Ethics Committee on Animal Use* of the Federal Universityof Amazonas and approved under the number 23105.021263/2022-01.

MATERIAL AND METHODS

Tucumã peels were collected at the Adolpho Lisboa Market, located in the historic center of Manaus, Amazonas. The experiment was conducted in the Buffalo Farming Sector of the Experimental Farm of the Federal University of Amazonas, located at kilometer 922 of the BR-174 highway, in Manaus, Brazil. The chemical analyses were carried out at the Forage and Pasture Laboratory, part of the Faculty of Agricultural Sciences of the Federal University of Amazonas.

The peels were pre-dried in a forced-air oven at 55 °C for 72 hours, ground using a 2 mm sieve, and placed in non-woven fabric (NWF, 100 g/m²) bags containing approximately 2.0 g of dry matter (DM) per bag, ensuring a density of approximately 20 mg/cm² of surface area. The chemical composition of tucumã peel was determined through analyses of DM, following the INCT-CA method no. G-003/1; mineral matter (MM), according to INCT-CA method no. M-001/1; and organic matter (OM), calculated by difference (OM = 100 – MM). CP was analyzed using the Kjeldahl method (INCT-CA no. N-001/1), and EE was determined following the INCT-CA method no. G-004/1. All analyses followed the procedures described by AOAC (Official…, 2019) in triplicate.

Neutral detergent fiber (NDF) was determined according to Van Soest *et al*. (1991), with the addition of thermostable α-amylase (Mertens, 2002; Foster *et al*., 2023) and the use of an autoclave (Senger *et al*., 2008). The NDF residue was incinerated in a muffle furnace at 600 °C for four hours to correct for ash content (aNDF). To correct for the protein content in NDF, insoluble protein in NDF (NDIP) was subtracted, following the methods described by Licitra *et al*. (1996), Mertens (2002) and Foster *et al*. (2023). Total carbohydrates (TC) were calculated using the equation: TC = 100 - (%CP + %EE + %MM).

The carbohydrate fraction was defined according to the equations proposed by Wei *et al*. (2021). Total carbohydrates (TC) were calculated using the formula: TC = 100 - (%CP + %EE + %ash). Fibrous carbohydrates (FC) corresponded to the NDF corrected for ash and protein (aNDFcp), while non-fibrous carbohydrates (NFC) were obtained by subtracting aNDFcp from TC. Fraction C was determined as the portion of indigestible NDF after 144 hours of in situ incubation, as described by Cabral *et al*. (2004), and fraction B2 was calculated as the difference between aNDFcp and fraction C.

CP, neutral detergent insoluble nitrogen (NDIN), and acid detergent insoluble nitrogen (ADIN) were determined according to the procedures described by AOAC (Official…, 2019). Nitrogen fractions were calculated as follows: fraction A, corresponding to non-protein nitrogen, was obtained by subtracting the residual nitrogen (Nr) from the total nitrogen content (Nt); fractions B1 + B2 were calculated by the difference between Nr and NDIN; fraction B3 was determined by subtracting ADIN from NDIN; and fraction C was equal to the value of ADIN. In this context, Nt refers to the total nitrogen content, Nr corresponds to the nitrogen insoluble after treatment with trichloroacetic acid (TCA), and NDIN and ADIN are as defined above.

The nitrogen insoluble in TCA was obtained by adding 50mL of distilled water to 0.5 g of sample, allowing it to stand for 30 minutes, followed by the addition of 10 mL of 10% trichloroacetic acid (TCA) and resting for an additional 20 to 30 minutes. After this period, the content was filtered through filter paper and washed with 50 mL of diluted TCA (1%). The retained residue was analyzed using the macro Kjeldahl method, according to AOAC (Official…, 2019).

For the evaluation of ruminal degradability, a male rumen-fistulated water buffalo (*Bubalus bubalis*) with an average body weight of 700 kg was used, under management approved by the Ethics Committee on Animal Use of the Federal University of Amazonas (protocol no. 1188623). The animal was fed BRS Capiaçu grass twice daily (8 a.m. and 4 p.m.) and had free access to mineral salt. The ruminal incubation times were: 0, 2, 4, 8, 12, 24, 48, 72, and 96 hours, as described by AFRC (1993). After removal, the bags were washed under running cold water until completely clean and then dried in a forced-air oven at 55 °C for 72 hours. The difference in weight before and after incubation was used to calculate DM degradability (DMD) and CP degradability (CPD), both expressed as a percentage.

Descriptive statistics were used to characterize the carbohydrate and protein fractions. To estimate the potential degradability of tucumã peel, the model proposed by Ørskov and McDonald (1979) was applied:

$$p = a + b(1 - e^{-ct})$$

where:
p = potential degradability,
a = soluble fraction,
b = potentially degradable fraction,
c = degradation rate of fraction
t = incubation time

Effective degradability (ED) was estimated based on the model proposed by the Agricultural Research Council (Nutrient…, 1984):

$$ED = \frac{\left(a + (bc)\right)}{c + k}$$

where k represents the ruminal passage rate, adopting values of 2, 5, and 8%/h, corresponding to low, medium, and high feed intake levels, respectively (AFRC, 1984).

RESULTS AND DISCUSSION

The use of agro-industrial residues in animal feeding represents a strategic alternative to enhance the sustainability of production systems, reduce pressure for the opening of new areas, and generate income (Clement *et al*., 2005;

Nascimento, 2010). Tucumã peel, although widely available in the Amazon region, is still underexplored in animal science studies (Silva *et al*., 2023; Chaves *et al*., 2024). Its bromatological composition is presented in Table 1.

Table 1. Bromatological analysis of tucumã (*Astrocaryum aculeatum*) peel

Variables	Chemical composition (%)
Dry matter	87.50
Crude Protein	10.10
Ether Extract	10.50
Neutral Detergent Fiber	70.40
aNDF[1]	60.00
Acid Detergent Fiber	48.30
Mineral content	5.80
Organic content	94.20
Total Carbohydrates	73.60
Non-Fibrous Carbohydrates	3.20
Hemicellulose	26.10
NDIN/Total Nitrogen[2]	1.61
ADIN/Total Nitrogen[3]	1.75

[1]aNDF: Neutral detergent fiber corrected for ash and protein.
[2]NDIN/Total Nitrogen: Neutral detergent insoluble nitrogen relative to total nitrogen.
[3]ADIN/Total Nitrogen: Acid detergent insoluble nitrogen relative to total nitrogen.

The peel showed a high content of NDF, 70.4%, a low content of NFC (3.2%), and a low hemicellulose content (26.1%). According to Góes *et al*. (2013), forages are characterized by low energy content and high levels of fiber or water. NDF, in turn, has a negative correlation with the energy value of the diet (Souza and Ribeiro, 2021), and the low NFC content in tucumã peel may limit the production of short-chain fatty acids (SCFA). According to Shen *et al*. (2023), NFC increases SCFA production and reduces ruminal ammonia concentration, improving energy efficiency and animal performance. Thus, tucumã peel can be classified as a forage, representing a potential fiber source for diet formulations, especially during periods of feed scarcity, and may even be used in pelleted rations.

Another noteworthy aspect is the high EE content of the peel, 10.5%, which is higher than that of several co-products used in ruminant feeding, such as rice bran (2.43%), babassu meal (0.24%), citrus pulp (3.23%), cocoa husk (4.68%), coffee husk (0.72%), and soybean hulls (1.57%) (Souza and Ribeiro, 2021). According to Ferreira *et al*. (2008), the EE of tucumã peel contains 68.77% unsaturated fatty acids (UFA), which, although toxic to ruminal microorganisms, are converted into saturated fatty acids through biohydrogenation (Palmquist and Mattos, 2006), thereby reducing their toxicity and potentially acting as a hydrogen sink, with the potential to mitigate methane emissions. Souza and Ribeiro (2021) emphasize that polyunsaturated fatty acids especially affect Gram-positive, methanogenic bacteria and protozoa.

The bromatological composition of the peel obtained in this study differs from previous results. Miller *et al*. (2013) reported values of 89.78% DM, 9.93% CP, 53.98% NDF, 38.63% acid detergent fiber (ADF), and 4.49% mineral matter (MM), while Frisso *et al*. (2017) found 51.3% DM, 11.19% CP, 51.3% NDF, 24.5% EE, and 4.5% MM. These variations may be attributed to the fruit species (two varieties exist in the Northern region) and the lack of standardization in the pulping process, which influences the amount of residual pulp adhered to the peel.

The carbohydrate and protein fractionation of tucumã peel is presented in Table 2 and allows inferences about its ruminal degradation dynamics. Fractions A+B1, B2, and C corresponded to 18%, 0.4%, and 81.6%, respectively. According to Villalba *et al*. (2021), A+B1 represents NFC, and B2+C represents FC. The low values for fraction A+B1 indicate that only 18% of the carbohydrates are rapidly degradable in the rumen, which limits the immediate energy availability for microorganisms (Santo *et al*., 2017). For comparison, Sun *et al*. (2025) observed values ranging from 15.4 to 23.2% of total carbohydrates in Tanzania grass (*Panicum maximum* cv. Tanzania).

Table 2. Carbohydrate and nitrogen compound fractionation of tucumã (*Astrocaryum aculeatum*) peel

Carbohydrate Fractions	% of Total Carbohydrates	Carbohydrates (g/kg DM)
A+B1	18	185
B2	0.40	4
C	81.60	811
Protein Fractions	**% of Crude Protein**	**Crude Protein (g/kg DM)**
Fraction A	81.40	813.90
Fraction B1+B2	15.22	152.20
Fraction B3	0.25	2.50
Fraction C	3.13	32.30

Fraction B2, which represents the potentially digestible fiber, showed a very low value (0.4%), while fraction C, corresponding to the indigestible portion, was predominant (81.6%), indicating low efficiency of ruminal utilization (Van Soest *et al.*, 1991). This composition suggests the possibility of reduced voluntary intake if the peel is included at high levels in the diet. Regarding the protein fraction, tucumã peel contained 81.4% non-protein nitrogen (NPN – fraction A), which is essential for microbial metabolism, especially during the fermentation of structural carbohydrates (Thers *et al*., 2021). Fraction B1+B2, corresponding to soluble true protein, was 15.22%, while fractions B3 and C, representing the less available portions, accounted for only 0.25% and 3.13%, respectively, indicating good potential for nitrogen release in the ruminal environment.

The ruminal degradation parameters of DM, CP, and NDF from tucumã peel are presented in Table 3. The observed values for potential degradability were low, similar to those reported by Geraseev *et al*. (2011) for elephant grass (52.97% DM; 71.52% CP; 43.44% NDF), supporting the classification of the peel as a forage-type feed.

Table 3. Ruminal degradation parameters of dry matter, crude protein, and neutral detergent fiber from tucumã (*Astrocaryum aculeatum*) peel

Deg.[1]	Variables[2]								
	PD	ED2%	ED4%	ED8%	a	B or Bp	I or Ip	c	R^2
DMD	42.50	33.14	28.46	26.46	21.45	21.05	57.50	0.025	99.78
CPD	28.22	17.83	13.37	9.90	3.83	24.39	71.78	0.027	49.27
NDFD	49.21	41.80	37.91	36.16	31.60	17.61	50.79	0.028	99.96

[1]DMD = Dry Matter Degradation. CPD = Crude Protein Degradation. NDFD = Neutral Detergent Fiber Degradation
[2]PD = Potential degradability (%). ED2%, ED4%, ED8% = Effective degradability at passage rates of 2%, 4%, and 8%/hour, respectively (%). a = Soluble fraction (%). B or BP = Potentially degradable insoluble fraction (%). I or IP = Undegradable fraction (%). c = Degradation rate of fraction B (%/h). R^2 = Coefficient of determination (%).

Frisso *et al*. (2017) reported effective degradability values of DM of 51.39%, 47.68%, and 45.44% for passage rates of 2, 4, and 6%/h, respectively, which were higher than those found in the present study. This difference is possibly related to a higher presence of endocarp, as evidenced by the higher EE content (24.5%). The low potential degradability of the peel is associated with reduced soluble (fraction "a") and degradable (fraction "b") components, reinforcing its low ruminal digestibility. Figure 1 presents the disappearance curves of DM, CP, and NDF from the peel after 96 hours of incubation.

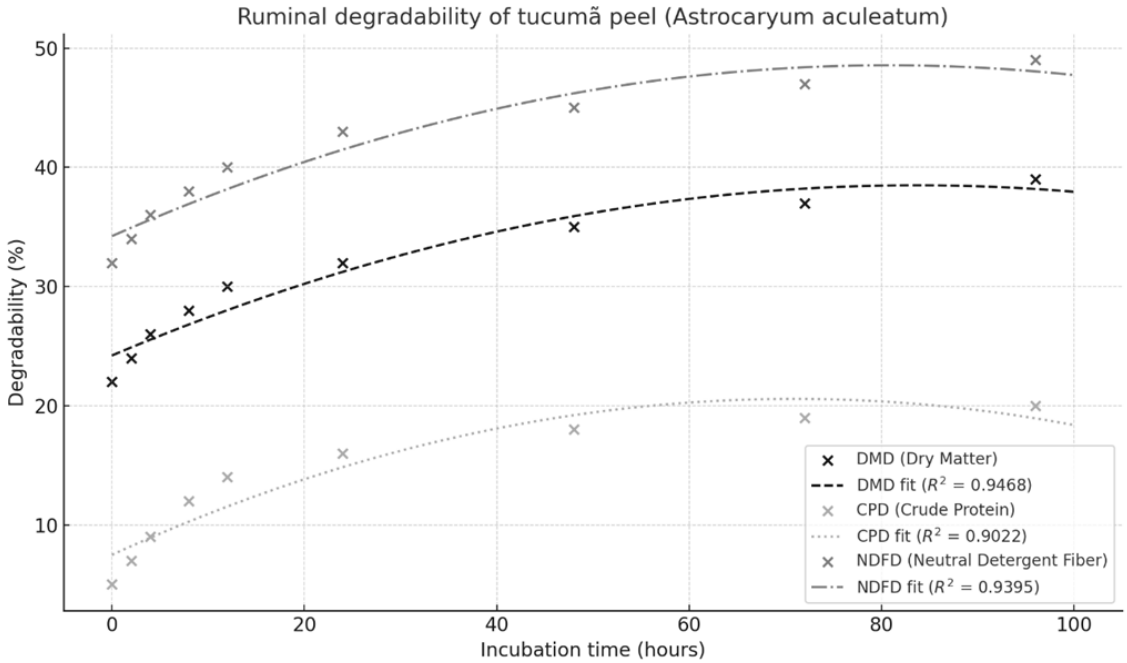


Figure 1. Degradability of tucumã (*Astrocaryum aculeatum*) peel for dry matter (DMD), crude protein (CPD), and neutral detergent fiber (NDFD) in the rumen.

According to Chen *et al*. (2022), fraction "a" consists of soluble compounds with rapid degradation; fraction "b" includes compounds such as starch and pectin, which degrade more slowly; and fraction "c" is composed of indigestible components such as highly lignified fibers. The low solubility of the peel's DM may be related to its high NDF and EE contents. According to Kozloski *et al*. (2014), high lipid levels reduce fiber digestibility through two mechanisms: (1) physical hindrance of microbial adhesion to the fiber and (2) the toxic effect of unsaturated fatty acids (UFA), which affect the integrity of ruminal microbial membranes and impair their fermentative activity.

CONCLUSIONS

Tucumã peel presents a bromatological composition compatible with feedstuffs classified as forages, standing out for its high NDF content and a significant level of EE, with a predominance of unsaturated fatty acids. Despite its low NFC content and high proportion of indigestible fraction (fraction C), its non-protein nitrogen content and soluble protein fraction suggest potential for nitrogen supply to the ruminal microbiota. The ruminal degradability of dry matter, crude protein, and NDF in the peel was considered low, reflecting the predominance of slow or non-degradable fractions. Nevertheless, its use as an alternative fiber source may be strategic, especially during forage shortage periods or in diets formulated with an emphasis on sustainability and the valorization of regional co-products. Thus, tucumã peel can be used as a fibrous ingredient in ruminant diets, provided its inclusion is technically supported and carefully managed, considering its nutritional limitations and fermentative characteristics. Further studies are recommended to assess its effects on voluntary intake, productive performance, and ruminal fermentation in different animal categories.

CONTRIBUTORS

K.N. Sá, F.J. Dias, H.H. Perdigão, L.P.A.A. Maciel, M.V. Maciel: study conception, objective, data analysis, discussion, manuscript writing, and approval of the version to be published.
T.J.N. Negreiros, M.M. Lopes: objective and data analysis, and approval of the version to be published.
D.B. Cardoso, J.P.F. Rufino: data analysis, discussion, manuscript writing, and approval of the version to be published.

DATA AVAILABILITY STATEMENT

The research data are available in the repository tede.ufam.edu.br/handle/tede/9884.

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