

Chemical characteristics, degradation kinetics and gas production of arboreal species for ruminants¹

Características químicas, cinética de degradação e produção de gases de espécies arbóreas para ruminantes

Leandro Pereira de Oliveira^{2*}, André Luiz Rodrigues Magalhães³, Ana Lúcia Teodoro⁴, Albericio Pereira de Andrade³, Kelly Cristina dos Santos⁵ and Gherman Garcia Leal de Araújo⁶

ABSTRACT - The breeding systems of the small ruminants are extensive in the great majority, in which the animals are created in areas of native pasture named Caatinga, being necessary the knowledge on the chemical composition and its characteristics of feed degradation is crucial to increase nutrient use efficiency. Thereat, the objective of this study was to evaluate the chemical composition, the minerals, the carbohydrates and nitrogenous compounds fractionation, the degradability, *in vitro* dry matter digestibility and the *in vitro* gas production of arboreal species, those are consumed by goats and sheep. The species evaluated were *Cnidocolus phyllacanthus* (Muell. Arg.) Pax. et K. Hoffman, *Mimosa tenuiflora* (Willd.) Poirer, *Myracrodruon urundeuva* Fr. All., *Poincianella bracteosa* (Tul.) L. P. Queiroz, *Spondias tuberosa* Arr. Cam. and *Ziziphus joazeiro* Mart. It was found that *Mimosa tenuiflora* has a higher crude protein quantity (174.9 g.kg⁻¹ DM). *Spondias tuberosa* and *Myracrodruon urundeuva* had the highest values for total carbohydrates compared to the other species analyzed. As for the fractionation of nitrogenous compounds, the highest proportion of fraction A was found for *Cnidocolus phyllacanthus* (375.5 g.kg⁻¹ CP). Among the species studied, *Cnidocolus phyllacanthus* is highlighted with the highest ruminal degradation (61.63%) and dry matter digestibility (627.1 g.kg⁻¹ DM), reflecting higher gas production (206.02 mL.g⁻¹ DM). *Cnidocolus phyllacanthus*, *Poincianella bracteosa* and *Myracrodruon urundeuva* showed a greater availability of nutrients in the rumen which is fundamental to increase the amount of ruminal microbial protein which reaches the small intestine for use by the animal.

Key words: Goats. Native pasture. Semi-arid. Sheep.

RESUMO - Os sistemas de criação dos pequenos ruminantes são extensivos na grande maioria, em que os animais são criados em áreas de pastagem nativa denominada Caatinga, sendo necessário o conhecimento da composição química e suas características de degradação alimentar para aumentar a eficiência do uso de nutrientes. Com isso, objetivou-se avaliar a composição química, os minerais, o fracionamento dos carboidratos e dos compostos nitrogenados, a degradabilidade, a digestibilidade *in vitro* da matéria seca e a produção de gás *in vitro* de espécies arbóreas, que são consumidas por caprinos e ovinos. As espécies avaliadas foram *Cnidocolus phyllacanthus* (Muell. Arg.) Pax. e K. Hoffman, *Mimosa tenuiflora* (Willd.) Poirer, *Myracrodruon urundeuva* Fr. All., *Poincianella bracteosa* (Tul.) L.P. Queiroz, *Spondias tuberosa* Arr. Cam. e *Ziziphus joazeiro* Mart. Verificou-se que *Mimosa tenuiflora* possui uma maior quantidade de proteína bruta (174,9 g.kg⁻¹ MS). *Spondias tuberosa* e *Myracrodruon urundeuva* apresentaram os maiores valores de carboidratos totais em comparação com as demais espécies analisadas. Quanto ao fracionamento de compostos nitrogenados, a maior proporção da fração A foi encontrada para *Cnidocolus phyllacanthus* (375,5 g.kg⁻¹ PB). Entre as espécies estudadas, *Cnidocolus phyllacanthus* é destacado com maior degradação ruminal (61,63 %) e digestibilidade da matéria seca (627,1 g.kg⁻¹ MS), refletindo uma maior produção de gás (206,02 mL.g⁻¹ MS). *Cnidocolus phyllacanthus*, *Poincianella bracteosa* e *Myracrodruon urundeuva* apresentaram maior disponibilidade de nutrientes no rúmen, o que é fundamental para o aumento potencial da quantidade de proteína microbiana ruminal que chega ao intestino delgado para ser utilizada pelo animal.

Palavras-chave: Caprinos. Pastagem nativa. Semiárido. Ovinos.

DOI: 10.5935/1806-6690.20200047

*Author for correspondence

Received for publication 24/04/2019; approved on 16/04/2020

¹Pesquisa financiada pela Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) e Banco do Nordeste do Brasil (BNB)

²Departamento de Zootecnia, Centro de Ciências Agrárias, Universidade Federal da Paraíba/UFPA, Rodovia BR 079 - Km 12, Areia-PB, Brasil, 58.397-000, leandrop.zootecnista@gmail.com (ORCID ID 0000-0002-3014-0915)

³Departamento de Zootecnia, Universidade Federal do Agreste de Pernambuco/UFPE, Garanhuns-PE, Brasil, andre30036@gmail.com (ORCID ID 0000-0003-2211-6795), albericio3@gmail.com (ORCID ID 0000-0002-1223-394X)

⁴Instituto Federal de Educação, Ciência e Tecnologia do Piauí, Paulistana-PI, Brasil, analuciatzoo@gmail.com (ORCID ID 0000-0002-2752-6737),

⁵Programa de Pós-Graduação em Zootecnia, Departamento de Zootecnia, Universidade Federal Rural de Pernambuco/UFRPE, Recife-PE, Brasil, kelly_venturosa@hotmail.com (ORCID ID 0000-0002-3704-1936)

⁶Empresa Brasileira de Pesquisa Agropecuária, Embrapa Semiárido, Petrolina-PE, Brasil, gherman.araujo@embrapa.br (ORCID ID 0000-0001-9605-1096)

INTRODUCTION

Brazilian Northeast has the largest national herd of goats and sheep (IBGE, 2017), specifically in Semi-arid region. The breeding systems of these animals are extensive in the great majority, in which the animals are created in areas of native pasture named Caatinga. This biome presents a great diversity of forage species and participates in about 70 % in the feeding of these animals, so that the dry period is prolonged, the contribution tends to increase due to the availability of dry leaves (NUNES *et al.*, 2016).

The diet of small ruminants in the Brazilian Semi-arid region is often based on the grazing of Caatinga native plants, which are the only sources of protein and energy for those animals. Given its botanical diversity, management practices should be adopted to ensure the preservation of the vegetation, which, according to Souza *et al.* (2013) makes the knowledge of quantitative and qualitative parameters necessary.

The knowledge on the chemical composition and its characteristics of feed degradation is crucial to increase nutrient use efficiency. As feed quality depends on its constituents, the nutritional evaluation of forages produced in Caatinga with a potential for feeding small ruminants is essential to increase the efficiency of the livestock in that region. The use of values presented in foreign tables of feed composition for diets formulation is common in the Brazilian Northeast region.

However, not all characteristics of feed available in the region are known. Studies on Caatinga arboreal species discussed the potential of these plants regarding its composition, especially crude protein content. However, it is important to note that such nutrients are complexed with the plant cell walls and secondary compounds, making them unavailable to animals (SANTANA *et al.*, 2011). Thus, this study aimed to evaluate the chemical characteristics, minerals, carbohydrates and nitrogenous compounds fractionation, degradability and *in vitro* digestibility of dry matter and the *in vitro* gas production of the browse species from Brazilian Semi-arid region.

MATERIAL AND METHODS

The samples were collected in the Caatinga area owned by the Embrapa Semi-arid Company located in the city of Petrolina, Pernambuco (PE), Brazil (9°09' S, 40°22' W, at 365.5 meters of altitude). The climate is classified, according to Köppen, as BSwH' (tropical semi-arid, hot and dry). Rainfall in the year of collection was 287.4 mm. The evaluated species were *Cnidoscolus phyllacanthus* (Muell. Arg.) Pax. et K. Hoffman, *Mimosa*

tenuiflora (Willd.) Poiret, *Myracrodruon urundeuva* Fr. All., *Poincianella bracteosa* (Tul.) L.P. Queiroz, *Spondias tuberosa* Arr. Cam. and *Ziziphus joazeiro* Mart. All species were evaluated *in natura*, and all in vegetative phenological stage with completely expanded leaves, shredded and processed for further analysis.

Four plant samples of every species were collected at random. The species have expanded and compound leaves, with the exception of *Cnidoscolus phyllacanthus*, which has simple leaves. The branches collected had a maximum diameter of eight millimeters, because the animals do not consume branches with larger diameter. Then, all analyses were performed at the Animal Nutrition Laboratory of Federal University of Agreste of Pernambuco (UFAPE), former Academic Unit of Garanhuns (UAG). Chemical composition analyses – dry matter (DM) (930.15), organic matter (OM) (942.05), ash (942.05), crude protein (CP) (954.01) and ether extract (EE) (Sohxlet) (920.39) - were performed according to the methodology described by the Association of Official Analytical Chemists (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1990). Neutral detergent fiber (NDF), acid detergent fiber (ADF) and NDF corrected for ash and protein (NDF_{ap}) were determined according to Van Soest (1963a) with modifications proposed by Senger *et al.* (2008). To determine lignin digested in acid (LDA), the methodology proposed by Van Soest (1963b) was used. The cellulose fraction (CEL) was estimated by the equation $CEL = ADF - LDA$. The determination of the minerals being the macronutrients - Potassium (K), Calcium (Ca), Magnesium (Mg), Phosphorus (P), Sulfur (S) and micronutrients: Boron (B), Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn), were determined by nitric-perchloric digestion according to Malavolta, Vitti and Oliveira (1997).

Total carbohydrates (TC) were calculated according to Sniffen *et al.* (1992), where $TC = 100 - (CP + EE + Ash)$, and fractionated in A+B1, B2 and C, being the nonfibrous carbohydrates (NFC), corresponding to the fractions A+B1, by the difference between TC and NDF_{ap}. The fraction C represented by the indigestible NDF was obtained according to Valente *et al.* (2011). The fraction B2, was obtained by the difference between NDF_{ap} and the C fraction. For the fractioning of nitrogenous compounds, the non-protein nitrogen (fraction A), the neutral detergent insoluble nitrogen (NDIN) and the acid detergent insoluble nitrogen (ADIN) were estimated according to the methodology described by Licitra, Hernandez and Van Soest (1996). The fraction B1+B2 was obtained by means of the equation: $B1+B2 = 100 - (A + B3 + C)$, while fraction B3 was obtained by the difference between NDIN and ADIN and fraction C considered as ADIN.

The *in vitro* dry matter degradability was determined according to the first stage of the Tilley and Terry (1963) method. Samples (milled in sieve of 2 mm) were incubated at 0, 3, 6, 9, 12, 18, 24, 36 and 48 hours at 39 °C. To estimate the parameters *a*, *b* and *c*, the model proposed by Ørskov and McDonald (1979) was used and processed by the PROC NLIN procedure of the SAS® statistical software, once the parameters *a*, *b*, and *c* were calculated, they were applied to the equation (ØRSKOV; McDONALD, 1979). The analysis of *in vitro* dry matter digestibility (IVDMD) was conducted according to Tilley and Terry (1963), with the modifications proposed by Holden (1999).

The *in vitro* gas production using technique a pressure transducer was used as proposed by Theodorou *et al.* (1994). The cumulative gas production was estimated by measuring the pressure of the gases produced during the fermentation process using a pressure transducer (LOGGER AG100 - Agricer) and graduated syringes for gas volume at 2, 4, 6, 8, 10, 12, 15, 18, 21, 24, 30, 36, 42 and 48 hours after incubation. Using pressure and volume data, an equation was generated, ($y = 5.1612x - 0.3017$), $R^2 = 0.9873$, where the pressure (psi) and the gas volume (mL) were related by the PROC REG of SAS® from 937 observations. In the equation developed at the Laboratory of Gas Production (-8°90'77" S, -36°49'49" W, altitude of 844 meters), it was observed that one psi = 4.859 mL of gases. From the equation, data (in psi) reported for volume of gas produced during incubation were used. To determine the parameters, the bicompartamental logistic model was used Schofield, Pitt and Pell (1994) with the aid of the PROC NLMIXED of SAS®. All incubations were used 1.0g of sample in each jar of glass (160 mL), and the ruminal fluid was taken from goats fed a balanced diet with *Pennisetum purpureum* and concentrate (80:20).

The treatments were arranged in a completely randomized design with ten replications ($Y_{ij} = \mu + \tau_i + e_{ij}$; Y_{ij} – observation *j*, submitted to treatment *i*; μ – general constant; τ_i – effect of treatment *i*; e_{ij} – random error associated with each observation). The data obtained from chemical analyses, fractionation of carbohydrates, nitrogenous compounds and IVDMD were submitted to analysis of variance using the PROC GLM procedure, and the means were compared by Tukey test at 0.05 significance level using the SAS® statistical software.

RESULTS AND DISCUSSION

The highest DM values found were 528.5 g.kg⁻¹ of natural matter (NM) for *Poincianella bracteosa*, followed by *Mimosa tenuiflora* and *Ziziphus joazeiro*, and the lowest value was found for *Spondias tuberosa* (297.4 g.kg⁻¹ NM)

and *Cnidocolus phyllacanthus* (270.1 g.kg⁻¹ NM) (Table 1). The highest DM values obtained for *P. bracteosa*, *Z. joazeiro* and *M. tenuiflora* can be explained by the different morphological characteristics of these forages. The highest concentration of ash was observed for *Z. joazeiro* (83.7 g.kg⁻¹ DM) and the lowest concentration was observed for *P. bracteosa* (45.4 g.kg⁻¹ DM). *M. tenuiflora* showed the highest ether extract (EE) content among species (79.4 g.kg⁻¹ DM) and *Z. joazeiro* presented the lowest quantity of EE (10.4 g.kg⁻¹ DM).

The highest concentrations of neutral detergent fiber corrected for ash and protein (NDFap) were 520.8 and 485.9 g.kg⁻¹ DM for *S. tuberosa* and *Z. joazeiro*, respectively, and the lowest concentration was 361.3 g.kg⁻¹ DM for *M. urundeuva*. For ADF, there was variation from 416.7 g.kg⁻¹ DM for *S. tuberosa* to 231.2 g.kg⁻¹ DM for *M. tenuiflora* (Table 1). The cellulose (CEL) concentration was the highest in *P. bracteosa* (307.5 g.kg⁻¹ DM) followed by *C. phyllacanthus* (227.3 g.kg⁻¹ DM) and *S. tuberosa* (210.9 g.kg⁻¹ DM), and the lowest concentration was observed for *M. tenuiflora* (117.0 g.kg⁻¹ DM). The highest concentration of LDA was observed for *S. tuberosa* (205.8 g.kg⁻¹ DM) and lowest concentration for *P. bracteosa* (85.5 g.kg⁻¹ DM) (Table 1).

For non-fibrous carbohydrates (NFC), *M. urundeuva* showed the highest concentration in its composition, 451.7 g.kg⁻¹ DM, followed by *P. bracteosa* (368.9) and *S. tuberosa* (314.3). The content of fibrous components presented in this study are similar to the values found by Neves *et al.* (2014) and Nunes *et al.* (2016). Part of the energy used by the ruminal microflora is obtained from the fermentation of dietary carbohydrates, which are converted into short-chain fatty acids (SCFA), glucose precursors and fatty acids (OWENS; BASSALAN, 2016).

The levels of minerals present in the evaluated species presented a difference, except for potassium (K) (Table 2). The highest amount of phosphorus (P) was observed in *P. bracteosa*, with 1.51 g.kg⁻¹ DM and the lowest in *S. tuberosa* with 0.83 g.kg⁻¹ DM. Calcium (Ca) found in *Z. joazeiro* was 22.18 g.kg⁻¹ DM and 2.35 g.kg⁻¹ in *M. tenuiflora*. The presence of sulfur (S) was higher in *Z. joazeiro* (2.22 g.kg⁻¹ DM). The iron content (Fe) observed in the species ranged from 78.5 to 142.05 mg.kg⁻¹ DM, with a higher concentration found in *C. phyllacanthus* and lower in *M. urundeuva*.

The quantity of total carbohydrates (TC) was observed in the composition of *S. tuberosa* (835.1 g.kg⁻¹ DM), followed by *M. urundeuva* (813.0 g.kg⁻¹ DM) and the lowest concentration was observed for *M. tenuiflora* (690.2) (Table 3). The highest concentration of TC presented by *S. tuberosa* does not mean more energy,

approximately 55% of the TC are not digestible (fraction C), in contrast, 70% of the TC of *M. urundeuva* can be degraded. Regarding the fractionation of carbohydrates (Table 3), the highest value for the fraction A+B1, corresponding to carbohydrates with a fast degradation rate, was obtained for *M. urundeuva* (555.6 g.kg⁻¹ TC) followed by *P. bracteosa* (474.6). The lowest values were observed for *S. tuberosa* (376.6) and *Z. joazeiro* (356.6). *C. phyllacanthus*, *Z. joazeiro*, *M. urundeuva* and *P. bracteosa* showed a higher fraction B2 of TC (166.9; 152.4; 149.5 and 132.6 g.kg⁻¹ TC, respectively) (Table 3).

Species with a higher proportion of the fraction B2, i.e., potentially digestible fibers, better support the growth of microorganisms that use fibrous

carbohydrates. Moreover, as the fiber undergoes a slow degradation, the use of protein sources with a slow degradation in the rumen is also appropriate because it allows a better synchronization between carbohydrates and proteins for a maximum efficiency of microbial protein synthesis and promotes a decrease in energy and nitrogen losses resulting from ruminal fermentation (LICITRA; HERNANDEZ; Van SOEST, 1996). *S. tuberosa* participated the most in the fraction C of TC, confirmed by the larger amount of lignin found in that forage. Pereira *et al.* (2010) performed the fractioning of the TC of *Z. joazeiro*, in vegetative phenological stage, and found 309.1 g.kg⁻¹ TC (A+B1), 284.5 g.kg⁻¹ TC (B2) and 406.3 g.kg⁻¹ TC (C), values close to those observed in this study.

Table 1 - Mean of dry matter (DM), ash, organic matter (OM), ether extract (EE), neutral detergent fiber (NDF), NDF corrected for ash and protein (NDF_{ap}), acid detergent fiber (ADF), cellulose (CEL), lignin digested in acid (LDA), neutral detergent insoluble protein (NDIP), acid detergent insoluble protein (ADIP), non-fibrous carbohydrates (NFC) and standard error median (SEM) of arboreal species

Species	Variable			
	DM ^{1**}	Ash ^{2**}	OM ^{2**}	EE ^{2**}
<i>Cnidoscolus phyllacanthus</i>	270.1 ± 15.4 c	64.3 ± 9.4 ab	935.7 ± 9.4 ab	40.7 ± 5.6 b
<i>Mimosa tenuiflora</i>	499.6 ± 19.9 ab	55.0 ± 8.6 b	945.0 ± 8.6 a	79.9 ± 5.5 a
<i>Myracrodruon urundeuva</i>	455.2 ± 7.3 b	45.5 ± 1.4 b	954.5 ± 1.4 a	30.5 ± 6.9 bc
<i>Poincianella bracteosa</i>	528.5 ± 2.8 a	45.4 ± 2.8 b	954.6 ± 2.8 a	32.3 ± 6.1 bc
<i>Spondias tuberosa</i>	297.9 ± 2.4 c	54.0 ± 2.8 b	946.0 ± 2.8 a	19.0 ± 7.4 cd
<i>Ziziphus joazeiro</i>	484.0 ± 20.4 ab	83.7 ± 10.2 a	916.3 ± 10.2 b	10.4 ± 2.6 d
SEM	21.95	3.38	3.38	4.52
	NDF ^{2**}	NDF _{ap} ^{2**}	ADF ^{2**}	CEL ^{2**}
<i>Cnidoscolus phyllacanthus</i>	461.7 ± 42.9 b	448.0 ± 35.5 bc	355.8 ± 29.6 b	227.3 ± 18.7 b
<i>Mimosa tenuiflora</i>	485.0 ± 69.1 b	424.6 ± 19.0 bcd	231.2 ± 7.4 c	117.0 ± 4.1 d
<i>Myracrodruon urundeuva</i>	393.5 ± 10.1 c	361.3 ± 6.6 d	283.9 ± 11.6 c	186.4 ± 11.5 bc
<i>Poincianella bracteosa</i>	446.6 ± 19.9b c	408.5 ± 15.1 cd	393.0 ± 12.8 ab	307.5 ± 18.3 a
<i>Spondias tuberosa</i>	571.9 ± 19.4 a	520.8 ± 20.0 a	416.7 ± 12.0 a	210.9 ± 13.9 bc
<i>Ziziphus joazeiro</i>	552.9 ± 9.9 a	485.9 ± 7.3 a	284.6 ± 17.4 c	175.8 ± 14.1 c
SEM	14.36	12.37	14.44	12.51
	LDA ^{2**}	NDIP ^{3**}	ADIP ^{3**}	NFC ^{2**}
<i>Cnidoscolus phyllacanthus</i>	128.5 ± 18.2 b	190.9 ± 34.5 c	153.2 ± 24.1 d	303.9 ± 20.7 cd
<i>Mimosa tenuiflora</i>	114.2 ± 5.0 bc	836.7 ± 95.8 a	402.2 ± 32.8 b	265.7 ± 17.2 d
<i>Myracrodruon urundeuva</i>	97.5 ± 6.6 bc	773.9 ± 51.6 a	397.5 ± 50.7 b	451.7 ± 7.1 a
<i>Poincianella bracteosa</i>	85.5 ± 6.0 c	391.2 ± 23.5 b	263.6 ± 17.9 cd	368.9 ± 12.9 b
<i>Spondias tuberosa</i>	205.8 ± 10.7 a	812.1 ± 29.3 a	581.3 ± 56.2 a	314.3 ± 5.5 c
<i>Ziziphus joazeiro</i>	108.8 ± 14.0 bc	685.4 ± 43.1 a	366.9 ± 20.9 bc	269.3 ± 5.6 d
SEM	8.98	53.05	30.47	14.16

Columns means with different superscripts differ significantly (**0.01 and *0.05 of probability). ¹g.kg⁻¹ NM; ²g.kg⁻¹ DM; ³g.kg⁻¹ CP

Table 2 - Composition of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) and standard error median (SEM) of arboreal species

Species	Variable			
	P ¹	K ^{1ns}	Ca ^{1**}	Mg ^{1**}
<i>Cnidoscolus phyllacanthus</i>	1.26 ± 0.1 ab	6.20 ± 0.5	15.57 ± 2.2 ab	2.92 ± 0.4 a
<i>Mimosa tenuiflora</i>	1.35 ± 0.09 a	5.70 ± 0.08	2.35 ± 0.4 c	0.07 ± 0.02 c
<i>Myracrodruon urundeuva</i>	0.95 ± 0.1b c	5.62 ± 0.1	11.42 ± 0.9 b	3.15 ± 0.2 a
<i>Poincianella bracteosa</i>	1.51 ± 0.04 a	5.70 ± 0.9	15.04 ± 0.9 ab	1.58 ± 0.9 ab
<i>Spondias tuberosa</i>	0.83 ± 0.1 c	7.30 ± 0.6	14.81 ± 0.4 ab	1.94 ± 0.2 a
<i>Ziziphus joazeiro</i>	1.27 ± 0.03 ab	7.80 ± 0.5	22.18 ± 4.4 a	2.800.3 a
SEM	0.05	0.25	1.38	0.26
	S ^{1**}	B ^{2**}	Cu ^{2**}	Fe ^{2**}
<i>Cnidoscolus phyllacanthus</i>	0.64 ± 0.1b c	139.50 ± 0.4 c	9.76 ± 0.9 ab	142.05 ± 9.3 a
<i>Mimosa tenuiflora</i>	0.12 ± 0.01 c	133.00 ± 0.4 c	2.09 ± 0.3 c	47.14 ± 17.8 c
<i>Myracrodruon urundeuva</i>	0.40 ± 0.09b c	145.00 ± 0.4 a	9.76 ± 0.5 ab	78.50 ± 2.4 bc
<i>Poincianella bracteosa</i>	1.01 ± 0.1 b	141.75 ± 0.7 b	11.50 ± 0.9 a	107.16 ± 8.7 ab
<i>Spondias tuberosa</i>	0.40 ± 0.08 bc	137.50 ± 0.8 c	8.40 ± 0.9 b	137.39 ± 10.9 a
<i>Ziziphus joazeiro</i>	2.22 ± 0.4 a	139.25 ± 0.3 c	12.17 ± 0.5 a	105.95 ± 13.4 ab
SEM	0.15	0.78	0.72	7.61
	Mn ^{2**}	Zn ^{3**}	-	-
<i>Cnidoscolus phyllacanthus</i>	118.14 ± 5.5 a	21.96 ± 4.7 bc	-	-
<i>Mimosa tenuiflora</i>	16.69 ± 2.2 c	17.03 ± 0.6 c	-	-
<i>Myracrodruon urundeuva</i>	26.66 ± 2.0 c	16.26 ± 0.3 c	-	-
<i>Poincianella bracteosa</i>	27.25 ± 2.8 bc	26.26 ± 0.7 b	-	-
<i>Spondias tuberosa</i>	52.40 ± 12.4 bc	19.78 ± 1.0 bc	-	-
<i>Ziziphus joazeiro</i>	71.54 ± 22.2 b	34.94 ± 1.5 a	-	-
SEM	7.83	1.45	-	-

Columns means with different superscripts differ significantly (**0.01 and *0.05 of probability). ¹g.kg⁻¹ MS; ²mg.kg⁻¹ MS

Table 3 - Mean of carbohydrates fractions of arboreal species

Species	Fractions			
	TC ^{1**}	A+B1 ^{2**}	B2 ^{2**}	C ^{2**}
<i>Cnidoscolus phyllacanthus</i>	751.8 ± 16.3 c	405.1 ± 35.6 c	166.9 ± 15.6 a	428.0 ± 49.3 bc
<i>Mimosa tenuiflora</i>	690.2 ± 12.1 d	384.8 ± 24.0 bc	72.4 ± 22.9 b	542.8 ± 37.4 a
<i>Myracrodruon urundeuva</i>	813.0 ± 12.1 ab	555.6 ± 4.9 a	149.5 ± 13.0 a	294.9 ± 8.3 d
<i>Poincianella bracteosa</i>	777.3 ± 8.7 bc	474.6 ± 17.5 b	132.6 ± 10.0 a	392.8 ± 17.8 c
<i>Spondias tuberosa</i>	835.1 ± 18.9 a	376.6 ± 9.7 c	68.7 ± 17.0 b	554.7 ± 22.8 a
<i>Ziziphus joazeiro</i>	755.2 ± 4.8 c	356.6 ± 8.1 c	153.4 ± 39.2 a	490.0 ± 43.1 ab
SEM	10.02	15.75	8.94	20.60

Columns means with different superscripts differ significantly (**0.01 and *0.05 of probability). ¹g.kg⁻¹ DM; ²g.kg⁻¹ TC. Standard error median (SEM)

The crude protein (CP) concentration was observed in larger amounts in *M. tenuiflora* (174.9 g.kg⁻¹ DM), *Z. joazeiro* (150.6 g.kg⁻¹ DM), *P. bracteosa* (145.0 g.kg⁻¹ DM) and *C. phyllacanthus* (143.2 g.kg⁻¹ DM), followed by *Myracrodruon urundeuva* (111.1 g.kg⁻¹ DM) and *S. tuberosa* (91.7 g.kg⁻¹ DM) (Table 4). Neves *et al.* (2014) and Nunes *et al.* (2016), also in vegetative phenological stage, observed values of CP above 110 g.kg⁻¹ DM, which confirms the potential use of these forage species as protein sources for ruminant feed, particularly in tropical regions. It should be noted that the formulation of diets considering only the feed CP content without the knowledge of its availability may hinder the efficiency of synthesis of rumen microorganisms. It is important to note that the CP contents presented, despite being considered a quality parameter for forages, had significant portions attached to the fiber, i.e., unavailable for micro-organisms. Similarly, the presence of tannins and lignin tend to increase neutral detergent insoluble protein (NDIP) and acid detergent insoluble protein (ADIP) (LICITRA; HERNANDEZ; Van SOEST, 1996; NUNES *et al.*, 2016). The highest proportion of neutral detergent insoluble protein (NDIP) was observed for the forages *M. tenuiflora*, *S. tuberosa*, *M. urundeuva* and *Z. joazeiro*, with 836.7, 812.1, 773.9 and 685.4 g.kg⁻¹ CP, respectively, while the lowest concentration was observed for *C. phyllacanthus* (190.9 g.kg⁻¹ CP). The highest ADIP content was obtained for *S. tuberosa* (581.3 g.kg⁻¹ CP), i.e., approximately 58 % of the protein present in its composition was unavailable.

For the fractioning of nitrogenous compounds, higher proportions of fraction A (NPN) were observed for *C. phyllacanthus* (375.5 g.kg⁻¹ CP). The fraction B1+B2 had higher concentrations in *P. bracteosa* (481.5) and *C. phyllacanthus* (433.6) (Table 4). For the fraction B3, the highest amount was found for *M. tenuiflora* and *M. urundeuva* (434.5 and 376.4 g.kg⁻¹ CP). For

the fraction C, there was a higher concentration in *S. tuberosa*, with 581.3 g.kg⁻¹ CP in its composition, and a lower concentration in *C. phyllacanthus* (153.2 g.kg⁻¹ CP) (Table 4).

The highest percentage of fraction A (nitrogenous compounds) indicates the possibility of using this forage as a source of nitrogen readily available for rumen microorganisms. The high amount of N in the fraction A of *C. phyllacanthus* is noteworthy when associated with the availability of carbohydrates in the fraction A+B1. This is a fraction that presents a fast ruminal degradation, characterizing a synchrony of nutrient degradation rates in the rumen when using these forages, as recommended by the Cornell Net Carbohydrate and Protein System (CNCPS). Thus, when a forage has a high protein content and most of this protein is in fast degradation fractions, it is necessary to supply a carbohydrate source with a high ruminal degradation rate so that the microbial synthesis in the rumen is efficient. The fraction B3 is associated with cell walls with a slow degradation rate in the rumen (LICITRA; HERNANDEZ; Van SOEST, 1996). Thus, it has a larger passage, being a potential source of amino acids in the small intestine to be absorbed by the animal.

The degradation parameters *a*, *b* and *c* correspond to the percentage of compounds which can be soluble (*a*), compounds that are insoluble but can be degraded by microorganisms according to incubation time (*b*), and *c* corresponds to the degradation rate of insoluble compounds according to incubation time (*t*). The degradation potential (Dp) ranged from 27.12% (*M. tenuiflora*) to 61.63% (*C. phyllacanthus*) (Table 5).

As for digestibility, the highest value was 627.1 g.kg⁻¹ DM (*C. phyllacanthus*) and the lowest value was 340.5 g.kg⁻¹ DM (*M. tenuiflora*) (Table 5). Pereira *et al.* (2012), working with hay the *C. phyllacanthus* found 636.6 g.kg⁻¹ DM digestibility. The degradation curves of

Table 4 - Mean of nitrogen compounds fractions of arboreal species

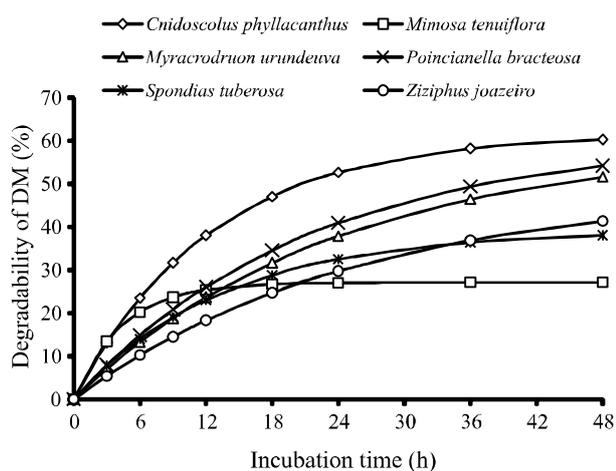
Species	Fractions				
	CP ^{1**}	A ^{2**}	B1+B2 ^{2**}	B3 ^{2**}	C ^{2**}
<i>Cnidocolus phyllacanthus</i>	143.2 ± 11.3 b	375.5 ± 38.6 a	433.6 ± 28.3 a	37.7 ± 12.5 d	153.2 ± 24.1 d
<i>Mimosa tenuiflora</i>	174.9 ± 2.2 a	29.0 ± 1.4 c	134.3 ± 96.9 b	434.5 ± 63.0 a	402.2 ± 32.8 b
<i>Myracrodruon urundeuva</i>	111.1 ± 6.5c	14.3 ± 6.6c	211.8 ± 53.8b	376.4 ± 87.3ab	397.5 ± 50.7b
<i>Poincianella bracteosa</i>	145.0 ± 6.6 b	127.3 ± 27.4 b	481.5 ± 33.3 a	127.6 ± 20.8 cd	263.6 ± 17.9 cd
<i>Spondias tuberosa</i>	91.7 ± 9.7 c	34.4 ± 5.7 c	153.5 ± 28.2 b	230.8 ± 73.4 bcd	581.3 ± 56.2 a
<i>Ziziphus joazeiro</i>	150.6 ± 7.2 ab	110.0 ± 28.7 b	204.6 ± 23.0 b	318.5 ± 41.8 abc	366.9 ± 20.9 bc
SEM	6.05	27.26	31.48	30.93	30.47

Columns means with different superscripts differ significantly (**0.01 and *0.05 of probability). ¹g.kg⁻¹ DM; ²g.kg⁻¹ CP. Standard error median (SEM)

Table 5 - Degradation and *in vitro* digestibility parameters of dry matter of arboreal species

Species	Parameters							
	a (%)	b (%)	c (h)	ED (%) (0.02. h ⁻¹)	ED (%) (0.05. h ⁻¹)	ED (%) (0.08. h ⁻¹)	PD (%)	IVDDM** (g.kg ⁻¹ DM)
<i>Cnidoscopus phyllacanthus</i>	25.87	35.76	0.08	54.72	48.24	44.13	61.63	627.1 a
<i>Mimosa tenuiflora</i>	9.67	17.44	0.23	25.71	23.99	22.60	27.12	340.5 d
<i>Myracrodruon urundeuva</i>	19.31	40.05	0.04	46.50	37.66	33.16	59.36	520.3 b
<i>Poincianella bracteosa</i>	22.46	38.09	0.05	49.16	40.89	36.53	60.55	516.0 b
<i>Spondias tuberosa</i>	20.19	18.98	0.07	35.12	31.50	29.30	39.17	411.2 cd
<i>Ziziphus joazeiro</i>	15.80	32.91	0.04	37.61	30.28	26.64	48.71	453.4 bc
SEM	-	-	-	-	-	-	-	19.9

ED = effective degradability for passage rate equal to 0.02, 0.05 and 0.08 per hour; PD = potential degradability represented by the sum of *a* and *b*. Columns means with different superscripts differ significantly significantly (**0.01 and *0.05 of probability). – Unvalued. Standard error median (SEM)

Figure 1 - Dry matter degradability curves of arboreal species in function of *in vitro* incubation time

the species evaluated showed distinct behaviors (Figure 1), reflecting the peculiarities of the composition of each species.

The low percentages of *in vitro* dry matter degradability (IVDDM) of *M. tenuiflora* and *S. tuberosa* are related to higher levels of LDA and fraction C of TC, although all plants were in the same phenological state, but presented early maturation of tissues., which influences nutritional value more than any other factor. As the plant matures, it tends to decrease the production of potentially digestible components, such as soluble carbohydrates

and proteins, and increase the production of cell wall constituents. As a result, a decrease in IVDDM and dry matter intake by animals is expected. Habib *et al.* (2016), evaluated plants of the same genus (*Ziziphus*) and found dry matter digestibility values close to this one.

Regarding *in vitro* gas production, the fermentation of TC generated the highest final volume of gas for *C. phyllacanthus* (203.0 mL.g⁻¹ DM), followed by *P. bracteosa* (197.91 mL.g⁻¹ DM) (Table 6), in relation to the others, demonstrating a greater availability of nutrients for rumen microorganisms. The contribution of fibrous carbohydrates (FC) in gas production was 86.0% (*Z. joazeiro*), 69.13% (*M. urundeuva*), 54.73% (*C. phyllacanthus*), 29.69% (*M. tenuiflora*), 24.09% (*S. tuberosa*) and 17.94% (*P. bracteosa*).

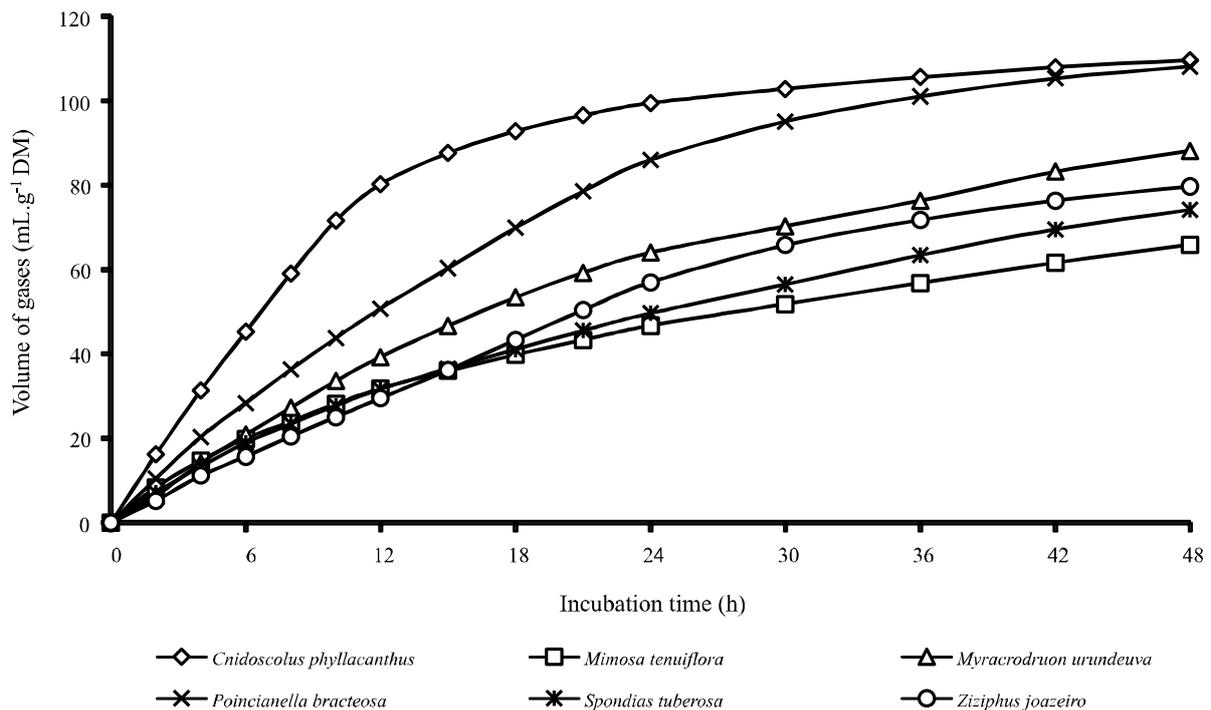
The total volume of gases observed (V_{t1}) was close to that found by the bicompartmental model (V_{t2}), proving the model adjustment. The lowest volume of gases produced by the fermentation of TC of *M. tenuiflora*, *Z. joazeiro* and *S. tuberosa* may have been caused because 54, 49 and 55% of the TC, respectively, were present in the fraction C, which is not degradable by ruminal microorganisms. During the early events of ruminal degradation, soluble nutrients are responsible for the greatest volume of gases produced, i.e., the A+B1 fraction is responsible for the initial volume (V_{t1}) of gases produced from its degradation, which promotes a greater gas production specific rate (k_1).

The greatest gas volumes produced by the fermentation of NFC were verified for *P. bracteosa* and

Table 6 - Parameters for *in vitro* gas production of arboreal species obtained by the bicompartimental logistic model

Species	Parameters						
	V_{t1}^{**}	V_{t2}	V_{f1}	k_1	V_{f2}	k_2	λ
<i>Cnidoscopus phyllacanthus</i>	203.0 ± 4.5 a	206.02	93.25	0.0216	112.77	0.0916	1.2764
<i>Mimosa tenuiflora</i>	148.9 ± 5.2 b	136.77	96.15	0.0220	40.62	0.0955	0.9597
<i>Myracrodruon urundeuva</i>	162.6 ± 2.6 ab	175.19	54.07	0.0866	121.12	0.0219	2.3282
<i>Poincianella bracteosa</i>	197.9 ± 1.6 a	199.04	163.33	0.0308	35.71	0.1305	2.3206
<i>Spondias tuberosa</i>	140.0 ± 4.0 b	151.00	114.62	0.0223	36.38	0.1081	1.8599
<i>Ziziphus joazeiro</i>	148.2 ± 4.6 b	148.3	20.76	0.1455	127.54	0.0293	2.6269
SEM	6.36	-	-	-	-	-	-

V_{t1} = total volume (mL.g⁻¹ DM); V_{t2} = total volume (mL.g⁻¹ DM) found using the model; V_{f1} = volume (mL) of gas produced by the degradation of the fraction A+B1 of the Cornell System (NFC); k_1 = specific rate (h) of production of gases by the degradation of the fraction A+B1 (NFC); V_{f2} = volume (mL) of gases produced by the degradation of the fraction B2 of the Cornell System (FC); k_2 = specific rate (h) of production of gases by the degradation of the fraction B2 (FC); λ = latency (h). Columns means with different superscripts differ significantly (**0.01 and *0.05 of probability). – Unvalued. Standard error median (SEM)

Figure 2 - Volume of gases produced during *in vitro* incubation of arboreal species

S. tuberosa. The lowest digestion rate (k_2) estimated for the FC of *M. urundeuva* leads us to infer that other factors may be related to k_2 , such as intermediaries of lignin synthesis and/or the presence of tannins. Although the presence of secondary compounds of

the evaluated species is still not well characterized, it is known that significant levels of tannins can affect fermentation, ruminal microbiota and suppress methanogenesis (BHATTA *et al.*, 2012; DURMIC *et al.*, 2017; PAL *et al.*, 2015).

CONCLUSIONS

1. *Cnidocolus phyllacanthus* had the highest predominance of the fractions A+B1 (NFC) of carbohydrates and the fraction A (NPN) of nitrogenous compounds, with a synchrony in the availability of these fractions;
2. *Cnidocolus phyllacanthus*, *Myracrodruon urundeuva* and *Poincianella bracteosa* showed the highest gas production;
3. In face of all values presented, all the evaluated species present satisfactory nutritional value, especially in the case of animal production in a Semiarid environment.

ACKNOWLEDGMENTS

We appreciate the support of the Bank of Northeastern Brazil (BNB) and of the Coordination for the Improvement of Higher Education Personnel (CAPES) in Brazil (project financing).

REFERENCES

- ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. **Official methods of analysis of AOAC international**. 15 th ed. Virginia: AOAC, 1990. 684 p.
- BHATTA, R. *et al.* Nutrient content, *in vitro* ruminal fermentation characteristics and methane reduction potential of tropical tannin-containing leaves. **Journal of the Science of Food and Agriculture**, v. 92, n. 15, p. 2929-9235, 2012.
- DURMIC, Z. *et al.* Differences in the nutrient concentrations, *in vitro* methanogenic potential and other fermentative traits of tropical grasses and legumes for beef production systems in northern Australia. **Journal of the Science of Food and Agriculture**, v. 97, n. 12, p. 4075-4086, 2017.
- HABIB, G. *et al.* Nutritive value of common tree leaves for livestock in the semi-arid and arid rangelands of Northern Pakistan. **Livestock Science**, v. 184, p. 64-70, 2016.
- HOLDEN, L. A. Comparison of methods of *in vitro* dry matter digestibility for ten feeds. **Journal of Dairy Science**, v. 82, n. 8, p. 1791-1794, 1999.
- IBGE. **Censo Agro 2017**. Disponível em: https://censoagro2017.ibge.gov.br/templates/censo_agro/resultadosagro/pecuaria.html. Acesso em: 20 fev. 2019.
- LICITRA, G.; HERNANDEZ, T. M.; Van SOEST, P. J. Standardization of procedures for nitrogen fractionation of ruminant feeds. **Animal Feed Science and Technology**, v. 57, p. 347-358, 1996.
- MALAVOLTA, E.; VITTI, G. C.; OLIVEIRA, S. A. **Avaliação do estado nutricional das plantas: princípios e aplicações**. 2. ed. Piracicaba: Potafos, 1997. 319 p.
- NEVES, A. L. A. *et al.* **Tabelas nordestinas de composição de alimentos para bovinos leiteiros**. Brasília: Embrapa, 2014. 184 p.
- NUNES, A. T. *et al.* Plants used to feed ruminants in semi-arid Brazil: a study of nutritional composition guided by local ecological knowledge. **Journal of Arid Environments**, v. 135, p. 96-103, 2016.
- ØRSKOV, E. R.; McDONALD, I. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. **Journal of Agricultural Science**, v. 92, p. 499-503, 1979.
- OWENS, F. N.; BASSALAN, M. Ruminal fermentation. In: MILLEN, D.; DE BENI ARRIGONI, M.; LAURITANO PACHECO, R. (ed.). **Rumenology**. Switzerland: Springer, 2016. p. 66-102.
- PAL, K. *et al.* Evaluation of several tropical tree leaves for methane production potential, degradability and rumen fermentation *in vitro*. **Livestock Science**, v. 180, p. 98-105, 2015.
- PEREIRA, E. S. *et al.* Determination of the proteins and carbohydrates fractions and estimative of the energy value of forages and by-products in Brazilian Northeast. **Semina: Ciências Agrárias**, v. 31, n. 4, p. 1079-1094, 2010.
- PEREIRA, V. L. A. *et al.* Valor nutritivo e consumo voluntário do feno de faveleira fornecido a ovinos no Semiárido pernambucano. **Revista Caatinga**, v. 25, n. 3, p. 96-101, 2012.
- SANTANA, D. F. Y. *et al.* Caracterização da caatinga e da dieta de novilhos fistulados, na época chuvosa, no Semiárido de Pernambuco. **Revista Brasileira de Zootecnia**, v. 40, n. 1, p. 69-78, 2011.
- SCHOFIELD, P.; PITT, R. E.; PELL, A. N. Kinetics of fiber digestion from *in vitro* gas-production. **Journal of Animal Science**, v. 72, n. 11, p. 2980-2991, 1994.
- SENGER, C. C. D. *et al.* Evaluation of autoclave procedures for fibre analysis in forage and concentrate feedstuffs. **Animal Feed Science and Technology**, v. 146, p. 169-174, 2008.
- SNIFFEN, C. J. *et al.* A net carbohydrate and protein system for evaluating cattle diets: II carbohydrate and protein availability. **Journal of Animal Science**, v. 70, n. 7, p. 3562-3577, 1992.
- SOUZA, C. *et al.* Disponibilidade e valor nutritivo da vegetação de Caatinga no Semiárido norte riograndense do Brasil. **Revista Holos**, v. 3, p. 196-204, 2013.
- THEODOROU, M. K. *et al.* A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feeds. **Animal Feed Science and Technology**, v. 48, p. 185-197, 1994.

TILLEY, J. M. A.; TERRY, R. A. A two-stage technique for the *in vitro* digestion of forage crops. **Journal British of Grassland Society**, v. 18, n. 2, p. 104-111, 1963.

VALENTE, T. N. P. *et al.* Evaluation of ruminal degradation profiles of forages using bags made from different textiles. **Revista Brasileira de Zootecnia**, v. 40, n. 11, p. 2565-2573, 2011.

Van SOEST, P. J. Use of detergents in the analysis of fibrous feeds. I. Preparation of fiber residues of low nitrogen content. **Journal of the Association of Official Agricultural Chemists**, v. 46, n. 5, p. 825-829, 1963a.

Van SOEST, P. J. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. **Journal of the Association of Official Agricultural Chemists**, v. 46, n. 5, p. 829-835, 1963b.



This is an open-access article distributed under the terms of the Creative Commons Attribution License