

Intake, digestibility, milk production, ingestive behavior and gas emissions of Saanen goats fed pornunça silage with levels of condensed tannin extracted from *Schinopsis brasiliensis*

Daniel Ribeiro Menezes

UNIVASF: Universidade Federal do Vale do Sao Francisco

Dalinne Tamara Queiroz Carvalho

UFBA: Universidade Federal da Bahia

Alita Ruth Ferraz de Lucena

UNIVASF: Universidade Federal do Vale do Sao Francisco

Polyana Deyse Rodrigues Marcelino

UFBA: Universidade Federal da Bahia

Lais Micaele Lopes de Moura

UNIVASF: Universidade Federal do Vale do Sao Francisco

Mário Adriano Ávila Queiroz

UNIVASF: Universidade Federal do Vale do Sao Francisco

Saete Alves de Moraes

EMBRAPA Centro de Pesquisa Agropecuária do Trópico Semiárido: EMBRAPA Centro de Pesquisa Agropecuaria do Tropico Semiarido

Glacyane Costa Gois

UNIVASF: Universidade Federal do Vale do Sao Francisco

Cláudia Horne da Cruz

UNIVASF: Universidade Federal do Vale do Sao Francisco

Anny Graycy Vasconcelos de Oliveira Lima (✉ annygraycy@gmail.com)

UNIVASF: Universidade Federal do Vale do Sao Francisco <https://orcid.org/0000-0002-5613-8047>

Thiago Vinicius Costa Nascimento

UFS: Universidade Federal de Sergipe

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Abstract

The objective of this study was to determine the greatest concentration of condensed tannin (CT) extracted from *Schinopsis brasiliensis* in pornunça silages based on intake, digestibility, milk production, ingestive behavior and estimated greenhouse gas (GHG) emissions in dairy goats. Eight multiparous Saanen goats at 30 days of lactation, with 38.0 kg of initial body weight, production of 2.0 ± 0.4 kg of milk/day, mean age of 2–3 years, were distributed in a double Latin square (4x4) with four experimental periods and four diets with different tannin levels at concentrations 0% (control), 2.4, 3.6 and 4.8% tannin of total diet. The CT levels in the silage of pornunça promoted a linear decrease for the intake of dry matter (DM, $P < 0.001$), organic matter (OM, $P < 0.001$), ash ($P < 0.001$), crude protein (CP, $P < 0.001$), neutral detergent fiber (NDF, $P < 0.001$), acid detergent fiber (ADF, $P < 0.001$) and water ($P < 0.001$). The inclusion of CT also promoted a linear decrease in apparent digestibility coefficients of DM ($P < 0.001$), OM ($P < 0.001$) and CP ($P < 0.001$), milk production ($P < 0.001$), NDF ($P < 0.001$), and GHG emission estimation ($P < 0.001$). The intake and rumination rates of DM and NDF showed a linear decrease ($P < 0.001$) with level of tannin in the diets. In the experimental conditions, the inclusion of condensed tannin extracted from *Schinopsis brasiliensis* in pornunça silages, at levels up to 2.4% DM basis, promotes a decrease in intake of DM (DMI) and OM (OMI) and milk production as decreases GHG emissions in Saanen goats.

Introduction

Dairy goats production represent one of the most important activities of the productive sector in the Brazilian semiarid region, being one of the main sources to ensure the food supply of rural families, generating jobs and income for the region. However, local climatic conditions promote an oscillation in the supply and nutritional value of forage, leading to a productive deficit in herds due to feed scarcity (Ramos et al., 2020; Silva et al., 2020).

In order to minimize these effects, it is essential to use technologies that aim to preserve the excess of forage produced during the rainy season. The pornunça or pornuncia (*Manihot* sp.) is a forage plant adapted to the Brazilian semiarid characterized by the high content of soluble carbohydrates in the leaves and thin stems, which is important to produce good quality silage. However, the crude protein content (167 g/kg – 275.8 g/kg in dry matter - DM; Nascimento et al., 2016; Carvalho et al., 2017) in its shoot can lead to a buffering effect and hinder the reduction of pH to optimal levels for silage fermentation (Voltolini et al., 2019). Thus, adding additives aims to improve fermentation patterns, the ensiled mass's nutritional value, and reduce fermentation losses (Restelatto et al., 2019). Among the additives that can be used in silages, we highlight condensed tannin (CT) because it has an affinity for polysaccharides, amino acids and thus proteins (Costa et al., 2021). According to Bueno et al. (2020) and Nascimento et al. (2021), CT also acts by reducing the concentration of soluble nitrogen and ammonia (NH_3) in the ensiled material, in addition to inhibiting microbial growth and increasing the aerobic stability of the silage after the silo is opened.

Pathak et al. (2017) declare that levels of 15 to 40 g CT/kg DM, considered low, are beneficial when used in the diet of small ruminants due to the better digestibility of the dietary protein, which results in less loss of nitrogen through the feces. Lucena et al. (2018), Frutos et al. (2020) and Nawab et al. (2020) believe that CT can reduce the internal parasite load in the animal, providing better performance and production.

Thus, the study aimed to determine the best concentration of condensed tannin extracted from *Schinopsis brasiliensis* in pornunça silage based on intake, digestibility, milk production, ingestive behavior and estimated greenhouse gas emissions in dairy goats.

Material and methods

Experiment site and ethical aspects

The experiment was conducted at the facilities of the Goat Production sector located at the Agricultural Sciences Campus of the Federal University of San Francisco Valley (UNIVASF), Petrolina, Pernambuco, Brazil (9° 19' 28" South, 40° 33' 34" West, 393m altitude). The climate is the hot semi-arid type, with rainy season (BSh) (Köppen and Geiger 1928), with average annual precipitation of 376 mm and temperature ranging from 14.7°C to 38.8°C.

The research was approved and certified by the Ethics Committee on the Use of Animals of UNIVASF (protocol nº 0002/120514).

Animals and experimental design

Eight multiparous lactating Saanen goats, with 38.0 kg of initial body weight, production of 2.0 ± 0.4 kg of milk/day, mean age of 2–3 years, and 30 days of lactation, were used in the experiment. All animals were identified, weighed, and treated against ecto and endoparasites. The experimental period lasted 80 days, being four periods of 20 days, in which 15 days of each period were destined for animals' adaptation to the experimental facilities and diets, and five days for data collection. The goats were randomly allocated in individual stalls (1.25 m x 2.24 m) equipped with feeders, drinkers, and salt troughs, previously identified according to your treatments.

Experimental diets

The experimental diets were composed by silage of pornunça (*Manihot* sp.) plus a commercial condensed tannin extracted from *Schinopsis brasiliensis* (Quebracho; Weibull® Tanac, Montenegro, RS, Brazil), at concentrations 0% (control treatment), 2.4, 3.6 and 4.8%, based on the dry matter (DM) content of the silages. The condensed tannin levels into silages were previously tested *in vitro*, but when performing an experimental pre-trial. Due to this factor, the condensed tannin levels used in this research were established.

The goats were fed with silage, concentrate based on soybean meal, ground corn, and mineral supplement (Caprinofós, Tortuga, São Paulo, Brazil). The diets were formulated to have similar protein

content and a forage:concentrate ratio of 60:40 (Tables 1 and 2), following the recommendations of the NRC (2007).

Table 1
Chemical composition of the ingredients of the experimental diets

Items	Ingredients			
	Pomunça	Ground corn	Soybean meal	Commercial tannin
Dry matter (g/kg NM)	283.2	820	845.8	883
Organic matter (g/kg DM)	923.6	987.5	934.9	942
Ash (g/kg DM)	76.4	12.4	65.0	58.0
Crude protein (g/kg DM)	117	75.2	524.5	18.0
Hemicellulose (g/kg DM)	164.5	156.6	61.2	-
Neutral detergent fiber (g/kg DM)	563.8	215.2	152.6	-
Acid detergent fiber (g/kg DM)	399.3	58.6	91.4	-
NM , natural material; DM , Dry matter				

Table 2
Proportion of ingredients and chemical composition of the experimental diets

Items	Levels of tannin (%)			
	0	2.4	3.6	4.8
Pornunça silage	600	576	564	552
Ground corn	256.0	248.0	242.7	234.7
Soybean meal	124.0	132.0	137.3	145.3
Mineral mixture*	20.0	20.0	20.0	20.0
Commercial tannin	0.00	24.0	36.0	48.0
<i>Nutrients</i>				
Dry matter (g/kg NM)	349.9	364.4	374.4	374.0
Organic matter (g/kg DM)	921.5	922.6	924.0	925.2
Ash (g/kg DM)	78.5	77.4	76.0	74.8
Crude protein (g/kg DM)	157.2	152.2	155.4	149.8
Ether extract (g/kg DM)	31.8	31.4	30.0	26.6
Neutral detergent fiber (g/kg DM)	526.6	526.0	519.3	517.5
Acid detergent fiber (g/kg DM)	281.2	308.3	304.4	294.6
*Composition of the mineral mixture (per kg of active elements): <i>Na</i> = 147 g; <i>Ca</i> = 120 g; <i>P</i> = 87 g; <i>S</i> = 18 g; <i>Zn</i> = 3.800 mg; <i>Fe</i> = 1.800 mg; <i>Mg</i> = 1.300 mg; <i>F</i> = 870 mg; <i>Cu</i> = 590 mg; <i>Mo</i> = 300 mg; <i>I</i> = 80 mg; <i>Co</i> = 40 mg; <i>Cr</i> = 20 mg; <i>Se</i> = 15 mg				

For the preparation of the silages, the upper third of the plants that had young leaves and tender stems were harvested manually when they averaged 1.5m in height. The harvested material was processed in stationary forage (PP-35, Pinheiro Máquinas, Itapira, São Paulo, Brazil) to obtain 2.0 cm long particles. Afterward, it was homogenized, and the treatments were formulated by adding commercial tannin at experimental levels to the material to be ensiled. After homogenization, the silage was carried out in plastic drums with a capacity of 200 L.

The goats were fed twice a day after milking (07h00 and 16h00), and water was offered *ad libitum*. The orts of the feeds were collected and weighed daily to adjust dry matter intake (DMI) to allow 10% of orts in the trough.

The samples of the ingredients, the feed offered, and the orts were collected and stored at - 15°C for further laboratory analyses.

Milking

The milking was performed manually, and the milking procedures followed the recommendations of the Technical Regulation of Production, Identity, and Quality of goat milk (BRASIL, 2000). The daily milk production of each goat was recorded daily and expressed in kg/animal/day. Milk samples were collected for further laboratory analysis.

Intake and digestibility of nutrients

The DMI and the other nutritional fractions were calculated by the difference between the DM or nutritional fraction ingested and the DM or nutritional fraction present in theorts, basis on the total DM.

The feces were collected for five days in the final portion of the rectum of the animals. In each experimental period, feces collections were performed at 07:00 am and 1:00 pm; 8 am and 2 pm; 9 am and 3 pm; 10 am and 4 pm; 11:00 am and 5:00 pm, according to Cochran et al. (1986). Samples from each animal were homogenized to form a sample/animal/treatment, and 10% of this total was stored in a freezer at -15°C at the end of each collection period.

Water consumption

Water consumption was assessed daily (kg/animal/day). The water was offered ad libitum in plastic buckets with a capacity of eight liters. The plastic buckets weighed before and after 24 h being supplied. Water lost by evaporation was estimated by leaving two buckets similar to those of the animals near the stall, without access of the animals, and the amount of water lost daily was considered as losses by evaporation (Church, 1976).

Evaluation of the ingestive behavior

During the data collection period, continuous visual observations were made for 24 hours with 10-minute intervals and the time spent in activities performed by the animals was recorded in a behavioral ethogram. Feeding time (hour/day), rumination time (hour/day), and idleness time (hour/day) were recorded, as well as the number of chews and the time spent ruminating each bolus according to Sant 'ana et al. (2022). DM intake rate (DMIR), NDF intake rate (NDFIR) per hour, DM rumination rate (DMRR), and NDF rumination rate (FNDR) were also calculated, according to the methodology described by Dulphy and Faverdin (1987) and Bürger et al. (2000).

Chemical analysis

Samples of the feed offered orts and feces were pre-dried in an oven with forced air circulation at 55 °C for 72-h and later they were ground in knife mills (Wiley Mill, Marconi, MA-580, Piracicaba, Brazil) with sieves of 1 and 2 mm. The analyses were performed following the methods described by the Association of Official Analytical Chemists (AOAC, 2016) to determine the contents of dry matter (DM; method 967.03), ash (method 942.05), crude protein (CP; method 981.10), ether extract (EE; method 920.29) and acid detergent fiber (ADF; method 973.18). Neutral detergent fiber (NDF) was determined according to Van Soest et al. (1991).

Fecal production (kg DM/day) of each animal was estimated using an internal indicator (indigestible neutral detergent fiber - iNDF). Samples of feces, feed, and orts, in duplicate, were incubated *in situ* for 240 hours, using non-woven bags (TNT – 100 g/m²) (Casali et al., 2008) and the residual material from the incubation was subjected to extraction with neutral detergent. Fecal dry matter production was obtained by dividing the NDF intake and NDF content in the feces (Silva and Leão, 1979).

The apparent digestibility coefficient (ADC) of nutrients was calculated as described by Silva and Leão (1979) through the equation:

$$ADC = \frac{[Nutrient\ intake\ (kg) - Nutrient\ excreted\ in\ feces\ (kg)]}{nutrient\ intake\ (kg)} \times 100$$

Emission of gases with greenhouse effect potential

For the estimates of greenhouse gas (GHG) emissions by animals, the semiautomatic *in vitro* model described by Maurício et al. (2003) was used, with adaptations made by Menezes et al. (2015). Therefore, it was attributed to the total gas emission per gram of sample of each diet tested for 24-h of incubation. The coefficients used were obtained by relating the data of the *in vivo* evaluations with the data obtained *in vitro* (Maurício et al., 2003) and based on documents of the Food and Agriculture Organization of the United Nations (FAO, 2018) and Intergovernmental Panel on Climate Change (IPCC, 2006).

Statistical analysis

The experimental design adopted was a double Latin square (4x4), with four experimental periods and four diets. The data were submitted to analysis of variance (ANOVA) by the PROC GLM procedure (General Linear Models) of the Statistical Analysis System version 9.1 (SAS Institute, Cary, NC, USA), followed by regression analysis using PROC REG, considering significant probability values below 5%. The statistical model was as follows:

$$y_{ijk} = \mu + \alpha_i + \beta_j + P_k + e_{ijk}$$

where: μ = general constant; α_i = effect referring to tannin levels i ; β_j = effect referring to the animal j ; P_k = effect referring to the experimental period k ; and e_{ijk} = random error, associated with each observation.

The behavior data were analyzed according to a Latin square design, with two simultaneous Latin squares. Thus, the treatment and square effects were considered fixed effects, and the period and animal were considered random effects (square). The sum of squares of treatment was decomposed using orthogonal contrasts to evaluate the effects of tannin inclusion, the linear and quadratic effects of tannin inclusion. All analyses were conducted using the MIXED procedure of SAS, and the significance level of 5% was adopted for all analyses.

Results

Intake and digestibility of nutrients

The levels of CT in the silages of pornunça promoted a linear decrease for the intake of DM ($P < 0.001$; Table 3), OM ($P < 0.001$), MM ($P < 0.001$), CP ($P < 0.001$), NDF ($P < 0.001$), ADF ($P < 0.001$) and water consumption ($P = 0.001$). It was observed that the goats reduced their intake by 0.203 (DM), 0.181 (OM), 0.019 (MM), 0.045 (CP), 0.112 (NDF), 0.056 (ADF) and 0.378(water) kg/day, every 1% of CT inclusion in the diets.

Table 3

Daily intake of nutritional components, water consumption and apparent digestibility of the nutrients in Saanen goats fed diets containing silage of pornunça with levels of condensed tannins extracted from *Schinopsis brasiliensis*

Items	Levels of tannin (%)				SEM	Pvalue	
	0	2.4	3.6	4.8		Linear	Quadratic
<i>Intake (kg/day)</i>							
Dry matter ^b	2.00	2.07	1.90	1.38	0.073	< 0.001	0.002
Organic matter ^c	1.83	1.91	1.75	1.28	0.014	< 0.001	0.002
Ash ^d	0.16	0.16	0.15	0.10	0.067	< 0.001	0.003
Crude protein ^e	0.35	0.34	0.31	0.21	0.038	< 0.001	0.011
Neutral detergent fiber ^f	1.03	1.07	1.00	0.68	0.024	< 0.001	< 0.001
Acid detergent fiber ^g	0.51	0.59	0.54	0.34	0.006	0.002	< .0001
Water ^h	3.74	3.65	3.26	2.61	0.179	< 0.001	0.207
<i>Digestibility (g/kg)</i>							
Dry matter ⁱ	612.8	600.2	554.3	525.0	0.755	< 0.001	0.293
Organic matter ^j	627.2	611.0	558.1	534.5	0.774	< 0.001	0.442
Crude protein ^k	623.5	589.6	513.5	428.9	1.149	< 0.001	0.063
Neutral detergent fiber ^l	554.6	545.4	549.1	487.3	0.521	< 0.001	< 0.001
SEM , Standart error of the mean; Significant at 5% probability level.							
Regression equations: Y ^b = 2.345–0.203x, R ² = 0.70; Y ^c = 2.145-0.181x, R ² = 0.68; Y ^d = 0.19-0.019x, R ² = 0.73; Y ^e = 0.415-0.045x, R ² = 0.83; Y ^f = 1.225 -0.112x, R ² = 0.66; Y ^g = 0.635-0.056x, R ² = 0.75; Y ^h = 4.26-0.378x, R ² = 0.90; Y ⁱ = 65.04-3.093x, R ² = 0.96; Y ^j = 66.095-3.175x, R ² = 0.95; Y ^k = 70.385-6.599x, R ² = 0.97; Y ^l = 51.79 + 4.593x -1.315x ² , R ² = 0.89							

Each increase of 1% of CT in the diets provided a linear reduction of the digestibility coefficients of 3.093 g/kg in DM ($P < 0.001$), 3.175 g/kg in OM ($P < 0.001$), 6.599 g/kg in CP ($P < 0.001$) and NDF (Table 3). For digestibility, a quadratic effect ($P < 0.001$) was verified.

Evaluation of the ingestive behavior

There were no statistical differences ($P = 0.107$; Table 4) for the evaluated parameters of ingestive behavior, except for the intake and rumination rate calculations. The DMIR ($P = 0.003$), NDFIR ($P = 0.002$),

DMRR ($P < 0.001$) and NDFRR ($P < 0.001$), all showed a linear decrease with increasing level of tannin in the diets.

Table 4

Ingestive behavior of Saanen goats fed diets containing silage of pornunça with levels of condensed tannins extracted from *Schinopsis brasiliensis*

Items	Levels of tannin (%)				SEM	Pvalue		
	Control	2.4	3.6	4.8		Tannin	L	Q
Number of chews per bolus	79.50	76.12	79.12	76.00	3.54	0.502	0.977	0.424
Time of rumination per bolus (sec)	52.34	52.90	54.98	57.92	3.48	0.239	0.107	0.867
Rumination time (min/day)	558.13	525.25	527.75	533.25	27.69	0.179	0.529	0.655
Feeding time (min/day)	389.38	375.50	373.63	395.88	22.37	0.761	0.514	0.654
Idling time (min/day)	492.50	539.25	538.63	540.88	34.15	0.197	0.970	0.969
DMIR (kg DM/h)	0.311	0.334	0.321	0.215	0.027	0.469	0.003	0.132
NDFIR (kg NDF/h)	0.156	0.173	0.168	0.106	0.013	0.6337	0.002	0.077
DMRR (kg DM/h)	0.214	0.244	0.216	0.164	0.014	0.6749	< 0.001	0.403
NDFRR (kg NDF/h)	0.108	0.124	0.114	0.081	0.005	0.8486	< 0.001	0.117
SEM , Standart error of the mean; L , linear effect; Q , quadratic effect; Significant at 5% probability level.								
DMIR , Dry matter intake rate; NDFIR , Neutral detergent fiber intake rate; DMRR , Dry matter rumination rate; NDFRR , Neutral detergent fiber rumination rate.								

Milk production and greenhouse gas emission estimation

Milk production of Saanen goats was reduced as CT levels increased in the diets ($P < 0.001$; Table 5), with a reduction of 0.223 kg of milk/animal/day at each increase of 1% of CT in the experimental diets. The same behavior was observed for GHG emission estimates, which decreased linearly with the increase of CT levels ($P < 0.001$; Table 5).

Table 5

Milk production and greenhouse gas emission by Saanen goats fed diets containing silage of pornunça with levels of condensed tannins extracted from *Schinopsis brasiliensis*

Items	Levels of tannin (%)				SEM	Pvalue	
	0	2.4	3.6	4.8		Linear	Quadratic
<i>Milk production</i>							
kg/animal/day ^b	1.78	1.81	1.53	1.13	0.070	< 0.001	0.001
<i>Greenhouse gas emission</i> [*]							
mL/g DM/24hour ^c	40.42	38.44	35.78	34.06	0.438	< 0.001	< 0.001
L/kg MSI/day ^d	64.54	59.03	55.66	51.97	0.438	< 0.001	< 0.001
L/kg DMI/day ^e	49.21	45.82	43.65	40.87	0.389	< 0.001	< 0.001
L/animal/day ^f	128.52	122.46	106.13	77.86	3.037	< 0.001	0.002
L/kg of milk/day ^g	72.41	66.93	65.92	62.89	0.438	< 0.001	< 0.001
*Values estimated by in vitro gas production (Mauricio et al., 2003) associated with <i>In vivo</i> experiment; DMI , Dry matter intake; OMI , Organic matter intake.							
SEM , Standart error of the mean; Significant at 5% probability level.							
Regression equations: Y ^b = 2.12 -0.223x, R ² = 0.84; Y ^c = 42.61-2.174x, R ² = 0.99; Y ^d = 68.07–4.108x, R ² = 0.99; Y ^e = 51.685-2.719x, R ² = 0.99; Y ^f = 150.82-16.831x, R ² = 0.92; Y ^g = 74.43-2.957x, R ² = 0.93							

Discussion

Dry matter and nutrients intake by the goats was reduced with levels of condensed tannin. This effect was probably attributed to astringency and bitter taste from the binding of tannin with salivary glycoproteins reducing feed acceptance by animals (Adejoro et al., 2019; Rinaldi and Moio, 2020). Sant'Ana et al. (2022) highlighted that Semiarid naturalized goats (Canindé and Repartida breeds) are animals more adapted to tannin, because these breeds are raised in extensive/semi-extensive systems and have been intaking native caatinga plants which have this tannin, different of the exotic breeds such as Saanen. They did not observe a significant difference in dry matter intake with the presence or absence of tannin in the diets. Furthermore, in the present study, 4.8% CT was included in the total diet DM, a value within the limit (4.5 to 10% DM) proposed by Min and Solaiman (2008) in order not to affect the DMI from animals.

However, several studies pointed out that when the tannin content is between 3–4%DM there are no deleterious effects on DM intake and digestibility, increasing the efficiency of dietary nitrogen use and

reducing the emission of greenhouse gases (Lamy et al. 2011; Hassanat and Benchaar, 2012; Min and Solaiman, 2018; Costa et al. 2021).

DM and NDF feeding, and rumination rates were reduced with the tannins inclusion in the goats' diet. Since the calculations are based in the amount of DM and NDF ingested and no change was observed for ruminating and feeding time, we can say that the decrease in the intake was responsible for the decrease in the rates. In other words, a smaller amount of food was ingested and consequently ruminated per unit of time. Unlike the results reported by Nascimento et al (2021), the animals did not increase rumination time in an attempt to produce a greater amount of saliva to process the food bolus and decrease the CT astringency sensation, they simply reduced intake.

Elevated levels of condensed tannin reduced the apparent digestibility of crude protein probably due to the formed tannin-protein complex that inhibited the growth and action of proteolytic bacteria, making the protein unavailable for ruminal degradation and consequently increasing the non-degradable protein in the rumen (Aganga and Adogla-Bessa, 1999; Mergeduš et al., 2018; Nawab et al., 2020). However, some proteins can be dissociated from the tannin-protein complexes and be released later in the abomasum due to the pH (2.5–5.1), which allows their digestion and absorption in the small intestine (Mkhize et al., 2018; Zhang et al., 2019; Nascimento et al., 2022). Due to the low availability of nitrogen in the rumen (Naumann et al., 2017), the CT can transfer N from the urine to the feces, reducing the emission of nitrous oxide, further contributing to the environmental sustainability of ruminant production (Powell et al., 2010).

Free tannins, in addition to binding to proteins, can also bind to carbohydrates, binding strongly to cellulose and ruminal microbes (Makkar and Singh, 1995), preventing microbial digestion, and leading to a reduction in ruminal gas production (Lamy et al, 2011). This behavior can be observed in our research when observing the NDF digestibility that was reduced with the inclusion of CT in the diet of the goats, so the CT promoted an inhibitory effect on the degradation of carbohydrates which consequently reduced the

concentration of VFA in the rumen (Patra and Saxena, 2011).

Increasing the levels of condensed tannin in the diet of lactating goats reduced the availability of nutrients for ruminal microorganisms, which consequently reduced the production of greenhouse gases. This reduction in gas production, especially CH₄, may be related to the lower degradation of OM and NDF (Hassanat and Benchaar, 2012). The 34.51% reduction observed in milk production from the treatment with 4.8% tannin compared to the control diet was attributed to reduced intake and digestibility of nutritional fractions. Thus, with the lower availability of nutrients, there was a reduction in milk production. Since dairy production is a highly energy-dependent metabolic process (Goetsch, 2019), the reduction in the emission of gases can improve the animal energy balance. Because the formation of methane is a mechanism of hydrogen elimination from the rumen, but it is accompanied by carbon loss (Beauchemin et al., 2020), promoting energy loss (2 and 12% of the crude energy) of the goats feed intake (Fernández et al., 2021).

Given the observations, we can infer that the use of CT in diets for lactating goats acted to decrease H₂ production due to lower fiber digestibility, which directly inhibited the ruminal methanogenic population or the activities of fibrolytic enzymes, reducing the contribution of H₂ production of farming dairy goat for global warming. According to Sintari et al. (2019), the extensive, semi-intensive and intensive goat milk production systems there are estimated GHG emissions per kg of milk produced around 4.08, 2.04, and 1.82 kg of CO₂ -eq, respectively. In this way, we observed a reduction in GHG emissions per kg of gas emitted with the increase in tannin levels, which is favorable for reducing the carbon footprint in animal production, but at the expense of also decreasing milk production.

The inclusion of condensed tannin extracted from *Schinopsis brasiliensis* in pornunça silages, at levels up to 2.4% DM basis, promotes an increase in DMI, OMI, and milk production as decreases GHG emissions in Saanen goats.

Declarations

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Dalinne Tamara Queiroz Carvalho, Alita Ruth Ferraz de Lucena, Polyana Deyse Rodrigues Marcelino, and Lais Micaele Lopes de Moura. The conceptualization, formal analysis, investigation, methodology, project administration, resources, supervision, were performed by Daniel Ribeiro Menezes, Mário Adriano Ávila Queiroz, and Salete Alves de Moraes. The first draft of the manuscript was written by Dalinne Tamara Queiroz Carvalho and Alita Ruth Ferraz de Lucena. The visualization, data curation, writing review, and editing were performed by Glayciane Costa Gois, Cláudia Horne da Cruz, Anny Graycy Vasconcelos de Oliveira Lima, and Thiago Vinicius Costa Nascimento. All authors read and approved the final manuscript.

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