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REGULAR ARTICLES

Intake, digestibility, growth performance, and enteric methane emission of Brazilian semiarid non-descript breed goats fed diets with different forage to concentrate ratios

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Abstract The aim of this study was to evaluate the intake, digestibility, growth performance, and enteric methane emissions of Brazilian semiarid non-descript breed goats (NDG) fed diets with different forage:concentrate ratios (100:0, 80:20, 60:40, 40:60, and 20:80) on a dry matter basis. Forty uncastrated male NDG with an average initial body weight of 13.3 kg ± 4.7 kg were distributed in a completely randomized design, with five treatments and eight replications. Ground Tifton-85 hay was used as forage and ground corn and soybean meal were used as concentrate. The sulfur hexafluoride tracer technique was used to measure methane emissions. The intake of dry matter, organic matter, crude protein, and ether extract increased linearly while the intake of neutral detergent fiber decreased linearly as the concentrate proportion increased ($P < 0.05$). The digestibility of dry matter and organic matter increased while the digestibility of neutral detergent fiber decreased as the concentrate level increased ($P < 0.05$). There were linear increases in final body weight, total weight gain, average daily gain, and feed efficiency ($P < 0.0001$). Methane emissions per unit of body weight (ranging from 1.9 to 0.5 g/kg), metabolic body weight (ranging from 3.9 to 1.2 g/kg), and dry matter intake (ranging from 58.8 to 21.9 g/kg) reduced linearly as the concentrate proportion increased ($P < 0.01$). Decreasing the forage to concentrate ratio in the diet decreased methane emission and increased growth performance of NDG. The 80:20 ratio could be considered more appropriate to reduce methane emissions from NDG, which did not change much at higher levels of concentrate.

Keywords Forage:concentrate ratio · Goats · Methane · Ruminal fermentation

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Introduction

Due to growing concerns about global warming in response to increased greenhouse gas emissions, several studies on feeding management strategies for ruminants affecting enteric methane emissions have been conducted because ruminal fermentation is one of the main sources of methane contributing to global warming (Cota et al. 2014; Kang et al. 2016; Granja-Salcedo et al. 2016). The use of diets with low forage:concentrate ratio is one of the major management strategies to reduce enteric methane emissions from ruminants through changes in ruminal fermentation (Hristov et al. 2013). Despite this, few studies have been conducted to evaluate the effect of different forage:concentrate ratios on enteric methane emissions in goats (Lima et al. 2016; Na et al. 2017).

The semiarid region of northeastern Brazil has a goat flock of approximately 9 million animals, representing more than 90% of the Brazilian herd (IBGE 2015). Non-descript breed goats (NDG) represent the majority of this flock and originated from random mating of breeds introduced by Portuguese colonizers. They are characterized by their rusticity and adaptation to semiarid conditions. Although goat farming has a great economic, social, and cultural importance in the semiarid region of Brazil, production systems are usually characterized by low productivity due to poor feeding management.

In this way, higher enteric methane emissions per kilogram of animal protein have been reported in regions where livestock production systems have low productivity in response to poor feeding practices (Herrero et al. 2013). Thus, our hypothesis was that enteric methane emissions from NDG could be reduced by decreasing the forage:concentrate ratio in the diet. The aim of this study was to evaluate the effect of forage:concentrate ratio on intake, digestibility, growth performance, and enteric methane emissions of NDG.

Materials and methods

Ethical approval

All animal procedures were approved by the Animal Care and Use Committee of the Universidade Federal do Vale do São Francisco, Brazil, protocol number 0009/140415.

Location and animals

The experiment was conducted at the Animal Metabolism Sector of the Agricultural Sciences Campus of the Universidade Federal do Vale do São Francisco (UNIVASF), Petrolina, PE, Brazil. The climate of the region, according to the Köppen classification, is of the tropical and subtropical steppe type (Bsh), characterized by high temperatures, low humidity, high evaporation rates, and especially marked by the scarcity and irregularity in rainfall distribution.

Forty uncastrated male NDG with an average initial body weight of 13.3 kg ± 4.7 kg and an average age of 5 months were used. The goats were subjected to a 15-day adaptation period to the facilities and the experimental diet. The animals were housed in individual covered stalls, with concrete floor and fitted with drinking and feeding troughs.

Treatments and experimental design

A completely randomized design was used, with five treatments and eight replications, totalizing 40 experimental units. The treatments consisted of different forage:concentrate ratios (100:0, 80:20, 60:40, 40:60, and 20:80) calculated on a dry matter basis. Ground Tifton-85 hay (4-cm sieve) was used as forage and ground corn and soybean meal were used as concentrate (Tables 1 and 2). In addition, a mineral supplement was provided ad libitum.

Different concentrated mixtures were prepared for each treatment from different ground corn:soybean meal ratios. The diet containing 60:40 forage:concentrate ratio was formulated to meet crude protein (CP) requirements for growth of uncastrated indigenous goat kids with 20 kg of body weight and average daily gain of 100 g (NRC 2007). The treatment with forage:concentrate ratio of 80:20 was formulated to have CP content similar to that of Tifton-85 hay. The diets containing forage to concentrate ratios of 40:60 and 20:80 were prepared to have CP content similar to that of 60:40.

Table 1 Chemical composition of feeds used in diets of Brazilian semiarid non-descript breed goats

	Tifton-85 hay	Ground corn	Soybean meal
Dry matter (DM), g/kg	898	871	889
Organic matter, g/kg DM	937	988	935
Ash, g/kg DM	63	12	65
Crude protein, g/kg DM	95	75	524
Neutral detergent fiber, g/kg DM	712	153	153
Acid detergent fiber, g/kg DM	355	59	91

Intake and performance

The animals were fed twice a day at 0800 and 1500 h, allowing no more than 10% of orts. Hay and concentrate were mixed directly in the trough. Amounts of feed offered and refused were weighed and recorded to calculate intake. Daily samples of concentrate, hay, and leftovers were collected and frozen at − 20 °C for subsequent chemical analyzes.

Table 2 Ingredients and chemical composition of diets of Brazilian semiarid non-descript breed goats with different forage to concentrate ratios

	Forage to concentrate ratios				
	100:0	80:20	60:40	40:60	20:80
Ingredients					
Ground Tifton-85 hay, g/kg DM	1000	800	600	400	200
Ground corn, g/kg DM	0	180	340	500	670
Soybean meal, g/kg DM	0	20	60	100	130
Chemical composition					
Dry matter, g/kg	898	877	871	867	881
Ash, g/kg DM	63	32	31	30	37
Organic matter, g/kg DM	937	968	969	970	963
Crude protein, g/kg DM	95	100	123	134	163
Neutral detergent fiber, g/kg DM	712	600	488	376	265
Acid detergent fiber, g/kg DM	355	339	279	248	222
Lignin, g/kg DM	9	5	3	1	1
Ether extract, g/kg DM	16	23	27	34	38

Mineral supplement: 173 g Ca/kg, 8.8 g P/kg, 30 mg S/kg, 10 g Mg/kg, 70 g Co/kg, 1550 mg Na/kg, 45 mg Fe/kg, 24 g Mn/kg, 146 mg Se/kg, 3060 mg Zn/kg, 1840 mg I/kg, 450 mg F/kg, 320,000 IU vitamin A/kg, 50,000 IU vitamin D3/kg, and 800 IU vitamin E/kg

Following the adaptation period, goats were confined for 57 days. The animals were weighed, prior to the first meal, at the beginning and the end of feedlot period to obtain the initial body weight, final body weight, total weight gain, and average daily gain. Feed conversion and efficiency were calculated through the average daily gain and dry matter intake.

Total apparent digestibility

The total apparent digestibility assay was started on day 42 of the feedlot. All animals were housed in metabolic cages containing drinking troughs and feeders for a period of 8 days, five for adaptation and three for total feces collection. Samples of feces, feed, and leftovers were collected and frozen at − 20 °C. Composite samples of the collected material were pre-dried in a forced ventilation oven at 55 °C for 72 h, ground to pass a 1-mm screen (Wiley mill, Marconi, MA-580, Piracicaba, Brazil) and stored in sealed plastic containers for subsequent analyses.

Dry matter (DM, method 934.01), organic matter (OM, method 924.05), CP (method 920.87), and ether extract (EE, method 920.85) were analyzed according to AOAC (1990). Neutral detergent fiber (NDF) was determined according to Mertens (2002), using heat-stable amylase and expressed inclusive of residual ash. Acid detergent fiber (ADF) was analyzed according to method 973.18 of AOAC (AOAC 1990). Lignin (sa) was obtained according to Robertson and Van Soest (1981).

The total apparent digestibility coefficients (DC) of DM and nutrients were calculated by the following formula:

$$\mathrm{DC} = \left[(kilogram\ of\ nutrient\ ingested - kilogram\ of\ nutrient\ excreted)\Big/ kilogram\ of\ nutrient\ ingested\right].$$

Enteric methane emission

Methane measurements were started on day 36 of the confinement period. The sulfur hexafluoride (SF6) tracer technique described by Johnson et al. (1994) and adapted for use in goats by Meister et al. (2013) was used to measure methane enteric emissions. The animals were adapted to the gas sampling apparatus for a period of 10 days prior to measurement. The apparatus consisted of a collector cylinder and a capillary tube extending from the collector cylinder to just above the animal's nostrils. The collector cylinder was attached to the back of the animal with the aid of an apparatus similar to a saddle.

SF6 capsules with a release rate of 1.58 ± 0.12 mg/day were introduced orally into the rumen of goats. Measurements were performed for 5 consecutive days with changes of collector cylinders every 24 h. Gas samples were collected and transferred to a sealed vacuum glass vial. Concentrations of methane and SF6 were measured by gas chromatography using a gas chromatograph (GC–2010 Plus, Shimadzu, Japan) equipped with flame ionization detector and electron capture detector.

Methane emission was calculated as follows:

$$\mathrm{QCH_4} = \mathrm{QSF_6} \times [\mathrm{CH_4}]\Big/[\mathrm{SF_6}],$$

where QCH_4 is the methane emission rate (g/day), QSF_6 is the release rate of SF_6 (g/day), and $[CH_4]$ and $[SF_6]$ are the measured concentrations in the collector cylinders.

Statistical analysis

All data were analyzed by ANOVA using the GLM procedure of SAS (Statistical Analysis System, version 9.1; 2003), according to the following statistical model: $Y = \mu + \alpha + e$, where Y = measured variable, μ = mean, α = effect of treatment, and e = random error. Linear and quadratic responses to the increasing concentrate levels were assessed using orthogonal polynomial contrast at a significance level of 5%.

Results

The intake of DM, OM, CP, and EE increased linearly ($P < 0.05$), while the intake of NDF decreased linearly ($P < 0.0001$) as the ratio of concentrate increased (Table 3). The digestibility of DM and OM increased ($P < 0.01$), while the digestibility of NDF decreased ($P = 0.0160$) as the proportion of concentrate increased (Table 3).

There were linear increases ($P < 0.0001$) in final body weight, total weight gain, and average daily gain (Table 4). Feed efficiency increased linearly ($P = 0.0091$), while feed conversion decreased linearly ($P = 0.0007$) with increasing concentrate in diets (Table 4).

Enteric methane production per day and per year for each goat had a quadratic behavior ($P < 0.0001$) as the concentrate levels increased (Table 5). However, methane emissions per unit of body weight, metabolic body weight, and DM intake reduced linearly ($P < 0.01$) as the concentrate proportion increased (Table 5).

Discussion

The increase in intake of DM, OM, CP, and EE, and decrease in intake of NDF as the forage:concentrate ratio decreased may be explained by an increase in the content of soluble

Table 3 Intake and digestibility of Brazilian semiarid non-descript breed goats fed diets with different forage to concentrate ratios on a dry matter (DM) basis

	Forage to concentrate ratios					SEM	*P* value	
	100:0	80:20	60:40	40:60	20:80		Linear	Quadratic
Intake								
DM, g/day	466	506	580	590	580	22.1	0.0445	0.0907
OM, g/day	435	469	539	556	547	20.1	0.0327	0.0750
CP, g/day	44.8	53.3	74.1	80.2	95.7	4.72	< 0.0001	0.0001
EE, g/day	6.7	11.1	14.7	20.4	23.0	1.24	< 0.0001	< 0.0001
NDF, g/day	333	298	261	197	114	16.8	< 0.0001	< 0.0001
ADF, g/day	165	170	168	142	127	7.6	0.0521	0.0903
Total apparent digestibility								
DM, g/kg	604	664	683	722	800	1.8	0.0002	0.0009
OM, g/kg	614	669	692	719	805	1.5	< 0.0001	0.0003
CP, g/kg	685	703	711	727	804	1.8	0.0786	0.1023
NDF, g/kg	619	568	561	543	492	1.6	0.0160	0.0571

DM dry matter, *OM* organic matter, *CP* crude protein, *EE* ether extract, *NDF* neutral detergent fiber, *ADF* acid detergent fiber, *SEM* standard error of the means

nutrients and a decrease in the fiber content, which could also explain the increases in digestibility of DM and OM. The decrease in NDF digestibility could be related to increased content of soluble nutrients as the forage:concentrate ratio decreased, which could reduce rumen pH and increase digesta passage rate, reducing fiber digestibility. Similar results were obtained by Ma et al. (2014) and Bayat et al. (2017) in sheep and cow, respectively.

To the best of our knowledge, this is the first study that has measured enteric methane emissions from Brazilian semiarid NDG. The annual enteric methane emission from exclusively forage-fed goats was approximately 6.5 kg higher than the mean value obtained from animals fed diets with different forage to concentrate ratios, which in turn was similar to those obtained for goats under grazing (5.3 kg/animal/year) using the SF6 tracer technique (Meister et al. 2013). Animals fed diets containing 40, 60, and 80% concentrate had methane emission per kilogram of DM intake similar to the mean value (20.0 g/kg DM intake) obtained through open-circuit respirometry in dairy goats fed diets with forage to concentrate ratio of about 33:67 (Ibáñez et al. 2016). The relatively high production of enteric methane by goat exclusively fed forage could be partially explained by the use of high-fiber hay (71.2% NDF) and the low DM intake, since these factors could increase the retention time of feed particles in the rumen, increasing their exposure to fermentation and promoting a better rumen environment for methanogens (Wanapat et al. 2015).

Low forage:concentrate ratio in ruminant diets has been one efficient strategy to reduce enteric methane emission (Kumar et al. 2013; Granja-Salcedo et al. 2016; Na et al. 2017). Changes in the proportion of short-chain fatty acids are reported to be one of the main mechanisms explaining this effect because the fermentation of starch-rich concentrate and soluble sugars produces a higher proportion of propionate compared to the fermentation of fiber-rich forage, which in

Table 4 Performance of Brazilian semiarid non-descript breed goats fed diets with different forage to concentrate ratios on a dry matter (DM) basis

Parameters	Forage to concentrate ratios					SEM	*P* value	
	100:0	80:20	60:40	40:60	20:80		Linear	Quadratic
IBW, kg	11.8	12.1	13.7	14.6	13.6	0.39	0.0567	0.1255
FBW, kg	14.3	16.1	18.2	19.8	20.2	0.48	< 0.0001	0.0002
TWG, kg	2.5	4.1	4.5	5.2	6.6	0.28	< 0.0001	0.0003
ADG, g/d	35.3	58.0	63.7	75.0	93.7	0.00	< 0.0001	0.0003
FE, g/kg	80	130	110	130	160	0.0	0.0091	0.0346
FC, kg/kg	13.2	10.3	9.1	9.0	6.6	0.60	0.0007	0.0031

IBW initial body weight, *FBW* final body weight, *TWG* total weight gain, *ADG* average daily gain, *FE* feed efficiency, *FC* feed conversion, *SEM* standard error of the means

Table 5 Enteric methane emission (CH_4) from Brazilian semiarid non-descript breed goats fed diets with different forage to concentrate ratios on a dry matter (DM) basis

Parameters	Forage to concentrate ratios					SEM	*P* value	
	100:0	80:20	60:40	40:60	20:80		Linear	Quadratic
CH_4, g/day	31.0	12.1	14.0	13.1	13.1	1.58	0.0004	< 0.0001
CH_4, kg/year	11.3	4.4	5.1	4.6	4.8	0.58	0.0004	< 0.0001
CH_4, g/kg BW	1.9	0.7	0.7	0.8	0.5	0.08	< 0.0001	< 0.0001
CH_4, g/kg $BW^{0.75}$	3.9	1.4	1.4	1.5	1.2	0.17	< 0.0001	< 0.0001
CH_4, g/kg DMI	58.8	29.9	25.0	23.5	21.9	2.00	0.0012	0.0031

BW body weight, $BW^{0.75}$ metabolic body weight, *DMI* dry matter intake, *SEM* standard error of the means

turn produces greater proportion of acetate (Knapp et al. 2014). The lower the acetate:propionate ratio, the lower the methane production (Hristov et al. 2013). Thus, decreasing NDF intake as the forage:concentrate ratio decreased could reduce substrate availability for methanogenesis.

Furthermore, lower ruminal pH and retention time are also reported to decrease enteric methane emissions as the concentrate is increased in ruminants diets (Knapp et al. 2014; Kumar et al. 2014). These factors could also help explain the decrease in enteric methane emissions per unit of body weight, metabolic body weight, and DM intake with increasing concentrate in diets. Decreasing NDF digestibility could indicate the occurrence of these changes because it could be linked to a higher ruminal passage rate and a lower activity and growth of fiber carbohydrate-fermenting bacteria in response to a lower ruminal pH. These bacteria are primarily responsible for acetate production (Morgavi et al. 2010).

Unlike our results, in a previous study, it was reported that enteric methane emissions per unit DM intake from goats fed with low forage:concentrate ratio (18:82) did not decrease compared to those of animals fed high forage:concentrate ratio (70:30) (Bhatta et al. 2008). This difference could be partially explained by differences between diets. In the previous study, a lower quality concentrate was used, containing soybean hull, cotton meal, beet pulp and brewers grains, among other ingredients. In our study, a ground corn and soybean meal-based concentrate was used. Concentrates rich in starch have been reported to have a greater negative effect on methane production than fibrous concentrates such as beet pulp (Wanapat et al. 2015).

However, there were no reductions in methane emissions from goats in response to decreased forage:concentrate ratio in two recent studies, in which a corn and soybean meal-based concentrate was used (Lima et al. 2016; Na et al. 2017). These conflicting results could be due to differences in forage quality between studies. In addition, diets based exclusively on forage have not been used in the abovementioned studies.

Regarding the quadratic responses in enteric methane emissions per animal per day and year as the forage:concentrate ratio decreased, the increase in DM intake could explain this effect. Because at the same time that the inclusion of concentrate would have been unfavorable for methanogenesis, it promoted a linear increase in DM intake, consequently, higher amount of feed was available for ruminal fermentation. Despite this, the value obtained from exclusively forage-fed goats was approximately twice that of those from goats fed diets containing concentrate. However, when methane production was relative to body weight or DM intake, it had a decreasing linear function as the forage:concentrate ratio decreased. Similar findings have recently been reported, in which increased enteric methane emission from cattle was observed in response to increased DM intake when a better quality feed was offered. However, methane production decreased when it was expressed per unit of DM intake (Cota et al. 2014; Montenegro et al. 2016).

As the decrease in forage:concentrate ratio increased the intake and digestibility of DM, there were increases in final body weight, average daily gain, and feed efficiency. Additionally, enteric methane emissions represent a significant fraction of the dietary energy lost by ruminants (Zou et al. 2016). Thus, the increase in performance of goats with increasing concentrate in diets could also be linked to a higher digestive efficiency.

Goat farming is one of the main economic activities in tropical arid and semiarid regions. Thus, our study could contribute to the Intergovernmental Panel for Climate Change (IPCC) by both providing information on methane emissions of goats in arid and semiarid regions and showing that these emissions can be mitigated by increasing concentrate in their diet.

Conclusion

Decreasing the forage to concentrate ratio in the diet decreased methane emission and increased growth performance of NDG reared under semiarid conditions of Brazil. The 80:20 forage:concentrate ratio reduced methane emissions by approximately 50% compared to diet based exclusively on forage. This inclusion level could be considered more appropriate to reduce methane emissions from NDG, which did not change much at higher levels of concentrate inclusion.

In general, and across the major farmed ruminant species, decreasing forage:concentrate ratios has been shown to decrease methane production and our results are consistent with that. This is especially true where concentrates have high starch contents. Though there remain apparent inconsistencies for goats, as witness the comparison between our results and those of Lima et al. (2016) and Na et al. (2017). As data have accumulated on this topic, opportunities should be taken to exploit the variation in differences among feed qualities that have been used in different experiments to interrogate cognate datasets together so as to tease out dietary variables that have major impact. It then becomes a matter of practicality as to the potential to use this knowledge to commercial and environmental advantage.

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Compliance with ethical standards

Statement of animal rights The experimental procedures followed the animal care of the Committee of the UNIVASF (0009/140415).

Conflict of interest The authors declare that they have no competing interests.

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