

Use of banana (*Musa sp.*) pseudostem hay in feedlot sheep feeding

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ABSTRACT - The objective with this study was to evaluate intake, feeding behavior, rumen fluid characteristics, performance, and nutrient digestibility of sheep fed banana pseudostem hay (BPH) with and without virginiamycin (VM). Thirty-two uncastrated male crossbred Dorper × Santa Inês lambs at approximately five months of age, with an average initial body weight of 25.00±1.95 kg, were used in the experiment. Four diets were tested, as follows: Tifton grass hay (TGH) plus concentrate with VM; BPH replacing 60% of TGH plus concentrate with VM; TGH plus concentrate without VM; and BPH replacing 60% of TGH plus concentrate without VM. The experiment was set up as a completely randomized design in a 2×2 factorial arrangement, in which the factors were represented by BPH and TGH with and without VM, organized in an orthogonal contrast. Banana pseudostem hay inclusion influenced nutrient intake, except for non-fibrous carbohydrates corrected for ash and protein. Neither idling nor water intake times were changed by VM inclusion or banana pseudostem hay addition. Rumen fluid pH did not differ among the contrasts (THV+BHV) vs. (TH+BH), THV vs. TH, and BHV vs. BH, which were used to evaluate VM influence. Banana pseudostem increased rumen fluid pH in the contrast THV vs. BHV, both treatments including VM. Mean temperature of rumen fluid was 34.07 °C, and it did not change by inclusions of VM or banana pseudostem hay. No difference was observed for crude protein digestibility in the evaluated contrasts. When associated with virginiamycin, banana pseudostem hay provides satisfactory performance and nutritional parameters for feedlot sheep. Virginiamycin does not change the performance or nutritional parameters of these animals when Tifton grass hay is used as the only roughage source.

Keywords: digestibility, feeding additive, feed evaluation, feed intake, tannin

Introduction

Sheep farming is a segment of great importance in the Brazilian agricultural sector. This is especially true for family agriculture and for the semiarid region of the northeast part of the country, where the activity is carried out with low use of technologies and with long production cycles. In addition, inputs are supplied seasonally, depending on rainfall, which leads to a dearth of feed for the animals during the dry season.

The use of alternative feedstuffs for small ruminants is a strategy aimed at lessening feed costs and overcoming the herbage scarcity problem occurring at critical times as well as anticipating the sale of those animals for slaughter and producing better-quality carcasses.

Banana (*Musa sp.*) is one of the main fruit species grown in Brazil and widely present in the northeastern semiarid region, where it is cultivated under irrigation. The crop generates large amounts of waste during its harvesting and other cultivation practices. This waste can be used in the feeding of ruminants as roughage source.

In ruminant feedlotting, the concentrate can be purchased from the market. In this scenario, Brazil is a big producer of grains and agroindustrial byproducts. Roughage feeds, however, must be produced locally, as their transport incurs elevated costs. The use of concentrate feeds in ruminant feedlotting may lead to gastrointestinal disorders, mainly clinical or subclinical rumen acidosis. In this regard, the inclusion of rumen-fermentation modulators such as virginiamycin (VM) can prevent such disorders in rumen fermentation.

Virginiamycin is a non-ionophore antibiotic that inhibits the growth of lactic acid-producing Gram-positive bacteria. As such, it enhances animal performance when included in high-grain diets, commonly used in feedlots.

Considering the above-described facts, the present study proposes to evaluate intake, performance, digestibility, feeding behavior, and rumen fluid characteristics of sheep fed banana pseudostem hay (BPH) and Tifton grass hay with and without VM.

Material and Methods

The experiment was developed in Itapetinga - BA, Brazil (15°15'12.48" S, 40°15'19.78" W, 300 m asl), from January to December 2016. All experimental procedures were approved by the Ethics Committee on Animal Use (case no. 116/2015).

Environmental temperature was measured daily at three shifts per day using a digital thermometer, and averages were of 26.06, 30.58, and 25.34 °C for morning, afternoon, and evening shifts, respectively.

Thirty-two uncastrated male crossbred Dorper × Santa Inês lambs, at an average age of five months and initial average body weight of 25.00±1.95 kg, were housed in individual 1.2×1.0 m stalls with slatted floors equipped with feed and water troughs.

The experimental period was 99 days, the first 15 of which were used for the animals to acclimate to the facilities and diets, which were the same used during the data collection period. The concentrate feed was introduced gradually during the acclimation period at 20% every three days, with 100% provided on the last three days.

On the first day of the acclimation period, each animal received the diet in the amount of 4% of their live weight (LW), on a dry matter (DM) basis. For the subsequent days of the entire experimental period, the feed supply was adjusted based on the orts in the trough from the previous day, so that the daily orts would represent 10% of the total supply. Lambs were fed *ad libitum*, twice daily (60% in the morning, at 06.30 h; and 40% in the afternoon, at 16.30 h). All experimental diets contained equal amounts of nitrogen and a roughage:concentrate ratio of 40:60% (DM basis). Banana (*Musa sp.* variety Prata Anã) pseudostem was cut, dried, and ground for hay-making at 2-cm particle size.

Still in the adaptation period, the animals were identified by numbered earrings, their hooves were trimmed, and then they were vaccinated and subjected to endoparasite control. The following vermifuges were applied for the last step: monepantel 25 mg mL⁻¹, administered orally in a single dose of 0.1 mL kg⁻¹ LW of the active ingredient (Zolvix®, Elanco Animal Health, Eli Lilly Australia Pty Ltd Division), and coccidiostat (active ingredient: toltrazuril 5 g 100 mL⁻¹), administered orally in a single dose of 20 mg kg⁻¹ LW of the active ingredient (Isocox®, Ouro Fino Saúde Animal Ltd, SP, Brazil). Lambs were vaccinated with a multipurpose vaccine against clostridial infections (Excell 10®, Venco Saúde Animal, PR, Brazil).

The remaining 84 days were used for data collection, divided into four 21-day phases. The animals were weighed on the first day of the data collection period and at the end of each 21-day phase. The first and last weighing sessions were preceded by a 16-h solid feed deprivation period.

At the end of each 21-day phase, samples of orts from the trough, diet ingredients (Tifton grass hay, banana pseudostem hay, and concentrate feed with and without VM), and feces were collected. These were identified, packed in plastic bags, and frozen at $-20\text{ }^{\circ}\text{C}$ for later analysis.

On the 20th day of each 21-day phase, the feeding behavior of the animals was evaluated, in a total of four analysis throughout the experimental phase. On the day of evaluation, behavioral measures began at 00.00, 06.00, 12.00, and 18.00 h. The studied behavioral variables were feed intake time, rumination time, idling time, and water intake time. Observations were performed using digital stop watches, according to the methodology of Pardo et al. (2003). To record the time expended on each of these activities, the animals were visually observed at every 10 min, according to an adaptation of the methodology proposed by Mezzalira et al. (2011). Total feeding time was determined as the feed intake time, in minutes, while total chewing time (TCT) was determined by the following equation:

$$\text{TCT} = \text{INT} + \text{RUM},$$

in which INT = intake time (min); RUM = rumination time (min).

Rumen temperature and pH were measured by a digital thermometer and a bench pH meter, respectively. Ruminal fluid was collected using an oral speculum and esophageal probe (Dirksen, 1993).

Lambs were allocated at random to four treatments with eight replicates, in which each lamb represented an experimental unit. The following four diets (treatments) were tested: THV – Tifton grass hay plus concentrate with VM; BHV – banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate with VM; TH – Tifton grass hay plus concentrate without VM; and BH – banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate without VM. In treatments THV and BHV, VM was included at $17.4\text{ mg kg}^{-1}\text{ DM}$ (Table 1). As roughage:concentrate ratio, we used a value mostly used in intensive farming systems.

Samples of feeds, orts, and feces were dried in a forced-air oven ($55\text{ }^{\circ}\text{C}/72\text{ h}$) and ground through a Wiley mill to 2-mm particles for *in situ* incubation and to 1-mm particles to determine the chemical composition. Samples of feeds, orts, and feces were incubated in duplicate (20 g DM/cm^2), inside non-woven fabric (TNT) bags, for 288 h in the rumen of two crossbred steers receiving a mixed diet, following Valente et al. (2011). After this period, the remaining material from incubation was subjected to extraction with neutral detergent for the quantification of the indigestible neutral detergent fiber (iNDF) contents, in accordance with Detmann et al. (2012).

Laboratory analyses were performed for the determination of DM, mineral matter (MM), crude protein (CP), ether extract (EE), lignin, neutral detergent fiber (NDF), acid detergent fiber (ADF), and NDF corrected for ash and protein (NDFap) (Sniffen et al., 1992). Analyses of CP, EE, and MM were undertaken by following the procedures proposed by AOAC (1990), whereas NDF, ADF, and lignin were analyzed as suggested by Van Soest and Wine (1967). Total carbohydrates (TC) were estimated by the following formula: $\text{TC} = 100 - (\% \text{CP} + \% \text{EE} + \% \text{MM})$. Non-fibrous carbohydrates (NFC) content was obtained by using the equation recommended by Hall et al. (1998), as follows: $\text{NFC} (\%) = 100 - [(\% \text{CP} - \% \text{CP}_{\text{urea}} + \% \text{urea})] + [\% \text{NDFap} + \% \text{EE} + \% \text{ash}]$, in which CP_{urea} represents the CP from urea (Sniffen et al., 1992). Total digestible nutrients (TDN) were calculated according to Weiss (1999), but using NDF and NFC corrected for ash and protein (Table 2).

The tannin content was determined using 20-g samples of the banana-pseudostem and Tifton-grass hays. The total proanthocyanidin content was quantified in the extract of the two species and in their fractions after solvolysis, acid-catalyzed with *n*-BuOH/37% HCl (95:5), following the methodology described by Hiermann et al. (1986). Absorbance in the solution was read at 540 nm, with values expressed as cyanidin chloride (Table 2).

Table 1 - Proportion and nutritional composition of experimental diets on a dry matter basis

Item	Experimental diet ¹			
	THV	BHV	TH	BH
Ingredient (g kg ⁻¹)				
Tifton grass hay	400	160	400	160
Banana pseudostem hay	0	240	0	240
Corn meal	300	300	300	300
Soybean meal	30	30	30	30
Soybean hull meal	180	180	180	180
Wheat bran	60	60	60	60
Urea	12	12	12	12
Mineral mixture	18	18	18	18
Total	1000	1000	1000	1000
Variable (g kg ⁻¹)				
Dry matter	871.3	863.3	866.5	858.6
Crude protein	207.0	167.9	206.4	167.3
Ether extract	51.0	46.7	54.0	49.7
Mineral matter	74.2	86.7	71.8	84.3
Total carbohydrates	668.4	690.0	667.8	698.8
NFCap	270.8	307.0	272.6	308.8
Neutral detergent fiber	513.8	493.4	515.6	495.2
NDFap	418.8	413.8	422.4	417.4
Acid detergent fiber	330.2	314.8	330.8	315.4
Lignin	67.6	50.8	68.8	52.0
iNDF	113.4	124.4	99.0	110.0
Total digestible nutrients	718.0	721.1	726.4	729.5

NFCap - non-fibrous carbohydrates corrected for ash and protein; NDFap - neutral detergent fiber corrected for ash and protein; iNDF - indigestible neutral detergent fiber.

¹ THV - Tifton grass hay plus concentrate with virginiamycin; BHV - banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate with virginiamycin; TH - Tifton grass hay plus concentrate without virginiamycin; BH - banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate without virginiamycin.

Table 2 - Chemical composition of Tifton grass hay, banana pseudostem hay, concentrate with virginiamycin, and concentrate without virginiamycin on a dry matter basis

Variable (g kg ⁻¹)	Roughage		Concentrate	
	Tifton grass hay	Banana pseudostem hay	With virginiamycin	Without virginiamycin
Dry matter	839	805	893	885
Mineral matter	79	131	71	67
Crude protein	201	38	211	210
Ether extract	54	36	49	54
Neutral detergent fiber	734	649	367	370
NDFap	603	582	296	302
Acid detergent fiber	485	421	227	228
Lignin	145	75	16	18
Total carbohydrates	664	795	670	679
NFCap	62	213	410	413
Total digestible nutrients	490	503	870	884
iNDF	168	214	77	53
Total phenols ¹	5.87	5.75	-	-
Total tannins ²	3.09	5.18	-	-
Condensed tannins ²	0.25	3.03	-	-
Total sugars	71.5	150.1	-	-

NDFap - neutral detergent fiber corrected for ash and protein; NFCap - non-fibrous carbohydrates corrected for ash and protein; iNDF - indigestible neutral detergent fiber.

¹ Corresponding to 1 g of tannic acid per kilogram of DM.

² Corresponding to 1 g of leucocyanidin per kilogram of DM.

Total soluble sugars in the banana pseudostem and Tifton grass hays were quantified by the anthrone method (Dische, 1962) (Table 2).

Daily voluntary intake was calculated as the difference between the total feed supplied and orts collected in the morning throughout the experimental period. Digestibility was estimated based on the fecal excretion, using iNDF as an internal marker.

The digestibility trial was carried out after the end of the experimental period, and feces were harvested directly from the rectal ampulla of the animals once daily, at different times (07.00, 10.00, 13.00, 15.00, and 17.00 h).

For the evaluation of performance, initial body weight (IBW) was determined after a previous solid-feed fasting period of 16 h on the first day of the experiment, and final body weight (FBW) was obtained on the last day also after a 16-h solid feed deprivation period. Average daily gain (ADG) was calculated as the difference between FBW and IBW divided by the number of days in the feedlot.

Feed conversion (FC) and feed efficiency (FE) were calculated based on the DM intake (DMI) and ADG, as follows: $FC = DMI/ADG$ and $FE = ADM/DMI$.

The experiment was set up as a completely randomized design in a 2×2 factorial arrangement, whose factors were represented by banana pseudostem hay and Tifton grass hay with or without VM, organized in an orthogonal contrast. The obtained data were subjected to analysis of variance (Proc MIXED) adopting 0.05 as the critical level of probability for type-I error. The following statistical model was used in the data analysis:

$$\hat{Y}_{ijk} = \mu + A_i + B_j + AB_{ij} + \varepsilon_{ijk},$$

in which \hat{Y}_{ijk} = observed value of the variable; μ = overall mean; A_i = effect of roughage inclusion; B_j = effect of VM inclusion; AB_{ij} = effect of the interaction between factors; and ε_{ijk} = random error associated with each \hat{Y}_{ijk} observation.

Results

The intakes of DM, CP, and TDN for all treatments met the requirements established by the NRC (2006).

Banana pseudostem hay inclusion influenced nutrient intake ($P < 0.05$), except for NFCap in contrasts THV vs. BHV and TH vs. BH, and TDN in contrast TH vs. BH ($P > 0.05$) (Table 3).

In the analysis of the contrast THV vs. BHV for TDN intake (kg day^{-1}), VM inclusion provided equal results ($P > 0.05$) for the treatments with and without banana pseudostem hay, which was due the inclusion of VM in both. In the contrast TH vs. BH, however, in which no VM was included, TH treatment provided higher TDN intake values than BH treatment ($P < 0.05$) (0.929 and 0.784 kg day^{-1} , respectively) (Table 3).

Dry matter intake in kg day^{-1} , $\text{g kg}^{-0.75}$, and g kg^{-1} BW was not influenced by VM in contrasts (THV+BHV) vs. (TH+BH), THV vs. TH, and BHV vs. BH ($P > 0.05$). Banana pseudostem hay in contrasts THV vs. BHV and TH vs. BH, in turn, negatively affected DM intake in kg day^{-1} , $\text{g kg}^{-0.75}$, and g kg^{-1} BW ($P < 0.05$) (Table 3).

Virginiamycin did not influence NDFap intake in contrasts (THV+BHV) vs. (TH+BH), THV vs. TH, and BHV vs. BH in kg day^{-1} , $\text{g kg}^{-0.75}$, or g kg^{-1} BW ($P > 0.05$). The intake of NDFap in kg day^{-1} , $\text{g kg}^{-0.75}$, and g kg^{-1} BW showed differences in contrasts THV vs. BHV and TH vs. BH ($P < 0.05$), which evaluated the effect of banana pseudostem hay in the diets, demonstrating the influence of this ingredient in reducing this variable (Table 3).

Crude protein intake was the same for contrasts (THV+BHV) vs. (TH+BH), THV vs. TH, and BHV vs. BH, which evaluated the influence of VM ($P > 0.05$). In contrasts THV vs. BHV and TH vs. BH, which evaluated the influence of banana pseudostem hay addition, there was a difference in CP intake ($P < 0.001$) (Table 3).

There was a difference in feeding time in min day⁻¹ and min kg⁻¹ DM intake in contrasts (THV+BHV) vs. (TH+BH), which evaluated the influence of VM regardless of the roughage source, and BHV vs. BH, which evaluated the action of VM in the treatments including banana pseudostem hay. Shorter feeding times were found for the VM-containing treatments in both contrasts (P<0.05). In contrast TH vs. BH, banana pseudostem hay inclusion did not change feeding time in min day⁻¹ (P>0.05) but led to an increase in feeding time in min kg⁻¹ DM intake (P<0.05). In the contrast THV vs. TH, which examined the action of VM in the treatments with Tifton grass hay as the only roughage source, and in contrast THV vs. BHV, which evaluated the inclusion of banana pseudostem hay, both containing VM, there was no difference in feeding time in min day⁻¹ or in min kg⁻¹ DM intake (P>0.05) (Table 4).

Table 3 - Means and coefficients of variation (CV) for the nutrient intake of sheep fed Tifton grass and banana pseudostem hays plus concentrate with or without virginiamycin

Item	Treatment ¹				Mean	CV (%)	Contrast (P-value*)				
	THV	BHV	TH	BH			1	2	3	4	5
Intake in kg day ⁻¹											
DM	1.393	1.203	1.387	1.180	1.291	10.8	0.7683	0.9362	0.7336	0.0109	0.0047
CP	0.289	0.215	0.287	0.211	0.251	10.7	0.7298	0.8605	0.7528	0.0001	0.0001
NDFap	0.562	0.472	0.565	0.467	0.517	11.5	0.9755	0.9166	0.8794	0.0050	0.0020
NFCap	0.401	0.390	0.402	0.384	0.394	10.1	0.8952	0.9306	0.7807	0.5981	0.3652
TDN	0.858	0.764	0.929	0.784	0.834	12.8	0.2280	0.1887	0.7051	0.0883	0.0086
Intake in g kg ^{-0.75}											
DM	96.391	83.657	97.272	83.795	90.279	7.3	0.8269	0.7919	0.9662	0.0006	0.0002
NDFap	38.863	32.779	39.602	33.176	36.105	8.1	0.5789	0.6146	0.7802	0.0002	0.0001
Intake in g kg ⁻¹ BW											
DM	3.962	3.441	4.014	3.471	3.722	6.9	0.6433	0.6795	0.8106	0.0003	0.0001
NDFap	1.597	1.348	1.634	1.374	1.4883	7.5	0.4224	0.5080	0.6362	0.0001	0.0001

DM - dry matter; CP - crude protein; NDFap - neutral detergent fiber corrected for ash and protein; NFCap - non-fibrous carbohydrates corrected for ash and protein; TDN - total digestible nutrients.

¹ THV: Tifton grass hay plus concentrate with virginiamycin; BHV: banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate with virginiamycin; TH: Tifton grass hay plus concentrate without virginiamycin; BH: banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate without virginiamycin.

Contrasts: 1 = (THV+BHV) vs. (TH+BH); 2 = THV vs. TH; 3 = BHV vs. BH; 4 = THV vs. BHV; 5 = TH vs. BH.

*0.05 was adopted as the critical level of probability.

Table 4 - Mean values for the time expended on the feeding, rumination, idling, and water intake activities by sheep fed Tifton-grass or banana-pseudostem hays plus concentrate with or without virginiamycin

Item	Treatment ¹				Mean	CV (%)	Contrast (P-value*)				
	THV	BHV	TH	BH			1	2	3	4	5
Feeding											
min day ⁻¹	204	197	225	225	212.75	4.20	0.0040	0.1092	0.0091	0.5073	0.9911
min kg ⁻¹ DM	153	160	167	196	169	4.21	0.0022	0.2393	0.0009	0.4441	0.0229
Rumination											
min day ⁻¹	420	445	423	447	433.75	6.86	0.5312	0.7770	0.5391	0.1863	0.1338
min kg ⁻¹ DM	308	367	316	388	344.75	6.88	0.2496	0.6402	0.2438	0.0006	0.0002
Idling											
min day ⁻¹	785	770	772	741	767	8.07	0.0510	0.2910	0.0813	0.3485	0.1381
Water intake											
min day ⁻¹	30	28	20	27	26.25	1.93	0.1251	0.0629	0.7828	0.7452	0.1249

DM - dry matter.

¹ THV: Tifton grass hay plus concentrate with virginiamycin; BHV: banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate with virginiamycin; TH: Tifton grass hay plus concentrate without virginiamycin; BH: banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate without virginiamycin.

Contrasts: 1 = (THV+BHV) vs. (TH+BH); 2 = THV vs. TH; 3 = BHV vs. BH; 4 = THV vs. BHV; 5 = TH vs. BH.

*0.05 was adopted as the critical level of probability.

For rumination time in min day^{-1} and min kg^{-1} DM intake in contrasts (THV+BHV) vs. (TH+BH), THV vs. TH, and BHV vs. BH, which evaluated the influence of VM regardless of the roughage source, there was no difference ($P>0.05$). In contrasts THV vs. BHV and TH vs. BH, the inclusion of banana pseudostem hay did not change rumination time in min day^{-1} ($P>0.05$) but increased rumination time in min kg^{-1} DM intake ($P<0.05$) (Table 4).

Idling and water intake times were not changed by VM inclusion or by the addition of banana pseudostem hay to the diets in either min day^{-1} or min kg^{-1} DM intake ($P>0.05$) (Table 4).

Rumen fluid pH in contrasts (THV+BHV) vs. (TH+BH), THV vs. TH, and BHV vs. BH, which evaluated the influence of VM, did not differ ($P>0.05$). In the contrast TH vs. BH, both treatments without VM, addition of banana pseudostem hay did not change the rumen fluid pH ($P>0.05$). However, banana pseudostem hay increased the rumen fluid pH in the contrast THV vs. BHV, both treatments including VM ($P<0.05$) (Table 5).

Rumen fluid temperature was $34.07\text{ }^{\circ}\text{C}$ and did not change after addition of VM or banana pseudostem hay ($P>0.05$) (Table 5).

The digestibility of DM was lower with the inclusion of VM as shown in the contrast (THV+BHV) vs. (TH+BH) ($P<0.05$), which evaluated the action of VM irrespective of the roughage source. This can also be observed in contrast THV vs. TH ($P<0.05$), which compared the action of VM in the treatments with Tifton grass hay as the only roughage source. Virginiamycin did not influence the DM digestibility in contrast BHV vs. BH ($P>0.05$), which evaluated the effect of VM in the two treatments with the presence of banana pseudostem hay. Banana pseudostem hay inclusion did not influence the DM digestibility, with or without VM, as observed in contrasts THV vs. BHV and TH vs. BH ($P>0.05$) (Table 6).

No difference was observed for CP digestibility in contrasts (THV+BHV) vs. (TH+BH), THV vs. TH, and BHV vs. BH ($P>0.05$), which evaluated the effect of VM. In contrast TH vs. BH, in which none of the

Table 5 - Means and coefficients of variation (CV) for the pH and temperature of the rumen fluid of sheep fed Tifton grass or banana pseudostem hays plus concentrate with or without virginiamycin

Item	Treatment ¹				Mean	CV (%)	Contrast (P-value*)				
	THV	BHV	TH	BH			1	2	3	4	5
pH	6.46	6.70	6.51	6.52	6.54	3.19	0.4044	0.6116	0.0929	0.0341	0.9821
Temperature ($^{\circ}\text{C}$)	34.55	33.83	33.46	34.32	34.07	3.25	0.4565	0.0667	0.3610	0.2009	0.3610

¹ THV: Tifton grass hay plus concentrate with virginiamycin; BHV: banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate with virginiamycin; TH: Tifton grass hay plus concentrate without virginiamycin; BH: banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate without virginiamycin.

Contrasts: 1 = (THV+BHV) vs. (TH+BH); 2 = THV vs. TH; 3 = BHV vs. BH; 4 = THV vs. BHV; 5 = TH vs. BH.
*0.05 was adopted as the critical level of probability.

Table 6 - Means and coefficients of variation (CV) for the nutrient digestibility of sheep fed Tifton grass or banana pseudostem hays plus concentrate with or without virginiamycin

Item	Treatment ¹				Mean	CV (%)	Contrast (P-value*)				
	THV	BHV	TH	BH			1	2	3	4	5
	Digestibility (%)										
DM	58.825	61.262	63.462	62.533	61.521	5.3	0.0154	0.0086	0.4332	0.1493	0.5657
CP	54.087	50.375	58.425	50.189	53.269	12.8	0.3895	0.2131	0.9556	0.2849	0.0189
NDFap	44.012	46.712	51.487	50.767	48.245	12.1	0.0084	0.0160	0.1641	0.3632	0.8014
NFCap	93.412	93.550	91.500	94.189	93.163	3.3	0.5559	0.2221	0.6712	0.9291	0.0815
EE	49.800	55.050	59.762	56.444	55.264	14.4	0.0499	0.0182	0.7211	0.1975	0.3981

DM - dry matter; CP - crude protein; NDFap - neutral detergent fiber corrected for ash and protein; NFCap - non-fibrous carbohydrates corrected for ash and protein; EE - ether extract.

¹ THV: Tifton grass hay plus concentrate with virginiamycin; BHV: banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate with virginiamycin; TH: Tifton grass hay plus concentrate without virginiamycin; BH: banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate without virginiamycin.

Contrasts: 1 = (THV+BHV) vs. (TH+BH); 2 = THV vs. TH; 3 = BHV vs. BH; 4 = THV vs. BHV; 5 = TH vs. BH.
*0.05 was adopted as the critical level of probability.

treatments had VM, CP digestibility was lower ($P < 0.05$) for the treatment in which banana pseudostem hay was included. In contrast THV vs. BHV, however, which made the same comparison, but both treatments containing VM, there was no difference for this variable ($P > 0.05$). The CP digestibility in treatment THV was 54.087%, whereas in treatment TH it was 58.425%, suggesting a downward trend for CP digestibility in response to VM (Table 6).

The NDFap digestibility was lower in the presence of VM, as evidenced by contrast (THV+BHV) vs. (TH+BH) ($P < 0.05$), which evaluated the action of VM regardless of the roughage source. This was also confirmed in contrast THV vs. TH ($P < 0.05$), which compared the action of VM in the treatments with Tifton grass hay as the only roughage source. Virginiamycin did not affect NDFap digestibility in contrast BHV vs. BH ($P > 0.05$), which evaluated the action of VM in the treatments in which banana pseudostem hay was added. Inclusion of banana pseudostem hay did not influence this variable in contrasts THV vs. BHV, both treatments containing VM, and TH vs. BH, in which neither diet contained VM ($P > 0.05$) (Table 6).

The digestibility of NFCap was not influenced by VM in contrasts (THV+BHV) vs. (TH+BH), THV vs. TH, and BHV vs. BH ($P > 0.05$). Likewise, inclusion of banana pseudostem hay did not change the NFCap digestibility in contrasts THV vs. BHV and TH vs. BH ($P > 0.05$) (Table 6).

The EE digestibility was lower when VM was included, as observed in contrast (THV+BHV) vs. (TH+BH) ($P < 0.05$), which evaluated the action of VM irrespective of the roughage source. This fact was also true according to contrast THV vs. TH ($P < 0.05$), which compared the action of VM in the treatments with Tifton grass hay as the only roughage component. Virginiamycin did not influence EE digestibility in contrast BHV vs. BH ($P > 0.05$), which analyzed the action of VM in the treatments containing banana pseudostem hay. Inclusion of banana pseudostem hay did not influence this variable, as shown by contrast THV vs. BHV, in which both diets contained VM, and contrast TH vs. BH, neither treatment containing VM ($P > 0.05$) (Table 6).

Final body weight was not influenced by VM ($P > 0.05$) or by the addition of banana pseudostem hay in the diet ($P > 0.05$) (Table 7). Virginiamycin did not influence total weight gain (TWG) in contrasts (THV+BHV) vs. (TH+BH), THV vs. TH, and BHV vs. BH ($P > 0.05$). Banana pseudostem hay had a negative effect on TWG in contrast TH vs. BH ($P < 0.05$), in which treatment TH provided a TWG of 20.930 kg vs. the 17.693 kg obtained with treatment BH, both without VM. In contrast THV vs. BHV, which was the same comparison between roughages, though neither including VM, there was no difference for this parameter ($P > 0.05$) (Table 7).

Virginiamycin influenced ADG in contrasts (THV+BHV) vs. (TH+BH), THV vs. TH, and BHV vs. BH ($P > 0.05$). Banana pseudostem hay had a negative effect on ADG in contrast TH vs. BH ($P < 0.05$), whose treatments led to respective ADG of 0.249 and 0.211 kg day⁻¹, both without VM. Contrast THV vs. BHV,

Table 7 - Means and coefficients of variation (CV) for the performance of sheep fed Tifton-grass or banana-pseudostem hays plus concentrate with or without virginiamycin

Item	Treatment ¹				Mean	CV (%)	Contrast (P-value*)				
	THV	BHV	TH	BH			1	2	3	4	5
IBW (kg)	25.177	25.697	23.995	25.138	25.002	-	-	-	-	-	-
FBW (kg)	45.217	44.152	44.925	42.831	44.281	7.9	0.5139	0.8685	0.4438	0.5479	0.2285
TWG (kg)	20.040	18.455	20.930	17.693	19.280	14.8	0.9489	0.5364	0.5859	0.2743	0.0263
ADG (kg day ⁻¹)	0.238	0.220	0.249	0.211	0.230	14.8	0.9405	0.5355	0.5952	0.2744	0.0270
FC (kg day ⁻¹)	5.903	5.494	5.656	5.635	5.672	9.7	0.7847	0.3743	0.5982	0.1454	0.9382
FE (kg day ⁻¹)	0.171	0.182	0.178	0.179	0.178	9.2	0.7832	0.4074	0.6443	0.1939	0.9710

IBW - initial body weight; FBW - final body weight; TWG - total weight gain; ADG - average daily gain; FC - feed conversion; FE - feed efficiency.

¹ THV: Tifton grass hay plus concentrate with virginiamycin; BHV: banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate with virginiamycin; TH: Tifton grass hay plus concentrate without virginiamycin; BH: banana pseudostem hay replacing 60% of Tifton grass hay plus concentrate without virginiamycin.

Contrasts: 1: (THV+BHV) vs. (TH+BH); 2: THV vs. TH; 3: BHV vs. BH; 4: THV vs. BHV; 5: TH vs. BH.

*0.05 was adopted as the critical level of probability.

however, which made the same comparison between roughages, but with VM, showed no differences for this variable ($P>0.05$) (Table 7).

Feed conversion and FE were not affected in this study. There were no significant differences in any of the contrasts ($P>0.05$) for addition of neither VM nor banana pseudostem hay (Table 7).

Discussion

Inclusion of banana pseudostem hay affected nutrient intake except for NFCap with and without VM, and TDN with VM. The lack of differences for NFCap intake was attributed to the higher concentration of this indicator in the banana pseudostem hay, 213 g kg^{-1} , whereas Tifton grass hay contained 62 g kg^{-1} NFCap in the DM as well as higher concentration of total sugars, 150.1 vs. 71.5 g kg^{-1} for banana pseudostem hay and Tifton grass hay, respectively (Table 2). In the experimental diets, the concentration of NFCap in the DM was 270.8 , 307.0 , 272.6 , and 308.8 g kg^{-1} for THV, BHV, TH, and BH, respectively (Table 1).

In terms of TDN intake, VM inclusion provided equal results for the treatments with and without banana pseudostem hay, as it depressed THV intake in comparison with the TH diet (0.858 and $0.929 \text{ kg day}^{-1}$, respectively). According to Salinas-Chavira et al. (2016), VM improves FE and, consequently, tends to reduce TDN intake.

Dry matter intake in kg day^{-1} , $\text{g kg}^{-0.75}$, and g kg^{-1} BW was not influenced by VM, although it was negatively affected by banana pseudostem hay, which was likely due to its higher iNDF concentration than that of Tifton grass hay, 214 and 168 g kg^{-1} , respectively (Table 2). Virginiamycin is used as additive to improve performance, since it increases FE and maintains weight gain, reducing DM intake. These features have already been approached by Murray et al. (1992), who observed that VM decreased DM intake of sheep when added to diets at levels above 20 mg kg^{-1} LW. Muniz et al. (2012) stated that larger indigestible fractions in the diet limit DM intake. As in the current experiment, VM did not influence DM intake in Holstein steers (Salinas-Chavira et al., 2009; Salinas-Chavira et al., 2016), in $\frac{1}{4}$ Brahma and $\frac{3}{4}$ taurine crossbred steers (Montano et al., 2015), or in crossbred steers (Navarrete et al., 2017). Contrary to the present findings, VM contributed to lowering DM intake in kg day^{-1} and g kg^{-1} BW in Nellore steers fed diets containing 73 and 91% concentrate (Nuñez et al., 2013). According to Duffield et al. (2012), unlike ionophores, VM causes little or no alterations in DM intake.

The presence of tannin in banana byproducts, especially in the pseudostem, is considered an antinutritional factor. Even though ruminants are characterized as being more resistant to tannin than non-ruminants, one of the main effects of this polyphenol is the reduction of voluntary intake, as pointed out by Oliveira and Berchielli (2007). In our investigation, both Tifton grass hay and banana pseudostem hay had high total tannin contents, 3.09 and 5.18 g kg^{-1} DM, respectively. However, banana pseudostem hay had a higher condensed tannin content than Tifton grass hay, 3.03 and 0.25 g kg^{-1} DM, respectively (Table 2).

In the presence of condensed tannins, a decrease in voluntary intake is related to the formation of complexes between tannins and glycoproteins in the mouth (astringency) (Cannas, 2016). In the rumen, condensed tannins bind to proteins and other macromolecules, especially through hydrophobic interactions and hydrogen bridges. These bonds are irreversible, depending on the pH of complexes, and they can also inhibit the growth of proteolytic bacteria, which may reduce proteolysis. However, these effects were not consistently observed. Such discrepancies between studies are attributed to the tannin-protein interaction modes, which do not always work optimally, depending on the chemical structures of tannins and proteins (Min et al., 2003; Patra and Saxena, 2011).

The contribution of roughage feeds to the condensed tannin contents in the total diets was 7.6 and 1.0 g kg^{-1} DM for the diets with banana pseudostem hay (BHV and BH) and for the diets with Tifton grass hay as the only roughage source (THV and TH), respectively. However, in this experiment, the animals selected the feed despite its supply as a total diet. The lambs consumed first the concentrate and then the roughage. Therefore, upon roughage intake, the condensed tannin content was equivalent to that of roughage itself. Aerts et al. (1999) reported that the condensed tannin intake of 4 to 6% of

the diet DM by sheep increased their milk and wool production and weight gain; when at 6 to 12% DM, it caused a reduction of voluntary intake, digestive efficiency, and animal production. Gerassew et al. (2013) obtained a different result in an experiment in which feedlot sheep fed a diet with a roughage:concentrate ratio of 40:60% and *Cynodon spp.* or banana pseudostem hay as roughage sources. The treatment with *Cynodon spp.* provided a lower DM intake.

Virginiamycin did not influence NDFap intake. This result corroborates the reports of Salinas-Chavira et al. (2009, 2016), who described that it also did not change the NDF intake of Holstein steers. Banana pseudostem hay led to a lower NDFap intake, which is explained by the decreased DM intake following addition of this roughage component.

Virginiamycin did not influence CP intake. According to this experiment, VM did not change the intake of nitrogen from the diet of Holstein steers (Salinas-Chavira et al., 2009; Salinas-Chavira et al., 2016). Banana pseudostem hay provided a lower CP intake, which is related to the lower concentration of this indicator in the DM of this hay in comparison with the hay made of Tifton grass: 38 and 201 g kg⁻¹, respectively (Table 2). It is also associated with the lower CP intake in the DM of the total diets with the inclusion of banana pseudostem hay compared with the treatments in which Tifton grass hay was the only roughage source: 207, 167.9, 206.4, and 167.3 g kg⁻¹ for treatments THV, BHV, TH, and BH, respectively (Table 1).

Virginiamycin contributed to reducing feeding time in min day⁻¹ and in min kg⁻¹ DM intake regardless of the roughages. When associated with VM, the addition of banana pseudostem hay reduced feeding time in min day⁻¹ and min kg⁻¹ DM intake; without VM, only in mg kg⁻¹ DM. Virginiamycin increases the use efficiency of dietary nutrients as a result of the maintenance of rumen pH, increased propionate production, and decreased loss of energy as methane (Ives et al., 2002).

Virginiamycin did not influence rumination time in min day⁻¹ or in min kg⁻¹ DM intake, irrespective of the roughage sources. Banana pseudostem hay, in turn, did not influence rumination time in min day⁻¹, but increased it in min kg⁻¹ DM intake, with or without VM. This difference relates to the fiber quality in banana pseudostem hay, which showed a higher concentration of iNDF than did Tifton grass hay, 214 and 168 g kg⁻¹, respectively (Table 2). A diet with a higher iNDF content tends to require a longer rumination time per kilogram of DM consumed (Mendes Neto et al., 2007).

The pH of the rumen fluid of the evaluated sheep remained close to neutrality, averaging 6.54 across the treatments; the highest mean value was found in the diet with inclusion of banana pseudostem hay associated with VM, 6.7 (Table 5). The pH values found were normal, since high-fiber diets lead to a longer rumination time and, consequently, greater saliva production, elevating the pH. A normal pH value in rumen content varies between 5.5 and 7.4 throughout the day, according to the feeding management applied and the time passed since the last feed supply (Dirksen, 1993).

Rumen pH directly reflects the characteristics of the diet and fermentation products, but also the microbial growth rate; therefore, there may be variations in the predominant rumen microorganisms (Lavezzo et al., 1998). This assertion was corroborated by Freitas et al. (2017), who evaluated the pH of the rumen fluid from sheep fed banana leaf hay replacing *Cynodon dactylon* cv. Vaqueiro in the semiarid region of Brazil. In their study, the pH was not influenced by the inclusion of banana leaf hay, suggesting that this ingredient has little toxicity to the rumen microbiota of those animals.

The mean temperature of ruminal fluid (34.07 °C) is relatively lower than the pattern for ruminal environment described by Furlan et al. (2011), which is 39 °C. Despite being immediately measured, such a drop in temperature may have occurred due to losses between collection and measurement, since digestive processes were observed to be within normal patterns.

In high-grain diets, which are commonly used in ruminant feedlots, the action of VM alters the rumen kinetics, inhibiting Gram-positive bacteria and favoring the development of Gram-negative bacteria. In general, acetate-, butyrate-, and methane-producing bacteria are susceptible to VM, whereas lactate-consuming bacteria are resistant. This allows for a more stable rumen environment, with a lesser risk of acidosis and with a more advantageous fermentation for the host, since propionate production is

energetically more efficient than acetate and butyrate production (Nagaraja et al., 1987; Hutton et al., 2010). The DM of the diet with Tifton grass hay as the only roughage source plus VM was less digestible, especially because the digestibility of NDFap was affected by the impact of VM on certain fibrolytic bacteria. However, VM did not influence the DM digestibility in the treatments with banana pseudostem hay, and the inclusion of this hay in the diets did not affect the DM digestibility with or without VM. The impact of VM only on the digestibility of the fiber in Tifton grass hay can be explained by factors exclusive to other diet components that were not investigated in this study, e.g., the formation of complexes of condensed tannins with VM.

Our findings are in conflict with those reported by Oliveira et al. (2015), who worked with lactating Holstein/Zebu cows by comparing control group, without antimicrobials, with a group receiving salinomycin at the dose of 120 mg kg⁻¹ LW, a group receiving VM at 150 mg kg⁻¹ LW, and a group receiving salinomycin plus VM at 120 and 150 mg kg⁻¹ LW, respectively. The authors concluded that there was no difference in DM digestibility. In an experiment with Holstein calves receiving 22.5 mg kg⁻¹ VM in the DM, no differences were observed in DM digestibility (Salinas-Chavira et al., 2016). Navarrete et al. (2017) worked with crossbred steers fed 28 mg kg⁻¹ VM in the DM and obtained no differences in DM digestibility. In an experiment with crossbred steers, Lemos et al. (2016) tested several antimicrobials and combinations and also did not obtain differences in DM digestibility. Some of the antimicrobials tested were monensin at 30 mg kg⁻¹ DM, VM at 25 mg kg⁻¹ DM, monensin at 20 mg kg⁻¹ DM plus VM at 25 mg kg⁻¹ DM, flavomycin at 4.4 mg kg⁻¹ DM, and monensin at 20 mg kg⁻¹ DM plus flavomycin at 4.4 mg kg⁻¹ DM.

There were no differences for CP digestibility as influenced by VM. The digestibility of CP declined with the inclusion of banana pseudostem hay without VM. The higher concentration of condensed tannins in banana pseudostem hay compared with Tifton grass hay, 3.03 vs. 0.25 g kg⁻¹, respectively (Table 2), might have interfered with the CP digestibility. Condensed tannins form complexes with the dietary proteins, reducing this variable (Yisehak et al., 2016). In the contrast that makes the same comparison but without VM, there was no difference for CP digestibility when banana pseudostem hay was used, which was due to the depression of CP digestibility in THV treatment (with VM), where it was found at 54.087% vs. the 58.425% in TH treatment (without VM), indicating a trend towards a reduction of CP digestibility as affected by VM. In an experiment with steers receiving 19.5 mg kg⁻¹ VM in the DM, the authors observed a reduction in rumen ammoniacal N and in the proteolytic and amylolytic bacteria counts and no changes in the total bacterial count (Guo et al., 2010). The main species of proteolytic bacteria present in the rumen are Gram-sensitive, and thus sensitive to VM (Paster et al., 1993).

The NDFap digestibility was lower when VM was included in the diet, irrespective of the roughage component. Virginiamycin did not influence the NDFap digestibility in the comparison of the two diets containing banana pseudostem hay, and the hay, in turn, did not influence this variable. Our results disagree with those published by Salinas-Chavira et al. (2016), who conducted an experiment with Holstein steers receiving 16.0 mg kg⁻¹ VM in the DM, 22.5 mg kg⁻¹ VM in the DM, and a control diet without VM and concluded that VM did not interfere with the NDF digestibility. In an experiment with crossbred steers receiving 28 mg kg⁻¹ VM in the DM and a control treatment without it, the additive did not influence the NDF digestibility (Navarrete et al., 2017). The supply of 25 mg kg⁻¹ VM in the DM for crossbred steers did not alter the NDF digestibility (Lemos et al., 2016). In the current experiment, VM was supplied at the level of 17.4 mg kg⁻¹ DM in treatments THV and BHV.

Virginiamycin and banana pseudostem hay did not influence NFCap digestibility, which agrees with other experiments in which VM was included in diets for steers and did not change the digestibility of starch (Salinas-Chavira et al., 2009; Montano et al., 2015; Salinas-Chavira et al., 2016; Navarrete et al., 2017).

The EE digestibility was lower with VM inclusion regardless of the roughage source, and the same is observed as we compare the action of VM in the treatments with Tifton grass hay as the only roughage source. Banana pseudostem hay also did not influence EE digestibility, either with or without VM.

Disagreeing with our observations, Oliveira et al. (2015) worked with Holstein/Zebu cows and did not find differences in EE digestibility including VM or associating VM with salinomycin in the diet as compared with the group with antimicrobial agents.

Final body weight was not influenced by VM or by the addition of banana pseudostem hay. Virginiamycin did not influence TWG, irrespective of the roughage source. Addition of banana pseudostem had a negative impact on TWG compared with Tifton grass hay as the only roughage source, both without VM. When the same comparison was made between roughages, but both including VM, no difference was detected, and this result is attributed to the better action of VM on the BHV treatment than on BH (TWG: 18.455 vs. 17.693 kg, respectively). Furthermore, VM had a worse effect on THV treatment than on TH (TWG: 20.040 vs. 20.930 kg, respectively).

Virginiamycin did not influence ADG, regardless of the roughage component. When added to the diet, banana pseudostem hay affected ADG negatively as compared with Tifton grass hay supplied as the only roughage source, both without VM. In the comparison between both roughage sources with VM, no difference was observed. This lack of differences may be attributed to the better action of VM on the BHV treatment as compared with BH (ADG: 0.220 and 0.211 kg, respectively) and to the worse effect of VM on THV treatment than on TH treatment (ADG: 0.238 and 0.249 kg, respectively).

Average daily gain reflects the result found for CP digestibility. The action of VM increased CP digestibility when associated with the treatment including banana pseudostem hay, considering the lower percentage of CP in the roughage and in the total diet. Banana pseudostem hay likely reduced CP degradation in the rumen, increasing the bypass protein and improving the digestion and absorption of the dietary protein in the small intestine. According to Stewart et al. (2010), addition of VM to the diet of growing pigs increases the ileal digestibility of amino acids. Our results disagree with those obtained with sheep by Gerassev et al. (2013), who found a higher ADG for the treatment including banana pseudostem hay compared with the group fed *Cynodon sp.* (respective ADG: 0.190 and 0.106 kg day⁻¹), using the same roughage:concentrate ratio as that used here (60:40%) and no antimicrobial agent. On the other hand, the present study corroborates experiments in which VM did not change the ADG of steers receiving VM compared with control group, without the agent (Salinas-Chavira et al., 2009; Nuñez et al., 2013; Montano et al., 2015; Ferreira et al., 2015; Lemos et al., 2016; Navarrete et al., 2017; Salinas-Chavira et al., 2016). The same conclusion was made in an experiment with dairy heifers (Golder et al., 2014).

In this study, FC and FE were not affected by inclusion of neither VM nor banana pseudostem hay. A similar finding was reported by Gerassev et al. (2013), who worked with banana pseudostem hay replacing *Cynodon spp.* in the diet of feedlot sheep. The present results disagree with the observations of Maciel et al. (2015), who stated that the use of additives in ruminant nutrition improves their FE as a result of modifications in rumen fermentation. The latter authors reported that VM used in pasture supplementation resulted in better FC. In experiments with Holstein steers (Salinas-Chavira et al., 2009; Salinas-Chavira et al., 2016) and crossbred steers (Montano et al., 2015), VM improved FE. In studies with Nellore steers (Nuñez et al., 2013; Lemos et al., 2016) and crossbred steers (Navarrete et al., 2017), there was no difference in FE with the use of VM.

Conclusions

When associated with virginiamycin, banana pseudostem hay provides satisfactory performance and nutritional parameters for feedlot sheep. Virginiamycin does not change the performance or nutritional parameters of these animals when Tifton grass hay is used as the only roughage source.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: J.A. Silveira Junior, M.S. Pedreira, A.J. Del Rei, C.E.S. Freitas and A.A. Oliveira. Data curation: J.A. Silveira Junior, M.S. Pedreira and M.S. Soares. Formal analysis: J.A. Silveira Junior, M.S. Pedreira and M.S. Soares. Funding acquisition: J.A. Silveira Junior and M.S. Pedreira. Investigation: J.A. Silveira Junior, A.J. Del Rei, H.A. Silva, A.A. Oliveira and F.F. Hora. Methodology: J.A. Silveira Junior, M.S. Pedreira, A.J. Del Rei and C.E.S. Freitas. Project administration: J.A. Silveira Junior. Resources: J.A. Silveira Junior and M.S. Pedreira. Software: J.A. Silveira Junior, M.S. Pedreira and M.S. Soares. Supervision: J.A. Silveira Junior, M.S. Pedreira and A.J. Del Rei. Validation: J.A. Silveira Junior, M.S. Pedreira and A.J. Del Rei. Visualization: J.A. Silveira Junior, M.S. Pedreira and A.J. Del Rei. Writing-original draft: J.A. Silveira Junior. Writing-review & editing: J.A. Silveira Junior, M.S. Pedreira, C.E.S. Freitas, H.A. Silva and M.S. Soares.

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