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Sisal silage addition to feedlot sheep diets as a water and forage source

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ABSTRACT

The objective of this study was to evaluate the water and nutrient intake, apparent digestibility, productive performance and carcass traits of sheep fed diets containing levels of sisal pulp silage (SPS) in substitution of tifton hay. Forty Santa Ines lambs (average initial body weight of 22 ± 3.4 kg) were randomly distributed among four diets containing 0, 167, 333, and 500 g/kg of SPS in the total dietary dry matter (DM), containing 500 g/kg of concentrate. The experimental period lasted 72 days, after 21 days of adaptation to the diets. Linear and quadratic effects of SPS levels were analyzed using orthogonal contrast. Intake of DM and OM were not affected by the substitution of tifton hay with SPS ($P > 0.05$). Intake of crude protein (CP), ether extract (EE), neutral digestible fiber (NDF) and acid digestible fiber (ADF) decreased linearly as SPS increased ($P < 0.05$). The inclusion of SPS in the diets decreased linearly the voluntary water intake ($P < 0.05$). Apparent digestibility of nutrients increased linearly with increasing dietary SPS levels, except for non-fibrous carbohydrates. Productive performance and carcass characteristics did not show significant effects ($P > 0.05$). Sisal pulp silage is a suitable source to feed sheep, since animals showed similar intake and performances and it can be a consistent water source in arid and semiarid regions. Because of moderate concentration of physically effective fiber in the 333 g/kg SPS diet group, we recommend the inclusion of 333 g/kg of SPS in dietary dry matter in combination with tifton hay.

1. Introduction

Non-cultivated cactus, yuccas and agaves are widely used as forage source for ruminant feeding during drought periods in semiarid countries (Negesse et al., 2009; Zamudio et al., 2009; Costa et al., 2012). The use of non-conventional and adapted crops would impact positively in the sustainable intensification of livestock systems by reducing feed cost, decreasing competition for food with humans, contributing to decrease nutrient input from non-local sources and to the feed supply (Negesse et al., 2009).

Sisal (*Agave* sp.) is cultivated for fiber production in many hot climate and arid regions due to its adaptation to dry and hot environments (Kanwal et al., 2012), and its by-products are commonly used for ruminant feeding (Zamudio et al., 2009; Iniguez-Covarrubias et al., 2001). The by-product obtained from the defibrillation process consists of the pulp and some residual fiber, which

Abbreviations: SPS, sisal pulp silage; DM, dry matter; OM, organic matter; CP, crude protein; NFC, non-fibrous carbohydrates; aNDFom, neutral detergent fiber assayed with a heat stable amylase and expressed exclusive of residual ash ADF acid detergent fiber; TN, total nitrogen; NDIP, neutral detergent insoluble protein pef_8 and $pef_{1.18}$ physical effectiveness factor of neutral detergent fiber (NDF) determined as the sum of particles retained above 8-mm screen and above 1.18-mm screen respectively; $peNDF_8$ and $peNDF_{1.18}$, physically effective NDF determined by product between NDF content of sisal silage and pef8 and pef1.18 respectively; VWI, voluntary water intake; LEA, loin eye area; L*, luminosity index; a*, red index; b*, yellow index

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results in a feed with high moisture and non-fibrous carbohydrates, around 900 and 350 g/kg, respectively (Negesse et al., 2009; Brandao et al., 2011). In addition, some studies have showed that succulent plants represent a consistent water source for sheep in arid regions and that voluntary water intake (VWI) decreases when the dietary proportion of these plants increases, as observed for cactus pear (Vieira et al., 2008; Costa et al., 2009; Costa et al., 2012). However, there is scarce information about water intake among the studies published with sisal silage (Pinos-Rodríguez et al., 2009; Zamudio et al., 2009) and how it may impact DMI and animal performance (Ferreiro et al., 1977b).

The objective of this study is to test the hypothesis that sisal pulp silage (SPS; *Agave sisalana*, Perrine) can replace tifton hay in diets of feedlot sheep without affecting animal productive performance. Also, that SPS is a water source substitute for ruminants.

2. Materials and methods

2.1. Location

The experiment was conducted at the Experimental Farm of the School of Veterinary Medicine and Animal Science (*Escola de Medicina Veterinária e Zootecnia* – EMEVZ) of the Federal University of Bahia (*Universidade Federal da Bahia* – UFBA), Brazil.

2.2. Ingredients and experimental diets

Twelve-kilogram bales of commercial tifton (*Cynodon dactylon*) hay were shredded using a hay shredder machine (model TF150, Laboremus – Industria e Comércio de Márquinas Agrícolas Ltd, Campina Grande, Brazil). The hay was bought from a commercial farm and passed through a 2-cm screen during the shredding step. The sisal silage was produced by the *Companhia Sisal do Brasil* (COSIBRA) farm, in Santa Luz, Bahia, Brazil.

Sisal by-product, which will be called sisal pulp, was collected during the fiber-extraction process of *Agave sisalana* leaves. Once collected, sisal pulp was placed in a manual rotary sieve, developed by the Brazilian Corporation of Agricultural Research – Cotton Division, to separate the residual fiber that remains from the sisal defibration process (*Embrapa Algodão*; da Silva et al., 1998). The material was wilted for 24 h before ensiling in 100 L plastic drums with a packing density of 700 kg/m^3 (fresh weight). Drums were opened at least 44 days after ensiling.

The forage:concentrate ratio of the experimental diets was 50:50 and the forage fraction contained different proportions of tifton hay (*Cynodon* sp.) and sisal pulp silage (SPS; *Agave sisalana*, Perrine). The control diet (Table 2) was formulated according to the National Research Council (NRC, 2007) for an average daily gain of 200 g.

2.3. Experimental design, animal management, and data collection

Forty Santa Ines lambs, with an average initial body (BW) weight of 22 ± 3.4 kg were housed indoor and randomly assigned to individual 1.0 m^2 pens with slatted floors in a completely randomized design, with ten replicates per treatment. The dietary treatments were defined by the inclusion of SPS to the diet as follow: 1) 0, without SPS; 2) 167 g/kg; 3) 333 g/kg; and 4) 500 g/kg of SPS in total dietary dry matter (DM); which can also be specified as 0, 33, 67 and 100% replacement of tifton hay by SPS silage, respectively. Experimental periods lasted 72 days, with 21 days of adaptation. During the adaptation period, the animals were vaccinated against rabies and clostridial diseases, dewormed orally with Closantel-based anthelmintic and given 2-mL subcutaneous injections of fat-soluble vitamins (A, D and E). The experimental diets (Table 1) were offered at 9 am and 4 pm, and water was supplied ad libitum. The management and care of animals was performed in accordance with the guidelines and recommendations of the Committee of Ethics on Animal Studies at the UFBA.

The voluntary water intake (VWI) was evaluated using 20 animals in three time points during the experimental period (28, 42 and 67 days). The VWI was measured during four days for each evaluation by the difference between the weight of offered water (0 h) and after 24 h minus the evaporation loss. The water loss due to evaporation was estimated using two buckets with water that were weighed at the beginning and the end of the 4 days of VWI measurement period. Individual VWI was calculated as the average of the four days, during the three time points.

Apparent nutrient digestibility was evaluated during the same periods described for the VWI. Samples of feed, orts and feces were collected daily. The total fecal collection was performed using leather collection-bags attached to the animals. The composited feces samples were stored, identified by animal and treatment, and stored in plastic bags in a freezer at −15 °C for further analysis.

To determine the productive performance, the animals were weighed at the beginning and the end of the experimental period (day 0 and 72, respectively). A platform scale (Welmy, W 300 W LCD BAT, Welmy Ind Com Ltda, Santa Bárbara d́Oeste, Brasil), with a capacity of 300 kg and accuracy of 100 g was used. Total weight gain (TWG) was calculated as the difference between the weight of the animals at the beginning and at the end of the experimental period, always after a period of 16-h solid fast. The feed conversion (FC) was calculated as DM intake/TWG. The average daily weight gain (ADG) was calculated as TWG/72, with 72 representing the number of days in the experimental period.

2.4. Laboratory analysis

Samples of tifton hay and SPS were collected three times during the experiment (28, 42 and 67 days), to evaluate the particle size distribution and physical effectiveness of the neutral detergent fiber (NDF). The evaluation was performed by using the particle

Table 1
Chemical composition (g/kg dry matter plus standard error) of the ingredients used in the experimental diets.

Item	Ground corn (n = 4)	Soybean meal (n = 4)	Tifton hay (n = 4)	SPS[a] (n = 8)
Dry matter (g/kg wet)	860 (1.97)	878 (0.35)	847 (1.68)	274 (19.3)
Organic matter	986 (12.2)	934 (9.76)	923 (37.3)	880 (98.8)
Ash	14.0 (0.19)	66.0 (0.69)	77.0 (3.81)	120 (14.4)
Crude protein	64.0 (0.25)	465 (12.6)	71.0 (5.65)	46.0 (5.53)
Ether extract	51.0 (1.38)	18.0 (0.89)	14.0 (0.23)	12.0 (13.3)
Non-fibrous carbohydrates	760 (30.4)	329 (18.8)	79.0 (3.63)	571 (22.6)
Neutral detergent fiber	100 (8.57)	122 (4.52)	759 (12.1)	251 (11.9)
Acid detergent fiber	50.0 (4.44)	88.0 (4.11)	382 (3.23)	202 (5.46)
Cellulose	30.0 (6.62)	66.0 (5.84)	328 (14.54)	123 (7.67)
Hemicellulose	56.0 (4.14)	34.0 (8.63)	378 (6.03)	49.0 (6.82)
Lignin	22.0 (1.19)	22.0 (9.95)	54.0 (0.59)	80.0 (5.63)
NDIP[b] (% TN[c])	56.0 (1.32)	140 (2.99)	29.0 (11.1)	20.0 (10.7)
Particle size distribution[d], %				
19 mm	0.0 (0.00)	0.0 (0.00)	57.1 (6.85)	5.94 (1.49)
8 mm	29.1 (3.34)	0.0 (0.00)	17.5 (1.98)	9.56 (2.24)
1.18 mm	62.0 (8.49)	56.1 (7.24)	16.9 (2.11)	65.5 (16.04)
Bottom	8.90 (1.27)	43.9 (5.79)	8.50 (1.23)	19.0 (4.14)
Physical fiber effectiveness[e]				
$pef_{>8}$	0.29	0.0	0.75	0.15
$pef_{>1.18}$	0.91	0.56	0.91	0.81
$peNDF_{>8}$	29.0	0.0	569	37.7
$peNDF_{>1.18}$	91.1	68.3	690	203

[a] Sisal pulp silage.
[b] Neutral detergent insoluble protein.
[c] Total nitrogen.
[d] Percentage of particles retained in screens from the Penn State Particle Separator (PSPS; Kononoff et al., 2003).
[e] $pef_{>8}$ and $pef_{>1.18}$ = physical effectiveness factor determined as the proportion of the sum of particles retained above 8-mm screen (Lammers et al., 1996) and above 1.18-mm screen (Kononoff et al., 2003), respectively; $peNDF_{>8}$ and $peNDF_{>1.18}$ = physically effective NDF (g/kg DM) determined as NDF content multiplied $pef_{>8}$ and $pef_{>1.18}$, respectively.

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

Ingredient (g/kg dry matter)	Sisal pulp silage (g/kg dry matter)			
	0	167	333	500
Soybean meal	160	160	160	160
Ground corn	315	315	315	315
Vitamin and mineral supplement	15	15	15	15
Urea	10	10	10	10
Tifton-85 hay	500	333	167	0
Sisal pulp silage	0	167	333	500
Chemical composition				
Dry matter (g/kg wet)	889	794	698	603
Organic matter	936	930	923	916
Ash	64.0	70.0	77.0	84.0
Crude protein	169	164	160	156
Ether extract	23.0	22.0	22.0	21.0
Non-fibrous carbohydrates	319	401	484	566
Neutral detergent fiber	444	360	275	190
Acid detergent fiber	215	185	155	125
Lignin	27.0	31.0	35.0	40.0
Total digestible nutrients	685	701	717	733
Physical fiber effectiveness[a]				
$pef_{>8}$	0.38	0.27	0.18	0.08
$pef_{>1.18}$	0.72	0.70	0.68	0.67
$peNDF_{>8}$	169	97	50	15
$peNDF_{>1.18}$	320	252	187	127

[a] $pef_{>8}$ and $pef_{>1.18}$ = physical effectiveness factor determined as the proportion of the sum of particles retained above 8-mm screen (Lammers et al., 1996) and above 1.18-mm screen (Kononoff et al., 2003), respectively; $peNDF_{>8}$ and $peNDF_{>1.18}$ = physically effective NDF (g/kg DM) determined as the dietary NDF content multiplied by $pef_{>8}$ and $pef_{>1.18}$, respectively.

screen stratification method using the Penn State Particle Separator – PSPS developed by Lammers et al. (1996) and modified by Kononoff et al. (2003). The physical effectiveness factor (pef) was calculated using the sum of the percentages of particles larger than 8 mm (pef $>_{8}$; Lammers et al., 1996) and from the sum of the percentages of particles larger than 1.18 mm (pef $>_{1.18}$; Mertens, 1997; Kononoff et al., 2003). Physically effective neutral detergent fiber (peNDF) was calculated by multiplying neutral detergent fiber content by the previously determined pef.

Samples of feed and orts were dried at 60 °C for 72 h in a forced air oven, ground in a Wiley mill (Wiley mill, Arthur H. Thomas, Philadelphia, USA) with a 1-mm screen, and stored in plastic containers for determination of dry matter (method 934.01), organic matter (OM; method 942.05), crude protein (CP; method 984.13), ether extract (EE; method 920.39) and acid detergent fiber (ADF; method 973.18), according to AOAC (2000). For NDF analysis, samples were treated with heat-stable alpha-amylase without the use of sodium sulfite and were corrected for residual ash (Mertens, 1997). Correction of the NDF and ADF for nitrogen compounds and estimation of neutral detergent insoluble nitrogen (NDIN) and acid detergent insoluble nitrogen (ADIN) were performed according to Licitra et al. (1996). The concentration of lignin was determined through cellulose solubilization with sulfuric acid (Van Soest et al., 1991).

Non-fibrous carbohydrates (NFC) concentration was estimated according to the equation: NFC (%) = 100% − (% NDF + % CP + % EE + % Ash).

2.5. Slaughter and carcass evaluation

At the end of the experiment, all animals were slaughtered after a 16-h fast in a commercial slaughterhouse. The animals were stunned by electronarcosis (220 V for 10 s) and subsequently bled via the jugular vein. All abdominal and thoracic viscera were removed from the carcasses. After slaughtering, the carcass of each animal was divided into two half-carcasses, which were weighed and cooled at 4 °C for 24 h. After this time, the half-carcasses were removed and weighed again.

To evaluate the meat physical and chemical characteristics, sections of the *Longissimus dorsi* muscle between the 12th and 13th ribs were taken according to the recommendation of Colomer-Rocher et al. (1987). The loin eye area (LEA) was drawn on tracing paper, which was then scanned with an Epson Stylus CX5600 scanner (Seiko Epson Corporation, São Paulo, Brazil) with a resolution of 300 dpi. The imaging software Quant Plant Disease Severity v.1.0 was used to calculate the area in cm^2. Qualitative carcass conformation and fattening state scores on a scale of 0–5 with 0.5-point intervals were attributed (Osório et al., 1998; Osório and Osório2003).

The pH of the *L. dorsi* samples containing bone and fat was measured in three different sites with a digital pH meter (Testo, 205 Geräte Set, Testo Brasil, Campinas, Brasil), and the average of the three measurements was used. The samples of meat containing bone were dissected out and wrapped in PVC film and aluminum foil and stored at −20 °C for further analyses. The loins from the right and left sides of the carcass were thawed in a refrigerator for 24 h, and the right side of the carcass was then subjected to physicochemical analysis. The sample from the left side of the carcass was divided into two parts for analysis of the chemical composition. The samples were cooked in an electric oven at 170 °C until the internal temperature of the meat reached 70 °C. The meat samples were removed from the oven and cooled to room temperature, and three cylindrical samples were taken to measure shear force (SF) using a 1000-N Mecmesin Basic Force Gauge, (Mecmesin Limited, Slinfold, United Kingdom).

Samples were sectioned longitudinally and the myoglobin was exposed to oxygen for five minutes to determine the luminosity of the meat using a colorimeter (Minolta CR-410, Konica Minolta Technoproducts Co. Ltd, Tokyo, Japan) previously calibrated for the white color. The luminosity index (L*), red index (a*) and yellow index (b*) were measured.

To determine the loin chemical composition, each sample was dissected from all visible fat and aponeuroses, grounded in a blender and stored in PVC containers. Samples were then desiccated and ground through a 1-mm Willey Mill screen (Cienlab, EC-430, Scientific Equipment ltd Cienlab, Campinas, Brazil). The DM, ash, CP and EE contents were analyzed in the fresh thawed samples according to the procedures of AOAC (2000) previously described for feed samples.

2.6. Statistical analysis

The data were analyzed using the PROC MIXED of SAS (SAS Institute, 2004) in a completed randomized design. Heterogeneity of variances were tested by the command REPEATED and used when significant. Orthogonal contrasts were used to test the linear, quadratic and cubic effects of SPS inclusion in the diets. The PROC IML was used to determined the contrast coefficients. The initial body weight was tested as covariable and used when significant. Significance was declared at $P \leq 0.05$ and tendency at $0.05 < P \leq 0.10$. Because the cubic contrast was not significant for any of the variables studied, its P value is not shown.

3. Results

3.1. Nutrient intake and digestibility

Intake of DM and OM were not affected ($P > 0.05$) by the substitution of tifton hay by SPS (Table 3). However, the OM intake tended to decrease ($P = 0.07$) with increasing dietary SPS. Intake of CP, EE, NDF and ADF decreased linearly as the dietary levels of SPS increased. The NFC intake increased linearly with increasing SPS in the diets. When expressed in relation to BW, the intake of DM and NDF showed the same pattern as previously explained for these parameters. The VWI decreased linearly ($P < 0.05$) as SPS levels increased.

Table 3
Nutrient intake of lambs fed diets containing levels of sisal pulp silage in substitution of Tifton hay.

Nutrient[a]	Sisal pulp silage (g/kg dry matter)				SEM[b]	P-value[c]	
	0	167	333	500		L	Q
	g/d						
Dry matter	1190	1190	1190	1130	32.8	0.16	0.31
Organic matter	1120	1100	1110	1040	30.4	0.07	0.32
Crude protein	222	212	200	180	5.90	< 0.01	0.51
Ether extract	29	28	27	25	0.81	< 0.01	0.38
NFC	427	535	581	635	23.5	< 0.01	0.24
aNDFom	468	377	319	203	14.5	< 0.01	0.35
ADF	222	194	178	133	8.06	< 0.01	0.24
VWI	3540	2380	1940	1860	320	< 0.01	0.10
	g/kg body weight						
Dry matter	39.6	39.0	39.3	37.7	0.09	0.20	0.63
aNDFom	15.5	12.1	10.6	7.0	0.03	< 0.01	0.74

[a] NFC: non-fibrous carbohydrates, aNDFom: neutral detergent fiber assayed with a heat stable amylase and expressed exclusive of residual ash, ADF: acid detergent fiber; VWI: voluntary water intake.
[b] SEM: standard error of the mean.
[c] Probability for the linear (L) and quadratic (Q) contrasts.

Apparent digestibility of DM, OM, EE, and aNDFom increased linearly ($P < 0.05$) when SPS level increased in the diets (Table 4). Only EE and NFC digestibility showed a quadratic effect.

3.2. *Animal performance and carcass characteristics*

Final BW, ADG and feed conversion were not affected ($P > 0.05$) by the inclusion of SPS in the diets (Table 5). The inclusion of SPS did not affect ($P > 0.05$) the carcass characteristics. There were no differences ($P > 0.05$) for the L, a and b indexes of the *L. dorsi* muscle among treatments (Table 5). The pH of the *L. dorsi* muscle 24 h after slaughter did not differ among treatments ($P > 0.05$). The SF tended to decrease as the silage content increased ($P = 0.08$). Regarding the chemical composition of the carcass, only the EE concentration increased linearly with increasing dietary SPS levels.

4. Discussion

4.1. *Nutrient intake and digestibility*

The similar consumption of DM and OM among treatment diets indicates that there was no intake limitation when SPS levels increased. However, the CP, EE and NDF intake decreased because the proportion of dietary concentrations of these nutrients decreased as the SPS increased. The fiber-extraction process of agave leaves produces a material with high concentrations of NFC; therefore, as the dietary SPS increased, NFC intake also increased with a concomitant decrease in the intake of the other nutrients. Increased DM intake with higher dietary concentration of NFC has been observed before (Bispo et al., 2007), when elephant-grass was substituted by spineless cactus (*Opuntia ficus*) in sheep diets. However, this pattern was not observed in the present study because the DM intake of the diet containing only hay may not have been limited by the physical effect of ruminal filling. Therefore, increasing

Table 4
Apparent digestibility of nutrients (g/kg dry matter) in lambs fed diets containing levels of sisal pulp silage in substitution of tifton hay.

Nutrient[a]	Sisal pulp silage (g/kg dry matter)				SEM[b]	P-value[c]	
	0	167	333	500		L	Q
Dry matter	741	769	818	845	10.1	< 0.01	0.96
Organic matter	756	787	836	867	9.7	< 0.01	0.96
Crude protein	796	786	834	838	10.3	< 0.01	0.51
Ether extract	748	809	866	878	9.2	< 0.01	0.04
NFC	950	922	944	960	5.6	0.06	< 0.01
aNDFom	433	507	601	621	20.7	< 0.01	0.27

[a] NFC: non-fibrous carbohydrates, aNDFom: neutral detergent fiber assayed with a heat stable amylase and expressed exclusive of residual ash.
[b] SEM: standard error of the mean.
[c] Probability value for the linear (L) and quadratic (Q) contrasts.

Table 5
Productive performance and carcass characteristics of lambs fed diets containing levels of sisal pulp silage in substitution of Tifton hay.

	Sisal pulp silage, g/kg dry matter				SEM[a]	P-value[b]	
	0	177	333	500		L	Q
Productive performance							
Initial body weight, kg	22.7	23.4	21.0	22.0	–	–	–
Final body weight, kg	37.7	38.0	38.7	37.0	0.80	0.62	0.18
Total weight gain, kg	15.5	15.7	16.7	14.6	0.78	0.63	0.18
Average daily gain, kg/d	0.215	0.218	0.230	0.203	0.01	0.63	0.18
Feed conversion	5.47	5.84	5.45	5.49	0.17	0.66	0.32
Carcass characteristics[c]							
Chilled carcass yield, %	45.2	45.5	45.7	46.4	0.54	0.14	0.74
LEA, cm^2	13.9	13.5	14.9	13.5	0.53	0.99	0.34
Carcass grade	3.29	3.45	3.57	3.44	0.13	0.35	0.29
Carcass fat thickness	2.67	2.91	2.90	2.92	0.14	0.23	0.43
L*	36.42	35.82	35.63	35.41	0.74	0.34	0.80
a*	19.94	19.45	19.55	19.45	0.40	0.45	0.63
b*	7.17	6.84	6.71	6.71	0.45	0.46	0.72
pH	5.66	5.61	5.70	5.68	0.07	0.68	0.82
Shear force, kgf/cm	3.47	3.24	3.55	2.75	0.23	0.08	0.21
Water, %	739	737	742	733	3.1	0.32	0.23
Ash, %	10.0	9.8	10.9	9.9	0.4	0.56	0.27
Crude protein, %	203	204	199	201	2.7	0.43	0.73
Ether extract, %	33.1	33.3	33.5	44.1	2.8	0.01	0.07

[a] SEM: standard error of the mean.
[b] Probability value for the linear (L) and quadratic (Q) contrasts.
[c] LEA: Loin eye area; Carcass grade: 1 – inferior; 2 – regular; 3 – good; 4–very good; 5 – excellent (0,5 scale); Carcass fat thickness: 1 – very thin; 2 – thin; 3 – normal; 4 – fat; 5 – very fat (0,5 scale); L*: luminosity index, a*: red index, b*: yellow index.

dietary NFC levels (and decreasing NDF levels) with SPS inclusion resulted in similar DM intake. No effect of agave silage on DM intake (4.1% of BW) was also observed by Zamudio et al. (2009) when evaluating the *Agave salmiana* silage in diets for goats (24% of dietary DM).

Lambs fed the diet containing 500 g/kg SPS consumed 23.3% less CP than the animals fed the diet containing only Tifton hay; however, no differences in performance were observed among all diets. Even the lowest intake of CP observed in this study (180 g/day) is higher than the value of 137 g recommended by the NRC (2007) for lambs with 30 kg BW with ADG of 200 g/day. Besides the changes in the proportions of ingested nutrients, the values observed for the present study agree with the predicted values from the NRC for lambs with 200 g of ADG (NRC, 2007).

The animals were housed indoors, with an average temperature and evaporation loss of 26 °C and 590 g/day, respectively. The VWI decreased markedly with increasing dietary SPS levels because of its low DM content, which represents a high dietary water source. The estimated water intake obtained from the diet without SPS was 149 g, while the diet containing 500 g/kg SPS provided 744 g of water. According to the NRC (2001), the water requirement can be met by three sources: voluntary intake (drinking water), feed water, and metabolic water from nutrient catabolism. As observed with cactus pear and other succulent plants (Costa et al., 2009; Costa et al., 2012), the results from the present study highlight the importance of SPS as a water source in arid and semiarid regions, where it can be a limiting factor for livestock production (Silanikove, 2000).

Apparent digestibility increased with SPS dietary levels because of the increase in rapidly fermented carbohydrates in the diet. The chemical composition of SPS shows higher NFC concentration than the tifton hay (571 vs. 79 g/kg DM). The NFC are rapidly and almost completely digested in the rumen and, therefore, provides a more immediate energy supply to the ruminal ecosystem, enhancing fiber digestion. The increased supply of NFC in the treatments with silage may have offset the reduction in intake of CP, EE and NDF.

4.2. Animal performance and carcass characteristics

The particle stratification into different sizes allows the inference about parameters with nutritional relevance, such as peNDF, which are directly related to intake, digestibility and performance (Mertens, 1997; Zebeli et al., 2012). There was a large difference in the NDF physical effectiveness between the forage sources (Table 1), reflecting on a decrease in dietary physical effectiveness as SPS increased in the diets (Table 2).

The linear increase in digestibility would result in increasing nutrient intake and more available energy, but it did not affect the productive performance. There was a drastic reduction in the dietary peNDF when 500 g/kg of SPS was included, which probably increased the passage rate and decreased rumination activity. This explanation justifies the absence of effect on the DM intake and on the final BW and ADG. However, the possible reduction in the rumination time with increasing dietary SPS did not compromise rumen fermentation because digestibility increased linearly for all nutrients. Also, all animals were able to meet the energy requirements and show similar productive performance as SPS increased. None to moderate change in ruminal VFA pattern and anima performance has also been reported when sisal is fed alone or with other forage source (Dixon et al., 1981; Ferreiro et al., 1977a).

No changes in the LEA were expected because there were no differences in carcass weight and yield among diets, which supports that the protein and energy requirements were met. The absence of differences in cold carcass yield among the treatments was also expected, as no differences in slaughter live weight were observed. According to Dantas et al. (2008), changes in cold carcass weight and cold carcass yield result in alterations in the LEA.

In this study, the carcasses obtained an average score of 3.4 points on the scale proposed by Osório and Osório (2005). According to these authors, a lamb is ready for slaughter when it has a body condition score between 3.0 and 3.5 and a FAT score between 3.0 (normal distribution of fat) and 3.5 (slightly fatty). The FAT state of a carcass indicates the degree of finishing and the degree to which efficient storage and protection against chill drying can be achieved. The lambs in this study had a mean score of 2.9, and their carcasses were slightly lean (2.5) to normal (3.0).

The color characteristics of the meat were not affected by the SPS dietary inclusion because the intake of DM did not differ among the treatments, and for the same reasons productive performance was not different. Average values of luminosity and color indexes of the meat are within the ranges established by Warris (2003) of 30.0–49.5, 8.24–23.5 and 3.38–11.1, for L*, a*, and b*, respectively. These authors also reported that the meat color depends on the meat pH and *post mortem* chemical reaction rates (glycolysis). When an animal is subjected to stress before slaughter, it experiences a decrease in muscle glycogen content, resulting in a higher final pH (above 6.0). In this study, the average pH of the meat was 5.7, which is within the desirable range of 5.5–5.8 12–24 h after slaughter (Silva Sobrinho et al., 2005).

The animals fed the diets containing 500 g/kg SPS showed the lowest value of shear force (2.75 kgf/cm^2; Table 5), and the loins of these animals had the highest EE value (Table 4), which may have contributed to increase the tenderness of the meat. Bressan et al. (2001) reported shear force values of lamb meat lower than 4.75 kgf/cm^2, which indicates a soft and highly acceptable meat. The average shear force value observed in the loins of the animals in this study suggests that the lamb meat from the *L. dorsi* muscle would be considered just as soft. Because energy input was not affected, the carcass characteristics were also similar among the diets and the values showed in general a satisfactory quality of the meat.

5. Conclusions

In general, sisal pulp silage is a suitable source to feed sheep in semiarid regions, since animals showed similar intake and performance as those given by tifton hay. As a non-conventional feed, SPS did not affect any characteristic related to meat quality. In addition, we observed that SPS can be a consistent water source in arid and semiarid regions. Compared with hay, the use of SPS would reduce feeding costs.

Sisal pulp silage can be used exclusively or in combination with tifton hay in diets for feedlot lambs with average daily gain of 200 g. However, we do not recommend to include only SPS in the diet because of its low concentration of physically effective fiber. Therefore, the inclusion of up to 333 g/kg SPS in the diet (DM basis) in combination with tifton hay is recommended. If levels higher than 333 g/kg are used, we recommend including some roughage source to increase dietary physical effective fiber.

Conflict of interest

None.

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