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Evaluation of high-concentrate diets that vary in physically effective neutral detergent fibre for finishing lambs

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Abstract

The objective of this research was to evaluate lamb diets with a high proportion of concentrate and various levels of physically effective neutral detergent fibre (NDF) using tropical ingredients. Four diets were formulated: D1 with 16.5% physically effective NDF (peNDF), D2 with 21.4% peNDF, D3 with 23.3% peNDF, and D4 with 24.6% peNDF. Twenty male Santa Inês lambs at four months old with an average liveweight (LW) of 18.6 ± 3.4 kg were fed for 49 days. There were no differences (P >0.05) among the diets in dry matter (DM) intake. Crude protein (CP) intake, relative to either LW or metabolic live weight ($LW^{0.75}$) or LW, was greater (P ≤0.05) for D2 and D3 than for D1 or D4. Lower (P ≤0.05) NDF intake, relative to $LW^{0.75}$ or LW, was lower for D1 than for the other diets. Selection indexes (SIs) were similar (P >0.05) among diets. Animals that consumed D1 had less (P ≤0.05) rumination time per bolus. Meaningful variations were not observed in performance and efficiency of finishing lambs that were related to differences in peNDF among the diets. Santa Inês lambs were able to adapt to diets with low levels of peNDF by increasing rumination time as a consequence of increased fibre consumption and greater particle size selection.

Keywords: agro-industrial by-products, average particle size, rumen bypass protein, sheep, tropical feedstuffs

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Introduction

Native Caatinga rangelands of north-eastern Brazil represent up to 90% of the feed source for sheep in that region (Costa *et al.*, 2019). Forage potential of these semi-arid rangelands and seasonal changes in vegetation depend on climatic conditions, so quantity and quality peak for a few months of the year (Araújo Filho, 2013). In addition, most of the plant species in the Caatinga pastures are not selected by grazing sheep (Santos *et al.*, 2010).

Therefore, feeding lambs in confinement becomes a viable alternative during low forage availability. A large part of the cost of production is linked to food. Therefore, evaluating alternative diets for sheep in confinement is necessary owing to the diversity of local ingredients. These evaluations can provide recommendations for feedstuffs that could minimize costs with minimal effect on animal performance. When balancing diets for confined animals, the fibre content of the ration requires attention. Ruminant animals need fibre in their diet to maintain adequate ruminal fermentation and consequently their health (Sousa *et al.*, 2018). Gallo *et al.* (2019) found that a high-concentrate diet with 15% NDF produced better weight gain in finishing lambs than diets that were higher in fibre.

The physical and chemical characteristics of the feed modify feeding behaviour by affecting the motility of the fore-stomach, the rate of passage and the supply of nutrients to the animal (NRC, 2007).

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Mastication for example is related to the size of the feed particle that reaches the rumen and can affect feed digestibility and consequently intake (Francisco *et al.*, 2020). Feed intake studies identify feeding habits that dictate whether small ruminants attain nutrient intake that meets their nutritional needs. In this type of study, parameters such as duration and frequency of feed intake, rumination and mastication become important (Nicory *et al.*, 2015).

Offering feeds with varying average particle sizes (APS) and densities often allows for feed separation during mixing and transport, and for diet selection by animals. Particle size therefore can be important for predicting feed value (Leonardi *et al.*, 2005). Variations in APS can cause the nutritive value of feed that is ingested to differ from what is offered. Sheep breeds such as the Santa Inês, which are adapted to Brazilian semi-arid rangelands, use diets that are high in fibre, but low in peNDF by increasing rumination time through selection of smaller APS from feed.

The objective of this research was to evaluate diets formulated for lambs with tropical ingredients that had a high proportion of concentrate and various levels of peNDF. Effects on intake, performance, diet selection, and feeding behaviour were of primary interest

Materials and Methods

The experimental protocol was approved by the Animal Experiment Committee of the Universidade Estadual Vale do Acaraú (Ethics Committee approval no. 031.12/2007). The trial was conducted at Universidade Estadual Vale do Acaraú, Sobral, in the Sertão Cearense zone at 3°36’ south, 40°18’ west, at an evaluation of 56 m.

Native grass silage was obtained from a Type VI unit of the Brazilian Caatinga forest on the banks of a river, with Gaussen xerothermic indices varying between 150 and 200 (Andrade-Lima, 1981). The woody vegetation was thinned to reduce canopy suppression of the herbaceous stratum by 35% to 40%. Forage was harvested when 50% of the plants were flowering to standardize the material to be ensiled and ensure balance of quality and quantity.

Species in native pasture that was ensiled for this trial included *Borreria verticillata* G.F.W. Mayer, *Commelina diffusa* M.F. Burn, *Sida cordifolia*, *Digitaria sanguinalis* (L.). Scop, *Arachis pintoi*, *Calotropis procera*, *Stylosanthes humilis*, *Ipomea glabra* Choisy, and *Jacquemontia asarifolia* L.B. Smith. These were harvested in the rainy season from March to May, mixed with 13% wheat bran, and ensiled in 200 L plastic barrels (n=5 per month). Ingredients used in the diets for finishing the lambs included native pasture silage, annatto by-product, obtained from the extraction of the apocarotenoid food colouring from the seeds, soybean meal (*Glycine max* (L.) Merr.) obtained from oil extraction, ground maize (*Zea mays* L.) and limestone (Table 1).

Laboratory analyses of the feedstuffs were carried out at the Animal Nutrition Laboratory of the Animal Science Department at Universidade Estadual Vale do Acaraú. To determine DM, OM, ash, ether extract (EE), and CP contents, AOAC (1990) methods were followed. Methods described by Van Soest *et al.* (1991) were used to determine NDF, acid detergent fibre (ADF), cellulose (CEL), hemicellulose (HCEL), and acid detergent lignin (ADL). The Cornell System (Sniffen *et al.,* 1992) was used to determine total carbohydrates (TCHO), and the total digestible nutrient (TDN) content was determined from the proximate analysis of the diets. The equation described by Weiss (1993) was used to determine non-fibrous carbohydrate (NFC).

The diets were formulated to meet the requirements of growing lambs between four and seven months old with average live weight (LW) of 20 kg that were gaining 200 g/d (NRC 1985, 2007). The treatments (D1, D2, D3, and D4 contained 16.5% (NRC, 1985), 21.4%, 23.3%, and 24.6% (NRC, 2007) peNDF, respectively (Table 2).

Twenty male Santa Inês lambs, approximately four months old and weighing an average of 18.6 ± 3.4 kg, were assigned in a completely randomized design to the four diet treatments (five lambs per treatment diet). Each lamb was housed in a 1.5 m x 1.0 m x 0.8 m pen fitted with feeders, watering devices and plastic salt holders and was deemed sufficient for its comfort. The building that contained the pens (Núcleo de Pesquisa em Nutrição de Pequenos Ruminantes) was 196 m^2, with concrete floors, 7 m high walls and a tile roof that allowing for air circulation and thus afforded comfortable temperatures. There was no inter-animal competition for feed and space, and environmental enrichment (jolly balls) was provided in the pens. The animals were fed twice a day (at 07h00 and 16h00) during the experiment. One month before the study, all lambs were examined for disease, dewormed, and vaccinated against clostridia by a licensed veterinarian. Consumption was measured as the difference between feed offered and orts in a 24-hour period. Rejected orts were weighed each day and the following day’s feed was adjusted to achieve 15% to 20% excess to provide for ad libitum consumption. Water and mineralized salt were provided ad libitum. Samples of feed and orts were collected weekly in the morning (07h00).

Table 1 Nutritional analysis of feedstuffs used in formulating diets that differed in the level of physically effective neutral detergent fibre for finishing lambs

Nutrients	Native grass silage	Annatto	Soybean meal	Maize	Limestone
Dry matter, % as is basis	33.5	87.3	87.3	87.4	100.0
Composition, % of dry matter					
Organic matter	82.6	88.6	90.8	92.7	
Crude protein	13.0	14.9	52.6	10.1	
Neutral detergent fibre (NDF)	53.5	43.2	24.2	15.6	
NDF (corrected for ash and protein)	37.5	31.4	12.9	11.5	
Acid detergent fibre (ADF)	33.3	27.1	11.0	3.9	
Ether extract	2.37	1.12	0.94	1.51	
Hemicellulose	20.2	16.0	13.1	11.7	
Cellulose	26.3	18.5	10.4	3.5	
Lignin	5.9	6.1	0.6	0.5	
Total carbohydrate	73.5	77.5	39.8	87.0	
Non-fibre carbohydrate	35.9	46.1	26.9	75.5	
Gross energy, Mcal/kg	3.25	3.95	4.42	4.33	
Total digestible nutrients	58.8	59.8	71.6	80.9	
Nitrogen (N) in NDF as % of total N	40.3	31.5	8.4	10.6	
N in ADF as % of total N	3.1	14.7	1.0	1.9	
Particles > 19 mm, %	74.3				
Particles between 8 and 19 mm, %	2.2				
Particles between 1.18 and 8 mm, %	10.4	7.9	14.1	91.4	93.7
Particles < 1.18 mm, %	13.1	92.1	85.9	8.6	6.3

Confinement lasted 49 days, that is, 10 days for adaptation and 39 days for data collection. Animals were weighed at the beginning of the adaptation period to adjust feed on offer and percentages of leftovers, which were measured as g DM/kg $LW^{0.75}$ (Schneider & Flatt, 1975). The animals were subsequently weighed every seven days, starting on day 7, after 16 hours without feed. Intake was calculated as g/kg $LW^{0.75}$ and g/d, whereas DM, organic matter (OM), CP and NDF intake were calculated only as percentages of LW. The differences between final LW and initial LW were used to calculate average daily gain (ADG) and feed efficiency.

Feeding behaviour was monitored on days 18 and 19 of the trial. During a 24-hour period, time spent ingesting feed, ruminating, idling and other activities that were not related to ingestion, rumination and idling were recorded every five min (Johnson & Combs, 1991). On the 19th day, the average number of mastications and time spent masticating per bolus was obtained during three two-hour periods from 10h00 to 12h00, 14h00 to 16h00, and 18h00 to 20h00 (Bürger *et al.*, 2000). A digital chronometer was used to measure time. Artificial illumination was used throughout the trial so that the lambs were adapted to the conditions for observation. Feeding behaviour data were summarized (Polli *et al.*, 1996). Total feeding time was the sum of times spent ingesting and ruminating. Number of boluses (NDB) was the ratio of rumination time and rumination time per bolus. Number of mastications was the product of number of mastications per bolus and NDB. Efficiencies of intake (IE) and rumination (RE) were calculated as ratios of intake and time spent ingesting feed and ruminating, respectively. A bolus was defined as that portion of the feed that was regurgitated to the mouth for remastication during rumination. Samples of the feedstuffs and orts were used to measure APS. Samples were collected every seven days. At the end of the trial, samples from each animal were pooled. Average particle size was measured using sieves in a Penn State particle size separator (University Park, Pennsylvania, USA) (Lammers *et al.*, 1996). This separator had four trays that retained particles greater than 19 mm, 19 mm to 8 mm, 8 mm to 1.18 mm, and less than1.18 mm. The APS of the diet was estimated as the proportion of the diet of each feedstuff multiplied by the proportional contribution of each particle size category to the total. The average particle size data are described in Table

1. Four fractions (> 19 mm, 19 to 8 mm, 8 to 1.18 mm and <1.18 mm) for the diets, orts, and effective consumption were calculated for each animal, adjusted to 100%.

Table 2 Ingredients in experimental diets for finishing lambs that differed in physically effective neutral detergent fibre and nutritional composition

Ingredients	D1	D2	D3	D4
Native pasture silage including 13% wheat bran	15.3	32.6	37.5	40.8
Annatto by-product	11.6	11.2	10.9	11.0
Soybean meal	11.3	18.2	15.0	13.1
Maize	60.6	36.7	35.3	33.8
Limestone	1.3	1.3	1.3	1.3
Nutritional composition				
Dry matter (DM), % as fed	79.4	70.0	67.3	65.6
Organic matter, % DM	94.7	92.6	92.3	92.2
Crude protein, % DM	15.7	19.1	18.0	17.3
Ether extract, % DM	1.51	1.62	1.68	1.72
Neutral detergent fibre (NDF), % DM	25.4	32.5	34.3	35.8
Acid detergent fibre, % DM	11.8	17.3	18.4	19.3
Lignin, % DM	2.00	2.92	3.17	3.35
Total carbohydrates, % DM	77.5	71.8	72.6	73.1
Non-fibrous carbohydrates, % DM	59.6	49.5	49.1	48.8
Neutral detergent fibre nitrogen (N), % total N	15.8	17.9	19.6	20.8
Percent NDF from forage	8.2	17.4	20.0	21.8
Physically effective NDF	16.5	21.4	23.3	24.6
Acid detergent fibre N, % total N	3.12	2.82	2.98	3.11
Total digestible nutrients	73.0 ± 0.7	67.7 ± 0.7	68.8 ± 0.7	66.9 ± 0.7

D1, D2, D3, D4: diets providing 16.5%, 21.4%, 23.3% and 24.6% physically effective neutral detergent fibre, respectively

Selection among dietary constituents was quantified as proposed by Leonardi and Armentano (2003). Predicted intake was as-fed intake for the total diet multiplied by the as-fed fraction of that particle size in the diet. Observed intake was the difference between the percentage of a particular particle size category in the diet as-fed and the percentage of a particular particle size in the orts. The ratio of observed intake to predicted intake was used as a metric to quantify dietary selection with values less than 100% indicating rejection, values greater than 100% indicating preference, and values equal to 100% indicating the absence of selection.

Because the lambs were fed individually, they were considered the experimental units. Thus, there were three degrees of freedom for the fixed effects of diets and 15 degrees of freedom of random residual variance in the analyses of variance for consumption, feeding behaviour and performance. Data were tested for normality and homoscedasticity prior to analyses of variance using PROC UNIVARIATE (SAS Institute Inc., Cary North Carolina, USA). The linear model used for these analyses was:

$$Y_{ij} = \mu + d_i + e_{ij}$$

where: Y_{ij} was a dependent variable measured on the jth lamb consuming the ith diet (d), μ was the overall mean, and e_{ij} was the random residual error. Means of the diet effects were compared using Tukey's test at 5% probability.

Indexes of selection (SI) among dietary constituents were analysed with a repeated measures analysis of variance using PROC MIXED (SAS Institute Inc., Cary North Carolina, USA). The covariance structure for the variance among experimental units was chosen using Akaike's information criterion. The linear model used for this analysis was:

$$Y_{ijk} = \mu + d_i + l_{ij} + ps_k + dps_{ik} + e_{ijk}$$

where: Y_{ijk} was a measurement of SI from an individual lamb that consumed the ith diet, μ was the overall mean, l_{ij} was the random effect of the jth lamb (analogous to the residual error in the first model), ps_k was the effect of the k^{th} particle size category, dps_{ik} was the effect of the interaction between dietary treatment and particle size category, and e_{ijk} was the random residual error. Means were again contrasted at the 5% level of probability.

Results and Discussion

Diets for finishing lambs generally require the inclusion of a greater amount of concentrate. In the present experiment this resulted in higher proportions of particles smaller than 8 mm (8–1.18 mm and less than 1.18 mm). The greatest proportion of particles between 8 and 1.18 mm was found in D1 (Figure 1), which contained 73% concentrate. That diet was fed at a rate of 1126 g/lamb/d with 208 g/lamb/d refused, resulting in 918 g/lamb/d being consumed. Diet D2 was fed at 1173 g/lamb/d with 969 g/lamb/d being consumed. Diet D3 was fed at 1127 g/lamb/d with 963 g/lamb/d being consumed. Finally, D4 was fed at 1037 g/lamb/d with 868 g/lamb/d being consumed.

No differences among treatments were detected in dry matter intake (DMI) or organic matter intake (OMI), whether expressed as g/kg $LW^{0.75}$ or percentage LW (Table 3). Lambs fed D2 and D3 had greater CP intake compared with D1 and D4 because of the greater proportion of CP in those diets. D2 had greater NDF intake than D1. There were no differences in ADG and feed efficiency among treatments.

No interaction effects were detected between diet and particle size that affected diet selection by the lambs. The lambs refused feed equally across diets (Table 4). However, the differences among particle size categories were significant, indicating that the lambs sorted their feed according to particle size (Table 4). Small particle sizes and very large particles were consumed without apparent sorting. However, particles between 1.18 and 8 mm were rejected relative to their contribution to the diets.

No differences were detected among treatments for time spent ingesting, ruminating, masticating, resting or other activities (Table 5). Likewise, DMI, NDF intake, and the rates reflecting efficiencies of intake, DM rumination, and NDF rumination were not affected significantly by the dietary treatments (Table 6). The lambs fed D1 spent less time ruminating each bolus than the lambs that were fed diets that were higher in physically effective NDF.

Daily intake can be described by the number of times lambs feed, time spent feeding, and feed intake rate. The quantity of feed intake may vary by 40% to 60%, depending on factors inherent in individual animals, by 20% to 30%, depending on the characteristics of feed on offer, and by 10% to 15%, depending on environment and management (Van Soest, 1994). This confirms that management can affect feeding behaviour, which will result in altered animal performance, and the economic viability of the production system (Eustáquio Filho *et al.*, 2014; Custodio *et al.*, 2016).

Sheep are able to ingest high amounts of energy and low fibre without drastically changing the consumption of dry material (Gallo *et al.*, 2019). In the present study, the average DMI was greater than that reported by Moreno *et al.* (2010) for lambs fed tropical diets. Macedo Junior *et al.* (2006) reported that Santa Inês sheep fed forage with 35% NDF consumed CP at 17 g/kg $LW^{0.75}$ and NDF at 33 g/kg $LW^{0.75}$, which was greater than the intake levels observed in this study. For finishing lambs, NRC (2007) recommends 64.5 g DMI/kg $LW^{0.75}$ and 12.3, 11.7 and 11.3 g CP/kg $LW^{0.75}$ when fed rumen-undegradable protein levels of 20%, 40% and 60%, respectively. In the present study, intake levels were greater than these recommendations.

In the present study, ADG averaged 242.5 g/d across all diets. Thus, these Santa Inês lambs grew more slowly than those that were studied by Moreno *et al.* (2010), who reported gains of 314.3 g/d. Medeiros *et al.* (2007), who studied Morada Nova lambs that were fed various levels of concentrate, reported less efficient feed conversion (7.23 kg/kg) than was observed in this study ,in which the feed conversion averaged 3.70 kg/kg. Thus, it is possible that diets with 15% NDF were safe for lambs, as they did not affect animal health adversely or the digestion of feedstuffs (Costa *et al.*, 2013; Gallo *et al.*, 2019).

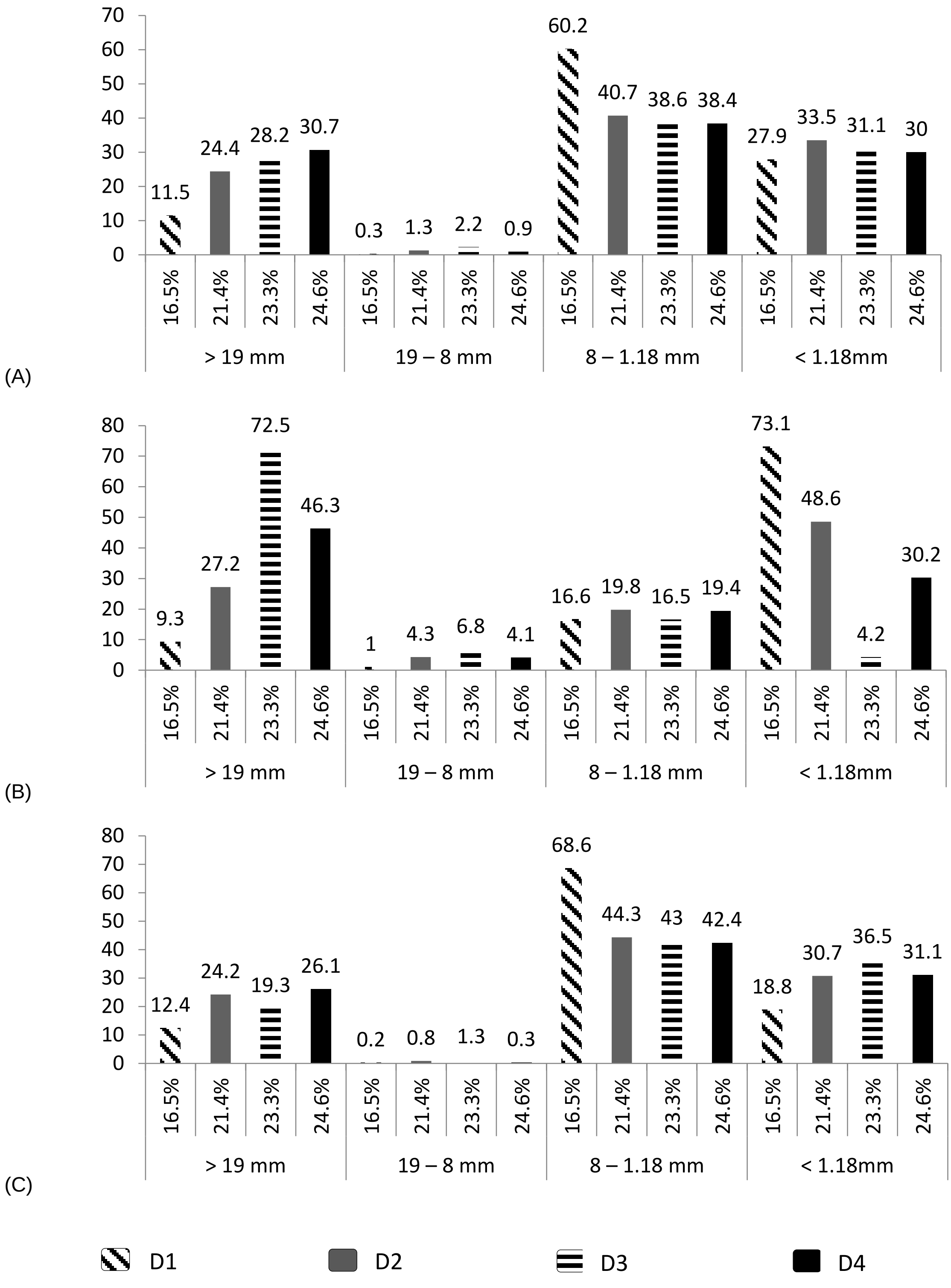

Figure 1 Average particle size (%) offered (A), rejected (B) and consumed (C) for lambs fed diets providing 16.5% (D1), 21.4% (D2), 23.3% (D3) and 24.6% (D4) physically effective neutral detergent fibre

Table 3 Performance and daily consumption of nutrients by finishing lambs fed diets formulated to provide various levels of physically effective neutral detergent fibre

	D1	D2	D3	D4	SE	*P*-value
Intake, g/kg live weigt						
Dry matter	78.3	88.0	90.1	90.3	2.9	>0.05
Organic matter	68.7	75.2	75.5	72.4	1.3	>0.05
Crude protein	12.2[c]	17.0[a]	16.5[a]	15.0[b]	0.5	<0.05
Neutral detergent fibre	22.5[b]	28.9[a]	29.7[a]	29.6[a]	1.2	<0 .05
Intake, % live weight						
Dry matter	3.62	3.97	4.18	4.23	0.10	>0.05
Organic matter	3.18	3.39	3.50	3.34	0.10	>0.05
Crude protein	0.568[c]	0.768[a]	0.767[a]	0.694[b]	0.02	<0.05
Neutral detergent fibre	1.04[b]	1.30[a]	1.38[a]	1.36[a]	0.10	<0.05
Average daily gain, g	229	246	248	247	9.01	>0.05
Feed conversion	3.50	3.92	3.69	3.71	0.14	>0.05

[a,b,c] With a row, means followed by a similar superscript were not different at probability *P* =0.05
D1, D2, D3, D4: diets providing 16.5%, 21.4%, 23.3% and 24.6% physically effective neutral detergent fibre, respectively

Table 4 Indexes of diet selection by lambs fed diets with various levels of physically effective neutral detergent fibre

Diets	Index	Particle size	Index
D1	84.2	< 1.18 mm	84.1[a]
D2	86.2	1.18 - 8 mm	48.9[b]
D3	87.9	8 - 19 mm	106.3[a]
D4	83.2	> 19 mm	100.8[a]

[a,b] With a column, means followed by a similar superscript were not different at probability *P* =0.05; SE = 3.3
D1, D2, D3, D4: diets providing 16.5%, 21.4%, 23.3% and 24.6% physically effective neutral detergent fibre, respectively

Table 5 Allocation of time by lambs fed diets that varied in the level of physically effective neutral detergent fibre

Allocation of time	D1	D2	D3	D4	SE	*P-value*
Intake (h/d)	4.2	4.7	4.4	4.6	0.4	>0.05
Rumination (h/d)	6.2	7.3	6.3	6.9	0.2	>0.05
Idle (h/d)	12.7	11.1	12.4	11.7	0.1	>0.05
Total mastication time (h/d)	10.4	12.0	10.0	10.4	0.4	>0.05
Rumination time/bolus (sec/bolus)	26.4[b]	34.7[a]	32.8[a]	34.4[a]	0.9	<0.05
Other activities (h/d)	0.9	0.9	0.9	0.8	0.4	>0.05

[a,b] Within a column, means followed by a similar superscript were not different at probability *P* =0.05
D1, D2, D3, D4: diets providing 16.5%, 21.4%, 23.3% and 24.6% physically effective neutral detergent fibre, respectively

Table 6 Rates at which dry matter and neutral detergent fibre were consumed and efficiencies associated with rumination and mastication

Variable	D1	D2	D3	D4	SE	*P*-value
Dry matter intake, g/d	918	969	963	868	35	>0.05
Neutral detergent fibre intake, g/d	236	304	305	289	13	>0.05
Feed intake efficiency, g/h	223	220	241	190	16	>0.05
DM rumination efficiency, g/h	151	136	184	128	11	>0.05
NDF rumination efficiency, g/h	39.2	43.1	58.9	42.4	3.7	>0.05
Number of boluses/day	845	755	689	720	35	>0.05
Rumination mastications/day	39969	43262	36173	41760	2346	>0.05
Rumination mastications/bolus	47.3	57.3	52.5	58.0	1.6	>0.05

Intake is limited by energy requirements rather than rumen fill when the diet contains less than 50% to 60% NDF. Animals fed highly digestible diets tend to ingest their feed in less time than grazing animals and shortly after meeting their energy requirements feed intake decreases (Hall & Mertens, 2017). In the present study, the mean time spent ingesting feed was relatively short. The short feeding time was probably a reflection that these lambs, which were fed in confinement, were able to satisfy their energy requirements quickly and without much need for selection among diet constituents. Kozloski *et al.* (2006, who fed confined lambs diets with low energy density and high levels of NDF, found the lambs spent approximately 50% more time ingesting feed than the lambs in the present study. This suggests that under these conditions intake rates depended largely on the animal's physiological status (Moyo *et al.*, 2019).

As the roughage portion of the diet increased, so did rumination time (Van Soest, 1994; Cardoso *et al.*, 2006). However, in the present study, even with NDF concentrations that exceeded the NRC (2007) recommendations for lambs, there was no measurable increase in time spent ruminating. Cardoso *et al.* (2006) reported that lambs increased time spent ruminating, up to 8.05 h/d, as dietary fibre concentration increased.

Differences in the time spent feeding and the time that feeding occurred are frequently observed in trials in which diet fibre concentration is variable (Mendes *et al.*, 2010). This was demonstrated in lambs fed diets that were low in fibre in which they adapted to this condition by selecting a greater proportion of larger particles. This may have been an adjustment to greater concentrations of organic acids in the rumen from the rapid degradation rates of concentrate (Hall & Mertens, 2017). If lambs fail to make this adjustment, rumen pH can be affected (Tedeschi *et al.*, 2010). This indicates that lambs adjust selectivity to compensate for low dietary fibre concentration to maintain a healthy rumen environment with an adequate pH. Regadas Filho *et al.* (2014) recommended a minimum level of 20% peNDF in the diet in lactating ewes or growing lambs,

Smaller APS can influence mastication activity and ruminal pH negatively in confined lambs. Conversely, larger APS can result in fibre component rejection with similar negative results to those in which diets contain insufficient fibre. In the present study, the greater time spent masticating by animals on D2, D3 and D4 was a direct result of larger APS in those diets compared with D1. In diets with lower levels of fibre time spent chewing was reduced, as was observed with D1. Others have shown that mastication time increased with NDF concentration, but declined with decreased APS (Hall & Mertens, 2017). However, mastication time per kilogram of DM is not solely a factor of feed characteristics, but rather a cumulative effect of feed and animal.

Conclusions

Meaningful differences in performance and efficiency were not observed that were related to differences in peNDF among the diets. The trial indicated that diet APS does not affect lamb feed intake, short-term ADG and feeding behaviour because of compensatory selectivity by lambs.

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Authors' Contributions

HHAC, MCPR and RCFFP designed the experiment and carried out the research trial. RNBL and ARL completed the statistical analyses. MCPR, LFG, CSC, ESP and JPM structured the scientific content and drafted the manuscript. All authors provided editorial suggestions and approved the final manuscript.

Conflict of Interest Declaration

The authors declare that there is no conflict of interest

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