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ANIMAL SCIENCE

Different proportions of starch and neutral detergent-soluble fiber in diets for feedlot lambs

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Abstract: This study evaluated the replacement of starch (ST; cracked corn) by neutral detergent-soluble fiber (NDSF; citrus pulp) and its effects on feed intake, performance, digestibility, carcass traits, and nitrogen balance of lambs. In Experiment 1, male lambs (n = 24, 19.1 ± 1.9 kg body weight [BW]) received: Starch (ST) = 250 g starch/kg dry matter (DM); ST/NDSF = 180 g starch/kg DM + 180 g NDSF/kg DM; or NDSF = 250 g NDSF/kg DM. After 84 d, animals were slaughtered and carcasses were evaluated. In Experiment 2, male lambs (n = 15, 23.2 ± 2.3 kg BW) were used to assess digestibility and nitrogen balance. Final BW, average daily gain, gain to feed and feed intake decreased when animals were fed NDSF ($P \leq 0.002$), reflecting in lighter carcasses ($P<0.0001$). The NDSF decreased edible non-carcass components ($P=0.0006$), total usable products ($P<0.0001$), commercial cuts and intramuscular fat ($P \leq 0.02$). Except for NDSF and ST, the digestibility of nutrients was improved for NDSF diet ($P \leq 0.04$). The use of 250 g NDSF/kg DM as citrus pulp in finishing diets for lambs impairs performance, carcass, meat traits and nitrogen balance. However, the moderate replacement of corn by citrus pulp does not change productive variables.

Key words: citrus pulp, corn, finishing performance, soluble fiber, sheep.

INTRODUCTION

The production of sheep is an activity of great economic importance worldwide, as occurs in the southern and northeastern Brazil. Therefore, there is a need to intensify ruminant production systems, in order to increase land use efficiency and improve the quality of end products. This has led to the development of more research focused on technologies that subsidize livestock production in this new scenario, such as feedlot and/or semi-feedlot and the use of specific nutrients, ingredients and diets.

In an attempt to shorten the time of finishing period on feedlot and provide the market with meat of great quality, animals are often fed diets containing large amounts of concentrate (especially cereal grains), which present great proportions of soluble carbohydrates. This allows great intake of digestible energy and, consequently, great average daily gains. However, it is known that, although soluble carbohydrates comprehend a wide range of compounds with similar characteristics, they present different ruminal fermentation patterns that can alter the kinetics of digestive processes as well as the performance of feedlot-finished animals. Regarding these changes, sugars, starch and fructose can be fermented to lactic acid by continuing to ferment at low pH and producing more propionate. This limits the digestion of fibrous carbohydrates by promoting increase in the number of bacteria that produce lactic acid, as well as reducing the activity of cellulolytic bacteria, increasing the possibility of occurrence of ruminal acidosis (McAllister & Cheng 1996).

Neutral detergent-soluble fiber (NDSF) has the characteristic of promoting greater acetate production, maintaining rumen pH values close to neutrality. Concentrated FSDN-rich ingredients, such as citrus pulp, can be an important source of energy for ruminants. First, because of the benefits brought to the ruminal environment, without drastically reducing the pH, which provides a better use of the NDF of roughages sources (Henrique et al. 2003) and, second, because of the difficulty of using these ingredients in diets for non-ruminants, since these animals do not produce enzymes able to digest carbohydrates found in the NDSF (Faturi et al. 2006).

Thus, it was hypothesized that the increase of NDSF (as citrus pulp) in starch-based diets (corn) can improve feed efficiency, performance and nitrogen retention in sheep. Therefore, the objective of this study was to verify the effects of diets containing different starch:NDSF ratios on feedlot performance, carcass characteristics, carcass components, commercial cuts yield, chemical composition of the meat, total tract apparent digestibility of nutrients and nitrogen balance in feedlot sheep.

MATERIALS AND METHODS

Two experiments were conducted at the Animal Unit of Digestive and Metabolic Studies from Animal Science Department of São Paulo State University, Jaboticabal, Brazil. The São Paulo State University Institutional Animal Care and Use Committee approved all experimental protocols adopted in the current study (approval number: 01893108).

Experiment 1

Animals, diets, experimental design and management

Twenty-four crossbred (Santa Inês × Dorper), uncastrated male lambs (19.1 ± 1.9 kg body weight [BW], ~90 d old) were blocked by initial BW and randomly sorted into three experimental treatments, containing similar amounts of crude protein and metabolizable energy (122 g/kg and 2.9 Mcal/kg Dry matter [DM], respectively). Diets were formulated to provide average daily gains (ADG) of 0.200 kg, according to NRC (2007), with a roughage:concentrate ratio of 30:70. The roughage chosen was the corn silage and the concentrates were composed of corn cracked grain, citrus pulp, soybean hull, sunflower meal, urea, limestone, dicalcium phosphate and common salt, arranged to promote different concentrations of starch and neutral detergent-soluble fiber (NDSF) by changing the proportions of corn and citrus pulp (Table I). The citrus pulp used was obtained from an orange juice factory plant located at northwest São Paulo, Brazil.

Upon arrival, animals were weighed, tagged with numbered necklaces, dewormed, and housed in individual pens (1.2 m^2) indoor, equipped with individual feed bunks and collective waterers. For the first 7 d, lambs were fed exclusively corn silage and subsequently adapted for 14 d to the finishing feedlot diets, using three step-up diets, containing 200, 350 and 700 g/kg concentrate.

The experimental finishing diets were labeled as: Starch (ST), ST/NDSF and NDSF. The ST and NDSF diets presented, respectively, 250 g of these nutrients/kg DM, whereas the ST/NDSF diet presented equivalent contents of starch and NDSF (approximately, 180 g/kg DM of each). Urea and sunflower oil were used to complement protein and energy contents according to nutritional requirements. The inclusion of urea compensated the reduction of sunflower meal in order to obtain the proportions of corn and citrus pulp, used to reach 250 g of starch and NDSF/kg DM.

Table I. **Composition of experimental diets.**

Item	Treatments[1]		
	ST	ST/ NDSF	NDSF
Ingredient (g/kg)			
Corn silage	300.0	300.0	300.0
Corn cracked grain	290.0	166.3	115.0
Citrus pulp	180.0	358.4	569.6
Soybean hulls	50.0	50.0	35.0
Sunflower meal	142.1	75.2	20.0
Sunflower oil	24.0	29.5	37.6
Urea	3.4	9.6	15.5
Dicalcium phosphate	4.4	7.0	8.1
Limestone	4.4	2.3	1.0
Common salt	1.5	1.5	1.5
Antioxidant Banox	0.2	0.2	0.2
Nutritional composition			
Dry matter, g/kg	749.8	744.1	737.6
Crude protein, g/kg DM	121.7	121.6	121.7
Ether extract, g/kg DM	51.9	55.0	60.1
Neutral detergent fiber, g/kg DM	349.6	343.6	337.2
Acid detergent fiber, g/kg DM	210.8	215.5	220.7
Neutral detergent-soluble fiber, g/kg DM	133.6	184.1	242.7
Starch, g/kg DM	266.1	184.2	82.7
Metabolizable energy[2], Mcal/kg DM	2.8	2.8	2.8
Calcium, g/kg DM	4.1	4.1	4.1
Phosphorus, g/kg DM	3.2	3.3	3.2

[1]ST = starch-rich diet; ST/NDSF = similar proportions of starch and neutral detergent-soluble fiber; NDSF = neutral detergent-soluble fiber-rich diet.
[2]Estimated using values from NRC 2007.

The experimental period lasted 84 d, in which the animals were fed twice daily (0800 and 1730 h). The silage and the concentrate were mixed prior to feed delivery and fed half of total in each meal. To adjust the daily feed delivery, the orts from the previous day were weighed and 10% of total were collected for nutrient intake calculations. To ensure *ad libitum* feeding, orts were kept at approximately 15% of total feed delivered. Weekly, samples of corn silage and concentrates were collected and frozen at -15°C and, opportunely, thawed and composed for chemical analysis.

Chemical and bromatological analyses

Samples of feed delivered and orts were dried using a forced-air oven (55 °C, 72 h) and ground using a Willey-type mill equipped with a 1-mm sieve (AOAC 1998; method 934.01). The samples' DM was obtained drying at 105 °C for 24 h (AOAC 1995; method 930.15), and minerals' content (MM) was obtained by incineration using a muffle furnace at 600 °C for 3 h (AOAC 1990; method 942.05). Crude protein (CP) was calculated by multiplying N content, which was determined by nitrogen concentration using the micro-Kjeldahl method (AOAC 1998; method 988.05), by 6.25. The ether extract (EE) content was determined by extraction using petroleum ether in a Soxhlet device for 4 h (AOAC 1990; method 930.15). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were estimated according to Van Soest & Wine (1967), using a heat-stable α-amylase, without sodium sulfite, and expressed inclusive of residual ash, using an autoclave (60 min. at 0.5 atm and 111 °C; adapted from Pell & Schofield 1993). The NDSF was estimated according to Hall et al. (1999), and the starch following the methodology proposed by Hendrix (1993).

Performance, carcass and meat characteristics

To follow the evolution of body weight gain, the animals were weighed every 28 d during the 84-d feedlot period. One day prior to slaughter animals were submitted to a 12-h fasting period. The body condition score was evaluated according to Thompson & Meyer (1994). The lambs were weighed (live weight at slaughter) and then harvested at the São Paulo State University Experimental Abattoir. After stunning, the jugular veins and carotid arteries were sectioned for bleeding. After evisceration, the carcasses were weighed (hot carcass weight

[HCW]) and transferred to a cold chamber at 4 °C for 24 h, suspended by the gastrocnemial tendon, using appropriate hooks to keep the tarsal-metatarsal joints at 17 cm apart. At the end of this period, the carcasses were reweighed (cold carcass weight [CCW]), calculating the dressing percentages (DP). The carcasses were divided longitudinally, and the left half was sectioned into five anatomical regions: neck, shoulder, rib, loin and leg.

The loin area (LMA) was obtained by exposing the *Longissimus lumborum* muscle, after a transversal cut between the 12th and 13th ribs, using the formula: (A/2 × B/2) × π, where A is the maximum length and B is the maximum depth of muscle. The back-fat thickness (BF) was measured at the same spot using a digital caliper. Samples of *Longissimus* muscle were collected and freeze-dried for 72 h, to evaluate the moisture, and contents of crude protein, ether extract and minerals, according to AOAC (2005).

The carcasses were visually evaluated by three trained observers and graded from 1 to 5 for conformation, considering the carcass shape (1 = straight and 5 = concave), according to Silva Sobrinho (2006). Edible non-carcass components (blood, testicles, tongue, lungs + trachea, liver + gall bladder, heart, kidneys, spleen, gastrointestinal tract [reticulum, rumen, omasum, abomasum and intestines], and internal fats were weighed separately. Total yield of usable products (TUP) was calculated as the sum of HCW and total edible non-carcass components (TENCC), according to van Cleef et al. (2016).

Statistical analysis

The residual normality and homogeneity tests were performed using the PROC UNIVARIATE and Levene's test, respectively, considering a 5% significance level (SAS Inst. Inc., Cary, NC). The DM and nutrient intakes, performance, carcass and meat characteristics data were analyzed as a randomized complete block design by using the PROC MIXED (SAS Inst. Inc., Cary, NC). Animal was the experimental unit for all the variables studied. The statistical model used was: $Y_{ij} = \mu + B_i + D_j + E_{ij}$, where μ is the overall mean, B_i is the block effect (i = 1 - 4), D_j is the diet effect (j = 1 - 3), and E_{ij} is the residual error. The block was included as a random effect. Means were compared with Tukey test, and significance was defined as $P<0.05$ and trends as $0.05 \leq P \leq 0.10$.

Experiment 2

Animals, diets, experimental design and management

Fifteen crossbred (Santa Inês × Dorper), uncastrated male lambs (23.2 ± 2.3 kg body weight [BW], ~110 d old) were sorted in a completely randomized design the same three experimental treatments described in Experiment 1. Animals were housed in suspended metabolism cages (1.2 m^2), equipped with feces and urine collectors, and individual feed bunks and waterers. The animals were adapted for 14 d as described in Experiment 1.

The total tract apparent digestibility and nitrogen balance were estimated using total fecal and urine collection method, with sampling period of 5 d. Daily samples of feed delivery (15%) and feces and urine (20%) were collected twice daily (before feed delivery) during the experimental period. The urine excreted daily was collected in plastic buckets containing 20 ml of chloridric acid 1:1. Aliquots corresponding to 20% of the daily total were stored in plastic vials and stored at -20°C for further analysis. One fifth of collected feces was also stored at -20°C.

Total tract apparent digestibility calculations

To estimate the apparent digestibility coefficient of DM, OM, CP, NDF, ADF, HEM, NDSF, and Starch, the same analytical methods described in Experiment 1 were used for samples of feed delivered and feces. The digestibility (%) was obtained by the formula: DIG = ((nutrient ingested – nutrient in feces) / nutrient ingested) * 100. The nitrogen balance was calculated as: NB = N ingested – (N in feces + N in urine) and the biological value of CP (%) was calculated as: BVCP = (CP ingested - CP in feces - CP in urine) / (CP ingested - CP in feces) * 100.

Statistical analysis

The residual normality and homogeneity tests were performed using the PROC UNIVARIATE and Levene's test, respectively, considering a 5% significance level (SAS Inst. Inc., Cary, NC). Data from Experiment 2 were analyzed as a completely randomized design using PROC GLM (SAS Inst. Inc., Cary, NC). Animal was the experimental unit for all the variables studied. The statistical model used was: $Y_{ij} = \mu + D_i + E_{ij}$, where μ is the overall mean, D_i is the diet effect (i = 1 - 3), and E_{ij} is the residual error. Means were compared with Tukey test, and significance was defined as *P*< 0.05 and trends as 0.05≤*P*≤ 0.10.

RESULTS

Experiment 1

Nutrient intake and feedlot performance

The changes in the proportion of starch and neutral detergent-soluble fiber did not affect DM and OM intakes when the inclusion of NDSF was at 180 g/kg DM. However, when the amount of NDSF used was approximately 250 g/kg DM, the DM and OM intakes were drastically reduced (*P*<0.0001; Table II). The intakes of all nutrients evaluated (CP, crude energy, NDF, ADF, hemicellulose, NDSF) followed the same trend. No differences observed between ST and ST/NDSF treatments and a decrease in NDSF treatment (*P*≤0.0008), excepting for the starch intake, which was decreased from ST to NDSF treatments, and with intermediate values for ST/NDSF treatment (*P*<0.0001).

The initial body weight of lambs was similar among treatments (average = 19.1 kg; *P* = 0.60). Final body weight and slaughter body weight were similar in ST and ST/NDSF treatments and lesser in NDSF treatment (*P*<0.0001). The ADG and gain to feed (G:F) and body condition score followed the same trend, with lesser values observed in lambs fed NDSF treatment (*P*≤0.002).

Carcass characteristics

The HCW and CCW were affected by experimental treatments (*P*<0.0001; Table III). Carcasses' weights were decreased with increasing concentrations of NDSF in the diets. The dressing percentages tended to decrease with NDSF inclusion (hot dressing percentage, *P* = 0.08; cold dressing percentage, *P* = 0.09). However, BF (average = 1.95 mm) and LMA (average = 11.7 cm^2) were not affected by the treatments.

Edible non-carcass components and total usable products

The amount of blood from NDSF-fed animals was lower when compared with the others (*P* = 0.003, Table IV). The weight of respiratory tract tended to decrease, following the same trend as blood (*P* = 0.07). The weight of liver was also reduced from ST treatment to NDSF (*P* = 0.002). The spleen, kidneys, gastrointestinal tract, and internal fat were affected by treatments the same way, with no differences between ST and ST/NDSF treatments and a decrease in NDSF (*P* = 0.01, *P* = 0.001, *P* = 0.04, *P* = 0.01, respectively). However, important non-carcass components' weights were not altered, such as testicles (average = 0.33 kg, *P* = 0.12), tongue (average = 0.09 kg, *P* =

Table II. Performance and nutrient intakes of feedlot crossbred lambs (n = 24) fed diets containing different proportions of starch and neutral detergent-soluble fiber.

Item	Treatments[2]			SEM	*P*-value
	ST	ST/NDSF	NDSF		Treatment
Initial body weight, kg	19.28	18.95	18.97	0.43	0.60
Final body weight, kg	34.93 [a]	33.09 [a]	26.15 [b]	1.01	<0.0001
Slaughter body weight, kg	33.16 [a]	31.61 [a]	25.19 [b]	0.94	<0.0001
Average daily gain, kg	0.213 [a]	0.191 [a]	0.096 [b]	0.013	<0.0001
Body condition score[1]	3.07 [a]	3.19 [a]	2.33 [b]	0.11	0.002
Gain:feed	0.228 [a]	0.205 [a]	0.143 [b]	0.010	<0.0001
Nutrient intake					
Dry matter, kg/d	0.932 [a]	0.929 [a]	0.646 [b]	0.03	<0.0001
Organic matter, kg/d	0.890 [a]	0.882 [a]	0.609 [b]	0.03	<0.0001
Crude protein, kg/d	0.114 [a]	0.113 [a]	0.079 [b]	0.004	<0.0001
Crude energy, Mcal/d	3.96 [a]	3.86 [a]	2.68 [b]	0.15	<0.0001
Neutral detergent fiber, kg/d	0.326 [a]	0.319 [a]	0.218 [b]	0.012	<0.0001
Acid detergent fiber, kg/d	0.197 [a]	0.200 [a]	0.143 [b]	0.007	<0.0001
Hemicellulose, kg/d	0.129 [a]	0.119 [a]	0.075 [b]	0.005	<0.0001
Neutral detergent-soluble fiber, kg/d	0.125 [b]	0.171 [a]	0.158 [a]	0.006	0.0008
Starch, kg/d	0.247 [a]	0.171 [b]	0.052 [c]	0.017	<0.0001

[1]Scale 1–5 (Thompson & Meyer 1994).
[2]ST = starch-rich diet; ST/NDSF = similar proportions of starch and neutral detergent-soluble fiber; NDSF = neutral detergent-soluble fiber-rich diet.
Means with different letter in the line differ by Tukey test, *P*<0.05.

0.45), heart (average = 0.20 kg, p = 0.37). All these results led to a progressive reduction of TENCC' weight from to NDSF treatment (*P* = 0.0006) and, when the HCW were summed to TENCC to obtain TUP, the same trend was observed (*P*<0.0001).

Weight and yield of carcass cuts and proximate composition of meat

As a reflect of carcass weight, the weight of commercial cuts leg, rib, shoulder and loin were similar between treatments ST and ST/NDSF and lesser for the NDSF (*P*<0.0001, *P*<0.0001, *P*<0.0001, *P* = 0.02, respectively; Table V). The weight of neck was greater for ST and ST/NDSF treatments, which did not differ from NDSF (*P* = 0.02). When the percentage of commercial cuts was evaluated, no differences were observed among treatments (average leg = 316 g/kg, average rib = 254 g/kg, average shoulder = 196 g/kg, average loin = 129 g/kg, average neck = 105 g/kg; *P*>0.12).

The *Longissimus* muscle moisture (71.4 g/100 g meat; *P* = 0.39), ash (1.7 g/100 g meat; *P* = 0.21), and crude protein (24.4 g/100 g meat, p = 0.30) were unaffected by the proportions of starch and NDSF in the diets. However, both ST and ST/NDSF treatments promoted greater concentrations of ether extract in the meat (*P* = 0.006; Table VI).

Table III. Carcass characteristics of crossbred feedlot lambs (n = 24) fed diets containing different proportions of starch and neutral detergent-soluble fiber.

Item	Treatments[1]			SEM	*P*-value
	ST	ST/NDSF	NDSF		Treatment
Hot carcass weight, kg	16.83 [a]	15.96 [b]	12.22 [c]	0.52	<0.0001
Cold carcass weight, kg	16.45 [a]	15.63 [b]	11.96 [c]	0.51	<0.0001
Hot dressing percentage, %	50.70	50.45	48.66	0.45	0.08
Cold dressing percentage, %	49.57	49.38	47.63	0.44	0.09
12th rib fat thickness, mm	2.21	2.26	1.38	0.30	0.36
Longissimus muscle area, cm^2	12.27	12.80	10.01	0.63	0.15

[1]ST = starch-rich diet; ST/NDSF = similar proportions of starch and neutral detergent-soluble fiber; NDSF = neutral detergent-soluble fiber-rich diet.
Means with different letter in the line differ by Tukey test, *P*<0.05.

Table IV. Edible non-carcass components and total usable products of crossbred lambs (n = 24) fed diets containing different proportions of starch and neutral detergent-soluble fiber.

Item[2]	Treatments[1]			SEM	*P*-value
	ST	ST/NDSF	NDSF		Treatment
ENCC, kg					
Blood	1.48 [a]	1.37 [b]	1.19 [c]	0.04	0.003
Testicles	0.44	0.30	0.26	0.05	0.12
Tongue	0.089	0.091	0.078	0.004	0.45
Trachea + lungs	0.71	0.63	0.59	0.02	0.07
Heart	0.19	0.21	0.19	0.008	0.37
Liver + gall bladder	0.57 [a]	0.51 [ab]	0.44 [b]	0.16	0.002
Spleen	0.058 [a]	0.052 [a]	0.037 [b]	0.003	0.01
Kidneys	0.088 [a]	0.086 [a]	0.070 [b]	0.003	0.001
Gastrointestinal tract	2.97 [a]	2.84 [a]	2.36 [b]	0.10	0.04
Internal fat	1.19 [a]	1.31 [a]	0.71 [b]	0.02	0.01
TENCC, kg	8.09 [a]	7.65 [b]	6.11 [c]	0.24	0.0006
TUP, kg	24.91 [a]	23.61 [b]	18.33 [c]	0.74	<0.0001

[1]ST = starch-rich diet; ST/NDSF = similar proportions of starch and neutral detergent-soluble fiber; NDSF = neutral detergent-soluble fiber-rich diet.
[2]ENNC = edible non-carcass components; TENCC = total edible non-carcass components; TUP = total usable products (TENCC + HCW).
Means with different letter in the line differ by Tukey test, *P*<0.05.

Experiment 2

Total tract apparent digestibility

The use of greater proportion of NDSF in the diets resulted in an increased DM and OM total tract apparent digestibility (*P* = 0.04, *P* = 0.01, respectively; Table VII). The CP, NDF, and starch were similarly affected by treatments (*P* = 0.03, *P*<0.0001, *P*<0.0001, respectively), with no differences observed between ST and ST/NDSF treatments and greater values in treatment NDSF. The acid detergent fiber digestibility was progressively improved with greater proportions of NDSF in the diets (*P*<0.0001), increasing approximately 11% from ST to NDSF treatments.

Table V. **Weight and yield of carcass cuts of crossbred feedlot lambs (n = 24) fed different proportions of starch and neutral detergent-soluble fiber.**

Item	Treatments[1]			SEM	*P*-value
	ST	ST/NDSF	NDSF		Treatment
Weight, kg					
Leg	2.57 [a]	2.45 [a]	1.88 [b]	0.08	<0.0001
Rib	2.04 [a]	2.00 [a]	1.50 [b]	0.07	<0.0001
Shoulder	1.55 [a]	1.49 [a]	1.22 [b]	0.04	<0.0001
Loin	1.01 [a]	1.05 [a]	0.77 [b]	0.04	0.02
Neck	0.86 [a]	0.76 [ab]	0.68 [b]	0.03	0.02
Yield, g/kg					
Leg	319.3	314.8	314.0	2.7	0.72
Rib	255.1	259.5	246.6	2.9	0.22
Shoulder	193.8	192.6	202.1	2.2	0.21
Loin	126.0	135.2	126.0	2.9	0.33
Neck	105.7	98.0	111.3	2.6	0.12

[1]ST = starch-rich diet; ST/NDSF = similar proportions of starch and neutral detergent-soluble fiber; NDSF = neutral detergent-soluble fiber-rich diet.
Means with different letter in the line differ by Tukey test, *P*<0.05.

Table VI. **Proximate composition of meat from crossbred lambs (n = 24) fed diets containing different proportions of starch and neutral detergent-soluble fiber.**

Item (g/100g meat)	Treatments[1]			SEM	*P*-value
	ST	ST/NDSF	NDSF		Treatment
Moisture	70.36	71.04	72.80	0.80	0.39
Ash	1.81	1.73	1.60	0.05	0.21
Crude Protein	25.28	24.51	23.27	0.57	0.30
Ether extract	3.94 [a]	3.90 [a]	2.23 [b]	0.26	0.006

[1]ST = starch-rich diet; ST/NDSF = similar proportions of starch and neutral detergent-soluble fiber; NDSF = neutral detergent-soluble fiber-rich diet.
Means with different letter in the line differ by Tukey test, *P*<0.05.

On the other hand, NDSF digestibility was unaffected by experimental treatments (*P* = 0.14).

Nitrogen balance

The nitrogen intake was greater in ST treatment followed by ST/NDSF and NDSF (*P*<0.0001), and the same trend was observed in fecal nitrogen (*P* = 0.0008), and protein biological value (*P*<0.0001; Table VIII). The urinary nitrogen was not affected by treatments (*P* = 0.14), and the data registered in this trial resulted in greater nitrogen balance in treatment ST, compared with the other two treatments, which were similar between them (*P*<0.0001).

DISCUSSION

Experiment 1

Nutrient intake and feedlot performance

The DM intake of animals fed the NDSF treatment (0.641 kg/d), is below that recommended by the

Table VII. Dry matter and nutrient total tract digestibility of diets containing different proportions of starch and neutral detergent-soluble fiber (n = 15).

Digestibility, g/kg	Treatments[1]			SEM	*P*-value
	ST	ST/NDSF	NDSF		Treatment
Dry matter	816.7 [b]	822.5 [ab]	837.5 [a]	3.8	0.04
Organic matter	835.6 [b]	845.5 [ab]	860.4 [a]	3.7	0.01
Crude protein	766.4 [b]	757.6 [b]	791.6 [a]	5.9	0.03
Neutral detergent fiber	687.5 [b]	701.6 [b]	745.6 [a]	7.1	<0.0001
Acid detergent fiber	599.7 [c]	628.0 [b]	665.5 [a]	7.5	<0.0001
Neutral detergent-soluble fiber	995.3	988.1	986.5	1.6	0.14
Starch	962.3 [a]	971.3 [a]	918.4 [b]	6.4	<0.0001

[1]ST = starch-rich diet; ST/NDSF = similar proportions of starch and neutral detergent-soluble fiber; NDSF = neutral detergent-soluble fiber-rich diet.
Means with different letter in the line differ by Tukey test, *P*<0.05.

NRC (2007) for growing sheep (0.830 kg/d). The other diets provided satisfactory and greater DM intakes than the recommendation (0.932 and 0.929 kg/d, respectively for ST and ST/NDSF). These results agree with the ones commonly found for Santa Inês lambs fed diets containing low roughage:concentrate ratio (Urano et al. 2006, Queiroz et al. 2008).

Several studies in the literature have demonstrated that the replacement of corn by NDSF-rich by-products, has provided different responses regarding ruminant performance variables. Henrique et al. (1998) found that the supply of diets with a low proportion of concentrate (200 g/kg), in which citrus pulp totally replaced corn, did not change animal performance and carcass characteristics. However, in the treatments with 800 g/kg concentrate, the replacement resulted in considerable reduction in DM intake and ADG.

Assuming that the partial replacement of starch from cereal grains, such as corn, by high digestible by-products rich in NDSF, such as citrus pulp, could provide positive effects on DM intake, it was expected that the animals fed the NDSF diet (570 g/kg citrus pulp) had the greatest intake, since this ingredient favors a ruminal fermentation pattern similar to that promoted by roughages.

It is possible that the intake depression observed in the present research and in other studies in the literature is more related to the quality and quantity of citrus pulp used in ruminant diets, than to the great concentration of the NDSF present. Faturi et al. 2006 pointed out that acceptability of citrus pulp may vary with the inclusion of lemon pulp, storage time or processing issues, such as burning of the pulp, which justifies the concern with the quality of the product, since the problems related to citrus pulp-rich diets are not confirmed by all authors.

The intake of the other nutrients was influenced by the observed behavior of DM intake. The animals that received the ST and ST/NDSF diets had crude protein intakes greater than those recommended by the NRC (2007), for 0.200 kg ADG of growing sheep (0.101 kg PB/d). The NDSF-fed animals, on the other hand, consumed, on average, 23 g less crude protein than the recommended value.

One of the main concepts involving the characteristics of the diet on the regulation of consumption establishes that the control of the intake of more digestible and energetically dense diets is carried out primarily by

Table VIII. Nitrogen balance and biological value of protein from diets containing different proportions of starch and neutral detergent-soluble fiber (n = 15).

Item	Treatments[1]			SEM	*P*-value
	ST	ST/NDSF	NDSF		Treatment
Nitrogen intake, g/d	30.67 [a]	24.62 [b]	21.41 [c]	1.08	<0.0001
Urinary nitrogen, g/d	3.31	3.06	2.78	0.36	0.14
Fecal nitrogen, g/d	7.65 [a]	6.41 [b]	4.89 [c]	0.11	0.0008
Nitrogen balance, g/d	19.71 [a]	15.42 [b]	13.45 [b]	0.77	<0.0001
Protein biological value, %	85.56 [a]	83.76 [b]	80.90 [c]	0.58	<0.0001

[1]ST = starch-rich diet; ST/NDSF = similar proportions of starch and neutral detergent-soluble fiber; NDSF = neutral detergent-soluble fiber-rich diet.
Means with different letter in the line differ by Tukey test, *P*<0.05.

metabolic mechanisms, usually associated to the nutritional demands of the animal (Faturi et al. 2006). However, the intake of diets with less energy density or less digestible is first physically controlled by the limitation of space in the gastrointestinal tract (Waldo 1986). In the current study, it was verified that the NDF content was not responsible for the reduction in the DMI of animals fed NDSF diet, considering that this fraction was around 340 g/kg in all experimental diets.

The ADG obtained with ST and ST/NDSF diets agree with those reported in the literature for lambs fed diets with a high proportion of concentrate and similar breed composition (Rocha et al. 2004). Bueno et al. 2004 working with feedlot lambs, replacing corn with citrus pulp at up to 100%, verified an ADG of 213 g, which is close to that observed in present study in animals from ST and ST/NDSF diets.

As observed in the current study, the total replacement of dietary corn by citrus pulp also impaired feed efficiency of sheep fed diets containing high proportions of concentrate (Rodrigues et al. 2008). However, these results differ from those obtained by Bueno et al. 2004 who did not observe changes in feed efficiency of lambs fed diets containing citrus pulp. It is important to emphasize that in the latter, the maximum value of citrus pulp used was 405 g/kg DM, which is much lower than that used in the current study (570 g/kg).

One alternative NDSF-rich by-product to citrus pulp could be sugar beet by-product. The soluble and insoluble neutral detergent fiber found on it are highly digestible (Hall et al. 1998). However, the results found in literature show reductions in feed intake and performance when lambs are fed those ingredients (Mandebvu & Galbraith 1999), even when fed at less than 15% DM (Bodas et al. 2007).

Carcass characteristics

The reductions in dry matter intake negatively influenced ADG, especially in animals fed NDSF diet, which also reflected in losses in most of the carcass traits evaluated. The HCW is an important information, since it represents the profitability of the largest edible portion, and the average value found in the present study is considered good for Santa Inês derived lambs. The results disagree with Henrique et al. (1998), who did not observe differences in the percentage of HCW when replaced corn by citrus pulp.

The smallest LMA found in the present study, which were verified for the NDSF diet, with only 9.6 cm^2 can be also attributed to the lower slaughter and carcass weights. However, the diets ST and ST/NDSF promoted LM similar to the ones observed by Notter et al. (2004), which worked with Dorper and Dorset lambs (12.3 and 12.8 cm^2, respectively). Rodrigues et al. (2008) also found mean values for the LMA of lambs fed diets in which citrus pulp totally replaced corn of 12.6 cm^2, quite similar to that observed in the current study.

The lower values observed in the BF of NDSF treatment animals (1.4 mm) are also a result of the lower performance of these animals during the feedlot period and corroborates with other studies, such as Henrique et al. (2003), which observed linear reduction of LMA with the addition of 550 g/kg DM citrus pulp in diet of feedlot cattle.

Edible non-carcass components and total usable products

According to Huntington (1990), the major functions of the internal organs are digestion and absorption of dietary nutrients, and the supply of hormones. Thus, the weight of the internal organs reflects growth, health and general body condition (Zhang et al. 2017). The evaluation of non-carcass components, which can account for approximately 40% of the body weight of sheep, is becoming more important, especially in developing countries. This importance is not only related to the possibility of increasing the activity's profit when the producers sell those products, but also to the amount of edible and highly nutritious material that is being lost throughout the production process (Yamamoto et al. 2004). In the current study, the treatment containing intermediate or high concentration of NDSF promoted lighter animals, with less blood, consequently with lighter non-carcass components, leading to a reduction of 5% of TUP in treatment ST/NDSF and of 26% in treatment NDSF, which decreases the profit of overall operation.

Olmedo et al. (2018) replacing corn by dried citrus pulp in diets for lambs at up to 600 g/kg DM, did not find differences in non-carcass components since animals had similar feedlot performance, the opposite to what happened in this study. The above-mentioned authors stated that NDF content could promote an increase in TGI development due to its low digestion rate. However, the maximum difference in NDF contents among diets in the current study was less than 4%, with an increase of 82% in NDSF, which probably mitigated any effect of fiber content.

Weight and yield of carcass cuts and proximate composition of meat

The decrease in the weight of leg, rib, shoulder, loin and neck observed when the NSDF was used in greater concentrations, followed the same trend as the body weight gain during the experimental period. This was confirmed when the yield of carcass' cuts was unaffected by treatments.

Regarding the proximate composition of the meat, the decrease observed in ether extract concentration is related to the lack of finish, due to the slaughter of light animals, especially from NSDF treatment. As the fat tissues (intramuscular and external) are the last ones to be deposited (Irshad et al. 2013), there was no time sufficient to accumulate this tissue. Considering that the presence of intramuscular fat is one important factor associated with consumer´s perception of meat quality, influencing flavor and sensory attributes (Hunt et al. 2016), the meat from lambs fed NDSF treatment would be less appreciated by final consumers.

Experiment 2

Total tract digestibility

Peixoto et al. (2015), studying the substitution of corn meal by citrus pulp to sheep (up to 265 g/kg DM) did not find any effect on DM and nutrient digestibility. When sugar beet pulp was used as NSDF source, at up to 900 g concentrate mix/kg DM, in diets for Ossimi lambs, based on clover hay, no significant effects were observed on nutrient digestibility (Omer et al. 2013). On the other hand, except for NDF and starch, all nutrients had their digestibility improved when the proportion of NDSF was the greater. This fact may be associated to the improvement that the NDSF-rich ingredients (citrus pulp) promoted in the rumen environment, avoiding metabolic disorders, such as acidosis, which would impair nutrient degradation in the rumen. The main component found in NDSF is pectin, and its fermentation usually generates more acetate and less propionate and lactate than starch (Leiva et al. 2000). Because the p*K*a of acetate (4.76) and propionate (4.87) are greater than that of lactate (3.86; Dijkstra et al. 2012), citrus pulp usually reduces the occurrence of clinical and subclinical acidosis in ruminants. Barrêto Júnior et al. (2008) compared diets rich in sucrose or citrus pulp (1.65% of BW) to dairy cows and found citrus pulp reduced the risk of acute ruminal lactic acidosis.

Nitrogen balance

The nitrogen intake followed the same trend observed in DM and nutrient intake, reducing as the concentration of NSDF increased. As the fecal nitrogen significantly decreased, it resulted in lesser nitrogen balance in NSDF and ST/NSDF treatments, which caused a progressive decrease in protein biological value.

The starch-rich diet promoted a better use of the available nitrogen in the rumen, which was reflected in the nitrogen balance of the animals that consumed it. This result disagrees with those found by Ariza et al. (2001), who stated that there is a greater efficiency in the microbial synthesis with soluble fiber, relating this fact to the greater supply of carbohydrates available in the rumen for microbial growth, which would result in more efficient N-NH_3 captured than in diets containing starch. Bhattacharya & Harb (1973) and Pascual & Carmona (1980) found a decrease in retained nitrogen with an increase in the concentration of citrus pulp in the diet, while Esteves et al. (1987) did not find differences for the nitrogen ingested, excreted and retained by cattle, with the replacement of the disintegrated corn with straw and cob by the citrus pulp. Unlike the results of the current study, Henrique et al. (2003) observed greater values for nitrogen of sheep when they were greater amounts of citrus pulp. This author also presented increased percentage of nitrogen retained in relation to the absorbed nitrogen in those animals.

Other studies using similar roughage:concentrate ratios and citrus pulp as NSDF source did not find differences in nitrogen balance. Sharif et al. (2018) for example, feeding Lohi lambs, diets with 30% forages and 70% concentrate and up to 400 g dried citrus pulp/kg DM, did not find differences in nitrogen balance variables.

In conclusion, the use of 250 g NDSF/kg DM as citrus pulp in diets for crossbred lambs impairs animal intake and performance, negatively affecting carcass and meat traits and nitrogen balance. However, the moderate replacement of starch for NDSF does not change significantly productive variables and can be an alternative, depending on the price of the by-product.

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JSG: Conceived and planned the trials, conducted field trials and laboratory analysis, wrote and reviewed the manuscript. JMBE: Conceived, planned the trials and reviewed final version. ACHJ: Conducted field trials and laboratory analysis. FOSVC: Ran statistical analysis, wrote and reviewed final version. ORMN: Wrote, discussed and reviewed final version. EHCBVC: Conducted field trials, laboratory and statistical analysis, wrote, reviewed and translated final version.