

Soybean molasses to replace corn for feedlot lambs on growth performance, carcass characteristics, and meat quality

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ABSTRACT: Soybean molasses (SBM) is a byproduct of the manufacture of soy protein concentrate and has high energy value. This byproduct has a high potential for use in the nutrition of ruminant animals, mainly in the replacement of other energy feeds such as corn grain. The objective of this study was to evaluate the inclusion of SBM to replace corn grain up to 30% dry matter (DM) in the total diet on growth performance, feeding behavior, carcass characteristics, and meat quality of feedlot lambs (½ Santa Inês × ½ Dorper). Forty intact male lambs with an initial average body weight of 20.6 ± 2.5 kg and approximate age of 120 d were used. The animals were distributed in four treatments (0%, 10%, 20%, and 30% SBM), divided into five randomized blocks according to the initial weight and adapted for 16 d, with diets containing increasing concentrations of concentrate and SBM. Feeding behavior was analyzed at the beginning, middle, and final of the finishing period, and when animals reached 42 d on the finishing diet they were slaughtered. Data were evaluated using SAS software (version 9.4), by polynomial orthogonal contrasts, where the growth performance, carcass characteristics, and meat quality values were analyzed as randomized

blocks, and the feeding behavior data as randomized blocks with a repeated measure over time. Significant differences were detected for the contrast 0 vs. SBM treatments, which the inclusion of SBM caused an increase ($P \leq 0.05$) in ash intake but decreased the ether extract intake. The intake of DM in % body weight was higher for SBM treatments than 0% treatment ($P \leq 0.05$). Feeding behavior, ruminating while lying down and drinking water presented a decreasing linear effect ($P \leq 0.05$), and for feeding, efficiency increased with the addition of SBM ($P \leq 0.05$). Fatty acids C14:0, C17:0, C17:1, C18:2n6c, C20:2, and C20:3n6 showed lower values with the inclusion of SBM ($P \leq 0.05$), while fatty acids C22:0 and C22:6n3 increased. The values of n6 polyunsaturated fatty acids and n-6/n-3 ratio were lower ($P \leq 0.05$) for SBM treatments. The values of total polyunsaturated fatty acids showed a decreasing linear effect ($P \leq 0.05$) with the inclusion of SBM. The use of up to 30% SBM in DM did not impair animal growth performance and feeding behavior did not cause damages to carcass parameters and still made the meat healthier, improving the n-6/n-3 ratio, therefore can be used to feed finishing lambs.

Key words: byproduct, fatty acid, finishing, ruminant

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INTRODUCTION

To improve the profitability and quality of the product that will be made available to the market, producers search for feeding strategy like the feedlots. The finishing of lambs in feedlots brings benefits such as greater weight gain, higher carcass yield, lower age at slaughter, lower animal mortality, and lower incidence of worms (Barros et al., 2009).

Feed is the costliest item in this production system, with the concentrate being more expensive than the roughage, making the cost of diets proportionally higher with the use of concentrate (Pacheco et al., 2014). In these cases, the use of alternative feedstuff for confined animals, such as byproducts, becomes interesting when it has a good response in animals.

Soybean molasses (SBM) is a byproduct of the production of soy protein concentrate and is a good source of energy, with great quantities of sucrose, raffinose, and stachyose. Raffinose and stachyose are oligosaccharides that have galactose and glucose molecules linked by α -1,6-type bonds, that are broken by α -galactosidase enzymes, which are not produced by monogastric (Brasil et al., 2010; Shang et al., 2018). The use of SBM as an energy source, in addition to allowing the possibility of reducing costs, also make livestock more sustainable. Previous studies demonstrated that SBM promoted good response in sheep nutrition. The inclusion of SBM up to 20% in dry matter (DM) increased the DM consumption of confined lambs and promoted good weight gain, in addition to not changing pH values, ammonia nitrogen, and fatty acids in the rumen of adult sheep (Almeida et al., 2018c; van Cleef et al., 2018).

There is still little information on the use of this byproduct in sheep feeding evaluating its implications on growth performance parameters and nutritional metabolic disorders. However, despite some studies with soy molasses showing positive results in feeding ruminants (Drouillard et al., 1999; Almeida et al., 2018c; Pereira Junior et al., 2018; van Cleef et al., 2018), there are still few studies evaluating the increasing inclusion of SBM in the sheep diet in relation to carcass characteristics and meat quality of lambs finished in confinement besides these studies use only up to 20% SBM in DM.

Thus, the objective of this study was to evaluate the growth performance, feeding behavior, carcass characteristics and meat quality of lambs fed up to 30% of SBM in DM replacing corn grain.

MATERIAL AND METHODS

The experiment was conducted at the Animal Unit for Digestive and Metabolic Studies belonging to the Animal Science Department of the São Paulo State University in Jaboticabal. The work was approved by the Ethics Committee on the Use of Animals—CEUA, protocol 010824/18.

Animals, Experimental Design, and Treatments

Forty crossbred intact male lambs ($\frac{1}{2}$ Santa Inês \times $\frac{1}{2}$ Dorper) from the same farm, with similar nutritional background, at approximately 120 d of age and initial body weight of 20.6 ± 2.5 kg were used. The animals were housed in a covered shed, in individual pens with slatted floors elevated from the floor, with approximately 1.5 m² area, with individual feeder and collective waterer.

The animals were distributed in five randomized blocks according to the initial weight, allocated in four treatments that consisted of including 0%, 10%, 20%, or 30% of SBM in DM of the total diet, replacing the corn grain. Two animals of each block were allocated in each treatment, totalizing 40 animals, 10 animals per treatment, that were the experimental unit.

Feed Management and Experimental Diets

The pre-experimental phase lasted 15 d, when animals were identified, received anthelmintic [Ivermectin 1% = 1 mL for 50 kg body weight] and were fed with corn silage (~23% of grains) and water ad libitum. During this period, the objective was to adapt the animals to management, facilities, and standardize the ruminal microbiota, so during this period no assessment was made.

The adaptation period to the experimental diets was conducted in two steps (Table 1), and consisted of increasing levels of concentrate (50% and 65% DM total diet) and SBM in diet, according to the treatment, over 16 d (8 d for each diet) until reaching the level of concentrate (20:80) and molasses of the finishing experimental diet.

The experimental diets (Tables 2 and 3) were similar in terms of crude protein (172 g/kg) and metabolizable energy (2.6 Mcal/kg) respecting the nutritional requirements for gaining 0.250 kg/d according to NRC (2007). The animals received two daily meals, 50% at 8 a.m. and the other 50% at 4 p.m., controlling the amount of offered according to the leftovers from the previous day, with adjustments made daily for each animal, considering 5% leftover (Pritchard and

Table 1. Composition of diets for the adaptation period of confined lambs fed different levels of soybean molasses

Ingredients (g/kg of DM)	Inclusion levels of SBM ^a							
	Adaptation 1				Adaptation 2			
	0	10	20	30	0	10	20	30
Corn silage	650	650	650	650	450	450	450	450
Soybean molasses ^b	0	33	66	100	0	66	133	200
Corn grain	180	150	120	90	310	250	180	120
Wheat bran	114	110.5	107	102.5	154	147	149	144
Soybean meal	40	40	40	40	65	65	65	65
Urea	3	3.5	4	4.5	5	6	7	8
Limestone	8	8	8	8	11	11	11	11
Mineral supplement ^c	5	5	5	5	5	5	5	5
Chemical composition (% of DM)								
DM ^d	54.9	54.3	53.8	53.2	64.9	63.8	62.6	61.5
CP ^e	18.9	18.9	18.9	18.9	18.8	18.8	18.9	18.8
NDF ^f	42.6	42.2	41.7	41.1	35.4	34.4	33.7	32.8
ADF ^g	21.9	21.7	21.5	21.3	17.4	17.0	16.7	16.3
EE ^h	3.07	3.02	2.96	2.90	3.24	3.13	3.01	2.90
Ash	7.69	7.90	8.10	8.31	6.88	7.29	7.75	8.16
Calcium*	0.60	0.60	0.59	0.59	0.67	0.67	0.66	0.66
Phosphorus*	0.35	0.34	0.33	0.32	0.41	0.39	0.37	0.35
Potassium*	0.88	0.96	1.03	1.11	0.82	0.97	1.13	1.29
Metabolizable energy, Mcal/kg*	2.50	2.50	2.49	2.48	2.58	2.57	2.55	2.54

^aAdaptation 1: period between day 1 and 8; adaptation 2: period between day 9 and day 16; 0 (Control); 10 (10% soybean molasses); 20 (20% soybean molasses); 30 (30% soybean molasses).

^b Composition: 66.2% DM, 10.0% ash, 10.3% CP, and 2.3% EE.

^c Composition/kg: P (60 g), Ca (100 g), Na (195 g), Cl (300 g), Mg (10 g), S (25 g), Zn (4 g), Cu (0.6 g), Mn (0.6 g), Fe (1.2 g), Co (0.1 g), I (0.18 g), Fl (0.06 g).

^dDM = dry matter.

^e CP = crude protein.

^f NDF = neutral detergent fiber.

^g ADF = acid detergent fiber.

^h EE = ether extract.

* Estimated values with the aid of the SRNS program.

Bruns, 2003). The rejected feed was weighed daily before the morning feedings. Therefore, the average DM intake was calculated and then the DM intake in relation to the body weight (given in percentage).

During the experimental period, the feed and leftovers were sampled weekly, kept in the freezer (−20 °C) and at the end of the experiment they were dried in a forced ventilation oven at 55 °C for 72 h, and ground through a 1-mm sieve (AOAC, 1998; method 934.01). The content of DM was determined according to AOAC (1995; method 930.15), and the content of ash was determined by incinerating material in a muffle furnace at 600 °C for 3 h (AOAC, 1990; method 942.05), also determining organic matter (OM = DM – ash). The content of ether extract (EE) was determined by washing the samples in petroleum ether through the Soxhlet apparatus for 4 h (AOAC, 1990; method 930.15). The concentration of nitrogen was defined by the

Kjeldahl method (AOAC, 1998; method 988.05) and the estimated crude protein content by multiplying the nitrogen content by 6.25. The contents of acid detergent fiber and neutral detergent fiber were estimated according to Van Soest and Wine (1967) using thermostable α-amylase, without sodium sulfite. The nonfibrous carbohydrate content was calculated according to Hall et al. (2000), where: $1000 - [(CP - \text{urea CP} + \text{urea}) + EE + \text{ash} + \text{NDF}]$, expressed in % of DM. The ME content was estimated with the aid of SRNS program.

Growth Performance

Animals were weighed at the beginning of adaptation period (day 1), end of adaptation (first day with the final diets, before the first meal; day 17) and the end of the finishing period (day 58), after 16-h fasting for solids.

Table 2. Composition of final diets for the termination period of confined lambs fed different levels of soybean molasses

Ingredients (g/kg of DM)	Inclusion levels of SBM ^a			
	0	10	20	30
Corn silage	250	250	250	250
Soybean molasses ^b	0	100	200	300
Corn grain	400	300	200	100
Wheat bran	158	157	156	155
Soybean meal	167	166	165	164
Urea	8	10	12	14
Limestone	12	12	12	12
Mineral supplement ^c	5	5	5	5
Chemical composition (% of DM)				
DM ^d	62.7	61.7	60.3	59.2
CP ^e	17.3	17.0	17.1	17.3
NDF ^f	36.9	36.5	34.3	31.9
ADF ^g	26.4	22.8	21.5	21.2
EE ^h	3.67	2.80	2.68	2.65
Ash	4.97	5.74	6.55	7.60
NFC ⁱ	38.6	39.8	41.5	43.1
Ca*	0.68	0.68	0.68	0.67
P*	0.46	0.44	0.41	0.39
K*	0.87	1.11	1.35	1.58
Metabolizable energy, Mcal/kg*	2.68	2.66	2.64	2.62

^a 0 (Control); 10 (10% soybean molasses); 20 (20% soybean molasses); 30 (30% soybean molasses).

^b Composition: 66.2% DM, 10.0% ash, 10.3% CP, and 2.3% EE.

^c Composition/kg: P (60 g), Ca (100 g), Na (195 g), Cl (300 g), Mg (10 g), S (25 g), Zn (4 g), Cu (0.6 g), Mn (0.6 g), Fe (1.2 g), Co (0.1 g), I (0.18 g), Fl (0.06 g).

^d DM = dry matter.

^e CP = crude protein.

^f NDF = neutral detergent fiber.

^g ADF = acid detergent fiber.

^h EE = ether extract.

ⁱ NFC = nonfibrous carbohydrate.

* Estimated values with the aid of the SRNS program.

The animals received adaptation diets for 16 d (two diets, 8 d each) and final diets for 42 d, and then were slaughtered. The average daily gain (ADG) per period (day 1 to day 16, day 17 to day 58, and day 1 to day 58) were calculated at the end of the experiment. The intake fluctuation was analyzed per animal, during the final diet period, calculating the difference in daily intake of DM in relation to the previous day, expressed as a percentage (e.g., difference between intake on days 9 and 10, expressed in percentage in relation to intake on day 9).

Feeding Behavior

Animals were evaluated three times during the confinement period [beginning (day 5), middle (day 22), and end (day 40)]. Behavioral activities were recorded at five-min intervals for 24 h, by eight evaluators according to the methodology described by

Almeida et al. (2018a). The lying idle time, standing idle, lying ruminating, standing ruminating, interaction with the feeder, drinking water, other activities, and stereotypes were evaluated. Interaction with feeder was defined as the time that animal was on the feeder, eating, or chewing the feed. Subsequently, rumination efficiency (DM intake/time spent ruminating; g/DM/h), feeding efficiency (DM intake/time spent in the interaction with feeder; g/DM/h), total chewing time (time spent ruminating + time spent interacting with the feeder), number of chews per cud (N/C) and frequency of visits to the feeder (FVF; times that the animal went to the feeder) were calculated. The FVF was

Carcass Characteristics

At the end of the experimental period, the animals underwent a 16 h solid fasting, and then were

Table 3. Fatty acid profile of final diets of feedlot lambs fed different levels of soybean molasses

Fatty acids (g/100 g)	Inclusion levels of SBM ^a			
	0	10	20	30
C8:0	0.027	0.033	0.035	0.041
C11:0	0.268	0.314	0.312	0.371
C12:0	0.050	0.051	0.044	0.056
C14:0	0.099	0.110	0.111	0.127
C15:0	0.052	0.326	0.335	0.413
C16:0	14.76	15.73	16.10	16.80
C16:1	0.133	0.126	0.139	0.129
C17:0	0.124	0.134	0.122	0.131
C17:1	0.047	0.077	0.061	0.067
C18:0	2.877	2.883	2.955	2.896
C18:1n9t	0.148	0.000	0.000	0.000
C18:1n9c	30.81	28.31	26.86	23.62
C18:2n6t	0.036	0.034	0.043	0.047
C18:2n6c	46.46	47.46	48.08	49.82
C18:3n3	2.578	3.002	3.405	4.062
C18:3n6	0.016	0.015	0.016	0.052
C 20:0	0.518	0.457	0.426	0.375
C20:1n9	0.300	0.297	0.293	0.296
C20:2	0.029	0.023	0.034	0.049
C20:4n6	0.047	0.055	0.061	0.070
C22:0	0.251	0.236	0.249	0.259
C22:6n3	0.051	0.026	0.028	0.037
C23:0	0.063	0.061	0.051	0.051
C24:0	0.254	0.243	0.238	0.235
SFA ^b	19.34	20.58	20.98	21.75
MUFA ^c	31.44	28.81	27.35	24.11
PUFA ^d	49.22	50.61	51.67	54.14
n-3 PUFA	2.629	3.028	3.433	4.099
n-6 PUFA	46.56	47.56	48.20	49.99

^a 0 (Control); 10 (10% soybean molasses); 20 (20% soybean molasses); 30 (30% soybean molasses).

^b Saturated fatty acids.

^c Monosaturated fatty acids.

^d Polyunsaturated fatty acids.

weighed and taken to the slaughterhouse. At the slaughterhouse, they were stunned by electronarcosis, with electrical discharge to head and heart, and then bleed through the section of the jugular veins and carotid arteries, respecting the procedure that characterizes humanitarian slaughter (Monteiro Júnior, 2000).

The hot carcass weight (HCW) was obtained after skinning and evisceration of the animals, which after weighing were stored in a cold chamber at 4 °C for 24 h, then they were weighed again to determine the cold carcass weight (CCW). After weighing, the hot carcass yield (HCY = HCW / BW × 100) and cold carcass yield (CCY = CCW / BW × 100) was calculated.

In the Longissimus thoracis et lumborum muscle, at the height of the 13th rib, subcutaneous fat thickness and loin eye area (LEA) were measured. The subcutaneous fat thickness was measured

with the aid of a digital caliper. The LEA was measured according to Cezar et al. (2007) with modification. With the help of a sheet of parchment paper over the section area, the muscle outline was drawn with a pen. Subsequently, the sheets were scanned and read in the computer program ImageJ, previously calibrated to measure the area in cm².

Ruminitis

For the evaluation of the ruminitis severity (RS), after the slaughter, the rumens were washed and evaluated by two trained evaluators. The ruminal epithelium was classified according to the incidence of lesions (rumenitis and hyperparakeratosis) and other abnormalities in it, following the methodology of Bigham and McMamus (1975) based on a scale from 0 to 10.

Liver Abscess

The liver of the animals was examined and classified according to the size and number of abscesses (1 = one to two small abscess, 2 = two to four small abscess, and 3 = one or more large abscess greater than 2.5 cm, according to the methodology proposed by Brink et al. (1990). Livers without abnormalities were labeled as normal and received a grade of 0.

Meat Quality

After 24 h in a cold chamber, samples of the Longissimus thoracis et lumborum muscle were collected from the left side of the carcass (between 5th and 13th ribs), vacuum-packed in polyethylene bags, transported to the Meat Technology Laboratory at São Paulo State University campus Jaboticabal and stored at $-20\text{ }^{\circ}\text{C}$ until the analysis procedure.

Meat color parameters were evaluated as described by Houben et al. (2000), using a colorimeter (Minolta Chroma Meter CR-300, Osaka, Japan). The parameters evaluated were luminosity (L^*), red intensity (a^*), and yellow intensity (b^*), which were evaluated by the CIE $L^* a^* b^*$ color system (CIE, 2004). The color was read at three different points and the averages were calculated. The pH was measured using meat pH meter (Testo 205). Both parameters were measured after 45 min (room temperature) and 24 h (at $4\text{ }^{\circ}\text{C}$ in a cold chamber) after slaughter.

The samples were thawed at room temperature, crushed, and lyophilized for 72 h. After the lyophilization process, the DM was determined according to AOAC 1995 (method 930.15), the ash content obtained by incinerating the samples in a muffle furnace at $600\text{ }^{\circ}\text{C}$ for 3 h (AOAC, 1990; method 942.05), the concentration of nitrogen (N) was determined by the Kjeldahl method (AOAC, 1998; method 988.05), and the crude protein content multiplied by 6.25. Fat was according to Bligh and Dyer (1959), without subcutaneous fat, to determine the proximate composition.

Water holding capacity (WHC) was measured by subjecting approximately 2 g of meat to 10 kg of pressure for 5 min. The difference between the weight of the meat before and after the procedure was used to calculate the WHC, expressed in % (Hamm, 1986). For the determination of cooking loss (CL), two samples of each animal were thawed at room temperature, weighed, and grilled at $200\text{ }^{\circ}\text{C}$ in a preheated grill. When the geometric center of the sample reached $71\text{ }^{\circ}\text{C}$ (thermometer), cooking

was stopped and the samples were weighed again when they reached room temperature (AMSA, 1978). The CL was considered by the difference in weight of the samples before and after cooking. The same samples used to determine CL were used to assess shear force using a Warner–Bratzler blade (WBSF), where six-round cores (1.27 cm in diameter) of meat, free of visible fat and connective tissue, were cut in parallel along the muscle fibers (AMSA, 1995), and each nucleus was sheared perpendicular to the direction of the fiber, and then averages per animal were made. The results were expressed in Newton (N) per 1 cm^2 .

Fatty acid profile was extracted according to the methodology proposed by Bligh and Dyer (1959) with some modifications. Approximately 3 g of lyophilized meat samples were transferred to a 125 mL Erlenmeyer and 10 mL of chloroform, 20 mL of ethanol, and 8 mL of distilled water were added. The containers were shaken for 30 min on a horizontal shaker (model SL-0031, Solab, Piracicaba, Brazil), 10 mL of chloroform and 10 mL of 1.5% sodium sulfate solution were added for another 2 min of stirring. The entire contents were filtered with quantitative filter paper and transferred to 50 mL Falcon flasks. After separation, the top layer was discarded, and 10 mL of the filtrate was transferred to previously tared glass beakers. The container was placed in a force air oven at $55\text{ }^{\circ}\text{C}$ for 24 h, to evaporate the solvent. After cooling in the desiccator were weighed again and the fat content calculated by the difference.

For the transesterification of triglycerides, approximately 50 mg of lipids were transferred to 15 mL Falcon flasks, and 2 mL of heptane were added. The mixture was stirred until the complete fat dissolved and then 2 mL of KOH (2 mol/L of methanol) was added. The new mixture was vigorously stirred for 5 min. After separation of the phases, 1 mL of the upper layer, composed of heptane and methyl esters of fatty acid was transferred to 1.5 mL microtubes and frozen at $-18\text{ }^{\circ}\text{C}$ until analysis.

Fatty acid profile analyzes were performed using a gas chromatograph (model 14-B, Shimadzu, Kyoto, Japan), along with a fused silica capillary column, type Omewax250 ($100\text{ m} \times 0.25\text{ mm} \times 0.25\text{ }\mu\text{m}$) Cat. No. 24136-Supelco. The activities of Δ^9 desaturase (16 and 18) and elongase were estimated according to Malau-Aduli et al. (1997), and the atherogenicity index was estimated according to Ulbricht e Southgate (1991), as follows:

$$\Delta^9\text{desaturase } 16 = 100 \left[\frac{\text{C16 : 1c9}}{\text{C16 : 1c9} + \text{C16 : 0}} \right]$$

$$\Delta^9\text{desaturase } 18 = 100 \left[\frac{\text{C18 : 1c9}}{\text{C18 : 1c9} + \text{C18 : 0}} \right]$$

Elongase =

$$100 \times \frac{18 : 0 + \text{C18 : 1c9}}{(\text{C : 16 : 0} + \text{C16 : 1c9}) + (\text{C18 : 0} + \text{C18 : 1c9})}$$

Atherogenicity index =

$$\frac{\text{C12 : 0} + 4(\text{C14 : 0}) + \text{C16 : 0}}{\Sigma\text{MUFA} + \Sigma\text{PUFA}}$$

Statistical Analysis

Growth performance, ruminitis and liver abscess severity, carcass, and meat quality data were analyzed using the MIXED procedure of SAS software (SAS Inst., Inc., Cary, NC; version 9.4). The model included the fixed effects of including the SBM, and the blocks as random effects (RANDOM SAS option). The linear and quadratic effects of the inclusion of SBM were tested, as well as the contrasts 0 (control) vs. SBM treatments (10%, 20%, and 30%).

Feeding behavior, pH and color of meat were evaluated as a repeated measure over time, including the effects of treatments. The response variables were subjected to tests with different covariance structures and the structure that resulted in the lowest AIC (Akaike Information Criterion) value for each response variable was chosen for analysis because it better accommodates the data. Values of

$P \leq 0.05$ were considered significant and $0.05 < P \leq 0.10$, as tendency.

RESULTS

Dry Matter and Nutrients Intake, Growth Performance, and Feeding Behavior

The increasing inclusion of SBM did not affect the intake of DM, CP, NDF, and ADF ($P = 0.153$, 0.163 , 0.440 , and 0.177 , respectively; Table 4). There was a difference for EE and ash intake ($P < 0.01$ for both), in which the treatment with 0% SBM inclusion consumed 13.3g more EE (44.2% more) than lambs fed 30% SBM diet. The NDF consumption showed quadratic tendency ($P = 0.054$) while the ADF consumption presented a linear tendency ($P = 0.052$) with SBM inclusion. The severity of liver abscess showed tendency ($P = 0.066$) when SBM was included in the diets.

When the growth performance was evaluated, the increasing inclusion of SBM did not affect any of the variables analyzed ($P > 0.10$; Table 5) in any of the feedlot periods (adaptation period, finishing period, and total period).

For the feeding behavior, the increasing inclusion of SBM provided a linear reduction in the time spent in ruminating while lying down (RL; $P = 0.041$) and an increase in the rumination efficiency (REF; $P = 0.028$; Table 6). Animals that received 30% SBM spent an average of 39.6 min less ruminating while lying down compared to the lambs fed 0% SBM. The inclusion of SBM reduced the time drinking water (DW; $P = 0.026$; 0 vs. SBM), reducing by 6.9 min

Table 4. Dry matter and nutrients intake of feedlot lambs fed different levels of soybean molasses

Item	Inclusion levels of SBM				SEM ^a	P-value ^b		
	0	10	20	30		L	Q	0 vs. SBM
DMI ^c , g/d	1135	1281	1173	1185	32.8	0.831	0.280	0.153
EEI ^d , g/d	43.4	35.4	30.2	30.1	1.26	<0.01	0.038	<0.01
CPI ^e , g/d	193	219	201	205	6.04	0.718	0.361	0.163
NDFI ^f , g/d	410	475	408	391	12.1	0.083	0.054	0.440
ADFI ^g , g/d	278	263	247	241	8.86	0.052	0.789	0.177
ASHI ^h , g/d	55.9	73.0	76.1	89.3	2.83	<0.01	0.614	<0.01
DMIF ⁱ , %	9.74	8.50	11.1	9.88	0.61	0.517	0.858	0.993

^a SEM = standard error mean.

^b L = linear effect; Q = quadratic effect; 0 vs. MSO = contrast 0% vs. SBM treatments.

^c DMI = dry matter intake.

^d EEI = ether extract intake.

^e CPI = crude protein intake.

^f NDFI = neutral detergent fiber intake.

^g ADFI = acid detergent fiber intake.

^h ASHI = ash intake.

ⁱ DMIF = dry matter intake fluctuation.

Table 5. Performance (kg), ruminitis, and liver abscess severity of feedlot lambs fed with different levels of soybean molasses

Item	Inclusion levels of SBM				SEM ^a	P-value ^b		
	0	10	20	30		L	Q	0 vs. SBM
IBW 1d ^c	20.9	20.1	20.9	20.9	0.43	0.851	0.625	0.746
IBW 17d ^d	24.5	25.3	24.4	25.2	0.50	0.529	0.964	0.378
FBW 58d ^e	34.4	35.9	34.9	34.9	0.73	0.889	0.551	0.504
ADG 1-16d ^f	0.23	0.35	0.24	0.27	0.04	0.951	0.515	0.275
ADG 17-58d ^g	0.24	0.25	0.25	0.23	0.01	0.808	0.385	0.687
ADG 1-58d ^h	0.23	0.28	0.24	0.24	0.01	0.999	0.386	0.411
RS ⁱ	1.36	1.37	1.49	0.60	0.35	0.495	0.503	0.831
LAS ^j	0.11	0.44	0.33	0.44	0.09	0.201	0.536	0.066

^a SEM = standard error mean.

^b L = linear effect; Q = quadratic effect; 0 vs. SBM = contrast 0% vs. SBM treatments.

^c IBW 1 d = initial body weight on first day of adaptation.

^d IBW 17 d = initial body weight on first day with final diets/final of adaptation.

^e FBW 58 d = final body weight of feedlot.

^f ADG 1-16 d = average daily gain on adaptation.

^g ADG 17-58 d = average daily gain with final diets.

^h ADG 1-58 d = average daily gain on experimental period.

ⁱ RS = ruminitis severity.

^j LAS = liver abscess severity.

Table 6. Feeding behavior (min/d) of feedlot lambs fed with different levels of soybean molasses

Item	Inclusion levels of SBM				SEM ^a	P-value ^b		
	0	10	20	30		L	Q	0 vs. SBM
Idle lying	755	754	754	770	9.06	0.688	0.746	0.876
Idle standing	161	143	161	154	5.27	0.930	0.707	0.601
Ruminating while lying down	276	278	250	236	6.26	0.041	0.594	0.230
Ruminating standing	5.16	9.47	6.47	6.00	0.90	0.962	0.309	0.463
Feeder interaction	166	166	167	189	4.39	0.236	0.400	0.587
Drinking water	18.7	15.5	13.2	11.8	0.95	0.013	0.644	0.026
Other activities	35.5	31.6	44.4	34.9	1.99	0.628	0.601	0.801
Stereotypes	18.2	16.9	20.8	24.2	1.66	0.294	0.614	0.642
REF ^d , (g MS/h)	240	272	275	309	10.8	0.033	0.970	0.028
FEF ^e , (g MS/h)	429	489	426	391	20.1	0.266	0.214	0.892
Total chewing time	456	463	433	432	7.25	0.202	0.831	0.503
N/Cud ^c	43.3	39.9	38.3	41.7	0.49	0.192	0.006	0.015
FVF ^f	17.4	17.5	18.6	20.2	0.44	0.066	0.518	0.275

^a SEM = standard error mean.

^b L = linear effect; Q = quadratic effect; 0 vs. SBM = contrast 0% vs. SBM treatments.

^c N/Cud = number of chews per bolus.

^d REF = rumination efficiency.

^e FEF = feeding efficiency.

^f FVF = frequency of visits to feeder (times that the animal went to the feeder).

the time spent DW by the lambs fed 30% SBM when compared to 0% SBM. There was a decreased linear effect for the time spent chewing cud ($P = 0.015$) with the inclusion of SBM in the diets, with the lowest values for SBM treatments. The frequency of visits to the feeder showed a linear increasing tendency ($P = 0.066$), where the lambs that received 30% SBM tended to go 2.9 more times to the feeder than the 0% SBM treatment.

Carcass Characteristics and Meat Quality

The increasing inclusion of SBM did not influence the carcass parameters and physical analysis of the meat ($P > 0.10$, Table 7).

For the fatty acid profile of the meat, there was a linear reduction for acids C14:0, C17:0, C17:1, C20:3n6, and PUFA ($P = 0.05, 0.028, 0.031, 0.030,$ and 0.019 , respectively; Tables 8 and 9) concentrations.

Table 7. Parameters of carcass and meat of feedlot lambs fed different levels of soybean molasses

Item	Levels of SBM				SEM ^a	P-value ^b		
	0	10	20	30		L	Q	0 vs. SBM
HCW ^c , kg	15.6	16.8	16.4	16.4	0.36	0.551	0.421	0.249
CCW ^d , kg	15.3	16.2	15.8	15.8	0.36	0.662	0.434	0.295
HCY ^e , %	42.8	45.4	44.2	44.3	0.97	0.551	0.421	0.248
CCY ^f , %	41.5	43.8	42.7	42.6	0.97	0.661	0.434	0.294
FT ^g , mm	3.70	3.45	3.57	3.46	1.39	0.665	0.805	0.552
LEA ^h , cm ²	11.8	11.5	11.0	12.1	0.30	0.825	0.249	0.780
CL ⁱ , %	26.1	24.7	25.5	26.1	0.61	0.910	0.462	0.735
WHC ^j , %	67.4	67.7	65.7	68.0	0.40	0.957	0.219	0.660
WBSF ^k , N	25.7	22.9	21.7	25.7	1.26	0.920	0.154	0.342
pH	6.11	6.08	6.15	6.11	0.04	0.703	0.940	0.934
L*	31.1	30.5	30.6	31.2	0.32	0.915	0.412	0.684
a*	12.5	11.1	11.9	11.8	0.18	0.602	0.189	0.131
b*	2.45	1.93	2.20	2.39	0.08	0.924	0.138	0.312

^a SEM = standard error mean.

^b L = linear effect; Q = quadratic effect; 0 vs. MSO = contrast 0% vs. SBM treatments.

^c HCW = hot carcass weight.

^d CCW = cold carcass weight.

^e HCY = hot carcass yield.

^f CCY = cold carcass yield.

^g FT = subcutaneous fat thickness.

^h LEA = loin eye area.

ⁱ CL = cooking loss.

^j WHC = water hold capacity.

^k WBSF = Warner–Bratzler shear force.

For C18:2n6c, C20:2, and n6-PUFA acids, the inclusion of SBM provided a reduction in concentrations ($P = 0.007$, 0.004 , and 0.046 , respectively) in addition to decreasing the n-6/n-3 ratio ($P = 0.016$), while for C22:0 and C22:6n3 fatty acids, the concentration increased ($P = 0.022$ and 0.002). C20:5n3 acid showed a tendency ($P = 0.084$), with higher values for SBM treatments.

Regarding the proximate composition (Table 10), the inclusion of SBM did not provide significant differences ($P > 0.10$).

DISCUSSION

Dry Matter and Nutrients Intake, Growth Performance, and Feeding Behavior

The similarity in DM intake with the increasing inclusion of SBM can be due to meeting the requirements of the animals since the diets were similar in terms of metabolizable energy and NDF content that could interfere with consumption. This result corroborates with [Oltamari et al. \(2016\)](#), who evaluated the supplementation of calves with the inclusion of up to 10% sugarcane molasses in

the DM and observed no significant difference in the DMI. [Fimbres-Durazo et al. \(2013\)](#) also found no differences for DMI, weight gain, and feed conversion ratio of lambs fed increasing levels of blackstrap molasses, showing very close results for weight gain using the same animal category, with similar initial weight, age and high concentrate proportion, as in this study.

The lower intake of ether extract combined with the higher intake of ash for treatments with SBM is due to the difference of these nutrients in the diets. The SBM has lower EE content and higher ash content compared to corn, therefore, the replacement of corn with molasses provided lower concentrations of EE and higher ash, and since the DMI did not show any significant difference, the intake of these nutrients followed the composition of the diets.

The quadratic tendency for the neutral detergent fiber intake is probably due to higher DM intake, numerically, in the treatment 10% of SBM, although this variable did not present a significant difference since the treatments presented decreasing NDF content. The tendency towards ADF intake is also due to the variation in concentrations in diets. NDF intake is negatively correlated with dietary

Table 8. Fatty acid profile of *Longissimus thoracis et lumborum* (mg/100 g) of feedlot lambs fed different levels of soybean molasses

Item	Levels of SBM				SEM ^a	P-value ^b		
	0	10	20	30		L	Q	0 vs. SBM
C10:0	11.3	11.8	8.07	9.70	0.57	0.142	0.783	0.373
C12:0	4.83	4.98	4.05	4.57	0.30	0.415	0.428	0.986
C14:0	171	164	133	137	7.81	0.050	0.709	0.156
C15:0	14.1	11.3	10.1	11.0	1.00	0.398	0.441	0.308
C16:0	1977	1845	1675	1805	70.2	0.226	0.324	0.159
C17:0	70.2	63.0	49.3	52.1	3.44	0.028	0.409	0.093
C18:0	1287	1144	1091	1088	53.1	0.214	0.508	0.177
C20:0	5.90	6.57	5.72	5.85	0.41	0.801	0.742	0.903
C21:0	25.6	28.3	24.1	27.0	1.54	0.999	0.967	0.792
C22:0	9.60	12.18	11.51	10.80	0.58	0.433	0.125	0.022
C14:1	9.56	11.04	4.97	6.34	1.11	0.214	0.808	0.839
C16:1n9c	124	130	106	118	5.34	0.231	0.755	0.498
C17:1	38.2	40.1	29.4	29.6	1.78	0.031	0.193	0.671
C18:1n9t	0.07	0.08	0.11	0.07	0.01	0.551	0.635	0.968
C18:1n9c	3457	3197	3059	3266	118	0.519	0.339	0.333
C18:2n6t	2.63	2.46	2.19	2.29	0.18	0.472	0.714	0.556
C18:2n6c	212	195	170	162	7.26	0.004	0.703	0.007
C18:3n6	3.91	3.13	2.95	2.51	0.21	0.092	0.828	0.241
C18:3n3	9.59	9.33	6.80	8.61	0.44	0.184	0.178	0.158
C20:2	1.61	1.32	1.45	1.23	0.06	0.021	0.705	0.004
C20:3n6	6.07	6.41	5.77	4.85	0.28	0.030	0.214	0.345
C20:4n6	51.4	60.7	58.4	53.6	2.85	0.835	0.199	0.178
C20:5n3	3.68	6.09	4.08	4.07	0.42	0.731	0.154	0.084
C22:4n6	5.29	5.12	6.05	5.42	0.25	0.475	0.594	0.537
C22:5n3	8.56	12.03	9.04	9.22	0.68	0.581	0.225	0.107
C22:6n3	1.71	2.80	2.39	2.22	0.15	0.253	0.028	0.002

^a SEM = standard error mean.

^b L = linear effect; Q = quadratic effect; 0 vs. MSO = contrast 0% vs. SBM treatments.

energy (Van Soest, 1994), the latter with a greater influence on intake when NDF is not enough to cause physical filling. In this study, NDF concentration ranged from 36.86 to 31.88 g/kg, very close levels, as well as the levels of DM.

The lower intake of neutral detergent fiber may explain the less time spent ruminating while lying down with SBM inclusion. According to Van Soest (1994), the time spent on rumination is proportional to the intake of NDF. Thus, the lowest NDF levels, associated with the lowest NDF intake for diets with SBM, may have contributed to the shorter times ruminating while lying down by the animals, since the shorter times were found for the treatments with higher amount of molasses. This fact, which also contributed to the shorter chewing times per cud with the inclusion of SBM. The NDF reduction is related to the chewing time, which decreases as the NDF concentration also decreases (Muhammad et al., 2016).

The lower time drinking water in the treatments with SBM is due to the lower DM of these diets,

that is, the larger presence of water in these diets reduced the time drinking water. Molasses has approximately 68% DM, against 87% cornmeal, a difference of 19 units. Calculating the difference in water intake through diets intake, there was 94.8 g water/kg DM ingested more in the treatment 30% compared to 0% treatment.

The highest values of rumination efficiency showed the animals that consumed SBM obtained better efficiency. The higher NFC in the diets can lead the feed a less necessity of rumination and higher passage rate, increasing the rumination efficiency (Mendes et al., 2015). Just as NFC may have contributed, the sugars in the SBM may have contributed strongly to this result as it must have been rapidly dissolved in the rumen since the roughage:concentrate ratio was the same to the treatments.

The linear tendency in the frequency of visits to the feeder showed that the greater the inclusion of molasses, the greater the number of times the animals tend to go to the feeder. The greater

Table 9. Quantification of fatty acids and Δ^9 desaturase and elongase activity of *Longissimus thoracis et lumborum* muscle (mg/100 g) of feedlot lambs fed different levels of soybean molasses

Item	Levels of SBM				SEM ^a	P-value ^b		
	0	10	20	30		L	Q	0 vs. SBM
TFA ^c	7526	6987	6497	6836	247	0.254	0.372	0.187
SFA ^d	3581	3289	3011	3151	129	0.177	0.382	0.138
MUFA ^e	3641	3389	3213	3429	124	0.482	0.363	0.332
PUFA ^f	307	304	268	256	10.0	0.019	0.793	0.078
n-3 PUFA ^g	23.4	30.1	22.2	24.1	1.31	0.402	0.568	0.781
n-6 PUFA ^h	282	272	245	230	9.34	0.017	0.879	0.046
n-6/n-3 ⁱ	12.0	9.67	11.5	10.1	0.48	0.274	0.578	0.016
AI ^j	0.68	0.68	0.63	0.64	0.01	0.145	0.954	0.315
Δ^9 des16 ^k	6.00	6.74	5.86	6.21	0.19	0.834	0.606	0.456
Δ^9 des18 ^l	72.9	73.9	73.4	75.4	0.67	0.238	0.698	0.450
Elongase	69.2	68.6	70.1	69.3	0.31	0.519	0.898	0.852

^a SEM = standard error mean.

^b L = linear effect; Q = quadratic effect; 0 vs. MSO = contrast 0% vs. SBM treatments.

^c TFA = total fatty acids.

^d SFA = saturated fatty acids.

^e MUFA = monounsaturated fatty acids.

^f PUFA = polyunsaturated fatty acids.

^g n-3 PUFA = n-3 polyunsaturated fatty acids.

^h n-6 PUFA = n-6 polyunsaturated fatty acids.

ⁱ n-6/n-3 = n-6 and n-3 fatty acids ratio.

^j AI = Atherogenicity index.

^k Δ^9 des16 = Δ^9 desaturase 16 activity.

^l Δ^9 des18 = Δ^9 desaturase 18 activity.

Table 10. Proximate composition of *Longissimus thoracis et lumborum* muscle (g/100 g) of feedlot lambs fed different levels of soybean molasses

Item	Levels of SBM				SEM ^a	P-value ^b		
	0	10	20	30		L	Q	0 vs. SBM
Moisture	70.4	71.3	71.5	71.3	0.23	0.136	0.281	0.126
Ash	1.28	1.24	1.30	1.28	0.03	0.824	0.843	0.911
Crude protein	20.3	20.1	19.9	20.4	0.10	0.882	0.137	0.611
Total fat	7.97	7.36	7.22	6.95	0.25	0.149	0.736	0.185

^a SEM = standard error mean.

^b L = linear effect; Q = quadratic effect; 0 vs. MSO = contrast 0% vs. SBM treatments.

fractionation of intake throughout the day is desirable, as it is related to greater health and better welfare in animals (Nielsen et al., 2016). This tendency can also be related to the rapid fermentation and production of fatty acids in the rumen promoted by sugars (Martel et al. 2011; Soder et al., 2011) contained in SBM, quickly increasing the osmotic pressure and concentration of fatty acids in the rumen, causing that animals reach “brain regulation of satiety” earlier, thus leading to greater fractionation of intake as a measure to prevent metabolic disorders (Ginane et al., 2015).

In addition, the frequency of visits to the feeder may also be related to a possible higher rate of

passage of treatments with SBM and consequent shorter time in the rumen. Whitlow et al. (1976) found a higher concentration of chromium in the abomasum of cows when supplemented with commercial products based on sugarcane molasses, compared to the 0% treatment, indicating a higher rate of passage through the reticulum-rumen in animals fed with molasses. Therefore, the possible shorter time the feed remained in the rumen may have caused a greater number of visits to the feeder, which also justifies the higher DMI in relation to BW.

The feeding intake fluctuation can be due to the increase in rumen osmotic concentration through

the large production of volatile fatty acids can increase rumen acidification due to the greater difficulty in absorbing fatty acids, quickly decreasing the pH and causing feeding intake fluctuation, which is common in ruminants fed high-concentrate diets and values above 350 mOsmol are sufficient to cause subclinical ruminal acidosis (Millen et al., 2016). The feeding intake fluctuation can be extended from the adaptation period to the initial phase of confinement, mainly for ad libitum feedings (Soto-Navarro et al., 2000).

The fluctuations in dry matter intake were 9.74%, 8.50%, 11.1%, and 9.88%, respectively for treatments with 0%, 10%, 20%, and 30% of SBM. This result can be due to high concentrate content in the diets. Soto-Navarro et al. (2000) verified a decrease in the growth performance of steers in the initial confinement phase with a 10% fluctuation in DMI, explaining this result to the presence of subacute ruminal acidosis. Maybe the treatments have caused subacute ruminal acidosis but there was no difference observed in growth performance.

The high amount of concentrate in diets leads to a greater concentration of volatile fatty acids in rumen, that can damage the ruminal tissues, causing ruptures in the epithelium and rumen wall, making space for microorganisms such as *Fusobacterium necrophorum*, which fall into the bloodstream and are carried to the liver causing liver abscesses (Millen et al., 2016). Thus, the appearance of liver abscesses can be associated with the feeding intake fluctuation in molasses treatments but not caused differences in severity between treatments.

Despite the presence of liver abscess and ruminitis, the growth performance was satisfactory, close to the target according to NRC (0.250 kg against 0.230, 0.246, 0.243, and 0.226 kg for 0%, 10%, 20%, and 30% treatments, respectively). In addition to feeding intake fluctuation, no other signs of acidosis were observed in the animals during the feeding period in any treatment.

Carcass Characteristics and Meat Quality

The values obtained for the carcass parameters and physicochemical characteristics of the meat are close to those found in the literature for Dorper × Santa Inês lambs (Carvalho et al., 2015; Bezerra et al., 2016). Corroborating the results obtained, Queiroz et al. (2015), evaluating the meat and carcass characteristics of Santa Inês lambs slaughtered with different subcutaneous fat thicknesses

measures, observed values of hot carcass weight and loin eye area close to those found in the present study, which were 16.3 kg and 11.6 cm² of mean, respectively.

The high values of subcutaneous fat thickness and intramuscular fat in the Longissimus thoracis et lumborum muscle may be associated with the level of concentrate in the diets, which has a great influence on these characteristics (Majdoub-Mathlouthi et al., 2013). The amount of intramuscular fat in meat generally increases with the addition of concentrate to the diet in a positive correlation, caused by greater energy intake, and greater production of propionate in the rumen, which stimulates fat synthesis through the high availability of glucose in the blood, the great precursor of intramuscular fat deposition (Mushi et al., 2009; Jacques et al., 2011; Ladeira et al., 2018). In the study by Barros et al. (2015), the concentration of total lipids in the Longissimus dorsi of Dorper × Santa Inês lambs, fed with increasing concentrations of glycerin in roughage:concentrate ratio of 52:48, and slaughtered between 9 and 10 mo of age, reached 6.13% in the 0% treatment, also a high value.

In the present study, the maximum mean for shear force was 25.7 N, which is smaller than the values found by Souza et al. (2016), that evaluated two crosses of Dorper × Santa Inês breed, slaughtered with approximately 36 kg of live weight, that observed values for shear force smaller than 3.4 kgf/cm² (approximately 33.3 N). According to Lawrie (2017), the meat needs to be below 3 kgf (approximately 29 N) to have good acceptance by the consumer, thus the meat of the present study is in this category, being below 29 N and considered soft and with good acceptance.

The low values for shear force can be related to the relatively high amount of lipids in the muscle. According to Starkey et al. (2016), the intramuscular fat is related to the shear force in the Longissimus thoracis muscle of lambs, and 1% of increase in this fat can promote a decrease in the shear force by 3.9 N.

According to Kerry et al. (2002), meat palatability is strongly related to the amount of intramuscular fat, and values less than 3% show a radical reduction in palatability, while meat with values above 7.3% was considered very greasy by consumers. However, despite the fat of treatments did not show any significative difference, the treatments with SBM are also in agreement within the acceptance range.

The reduction in the concentration of n-6, C18:2n6c and C20:4n6, influenced the total

concentration of polyunsaturated fatty acids, and consequently the n-6/n-3 ratio since the n-3 concentration did not vary.

Although molasses treatments have higher amounts of polyunsaturated fatty acids, the consumption of ether extract may have impacted on the result, being higher in the 0% treatment (43.4 g/d) and reducing with the inclusion of molasses (35.4, 30.2, and 30.1 g/d for treatments with 10%, 20%, and 30% of SBM, respectively). As they are high concentrate diets, the high passage rate combined with the consumption of superior ether extract in the 0% treatment may have resulted in a greater escape of these fatty acids from biohydrogenation, being incorporated in a higher concentration in the meat.

In the present study, there was an increase of DHA (C22:6n3) in the treatments with molasse, which may have occurred due to higher concentration of linoleic acid (C18:3) in the diets with molasses, a precursor of n-3 fatty acids such as DHA, which is present in higher concentrations in soy compared to corn (Bezerra et al., 2016; Fonteles et al., 2018).

Consumption of n-3 fatty acids, mainly EPA (C20:5n3) and DHA has long been associated with prevention of cancer and heart, metabolic, and inflammatory diseases in humans (Chikwanha et al., 2018), and n-6 fatty acids as having the opposite function, associated with the onset of inflammation, thrombosis, increased blood viscosity, and vasoconstriction, resulting in the need to maintain a low relationship between these fatty acids in human nutrition (Simopoulos, 2016). As a result, meat has come to be considered an important part mainly in the manifestation of heart diseases.

Recent studies have questioned the association of greater consumption of n-6 with harm to human health, in addition to the better n-6/n-3 ratio (Sheppard e Cheatham, 2018; Zhuang et al., 2019). Zhuang et al. (2019) recommended the consumption of rations between 6 and 10 of n-6/n-3 for the Chinese population, as they did not observe a link between this consumption and a higher mortality rate, while Sheppard and Cheatham (2018) showed the ratio of 7:11 as safe for the North American population.

Taking into account the possible non-harmful relationship of n-3 fatty acids in relation to n-6, treatments with SBM inclusion promoted a better quality of the meat, since they decrease the n-6/n-3 ratio, being within the consumption recommendations proposed by some authors (Sheppard and Cheatham, 2018; Zhuang et al., 2019).

CONCLUSION

The inclusion of up to 30% of SBM for feedlot lambs does not affect the growth performance and carcass and meat parameters, besides to promote a lower n-6/n-3 ratio, making the meat healthier for human consumption, therefore it can be used as an alternative ingredient to replacing corn grain.

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LITERATURE CITED

- Almeida, M. T. C., J. M. B. Ezequiel, J. R. Paschoaloto, H. L. Perez, V. B. Carvalho, E. S. Castro Filho, and E. H. C. B. Van Cleef. 2018a. Effect of high concentration of crude glycerin in diets for feedlot lambs: feeding behavior, growth performance, carcass and non-carcass traits. *Anim. Prod. Sci.* 58:1271–1278. doi:10.1071/AN16628
- Almeida, M. T. C., J. R. Paschoaloto, E. S. Castro Filho, R. S. Barducci, G. P. Soragni, E. A. Zampieri Neto, A. E. Pedro, J. M. B. Ezequiel. 2018c. Effects of increasing inclusion of soybean molasses on rumen fermentation of feedlot lambs. *J. Anim. Sci.* 96(Suppl.3):476. doi:10.1093/jas/sky404.1040
- AMSA. 1978. Guideline for cooking and evaluation of meat. Chicago, IL: American Meat Science Association and National Livestock and Meat Board.
- AMSA. 1995. Research guidelines for cookery, sensory and instrumental tenderness measurements of fresh meat. Chicago, IL: American Meat Science Association and National Livestock and Meat Board.
- AOAC. 1990. Official methods of analysis. 15th ed. Arlington, VA: Association of Official Analytical Chemists.
- AOAC. 1995. Official methods of analysis. 16th ed. Washington, DC: Association of Official Analytical Chemists.
- AOAC. 1998. Official methods of analysis of the AOAC International. 16th ed. Gaithersburg, MD: Association of Official Analytical Chemists.
- Barros, C. S., A. L. G. Monteiro, C. H. E. C. Poli, J. R. Dittrich, J. R. F. Canziani, and M. A. M. Fernandes. 2009. Economic return of sheep production on pasture and in feedlot. *Braz. J. Anim. Sci.* 38:2270–2279. doi:10.1590/S1516-35982009001100029
- Barros, M. C. C., F. F. Silva, R. R. Silva, J. I. Simionato, G. S. Guimarães, L. L. Silva, and L. M. A. M. Facuri. 2015. Crude glycerin in diets in feedlot weathers. Centesimal composition and fatty acids profile of longissimus dorsi. *Sêmina* 36:431–442. doi: 10.5433/1679-0359.2015v36n1p431
- Bezerra, L. S., A. M. Barbosa, G. G. P. Carvalho, J. I. Simionato, Freitas, J. E. Jr., M. L. G. M. L. Araújo, L. Pereira,

- R. R. Silva, E. C. Q. Lacerda, and B. M. A. Carvalho. 2016. Meat quality of lambs fed diets with peanut cake. *Meat Sci.* 121:88–95. doi:10.1016/j.meatsci.2016.05.019.
- Bigham, M. L., and W. R. Mcmanus. 1975. Whole wheat grain feeding of lambs. V. Effects of roughage and wheat grain mixtures. *Austr. J. Agric. Res.* 26:1053–1062.
- Bligh, E. G., and W. J. Dyer. 1959. A rapid method of total lipid extraction and purification. *Can. J. Biochem. Physiol.* 37:911–917. doi:10.1139/o59-099.
- Brasil, A. P., S. T. Rezende, M. C. G. Pelúzio, and V. M. Guimarães. 2010. Removal of oligosaccharides in soybean flour and nutritional effects in rats. *Food Chem.* 118:251–255. doi:10.1016/j.foodchem.2009.04.124
- Brink, D. R., S. R. Lowry, R. A. Stock, and J. C. Parrott. 1990. Severity of liver abscesses and efficiency of feed utilization of feedlot cattle. *J. Anim. Sci.* 68:1201–1207. doi:10.2527/1990.6851201x.
- Carvalho, V. B., R. F. Leite, M. T. Almeida, J. R. Paschoaloto, E. B. Carvalho, D. P. Lanna, H. L. Perez, E. H. Van Cleef, A. C. Homem Junior, and J. M. Ezequiel. 2015. Carcass characteristics and meat quality of lambs fed high concentrations of crude glycerin in low-starch diets. *Meat. Sci.* 110:285–292. doi:10.1016/j.meatsci.2015.08.001
- Cezar, M. F., and H. S. Wandrick. 2007. Carcaças ovinas e caprinas – Obtenção, avaliação e classificação. 1st ed. Uberaba, MG: Editora Agropecuária Tropical.
- Chikwanha, O. C., P. Vahmani, V. Muchenje, M. E. R. Dugan, and C. Mapiye. 2018. Nutritional enhancement of sheep meat fatty acid profile for human health and wellbeing. *Food Res. Int.* 104:25–38. doi:10.1016/j.foodres.2017.05.005.
- CIE. 2004. Technical report - Colorimetry.
- Drouillard, J. S., C. K. Schoenholz, R. D. Hunter, and T. A. Nutsch. 1999. Soy molasses as a feed ingredient for finishing cattle. *Cattlemen's Day* 89–92. (Abstr.).
- Fimbres-Durazo, I., R. Ramírez-Romero, J. C. Michael-Gallegos, and J. C. Kawas. 2013. Molasses level in lamb high-energy diets on productive performance, blood chemistry, liver minerals and histopathology. *Livest. Sci.* 157:113–124. doi:10.1016/j.livsci.2013.06.019
- Fonteles, N. L. O., S. P. Alves, M. S. Madruga, R. R. E. Queiroga, A. P. Andrade, D. S. Silva, A. P. Leal, R. J. B. Bessa, and A. N. Medeiros. 2018. Fatty acid composition of polar and neutral meat lipids of goats browsing in native pasture of Brazilian Semi-arid. *Meat Sci.* 139:149–156. doi:10.1016/j.meatsci.2018.01.021
- Ginane, C., M. Bonnet, R. Baumont, and D. K. Revell. 2015. Feeding behavior in ruminants: a consequence of interactions between a reward system and the regulation of metabolic homeostasis. *Anim. Prod. Sci.* 55:247–260. doi:10.1071/AN14481
- Hall, M. B. 2000. Calculation of non-structural carbohydrate content of feeds that contain non-protein nitrogen. Gainesville, FL: University of Florida; p. A-25 (Bulletin, 339).
- Hamm, R. 1986. Functional properties of the myofibrillar system and their measurement. In: Bechtel P.J., editor. *Muscle as food*. Orlando, FL: Academic Press; p. 135–199.
- Houben, J. H., A. van Dijk, G. Eikelenboom, and A. H. Hoving-Bolink. 2000. Effect of dietary vitamin E supplementation, fat level and packaging on colour stability and lipid oxidation in minced beef. *Meat Sci.* 55:331–336. doi:10.1016/s0309-1740(99)00161-8
- Jacques, J., J. Berthiaume, and D. Cinq-Mars. 2011. Growth performance and carcass characteristics of Dorset lambs fed different concentrates: forage ratios or fresh grass. *Small Rumin. Res.* 95:113–119. doi:10.1016/j.smallrumres.2010.10.002
- Kerry, J. P., J. F. Kerry, and D. Ledward. 2002. *Meat processing: improving quality*. 1st ed. Cambridge, United Kingdom: Woodhead Publishing Limited.
- Ladeira, M. M., J. P. Schoonmaker, K. C. Swanson, S. K. Duckett, M. P. Gionbelli, L. M. Rodrigues, and P. D. Teixeira. 2018. Review: nutrigenomics of marbling and fatty acid profile in ruminant meat. *Animal* 12(s2):s282–s294. doi:10.1017/S1751731118001933
- Lawrie, R. A., and D. A. Ledward. 2017. *Lawrie's meat science*. 8th ed. Cambridge, United Kingdom: Woodhead Publishing Limited.
- Majdoub-Mathlouthi, L., B. Saïd, A. Say, and K. Kraiem. 2013. Effect of concentrate level and slaughter body weight on growth performances, carcass traits and meat quality of Barbarine lambs fed oat hay based diet. *Meat Sci.* 93:557–563. doi:10.1016/j.meatsci.2012.10.012
- Malau-aduli, A. E. O., B. D. Siebert, C. D. K. Bottema, and W. S. Pitchford. 1997. A comparison of the fatty acid composition of triacylglycerols in adipose tissue from Limousin and Jersey cattle. *Austr. J. Agric. Res.* 48:715–722.
- Martel, C. A., E. C. Titgemeyer, L. K. Mamedova, and B. J. Bradford. 2011. Dietary molasses increases ruminal pH and enhances ruminal biohydrogenation during milk fat depression. *J. Dairy Sci.* 94:3995–4004. doi:10.3168/jds.2011-4178
- Mendes, F. B., R. R. Silva, G. G. de Carvalho, F. F. da Silva, T. O. Lins, A. L. da Silva, V. Macedo, G. Abreu Filho, S. O. de Souza, and J. O. Guimarães. 2015. Ingestive behavior of grazing steers fed increasing levels of concentrate supplementation with different crude protein contents. *Trop. Anim. Health Prod.* 47:423–428. doi:10.1007/s11250-014-0741-z
- Millen, D. D., R. D. L. Pacheco, L. S. Cabral, L. L. Cursino, D. H. M. Watanabe, and A. L. N. Rigueiro. 2016. Ruminal acidosis. In: Millen, D.D., M.B. Arrigoni, R.D.L. Pacheco, editors. *Rumenology*. Springer, Cham, Switzerland; p. 127–156. doi:10.1007/978-3-319-30533-2
- Monteiro, A. S. Jr., I. N. Prado, L. M. Zequila, A. F. Branco, and W. G. Nascimento. 2000. Digestibilidade aparente de dietas contendo milho ou casca de mandioca como fonte energética e farelo de algodão ou levedura como fonte proteica em novilhas. *Braz. J. Anim. Sci.* 29:269–277. doi:10.1590/S1516-35982000000100035
- Muhammad, A. U., C. Q. Xia, and B. H. Cao. 2016. Dietary forage concentration and particle size affect sorting, feeding behaviour, intake and growth of Chinese Holstein male calves. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 100:217–223. doi:10.1111/jpn.12349
- Mushi, D. E., J. Safari, L. A. Mtenga, G. C. Kifaro, L. O. Eik. 2009. Effects of concentrate levels on fattening performance, carcass and meat quality attributes of Small East African × Norwegian crossbred goats fed low quality grass hay. *Livest. Sci.* 124:148–155. doi:10.1016/j.livsci.2009.01.012
- Nielsen, B. L., I. C. De Jong, and T. J. De Vries. 2016. The use of feeding behavior in the assessment of animal welfare.

- In: Phillips, C.J.C., editor. Nutrition and the welfare of farm animals. Gattton, Australia: Springer; p. 59–84. doi:10.1007/978-3-319-27356-3
- NRC. 2007. Nutrient requirements of small ruminants: sheep, goats, cervids and new world camelids. Washington, DC: National Academic Press.
- Oltramari, C. E., G. G. O. Nápoles, M. R. D. De Paula, J. T. Silva, M. P. C. Gallo, M. H. O. Pasetti, and C. M. M. Bittar. 2016. Performance and metabolism of calves fed starter feed containing sugarcane molasses or glucose syrup as replacement of corn. *Asian Australas. J. Anim. Sci.* 29:971–978. doi:10.5713/ajas.15.0550
- Pacheco, P. S., R. M. Silva, J. T. Padua, J. Restle, R. Z. Taveira, F. N. Vaz, L. L. Pascal, J. L. Olegario, F. R. Menezes. 2014. Economic analysis of finishing feedlot steers fed different proportions of sugar cane and concentrated. *Semina: Ciências Agrárias.* 35:999–1012. doi:10.5433/1679-0359.2014v35n2p999
- Pereira, S. A. G. Jr., R. V. Costa, E. S. Castro Filho, M. T. C. Almeida, J. L. Rodrigues, A. L. Feliciano, R. S. Barducci, E. H. C. B. Van Cleef, and J. M. B. Ezequiel. 2018. Soybean molasses improves texture of meat from feedlot lambs. *J. Anim. Sci.* 96(Suppl.3):477. doi:10.1093/jas/sky404.1042
- Pritchard, R. H., and K. W. Bruns. 2003. Controlling variation in feed intake through bunk management. *J. Anim. Sci.* 81:133–138. doi:10.2527/2003.8114_suppl_2E133x
- Queiroz, L. O., G. R. A. Santos, F. A. F. Macêdo, N. H. A. P. Mora, M. G. Torres, T. E. Z. Santana, and F. G. Macêdo. 2015. Características quantitativas da carcaça de cordeiros Santa Inês abatidos com diferentes espessuras de gordura subcutânea. *Rev. Bras. Saúde Produção Anim.* 16:712–722. doi:10.1590/S1519-99402015000300021
- Shang, Q. H., X. K. Ma, L. H. Zhang, J. X. Hu, and S. S. Piao. 2018. Effects of α -galactosidase supplementation on nutrient digestibility, growth performance, intestinal morphology and digestive enzyme activities in weaned piglets. *Anim. Feed Sci. Technol.* 236:48–56. doi:10.1016/j.anifeedsci.2017.11.008
- Sheppard, K. W., and C. L. Cheatham. 2018. Omega-6/omega-3 fatty acid intake of children and older adults in the U.S.: dietary intake in comparison to current dietary recommendations and the Healthy Eating Index. *Lipids Health Dis.* 17:43. doi:10.1186/s12944-018-0693-9
- Simopoulos, A. P. 2016. Evolutionary aspects of the dietary omega-6/omega-3 fatty acid ratio: medical implications. In: Alvergne, A., C. Jenkinson, C. Faurie, editors. *Evolutionary thinking in medicine.* Londres, England: Springer; p. 119–136. doi:10.1007/978-3-319-29716-3
- Soder, K. J., A. F. Brito, and K. Hoffman. 2011. Effect of molasses supplementation and nutritive value on ruminal fermentation of a pasture-based diet. *Profess. Anim. Scientist.* 27:35–42. doi:10.15232/S1080-7446(15)30442-3
- Soto-Navarro, S. A., G. C. Duff, C. R. Krehbiel, M. L. Galyean, and K. J. Malcolm-Callis. 2000. Influence of feeding intake fluctuation, feeding frequency, time of feeding and rate of gain on performance by limit-fed steers. *Profess. Anim. Scientist.* 16:13–20. doi:10.15232/S1080-7446(15)31655-7
- Souza, D. A., A. B. Selaive-Villaruel, E. S. Pereira, E. M. C. Silva, and R. L. Oliveira. 2016. Effect of the Dorper breed on the performance, carcass and meat traits of lambs bred from Santa Inês sheep. *Small Rumin. Res.* 145:76–80. doi:10.1016/j.smallrumres.2016.10.017
- Starkey, C. P., G. H. Geesink, D. Collins, V. Hutton Oddy, and D. L. Hopkins. 2016. Do sarcomere length, collagen content, pH, intramuscular fat and desmin degradation explain variation in the tenderness of three ovine muscles? *Meat Sci.* 113:51–58. doi:10.1016/j.meatsci.2015.11.013
- Ulbricht, T. L., and D. A. Southgate. 1991. Coronary heart disease: seven dietary factors. *Lancet* 338:985–992. doi:10.1016/0140-6736(91)91846-m
- Van Cleef, E. C., M. T. C. Almeida, J. R. Paschoaloto, E. S. Castro Filho, R. S. Barducci, G. P. Soragni, E. A. Zampieri Neto, and J. M. B. Ezequiel. 2018. Effects of increasing concentrations of soybean molasses on feed intake, growth performance, carcass and meat traits of feedlot lambs. *J. Anim. Sci.* 96(Suppl. 3):471.
- Van Soest, P. J. 1994. *Nutritional ecology of the ruminant.* 2nd ed. New York: Cornell University Press; 476 p.
- Van Soest, P. J., and R. H. Wine. 1967. Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell wall constituents. *JAOAC.* 50:50–55.
- Whitlow, L. H., S. P. Marshall, H. H. Van Horn, and J. R. Flores. 1976. Liquid feed passage route into stomach compartments, influence of abomasal infusions on plasma glucose, and supplementation of dry rations with liquid feeds from lock-wheel feeders. *J. Dairy Sci.* 39:675–681. doi:10.3168/jds.S0022-0302(76)84257-9
- Zhuang, P., W. Wang, J. Wang, Y. Zhang, and J. Jiao. 2019. Polyunsaturated fatty acids intake, omega-6/omega-3 ratio and mortality: findings from two independent nationwide cohorts. *Clin. Nutr.* 38:848–855. doi:10.1016/j.clnu.2018.02.019