Performance and meat quality of lambs fed detoxified castor meal

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ABSTRACT

Objectives: The objective of this experiment was to evaluate the performance and meat quality of lambs fed diets containing four levels of substitution (0, 33, 67, and 100 %) of soybean meal for detoxified castor meal (CM). **Methods:** Twenty-four sheep (18.5 ± 2.71 kg initial body weight) were distributed in a completely randomized design with four treatments and six replicates. **Results:** The intakes of dry matter (DM), crude protein (CP) and metabolizable energy were not affected ($p > 0.05$) by the CM levels. The neutral detergent fiber (NDF) intake increased linearly ($p < 0.05$) and the non-fiber carbohydrates intake (NFC) had a linear decrease ($p < 0.05$). Final body weight and average daily gain had a decreasing linear effect ($p < 0.05$) with the inclusion of the CM levels in the diet. Effects of the inclusion of CM were not observed ($p > 0.05$) on the percentage of total lipids of the lamb meat, but the inclusion of CM in the concentrate had a positive quadratic ($p < 0.05$) the oleic acid (C18:01n9) in lipids of the lamb meat. **Conclusions:** Inclusion of detoxified castor meal in the concentrate impairs the productive performance, however it contributed to increase monounsaturated fatty acids content in the meat of lambs. Replacing up to 33% soybean meal with detoxified castor meal is recommended.

Key words: biodiesel by-product, lamb performance, *Ricinus communis*, sheep, sugarcane silage

INTRODUCTION

Rearing sheep in feedlots has aroused interest in intensifying the production system, as it reduces the loss of young animals due to nutritional deficiencies and

parasitic infections, maintains the regularity of supply of meat and hides throughout the year, and provides a faster return of the invested capital by reducing the age at slaughter [1]. However, the major disadvantage of a feedlot is the high production cost, especially regarding concentrate feed, which makes up one of the highest expenses in intensive systems. This situation leads to a search for low-cost alternative feeds with good nutritional value, such as plant by-products, which represent a possible way of minimising expenditures on feed [2].

Currently, with the increasing valuation of renewable energy sources, such as biodiesel for example, the use of agroindustrial by-products such as castor bean has generated a large production of waste in the form of meal (0.9 million metric tons; [3], among others, which can be used in ruminant nutrition [4]. In this regard, castor meal (CM), which contains 904 ± 21 g/kg dry matter, 357 ± 81 g/kg crude protein, 21.9 ± 16.3 g/kg ether extract, 427 ± 87 g/kg neutral detergent fibre, 84.5 ± 54.0 g/kg non-fibrous carbohydrates and 281 ± 31 g/kg lignin [5, 6, 7] has emerged as an option for the substitution of soybean meal as a protein supplement in animal feed. Nevertheless, despite the potential of use of CM as a feed for animals, its use is restricted due to the presence of anti-nutritional factors: ricin, ricinine and CB-1 A allergen complex [8]. These factors may be inactivated by the detoxification processes, rendering the CM a potential substitute for traditional protein feeds [9, 10].

Some studies of CM replacing soybean meal have shown no effect on nutrient intake and weight gain in lambs [11, 12], while others have shown that adding CM reduces feed intake, crude protein digestibility and the performance of lambs and kids [5, 6]. Therefore, it is not established what the effects are of increasing levels of CM on lamb performance and meat quality, especially in animals finished in a tropical environment.

The objective of this study was to evaluate the influence of the substitution of soybean meal by detoxified CM on the productive performance and meat quality of male Santa Inês lambs.

MATERIAL AND METHODS

All animal management and experimental procedures for this study were approved by the Animal Ethics Committee of Federal University of Viçosa and conducted under the rules and regulations of experimental field management protocols (licence 044/2015) in accordance with the Law No. 11,794, of October 2008, establishes procedures for the scientific use of animals in Brazil.

Management of animals and diets

The experiment was carried out in southwest Bahia, BA, Brazil. The city has an average temperature of 20.5 ± 2.8 ℃ and rainfall of 80 cm/year. Twenty-four intact male Santa Inês sheep of 18.5 ± 2.71 kg initial body weight (BW) and 4 months of age were used. Before the start of the experiment the sheep were dewormed and received supplementation with injectable vitamins A, D and E subcutaneously, and kept in individual stalls provided with feed and water troughs measuring 1.5 m^2 in an open area.

The animals were distributed in a completely randomised design with four treatments and six replicates. Four levels of substitution (0, 33, 67 and 100%) of soybean meal by detoxified CM were adopted. The animals were subjected to a period of 99 days in the feedlot, with 15 of these days being used for adaptation and 84 days for the actual experimental period (three 28-day periods).

For the silage production, sugarcane (*Saccharum officinarum L.*) was chopped manually and the Brix degree was determined by a refractometer, averaging 21 º. Subsequently, the material was chopped to particles of approximately 2 cm in an ensiling machine coupled to a tractor. The micro-pulverised limestone was added immediately after the sugarcane was harvested and fractionated in the ensiling machine in the proportion of 5 g/kg on a fresh-matter basis.

The CM used was acquired from an agro-industry in the metropolitan region of Salvador/BA, Brazil. This product was previously detoxified – the anti-nutritional factor: ricin – by the use of a micro-pulverised lime solution, with every kilogram diluted in 10 L water, and applied at the rate of 60 g/cal.kg of CM on a fresh-matter basis, as recommended by Oliveira et al. [9]. After mixing the meal with the limestone solution, the material was left to rest for 12 h (overnight), and subsequently dried in a cemented area covered with canvas. The drying time varied according to the climatic conditions, but was approximately 48–72 h.

The animals were fed a diet containing 60% sugarcane silage and 40% concentrate on a dry-matter basis. Diets were formulated to be isonitrogenous and to provide a weight gain of 250 g/day, according to the NRC [13] (Table 1). The chemical composition of silage, CM and diets are shown in Tables 2 and 3.

The animals were fed TMR *ad libitum* – at 08:00 a.m. and at 04:00 p.m. – that was adjusted daily according to the intake of the previous days, allowing for 10% as orts. The amounts of feed supplied to and left over by each animal were weighed daily, sampled, and then conditioned in labelled plastic bags and stored in a freezer.

Intake, digestibility and performance

125 The indigestible neutral detergent fibre (iNDF) marker was used to estimate the
126 voluntary roughage intake, obtained after ruminal incubation of 0.5 g of samples of feed,
127 orts and faeces inside non-woven fabric bags (5 × 5 cm; paper density 100 (100 g/m^2))
128 for 240 h [14]. The remaining material after incubation was subjected to extraction with
129 neutral detergent to determine the iNDF.
130 The dry matter intake (DMI) from the roughage was calculated as follows: DMI
131 (kg/day) = [(FE × CMF)/CMR]. Where: FE = faecal excretion (kg/day), obtained using
132 LIPE®; CMF = concentration of marker in faeces (kg/kg); and CMR = concentration of
133 marker in roughage (kg/kg).
134 The concentrate DMI was estimated by using the chromic oxide marker, which
135 was supplied for 13 days at the rate of 5 g/animal.day mixed with the concentrate, in
136 two instalments from the 39th day of the experimental period. Faeces were collected
137 from the 48th to the 51st day directly from the rectal ampulla, pre-dried, ground and
138 compound samples made as described previously.
139 The LIPE® (isolated, purified and enriched lignin from *Eucalyptus grandis*) was
140 used in the determination of the digestibility as a marker, supplied in capsule form
141 directly into the oesophagus of the animals from the 45th day of the experimental period,
142 for seven consecutive days, to estimate the faecal production. From the fourth day of
143 supply (48th day of the experimental period), samples of faeces were collected directly
144 from the rectal ampulla at alternate times: at 04:00 p.m. on the 48th day, at 02:00 p.m.
145 on the following day, at 00:00 p.m. on the 50th day, and at 10:00 a.m. on the 51st day,
146 which was the last collection day. Faeces were conditioned in aluminium containers and
147 pre-dried in a forced-ventilation oven at 60 ℃ for 72 h. These were subsequently
148 ground in a 1-mm screen mill and grouped proportionally, thus making composite
149 samples of each animal, and stored for later analyses. One part of each composite

150 sample (approximately 10 g) of faeces was sent to Universidade Federal de Minas
151 Gerais for analysis of LIPE® based on two reading methods, as described by Saliba and
152 Cavalcanti [15], to estimate the faecal dry matter (DM) production by the animals.

153 The animals were weighed at the beginning and end of the experiment after
154 having been feed-deprived for 16:00 hours. Animal performance was determined as the
155 difference between the initial and final body weights divided by the experimental period
156 in days. Feed conversion was determined as a function of the intake and animal
157 performance.

158

159 **Laboratory analyses**

160

161 The concentration of chromium was determined by acid digestion using nitric-
162 perchloric acid, followed by filtration, to obtain the solution in a volumetric flask,
163 making up the volume to 50 mL. Subsequently, aliquots of the solution were transferred
164 to polyethylene pots. Readings were performed in an atomic absorption spectrometer
165 using a hollow-cathode lamp for chromium (357.9 nm wavelength) and a nitrous oxide-
166 acetylene flame.

167 The dry matter (DM, method 934.01), ash (method 942.05), crude protein (CP,
168 method 981.10) and ether extract (EE, method 920.39) contents in the samples of feed,
169 leftovers and faeces were analysed according to AOAC [16]. The organic matter (OM)
170 content was estimated by subtracting the ash content from the DM content. Analyses
171 neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined
172 according to Van Soest et al. [17]. Corrections of NDF for ash and protein to obtain
173 NDFap were performed according to methodology described by Mertens [18] and
174 Licitra et al. [19], respectively. The levels of non-fibre carbohydrates (NFC) corrected

for ash and protein (NFCap) were calculated as proposed by Hall [20]: NFCap = (100 – %NDFap – %CP – %EE – %ash). The total digestible nutrients (TDN) were calculated according to Weiss et al. [21], but using NDF and NFC corrected for ash and protein, by the following equation: TDN (%) = DCP + DNDFap + DNFCap + (2.25 × DEE), where: DCP = digestible CP; DNDFap = digestible NDFap; DNFCap = digestible NFCap; and DEE = digestible EE. The TDN was later transformed into digestible energy (DE), using the following equation: DE = (TDN/100) × 4.409, and DE was converted to metabolisable energy (ME), as follows: ME = DE × 0.82. The digestibility coefficients of DM, OM, CP, EE, NDFap, TC and NFCap were determined with the following formula: [(Intake of the nutrient in grams – grams of the nutrient in faeces)/Intake of the nutrient in grams] × 100.

Slaughter and meat quality

At the end of the experimental period (99th day), when sheep were of average body weight 29.31 kg, they were submitted to a 16-h period of solid fasting, after which they were transported to a slaughter house where they were slaughtered. The animals were stunned by the penetrative percussive method using a captive dart gun, suspended by the hind limbs with ropes and bled by splitting the carotid arteries and jugular veins. Blood was collected and weighed.

The remaining components of the animals' body weight were then removed (head, feet, tail and reproductive system) to determine the hot carcass weight. The carcasses were taken to a cold chamber with an average temperature of 4 ℃ for 24 h cooling, suspended by hooks through the tendon of the gastrocnemius muscle. After this cooling period, they were weighed to obtain cold carcass weight. In addition, the carcass

conformation was determined with a score from 1 to 5 (poor to excellent) and carcass fatness with a score from 1 to 5 (fat absence to excessive fat) with a scale of 0.25.

After the cooling period, a section from the *Longissimus lumborus* muscle between the 12^{th} and 13^{th} ribs of each left half-carcass was removed and submitted to analysis. The subcutaneous fat thickness (SFT) in the *Longissimus dorsi* muscle was measured by caliper, ¾ of the distance from the medial side of the muscle.

For chemical analysis, the meat samples were defrosted in a freezer at 10 ℃ for 20 h. The back fat was then removed and ground and a part of the muscle lyophilised for 72 h; the moisture (method 934.01), ash (method 942.05), crude protein (CP, method 981.10) and ether extract (EE, method 920.39) contents were determined according to the methodology proposed by the AOAC [16]. Another part of the fresh sample was submitted to analysis of fatty acid composition.

Initially, extraction of the lipid fraction of the meat was performed according to Bligh and Dyer [22] in order to determine the fatty acid composition (% total fatty acid). The transesterification of the triglycerides was performed according to Method 5509 of the ISO [23] in order to obtain the methyl esters of the fatty acids. These were analysed by gas chromatography (model CG-17 A, Shimadzu) equipped with FID. For the analysis of the recordings and chromatograms, the equipment was coupled to a microcomputer using GC Solution software. The compounds were separated by a capillary column, SPTM-2560–100 m × 0.25 mm diameter. For the chromatographic separation, 1 µL of the sample was injected by using a 10 µL syringe (Hamilton®) in a Split system = 10. Nitrogen gas was used as a carrier and had a linear speed set at 43.2 cm/s; hydrogen and synthetic air formed the flame in the detector. A five-temperature ramp was scheduled, starting at 140 ℃ (maintained for five min), increasing at 4 ℃/min until 220 ℃ (maintained for 20 min). The injector and detector

temperatures were 240 ℃ and 260 ℃, respectively. The flow of carrier gas in the column was 1.0 mL/min. Quantification of the fatty acids was performed after area standardisation. The peaks were identified by comparisons with the retention times of Sigma (USA) standards of the methyl esters of fatty acids, and then verification of the equivalent lengths of the chains was conducted.

Statistical analysis

The data were interpreted by analysis of variance and regression study by orthogonal polynomials, using the statistical model:

$$Yijk = \mu + Ti + eijk$$

Where: Yij=observed value of the dependent variable; μ is the general mean; Ti is the treatment effect i, where i =1, 2, 3, and 4 and eij is the experimental error. In the regression study by orthogonal polynomials, in the choice of models the significance, coefficients of determination and the observed behaviour for the variable in question were taken into account. A significance level of 0.05 probability was adopted.

RESULTS

The replacement of soybean meal with detoxified CM did not change the DM intake (g/day), which averaged 0.884 kg/day (Table 4). But the NDF intake (g/day) increased linearly ($p < 0.05$) with inclusion of CM levels in the diet. A decreasing linear response was observed ($p < 0.05$) for the intakes of NFC and EE. Every unit of CM added caused a reduction of 0.66 percentage points in NFC. The average NFC intake values were 0.329 and 0.265 kg/day for 0 and 100% inclusion of CM, respectively. No

effect ($p > 0.05$) of the levels of substitution of soybean meal by CM was found on the digestibility coefficient of DM, OM, CP, NDFap and NFCap.

Final body weight, average daily gain and total weight gain decreased linearly ($p < 0.05$) with the replacement of soybean meal by CM. Feed conversion had a linear increase (Table 5) with the level of inclusion of CM in the diet. Cold carcass weight, leg weight and internal carcass length decreased linearly ($p < 0.05$) with the replacement of soybean meal by CM in the diet. However, fat thickness and fatness were not influenced ($p > 0.05$) by the inclusion of CM in the diet.

Effects of the levels of substitution of soybean meal by CM were not observed ($p > 0.05$) on the proximate composition of the *Longissimus lumborus* muscle of lambs (Table 6). The following fatty acids were not influenced ($p > 0.05$) by the substitution of soybean meal by CM: lauric (C12:00); myristic (C14:00); myristoleic (C14:01); pentadecanoic (C15:01); palmitic (C16:00); palmitoleic (C16:01); margaric (C17:00); heptadecanoic (C17:01); stearic (C18:00); vaccenic (C18:01 t); linoleic (C18:02n6c); CLA (18:02c9t11); eicosatrienoic (C20:03n6); arachidonic (C20:04n6), and eicosapentainoic (C20:05n3) acids. Saturated fatty acids (SFAs), polyunsaturated fatty acids (PUFAs), omega-6 family (n6), omega-3 family (n3); PUFA/SFA and the n6/n3 ratios were not influenced ($p > 0.05$) by substitution of soybean meal by CM.

DISCUSSION

The DM intake obtained in this study, of 0.884 kg/day, demonstrates that the complete substitution of soybean meal by CM in the concentrate did not compromise the DM intake by sheep. This result is close to that reported by Borja et al. [10], who worked with different methods of detoxification of CM for sheep. Increased intake of

NDF may be explained by the elevation in the dietary NDF content with the replacement of soybean meal by CM, which has a high NDF content (39.50%). The NDF intake in %BW rose from 1.33 to 1.76% BW with CM substitution levels of 0.0 and 100%, respectively. Gionbelli et al. [11] observed an increase in NDF intake, which was corroborated by the results of the current study. The replacement of soybean meal by CM reduced NFC intake. This response pattern is caused by the reduction in the NFC content of the diets with inclusion of CM. Nicoy et al. [5] and Menezes et al. [6] also observed a decrease in NFC intake with inclusion of CM in lamb diet.

Although the estimated TDN levels of the diets decreased with inclusion of CM, probably due to the increase in the NDF and ADF contents of the diet (65.33% to 55.87% with inclusion of CM in the diet at inclusion levels of 0 and 100%, respectively), no effect was observed on TDN intake. This result can be explained by the response pattern of DM intake and the digestibility coefficient of the diets, which did not differ with inclusion of CM. But the animal performance (average daily gain and final body weight) and cold carcass weight of the animals decreased with inclusion of CM in the diet. The reduction in FBW with the increase in CM levels was probably due to the increase in the iNDF content (20.4% to 26.6% with inclusion of CM in the diet at levels of 0 and 100%, respectively) and the decrease in the NFC intake (0.32 kg/day to 0.26 kg/day with with inclusion of CM in the diet at levels of 0 and 100%, respectively), which in turn reduced the quality of the diet supplied. In addition, we also suspect that the low protein quality (the appeared digestibility of CP was low) of the detoxified castor bean meal [24] reduced the net protein for carcass gain. The alkalinization promoted by calcium hydroxide causes protein denaturation and reduces protein solubility of the by-product [9]. Working with the same levels of substitution of soybean meal by detoxified CM for goats, Palmieri et al. [7] observed a decrease in ADG, which was corroborated

300 by the results of the current study, while, Palmieri et al. [12] also observed a decrease in
301 cold carcass weight in goats when soybean meal was replaced by CM.

302 Effects of the inclusion of CM levels were not observed on the proximate
303 composition of lamb meat (*Longissimus*). The average values for moisture, ash, EE and
304 protein were 74.94%, 1.38%, 1.89%, and 21.97%, respectively. This result is close to
305 that shown by Oliveira et al. [25], who worked with castor bean cake for goats and
306 obtained average values for moisture, ash, EE and protein of 76.6%, 1.36%, 1.75%, and
307 20.23%, respectively, for goat meat (*Longissimus*).

308 When analysing the fatty acids composition, it was possible to observe the
309 predominance of SFAs in the *Longissimus lumborus* muscle of Santa Inês sheep in the
310 form of pentadecanoic (5.64%), palmitic (19.55%), and steric (14.94%) acids, while the
311 monounsaturated fatty acids included oleic acid (34.45%), and the polyunsaturated fatty
312 acids were linoleic (6.68%) and arachidonic (6.10%). Altogether, the total fatty acids
313 content of the lamb meat was 87.36%. Bezerra et al. [26] verified the presence of a great
314 concentration of SFAs in lamb meat, including palmitic (25.05%) and stearic (26.58%)
315 acids, the monounsaturated oleic acid (42.15%), and the polyunsaturated linoleic acid
316 (2.69%); this composition was similar to that found in the present study.

317 Studies related to human health indicate that the C12:0; C14:0 and C16:0 SFAs
318 are those that are associated with increases in the level of low-density lipoprotein
319 (LDL)-cholesterol in the blood [27]. Among these fatty acids, only palmitic (C16:0)
320 was found in greater amounts in sheep meat; this is valuable information because these
321 are the fatty acids that deserve more attention in order to minimise health disorders.

322 For the fatty acids docosanoic (C22:0) and γ-linolenic (C18:03n6), a decreasing
323 linear behaviour were observed, with values decreasing by 0.006 and 0.0004%,
324 respectively, per unit of CM added. This standard response for γ-linolenic acid can be

explained by the fact that, despite the increase in this acid with increasing CM levels in the diet, the biohydrogenation process that occurs in the rumen of ruminants results in the transformation of γ-linolenic acid to other fatty acids (monounsaturated or saturated), thereby decreasing its content in the meat of these animals [28]. When the concentrations of SFAs, monounsaturated fatty acids (MUFAs) and PUFAs in the diets were analysed, as well as the animals' meat, a reduction could be observed in the percentage of PUFAs and an increase in the others, thus confirming the occurrence of biohydrogenation.

Our results demonstrate that sheep meat has a greater content of SFAs (46.12%) and MUFAs (39.36%) but a lower content of PUFAs (14.54%). Working with the substitution of soybean meal by castor bean cake for goats, Oliveira et al. [25] found a greater proportion of SFAs (33.75%) and MUFAs (23.49%) and a lower proportion of PUFAs (7.02%), which correlates with the results in the present study.

The MUFA content showed a positive quadratic effect based on the levels of CM inclusion in the concentrate; a maximum value of 51.63% for the level of 40.43% CM was observed, while oleic acid (18:1 n-9) represented 87.50% of the total MUFA content (Table 5). The MUFAs are associated with the power to reduce LDL-cholesterol and to reduce mortality [29]. Thus, meat that presents a greater concentration of this fatty acid is healthier.

The total substitution of soybean meal by detoxified castor meal in the concentrate impairs the performance and carcass weight of lambs fed sugarcane silage but increases the oleic acid content in the meat. Replacing up to 33% soybean meal with detoxified castor meal is recommended.

CONFLICT OF INTEREST

The authors of the current research declare that there is no conflict of interest.

ACKNOWLEDGEMENTS

Thanks are due to the National Council for Technological and Scientific Development (Conselho Nacional de Desenvolvimento Tecnológico e Científico – CNPq, Brazil) for supporting this research.

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449 **Table 1.** Composition of the experimental diets, on a dry matter (DM) basis

Ingredient (g/kg)	Castor meal level (% DM)			
	0	33	67	100
Sugarcane silage	600.0	600.0	600.0	600.0
Corn	169.9	173.6	167.7	163.2
Soybean meal	214.3	136.0	69.2	0.00
Castor seed meal	0.00	70.5	141.2	209.1
Urea	6.2	10.3	12.8	18.1
Mineral mix[1]	5.9	5.8	5.8	5.7
Monoammonium phosphate	3.7	3.8	3.4	3.8

450 [1]Composition of mineral mix: calcium (max.) 300 g; calcium (min) 200 g; phosphorus (min) 50 g; magnesium (min) 16.5 g; sodium (min) 40 g; sulfur (min) 18 g;
451 selenium (min) 11 mg; copper (min) 122 mg; cobalt (min) 60 mg; iron (min) 3,960 mg; iodine (min) 85 mg; manganese (min) 2,000 mg; zinc (min.) 2,100 mg;
452 vitamin A (min) 112,000 IU; vitamin D3 (min) 22,000 IU; vitamin E (min) 830 IU; fluorine (max) 1,000 mg.

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Table 2. Chemical composition of soybean meal (SM), castor meal (CM), sugarcane silage, concentrates and experimental diets

	SM	CM	Silage	Castor meal level (% DM*)			
				0	33	67	100
Dry matter (DM) (g/kg fresh matter)	886.4	806.0	257.1	888.5	877.1	879.6	881.7
Organic matter[1]	933.9	865.5	911.8	939.7	927.3	916.2	909.8
Crude protein (CP)[1]	487.8	337.3	29.6	339.5	346.4	336.0	336.2
Neutral detergent insoluble protein (g/kg CP)	53.1	101.9	202.1	36.7	46.3	52.3	55.9
Acid detergent insoluble protein (g/kg CP)	24.6	64.2	132.0	21.1	25.5	33.1	35.0
Ether extract[1]	19.4	5.2	13.8	24.2	23.8	18.0	15.7
Ash[1]	64.8	134.5	88.2	60.3	72.7	83.8	90.2

NDFap[1#]	131.8	301.0	617.6	144.7	188.9	234.2	253.4
Acid detergent fiber[1]	86.6	282.0	508.8	81.9	145.0	161.5	205.7
Indigestible neutral detergent fiber[1]	19.1	323.8	337.5	4.1	66.9	115.0	159.7
Cellulose[1]	81.8	220.1	398.0	67.0	124.5	121.7	137.0
Lignin[1]	15.6	70.0	85.2	19.0	76.1	125.3	162.5
Non-fiber carbohydrates[1]	275.6	206.2	250.8	431.4	368.2	328.0	304.5
Estimated total digestible nutrients[2]	811.6	564.3	565.9	784.8	699.0	618.0	572.1
Digestible energy (Mcal/kg DM)[3]	3.92	2.74	2.40	3.73	3.37	3.01	2.81
Metabolizable energy (Mcal/kg DM)[3]	3.48	2.31	1.97	3.32	2.95	2.58	2.38
Diet components							
Dry matter (g/kg fresh matter)				509.7	505.1	506.1	507.0
Organic matter[1]				923.0	918.0	913.5	911.0
Crude protein[1]				153.6	156.3	152.2	152.2
Neutral detergent insoluble protein (g/kg CP)				136.0	139.8	142.2	143.6
Acid detergent insoluble protein (g/kg CP)				87.6	89.4	92.5	93.2
Ether extract[1]				17.9	17.8	15.5	14.6
Ash[1]				77.0	82.0	86.5	89.0
NDFap[1]				428.4	446.1	464.2	471.9

Acid detergent fiber[1]	338.0	363.3	369.9	387.5
Indigestible neutral detergent fiber[1]	204.1	229.2	248.5	266.4
Cellulose[1]	265.6	288.6	287.5	293.6
Lignin[1]	58.7	81.5	101.2	116.1
Non-fiber carbohydrates[1]	323.0	297.7	281.6	272.2
Estimated total digestible nutrients[2]	653.3	616.8	580.9	558.7
Digestible energy (Mcal/kg DM)	2.93	2.78	2.62	2.53
Metabolizable energy (Mcal/kg DM)	2.51	2.35	2.19	2.09

[1] g/kg dry matter; [2]Estimated according to the NRC (2001); [3]Calculated according to the NRC (1989). *DM = Dry matter; #NDFap = neutral detergent fiber corrected for ash and protein, non-fibrer carbohydrates.

Table 3. Fatty acid composition (% of total fatty acid) of castor meal (CM), sugarcane silage, and concentrates

Fatty acids	CM	Silage	Castor meal level (% DM*)			
			0	33	67	100
C12:00	0.18	1.58	-	-	-	-
C14:00	3.73	2.06	0.13	0.18	0.15	0.18
C16:00	19.8	32.05	24.74	28.66	24.55	21.59
C16:01	0.74	2.41	0.11	0.06	0.14	0.10
C18:00	10.13	9.97	5.35	6.84	5.26	5.35
C18:01n9	25.29	17.38	29.1	31.97	33.96	38.46
C18:02n6c	33.15	28.59	37.43	29.68	32.42	31.24
C18:03n6	3.23	1.01	0.15	0.33	0.61	0.78
C18:03n3	2.57	4.67	2.14	1.53	1.48	0.90
C20:02 n3	0.31	-	0.46	0.21	0.98	0.86
C20:05n3	-	-	0.12	0.21	0.13	0.17
C24:01 n6	0.65	0.28	0.26	0.32	0.33	0.37
$C_{18}H_{34}O_3$	0.22	-	-	-	-	-
SFA[1]	33.84	45.65	30.22	35.68	29.96	27.12
MUFA[2]	26.67	20.07	29.48	32.35	34.43	38.93
PUFA[3]	66.16	54.35	69.78	64.32	70.04	72.88

PUFA/SFA[4]	1.96	1.19	2.31	1.8	2.34	2.69

476 *DM = Dry Matter. [1] Saturated fatty acids (SFA). [2] Monounsaturated fatty acids (MUFA). [3] Polyunsaturated fatty acids (PUFA); [4] PUFA/SFA ratio

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478 **Table 4.** Intake and digestibility nutrient in lambs fed diets containing increase levels of substitution of soybean meal for castor meal

	Castor meal level (% DM*)				SEM[1]	P-value	
	0	33	67	100		L[2]	Q[3]
Dry matter (kg/day)	0.892	0.910	0.875	0.859	0.025	0.226	0.503
Organic matter (kg/day)	0.817	0.828	0.791	0.779	0.012	0.496	0.819
Crude protein (kg/day)	0.163	0.163	0.143	0.138	0.006	0.532	0.532
Neutral detergent fiber (kg/day)	0.338	0.379	0.391	0.400	0.012	0.000[a]	0.190
Non-fiber carbohydrates (kg/day)	0.329	0.305	0.278	0.265	0.008	0.002[b]	0.686
Ether extract (kg/day)	0.017	0.018	0.014	0.013	0.057	0.001[c]	0.386
Total digestible nutrients (kg/day)	0.636	0.652	0.611	0.594	0.023	0.462	0.747
Digestible energy (Mcal/kg DM/day)	2.81	2.88	2.70	2.63	0.103	0.462	0.747
Metabolizable energy (Mcal/kg DM/day)	2.31	2.36	2.22	2.15	0.084	0.462	0.747
Dry matter (g/kg)	754.3	753.4	753.1	744.3	0.74	0.673	0.804
Organic matter (g/kg)	772.0	775.8	769.5	705.0	2.38	0.141	0.272
Crude protein (g/kg)	786.4	788.1	783.8	812.2	0.92	0.405	0.493

Neutral detergent fiber (g/kg)	510.3	526.4	568.3	554.7	1.70	0.277	0.676
Non-fiber carbohydrates (g/kg)	936.8	938.6	942.6	929.7	0.53	0.739	0.524
Ether extract (g/kg)	806.0	835.0	845.2	846.9	0.64	0.021[d]	0.261

*DM = Dry Matter. [1]SEM = standard error of the mean; [2] Linear effect; [3] Quadratic effect. Equations: [a]$\hat{Y}$ = 0.34741 + 0.00059x, R^2=0.88; [b]$\hat{Y}$ = 0.32726 - 0.65749x, R^2=0.97; [c]$\hat{Y}$ = 0.01764 - 0.04515x, R^2=0.77; [d]$\hat{Y}$ = 81.3350 + 0.03986x, R^2=0.89.

Table 5. Performance and carcass characteristics in lambs fed diets containing increase levels of substitution of soybean meal for castor meal

	Castor meal level (% DM*)				SEM[1]	P-value	
	0	33	66	100		L[2]	Q[3]
Initial body weight (kg)	19.28	18.42	17.32	18.28	0.53	0.570	0.573
Final body weight (kg)	31.20	30.42	28.60	27.04	0.78	0.049[a]	0.978
Average daily gain (kg)	0.120	0.121	0.114	0.088	0.005	0.036[b]	0.213
Total weight gain (kg)	11.92	12.00	11.28	8.76	0.54	0.0363[c]	0.213
Feed conversion	7.59	7.61	7.71	10.28	0.35	0.004[d]	0.034
Cold carcass weight (kg)	13.30	13.02	11.68	9.97	0.53	0.016[e]	0.481
Leg weight (kg)	2.01	1.93	1.69	1.58	0.08	0.044[f]	0.924
Shoulder weight (kg)	1.16	1.25	1.11	0.98	0.04	0.098	0.244
Internal length (cm)	63.17	60.83	60.33	58.67	0.72	0.036[g]	0.804

Leg length (cm)	38.63	37.58	37.75	35.92	0.44	0.049[h]	0.656
Chest depth (cm)	23.75	25.00	25.00	23.20	0.47	0.697	0.101
Backfat thickness (mm)	2.08	2.08	1.42	2.00	0.18	0.588	0.427
Loin eye area (cm^2)	10.33	11.00	10.00	9.00	0.37	0.143	0.278
Conformation (1-5)	2.83	3.08	2.50	2.25	0.13	0.055	0.354
Fatness (1-5)	2.42	2.33	2.33	2.25	0.09	0.589	0.976

*DM = Dry Matter. [1]SEM = standard error of the mean; [2] Linear effect; [3] Quadratic effect. Equations: [a]$\hat{Y}$ = 31.4586 – 0.0428x, R^2=0.98; [b]$\hat{Y}$ = 0.12644 – 0.0003x, R^2=0.78; [c]$\hat{Y}$ = 12.5190 – 0.0305x, R^2=0.75; [d]$\hat{Y}$ = 7.0703 + 0.0245x, R^2=0.95.; [e]$\hat{Y}$ = 13.606-0.0338x, R^2=0.93; [f]$\hat{Y}$ = 2.0345-0.0046x, R^2=0.96; [g]$\hat{Y}$ = 62.841-0.042x, R^2=0.95; [h]$\hat{Y}$ = 38.667-0.024x, R^2=0.83.

Table 6. Proximate composition (g/kg) and fatty acid composition (% of total fatty acid) of lamb meat (*Longissimus lumborus*) fed diets containing increase levels of substitution of soybean meal for castor meal

	Castor meal level (% DM*)				SEM[1]	P-value	
	0	33	66	100		L^2	Q^3
Moisture (g/kg)	743.0	753.2	749.8	751.4	0.28	0.409	0.468
Ash (g/kg)	15.0	14.1	11.3	14.9	0.08	0.618	0.143

Crude protein (g/kg)	225.5	216.2	219.9	21.73	0.19	0.235	0.386
Ether extract (g/kg)	19.1	19.0	18.4	1.91	0.01	0.957	0.884
C12:00	0.09	0.09	0.11	0.08	0.006	0.965	0.418
C14:00	0.87	0.90	1.15	0.96	0.073	0.472	0.506
C15:00	6.14	5.47	4.93	6.02	0.185	0.549	0.016[a]
C16:00	18.99	19.48	19.97	19.78	0.209	0.141	0.421
C17:00	3.40	2.84	2.70	3.00	0.122	0.219	0.079
C18:00	14.59	14.97	15.15	15.06	0.172	0.335	0.523
C22:00	2.19	2.12	1.84	1.59	0.072	0.000[b]	0.451
SFA[4]	46.27	45.86	45.86	46.49	0.22	0.753	0.268
C14:01	0.17	0.21	0.22	0.21	0.011	0.184	0.343
C15:01	0.26	0.21	0.25	0.28	0.012	0.456	0.124
C16:01	2.11	2.15	2.37	2.14	0.087	0.720	0.470
C17:01	1.68	1.47	1.76	1.61	0.067	0.884	0.824
C18:01t	0.63	0.73	0.63	0.57	0.026	0.253	0.121
C18:01n9	33.70	34.92	35.51	33.66	0.344	0.869	0.028[c]
MUFA[5]	38.55	39.68	40.75	38.47	0.40	0.807	0.035[d]
C18:02n6c	7.08	6.75	6.24	6.65	0.198	0.327	0.378

C18:03n6	0.16	0.12	0.11	0.10	0.004	0.000[e]	0.082
C18:03n3	0.24	0.16	0.16	0.21	0.138	0.486	0.019[f]
18:02c9t11	0.40	0.44	0.32	0.29	0.035	0.198	0.614
C20:03n6	0.42	0.42	0.36	0.47	0.017	0.643	0.099
C20:04n6	6.24	6.06	5.66	6.43	0.169	0.914	0.179
C20:05n3	0.64	0.58	0.55	0.87	0.072	0.247	0.106
PUFA[6]	15.18	14.55	13.40	15.03	0.29	0.545	0.063
PUFA/SFA	0.33	0.32	0.29	0.32	0.01	0.493	0.070

*DM = Dry Matter. [1] SEM = standard error of the mean; [2] Linear effect; [3] Quadratic effect; [4] SFA = Σ saturated fatty acids; [5] MUFA = Σ monounsaturated fatty acids; [6] PUFA = Σ polyunsaturated fatty acids. Equations: [a]$\hat{Y}_1 = 6.21441 - 0.0420854x + 0.0003935x^2$, $R^2=0.88$; [b]$\hat{Y}_2 = 2.24764 - 0.00623222x$, $R^2=0.95$; [c]$\hat{Y}_3 = 33.6060 + 0.0705527x - 0.000690984x^2$, $R^2=0.93$; [d]$\hat{Y}_4 = 38.3847 + 0.0791494x - 0.000766480x^2$., $R^2=0.85$; [e]$\hat{Y}_5 = 0.149358 - 0.000494836x$, $R^2=0.92$; [f]$\hat{Y}_6 = 0.240494 - 0.00315453x + 0.0000291195x^2$, $R^2=0.99$.

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