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Effects of Castor Meal on the Growth Performance and Carcass Characteristics of Beef Cattle

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ABSTRACT : The purpose of this study was to evaluate the effect of replacing soybean meal with treated castor meal with (CMT) or without lime (CMNT) on the nutrient intake, performance, carcass characteristics, and yield of commercial cuts of beef cattle from a feedlot. Thirty male, castrated, crossbreed zebu cattle were used in the study, with an average initial weight of 360±30.27 kg. Five animals were used as a control group and were slaughtered at the beginning of the experiment; the remaining animals (n = 25) were distributed in random blocks (repetitions), with body weight as the criterion for block assignment. The animals were fed a diet containing 65% corn silage and 35% of concentrate on dry matter (DM) basis. Five diets consisted of four levels of soybean meal (SM) substituted with CMT (0, 33, 67 and 100%) on a DM basis and a diet with 100% of SM replaced with CMNT. At the end of the experiment, all animals were slaughtered, and their gastrointestinal tracts were emptied to determine their empty body weights (EBW). No significant effects were observed (p>0.05) for the substitution of soybean meal with CMT on intake of dietary nutrients, the average daily body weight gain (ADG) or EBW gain (EBWG). In spite of greater (p<0.05) ricin intake for the diet containing CMNT (3.06 mg/kg BW) compared to the CMT diet (0.10 mg/kg BW/d), there were no effects (p>0.05) on intake of dietary nutrients, ADG or EBWG. The average intake of DM and the ADG were 10,664.63 and 1,353.04 g/d, respectively. Regarding carcass characteristics, only carcass yield in relation to body weight was linearly reduced (p<0.05) upon substitution of SM by CMT. There was no effect (p>0.05) of the substitution of SM by CMT or CMNT on the yield of carcass basic cuts. CMT prices that are higher than 85% of the SM price do not economically justify the use of CMT. For CMT prices between 20 and 80% of the SM price, the optimal level was 67% substitution, while for prices below 15% of the SM price, the optimal level was 100% substitution with CMT. It can be concluded that treated castor meal with 6% lime can totally replace soybean meal in beef cattle diets. (**Key Words :** Soybean Meal, Weight Gain, Yield, Ricin, *Ricinus communis* L.)

INTRODUCTION

Currently, the growing demand for renewable fuel has increased interest in the growth and processing of oilseeds for production of lubricants and fuels such as biodiesel. With increased production of these products, a greater number and quantity of byproducts that can be used in animal diets have been made available, adding value to the agro-energetic productive chain.

Biodiesel discussions have sought to prioritize the oilseeds that provide a greater number of jobs as well as the inclusion of underdeveloped regions that are at the margins of the economic development process (PNPB, 2005). The castor crop (*Ricinus Communis* L.) is one of the most traditional crops in the Brazilian semi-arid region; it has social and economic relevance as well as several industrial applications. Therefore, the growth expectance of that crop creates opportunities for ruminant production through the potential availability of the main byproducts: castor pie and meal.

Despite the potential use for castor meal as a substitute for traditional protein sources (soybean and cotton meals) in ruminant diets, which could add more value and income to the productive chain, this product has only been used as an organic fertilizer to control nematodes because of the presence of a potent toxin (ricin) and allergenic factors in the castor meal (Severino, 2005).

The transformation of castor meal into a detoxified

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product that may be used for animal feed has been a subject of investigation for several researchers worldwide. Some satisfactory results have been obtained (Gardner et al., 1960; Perone et al., 1966), though some technological steps still need to be developed to allow the product to become economically viable.

In recent studies in Brazil, it was demonstrated that thermal treatment in an autoclave at 1.23 kg/cm^2 (15 psi) for 90 minutes or alkaline treatment with calcium hydroxide or calcium oxide diluted in water (1:10) at a dose of 60 g/kg of meal were efficient in denaturing the ricin present (Oliveira, 2008).

Hence, this work was developed with the objective of evaluating the effect of replacing soybean meal with castor meal that was treated with or without lime on the intake of diet components, performance, carcass characteristics, and yields of commercial cuts from beef cattle under feedlot conditions.

MATERIAL AND METHODS

Animals, experimental design, and diets

This experiment was conducted in the Animal Laboratory of the Department of Animal Science of Universidade Federal de Viçosa (UFV), in Viçosa-MG. Thirty male, castrated, crossbreed zebu cattle were used, with an average initial weight of 360±30.27 kg. Five animals that served as the control group were slaughtered at the beginning of the experiment, and the remaining animals (N = 25) were distributed in random blocks, with five treatments and five blocks (repetitions), using body weight as the criterion for block assignments.

The animals were submitted to a period of 14 days of adaptation and an 84-day experimental period (three periods of 28 days each) for evaluation of body weight gain, carcass weight and yield, and commercial cut yields.

The animals were fed a diet containing 65% corn silage and 35% concentrate on a dry matter (DM) basis. The five diets consisted of four levels of soybean meal substitution (SM) with lime treated castor meal (CMT) (0, 33, 67, and 100%) on a DM basis and a diet with 100% substitution of SM with non-treated castor meal (CMNT) (Table 1). A urea +ammonia sulfate mixture was used to adjust the crude protein content (CP) of the diets due to differences in CP levels of the protein foods.

After analyzing the available ingredients, the diets were

Table 1. Ingredients and chemical composition of experimental diets

	CMT level in diets (%)				CMNT[b]
	0[a]	33[a]	67[a]	100[a]	
Ingredient composition (g/kg DM)					
Corn silage	650	650	650	650	650
Corn ground	246.8	246.8	246.8	246.8	246.8
Soybean meal	91.4	60.9	30.5	0.00	0.00
Castor bean meal	0.00	30.5	60.9	91.4	91.4
Wheat bran	4.2	4.1	2.8	0.2	0.00
Urea/ammonium sulfate	1.8	3.6	4.9	7.5	6.1
Mineral salt	4.2	4.2	4.2	4.2	4.2
Limestone	1.8	0.00	0.00	0.00	1.6
Chemical composition (g/kg)					
Dry matter	485.1	485.6	487.4	485.6	485.4
Organic matter (g/kg DM)	945.6	944.4	941.3	941.2	946.7
Crude protein (g/kg DM)	122.3	120.3	120.8	120.3	120.2
Non-protein nitrogen (g/kg total nitrogen)	358.9	371.6	400.0	435.8	437.6
Rumen degraded protein (g/kg of CP)	644.0	643.3	640.4	639.4	653.5
Ricin (mg/kg DM)	0.00	1.19	2.38	3.58	104.53
Ether extract (g/kg DM)	28.0	28.5	28.2	28.0	28.0
CHO[c] (g/kg DM)	795.2	795.6	792.3	792.9	798.5
NDFap (g/kg DM)	410.3	413.2	411.7	415.3	412.1
NFCap (g/kg DM)	387.6	387.9	388.6	388.1	395.9
ADFap (g/kg DM)	218.5	211.8	220.2	223.8	235.7
Lignin[c] (g/kg DM)	28.3	31.3	37.4	36.9	37.5

[a] Replacement levels refer to treatments containing castor bean meal supplemented with 60 g of calcium oxide/kg.

[b] 100% of soybean meal replaced with unsupplemented castor bean meal.

[c] CHO = Total carbohydrates; NDFap = Neutral detergent fiber corrected for ash and protein; NFCap = Non-fiber carbohydrates corrected for ash and protein; ADFap = Acid detergent fiber corrected for ash and protein.

formulated to be isonitrogenous with 12.0% CP (DM basis) to meet zebu bovine nutritional demands of 360 kg of body weight and a weight gain of 1,250 g/d, according to Valadares Filho et al. (2006a). The average composition of the experimental diets is presented in Table 1, and the chemical composition of ingredients is presented in Table 2.

Alkaline treatment and castor meal obtainment

Castor meal was obtained from the BOM-BRASIL agro-industry, located in the surroundings of Salvador-BA. Castor meal treatment was performed using lime solution (CaO) (ICAL (Indústria de Calcinação Ltda), Belo Horizonte, Minas Gerais, Brazil), with each kg diluted in 10 liters of water and applied at 60 g of lime per kg of castor meal as recommended by Oliveira et al. (2007). After mixing the meal with the lime solution, the material rested for twelve hours (one night) and was then dried in a cemented area. The drying time, which varied according to weather conditions, took approximately 48 h.

Experimental procedures and sampling

The animals were confined to individual stalls with feeders and drinkers, which had a total area of 30 m^2, with 8 m^2 covered with asbestos tiles. The animals were initially weighed after a solid fast of 16 h, de-wormed and fed the experimental diets for 14 days of adaptation. After this period, five steers were slaughtered to determine their empty body weights and initial carcass yields. The remaining 25 animals were weighed again and distributed among the five previously described treatments.

The animals were fed twice a day at 7 am and 3 pm. Daily weights and samplings were performed for the diet quantities provided and the leftovers from each animal. To estimate intake, samples consisting of leftovers from each animal were first composited weekly and then composited every 28 days.

The animals were weighed at the beginning and end of the experiment, always after a 16-h solid fast to determine the average daily body weight gain (ADG).

At the end of the experiment, all of the animals were slaughtered followed by bleeding. All of the slaughters occurred after the 16-h fast and were performed by cerebral concussion followed by jugular and carotid venesection, as per the Normative Instruction no. 3 of 01/13/2000 (Technical Regulation of Methods for Humane Slaughtering of Livestock).

After slaughtering, the gastrointestinal tract of each animal was emptied and, together with the other organs, was washed, weighed, and added to the remaining body parts (carcass, head, skin, tail, legs, and blood) to determine the empty body weight (EBW). The relationship obtained between EBW and body weight (BW) of the control animals slaughtered at the beginning of the experiment, as well as the initial carcass yield, were used to estimate EBW and initial carcass weight, resulting in an estimate of the daily average empty body weight gain (EBWG) and the carcass average gain.

Each animal carcass was cut in half with an electric saw and weighed soon afterward to determine carcass gain and yield in relation to body weight (CYBW) and the empty body weight (CYEBW). First, the carcasses were refrigerated in 4°C chambers for approximately 24 h. Then,

Table 2. Chemical composition of the ingredients used in the experimental feeds

Items[a]	Ingredients					
	CS	Corn	SM	CMT	CMNT	WB
DM (g/kg)	287.6	867.2	872.1	883.8	907.0	880.1
Organic matter (g/kg DM)	938.9	988.9	940.0	822.8	916.6	926.9
Crude protein (g/kg DM)	76.7	93.5	512.9	344.4	357.8	166.3
Non-protein nitrogen (g/kg total nitrogen)	470.8	165.2	131.5	289.0	280.5	192.7
Rumen degraded protein[b]	737.7	412.2	600.9	426.2	619.3	800.0
Ricin (mg/kg DM)	0.00	0.00	0.00	39.16	1,143.7	0.00
Ether extract (g/kg DM)	35.0	41.9	15.6	17.1	17.3	35.3
CHO (g/kg DM)	827.3	853.6	411.5	461.3	541.5	736.8
NDFap	539.1	145.3	125.2	380.9	471.9	379.8
NFCap	288.1	708.3	285.3	80.5	69.6	352.9
ADFap	284.7	34.1	117.3	304.5	350.7	135.2
Lignin (g/kg DM)	35.4	10.3	16.8	60.8	51.0	40.0

CS = Corn silage; SM = Soybean meal; CMT = Alkaline treated castor bean meal; CMNT = Untreated castor bean meal; WB = Wheat bran (Valadares Filho et al., 2006d).

[a] CHO = Total carbohydrate; NDFap = Neutral detergent fiber corrected for ash and protein; NFCap = Non-fiber carbohydrates corrected for ash and protein; ADFap = Acid detergent fiber corrected for ash and protein.

[b] g/kg CP adopting a passing rate (Kp) of 0.04954 h^{-1} for concentrate feed, according to the predictive equation described by NRC (2001); tabulated values for CS and corn according to Valadares Filho et al. (2006d).

the carcass halves were taken from the cooling chambers and weighed again. In the right half of the carcass the length and the commercial cut yield were measured, separating the anterior and posterior quarters by cutting between the fifth and sixth ribs. The forequarter consisted of the chuck and shoulder, and the hindquarter consisted of the flank, round and rumpsteak. The left half of the carcass was analyzed by measuring the transversal area of the *Longissimus dorsi* muscle (rib eye area - REA) at the 12th rib height and subcutaneous fat thickness. Also, a part was removed from the section between the 9th and 11th ribs for dissection and estimation of muscle, bone, and fat tissue proportions, according to the equations by Hankins and Howe (1946):

Muscle proportion: Y = 16.08+0.80X

Fat tissue proportion: Y = 3.54+0.80X

Bone proportion: Y = 5.52+0.57X

Where: X = percentage of components in the rib cuts

Ricin measurement and analysis

The evaluation of ricin concentration in the castor meal was performed through the separation of fractions A (36 kDa) and B (29 kDa) by gel electrophoresis in 10% polyacrylamide under denaturing conditions (SDS-PAGE), according to the method suggested by Laemmli (1970), and by densiometric analysis. Electrophoresis was performed at the Molecular Laboratory of Plant II, Bioagro/UFV.

Initially, 250 mg of CMNT or CMT was added to 2-ml Eppendorf tubes, with 1 ml of 0.5 M TRIS extraction buffer (pH 3.8, adjusted with 37% sulfuric acid) and centrifuged at 9.739×*g* for 20 minutes at room temperature. The supernatant, referred to as the crude protein extract (CPE) was removed and placed in another Eppendorf tube, which was stored between 2°C and 6°C for immediate analysis.

To determine electrophoretic mobility, 10-µl aliquots were removed from crude protein extracts and placed in Eppendorf tubes with 20 µl of 60 mM Tris HCL sample extraction buffer, pH 6.8 (with 10% glycerol, 2% sodium dodecil sulfate (SDS), 0.025% bromophenol blue, and 0.025% B-mercaptoethanol). The material was incubated at 100°C for 5 minutes, and then 20 µl of this mixture was loaded into each gel well. Electrophoretic mobility was initially conducted at 50 Volts until the dye front reached the gel surface, when it was increased to 140 Volts and remained at that voltage until the gel run was finished, which was defined as the point at which the dye front moved closer to the lower edge of the gel. After the run was finished, the gels were removed from the plates and placed in staining solution (1.5 g Coomassie Brilliant Blue G, 90 ml glacial acetic acid, 450 ml methanol, and 460 ml deionized water) for 24 h and destaining solution (100 ml glacial acetic acid, 500 ml methanol, and 400 ml deionized water) for 12 h. The gel was photographed with a digital camera, and the image was submited to densitometric analysis by the gel analysis and graphic digitalization software UN-SCAN-IT Gel^{TM} (Demo Version, Silk Scientific Inc., Utah, USA). Ricin fraction identification was performed with molecular mass markers between 14 and 97 kDa in size (GE Healthcare).

Another aliquot of crude protein extract was removed for evaluation of total protein using the method described by Bradford (1976). The ricin content in CMNT was obtained using the following equation:

Ricin in CMNT (mg/kg of DM) = ((V1×ricin in CPE of CMNT (mg/dl)/sample weight (DM) in contact with extraction solution (g))×1.000, where: V1 = extraction buffer volume (1 ml); ricin in CPE of CMNT (mg/dl) = total PTN (mg/dl)×(ricin peak area obtained by densitometric analysis/total protein area obtained by densitometric analysis).

The ricin content in CMT was obtained using the following equation:

Ricin CMT (mg/kg of DM) = ((V1×ricin in CPE of CMNT (mg/ml)×ricin peak area in CPE of CMT obtained by densitometric analysis/ricin peak area of CPE in CMNT obtained by densitometric analysis)/sample weight (DM) in contact with extraction solution (g))×1,000.

Chemical analysis

Samples composed of supplied feed and leftovers, as well as the dry matter analysis (DM method no. 943.01), organic matter (OM, method no. 942.05), crude protein (CP, method no. 954.01), ether extract (EE, method no. 920.39), and acid detergent fiber (ADF, method no. 973.18), were prepared in accordance with the AOAC (1990). The lignin content for each sample was obtained by measuring cellulose solubility by sulfuric acid (Van Soest and Robertson, 1985). For analyzing the neutral detergent fiber (NDF) concentration, the samples were treated with alpha thermostable amylase without sodium sulfite and corrected for ash residue (Mertens, 2002) and residual nitrogen compounds (Licitra et al., 1996). The determination of feed non-protein nitrogen (NPN) was performed in accordance with Licitra et al. (1996).

The amount of total carbohydrates (CHO) was obtained using the following equation: CHO = 100-(% CP+% EE +% Ash), according to Sniffen et al. (1992). The non-fiber carbohydrate content, corrected for ash and protein (NFCap), was calculated as proposed by Hall (2000): NFCap = 100-((% CP-% CP derived from urea+% urea) +% NDFap+% EE+% Ash).

Degradable protein content in the rumen (RDP) was calculated according to the recommendation of the NRC (2001) using the following equation: RDP = A+B×(kd/kd +kp),where A, B, kd, and kp represent the water-soluble fraction, water insoluble fraction potentially degradable, rate of degradation of the B fraction and passage rate of the feed CP through the rumen, respectively. The A fraction, B fraction, and kd were estimated using the asymptotic growth model redesigned by Ørskov and McDonald (1979), described by the following function: $Y_t = a+b^* (1-e^{-kd\times t})$, where: Y_t = fraction degraded in time "t" (%) and t = time independent variable (h). The passage rate (kp) was calculated according to the NRC (2001), using the following equation: kp for concentrate feed = $2.904+1.375X_1-0.020X_2$, where "X_1" is the DM intake (% BW) and "X_2" is the percentage of concentrate in the diet (DM basis).

Statistical analysis

The experiment was analyzed with respect to the random blocks, and the data were submitted to variance analysis. Comparisons between treatment means were performed in accordance with the following orthogonal contrasts: linear, quadratic, and cubic effects for the substitution level of SM with CMT and the alkaline treatment effect (100% substitution of SM by CMT versus 100% substitution of SM by CMNT). Statistical analyses were performed using the procedure PROC GLM SAS 9.0 (SAS, 2005). The 0.05 level of probability was adopted for the type I error.

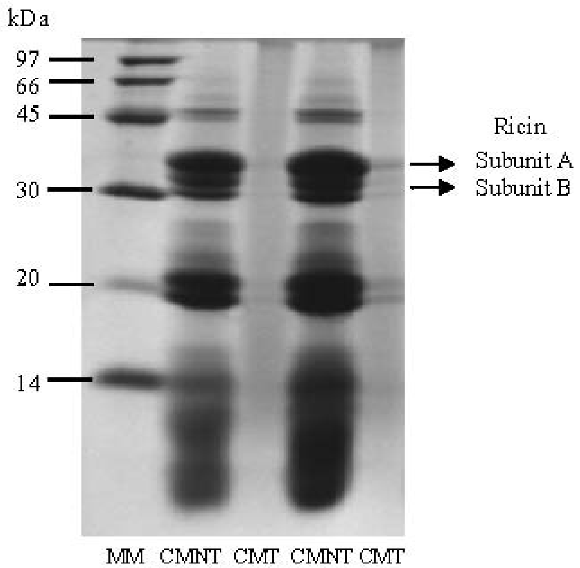

Figure 1. Polyacrylamide gel (SDS-PAGE) to evaluate the efficiency of castor meal treatment (CMNT) with 60 g of lime/kg (CMT) in the disappearance of the two ricin subunits (A, with 35 kDa, and B, with 29 kDa). MM = molecular mass marker (ranging from 14 to 97 kDa).

RESULTS

Ricin denaturation and quantification

The evaluation of the treatment effect of CMNT with 60 g of lime/kg in the disappearance of the two ricin subunits (A, approximately 35 kDa, and B, approximately 29 kDa) in SDS-PAGE is shown in Figure 1, while the densitometric analysis is shown in Figure 2. The presence of the two ricin subunits was verified as well as other soluble proteins in extraction buffer pH 3.8 in CMNT, which indicates that after the oil extraction process, ricin residues can still be found. This shows that detoxifying procedures are needed. Treatment efficiency can be evaluated by the difference in

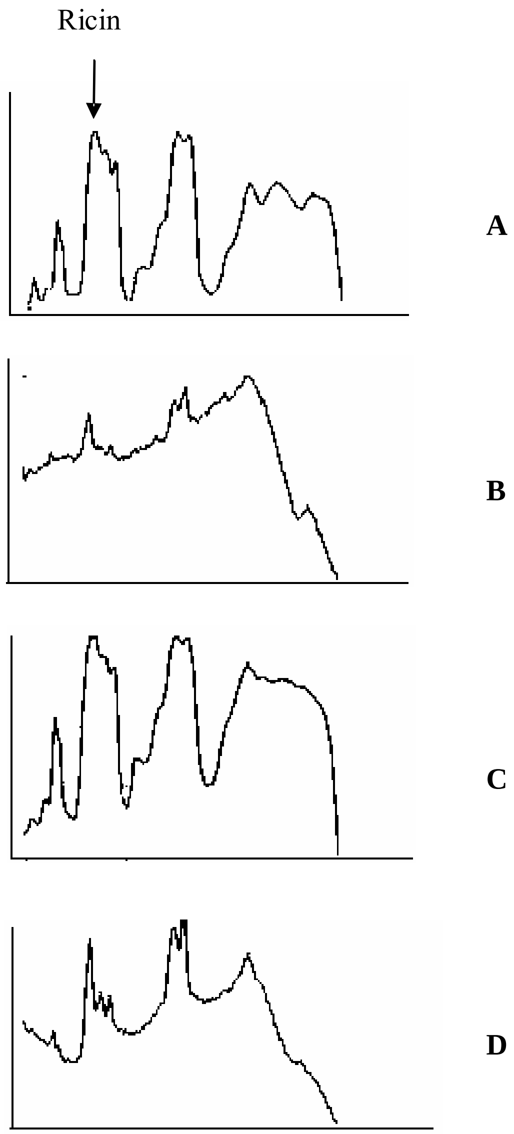

Figure 2. Gel densitometric analysis (SDS-PAGE) to evaluate the efficiency of castor meal treatment (CMNT) with 60 g of lime/kg (CMT). A and C represent CMNT; B and D represent CMT. The Y-axis represents relative density units, and the X-axis represents protein fractions expressed in relative molecular mass units (from higher to lower values). The ricin area is indicated by the arrow.

Table 3. Daily nutrients intake by cattle fed with different levels of castor meal

Items[a]	CMT level in diets (%)				CMNT[c]	Contrast (p-value)[d]			Lime[e]	CV[f] (%)
						Levels of CMT				
	0%[b]	33%[b]	67%[b]	100%[b]		L	Q	C		
Intake (g/d)										
DM	10,649.49	10,505.86	10,474.07	11,321.55	10,372.20	0.2385	0.2097	0.6378	0.0912	7.45
OM	9,243.15	9,159.09	9,221.86	9,864.49	9,006.85	0.1873	0.2641	0.7787	0.0709	7.28
EE	289.89	304.04	301.53	315.11	281.53	0.2381	0.8710	0.5477	0.0817	7.54
CP	1,228.34	1,190.04	1,217.60	1,273.14	1,161.31	0.3995	0.2888	0.8462	0.0761	7.26
NDFap	3,905.73	3,934.75	3,939.55	4,184.02	3,848.30	0.1663	0.4029	0.6303	0.0811	7.24
NFCap	3,858.23	3,788.43	3,891.59	4,146.42	3,833.35	0.1173	0.2498	0.9664	0.1060	7.28
TDN	6,931.61	6,902.75	6,676.36	7,464.91	6,827.05	0.3757	0.2450	0.4376	0.1995	10.52
g/kg BW										
DM	28.2	28.4	27.2	30.2	28.9	0.3228	0.2333	0.2464	0.4120	8.08
NDFap	9.8	10.0	9.6	10.5	10.0	0.2113	0.2999	0.2179	0.2645	7.11
Ricin										
mg/d	0.00	21.60	26.97	44.08	1,187.97	0.1246	0.8559	0.7370	<0.0001	17.23
mg/kg BW	0.00	0.04	0.06	0.10	3.06	0.0586	0.7889	0.8191	<0.0001	12.69

[a] DM = Dry matter intake; OM = Organic matter intake; EE = Ether extract intake; CP = Crude protein intake; NDFap = Neutral detergent fiber corrected for ash and protein intake; NFC = Non-fiber carbohydrates corrected for ash and protein intake; TDN = Total digestible nutrients.
[b] Substitution levels relative to treatment with treated castor meal with 60 g of lime/kg.
[c] 100% soybean meal substitution by non-treated castor meal.
[d] Linear contrast (L), quadratic (Q) and cubic (C). [e] 100% CMT *versus* 100% CMNT. [f] CV = Variation coefficient.

ricin subunit intensity. It was observed that treatment with 60 g of lime/kg led to the complete disappearance of ricin subunits in CMT, confirming the results obtained by Oliveira (2008).

According to densitometric analysis, the average detoxifying efficiency of CMNT was 96.6%, which is very close to the value of 97.35% found by Oliveira (2008). The ricin content observed for CMNT was, on average, 1,143.7 mg/kg of DM and 39.16 mg/kg of DM for CMT.

Ricin and diet component intake

Ricin and diet component intake means are presented in Table 3. The ricin intake of animals fed with 100% CMNT (1,187.97 mg/d or 3.06 mg/kg BW) was greater ($p<0.05$) than that observed for 100% CMT.

Although no effect was observed ($p>0.05$) for diet component intake in absolute terms, an average increase of 8.39% was confirmed in DM intake (DMI, in g/d) from animals fed the CMT diet compared to those fed the CMNT diet.

In absolute terms, an increase of 6% on DMI was observed in animals fed with 100% CMT compared to those fed with SM.

The average observed DMI was 10,664.63±0.33 g/d and 2.86±0.10% of the BW. The estimated DMI values, using the equations proposed by Valadares Filho et al. (2006b) for crossbred cattle of approximately 400 kg, was 9,420.00 g/d and 2.33% of the BW, respectively. The greater intake found in this work can be justified by the predominance of Holstein crossbreed in the animals studied.

Crude protein intake (CPI) was, on average, 1,214.08 g/d for all five diets, providing an average daily gain (Table 4) of 1,449.06 g/d. According to Valadares Filho et al. (2006a), castrated males weighing 400 kg with an average daily gain of 1,500.00 g/d should consume 1,161.15 g/d of CP, which is close to the value found in this work. The estimated total digestible nutrients intake (TDN) had an average value of 6,960.53 g/d for all five diets. According to Valadares Filho et al. (2006c), animals with the characteristics mentioned should consume 6,730.00 g/d of TDN, a value close to the observed value.

When expressed as a percentage of body weight, intake of DM and NDF were not influenced ($p>0.05$) by CMT levels or alkaline treatment.

Performance, carcass characteristics and commercial cut yields

The means, contrasts, and coefficients of variation for initial and final body weight (IBW and FBW), empty body weight (EBW), total body weight gain (TBWG), and total empty body weight gain (TEBWG), average daily body weight gain (ADG), empty body daily weight gain (EBWG), and the relations EBW/FBW and EBWG/ADG are presented in Table 4. Even though no statistical effect was observed ($p>0.05$) for these variables, the ADG was 20% greater for animals that consumed diets with 100% CMT compared to animals that were fed diets with 0% CMT; however, the carcass yields (CY) for these groups (Table 5)

Table 4. Performance of cattle fed with different levels of castor meal

Items[a]	CMT level in diets (%)				CMNT[c]	Contrast (p-value)[d] Levels of CMT			Lime[e]	CV[f] (%)
	0%[b]	33%[b]	67%[b]	100%[b]		L	Q	C		
IBW	353.89	341.93	357.23	341.31	325.73	0.6293	0.8551	0.2095	0.3048	6.50
FBW	461.49	459.59	472.99	475.65	456.89	0.2317	0.8302	0.5620	0.2133	4.74
EBW	414.35	404.66	413.06	421.60	401.38	0.5208	0.3886	0.7021	0.1851	5.46
EBW/FBW	0.90	0.90	0.89	0.88	0.87	0.1020	0.7312	0.6453	0.3362	1.98
TBWG	107.60	117.66	115.76	134.34	131.16	0.0667	0.6517	0.4162	0.8061	16.11
TEBWG	98.23	99.75	95.05	113.95	111.55	0.1683	0.2056	0.3269	0.7996	13.91
ADG	1,280.95	1,405.71	1,389.21	1,608.49	1,560.95	0.0655	0.6535	0.4166	0.8110	16.08
EBWG	1,174.90	1,198.86	1,139.47	1,362.12	1,338.39	0.1690	0.1958	0.3324	0.8010	13.89
EBWG/ADG	0.91	0.85	0.82	0.86	0.85	0.1321	0.0677	0.6266	0.6287	6.54

[a] IBW = Initial body weight (kg); FBW = Final body weight (kg); EBW = Empty body weight (kg); TBWG = Total body weight gain (kg); TEBWG = Total empty body weight gain (kg); ADG = Average daily body weight gain (g/d); EBWG = Empty body daily weight gain (g/d).
[b] Substitution levels relative to treatment with treated castor meal with 60 g of lime/kg.
[c] 100% soybean meal substitution by non-treated castor meal.
[d] Linear contrast (L), quadratic (Q) and cubic (C). [e] 100% CMT *versus* 100% CMNT. [f] CV = Variation coefficient.

were numerically similar.

The measurements of carcass characteristics and basic cut yields with the substitution of SM with CMT and alkaline treatment of CMNT are presented in Table 5. A linear effect was observed ($p<0.05$) only for carcass yield in relation to body weight (CYBW), which was linearly reduced ($p<0.05$) with an increase in substitution of SM with CMT. Gastrointestinal weight variations may explain this behavior, as carcass yield in relation to empty body weight (%) showed no difference ($p>0.05$) between diets. For the remaining carcass characteristics, no effect was observed ($p>0.05$), and carcass yield had an average value of 66.2 kg.

No effect was observed ($p>0.05$) for the levels of

Table 5. Carcass characteristics and commercial cut yields of cattle fed with different levels of castor meal

Items[a]	CMT level in diets (%)				CMNT[c]	Contrast (p-value)[d] CMT level			Lime[e]	CV[g] (%)
	0%[b]	33%[b]	67%[b]	100%[b]		Lf	Q	C		
Carcass characteristics										
CY	70.08	64.46	67.43	68.33	60.72	0.9443	0.6525	0.7417	0.4611	23.68
CADG	833.41	775.32	804.48	810.24	722.74	0.9436	0.6471	0.7361	0.4686	23.60
CYBW	53.68	53.24	52.31	51.36	51.69	0.0034	0.6211	0.8448	0.6521	2.11
CYEBW	59.68	59.81	59.43	59.32	59.30	0.4336	0.7629	0.6643	0.9685	1.48
COMP	1.31	1.33	1.34	1.35	1.32	0.1959	0.8235	0.9471	0.3592	2.90
REA	61.07	65.30	72.11	69.95	64.55	0.0532	0.3842	0.4814	0.3037	11.64
SFT	5.78	5.20	4.80	3.99	5.14	0.0718	0.8708	0.8492	0.2463	29.86
Basic cut yield (%)										
Forequarter	39.87	39.21	40.04	38.64	39.13	0.1712	0.4150	0.0820	0.4464	2.46
Chuck	22.83	21.87	22.36	21.58	21.42	0.1224	0.8432	0.1896	0.8014	4.39
Shoulder	17.04	17.34	17.68	17.06	17.72	0.7617	0.1223	0.4470	0.1215	3.52
Hindquarter	60.13	60.79	59.96	61.36	60.87	0.1712	0.4150	0.0820	0.4464	1.60
Flank	15.02	15.59	14.73	14.86	14.10	0.4607	0.5826	0.1923	0.1972	5.80
Round	26.97	27.59	27.34	28.06	28.92	0.0853	0.8907	0.2844	0.1194	2.87
Rumpsteak	18.14	17.61	17.88	18.44	17.85	0.4218	0.1100	0.7189	0.2131	3.89

[a] CY = Carcass yield (kg); CDAY = Carcass daily average gain (g/d); CYBW = Carcass yield in relation to body weight (%); CYEMW = Carcass yield in relation to empty body weight (%); COMP = Carcass length (m); REA = Rib eye area (cm^2); SFT = Subcutaneous fat thickness (mm).
[b] Substitution levels relative to treatment with treated castor meal with 60 g of lime/kg.
[c] 100% soybean meal substitution by non-treated castor meal.
[d] Linear contrast (L), quadratic (Q), and cubic (C). [e] 100% CMT versus 100% CMNT.
[f] $\hat{Y}CYBW = 61.908-0.5046\times CMT(r^2 = 90.17\%)$. [g] VC = Variation coefficient

Table 6. Carcass physical composition of cattle fed with different levels of castor meal

Items	CMT level in diets (%)				CMNT[a]	Contrast (p-value)[b] CMT Level			Lime[c]	CV[f] (%)
	0%	33%	67%	100%		L[d]	Q	C[e]		
Muscle %	55.73	53.97	59.04	56.12	56.74	0.2225	0.6022	0.0087	0.6935	4.22
Fat %	31.65	30.00	25.75	26.19	27.43	0.0077	0.4984	0.2977	0.5699	11.63
Bone %	14.24	16.74	16.08	17.85	16.49	0.0024	0.5693	0.0645	0.1462	8.34

[a] 100% soybean meal substitution by non-treated castor meal. [b] Linear contrast (L), quadratic (Q) and cubic (C).
[c] 100% CMT versus 100% CMNT.
[d] $\hat{Y}fat = 31.358-0.0605\times CMT$ ($r^2 = 84.29\%$); $\hat{Y}bone = 14.748+0.0306\times CMT$ ($r^2 = 79.01\%$).
[e] $\hat{Y}muscle = 55.608-0.3073\times CMT+0.0102\times CMT^2-0.00007142\times CMT^3$ ($r^2 = 53.83\%$).
[f] CV = Variation coefficient.

substitution of SM by CMT and alkaline treatment of CMNT on carcass basic cuts.

Carcass physical composition

The results related to physical carcass composition are presented in Table 6. A cubic effect was observed ($p<0.05$) for the substitution levels of SM by CMT on muscle proportion, with estimated maximum and minimum proportions of 60% and 52.97% of muscle, respectively, for the levels of 76.74% and 18.67% of CMT inclusion in substitution of SM in the diets. There was a linear reduction ($p<0.05$) in fat proportion and a linear increase ($p<0.05$) in bone proportion with increases in CMT in the diets.

Diet costs and sensitivity analysis

Table 7 shows the cost for each diet used in this work during the period from April to June of 2009. The diet with 100% CMNT had the lowest cost compared to the cost/ton of SM, followed by the diet with 100% CMT. However, in relation to the cost per 15 kg of carcass, the diet with 0% CMT had the lowest cost, as the animals that consumed this diet presented, in absolute terms, greater carcass yields. In this situation, the CMT value was 88.3% of the SM value.

Considering that food price is dependent on location, regional feed prices must be considered to decide which diet should be adopted. Therefore, a sensitivity analysis was performed to better discriminate which diet is more feasible according to the prices of CMT and SM (Table 8).

Table 7. Costs of diets used in the study with regard to food price in the time period from April to June of 2009

Ingredients	CMT level in diets (%)				CMNT[b]	Food prices R$/kg DM
	0[a]	33[a]	67[a]	100[a]		
Corn silage	65.00	65.00	65.00	65.00	65.00	0.3129
Corn flour	24.68	24.68	24.68	24.68	24.68	0.5189
Soybean meal	9.14	6.09	3.05	0.00	0.00	1.0367
Treated castor meal	0.00	3.05	6.09	9.14	0.00	0.9029
Non-treated castor meal	0.00	3.05	6.09	0.00	9.14	0.8093
Wheat meal	0.42	0.41	0.28	0.02	0.00	0.5747
Urea/ammonia sulfate	0.18	0.36	0.49	0.75	0.61	1.2000
Mineral salt	0.42	0.42	0.42	0.42	0.42	1.2500
Calcareous	0.18	0.00	0.00	0.00	0.16	0.1800
Diet cost (R$/ton of DM)	0.4364	0.4341	0.4308	0.4284	0.4183	
DMC kg/d	10.64	10.50	10.47	11.32	10.37	
Diet cost (R$/head/d)	4.64	4.56	4.51	4.85	4.34	
Carcass yield (kg/head/d)	0.83	0.77	0.80	0.81	0.72	
Diet cost (R$/15 kg of carcass)	83.91	88.71	84.58	89.80	90.37	

[a] Substitution levels referring to treatments with treated castor meal with 60 g of lime/kg.
[b] 100% substitution of soybean meal with non-treated castor meal.
[c] Corn silage (Viçosa/MG region) = RS 90.00/ton of NB; Corn flour (retail in Viçosa/MG) = R$ 450.00/ton of NB; Soybean meal = (Uberlandia/MG warehouse in Viçosa/MG) = R$ 830.00/ton of NB+R$ 74.10/ton of freight (considering cost of R$ 0.10/ton/km, according to Sifreca (2009)); Non-treated castor meal (BOM Brasil, Salvador/BA, warehouse in Viçosa/MG) = R$ 600.00/ton of NB+ R$ 134.00/ton of freight (considering cost of R$ 0.10/ton/km, according to Sifreca (2009)); Treated castor meal with 60 g of lime/kg = non-treated castor meal price+alkaline treatment (R$ 19.20/ton of meal relative to lime and R$ 45.00/ton of meal relative to labor considering R$ 3.00 manpower/hour); Wheat meal (retail in Viçosa/MG) = R$ 500.00/ton of NB; Urea+ammonia sulfate (retail in Viçosa/MG) = R$ 1.20/kg of NB; Mineral salt (retail in Viçosa/MG) = R$ 1.25/kg of NB; Calcareous (retail in Viçosa/MG) = R$ 0.18/kg of NB; NB = natural basis.

Table 8. Sensitivity analysis of cost per carcass yield of diets relative to prices of treated castor meal compared to soybean meal (%)

Price of CMT kg (% of the price per kg of SM)	Diet cost (R$/15kg of carcass)				
	CMT level in the diets (%)				CMNT[b]
	0[a]	33[a]	67[a]	100[a]	
10	83.91	83.79	75.00	74.46	74.97
15	83.91	84.11	75.62	75.44	75.95
20	83.91	84.43	76.23	76.42	76.93
25	83.91	84.75	76.84	77.40	77.92
30	83.91	85.07	77.45	78.38	78.90
35	83.91	85.39	78.06	79.36	79.89
40	83.91	85.71	78.67	80.34	80.87
45	83.91	86.03	79.28	81.32	81.85
50	83.91	86.35	79.90	82.30	82.84
55	83.91	86.67	80.51	83.28	83.82
60	83.91	86.98	81.12	84.26	84.81
65	83.91	87.30	81.73	85.24	85.79
70	83.91	87.62	82.34	86.22	86.78
75	83.91	87.94	82.95	87.20	87.76
80	83.91	88.26	83.56	88.18	88.74
85	83.91	88.58	84.18	89.16	89.73
90	83.91	88.90	84.79	90.14	90.71

[a] Substitution levels referring to treatments with treated castor meal with 60 g of lime/kg.
[b] The value of non-treated castor meal was calculated, subtracting alkaline treatment and labor costs (R$ 0.0642/kg) from the value of the treated castor meal.

DISCUSSION

Ricin denaturation and quantification

The efficiency of the alkaline treatment is attributed to ricin denaturation by lime. Denaturation represents extreme alterations in the three-dimensional structure of a protein, which does not involve the breaking of peptide bonds and is almost always associated with loss of protein function (Lehninger et al., 1995). With alkaline treatment, the pH values (12.5) surpass the ricin isoelectric value (5.2 to 5.5) (Kabat et al., 1947), turning the protein net charge negative, provoking electrostatic repulsion and breaking the hydrogen bridges that support the three-dimensional structure (Oliveira, 2008).

In addition to loss of function, hydrophobic groups are exposed during denaturation, resulting in decreased protein solubility in aqueous solutions. Therefore, the disappearance of ricin subunits indicates the loss of solubility in the extraction buffer at pH 3.8 (optimal value of ricin extraction according to Walker and Negi, 1958), as shown by the changes for the denatured state of the toxin when submitted to alkaline treatment (60 g lime/kg) (Oliveira, 2008).

Ricin intake and diet constituents

The non-interference of ricin intake on the remaining diet components is possibly explained by the low CMNT level in the diet (9.14%), as no clinical intoxication symptoms were observed. Considerable controversy exists in the literature regarding the tolerable level of ricin for different species (Alexander et al., 2008). Oliveira (2008), working with sheep fed diets consisting of 15% CMNT, observed ricin intake of 2.37 mg/kg of BW, but the animals presented no symptoms of intoxication.

The greatest intake, numerically presented, of animals that received 100% CMT compared to CMNT can be explained by a reduction in ricin levels and an increase in the ruminal degradation rate (kd) of the potentially degradable fraction of the NDF (NDFap) of castor meal with alkaline treatment.

According to Oliveira (2008), CMNT presents a high indigestible fraction of NDF (average of 66% of NDF) due to the high cutin content and treatment of CM with lime had no effect on the non-degradable fraction of NDF, but increased the ruminal degradation rate (kd) of the NDFap by an average of 7%. The possibility of subclinical effects in the animals fed CMNT cannot be discarded, which can partially explain the increase in DMI with a reduction in ricin toxicity promoted by alkaline treatment.

An explanation for the increase, numerically presented, of the DMI of animals fed with 100% CMT compared to animals fed with SM could be an increase in mineral concentration in CMT diets, as the addition of lime can favor the formation of calcium carbonate, which has a buffering effect. The buffers function to neutralize excess acid produced in the rumen in situations where the buffering systems are insufficient. According to Russell & Chow (1993), the actions of buffers in the rumen could be explained by an increase in water ingestion and a consequent increase in the liquid passage rate, which could result in greater DMI.

Performance, carcass characteristics, and commercial cut yields

Determination of the EBW of the animals is frequently used in studies of nutritional requirements and is very important for weight gain studies, as it eliminates errors due to variations in gastrointestinal contents of animals (Lana et al., 1992). In the present work, the relations EBW/FBW and EBWG/ADG had average values of 0.888±0.007 and 0.858±0.020, respectively. The NRC (1996) recommends values of 0.891 and 0.951 for livestock, and Paulino et al. (2006) mentions values of 0.896 and 0.933, respectively, for Nelore beef cattle. The divergence between the values mentioned in the literature and the ones found in this work can be explained by the genetic groups of the animals used in the experiment, in which the majority were crossbreed Holsteins.

The degree of carcass finishing is evaluated by SFT, which is the characteristic with the greatest impact on yield, as lean meat yield decreases with an increase in SFT. The main function of subcutaneous fat is cold protection, avoiding cold shortening (sarcomere cold shortening), which provokes muscle fiber shortening, making surface cuts more rigid. At the end of the experiment, all of the animals presented adequate finishing, meeting market requirements, as they presented greater than 3 mm fat thickness in the carcass, which is considered good quality in Brazil (Luchiari Filho, 2000).

The degree of boneless and fat-trimmed meat cut yield is an estimate of marketable meat quantity or edible proportion of a carcass. According to Luchiari Filho (2000), it is desirable for a carcass to contain approximately 45-50% subprime, 38-43% forequarter with 5 ribs and 12-16% flank. The results of the present work are in accordance with these values. In the literature, there is a scarcity of data regarding the study of carcass characteristics and commercial cut yields in cattle, especially when castor meal is used in the diet.

Carcass physical composition

A possible argument for the decrease in fat proportion with an increase in CMT addition to the diet would be the greater presence of Holstein crossbreed in the animals used in this work.

Determination of animal body composition is the first step in estimating their nutritional requirements; therefore, determination of carcass physical composition is very important. The proportion of tissues that comprises the carcass is directly related to its quality, which makes its acquisition interesting. Data related to the physical composition of carcasses from cattle fed with castor meal have not been found in the literature.

Diet costs and sensitivity analysis

It has been observed that the economically optimal diet (lowest cost per carcass yield) depends on price. If the CMT price is up to 15% of the SM value, the use of diets with 100% CMT is recommended. However, if the CMT value is equivalent to 85% or more of the soybean meal price, it is better to avoid using CMT. In considering the relationship between 20% and 80% of CMT compared to SM, it was shown that diets with 67% CMT substitution were the most advantageous. With regard to the substitution of CMT with CMNT, no situation was shown to be advantageous, as the carcass yield was numerically lower than for the other diets.

IMPLICATIONS

Total or partial substitution of soybean meal with treated castor meal with lime (60 g/kg) did not alter carcass performance or basic cut yields. Therefore, it can be concluded that soybean meal can be partially or totally replaced with treated castor meal.

Non-treated castor meal, which resulted in a daily ricin intake of 3.06 mg/kg of body weight, presented satisfactory performance results. However, considering the risk from the presence of this toxin, precautions should be taken in its use, as the results can be influenced by the quantities of ricin present in the different types of meal.

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