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REGULAR ARTICLES

Detoxified castor meal in substitution of soybean meal in sheep diet: growth performance, carcass characteristics and meat yield

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Abstract The aim of this study was to evaluate the intake, digestibility, performance, and carcass characteristics of lambs fed different levels of replacement (0, 15, 30, and 45 % based on dry matter, DM) of soybean meal (SM) by detoxified castor meal (DCM). Twenty-four and 32 intact hair lambs of nondescript breed (21.7±2.6 kg of initial average body weight and approximately 10 months old) were used, respectively, in the intake and digestibility and performance experiments. The diets were composed of buffel grass hay, ground corn grain, and different levels of SM, DCM, and urea, in a roughage-to-concentrate ratio of 40:60. There was no effect of treatments on DM intake. However, crude protein (CP) and neutral detergent fiber (NDF) intakes were higher at 30 and 45 % than at 0 and 15 % of DCM, which in turn showed higher intake of non-fiber carbohydrates (NFC) ($P<0.05$). The organic matter, CP, and NDF digestibilities were not affected, but the digestibility of NFC was lower at 30 and 45 % than at 0 % of DCM ($P<0.05$). The average daily gain, feed conversion, slaughter and carcass weights, chilling losses, ribeye area, and absolute values and yields of neck, ribs, loin, and leg were not affected. However, the carcass yield was lower at 45 % of DCM and the absolute value of shoulder was lower at 30 and 45 % of DCM ($P<0.05$). The replacement of SM by DCM up to 45 % in the feed of lambs did not negatively affect the intake, digestibility, performance, and main carcass features.

Keywords Biodiesel · Byproduct · Lambs · Performance · Protein concentrate · *Ricinus communis*

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Introduction

The global use of biofuels has increased in recent years in an attempt to reduce the negative effects of petroleum fuels in the environment. Furthermore, as the sources of petroleum fuels are finite, the development of renewable fuels is required (Sreenivas et al. 2011). The oil derived from castor seed (*Ricinus communis*) is used as biodiesel (Shrirame et al. 2011). Castor is an oilseed crop from the *Euphorbiaceae* family, and the largest world producers of castor oil are India (1, 644,000 t), China (60,000 t), Mozambique (60,000 t), and Brazil (11,593 t) (FAOSTAT 2013). The oil content of the seed is approximately 46–55 % (Ogunniyi 2006). Thus, even if all the oil is extracted, the amount of residue produced would still be approximately 50 %.

The castor seed meal is obtained after physical and chemical extraction of seed oil, and it has a high content of the proteic toxin, ricin. Thus, this material must be subjected to a process of detoxification before it is used in animal feed

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(Akande et al. 2015). Detoxified castor meal (DCM) has a high content (41 %) of crude protein (CP) (Silva et al. 2014), and therefore, it could be used to replace soybean meal (SM), the main protein source of feed for ruminants and one of the most expensive ingredients of concentrates.

There is little information about the use of DCM replacing SM in ruminant nutrition. Diniz et al. (2010, 2011) reported that DCM could totally replace SM without affecting the performance and digestibility of beef cattle. Silva et al. (2014) did not observe any effect of supplementation of sheep with DCM on carcass characteristics. In another study with sheep, Nicory et al. (2015) showed that the dry matter intake (DMI) in lambs reduced as SM was replaced by DCM.

Therefore, the aim of this study was to evaluate the intake of nutrients, digestibility coefficients, performance, and carcass characteristics of lambs fed different levels of substitution of SM by DCM.

Table 1 Chemical composition of the buffel grass hay (BGH), ground corn grain (GCG), soybean meal (SM), and detoxified castor meal (DCM)

Item (%)	Ingredients			
	BGH	GCG	SM	DCM
Dry matter, %	92.5	88.3	90.7	92.0
Organic matter, % DM	83.5	86.8	84.2	81.0
Ashes, % DM	9.0	1.5	6.5	11.0
Crude protein, % DM	8.0	9.5	50.2	25.3
Ether extract, % DM	3.3	3.7	2.1	4.0
Total carbohydrates, % DM	79.7	84.3	41.2	59.7
Non-fiber carbohydrates, % DM	3.2	68.7	7.2	5.1
Neutral detergent fiber, % DM	76.5	15.6	34.0	54.6
Acid detergent fiber, % DM	43.8	3.5	9.2	37.2
Lignin, % DM	8.6	0.9	0.6	29.1
Gross energy, Mcal/kg DM	3.16	4.52	4.20	3.67

DM dry matter

Materials and methods

The experiment was conducted at the Animal Nutrition Section of Semiarid Embrapa, in Petrolina, Pernambuco, Brazil. Twenty-four (n=6 by treatment) and 32 (n=8 by treatment) intact hair lambs of nondescript breed were used, in the intake and digestibility experiment (E1) and in the performance experiment (E2), respectively. The initial average body weight (IBW) was 21.7±2.6 kg and the average age was 10 months. All animals were dewormed (Ivomec, Merial, Campinas, Brazil) and vaccinated against clostridioses (Poli R, Vallée, São Paulo, Brazil) before the start of the experiment. The adaptation period for E1 lasted 15 days, while feed, leftovers, and feces were sampled for 3 days. The trial period for E2 was of 80 days.

The study was conducted in a completely randomized block design, with the initial body weight being used as the parameter to define the blocks. The animals were kept in a covered shed, either in metabolic cages (E1) or in individual pens (E2), fitted with feed and water troughs. Water and mineral salt were offered ad libitum, and the daily feed intake was recorded.

The treatments consisted of partial replacement of SM by DCM at 0, 15, 30, and 45 % dry matter (DM) basis. The diets were isonitrogenous and formulated according to NRC (2007) to obtain lambs with 30 kg of body weight and average daily gain (ADG) of 200 g. A roughage-to-concentrate ratio of 40:60 was used. The animals were fed twice a day at 0800 and 1600 hours. The chemical composition of feeds and diets are presented in Tables 1 and 2.

The castor seed meal was purchased from Brasil Ecodiesel in Iraquara, BA, and transported to the Semiarid Embrapa, where it was detoxified with calcium hydroxide ($Ca(OH)_2$) diluted in water (9 L of water/kg of $Ca(OH)_2$), in a ratio of 60 g of $Ca(OH)_2$ per kilogram of castor seed meal (Menezes et al. 2012). After detoxification, the material was placed in 200-L polyethylene containers for 24 h and then sun-dried for 12 h.

The ingredients and diets were analyzed for DM, organic matter (OM), CP, ether extract (EE), lignin (LIG), ashes, and gross energy (GE) according to AOAC (2000). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed according to Van Soest et al. (1991). Total carbohydrates (TC) and non-fiber carbohydrates (NFC) were estimated according to Sniffen et al. (1992) and Mertens (1997), respectively. The digestibility coefficients (DC) of DM and nutrients were calculated by the following formula: DC=[(kilogram of nutrient ingested−kilogram of nutrient excreted)/kilogram of nutrient ingested]×100.

The animals used in E2 were weighed at the beginning of the experiment, then every 7 days, prior to the first meal, and at the end of feedlot period to obtain the IBW, the average total gain and the ADG. Feed conversion was calculated as the amount of diet consumed per unit of body weight gain.

At the end of the experiment, animals from E2 were weighed after 18 and 12 h of feed and water withdrawal, respectively, to obtain the slaughter body weight (SBW). Animals were stunned, exsanguinated, skinned, and eviscerated. Head, feet, and genitals were also removed. The carcasses were weighed to obtain the hot carcass weight (HCW) and then refrigerated for 24 h at 4 °C, and reweighted to obtain the cold carcass weight (CCW). Carcass yield (%) was calculated as the carcass weight (hot and cold)× 100, divided by SBW, and chilling loss (CL) as: CL=[(HCW −CCW)/HCW]×100.

The carcasses were split into two longitudinal halves. The left half-carcass was cut into the retail cuts: neck, shoulder,

Table 2 Ingredients and chemical composition of the diets with different levels of partial replacement of soybean meal (SM) by detoxified castor meal (DCM)

	Replacement levels of SM by DCM, %			
	0	15	30	45
Ingredients				
Buffel grass hay, % DM	40.0	40.0	40.0	40.0
Ground corn grain, % DM	30.0	30.0	30.0	30.0
Soybean meal, % DM	30.0	25.0	21.0	16.0
Detoxified castor meal, % DM	0.0	4.7	8.5	13.3
Urea, % DM	0.0	0.3	0.5	0.7
Nutrients				
Dry matter, %	91.0	91.1	92.2	92.2
Organic matter, % DM	85.1	84.7	85.5	85.2
Ashes, % DM	3.9	4.6	5.1	5.7
Crude protein, % DM	20.6	20.6	20.4	20.5
Ether extract, % DM	3.4	3.4	3.5	3.6
Total carbohydrates, % DM	72.1	71.4	71.0	70.2
Non-fiber carbohydrates, % DM	26.6	24.6	23.9	22.4
Neutral detergent fiber, % DM	45.5	46.3	47.1	47.8
Acid detergent fiber, % DM	21.2	22.3	23.4	23.8
Lignin, % DM	3.9	5.2	6.3	7.7
Gross energy, Mcal/kg DM	3.88	3.85	3.81	3.77
Digestible energy, Mcal/kg DM	3.32	3.21	3.19	2.95
Metabolizable energy, Mcal/kg DM	2.61	2.60	2.62	2.40

Composition of the mineral salt per kilogram: Calcium 130 g; Phosphorus 75 g; Magnesium 5 g; Iron 1500 mg; Cobalt 100 mg; Copper 275 mg; Manganese 1000 mg; Zinc 2000 mg; Iodine 61 mg; Selenium 11 mg; Sulfur 14 g; Sodium 151 g; Chloride 245 g; Fluorine 175 mg

DM dry matter

ribs, loin, and leg, in accordance with Marques et al. (2013). The yields of retail cuts were calculated as the weight of the retail cuts divided by CCW.

The rib eye area (REA) was measured as the area of the cross-section of the *Longissimus dorsi* between the 12th and 13th ribs of the right half-carcass, using the formula $REA=(A/2\times B/2)\times\pi$, where A is the maximum length and B the maximum depth, both measured using a tape measure.

Statistical analyses were performed using SAS (2003). The GLM procedure and the Tukey test with a significance level of 5 % were used. The statistical model was as follows: $Y=\alpha+\beta+e$, where Y is the measured variable; α is the fixed effect of treatment (level of substitution of SM by DCM); β is the random effect of block; and e is the residual error.

Results and discussion

There was no effect ($P>0.05$) of treatment on DMI (Table 3). Similarly, Diniz et al. (2010) did not observe effect of replacement of SM by DCM on the DMI of cattle. On the other hand, Nicory et al. (2015) observed that the DMI decreased linearly as DCM was included in the diet to replace SM in the feed of lambs. However, in their study, higher levels of DCM were used (75 and 100 %) compared to the values used in this study.

Crude protein intake (CPI) was higher ($P<0.05$) in the treatment with 45 % of DCM (Table 3). Furthermore, the treatment with 30 % of DCM showed greater CPI than the treatments with 0 and 15 % of DCM. Gionbelli et al. (2014) also found no effect of replacing SM by DCM on DMI, but observed an increase in CPI, which was also greater in the higher level of replacement. As there was no effect of treatments on DMI, the variation in CPI could be related to feed selection by the animals in a possible response to lower absorption of metabolizable protein with the addition of DCM to the diet. Corroborating with this, Carrera et al. (2012) found that the digestibility of rumen undegradable protein of DCM was lower (65 %) than that of SM (94 %), while Nicory et al. (2015) observed a longer time spent chewing per unit of DM consumed and a greater feeding time per unit of DM consumed in lambs as DCM was included replacing SM.

The treatment with 45 % of DCM showed the highest ($P<0.05$) neutral detergent fiber intake (NDFI) (Table 3). Moreover, the NDFI at 30 % of DCM was higher than at 0 and 15 % of DCM. The acid detergent fiber intake (ADFI) was higher ($P<0.01$) at 30 and 45 % of DCM than at 0 and 15 % of

Table 3 Means and standard error of the means (SEM) of the intake and digestibility of dry matter (DM), crude protein (CP), non-fiber carbohydrates (NFC), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of lambs fed different levels of partial replacement of soybean meal (SM) by detoxified castor meal (DCM)

Item	Replacement levels of SM by DCM, %					
	0	15	30	45	SEM	Effect
Nutrient intake						
DM, g/day	865	803	924	946	0.04	ns
DM, g/kg BW	30.1	28.0	32.0	32.2	1.85	ns
CP, g/day	115c	115c	124b	155a	0.01	*
CP, g/kg BW	4.0	4.0	4.3	5.3	0.20	ns
NFC, g/day	215a	215a	205b	118c	0.02	*
NDF, g/day	451c	426c	490b	553a	0.02	*
ADF, g/day	112b	114b	168a	178a	0.01	**
Digestibility coefficient						
DM, %	69.0	68.6	68.8	64.8	1.10	ns
OM, %	71.4	71.0	71.0	66.6	1.09	ns
CP, %	61.1	64.0	65.2	68.0	1.97	ns
NDF, %	63.8	65.3	62.5	62.9	0.92	ns
NFC, %	93.0a	91.4ab	90.5b	73.8c	0.69	*

BW body weight, *ns* not significant

*Significant <5 %; **significant <1 %;

DCM (Table 3). Since the levels of these fractions in the treatments were similar, despite the higher NDF and ADF content of DCM, these results also suggest feed selection by animals in response to inclusion of DCM.

The treatments with 0 and 15 % of DCM showed the highest values ($P<0.01$) of non-fiber carbohydrate intake (NFCI) (Table 3). Furthermore, the NFCI was higher at 30 % of DCM than at 45 % of DCM. This result may be related to a reduction in levels of NFC as SM was replaced by DCM.

The digestibility coefficients of DM, OM, CP, and NDF were not affected ($P>0.05$) by replacement of SM by DCM (Table 3). On the other hand, the treatments with 30 and 45 % of DCM had lower digestibility of NFC than the treatment with 0 % of DCM ($P<0.05$), while the digestibility at 15 % of DCM did not differ ($P>0.05$) from that presented at 0 % of DCM (Table 3). Similarly, Oliveira et al. (2010) did not observe differences in the digestibility of DM, CP, and NDF, but observed lower digestibility of NFC in DCM when compared to SM in sheep.

Besides the lower NFC digestibility, there was also a less NFCI as SM was replaced by DCM. These results could also affect CPI. As urea was also added to the diet to maintain equal nitrogen levels between the treatments; the lowest intake and availability of NFC could limit the synthesis of microbial protein from urea. Thus, the animals would need to intake more protein to meet their requirements. In this regard, Menezes et al. (2012) reported a linear increase in the ammoniacal nitrogen concentration in the rumen fluid of sheep as SM was replaced by DCM in the same proportions used here, indicating an imbalance in the availability of energy and protein to microbial protein synthesis.

Treatments had no effect ($P>0.05$) on ADG, average total gain, feed conversion, slaughter and carcass weights, chilling losses, and REA (Table 4). Increasing levels of DCM also did not affect ADG, feed efficiency, slaughter and carcass weights, and REA of cattle (Diniz et al. 2010), as well as performance, SBW, and carcass traits in sheep (Gionbelli et al. 2014 and

Table 4 Means and standard error of the means (SEM) of the initial body weight (IBW), slaughter body weight (SBW), average total gain (ATG), average daily gain (ADG), feed conversion (FC), hot carcass weight (HCW), cold carcass weight (CCW), hot carcass yield (HCY), cold carcass yield (CCY), chilling losses (CL) and ribeye area (REA) of lambs fed different levels of partial replacement of soybean meal (SM) by detoxified castor meal (DCM)

Item	Replacement levels of SM by DCM, %				SEM	Effect
	0	15	30	45		
IBW, kg	22.4	23.1	22.7	23.5	0.58	ns
SBW, kg	34.0	33.4	34.0	34.2	0.74	ns
ATG, kg	11.6	11.3	11.3	10.7	0.50	ns
ADG, g/day	166	161	162	153	0.01	ns
FC, kg/kg	5.21	4.98	5.70	6.18	0.16	ns
HCW, kg	16.9	16.5	17.0	15.9	0.40	ns
CCW, kg	16.5	16.1	16.6	15.5	0.39	ns
HCY, %	49.6a	49.5a	50.0a	46.7b	0.38	*
CCY, %	48.5a	48.3a	48.7a	45.3b	0.39	*
CL, %	2.2	2.3	2.6	3.0	0.17	ns
REA, cm^2	13.9	13.2	13.4	12.8	0.40	ns

ns not significant

*Significant <5 %

Table 5 Means and standard error of the means (SEM) of the weights and yields of the retail cuts of lambs fed different levels of partial replacement of soybean meal (SM) by detoxified castor meal (DCM)

Cuts	Replacement levels of SM by DCM, %				SEM	Effect
	0	15	30	45		
Neck, kg	0.85	0.79	0.85	0.76	0.03	ns
Shoulder, kg	1.26a	1.25a	1.30b	1.10c	0.03	*
Ribs, kg	2.20	2.14	2.25	2.11	0.05	ns
Loin, kg	0.61	0.64	0.60	0.68	0.03	ns
Leg, kg	2.50	2.45	2.57	2.37	0.05	ns
Neck, % LHCW	11.1	10.9	11.2	10.7	0.30	ns
Shoulder, % LHCW	17.1	17.0	17.2	16.9	0.20	ns
Ribs, % LHCW	29.6	29.5	29.7	30.1	0.59	ns
Loin, % LHCW	8.2	8.8	8.0	8.4	0.21	ns
Leg, % LHCW	33.9	33.7	34.0	33.9	0.56	ns

LHCW left half carcass weight, *ns* not significant

*Significant <5 %

Silva et al. 2014). The absence of treatment effect on performance and carcass characteristics is in agreement with the results for intake and DM digestibility, indicating no limitation in the supply of nutrients to animal performance.

The hot carcass yield (HCY) and cold carcass yield (CCY) were lower ($P<0.05$) with 45 % of DCM (Table 4). Since HCY and CCY are calculated by the ratio between carcass weight and SBW, this difference could be related to different digesta retention rates between treatments, despite animals being subjected to the same fasting time. Differences in the gastrointestinal contents could have occurred due to variations in nutrient intake, which have different disappearance rates, as NDF and NFC, for example. In this direction, Diniz et al. (2010) also observed effect of replacement of SM by DCM on carcass yield when calculated in relation to SBW, but not when calculated in relation to empty body weight, which does not consider the gastrointestinal content.

The replacement of SM by DCM did not affect ($P>0.05$) the absolute values and the yields of neck, ribs, loin, and leg (Table 5), with the three latter representing the most expensive lamb cuts. On the other hand, the absolute value of the shoulder was greater in treatments with 0 and 15 % of DCM than in treatments with 30 and 45 % of DCM. Diniz et al. (2010) and Silva et al. (2014) also did not observe significant effect of replacement of SM by DCM on the weights and yields of retail cuts in cattle and sheep, respectively.

In conclusion, it was observed that the replacement of SM by DCM up to 45 % in the feed of lambs did not negatively affect intake and nutrient digestibility, performance and main features of the carcass. The Brazilian semiarid region has the largest sheep herd, and the greatest castor production in the country and the results obtained in this study indicate that the integration of these two activities in the region could be feasible. However, studies on the economic viability of the use of DCM replacing SM are recommended.

Compliance with ethical standards

Statement of animal rights The experimental procedures followed the animal care of the Committee of the Semiarid Embrapa.

Conflict of interest The authors declare that they have no competing interests.

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