

# Intake, digestibility and nitrogen balance in sheep fed diets containing detoxified castor cake<sup>1</sup>

Consumo, digestibilidade e balanço nitrogenado em ovinos alimentados com rações contendo torta de mamona destoxificada

Rafael Nogueira Furtado<sup>2\*</sup>, Roberto Cláudio Fernandes Franco Pompeu<sup>3</sup>, Magno José Duarte Cândido<sup>4</sup>, Elzânia Sales Pereira<sup>4</sup>, Marcos Neves Lopes<sup>5</sup> and Marcos Cláudio Pinheiro Rogério<sup>3</sup>

**ABSTRACT** - The effect of substituting soybean meal (SM) with four levels (0, 33, 67 and 100%) of detoxified castor cake (DCC) on intake, nutrient digestibility and nitrogen balance was evaluated in uncastrated, male, crossbred sheep in a randomised complete block design with four treatments and five replications. There was a decreasing linear effect from the levels of substitution on dry matter (DM), organic matter (OM) and crude protein (CP) intake, total carbohydrates (TC), non-fibrous carbohydrates (NFC) and total digestible nutrients (TDN), and on DM, OM and TC digestibility, for reductions of 2.04, 1.70, 0.35, 1.56, 1.89 and 1.67 g dia<sup>-1</sup> and 0.34, 0.53 and 0.51 g kg<sup>-1</sup> DM respectively, for each 1% SM substituted with DCC. DMI and NDFap expressed, in %BW and g kg<sup>-0.75</sup>, showed a quadratic response, with a maximum value of 3.85 and 1.73%BW, and 95.15 and 42.47 g kg<sup>-0.75</sup>, for 25.00, 65.00, 20.75 and 61.50% SM substituted with DCC respectively. There was a linear increase in the intake of acid detergent fibre and in ether extract digestibility. The nitrogen balance was not affected by the substitution of SM with DCC. Substituting soybean meal with castor cake detoxified by autoclaving in lamb diets alters nutrient intake and digestibility without affecting the nitrogen balance.

**Key words:** Biodiesel. Detoxification. Ricin. *Ricinus communis*. Nutritional value.

**RESUMO** - Avaliou-se a influência de quatro níveis de substituição (0; 33; 67 e 100%) do farelo de soja (FS) pela torta de mamona destoxificada (TMD) em rações sobre o consumo, digestibilidade dos nutrientes e balanço de nitrogênio em ovinos mestiços, machos, não castrados em delineamento em blocos completos ao acaso com quatro tratamentos e cinco repetições. Observou-se efeito linear decrescente dos níveis de substituição do FS pela TMD sobre o consumo de matéria seca (MS), matéria orgânica (MO), proteína bruta (PB), carboidratos totais (CT), carboidratos não fibrosos (CNF), nutrientes digestíveis totais (NDT), digestibilidade da MS, MO e CT com reduções respectivas de 2,04; 1,70; 0,35; 1,56; 1,89 e 1,67 g dia<sup>-1</sup> e 0,34; 0,53 e 0,51 g kg<sup>-1</sup> de MS, para cada 1% de substituição do FS pela TMD. O CMS e FDNcp expressos em %PC e g kg<sup>-0.75</sup> apresentaram resposta quadrática com valor máximo de 3,85 e 1,73%PC e 95,15 e 42,47 g kg<sup>-0.75</sup> com 25,00; 65,00; 20,75 e 61,50% de substituição do FS pela TMD, respectivamente. Houve aumento linear no consumo de fibra em detergente ácido e digestibilidade do extrato etéreo. O balanço de nitrogênio não foi influenciado pela substituição do FS pela TMD. A substituição do farelo de soja pela torta de mamona destoxificada por autoclavagem na ração de cordeiros altera o consumo e digestibilidade dos nutrientes sem influenciar o balanço de nitrogênio.

**Palavras-chave:** Biodiesel. Destoxificação. Ricina. *Ricinus communis*. Valor nutritivo.

DOI: 10.5935/1806-6690.20200012

\*Author for correspondence

Received for publication 29/11/2017; approved on 10/10/2019

<sup>1</sup>Parte da Tese de Doutorado do segundo autor apresentada; Pesquisa financiada pelo BNB

<sup>2</sup>Instituto Federal de Educação, Ciência e Tecnologia do Piauí/IFPI, *Campus* Paulistana, Paulistana-PI, Brasil, rafael.furtado@ifpi.edu.br (ORCID ID 0000-0002-4502-786X)

<sup>3</sup>Embrapa Caprinos e Ovinos, Sobral-CE, Brasil, roberto.pompeu@embrapa.br (ORCID ID 0000-0002-4099-3575), marcos.claudio@embrapa.br (ORCID ID 0000-0003-3567-5211)

<sup>4</sup>Departamento de Zootecnia, Universidade Federal do Ceará/UFC, Fortaleza-CE, Brasil, magno@ufc.br (ORCID ID 0000-0003-3573-6053), elzania@hotmail.com (ORCID ID 0000-0003-2003-5203)

<sup>5</sup>Instituto Federal de Educação, Ciência e Tecnologia do Piauí/IFPI, *Campus* Valença do Piauí, Valença do Piauí-PI, Brasil, marcos.neves@ifpi.edu.br (ORCID ID 0000-0002-1562-3919)

## INTRODUCTION

In semi-arid regions, the exploitation of sheep represents one of the principal sources of animal protein for human consumption, and is an activity of worldwide socio-economic importance. However, historically, sheep herds in these regions have been subject to food deficiency, mainly due to the prolonged period of drought. This scenario is likely to worsen as climate change forecasts for the coming years lead to more intense and constant extremes of climate, such as droughts and floods.

The lack of planning on the part of producers, and the low use of available technology to circumvent these limitations, make animal farming more vulnerable to the extremes of climate expected in the future. Among existing alternatives, sheep confinement has aroused interest for intensifying the production system, with the aim of minimising the impact of forage shortages, leading to a reduction in the age at slaughter, improving carcass quality, and maintaining the meat supply throughout the year to serve the domestic market (MEDEIROS *et al.*, 2009). However, the lack of bulk during the dry season raises the costs of confinement due to the higher demand for concentrate.

Castor cake, a by-product of castor-oil (*Ricinus communis* L.) extraction, has the potential for use as a protein ingredient in feeding ruminants, despite several studies (COBIANCHI *et al.*, 2012; GOMES *et al.*, 2017; NICORY *et al.*, 2015) showing that this by-product presents a wide variation in crude protein content (268.7, 357.4 and 380.0 g kg<sup>-1</sup> DM). In addition, the presence of ricin in the kernel, one of the most potent toxic proteins known in the plant kingdom, severely disturbs digestion, and can lead to death if ingested by sheep in an amount equal to 1.25 g kg<sup>-1</sup> body weight, according to Tokarnia *et al.* (2012). Because of this, Anandan *et al.* (2005), carried out research comparing the effectiveness of different methods of ricin detoxification of castor bean meal. Among the methods under evaluation, autoclaving at 1.23 kgf cm<sup>-2</sup> or 15 psi at 123 °C for 60 minutes completely destroyed the ricin.

In this context, evaluating the nutritional value of diets containing detoxified castor cake is essential for the safe use of this ingredient in sheep feed. As such, it is important to determine intake, nutrient digestibility and nitrogen balance in sheep fed on diets containing this by-product.

The aim of this study was to evaluate the influence of substituting soybean meal with detoxified castor cake on intake, nutrient digestibility and nitrogen balance in sheep.

## MATERIAL AND METHODS

The study was carried out at the Centre for Forage Studies (NEEF), of the Department for Animal Science at the Centre for Agricultural Sciences of the Federal University of Ceará (UFC) in Fortaleza, in the state of Ceará. The city of Fortaleza is located on the coast, at 3°43'02" S and 38°32'35" W and an altitude of 15.50 m.

Four levels (0, 33, 67 and 100%) of soybean meal substitution with detoxified castor cake in lamb diets were evaluated in a randomised complete block design with five replications, using Tifton 85 hay (*Cynodon* sp.) as bulk. The castor cake was obtained from the Fazenda Normal Farm via the Institute for Sustainable Development and Renewable Energy (IDER), in the municipality of Quixeramobim, Ceará, by mechanical extraction (pressing) of the seed oil at temperatures of between 90 and 100 °C, and detoxified at Embrapa – Agroindústria Tropical, by autoclaving (Sercon model HAE23 autoclave) at a pressure of 1.23 kgf cm<sup>-2</sup> or 15 psi at 123 °C for 60 minutes, as per Anandan *et al.* (2005). As the castor cake was found to be contaminated with the husk during seed processing, eight samples of the crude material (seed and husks) were randomly taken, fractionated and weighed to obtain the proportion of husk in the castor cake, before the seed oil was mechanically extracted.

The experimental diets were formulated based on the recommendations of the National Research Council (2007), and contained 135.2 g kg<sup>-1</sup> DM crude protein and 659.2 g kg<sup>-1</sup> DM total digestible nutrients, with a bulk to concentrate ratio of 50:50. The Tifton 85 hay was prepared at approximately 50 days of age.

Twenty crossbred sheep were used (½ Morada Nova red x ½ of no defined racial pattern), male, uncastrated, with a mean weight of 37.9 ± 4.4 kg and age of 11.5 months. The animals were housed in individual cages equipped with faeces and urine collectors and separators, as well as troughs for food, and drinking fountains with water available at will. The animals were weighed at the beginning and end of the experimental period and received an injectable supplement of vitamins A, D and E before the start of the experiment.

The experiment lasted 21 days: fourteen days for the animals to adapt to the diets and experimental environment, and seven days for collecting the supplied food, leftovers, faeces and urine. The experimental diet was provided daily in two meals, at 0800 and 1600, with the leftovers collected the following day. These were weighed and monitored, to remain at around 15%. The chemical composition of the ingredients is shown in Table 1, and the proportion of ingredients and chemical composition of the total diets are shown in Table 2.

**Table 1** - Chemical Composition of the ingredients (g kg<sup>-1</sup> DM)

Component	Ingredient			
	Tifton 85 hay	Cornflour	Soybean meal	Castor cake
Dry matter	914	898	889	906
Organic matter	854	879	826	845
Crude protein	60	100	481	302
Neutral detergent fibre corrected for ash and protein	798	137	120	453
Acid detergent fibre	430	39	97	402
Ether extract	13	59	18	61
Lignin	66	6	11	34
Neutral detergent insoluble nitrogen	699	112	50	157
Acid detergent insoluble nitrogen <sup>1</sup>	366	27	37	133
Non-fibrous carbohydrates	68	686	318	124
Total digestible nutrients <sup>2</sup>	505	893	803	715

<sup>1</sup>g kg<sup>-1</sup> TN; <sup>2</sup>Estimated as per the National Research Council (2001)

**Table 2** - Proportion of ingredients and chemical composition of diets containing different levels of soybean meal substitution with detoxified castor cake (DCC)

Ingredient	Level of substitution			
	0%	33%	67%	100%
Tifton 85 hay	501	504	506	505
Corn meal	336	325	317	306
Soybean meal	142	103	53	0
Detoxified castor cake	0	51	108	168
Urea	2.3	3.2	5.0	6.8
Ammonium sulphate	1.0	1.5	2.3	3.1
Common salt	5.0	5.0	5.1	5.0
Limestone	5.3	2.7	0.0	0.0
Dicalcium phosphate	2.9	0.8	0.0	2.4
Mineral premix <sup>1</sup>	4.0	4.0	4.0	4.0
Chemical composition (g kg <sup>-1</sup> DM)				
Dry matter	893	899	906	908
Organic matter	847	853	859	861
Crude protein	139	137	134	131
Neutral detergent fibre	485	504	525	545
Neutral detergent fibre corrected for ash and protein	463	482	502	521
Acid detergent fibre	242	260	278	297
Ether extract	29	31	33	35
Lignin	37	38	40	411
Neutral detergent insoluble nitrogen <sup>2</sup>	395	402	408	413
Acid detergent insoluble nitrogen <sup>2</sup>	198	204	210	215
Non-fibrous carbohydrates	310	296	282	265
Total digestible nutrients <sup>3</sup>	667	664	658	648

<sup>1</sup>Composition: Phosphorous, 65.0g; calcium, 160.0g; sulphur, 15.0g; magnesium, 6.5g; sodium, 150.0g; cobalt, 0.125g; zinc, 4.5g; iron, 1.7g; manganese, 4.5g; iodine, 0.06g; selenium, 0.03g; fluoride, 0.95g; medium, 1000g; <sup>2</sup>g kg<sup>-1</sup> TN; <sup>3</sup>Estimated as per the National Research Council (2001)

Each morning, the food, leftovers and faeces were weighed and sampled. The samples were placed in marked plastic bags and stored at -10 °C. At the end of the experiment, the samples from each animal were defrosted and homogenised, and a sample of approximately 300 g was removed and taken to the Animal Nutrition Laboratory of UFC, weighed and placed in a forced ventilation oven at 55 °C to constant weight. The levels of dry matter (DM), crude protein (CP), neutral detergent fibre corrected for ash and protein (NDFap), acid detergent fibre (ADF), ether extract (EE) and ash in the samples were then determined as per techniques described in Silva and Queiroz (2002).

The total carbohydrates (TC) were obtained with the equation  $TC = 100 - (\%CP + \%EE + \%ash)$ , as per Sniffen *et al.* (1992). The non-fibrous carbohydrates were estimated from the expression  $NFC = 100 - (\%CP + \%EE + \%NDFap + \%ash)$ . The levels of neutral detergent insoluble nitrogenous compounds (NDIN) and acid detergent insoluble nitrogenous compounds (ADIN) were estimated in the residue obtained from the NDF and ADF using the micro Kjeldahl procedure. The total digestible nutrient content (TDN) of the experimental diets was estimated from the equation  $TDN = DCP + DNDFap + (DEE \times 2.25) + DNFC$ , representing respectively, digestible crude protein, digestible ether extract, digestible neutral detergent fibre corrected for ash and protein, and digestible non-fibrous carbohydrates (SNIFFEN *et al.*, 1992).

From weighing and determining the DM and nutrient content of the food, leftovers and faeces, the nutrient intake and digestibility were obtained, and the digestibility coefficients of the DM, OM, CP, EE, NDFap, ADF, TC and NFC determined with the formula  $[(\text{Nutrient intake in grams} - \text{amount of nutrient in the faeces in grams}) / \text{Nutrient intake in grams}] \times 100$ .

Urine samples were taken on the last day of collection from the animals housed in metabolic cages using collection funnels, which fed the urine to plastic bottles containing 20 mL of 1:1 hydrochloric acid solution (HCL). After collection, the containers containing the urine were properly weighed to determine the total volume produced. Aliquots of approximately 10% of the total volume were then removed, properly identified and stored at -5 °C for the nitrogenous compounds to be later quantified.

The nitrogen contained in the faeces (faecal N) and urine (urine N) was determined following a methodology described in Silva and Queiroz (2002). The nitrogen balance was obtained by subtracting the faecal N and urine N from the ingested nitrogen ( $N_{\text{ingested}}$ ).

The data were submitted to analysis of variance and regression. The models were chosen based on the

significance of the linear or quadratic coefficients using Student's t-test at 5% probability and on the coefficient of determination. The GLM procedure of the SAS software (SAS INSTITUTE, 2003) was used as an aid to the statistical analysis.

## RESULTS AND DISCUSSION

A linear decreasing effect ( $P < 0.05$ ) was seen from the levels of soybean meal (SM) substitution with detoxified castor cake (DCC), estimated at 1482 and 1278 g day<sup>-1</sup> for dry matter intake (DMI) and 1252 and 1082 g day<sup>-1</sup> for organic matter intake (OMI) at substitution levels of 0 and 100% respectively (Table 3). The decrease in DMI and OMI in the animals fed at the higher substitution levels was due to the lower digestibility of the dry matter and the probable lower palatability of the DCC compared to the SM, results that were corroborated by visual evaluation of the animals during confinement, which, at the highest replacement levels, left the concentrate in the trough, preferring to consume the bulk. In addition, DCC contains a large amount of ricinoleic fatty acid, which can reach 89% of the total fatty-acid composition of the cake (BOMFIM; SILVA; SANTOS, 2009), leading to a reduction in nutrient intake (SANTOS *et al.*, 2011). Agreeing with this statement, Maia *et al.* (2010) noted a reduction in DMI when adding 5% castor oil to the diet of lactating crossbred goats. Furthermore, the higher levels of neutral detergent fibre corrected for ash and protein (NDFap) in the castor cake (453 g kg<sup>-1</sup> DM) and the high percentage of crude protein linked to the NDF (157 g kg<sup>-1</sup> DM) also contributed to this result, thereby affecting nutrient consumption.

When expressed as a percentage of body weight (%BW) and grams per unit of metabolic size (g kg<sup>-0.75</sup>), the DMI presented a quadratic response, with a maximum value of 3.85%BW and 95.15 g kg<sup>-0.75</sup> for 25.00 and 20.75% DCC respectively. Considering the DMI for maintaining adult sheep recommended by the National Research Council (2007), of 53.2 g kg<sup>-0.75</sup>, each of the diets met the requirements, and as such, there were no physical limitations on intake.

Crude protein intake (CPI) decreased linearly with the substitution of SM by DCC, with values estimated at 255.10 and 220.10 g day<sup>-1</sup> at substitution levels of 0 and 100%. Despite the diets having been formulated to be isoproteic and isoenergetic, there were reductions in CPI in response to the lower DMI for the levels of DCC in the experimental diets, corroborated by the high correlation between DMI and CPI ( $r = 0.98$ ,  $p < 0.0001$ ). The preference of the animals for consuming bulk over concentrate at

**Table 3** - Nutrient intake by sheep fed diets containing different levels of soybean meal substitution with detoxified castor cake

Variable	Level of substitution (%DM)				CV	P <sub>≤</sub>	R <sup>2</sup>
	0	33	67	100			
Intake (g dia <sup>-1</sup> )							
DMI <sup>1</sup>	1463	1435	1366	1258	11.38	0.0435	0.21
OMI <sup>2</sup>	1235	1218	1145	1070	11.44	0.0472	0.20
CPI <sup>3</sup>	251.5	244.4	240.2	213.5	11.38	0.043	0.21
EEI <sup>4</sup>	41.05	48.22	48.57	48.35	12.25	-	-
NDFapI <sup>5</sup>	585.9	635.1	631.3	622.6	12.11	-	-
ADFI <sup>6</sup>	295.2	328.9	351.7	349.6	11.95	0.0304	0.23
TCI <sup>7</sup>	1075	1056	990	924	11.49	0.038	0.22
NFCI <sup>8</sup>	519.6	448.5	390.9	328.2	11.80	<0.0001	0.69
TDNI <sup>9</sup>	1051	1011	958	883	11.92	0.0278	0.24
Intake (%BW)							
DMI <sup>10</sup>	3.78	3.85	3.67	3.31	6.89	0.0072	0.44
NDFapI <sup>11</sup>	1.52	1.70	1.69	1.64	7.08	0.0411	0.31
Intake (g kg <sup>-0.75</sup> )							
DMI <sup>12</sup>	94.26	94.89	90.57	82.15	6.49	0.0047	0.47
NDFapI <sup>13</sup>	37.76	41.98	41.84	40.66	6.71	0.0468	0.30

<sup>1</sup>DMI: dry matter intake  $\hat{Y}=1482-2.04DCC$ ; <sup>2</sup>OMI: organic matter intake  $\hat{Y}=1252-1.70DCC$ ; <sup>3</sup>CPI: crude protein intake  $\hat{Y}=255.01-0.35DCC$ ; <sup>4</sup>EEI: ether extract intake  $\hat{Y}=46.55\pm 6.16$ ; <sup>5</sup>NDFapI: ash and protein corrected neutral detergent fibre intake  $\hat{Y}=618.7\pm 72.50$ ; <sup>6</sup>ADFI: acid detergent fibre intake  $\hat{Y}=303.5+0.56DCC$ ; <sup>7</sup>TCI: total carbohydrate intake  $\hat{Y}=1089-1.56DCC$ ; <sup>8</sup>NFCI: non-fibrous carbohydrate intake  $\hat{Y}=516.3-1.89DCC$ ; <sup>9</sup>TDNI: total digestible nutrient intake  $\hat{Y}=1059-1.67DCC$ ; <sup>10</sup> $\hat{Y}=3.79+0.005DCC-0.0001CC^2$ ; <sup>11</sup> $\hat{Y}=1.52+0.0065DCC-0.00005DCC^2$ ; <sup>12</sup> $\hat{Y}=94.29+0.083DCC-0.0020DCC^2$ ; <sup>13</sup> $\hat{Y}=37.93+0.1477DCC-0.0012DCC^2$

the higher levels of substitution also contributed to this result.

Ether extract intake (EEI) in g day<sup>-1</sup> was not influenced by the levels of SM substitution, with a mean value of 46.55g day<sup>-1</sup>. This result is attributed to the higher EE content of DCC (61.0 g kg<sup>-1</sup> DM) in relation to the SM (18.0 g kg<sup>-1</sup> DM), which compensated for the lower DMI (g day<sup>-1</sup>). The DCC was obtained by mechanical extraction, which is less efficient than the solvent extraction used to obtain SM, and explains the greater EE content of DCC compared to SM. However, the greater EE content of the DCC was not enough to hinder digestion of the fibre, since each diet presented an EE content below the 6.0% limit, which, according to Van Soest (1994), causes a reduction in fibre digestion due to intoxication of fibrolytic ruminal microorganisms.

The intake of neutral detergent fibre corrected for ash and protein (NDFapI) was not influenced by the levels of DCC when expressed in g day<sup>-1</sup>. Despite the reduction in DMI with the levels of DCC, there was an increase in the NDFap content, which resulted in there being no effect on the NDFapI. The increase in the NDFap content of the diets at the higher levels of SM substitution with DCC is due to

the high NDFap content of DCC (453 g kg<sup>-1</sup> DM) compared to that of SM (120 g kg<sup>-1</sup> DM). When expressed in %BW and g kg<sup>-0.75</sup>, a quadratic effect from the substitution levels on NDFapI was seen, with a maximum of 1.73 %BW and 42.47 g kg<sup>-0.75</sup> when 65 and 61.5% of the SM was substituted with DCC respectively (Table 4). Furtado *et al.* (2012), testing different methods of detoxifying castor cake, found a NDFapI of 1.96 %BW in growing sheep consuming diets containing 67% autoclaved DCC.

Acid detergent fibre intake (ADFI) increased linearly as the percentage of DCC in the total diet increased. Each percentage increase in DCC increased the ADFI by 0.557 g kg<sup>-1</sup> DM. In this study, the greatest NDFap and ADF intake was seen in diets with a higher DCC content, and can be explained by the higher levels of these nutrients in DCC compared to SM, a result of the 15% castor bean husk present in DCC. Similar results to those obtained in the present study were reported by Ferreira *et al.* (2009), who found an NDFI greater than 2% body weight (BW) using diets containing agro-industrial by-products. Cunha *et al.* (2008) reported an NDFI equal to 2% BW when adding whole cottonseed cake to sheep diets. Therefore, despite the NDFap content of the diets having increased due to the higher percentage of DCC,

**Table 4** - Coefficients of apparent nutrient digestibility (g kg<sup>-1</sup>) in sheep fed diets containing different levels of soybean meal substitution with detoxified castor cake

Variable	Level of substitution (%DM)				CV	P	R <sup>2</sup>
	0	33	67	100			
DMD <sup>1</sup>	703.4	680.4	671.8	667.8	3.82	0.0384	0.21
OMD <sup>2</sup>	898.56	894.74	869.78	848.36	2.26	0.0003	0.52
CPD <sup>3</sup>	772.84	756.86	763.26	772.34	2.88	NS	-
EED <sup>4</sup>	839.6	870.3	894.22	890.86	2.48	0.0014	0.54
FDNapD <sup>5</sup>	567.74	557.3	540.44	553.34	8.28	NS	-
ADFD <sup>6</sup>	513.66	494.94	509.18	511.6	9.62	NS	-
TCD <sup>7</sup>	695.84	667.54	648.7	644.8	4.48	0.0098	0.32
NFCD <sup>8</sup>	857.12	843.32	851.88	847.08	2.38	NS	-

NS: Not significant; <sup>1</sup>Y=698.12 - 0.34DCC; <sup>2</sup>Y=904.16 - 0.53DCC; <sup>3</sup>Y=766.33 ± 21.37; <sup>4</sup>Y= 838.62 + 1.3022DCC - 0.0077DCC<sup>2</sup>; <sup>5</sup>Y=554.71±43.32; <sup>6</sup>Y=507.345 ± 45.40; <sup>7</sup>Y=689.94 - 0.51DCC; <sup>8</sup>Y=849.85 ± 19.30

other factors related to the characteristics of the DCC, such as palatability, may have influenced the behaviour of the animals, leading to a reduction in DMI as DCC was added to the diets.

The intake of total carbohydrates (TCI), non-fibrous carbohydrates (NFCI) and total digestible nutrients (TDNI) decreased linearly (P<0.05) as the SM in the diets was substituted with DCC. Each percentage point of DCC added to the diets reduced the TCI, NFCI and TDNI by 1.558, 1.890 and 1.668 g kg<sup>-1</sup> DM. The lower NFC content and intake in diets containing a greater proportion of DCC are responsible for the reduction in TCI and TDNI.

There was a linear decreasing effect (P<0.05) for the levels of SM substitution with DCC on dry matter digestibility (DMD) and organic matter digestibility (OMD), with reductions of 0.34 and 0.53 g kg<sup>-1</sup> DM for DMD and OMD with the addition of each percentage point of DCC to the diet. This result is attributed to the greater lignin content and the reduction in NFC content (high digestibility) of diets with higher levels of DCC. This relationship is corroborated by the results presented by Diniz *et al.* (2011), who, working with growing cattle, found no effect on DMD or OMD from substituting SM in the diet with detoxified castor meal, attributing this result to the similarity between the fibrous and non-fibrous carbohydrate content of the diets.

No effect was seen from the levels of SM substitution with DCC on crude protein digestibility (CPD), with a mean value of 766.33 g kg<sup>-1</sup> DM. This was not expected, as the acid detergent insoluble nitrogen (ADIN) content of the SM was 37 g kg<sup>-1</sup> TN, while the DCC showed an ADIN content of 133 g kg<sup>-1</sup> TN, which explains the lower CPD at the higher levels of DCC. However, it is possible that the presence of a greater

proportion of urea in diets with a higher percentage of DCC was enough to stimulate microbial action on the ingested diets, compensating for the limitations on CPD of the high levels of ADIN in the DCC.

An increasing linear effect (P<0.05) was seen for the levels of SM substitution with DCC on ether extract digestibility (EED), with estimated values of 838.6 and 968.8 g kg<sup>-1</sup> at substitution levels of 0 and 100% respectively. This result is attributed to the larger EED of the DCC, which contains a large proportion of polyunsaturated fatty acids, especially ricinoleic acid, which can represent up to 90% of the total fatty acids present in castor cake compared to SM. This statement is corroborated by Borja *et al.* (2017), who also found an increase in EED when including castor bean meal, detoxified by a mixed combination of calcium oxide and autoclaving, in the diet of growing sheep.

There was no effect from the levels of SM substitution with DCC on the digestibility of NDFap or ADF, with a mean value of 554.70 and 507.35 g kg<sup>-1</sup> DM respectively. This result was unexpected, given that the NDF and ADF content of the DCC were 47.99 and 40.23% respectively, against the 13.28 and 9.73% of the SM. However, the addition of urea may have optimised the amount of RDP and RNDP in the diet, favouring the growth of fibrolytic microflora, improving the digestion of digestible NDF, and increasing the passage rate of indigestible NDF, with a possible improvement in the digestibility of these nutrients (TEDESCHI; FOX; RUSSEL, 2000).

A linear reduction (P<0.05) was seen for the levels of SM substitution with DCC on total carbohydrate digestibility (TCD), estimated at 689.94 and 638.46 g kg<sup>-1</sup> at substitution levels of 0 and 100% respectively, which

can be explained by the greater proportion of structural carbohydrates in the DCC compared to the SM. No effect was seen for the levels of SM replacement with DCC on non-fibrous carbohydrate digestibility (NFCD), with a mean value of 849.85 g kg<sup>-1</sup>.

Nitrogen intake ( $N_{\text{intake}}$ ) expressed in grams per day (g day<sup>-1</sup>) and grams per kg metabolic weight (g kg<sup>-0.75</sup>) decreased linearly with the substitution of SM with DCC (Table 5). Each percentage point of SM substitution reduced  $N_{\text{intake}}$  by 0.056 g day<sup>-1</sup> and 0.0034 g kg<sup>-0.75</sup> respectively. This result is due to the reductions in DMI at the higher levels of DCC, and is confirmed by the high positive correlation between DMI and  $N_{\text{ingested}}$  expressed in g day<sup>-1</sup> ( $r=0.98$ ,  $p<0.0001$ ) and g kg<sup>-0.75</sup> ( $r=0.96$ ,  $p<0.0001$ ). Similarly, Palmieri *et al.* (2016) evaluated SM substitution with DCC, detoxified with calcium oxide, in growing goats, and saw a reduction in  $N_{\text{ingested}}$  resulting from the effect of the DCC in reducing DMI and CPD.

Faecal N expressed in g day<sup>-1</sup> and percentage of  $N_{\text{intake}}$  (%NI) was not influenced by the substitution of SM with DCC, with mean values of 8.89 g day<sup>-1</sup> and 23.37 %NI. When expressed in g kg<sup>-0.75</sup>, there was quadratic response from the levels of DCC on faecal N, with a maximum value of 0.63 g kg<sup>-0.75</sup> for 38.33% DCC. Furtado *et al.* (2014), evaluating castor cake not treated by detoxification or treated by different methods, in diets for growing sheep, also found no changes in faecal N content, with a mean value of 33.06 %NI.

Urine N decreased linearly with increasing levels of DCC in the diet, with variations of 13.15 and 9.15 g day<sup>-1</sup> between the levels of 0 and 100% SM substitution with DCC. Despite the lower intake of  $N_{\text{ingested}}$  at the higher DCC levels, there was no change in urine N expressed as %NI. This indicates that there was no increase in the loss of nitrogenous compounds via the urinary tract when SM was replaced with DCC. A positive correlation between  $N_{\text{intake}}$  and urine N ( $r=0.64$ ,  $p=0.0024$ ) was found in the present study, and explains the probable decrease in urine N as a result of  $N_{\text{intake}}$ , which was also reduced at the higher levels of DCC. Losses of urine N were higher than of faecal N, with mean values of 29.67 and 23.37 %NI respectively. The intake of dietary nitrogen was probably higher than that required to meet the demands of adult sheep, resulting in an excess of ammonia in the rumen environment and its later absorption by the rumen mucosa, which increased N excretion by the urine in the form of urea (LAVEZZO; LAVEZZO; BURINI, 1996).

The nitrogen balance was not influenced by the diets containing different levels of SM substitution, with mean values of 17.75 g day<sup>-1</sup>, 1.17 g kg<sup>-0.75</sup> and 46.96 %NI. It is worth pointing out that despite the reduction in  $N_{\text{intake}}$  at the highest levels of DCC, the nitrogen balance was positive for all levels of substitution, showing that the nitrogen intake met the requirements of the animals for nitrogenous compounds (FURTADO *et al.*, 2014) and caused no changes in the balance between non-protein nitrogen and true protein in the diet (SILVA *et al.*, 2016).

**Table 5** - Nitrogen balance in sheep fed diets containing different levels of soybean meal substitution with detoxified castor cake

Variable	Level of substitution (%DM)				CV	P≤	R <sup>2</sup>
	0	33	67	100			
Ingested nitrogen (g day <sup>-1</sup> ) <sup>1</sup>	40.23	39.10	38.44	34.17	11.38	0.0431	0.21
Ingested nitrogen (g kg <sup>-0.75</sup> ) <sup>2</sup>	2.59	2.59	2.55	2.23	7.32	0.0063	0.35
Faecal nitrogen (g day <sup>-1</sup> ) <sup>3</sup>	9.15	9.52	9.07	7.83	16.59	NS	-
Faecal nitrogen (g kg <sup>-0.75</sup> ) <sup>4</sup>	0.59	0.63	0.60	0.51	11.30	0.02	0.37
Faecal nitrogen (%NI) <sup>5</sup>	22.72	24.31	23.67	22.77	9.44	NS	-
Urine nitrogen (g day <sup>-1</sup> ) <sup>6</sup>	14.25	10.40	10.53	10.17	24.84	0.0459	0.20
Urine nitrogen (g kg <sup>-0.75</sup> ) <sup>7</sup>	0.91	0.68	0.70	0.66	19.92	0.0333	0.33
Urine nitrogen (%NI) <sup>8</sup>	35.18	26.48	27.57	29.45	18.77	NS	-
Nitrogen balance (g day <sup>-1</sup> ) <sup>9</sup>	16.83	19.17	18.84	16.17	13.56	NS	-
Nitrogen balance (g kg <sup>-0.75</sup> ) <sup>10</sup>	1.09	1.27	1.25	1.06	14.36	NS	-
Nitrogen balance (%NI) <sup>11</sup>	42.11	49.20	48.76	47.79	11.24	NS	-

<sup>1</sup> $\hat{Y} = 40.80 - 0.056\text{DCC}$ ; <sup>2</sup> $\hat{Y} = 2.66 - 0.0034\text{DCC}$ ; <sup>3</sup> $\hat{Y} = 8.89 \pm 1.50$ ; <sup>4</sup> $\hat{Y} = 0.59 + 0.0023\text{DCC} - 0.00003\text{DCC}^2$ ; <sup>5</sup> $\hat{Y} = 23.37 \pm 2.14$ ; <sup>6</sup> $\hat{Y} = 13.15 - 0.04\text{DCC}$ ; <sup>7</sup> $\hat{Y} = 0.90 - 0.0066\text{DCC} + 0.00004\text{DCC}^2$ ; <sup>8</sup> $\hat{Y} = 29.67 \pm 6.16$ ; <sup>9</sup> $\hat{Y} = 17.75 \pm 2.57$ ; <sup>10</sup> $\hat{Y} = 1.17 \pm 0.18$ ; <sup>11</sup> $\hat{Y} = 46.96 \pm 5.66$

## CONCLUSIONS

Castor cake, detoxified by autoclaving, as a substitute for soybean meal in sheep diets, alters nutrient intake and digestibility without affecting the nitrogen balance.

## ACKNOWLEDGEMENT

The authors wish to thank the Banco do Nordeste for their financial support of this research.

## REFERENCES

- ANANDAN, S. *et al.* Effect of different physical and chemical treatments on detoxification of ricin in castor cake. **Animal Feed Science and Technology**, v.120, n.1, p.159-168, 2005.
- BOMFIM, M. A. D.; SILVA, M. M. C.; SANTOS, S. F. Potencialidades da utilização de subprodutos da indústria de biodiesel na alimentação de caprinos e ovinos. **Revista Tecnologia & Ciência Agropecuária**, v. 3, n. 4, p.15-26, 2009.
- BORJA, M. S. *et al.* Effectiveness of calcium oxide and autoclaving for the detoxification of castor seed meal in finishing diets for lambs. **Animal Feed Science and Technology**, v. 231, n. 1, p. 76-88, 2017.
- COBIANCHI, J. V. *et al.* Productive performance and efficiency of utilization of the diet components in dairy cows fed castor meal treated with calcium oxide. **Revista Brasileira de Zootecnia**, v. 41, n. 10, p. 2238-2248, 2012.
- CUNHA, M. G. G. *et al.* Desempenho e digestibilidade aparente em ovinos confinados alimentados com dietas contendo níveis crescentes de caroço de algodão integral. **Revista Brasileira de Zootecnia**, v. 37, n. 6, p. 1103-1111, 2008.
- DINIZ, L. L. *et al.* Castor bean meal for cattle finishing: 1- Nutritional parameters. **Livestock Science**, v. 135, n. 2/3, p. 153-167, 2011.
- FERREIRA, A. C. H. *et al.* Desempenho produtivo de ovinos alimentados com silagens de capim-elefante contendo subprodutos do processamento de frutas. **Revista Ciência Agronômica**, v. 40, n. 2, p. 315-322, 2009.
- FURTADO, R. N. *et al.* Balanço de nitrogênio e avaliação ruminal em ovinos machos e fêmeas alimentados com rações contendo torta de mamona sob diferentes tratamentos. **Semina: Ciências Agrárias**, v. 35, n. 6, p. 3237-3248, 2014.
- FURTADO, R. N. *et al.* Valor nutritivo de dietas contendo torta de mamona submetida a métodos alternativos de detoxificação para ovinos. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v. 64, n. 1, p. 155-162, 2012.
- GOMES, F. H. T. *et al.* Consumo, comportamento e desempenho em ovinos alimentados com dietas contendo torta de mamona. **Revista Ciência Agronômica**, v. 48, n. 1, p. 182-190, 2017.
- LAVEZZO, O. E. N.; LAVEZZO, W.; BURINI, R. C. Efeitos nutricionais da substituição parcial do farelo de soja, em dietas de ovinos: comparação da digestibilidade aparente e balanço de nitrogênio com a cinética do metabolismo da n-glicina. **Revista Brasileira de Zootecnia**, v. 25, n. 2, p. 282-297, 1996.
- MAIA, M. O. *et al.* Consumo, digestibilidade de nutrientes e parâmetros sanguíneos de cabras mestiças moxotó suplementadas com óleos de licuri ou mamona. **Ciência Rural**, v. 40, n. 1, p. 149-155, 2010.
- MEDEIROS, G. R. *et al.* Efeito dos níveis de concentrado sobre as características de carcaça de ovinos Morada Nova em confinamento. **Revista Brasileira de Zootecnia**, v. 38, n. 4, p. 718-727, 2009.
- NATIONAL RESEARCH COUNCIL. **Nutrient requirements of small ruminants: sheep, goats, cervides, and world camelides**. Washington, D. C.: National Academy Press, 2007. 362 p.
- NATIONAL RESEARCH COUNCIL. **Nutrient requirements of the dairy cattle**. 7. ed. Washington: D. C.: National Academy Press, 2001.381 p.
- NICORY, I. M. C. *et al.* Ingestive behavior of lambs fed diets containing castor seed meal. **Tropical Animal Health and Production**, v. 47, n. 5, p. 939-944, 2015.
- PALMIERI, A. D. *et al.* Nutritional and productive performance of goats kids feddiets with detoxified castor meal. **Animal Feed Science and Technology**, v. 216, n. 1, p. 81-92, 2016.
- SANTOS, S.F.*et al.* Efeito da casca de mamona sobre a produção, composição e ácidos graxos do leite de cabra. **Archivos de Zootecnia**, v. 60, n. 1, p. 113-122, 2011.
- SAS INSTITUTE. **Statistical analysis systems user's guide**. Version 9.1. Cary: SAS Institute, 2003.
- SILVA, D. J.; QUEIROZ, A. C. **Análises de Alimentos: métodos químicos e biológicos**. 3. ed. Viçosa: Editora UFV, 2002. 235 p.
- SILVA, R. V. M. M. *et al.* Nitrogen balance, microbial protein synthesis and ingestive behavior of lambs fed diets containing cottonseed cake in substitution of soybean meal. **Semina: Ciências Agrárias**, v. 37, n. 4, p. 2155-2166, 2016.
- SNIFFEN, C. J. *et al.* A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. **Journal of Animal Science**, v. 70, n. 11, p. 3562-3577, 1992.
- TEDESCHI, L. O.; FOX, D. G.; RUSSELL, J. B. Accounting for the effects of a ruminal nitrogen deficiency within the structure of the Cornell Net Carbohydrate and Protein System. **Journal of Animal Science**, v. 78, n. 6, p. 1648-1658, 2000.
- TOKARNIA, C. H. *et al.* **Plantas tóxicas do Brasil para animais de produção**. 2. ed. Rio de Janeiro: Helianthus, 2012. 566p.
- VAN SOEST, P. J. **Nutritional ecology of the ruminant**. New York: Cornell University Press, 1994. 476p.



This is an open-access article distributed under the terms of the Creative Commons Attribution License