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Reproductive responses and productive characteristics in ewes supplemented with detoxified castor meal for a long period

Liliane Moreira Silva[1], Aline Maia Silva[1], Cláudio Henrique de Almeida Oliveira[1], Hilton Alexandre Vidal Carneiro[2], Priscila Teixeira de Souza[2], Frederico José Beserra[3], Cleidson Manoel Gomes da Silva[1], Davide Rondina[1]

[1] Universidade Estadual do Ceará, Fortaleza, Ceará, Brasil.
[2] Universidade de Tecnologia do Sertão Central, Instituto Centro de Ensino Tecnológico, Quixeramobim, Ceará, Brasil.
[3] Universidade de Fortaleza, Fortaleza, Ceará, Brasil.

ABSTRACT - The objective of the present study was to evaluate the effects of supplementation with detoxified castor meal (DCM) in the diet of ewes during pregnancy, partum, and post-partum on the weight development of their offspring and at slaughter. The study included 56 ewes with synchronized estrus that were naturally mated. At the beginning of pregnancy and in post-partum, hepatic and renal function-related parameters and progesterone levels were measured. At slaughter, the proximate composition and fatty acid profile were determined in the loin of ewes. There was no effect of diet on reproductive response after estrus synchronization. At the beginning of pregnancy, albumin and creatinine levels were lower in the DCM group. Supplementation with DCM did not alter the weight or body condition of ewes at partum. However, at weaning, the DCM group showed a higher loin-eye area (LEA) in relation to the group fed diets without detoxified castor meal (WDCM). At partum, as well as at weaning, the offspring of the ewes supplemented with DCM had a larger LEA than the WDCM group. In post-partum, levels of glucose, urea, protein, and cholesterol were lower in the DCM group. The return to cyclicity was similar in both groups, with an average of 47 days after partum. At slaughter, neither anatomical and carcass components nor the results of the proximate analysis were affected by the type of diet, except for an increase in heptadecanoic acid in the DCM group. Supplementation with detoxified castor meal in the diet of ewes does not affect lambing, pregnancy, prolificacy, return to cyclicity, milk production, blood biochemical parameters, or carcass characteristics.

Key Words: carcass, reproductive performance, *Ricinus communis*, sheep

Introduction

The growing worldwide concern for the environment, together with the search for sources of renewable energy, places biodiesel at the center of attention. In northeast Brazil, the cultivation of castor beans (*Ricinus communis*) for the production of biodiesel has greatly increased, as it is well adapted to the region and has a high productivity (Barbosa et al., 2010). In addition, castor bean byproducts, such as castor meal, contain 34-36% protein (Anandan et al., 2005), and are therefore a good source of protein for ruminants.

The use of these byproducts as forage, or as part of the concentrate in the feed of ruminants, has been investigated (Vieira et al., 2010). However, these by-products contain antinutritional or specific bioactive compounds, such as ricin, a ribosome-inactivating protein (Audi et al., 2005), making detoxification necessary before being introduced into the animal feed. Various studies, using different methods, have investigated the use of detoxified castor meal (DCM) in the feed of ruminants, and thus far, none has reported any adverse effects on the carcass, digestibility, or synthesis of proteins by ruminal microbiota (Oliveira et al., 2010; Diniz et al., 2011).

Regarding reproduction, studies conducted in rabbits have shown that castor bean extract negatively affects the processes of implantation and ovulation (Salhab et al., 1999), and induces abortion in rats (Salhab, 1996). In males, Sandhyakumary et al. (2003) observed a reduction in sperm motility *in vitro* and *in vivo* utilizing castor bean extracts in the semen of the epididymis tail of rats. Despite these studies, to the best of our knowledge, no work to date has investigated the effects of castor meal on the reproductive characteristics of livestock, or whether its use in the long-term can cause any adverse effects on ewe reproductive performance. Therefore, the aim of the present study was to evaluate the effects of DCM in substitution of soybean meal in the feed of ewes, during pregnancy, at partum and post-partum, on offspring weight development, and the carcass characteristics of the ewes at slaughter.

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Corresponding author: liligomesvet@hotmail.com
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Material and Methods

The study was approved by the Ethics Commission for the Use of Animals of Universidade Estadual do Ceará (CEUA-UECE), under Protocol No. 09503497-8/82.

The detoxification of the castor meal was carried out according to Anandan et al. (2005), with some modifications. Castor meal was added to calcium oxide solution (1 kg per 9 L of water), and after allowing it to stand overnight, the treated material was dried for storage and use. The efficiency of the detoxification process was verified by the absence of ricin, as demonstrated by 12% polyacrylamide gel electrophoresis under non-denaturing conditions (native-PAGE), where gels were stained with Coomassie Blue R250.

The experiments were conducted on Padre Joao Piamarta Farm, Itaitinga-CE, Brazil, (4°01'S and 38°31'W), between April 2010 and June 2011. The area is characterized by a constant photoperiod and has a warm, tropical, sub-humid climate, with a mean annual rainfall of 904.5 mm and a temperature of 26-28 °C, with a rainy season that runs from January to May and a dry season that runs from June to December.

Fifty-six crossbred Santa Inês × Morada Nova adult, cycling ewes, which were homogeneous in weight (33.03±0.65 kg) and body condition (2.31±0.06), were divided into two groups: without detoxified castor meal (WDCM, n = 29) and with detoxified castor meal (DCM, n = 27). In the WDCM group, the animals received soybean meal in the concentrate as a nitrogen source. In the DCM group, the animals were fed DCM, which replaced the soybean meal in the concentrate (Table 1).

Table 1 - Ingredient composition of the concentrate-based supplements

Component (% DM)	Diet	
	WDCM	DCM
Ground corn	81.8	79.6
Soybean meal	12.1	-
Detoxified castor meal	-	14.5
Urea	1.0	1.0
Vitamin mineralized premix	4.3	4.1
White salt	0.8	0.8

WDCM - diet without detoxified castor meal; DCM - diet containing castor meal.

Ewes were kept in two pens separated by a central feed alley, and they received mineral salts and water *ad libitum*. Each pen measured 40 × 50 m and contained a 40 × 3 m open front shelter. The feed alley and the front shelter were made of clay and concrete, and facing the east-west direction. The animals were acclimated for 30 days. During this period, internal and external parasite treatment and the control of ovary function by ultrasonography were conducted.

For both groups, the diets were composed of a mixture of guinea grass hay (*Panicum maximum* cv. Mombasa) and isocaloric (74% of TDN) and isonitrogenous (14% CP on a DM basis) concentrates (Table 2). The formulation of diets was based on the nutritional requirements of mature ewes (NRC, 2007). The feed was provided twice a day (07.00 h and 15.00 h) for 429 d, from 15 days before mating to slaughter, about 262 days after parturition.

Estrus was induced in all the females using an intravaginal device (Controlled Internal Drug Release device, CIDR®) impregnated with 0.33 g of P_4 (Eazi-Breed CIDR®, InterAg, Hamilton, New Zealand), which was inserted for 5 days. Upon removal of the device, the ewes received an application of 1 mL of prostaglandin $F_{2\alpha}$ (Lutalyse®, Upjohn, Kalamazoo, USA). Males of proven fertility and marked in the sternal region were placed together with the females for a period of 72 h, allowing the mated females to be identified by the presence of the marker paint in the region of the croup.

The diagnosis of pregnancy (carried out on the 30th day of pregnancy), as well as the determination of the number of fetuses and the monitoring of the embryonic/fetal development was carried out using real-time ultrasonography (Chisson D600 VET, Chisson Medical Imaging Co. Ltd., China), using a linear transrectal transducer set at 3.5-5.0 MHz. Fetal measurements were performed on the animals every 10 days. The following parameters were measured, following the methodology

Table 2 - Ingredient composition of diets

Ingredients	Composition (% DM)					
	Organic matter	Crude protein	Ether extract	Ash	Neutral detergent fiber	Acid detergent fiber
Guinea grass hay	92.80	6.81	1.20	7.20	69.98	40.46
Detoxified castor meal	89.35	41.35	2.00	10.65	40.07	33.80
Concentrate-based supplements						
WCM - diet	97.20	15.00	3.15	2.80	-	-
DCM - diet	97.09	14.99	3.48	2.91	-	-

WDCM - diet without detoxified castor meal; DCM - diet containing castor meal.

proposed by Santos et al. (2004): vesicle diameter (VD), from the 30th to the 40th day of pregnancy; crown-rump length (CRL), from the 30th to the 50th day of pregnancy; and the biparietal and abdominal diameters (BPD and AD, respectively), from the 40th to the 60th day of pregnancy. The thoracic diameter (TD) was measured from the 40th to the 60th day of pregnancy, according to Lee et al. (2005). For the measurement of the structures of interest, ultrasonographic examinations were recorded in the form of videos, followed by the capture of at least three images of each structure, which were measured using the Image J program (Image J, National Institutes of Health, Millersville, USA), which had been previously calibrated. In twin pregnancies, the mean of the two embryos/fetuses was considered, following the method described by Bulnes et al. (1998).

Pregnancy length (the period from the time of mating to partum), lambing rate (the proportion of lambed ewes to mated ewes), litter size (the proportion of lambs born to lambed ewes), and the incidence of twin births were recorded. In addition, the mortality rate of the offspring was determined from birth to weaning.

At partum and every 7 days up to weaning (60 days after partum), weight and body condition score of the ewes were evaluated, as well as loin-eye area and depth of *longissimus dorsi* by ultrasonography. In addition, the *in vivo* performance of the offspring was evaluated through weight (measured weekly from birth to weaning), LEA, and subcutaneous fat thickness (SFT, 14 days after birth to weaning, on a weekly basis). The ultrasonographic measurements were obtained using a B mode ultrasound instrument (Chisson D600 VET, Chisson Medical Imaging Co. Ltd., China), coupled to a 5.0 MHz linear transducer, as described by Teixeira et al. (2006).

Milk production was measured twice a week using the weigh-suckle-weigh technique, from the third day post-partum to weaning (60 days post-partum), according to Celi et al. (2008). Briefly, the day before the measurement, all the lambs were isolated from the dams at 16.00 h. Beginning at 08.00 h of the following day, each lamb was weighed before and after being allowed to suckle the dam. Suckling periods did not exceed 30 min. The difference between the pre- and post-suckling weights was recorded as the estimated milk production of the dam.

After 429 days of feeding, the animals were fasted for solids and liquids for 16 h, then weighed and slaughtered, according to RIISPOA guidelines (1980). The ewes were then skinned, eviscerated, and the head and the extremities were removed. After evisceration, the anatomical components were weighed (lung, heart, spleen, liver, kidneys, tongue, empty stomach, empty intestines, omentum, and cardiac and renal adipose tissue). After evisceration, the carcass was weighed to obtain the hot carcass weight. The carcasses were then stored at 4 °C for 24 h and reweighed to determine the cold carcass weight. The carcasses were then cut longitudinally into two half-carcasses, and the following cuts were made in the left half: shoulder, ham, loin, rib, and neck, as described by Cesar and Sousa (2007).

The loins of the slaughtered animals were identified and stored in a freezer at −18 °C for further tissue composition analysis. The loins were thawed inside plastic bags in a refrigerator at 10 °C for 20 h for tissue analysis. During dissection, muscle, adipose tissue, and bone tissue were separated using a scalpel, a knife, and an anatomical clamp.

The centesimal composition of the muscle was determined according to the AOAC (1990), and the moisture was obtained by drying a sample in an oven at 105 °C until it reached a constant weight. The nitrogen content was determined using the Kjeldahl method, and converted to crude protein using a factor of 6.25. The fixed mineral residue was determined by incineration at 550 °C. Total lipid content was determined using a hot extraction process with an organic solvent (hexane) at 120 °C. The fatty acid profile was quantified using a gas chromatograph (model GCMSQP5050A, Shimadzu, Brazil), connected to a flame ionization detector. The separation took place in a Carbowax 20M (Supelco) fused silica capillary column (stationary phase, polyethylene glycol) that was 60 m long, with an internal diameter of 0.53 mm and had a 1 μm film thickness. A 2 μL sample of the methyl ester was injected into a split/splitless injector at 250 °C. The chromatograms that contained the data (retention time and fatty acid area percentages) were stored on the PeakSimple software (ARI Instruments, USA). The fatty acids were identified by comparing the retention time of the methyl esters of the samples with authentic standards of fatty acid esters (Merck, USA).

Blood samples were collected to determine the main hepatic and renal function-related parameters before the start of the dietary treatment (day 0), at the time of natural mating (15 days of feeding), and every 10 days after mating, continuing to 60 days of pregnancy (75 days of feeding), and at slaughter (429 days of feeding). Blood was centrifuged at 3000 rpm for 15 min, and the plasma obtained was stored in the freezer at −20 °C. Plasma concentrations of urea (UR), creatinine, lactate dehydrogenase (LDH), glutamic pyruvic transaminase (GPT), glutamic oxaloacetic transaminase (GOT), and albumin (AL) were determined by spectrophotometric assays in an automated biochemical

analyzer (Labmax 240, Labtest®, Lagoa Santa, Brazil), using commercial kits (Labtest®). In addition, at partum and every 5 days until weaning (60 days post-partum), blood was collected for assays of UR, AL, total protein (TP), glucose (GL), cholesterol (CT), and triglycerides (TG) by spectrophotometric assays in an automated biochemical analyzer (Labmax 240, Labtest®), using commercial kits (Labtest®).

Upon removal of the CIDR® (day 0), and on days 4, 8, 12, 16, and 20 after removal of the device, blood samples were collected for P_4 determination by microparticle enzyme immunoassay (MEIA) (Abbott Diagnostics AxSYM® SYSTEM), using a commercial kit (Axsym P_4, Abbott, Tokyo, Japan). The sensitivity of the test was 0.2 ng/mL, and the intra- and interassay coefficients of variation were 7.9% and 3.3%, respectively. In addition, every 5 days after partum, until 60 days post-partum, blood samples were collected to determine the presence of corpora lutea in the ovaries, based on the progesterone concentration. A functional corpus luteus (CL) was confirmed when at least two consecutive samples showed progesterone levels of over 1 ng/mL; a non-functional CL was indicated by there being no detection of progesterone levels of over 1 ng/mL (Rodrigues et al., 2011).

The data were analyzed using the statistical program SAS (Statistical Analysis System, version 9.2.). An entirely randomized design was used for the statistical analysis. The data were evaluated by ANOVA of GLM procedures. For live weight, body condition, LEA, DLD, SFT, milk production, carcass anatomical parameters, tissue analysis, and fatty acid profile the factor tested was the dietary group (WDCM and DCM), and the comparisons between means were performed by the Student t-test. For the analysis of fetal growth, plasma progesterone levels, and other biochemical parameters, the factors tested were diet and time intervals and the interaction between these two sources of variation. The Duncan test was used for comparison between the means. The chi-square test was used for the variables in the form of frequencies, including the number of animals marked after estrus synchronization, rates of pregnancy, multiple pregnancy, lambing, multiple births, mortality, prolificacy, and the number of corpora lutea.

Results and Discussion

All of the dietary groups exhibited high rates of estrus synchronization and pregnancy (P>0.05; Table 3), with values similar to those reported by Motlomelo et al. (2002). Recently, Rodrigues et al. (2011) found that the substitution of 50% cashew bagasse for elephant grass did not have any effect on estrus synchronization rates and pregnancy in sheep. Saunders et al. (2012) also found that diets containing sources of protein of different ruminal degradability did not alter pregnancy rates in sheep.

Progesterone is essential for the maintenance of pregnancy (Inskeep, 2004). Thus, serum progesterone levels during the first 25 days of pregnancy can be an important tool for diagnosing possible early embryonic losses (Moore et al., 2005). In the present study, the plasma concentrations of progesterone measured on the removal of the synchronization device (day 0) to the 20th day after mating did not differ between the dietary treatments (P>0.05; Table 4). During the sampling interval after mating, both experimental groups exhibited elevated plasma progesterone levels (P<0.001), with values of over 3 ng/mL, starting on the 8th day in the WDCM group and on the 12th day in the DCM group, indicating the presence of a functioning CL. These findings are in accordance with earlier studies that have found that plasma progesterone levels significantly increase during the luteal phase (Berardinelli et al., 2001), and remain elevated during the entire pregnancy (Khanum et al., 2008). For all the parameters evaluated, embryonic and fetal development was not affected by diet (Table 5).

According to Berardinelli et al. (2001), the protein level of the diet can influence early embryonic development in ewes. These authors found that the ingestion of large amounts

Table 3 - Reproductive performance of ewes supplemented without (WDCM) or with (DCM) detoxified castor meal

Attributes	Time of feeding (days)	WDCM	DCM
No. of ewes exposed		29	27
Body weight, kg	0	33.52±0.82	33.96±1.35
Body condition	0	2.24±0.09	2.38±0.09
Response to estrus, %	15	89.7 (26)	88.9 (24)
Pregnancy rate, %	45	82.8 (24)	85.2 (23)
Twin pregnancy rate, %	45	4.2 (1/24)	21.7 (5/23)

Table 4 - Levels of progesterone (ng/mL) after estrus synchronization period in ewes supplemented without (WDCM) or with (DCM) detoxified castor meal for a long period

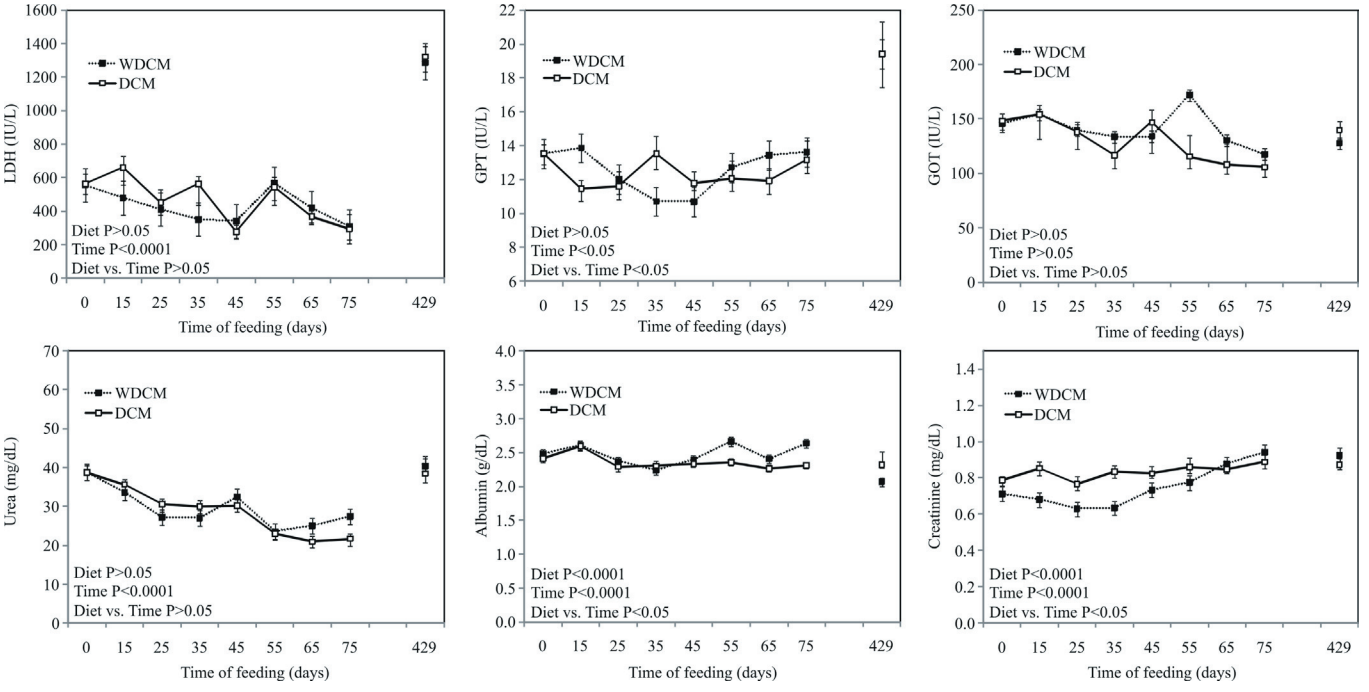
Attributes	Days after CIDR removal (Time of feeding - days)				
	Day 0 (14)	Day 8 (22)	Day 12 (26)	Day 16 (30)	Day 20 (34)
WDCM	5.5±0.6	3.30±0.40	3.69±0.32	4.69±0.67	5.53±0.84
DCM	6.2±0.9	2.19±0.39	3.52±0.61	4.95±1.00	4.83±0.99

of protein (twice the live weight maintenance requirement) caused alterations in embryo transport through the oviduct, leading to asynchrony between the stage of embryonic development and the uterine environment. This suggests that the amount of protein, not the origin of the protein, is responsible for altering the pattern of early embryonic development. In addition, Silva et al. (2013) found that the substitution of soybean meal with DCM in ewe diets over long periods did not alter the developmental pattern of pre-antral and antral follicles, or the quality of oocytes and early embryonic development *in vitro*. In evaluating the effect of time on embryonic/fetal development, we observed a significant growth (P<0.001) in all the variables analyzed (VD, CRL, AD, TD, and BPD). These results were expected, since the growth of the embryo/fetus exhibits a linear profile during pregnancy (Karen et al., 2009). In addition, it is important to point out that, from a clinical point of view, this analysis is highly efficacious in detecting fetal abnormalities as early as possible. Certainly, early-pregnancy diagnosis, together with the determination of the number of fetuses and estimates of fetal age, increases livestock productivity (Lega et al., 2007).

Table 5 - Embryonic/fetal development in ewes supplemented for a long period without (WDCM) or with (DCM) detoxified castor meal

Attributes	Time of feeding (days)	WDCM	DCM
Vesicle diameter			
30 days of pregnancy	45	24.35±0.23	24.31±0.31
40 days of pregnancy	55	36.71±0.23	37.82±0.19
Crown-rump length			
30 days of pregnancy	45	10.00±0.08	10.67±0.18
40 days of pregnancy	55	23.88±0.21	24.22±0.36
50 days of pregnancy	65	38.09±0.18	39.03±0.36
Abdominal diameter			
40 days of pregnancy	55	8.24±0.10	8.49±0.08
50 days of pregnancy	65	11.43±0.12	11.87±0.12
60 days of pregnancy	75	17.62±0.11	18.26±0.11
Thoracic diameter			
40 days of pregnancy	55	5.71±0.11	5.77±0.07
50 days of pregnancy	65	8.11±0.13	8.04±0.09
60 days of pregnancy	75	11.44±0.11	11.81±0.14
Biparietal diameter			
40 days of pregnancy	55	6.89±0.08	6.98±0.08
50 days of pregnancy	65	9.97±0.09	10.45±0.12
60 days of pregnancy	75	15.19±0.08	15.19±0.13

As regards the liver and kidney function-related parameters measured during the first 75 days of feeding (Figure 1), there was an effect of diet on the plasma concentrations of AL (WDCM 2.63±0.04 g/dL *vs*. 2.31±0.05 g/dL DCM, P<0.0001) and creatinine (DCM 0.94±0.05 mg/dL *vs*. 0.89±0.04 mg/dL WDCM, P<0.0001).



LDH - lactate dehydrogenase; GPT - glutamic pyruvic transaminase; GOT - glutamic oxaloacetic transaminase.
Values are given as means±SEM.
Statistically significant effect of Diet and Time treatments and Interaction given in the figure referred to 0 versus 75 days of feeding.

Figure 1 - Blood concentrations of metabolites during pregnancy and at slaughter in ewes supplemented without (WDCM) or with (DCM) detoxified castor meal for a long period.

All of the blood parameters measured varied significantly with time, with the exception of GOT. According to Payne and Payne (1987), the serum AL level is one of the main indicators of protein metabolism over a long period in ruminants, and is considered the most sensitive indicator for determining the protein nutritional state (Caldeira et al., 2007). However, despite the difference in AL levels, both groups had values that were consistently within the physiological range for this species (Piccione et al., 2009). With regard to creatinine levels, the values of both the groups appeared to be lower than the reference range for the species (Gonzalez and Silva, 2006), indicating a protein-deficient metabolism, possibly due to a greater metabolic demand during pregnancy (Piccione et al., 2009). With regard to the influence of time on the metabolites measured, it is well known that different reproductive stages influence the levels of various metabolites in ewes (Piccione et al., 2009), because of changes in protein and energy demand during these different stages.

In this study, the data obtained after partum were evaluated only in females with a single pregnancy. There were no significant differences (P>0.05) in any of the parameters measured, including pregnancy length, lambing rate, twinning rate, litter size, and mortality post-partum (Table 6). These results are in agreement with the results of Mexia et al. (2004), who recorded litter size rates of 1.19 to 1.32, 25% of which were twin births and 75% of which were single births, after investigating the reproductive behavior of Santa Inês ewes supplemented with cassava starch residue or soybean hulls.

During suckling, the live weight, body condition, LEA, and DLD of ewes exhibited a significant decrease (P<0.05) in both dietary treatments. In general, weight loss in lactating females in post-partum is common, due to the large supply of nutrients required for their maintenance and milk production, and they normally mobilize part of their body reserves to meet such demand. However, the measurements obtained at partum and weaning were not affected by diet (Table 6) with the exception of LEA, which was significantly greater (P<0.05) at weaning in the DCM group, indicating that there was less mobilization of body reserves in the animals in the DCM group compared with those in the WDCM group (Table 6). Subcutaneous fat thickness was greater at partum and lower at weaning in the DCM group (P<0.05). Despite this difference, it is difficult to explain this observation, since the SFT is measured together with the epidermis, hence the difficulty to precisely detect variations in the deposition of subcutaneous fat tissue in lactating ewes.

Milk production between the two groups was similar (P>0.05). There was a peak of lactation approximately three weeks after the beginning of lactation, with a mean milk yield of 0.32±0.07 L (Table 6). These values are lower than that reported by Araujo et al. (2008), who observed a milk production in Santa Inês ewes during lactation of 1.48 kg/day. These differences may be due to the method applied to evaluate milk production. According to Unal et al. (2007), the estimate of milk production in Santa Inês ewes by manual milking, after injection of oxytocin, results in a higher milk production than does the weigh-suckle-weigh method.

The performance parameters of the offspring (body weight (BW), LEA, and SFT) significantly increased (P<0.05) during the suckling period. The birth weight and SFT of the lambs, from birth to weaning (Table 6), did not differ between the groups (P>0.05). However, the LEA was significantly larger (P<0.001) in the DCM group at birth and at weaning, indicating a greater gain in muscle mass by the fetuses during pregnancy, which was reflected in a greater LEA at birth and consequently at weaning.

Table 6 - Reproductive and productive performance of ewes supplemented without (WDCM) or with (DCM) detoxified castor meal for a long period

Attributes	Time of feeding (days)	WDCM	DCM
Parturition	167		
Body weight, kg		36.08±1.04a	36.41±1.54a
Body condition		2.7±0.11a	2.7±0.11a
LEA, mm^2		523.25±6.61a	543.17±14.87a
DLD, mm		14.27±0.15a	14.03±0.31a
Parturition rate, %		79.31 (23)	70.37 (19)
Pregnancy length, d		151.86±0.74	152.11±0.93
Twinning rate, %		4.35 (1)	21.05 (4)
No. of lambs		24	22
Litter size		1.04	1.16
Mortality, %		4.17 (1)	4.54 (1)
Weaning	227		
Body weight, kg		32.64±0.76b	32.36±1.57b
Body condition		2.1±0.06b	1.9±0.06b
LEA, mm^2		399.37±8.08bB	432.89±9.30bA
DLD, mm		11.96± 0.20b	11.87±0.26b
SFT, mm		2.68±0.06A	2.48±0.06B
Milk yield	167-227		
Total, L		5.52±0.35	5.45±0.41
Average milk yield, L		0.32±0.08	0.32±0.07
Peak, week		3.47±0.23	3.00±0.33
Average yield at peak, L		0.49±0.03	0.51±0.03
Persistence 2nd mo, %		48.86±5.87	56.74±5.20
Lambs	167-227		
BW at birth, kg		3.06±0.10b	2.94±0.20b
LEA at birth, mm^2		290.54±6.44bB	325.86±6.99bA
SFT at birth, mm		1.47±0.03b	1.38±0.05b
BW at weaning, kg		9.15±0.42a	9.03±0.55a
LEA at weaning, mm^2		394.57±6.05aB	425.81±9.22aA
SFT at weaning, mm		2.04±0.05a	2.05±0.06a

a,b - significant difference between partum and weaning within the same group; A, B - significant difference between group (P<0.05).
LEA - loin-eye area; DLD - depth of *longissimus dorsi*; BW - body weight; SFT - subcutaneous fat thickness.

Table 7 - Concentrations of blood metabolites during post-partum in ewes fed diets without (WDCM) or with (DCM) detoxified castor meal for a long period

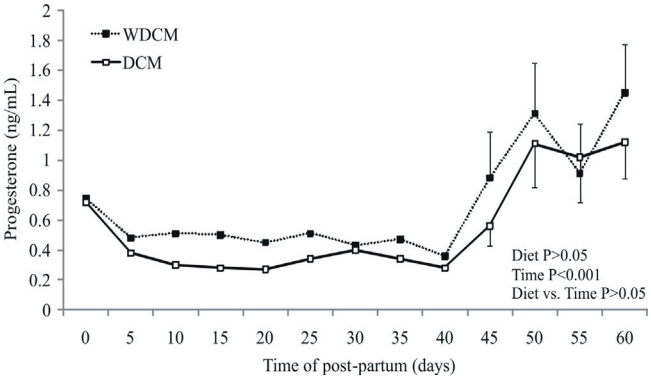
Attributes	Parturition (167 days of feeding)		Weaning (227 days of feeding)		D	T	D×T
	WDCM	DCM	WDCM	DCM			
Urea, mg/dL	17.20±1.36	17.28±0.81	23.36±2.17	21.79± 1.28	***	***	*
Albumin, g/dL	2.60±0.06	2.70±0.07	2.12±0.07	2.28±0.07	ns	***	**
Protein, g/dL	6.90±0.17	6.74±0.13	6.53±0.17	6.38±0.10	***	*	ns
Glucose, mg/dL	62.80±4.55	57.26±6.16	58.26±2.41	54.69±1.94	*	ns	ns
Cholesterol, mg/dL	61.50±3.22	58.95±2.28	65.16±2.03a	37.34±1.64b	***	***	***
Triglycerides, mg/dL	13.80±0.08	13.96±0.09	20.37±1.34	18.18±1.39	ns	***	ns

* P<0.05; ** P<0.01; *** P<0.001; ns - not significant.
a,b - comparison between columns (P<0.05).
D - diet; T - time.

At weaning, only the CT values were shown to be significantly higher in the WDCM group (P<0.05) (Table 7). According to Kaneko (1997), the reference value of CT for sheep varies between 52 and 76 mg/dL, indicating that CT levels in the DCM group were below normal for the species. According to Rabassa et al. (2009), CT concentrations lower than reference levels are a strong indication of energy deficiency in the diet. In evaluating the effect of time, all the metabolites examined were affected, except GL (P>0.05), indicating that the metabolic profile of ewes is dynamic during the lactation period (Piccione et al., 2009). The plasma levels of CT, GL, TP, and UR were affected by diet, and were higher in the WDCM group. The diet *vs.* time interaction was significant for UR, AL, and CT levels (P<0.05). Despite these differences, the values obtained in the present study are similar to reference values (Gonzalez and Silva, 2006), indicating that the diets tested provided adequate nutritional support for the metabolism of the animals during lactation.

Plasma progesterone levels in ewes are an indicator of ovarian activity (Morales-Teran et al., 2004) and directly reflect the functionality of the CL. In the present study, the time between partum and the presence of the first functional CL was similar between the groups (47 and 49 days in the WDCM and DCM groups, respectively; P>0.05, Figure 2).

In addition, there was no significant difference (P>0.05) between the two groups in the number of ewes that possessed functional corpora lutea (n = 6, WDCM; n = 4, DCM), non-functional corpora lutea (n = 9, WDCM; n = 10, DCM), or did not possess corpora lutea (n = 4, WDCM; n = 2, DCM). Investigating the effect of adding dehydrated cashew bagasse to the diet of ewes, Rodrigues et al. (2011) did not observe any influence of feed on the time of return of the first functional CL. In another study, Mbayahaga et al. (1998) reported an interval of 81 days between partum and the first activity of the CL, longer than that observed in our study.



Values are given as means±SEM.
Statistically significant effect of Diet, Time treatments and Interaction are shown in the figure.

Figure 2 - Profile of plasma progesterone 60 days post-partum of ewes fed diets without (WDCM) or with (DCM) detoxified castor meal for a long period.

Table 8 - Anatomic and carcass parameters of ewes at 429 days of supplementation without (WDCM) or with (DCM) detoxified castor meal

Parameters	WDCM	DCM
Fasting weight (kg)	31.90±1.14	32.53±1.56
Anatomic parameters (g)		
Lungs	338.75±17.47	335.85±18.05
Heart	149.58±6.78	158.75±9.98
Bladder	76.25±5.51	82.50±13.03
Liver	440.83±23.60	511.57±43.54
Kidney	79.58±2.64	82.50±3.11
Tongue	109.17 ±3.74	103.75±5.61
Empty stomach	1278.33±49.21	1323.33±83.43
Empty intestines	1473.33±87.24	1363.33±94.80
Omental fat tissue	812.92±134.83	693.75±137.42
Heart fat tissue	51.67±5.20	102.18±41.01
Renal fat tissue	375.58±80.65	326.75±66.89
Carcass parameters (kg)		
Hot carcass	14.71±0.48	14.67±0.81
Cold carcass	13.99±0.48	14.02±0.77
Half carcass	7.19±2.07	7.19±2.08
Leg	2.41±0.08	2.41±0.11
Shoulder	1.28±0.05	1.29±0.09
Loin	0.48±0.02	0.49±0.03
Neck	0.75±0.03	0.73±0.04
Ribs	2.12±0.10	2.12±0.14

No significant differences (P>0.05) were found between the dietary groups in the anatomical and carcass parameters (Table 8), or in the cuts and centesimal composition of the loins (Table 9), with the exception of bone weight, which was greater in the DCM group. These findings are in agreement with the results of Vieira et al. (2010), in that supplementation with detoxified castor cake at levels of up to 67% and 100% did not influence the carcass characteristics of ewes. With respect to the lipid profile of the *longissimus dorsi* muscle (Table 10), only heptadecanoic acid was higher in the animals fed DCM (P>0.05). This result suggests that the supply of DCM allowed for a greater synthesis of heptadecanoic acid by the microorganisms of the rumen, and consequently there was a greater deposition of this substance in the muscle tissue of the ewes.

Table 9 - Dissection and centesimal composition of *longissimus dorsi* muscle of ewes at 429 days of supplementation without (WDCM) or with (DCM) detoxified castor meal

Parameters	WDCM	DCM
Dissection (g)		
Loin	469.58±26.46	495.25±29.40
Muscle	238.01±6.26	260.34±17.47
Bone	71.45±5.97B	100.52±8.67A
Connective	68.82±5.64	57.07±4.95
Adipose	61.38±13.49	59.45±6.57
Composition (%)		
Moisture	76.24±0.46	77.27±0.34
Ash	1.20±0.05	1.15±0.08
Fat	2.39±0.23	2.48±0.23
Protein	20.15±0.46	19.08±0.39

A, B - significant difference between group (P<0.05).

Table 10 - Means and standard errors for the quantification of fatty acids in the lipid extract of the loin at 429 days of supplementation without (WDCM) or with (DCM) detoxified castor meal

Fatty acid		WDCM	DCM
Octanoic	C8:0	0.7353±0.1621	0.7025±0.3305
Decanoic	C10:1	1.1376±0.4500	0.8119±0.4019
Myristic	C14:0	1.4116±0.1188	1.6405±0.1174
Pentadecanoic	C15:0	0.7113±0.1476	1.3892±0.3729
Palmitic	C16:0	20.0170±1.8123	19.1118±1.3610
Sapienic	C16:1 n-10	0.9141±0.0835	1.0347±0.1684
Palmitoleic	C16:1 n-7	1.0489±0.1095	1.3865±0.1280
Heptadecanoic	C17:1	1.3062±0.1834B	2.6319±0.3902A
Stearic	C18:0	17.0000±1.2106	15.033±1.3676
Oleic	C18:1 n-9	31.3470±3.2798	31.2563±2.0245
Linoleic	C18:2 n-6	4.0217±0.7189	4.4002±1.3975
Arachidonic	C20:4	4.7265±1.5098	1.9749±0.5836
SFA	-	40.5514±2.7312	40.0210±2.2588
UFA	-	38.5154±2.8469	38.2615±2.6507
MUFA	-	34.0910±3.3308	34.0865±2.1959
PUFA	-	5.1618±0.6610	4.1750±1.0441
UFA/SFA	-	0.9552±0.0481	0.9700±0.0796
MUFA/SFA	-	0.8349±0.0489	0.8643±0.0670
PSFA/SFA	-	0.1404±0.0302	0.1057±0.0279
MSFA/PSFA	-	7.2180±1.3938	22.5904±10.6778
DFA	-	53.6706±3.7022	51.8506±2.8404

A, B - significant difference between group (P<0.05).
SFA - saturated fatty acids; UFA - unsaturated fatty acids; MUFA - monounsaturated fatty acids; PUFA - polyunsaturated fatty acids; MSFA - monosaturated fatty acids; PSFA - polysaturated fatty acids; DFA - desirable fatty acids.

Conclusions

Detoxified castor meal can be included at up to 15% in ewe diets without affecting conception and pregnancy rates, litter size, return to cyclicity, or milk production. Supplementation with detoxified castor meal does not affect the hepatic and renal function-related parameters or progesterone levels, but increases the heptadecanoic acid levels in the *longissimus dorsi* muscle of ewes supplemented with detoxified castor meal as well as the loin-eye area of their offspring.

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