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Article

Carcass characteristics and fatty acid profile of the meat of Creole lambs supplemented with cottonseed and corn

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Abstract:

The objective was to evaluate the carcass characteristics and fatty acid (FA) profile of the meat of Creole lambs supplemented with cottonseed (CS) and ground corn (GC). Twenty-four (24) males of 90 d and 16 ± 2 kg of initial weight were used. The lambs were assigned to four treatments, T0: grazing; T1: grazing + 25%-CS + 75%-GC; T2: grazing + 50%-CS + 50%-GC and T3: grazing + 75%-CS + 25%-GC, under a complete randomized design. After 127 d of supplementation, the animals were slaughtered, and the hot and cold carcass was weighed. Two hundred grams of the *Longissimus dorsi* muscle were taken to evaluate the proportion of FAs in each animal using gas chromatography. An analysis of variance was developed to determine the effect of diet. The supplemented animals had an average weight of 32.15 kg, being higher ($P<0.05$) than that registered by the lambs of the T0 (23.3 kg). Similarly, a higher average yield of the carcasses of lambs that received supplementation

(48.2 *vs* 39.5 %) was observed. Palmitic and stearic FAs increased in the meat of supplemented animals ($P \leq 0.05$), especially in those fed the T2 diet. Supplementation with CS and GC positively altered ($P \leq 0.05$) the ratio of monounsaturated acids (MFAs) and polyunsaturated acids (PFAs). The treatments did not influence ($P > 0.05$) the MFA:SFA ratio and the atherogenicity index. However, the diet affected ($P < 0.05$) the desirable PFA:SFA and FA ratio. Supplementation with CS and GC positively influenced slaughter weight, carcass yield and fatty acid profile in lambs.

Key words: Sheep, Energy-protein supplements, Biohydrogenation.

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Introduction

In Colombia, grasses are the main food source for sheep by virtue of their low cost of production (relative to feed), representing the most practical and economical form of feeding(1). However, despite their importance, their productivity is affected due to strong climatic variations throughout the year, which are manifested with periods of intense rainfall and prolonged periods of drought, lasting approximately four to five months, causing limitations in livestock production, mainly due to the decrease in the availability and nutritional quality of fodder, which leads to poor performance of the animals and affects the quality of the final product. In this sense, it is valid to incorporate technologies that lead to improve the productive parameters of sheep farming in the region, therefore, the use of energy-protein agro-industrial by-products can improve the nutritional quality of the diet and increase the weight gains, quality and conformation of sheep carcasses.

Cottonseed has been widely referenced as an agro-industrial by-product of high nutritional value for ruminant feeding, which is characterized by containing high concentrations of lipids, protein and fiber(2). However, its nutritional quality is affected by the gossypol content, so its inclusion in diets should be regulated(3). Cottonseed and its by-products are alternative food sources, which can decrease the cost of the animals' diet(4). These products have high concentrations of fatty acids, with an important effect on greater weight gain, increased fat deposition in the carcass and changes in the fatty acid profile of meat, which can influence their acceptability by the consumer and the impact on human health(5).

On the other hand, fatty acid composition and cholesterol concentrations in meat have received increasing attention due to their relationship with human health and product quality[6]. Therefore, the trend has been a lower consumption of the so-called saturated fats, since these lead to an increased risk of obesity, cancer and cardiovascular diseases. In this context, lamb meat has a high content of saturated fatty acids and, to a lesser extent, polyunsaturated fatty acids. The latter play an important role in the development of the brain and retina and prevent diseases such as immunodeficiency, carcinogenesis, atherosclerosis, hypertension, obesity and cardiovascular diseases[7]. Therefore, it is essential to enhance these healthy fatty acids, such as the n-3 series (the so-called omega 3), and the group of positional and geometric isomers of linoleic acid (the CLA fatty acids) in meat.

In the last decade, nutritional strategies have been used to modify the concentrations of the different fatty acids in the musculature of animals, one of them is the use of oilseeds, due to their high concentration of polyunsaturated fatty acids[8]. Work with diets for weaning lambs has shown an increase in the concentration of long-chain fatty acids in muscle and fat in intensively fattened lambs, also improving the color of subcutaneous fat[9]. For their part, Peng *et al*[10] mention that it is possible to have meat products of better quality in terms of the composition of beneficial fatty acids through supplementation with oilseeds, which would provide healthier options for the consumption of these products.

Given the growing importance of the sheep sector in Colombia, it is necessary to carry out this type of research, therefore, the objective of this study was to evaluate the characteristics of the carcass and the fatty acid profile of meat of lambs fed with cottonseed and ground corn.

Material and methods

The experiment was developed in the Experimental Farm of the Faculty of Veterinary Medicine and Zootechnics, of the University of Córdoba, Berástegui campus, municipality of Ciénaga de Oro, Córdoba-Colombia. The area is classified as tropical rainforest, located at 8º52’ N and 75º54’ W, altitude 18 m asl, average temperature of 28 ºC, relative humidity of 85 % and annual rainfall of 1,340 mm.

The area used in grazing was 10,000 m^2, established with 70 % Star grass (*Cynodon nlemfluensis* Vanderyst) and 30 % Angleton grass (*Dichantium aristatum* (Poir.) C.E. Hubb.), which was divided into 13 paddocks of 713 m^2 in order to establish a rotational system of 2-d of occupation and 24 d of rest. The sheep went out to graze in the morning hours (0800 h) and returned to the sheepfold in the afternoon (1600 h), where they were separated by treatment for the offer of the supplement.

Twenty-four Creole lambs with an initial weight of 16 ± 2 kg and an age of 3 mo were used, which were supplemented for 127 d, with isoenergetic and isoprotein diets based on cottonseed (CS) and ground corn (GC). The level of supplementation corresponded, on a dry basis, to 1 % of the live weight of the animals. The inclusion of cottonseed and ground corn, on a dry basis, varied to form to the treatments to be evaluated: T1) Grazing, T2) Grazing + 25% CS + 75% GC, T3) Grazing + 50% CS + 50% GC and T4: Grazing + 75% CS + 25% GC. The experimental diets were formulated according to the NRC[11], meeting the requirements of protein and metabolizable energy for an average daily weight gain of 160 g. During the test, adjustments were made according to the weight gain of the animals.

The nutritional quality of forage and supplements was determined from composite samples. The forage samples were collected through the method of grazing simulation (hand plucking), for each forage sample 500 g per sample were collected, which were dried in a forced ventilation oven at 60 °C for 48 h, then ground with a Willey-type mill, using a one-millimeter mesh. The processing of the samples was carried out in the Animal Nutrition Laboratory of Agrosavia R.C. Turipaná, where crude protein (Kjeldalh method), neutral detergent fiber (NDF), acid detergent fiber (ADF) according to the method of the Association of Official Analytical Chemists[12] and the *in situ* digestibility of dry matter (ISDDM) according to the nylon bag technique[13] were determined. . The nutritional composition of the diets was estimated according to the Small Ruminant Nutrition System (SRNS) (Table 1). Similarly, the fatty acid composition of the pasture and food sources used was determined (Table 2).

Table 1: Nutritional composition of the diets used in the feeding of lambs

Component	Nutritional composition of the diets			
	(T0) Pasture	(T1) 25CS:75GC	(T2) 50CS:50GC	(T3) 75CS:25GC
CP, %	13.0	14.8	15.6	15.0
ME, Mcal/kg	2.1	2.3	2.3	2.3
NDF, %	56.4	48.6	51.9	55.2
EE, %	2.4	3.6	4.9	6.1
Digestibility, %	48.0	56.2	58.6	59.0

CS= cottonseed; GC= ground corn; CP= crude protein, ME= metabolizable energy, NDF= neutral detergent fiber, EE= ethereal extract. T0= grazing, T1= grazing + 25% cottonseed (CS) + 75% ground corn (GC), T2= grazing + 50% CS + 50% GC and T3= grazing + 75% CS + 25% GC.

Table 2: Fatty acid profile (%) for pasture, cottonseed and ground corn, used in the feeding of lambs

Fatty acids	Pasture	Cottonseed	Ground corn
Saturated			
C12:0 (Lauric)	0.010	0.004	-
C14:0 (Myristic)	0.005	0.170	0.001
C16:0 (Palmitic)	0.490	5.560	0.260
C18:0 (Stearic)	0.085	0.770	0.050
C20:0 (Arachidic)	0.030	0.090	0.010
C22:0 (Behenic)	0.025	0.050	-
C24:0 (Lignoceric)	0.030	0.030	0.010
Monounsaturated			
C18:1.9 (Oleic)	0.135	4.370	0.660
Polyunsaturated			
C18:2 (Linoleic)	0.875	18.780	1.740
C18:3 (Linolenic)	2.800	0.100	0.050
SFA	0.675	6.674	0.331
MFA	0.135	4.370	0.660
PFA	3.675	18.880	1.790

SFA= saturated fatty acids, MFA= monounsaturated fatty acids, PFA= polyunsaturated fatty acids.

To determine the dry matter intake (DMI), it was necessary to estimate the volume of feces and the digestibility of the food, for which chromium oxide (Cr_2O_3) was used as an external marker and the indigestible acid detergent fiber (iADF) as an internal marker. For the estimation of the production of feces, Cr_2O_3 was dosed daily orally for 15 d. The dosage was carried out by gelatin capsules of 1 g, at 0700 h. In the last five days of dosing, the collection of feces was performed directly from the rectal ampoule twice a day at 0800 and 1600 h. The fecal samples were homogenized to form a composite sample per animal. The samples were then dried in a forced ventilation oven at 60 °C for 48 h and ground using a 1 mm mesh. For the determination of the concentration of Cr_2O_3 in the feces, the microwave digestion methodology (3051) proposed by the United States Environmental Protection Agency[14] was used. The fecal production estimated in grams of dry matter per day (g DM.day^{-1}) was obtained by the quotient of the dose of the marker, divided by the concentration of the marker in the feces[15].

After 45 d of starting the experiment, 3 g of samples composed of grass, food supplements and feces were taken from each animal to determine iADF. The samples were packed in triplicate in nylon bags of 5 x 12 cm, which were fixed to the cannula using nylon of 10 cm in length. The bags already attached to the chain were soaked three times in a bucket with clean water and then introduced into the rumen of a fistulated male bovine with a grazing-based diet, where they remained for 144 h. In the end, the bags were removed and washed with clean water. The bags were dried at 60 °C for 24 h, the residues corresponding to the repetitions of each sample were removed, and then subjected for one hour in solution in acid detergent and washed with hot water and acetone; once the samples were dried, the residue was considered as the iADF(16). Based on the iADF, the DM digestibility was estimated using equation (Eq.1)(17).

DMD = 100 – 100 x (% marker in the DM of the food) x (recovery rate of the marker in the feces) / (% of the marker in the DM of the feces) (Eq. 1).

DMI was determined based on fecal production and the digestibility estimated with the internal marker (Eq. 2). To do this, the equation established by Ramírez *et al*(15) was used.

$$\text{Voluntary intake (g/d)} = \frac{(\text{Fecal production, g DM/ d})}{\left[1-\left(\frac{DM\ Dig}{100}\right)\right]} \text{ (Eq.2).}$$

After 127 d of evaluation, the animals were transported by truck to a private slaughter and processing plant adapted and authorized by the competent authority for the slaughter of sheep (registration INVIMA 007OC), located in the municipality of Cereté (Colombia). Prior to the slaughter, the sheep fasted for a period of 12 h with access to water. The technical protocols established by the plant were followed, which include slaughter using a captive bolt gun for stunning sheep. Subsequently, the hot carcass weight (HCW) was determined and after remaining 24 h at 4 ºC, the cold carcass weight (CCW). Hot and cold carcass yield was calculated as the ratio of HCW, CCW and fasting live weight (LW).

From each carcass, 200 g of *Longissimus dorsi* muscle were obtained from the left half carcass of each animal, between the eleventh and thirteenth rib. Total lipids were extracted in duplicate using the ethereal extract procedure; for this purpose, 2 g of sample was weighed and washed with a solvent in a Golfish® equipment for the extraction of fat with petroleum ether for a period of 5 h. The total lipid content was determined gravimetrically by weight difference in the extraction vessels. The methylation of the fatty acids was carried out on 50 to 60 mg of the lipid extract, adding 500 µL of KOH 1N in methanol with stirring; subsequently, 700 µL of xylene was added to allow the complete separation of the fatty acid methyl esters in two phases; from the oily phase (xylene), 100 µL was taken and 50 µL of xylene was added, creating a dilution from which an aliquot of 5µL was injected into an Agilent Technologies gas chromatograph, model 6890N®, coupled to a flame ionization detector (FID), equipped with a DB-225 column and a Split/Splitless auto-injector. The operating conditions were as follows: the injection volume was 2 µl (at 250 °C), the carrier gas was helium (1 ml/min), and the detector temperature was kept constant at 220 °C. It started with a temperature of 70 °C and a heating ramp was programmed for time intervals until reaching a temperature of 220 °C with an increase of 2 °C per minute. The identification of fatty acids (FAs) was based on the comparison of retention times of the pattern and the area under the curve of the peaks. The FAs were quantified using Galaxie workstation software (Varian Inc., Palo Alto, California, USA).

Once the fatty acids were identified, the total sums of saturated (SFAs), monounsaturated (MFAs), polyunsaturated fatty acids (PFAs) were established and the MFA:SFA, PFA:SFA ratio calculated. Desirable fatty acids (DFAs) were calculated taking into account monounsaturated, polyunsaturated and stearic acids(18). Likewise, to determine the potential for obstruction of the arteries, the atherogenicity index was established using the equation proposed by Ulbrich and Southgate(19), AI=(C12:0+4*C14:0+C16:0)/ Unsaturated FA.

A completely randomized design was used, with four treatments and six repetitions to evaluate the effect of CS and GC inclusion percentages on carcass characteristics and fatty acid profile of sheep meat. The mathematical model that described the design was:

$$\mathbf{Y_{ij}} = \mu + T_j + e_{ij}$$

Where

$\mathbf{Y_{ij}}$ is the response variable; μ is the overall mean;

$\mathbf{T_j}$ is the effect of j-th treatment;

e is the random error of the i-th repetition that received the j-th treatment, distributed N (0,1) and σ^2 constant.

An analysis of variance (ANOVA) was performed, after fulfilling the assumptions of normality and homogeneity of the data, for which the Shapiro Wilk and Levene tests were used, respectively. For data analysis, the GLM procedure of the SAS statistical analysis package(20) was used. Treatment means were compared using the Tukey test with a significance level of $P \leq 0.05$.

This study was carried out with the endorsement of the Ethics Committee of the Faculty of Veterinary Medicine and Zootechnics of the University of Córdoba.

Results

The supplementation with cottonseed and ground corn influenced the sheep dry matter intake. The intake observed in the animals of the treatment 75CS:25GC was 1.4 kg.d^{-1}, with difference ($P \leq 0.05$) to that obtained by the animals of the control treatment, which presented average intakes of 0.514 kg.d^{-1}. However, no differences in intake were observed in animals that received supplementation 25CS:75GC, 50CS:50GC and 75CS:25GC (Table 3).

Table 3: Average dry matter and nutrient intake of Creole sheep supplemented with cottonseed and ground corn

Variables	(T0) Pasture	(T1) 25CS:75GC	(T2) 50CS:50GC	(T3) 75CS:25GC	*p*
TDMIT, kg.d^{-1}	0.514 ^{b}	0.788 ^{ab}	1.020 ^{ab}	1.400 ^{a}	0.0366
FDMI, kg.d^{-1}	0.514 ^{b}	0.463 ^{b}	0.695 ^{ab}	1.070 ^{a}	0.0021
Supplement, kg.d^{-1}	-	0.325	0.325	0.325	-
CPI, kg.d^{-1}	0.121	0.160	0.169	0.178	-
MEI, Mcal.d^{-1}	1.960	2.530	2.440	2.360	-

CS= cottonseed; GC= ground corn; TDMI= total dry matter intake, FDMI= forage dry matter intake, CPI= crude protein intake, MEI= metabolizable energy intake.

^{ab} Different letters in the rows differ statistically according to Tukey's test ($P \leq 0.05$).

The slaughter live weight differed ($P \leq 0.05$), as did the HCW, CCW, with the carcasses of the control treatment animals being the least heavy. Similarly, differences were found ($P \leq 0.05$) for the CCY, with the animals of the treatment 50CS:50GC having the highest yields with 45.17 %, exceeding by 5.6, 3.8 and 3.0 percentage units the yields registered in the carcasses of the treatments pasture, 25CS:75GC, and 75CS:25GC, respectively (Table 4).

Table 4: Characteristics of the carcass of Creole sheep supplemented with cottonseed and ground corn

Variable	(T0) Pasture	(T1) 25CS:75GC	(T2) 50CS:50GC	(T3) 75CS:25GC	*p*	R^2	CV (%)
SLW	23.30 ^{b}	32.03 ^{a}	31.78 ^{a}	32.65 ^{a}	0.0063	0.80	12.7
HCW, kg	11.00 ^{b}	15.26 ^{a}	16.03 ^{a}	15.40 ^{a}	0.0098	0.68	13.7
CCW, kg	9.51 ^{b}	13.54 ^{a}	14.48 ^{a}	13.90 ^{a}	0.0052	0.71	14.1
CCY, %	39.51 ^{b}	41.33 ^{ab}	45.17 ^{a}	42.14 ^{ab}	0.0290	0.62	5.5

CS= cottonseed; GC= ground corn; SLW= slaughter live weight, HCW= hot carcass weight, CCW= cold carcass weight, CCY= cold carcass yield.

^{ab} Different letters in the rows differ statistically according to Tukey's test ($P \leq 0.05$).

Although there was no difference in slaughter weight between the animals that received supplementation, the treatment 75CS:25GC proved to be the most economical, as it used US$10.4 in the purchase of the supplement, unlike the treatments 25CS:75GC and 50CS:50GC, which incurred a supplementation expense of US$13.1 and US$11.6, respectively. The feasibility of the treatment 75CS:25GC was due to a lower cost of cottonseed and the higher level of inclusion implemented.

A significant effect ($P \leq 0.05$) of the diets evaluated on the proportion of MFAs was found. The treatment 50CS:50GC presented the highest concentration with 10.14 %, followed by the treatments 25CS:75GC and 75CS:25GC with 9.0 % and 7.44 %, respectively, while the control treatment was the one that registered the lowest proportion 3.29 % (Table 5). Differences ($P \leq 0.05$) in the proportion of PFAs were identified. The treatments 25CS:75GC, 50CS:50GC and 75CS:25GC registered the highest abundance 1.52 %, in relation to the control treatment (0.78 %). The proportion of linoleic fatty acid (C18:2) ranged from 0.5 % in the control treatment to 1.47 % in the treatment 75CS:25GC ($P \leq 0.05$). Regarding linolenic fatty acid (C18:3), no differences ($P > 0.05$) between treatments were detected, with an average value of 0.2 %.

Table 5: Fatty acid profile (%) in the meat of Creole sheep supplemented with cottonseed and ground corn

Fatty acids	**(T0) Pasture**	**(T1) 25CS:75 GC**	**(T2) 50CS:50 GC**	**(T3) 75CS:25 GC**	***p***	**R^2**	**CV (%)**
Saturated	4.67 ^{b}	11.70 ^{ab}	13.51 ^{a}	10.78 ^{ab}	0.017	0.46	39.4
C10:0 (Capric)	0.01	0.02	0.03	0.03	0.230	0.24	56.6
C12:0 (Lauric)	0.01	0.03	0.03	0.02	0.234	0.27	77.5
C14:0 (Myristic)	0.15	0.45	0.50	0.36	0.128	0.54	49.7
C16:0 (Palmitic)	1.82 ^{b}	5.16 ^{ab}	6.05 ^{a}	4.71 ^{ab}	0.075	0.59	43.6
C18:0 (Stearic)	2.63 ^{b}	6.00 ^{ab}	6.83 ^{a}	5.60 ^{ab}	0.058	0.61	35.6
C20:0 (Arachidic)	0.03	0.04	0.05	0.04	0.698	0.10	43.7
C22:0 (Behenic)	0.01	.	0.02	0.01	0.247	0.43	28.1
C24:0(Lignoceric)	0.02	.	.	0.02	0.667	0.11	32.9
Monounsaturated	3.29 ^{b}	9.02 ^{ab}	10.14 ^{a}	7.44 ^{ab}	0.043	0.53	48.9
C18:1 (Oleic)	3.29 ^{b}	9.02 ^{ab}	10.14 ^{a}	7.44 ^{ab}	0.043	0.53	48.9
Polyunsaturated	0.78 ^{b}	1.42 ^{ab}	1.57 ^{a}	1.59 ^{a}	0.013	0.48	28.5
C18:2 (Linoleic)	0.50 ^{b}	1.19 ^{a}	1.39 ^{a}	1.47 ^{a}	0.004	0.77	25.4
C18:3 (Linolenic)	0.28	0.23	0.17	0.12	0.185	0.50	55.0
MFA:SFA	0.72	0.75	0.73	0.69	0.745	-	11.7
PFA:SFA	0.20 ^{a}	0.12 ^{b}	0.12 ^{b}	0.15 ^{ab}	0.015	0.47	24.7
DFA	6.71 ^{b}	16.45 ^{ab}	18.54 ^{a}	14.64 ^{ab}	0.028	0.42	41.4
AI	0.45	0.51	0.53	0.50	0.182	0.30	9.86

CS= cottonseed; GC= ground corn; *P*= probability, $R^{2=}$ coefficient of determination, CV= coefficient of variation. MFA/SFA= monosunsaturated:saturated, PFA/SFA= polyunsaturated:saturated, DFA= desirable fatty acids, AI= atherogenicity index.

^{ab} Different letters in the rows differ statistically according to Tukey's test ($P \leq 0.05$).

For the ratio of monounsaturated and polyunsaturated fatty acids, no differences were observed (P>0.05) between the treatments, with mean values of 0.72; however, for the PFA:SFA ratio, the analysis detected a significant effect (P≤0.05), with the control treatment registering the highest ratio (Table 5). The atherogenicity index (AI) of lamb meat ranged from 0.45 to 0.53, with no differences (P>0.05) between the diets evaluated.

Discussion

According to the results shown in Table 3, the highest intakes observed in the animals that received supplementation can be attributed to a higher nutritional quality of the diet (Table 1), which probably generated a greater contribution of energy and protein, thus improving the rumen environment and favoring the rate of passage of the organic matter ingested. These results are consistent with the statistical trend observed in forage consumption, in which it is observed that animals that were kept in the treatments 50CS:50GC and 75CS:25GC increased their forage consumption by 1.21 and 2.08 times more, compared to animals without supplementation. Overall, the level of dry matter and nutrient intake found in animals that received supplementation was adequate for sheep of 30 kg live weight(11). Results similar to those of this study were reported by Cunha *et al*(21), who evaluated the inclusion of cottonseed in 20, 30 and 40 % in the diet for Santa Inés sheep, they reported average consumptions of 1.23, 1.12 and 1.19 kg.d^{-1}, respectively. Similarly, De Sousa(22), when evaluating the inclusion of cottonseed in 7, 14, 21 and 28 % of the feeding of sheep in confinement, observed that consumption had a decreasing linear behavior as the contribution of cottonseed was increased, reporting average values of 1.12, 1.16, 1.02 and 0.82 kg.d^{-1}, respectively, consumptions slightly higher than those found in the present study.

The reduction in the DMI of sheep supplemented with cottonseed is directly related to the level of inclusion in the diet and its relationship with the content of ethereal extract, generally greater than 6 % in the diet(23). In this regard, Junior *et al*(24) reported a decrease in the consumption of Santa Inés x Dorper sheep from 21.55 % of inclusion of cottonseed in the diet, with a percentage of EE of 4.89 %, an opposite effect was observed in the present study, particularly in the treatment 75CS:25GC, where the inclusion of cottonseed represented 17.4 % of the total intake of dry matter, with a contribution of 6.1 % of EE, these levels did not affect the digestibility of the ingested organic matter. In this sense, Cunha *et al*(21) indicate that the inclusion of cottonseed up to 25 and 30 % of the total ration does not affect the digestibility of the fiber, managing to maintain adequate intakes.

The results achieved in this study show that the contribution of energy and protein from the supplement is used more efficiently for weight gains, being reflected in a higher live weight and meat yields. Based on this statement, the animal response may be influenced by the type of food[25]. Therefore, the low performance shown by the animals that received only pasture can be explained by the low consumption of protein and energy, which, in the case of this treatment, the contribution of these nutrients was given by the grazed grasses. In this regard, Calsamiglia[26] states that, when sheep consume only fodder and their nutritional value is of low quality, nutrient intake may be inadequate to obtain acceptable production levels. The mean values of LW, HCW, CCW and CCY obtained in this study are higher than those reported by Viana[27], who, evaluating the substitution of concentrate for cottonseed by 40 % in the diet of Santa Inés sheep, reported values of 32.4, 13.05, 12.71 kg and 42.64 %, respectively for LW, HCW, CCW and CCY. Likewise, to those obtained by Pires *et al*[28], which registered HCW and CCW of 13.0 and 12.5 kg in pure Santa Inés sheep; but similar to those published by Yamamoto *et al*[29], who evaluated different sources of vegetable oils in Santa Inés and Dorset x Santa Inés sheep, reporting HCW and CCW values of 14.56 and 14.18 kg for Santa Inés and 14.45 and 14.14 kg for the cross between Dorset x Santa Agnes, respectively.

The concentrations of SFAs in the *Longissimus dorsi* muscle showed differences ($P \leq 0.05$) between the treatments evaluated (Table 5). In this sense, the control treatment registered the lowest proportion of SFAs ($P \leq 0.05$), in relation to the proportions of SFAs of the meat of the treatments with supplementation. The highest concentrations of SFAs observed in the meat of animals that received supplementation (T1, T2 and T3) may be related to the nutritional composition of the diets they consumed, since a higher contribution of SFAs was observed. Madruga *et al*[30] stated that feeding with cottonseed contributes to increasing the proportion of SFAs in sheep meat due to its high concentration of ethereal extract.

Within the SFAs, palmitic acid (C16:0) and stearic acid (C18:0) were influenced ($P \leq 0.05$) by the diets evaluated. Myristic (C14:0) and palmitic (C16:0) fatty acids are considered hypercholesterolemic; however, stearic acid (C18:0), despite being a saturated fatty acid and representing between 10 and 20 % of the fats produced by ruminants, does not have this property[30]. Stearic acid presented the highest ($P \leq 0.05$) proportions in the treatments that received cottonseed in relation to the control treatment, interesting results considering that stearic acid is a precursor of oleic acid (C18:1), which is an abundant acid in the meat of lambs[31]. The percentage of myristic acid (C14:0) did not differ ($P > 0.05$) between treatments, which is convenient when thinking about human health benefits, as this is a hypercholesterolemic acid. However, for the ratio of palmitic acid (C16:0), this was higher ($P \leq 0.05$) in the supplemented treatments. For some researchers[30,32], high concentrations of hypercholesterolemic acids can lead to increases in cholesterol synthesis and promote the accumulation of low-density lipoproteins, which represent a risk factor for the occurrence of cardiovascular diseases. The concentrations found in the present study are lower than those indicated in other studies[22,33], where they evaluated percentages of inclusion of cottonseed between 15 and 30 % in the diet of Santa Inés sheep, and reported concentrations of hypercholesterolemic acids 71 % higher than those achieved in this study.

The content of monounsaturated fatty acids (oleic C18:1) varied between the different treatments, being influenced ($P \leq 0.05$) by the diets. Likewise, the proportion of polyunsaturated fatty acids (sum of C18:2, linoleic and C18:3, linolenic) was also affected ($P \leq 0.05$) by the diets, with the treatments with supplementation presenting the highest proportions. In relation to these results, Madruga *et al*[30] reported values higher than those of the present study; however, these authors found no differences in the concentrations of monounsaturated and polyunsaturated fatty acids when evaluating the inclusion of cottonseed in a 20, 30 and 40 in the diet of Santa Inés sheep, which contrasts with the results obtained in this research, where the inclusion of cottonseed produced a significant increase in the concentrations of monounsaturated and polyunsaturated fatty acids in favor of treatments that received cottonseed.

The increase in unsaturated fatty acids is beneficial for human health, as they are hypocholesterolemic, since they tend to lower blood cholesterol[34,35]. In this study, an increase ($P \leq 0.05$) in the proportions of monounsaturated and polyunsaturated fatty acids in the meat of animals linked to treatments with supplementation was observed. The factors that may have contributed to these results are related to the nutritional content of the food sources used, which generated an increase in monounsaturated and polyunsaturated fatty acids in meat. Another justification for the results obtained may be that the diet of the treatments that received supplementation presented a greater digestibility, which possibly promoted a higher rate of passage of the ingested organic material, which could generate an incomplete biohydrogenation at the rumen level. In this regard, Bauman *et al*[36] affirm that diets with a higher proportion of concentrates increase the rate of passage in rumen.

For their part, Vargas *et al*[37] indicated that, in diets with a higher proportion of linoleic acid compared to linolenic acid, they contribute to greater accumulation and rate of passage of linoleic acid by escape to the process of total biohydrogenation. These same authors indicate that the accumulation of linoleic acid, due to its lower rate of biohydrogenation, contributes to increasing the rate of passage of trans fatty acids (conjugated linoleic acid and vaccenic acid) as a product of the incomplete biohydrogenation process. This suggests that diets that included cottonseed may have affected the biohydrogenation process, as suggested by the tendency to a lower proportion of stearic and oleic fatty acid in the treatment that received 75CS:25GC compared to the other supplemented treatments. This could generate an accumulation and higher rate of passage of linoleic acid and possibly its intermediate products of biohydrogenation, as it evidenced a greater participation of this fatty acid in the muscle of the supplemented lambs, *versus* the control treatment. It is important to note that linoleic acid is considered an essential fatty acid for humans, whose only source is the diet[38].

The PFA:SFA ratio found in this study was within the range 0.15 to 0.25 proposed for animals raised on pasture(39,40). According to Jakobsen(41), the intake of fats rich in cholesterol and saturated fatty acids should be reduced and the consumption of monounsaturated and polyunsaturated fatty acids should be increased, since they contribute to reducing the risks of obesity, cancer and cardiovascular diseases. Fats that have a low ratio of PFA:SFA are considered unfavorable, as they can induce an increase in blood cholesterol(42).

The desirable fatty acids in the supplemented treatments were 60 % higher ($P \leq 0.05$) in relation to the control treatment, these results may possibly be due to the effect of the diet, since the treatments that received cottonseed and ground corn made a greater contribution of MFAs and PFAs, which generated significant increases in the proportions of these acids in the meat. This effect is considered convenient given that MFAs and PFAs reduce low-density lipoprotein levels and consequently the risk of obesity, cancer and cardiovascular diseases(42,43). However, the results found in this study are lower than those reported in the literature(31,42,43), possibly due to the higher levels of inclusion of cottonseed evaluated in the diet of Santa Inés sheep, which ranged between 15 and 40 %.

With regard to the atherogenicity index (AI), this indicates the potential for platelet aggregation stimulation, and suggests that, at low AI values, the greater the amount of antiatherogenic fatty acids and the greater the potential for preventing the occurrence of cardiovascular diseases(41). The results found in this study are within the values recommended by Ulbricht and Southgate(19), which propose an ideal value of <1.0 for lamb meat.

Conclusions and implications

Supplementation with cottonseed and ground corn promoted a greater slaughter weight and carcass yield, as well as increasing the concentrations of monounsaturated and polyunsaturated fatty acids in sheep meat. Although no decrease in digestibility and dry matter consumption was observed in treatments that received supplementation with cottonseed, it is recommended to carry out further studies to determine the maximum level of inclusion of this raw material in diets for small ruminants. Under the conditions of this study, it is recommended to supplement at the rate of 1 % of the live weight and use cottonseed and corn in the proportions 75:25, since from the economic point of view, it turned out to be the diet with the lowest costs.

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Literature cited:

1. Socarrás ZM, Fandiño R, Miranda Á, Fernández RG. Manejo de ovinos de pelo en el trópico. Valledupar, Colombia: Corporación Colombiana de Investigación Agropecuaria, Corpoica; 2009.

2. Osti NP, Pandey SB. Use of whole cotton seed and cotton seed meal as a protein source in the diet of ruminant animals: Prevailing situation and opportunity. 6th National Workshop on Livestock and Fisheries Research. Khumaltar, Nepal. 2006:111-119.

3. Akande KE. Major antinutrients found in plant protein sources: their effect on nutrition. Pak J Nutr 2010;9(8):827-832.

4. Paim TP, Louvandini H, Mcmanus CM, Abdalla AL. Uso de subprodutos do algodão na nutrição de ruminantes. Ciênc Vet Tróp 2010;(13):24–37.

5. Calkins CR, Hodgen JM. A fresh look at meat flavor. Meat Sci 2007;(77):63-80.

6. Linares M Gallo C. Perfil de ácidos grasos de carne de ovino y caballo criados bajo un sistema de producción extensiva. Rev Investig Vet 2013;24(3):257-263.

7. Bhattacharya A, Banu J, Rahman M, Causey J, Fernandes G. Biological effects of conjugated linoleic acids in health and disease. J Nutr Biochem 2007;17(12):789-810.

8. Zhang RH, Mustafa AF, Zhao X. Effects of feeding oilseeds rich in linoleic and linolenic fatty acids to lactating ewes on cheese yield and on fatty acid composition of milk and cheese. Anim Feed Sci Technol 2006;(127):220–233.

9. Berthelot V, Bas P, Pottier E, Normand J. The effect of maternal linseed supplementation and/or lamb linseed supplementation on muscle and subcutaneous adipose tissue fatty acid composition of indoor lambs Effects on methane production, rumen fermentation, and milk production. Meat Sci 2012;(90):548–557.

10. Peng YS, Brown MA, Wua JP, Liu Z. Different oilseed supplements alter fatty acid composition of different adipose tissues of adult ewes. Meat Sci 2010;(85):542–549.

11. NRC, National Research Council. Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World camelids. Washington; DC, USA: National Academic Press; 2007.

12. AOAC, Association of Official Analytical Chemists. Official Methods of Analysis. XIII ed. Washington; DC, USA; 2002.

13. Orskov ER, Howell FD, Mould F. The use of nylon bag technique for the evaluation of feedstuff. Trop Anim Prod 1980;15(3):195-213.

14. EPA. Method 3051A, Microwave assisted acid digestion of sediments, sludges, soil and oil; 2007.

15. Ramírez-Pérez AH, Buntinx SE. Tapia-Rodríguez CY, Rosiles R. Effect of breed and age on the voluntary intake and the micromineral status of non-pregnant sheep. 1. Estimation of voluntary intake. Small Ruminant Res 2000;(37):223–229.

16. Ferreira MA, Valadares FSC. Avaliação de indicadores em estudos com ruminantes: digestibilidade. Rev Bras Zootec 2009;38(8):1568-1573.

17. Correa H, Pabón M, Sánchez M, Carulla J. Efecto del nivel de suplementación sobre el uso del nitrógeno, el volumen y la calidad de leche en vacas Holstein de primero y segundo tercio de lactancia en el trópico alto de Antioquia. Livest Res Rural Develop 2011;23(4). http://www.lrrd.org/lrrd23/4/corr23077.html.

18. Landim LA, Cardoso M, Castanheira M, Fioravanti M, Louvandini H, Mcmanus C. Fatty acid profile of hair lambs and their cross-breds slaughtered at different weights. Trop Anim Health and Prod 2011;(43):1561-1566.

19. Ulbricht TL, Southgate DA. Coronary heart disease: seven dietary factors. Lancet 1991;(338): 985–992.

20. SAS. SAS/STAT User's Guide (Release 9.1.3). Cary NC, USA: SAS Inst. Inc. 2007.

21. Cunha MGG, Carvalho FRR, Véras ASV, Batista AMY. Desempenho e digestibilidade aparente em ovinos confinados alimentados com dietas contendo níveis crescentes de caroço de algodão integral. Rev Bras Zootec 2008;37(6):1103-1111.

22. De Sousa AR. Caroço de algodão moído na alimentação de cordeiros (as) em confinamento [tese mestrado]. Piracicaba, Brasil: Escola Superior de Agricultura Luiz de Queiroz; 2014.

23. Palmquist DL. Digestibility of cotton lint ber and whole oilseeds by ruminal microorganisms. Anim Feed Sci Technol 1995;56(3):231-242.

24. Junior JR, Carvalho DMG, De Souza JG, Cabral LS, Da Silva JJ, Riveiro MD, Arnoldo TRQ, De Oliveira AS, Soares JQ. Caroço de algodão em dietas sem volumoso para cordeiros confinados. Semina: Ciênc Agrárs 2015;36 (4):2727-2738.

25. Piona MNM, Cabral LS, Zervoudakis JT, Abreu JG, Galati RL, Caetano GGG, Silva AR. Niveis de Caroço de algodão na dieta de cordeiros confinados. Rev Bras Saúde Prod Anim 2012;13(1):110-122.

26. Calsamiglia SE. La suplementación en los ovinos. Memorias IV Congreso Nacional Ovinos, Querátaro, Mexico. 1998:64-75.

27. Viana GP. Desempenho e avaliação da carcaças de ovinos Santa Inês suplementados com caroço de algodão e seus co-produtos [PhD Dissertation]. Brasilia, Brasil: Universidade de Brasilia; 2011.

28. Pires CC, Galvani BD, Carvalho S, Cardoso RA, Gasperin BG. Características da carcaça de cordeiros alimentados com dietas contendo diferentes níveis de fibra em detergente neutro. Rev Bras Zootec 2006;35(5):2058-2065.

29. Yamamoto SM, Macedo FAF, Zundt M. Fontes de óleo vegetal na dieta de cordeiros em confinamento. Rev Bras Zootec 2005;34(2):703-710.

30. Madruga SM, Vieira LTR, Cunha GMG, Filho PMJ, Queiroga RC, Sousa HW. Efeito de dietas com níveis crescentes de caroço de algodão integral sobre a composição química e o perfil de ácidos graxos da carne de cordeiros Santa Inês. Rev Bras Zootec 2008;37(8):1496-1502.

31. Diaz MT, Álvarez I, De La Fuente J, Sañudo C, Campo MM, Oliver MA, Fontifurnols M, Montossi F, San Julián R, Nute GR, Cañeque V. Fatty acid composition of meat from typical lamb production systems of Spain, United Kingdom, Germany and Uruguay. Barking Meat Sci 2005;71(2):256-263.

32. Moloney AP, Mooney MT, Kerry JP, Troy DJ. Producing tender and flavor some beef with enhanced nutritional characteristics. Nutrition Society. Cork, Ireland. 2001:221-229.

33. Pérez LH. Milho, amido ou caroço de algodão associados a glicerina bruta em dietas para ovinos [PhD Dissertation]. Jaboticabal, Brasil: Universidade Estadual Paulista; 2015.

34. Williams CM. Dietary fatty acids human health. Annal de Zootec 2000;49(3):165-180.

35. Valsta LM, Tapanainen H, Männistö S. Meat fats in nutrition. Meat Sci 2005;70(3):525-530.

36. Bauman DE, Baumgard LH, Corl BA, Griinari JM. Biosynthesis of conjugated linoleic acid in ruminants. 91st American Society of Animal Science. Indianapolis, Indiana, USA. 1999:1-15.

37. Vargas JA, Olivera-Angel M, Ribeiro CV, Daza C, Edgar E. *In vitro* rumen biohydrogenation kinetics of mixed linoleic and alfa-linolenic acids. Rev Colomb Cienc Pecu 2018;31(3):213-222.

38. Wood JD, Enser M, Fisher AV, Nute GR, Sheard PR, Richardson RI. Fat deposition, fatty acid composition and meat quality: A review. Meat Sci 2008;78(4):343–358.

39. Lee J, Kannan G, Eega K, Kouakou B, Getz W. Nutritional and quality characteristics of meat from goats and lambs finished under identical dietary regime. Small Ruminant Res 2008;74:255- 259.

40. Dierking R, Kallenbach R, Grün I. Effect of forage species on fatty acid content and performance of pasture finished steers. Meat Sci 2010;85:597-605.

41. Jakobsen K. Dietary modifications of animal fats: status and future perspectives. Fett Lipid 1999;101(12):475-483.

42. Arruda PCL, Pereira ES, Pimentel PG, Bomfim MAD, Mizubuti IY, Ribeiro ELA, Fontenele RM, Regadas JGL. Perfil de ácidos graxos no *Longissimus dorsi* de cordeiros Santa Inês alimentados com diferentes níveis energéticos. Semina: Ciênc Agrár 2012; 33(3):1229-1240.

43. Paim TDP, Viana P, Brandão E, Amador S, Barbosa T. Carcass traits and fatty acid profile of meat from lambs fed different cottonseed by-products. Small Ruminant Res 2014;116:71-77.