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Growth, carcass characteristics, chemical composition and fatty acid profile of the *longissimus dorsi* muscle in goat kids fed diets with castor oil

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ABSTRACT - The objective in this study was to determine growth, carcass characteristics, chemical composition and fatty acid profile of the *longissimus dorsi* of crossbred Boer × Saanen kids fed castor oil. Twenty-four kids (12 males and 12 females) were assigned in a randomized complete block design with two treatments and twelve replications. Blocks were defined according to weight, gender and initial age of animals for the evaluation of performance. The experimental treatments consisted of two diets containing 900 g concentrate/kg: a control diet (without addition of oil) and another containing castor oil at 30 g/kg (on a dry matter basis). After they reached an average body weight of 25 kg, males were slaughtered for the evaluation of carcass characteristics, chemical composition and fatty acid profile of the *longissimus dorsi* muscle. The addition of castor oil in the diet did not affect the intake of dry matter, crude protein and neutral detergent fiber; the average daily gain; and feed conversion, but increased the ether extract intake. No difference was observed for the carcass characteristics, chemical composition of the meat, concentration of C18:2 cis-9, trans-11 (CLA) and total concentration of saturated, monounsaturated and polyunsaturated fatty acids and their relations; however, there was increase in the concentrations of C18:2 trans-10, cis-12 (CLA) and C20:4 ω-6. The addition of castor oil to the diet of crossbred Boer × Saanen kids containing a high content of concentrate did not promote benefit to the characteristics evaluated.

Key Words: conjugated linoleic acid, feedlot, lipid supplementation

Introduction

Goat meat consumption in Brazil, in spite of still being low, has been on the rise, mainly in large cities (Sousa, 2007). Goat meat is considered lean and contains more polyunsaturated fatty acids in comparison with meat from other ruminants (Banskalieva et al., 2000).

Different nutritional conditions may alter fatty acid composition in the muscles of ruminants. Lipid supplementation, in addition to promoting higher weight gain and better carcass composition due to the higher energetic density (Marinova et al., 2001), has been credited as one of the main factors to increase concentration of mono and polyunsaturated fatty acids, as well as the ratio between ω6 and ω3 families (Boles et al., 2005; Bas et al., 2007; Lewis et al., 2008).

Among the seed oils available, castor seed stands out for its high potential of oil production per surface unit in comparison with annual oilseeds (Barros et al., 2006), and also for its potential for cultivation in regions marginalized by the economic development. In addition to the easy adaptation to adverse climates, it is able to be successfully cultivated in several regions in the country (Oliveira et al., 2010). For these reasons, castor is considered an important oilseed for biodiesel production in Brazil.

Castor oil is comprised of approximately 80 g of ricinoleic fatty acid (acid 12-hydroxy-9-cis-octadecenoic)/ 100 g of oil. The hydroxyl group found in the carbon 12 of the ricinoleic acid gives the castor oil the exclusive property of solubility in alcohol and is also responsible for the lower oil rancidity, making it more attractive for animal consumption (Moshkin, 1986).

Castor oil does not contain ricin, a highly toxic protein that inactivates specifically and irreversibly eukaryotic ribosomes, once all seed protein remains in the meal after extraction and because it is an oil-insoluble protein (Severino, 2005).

Due to the lack of results of lipid supplementation in goat diets and the need for research to investigate the use of castor oil in ruminant diets, this study evaluated weight gain, carcass characteristics, chemical composition and fatty acid profile in the *longissimus dorsi* muscle of crossbred Boer × Saanen goats fed diets with castor oil.

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Material and Methods

This experiment was conducted at the Departamento de Zootecnia, Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ), Universidade de São Paulo, Piracicaba, state of São Paulo, Brazil. Twenty-four crossbred Boer × Saanen goat kids (12 males and 12 females), with initial body weight of 13.4±2.0 kg at 66±4 days of age were used.

Animals were confined for 56 days in individual indoor pens with concrete floor, feed bunks and water trough. Twelve pens were used for each treatment. The experimental treatments were composed of two diets: a control diet (no oil added) and another diet containing 30 g of castor oil/kg of DM. Diets were formulated to be isonitrogenous (Table 1) and contained 100 g of roughage (coastcross hay) and 900 g concentrate/kg of DM, to meet the requirements of growing goats (NRC, 2007).

Corn was ground in a mill, characterizing a coarse grinding. Coastcross hay was coarsely chopped with the same mill equipped with a 1 cm pore sieve. All concentrate ingredients were previously weighed and homogenized in a horizontal Lucato® mixer with 500 kg capacity. Castor oil (Table 2) was weighed daily on an electronic scale with 5 g precision and mixed with the concentrate and hay prior to feeding.

The diet was offered daily *ad libitum* and approximately 100 g of refusals/kg were allowed. Samples of each diet batch and a weekly ort aliquot of 100 g/kg from each pen were collected. The samples were stored at -18 °C for later laboratorial analyses. Diet samples and orts were processed in a Wiley mill equipped with a 1 mm sieve and analyzed to determine dry matter (DM), mineral matter (MM), and ether extract (EE) in accordance with the AOAC (2000).

Table 1 - Ingredients and chemical composition of the experimental diets (g/kg)

Ingredients	Diets	
	Control	Castor oil
Coastcross hay	100	100
Ground corn	761	724
Soybean meal	107	114
Castor oil	-	30
Limestone	12	12
Mineral premix[1]	15	15
Ammonium chloride	5	5
Chemical composition		
Dry matter	893	896
Crude protein	146	146
Neutral detergent fiber	211	206
Ether extract	39	67

[1] Composition: Ca - 13.4%; P - 7.5%; Mg - 1%; S - 7%; Cl - 21.8%; Na - 14.5%; Mn - 1100 mg/kg; Fe - 500 mg/kg; Zn - 4600 mg/kg; Cu - 300 mg/kg; Co - 40 mg/kg; I - 55 mg/kg; Se - 30 mg/kg.

Neutral detergent fiber (NDF) was determined with sodium sulfite and enzyme thermostable α-amylase (Van Soest et al., 1991) using a fiber analyzer model ANKOM^{220} (ANKOM® Technology Corp.) as described in Holden (1999). The values obtained were corrected for ash after residue incineration. Total nitrogen determination was performed from sample combustion in a LECO® analyzer (Wiles et al., 1998), model FP 528 with combustion temperature of 835 °C. Crude protein content was obtained by multiplying the total nitrogen content by 6.25.

To quantify the average daily gain (ADG), animals were weighed on days 0, 28 and 56 of the experimental period, after a fasting period of 14 hours, on an electronic scale of 50 g accuracy.

When 25 kg of body weight (BW) was achieved, animals were weighed, after a 14-hour fasting period, to determine final body weight and slaughter body weight (SBW). After, males were slaughtered for determination of the carcass composition, subcutaneous fat thickness (SFT) over the 12th rib and *longissimus muscle* area (LMA). After slaughter and evisceration, carcasses were weighed to obtain the hot carcass weight (HCW). Carcasses were chilled for 24 hours at 4.0 °C in a controlled temperature room and weighed again for chilled carcass weight (CCW). To determine dressing percentage, chilled carcass yield (CCY) and shrink after chilling (SAC), the following formulas were used: Dressing percentage = (HCW/SBW) × 100; CCY = (CCW/SBW) × 100; SAC = [(HCW-CCW)/HCW] × 100. After weighing, the cold carcasses were divided in two halves separated longitudinally, and the *longissimus dorsi* muscle was then exposed between the 12th and 13th ribs to determine SFT and LMA.

Longissimus dorsi muscle area and SFT were determined between the 12th and 13th ribs using a digital caliper (Battery, model SR44) graded in mm. The *longissimus dorsi* muscle shape was traced on an acetate paper and the muscle area was determined by using a planimeter graded in cm^2. These measurements were performed on the right and left sides of the carcass and the values represent their averages.

Table 2 - Castor oil fatty acid composition (g/100 g)

Fatty acid	g/100 g
C16:0 (palmitic)	1.28
C18:0 (estearic)	2.06
C18:1 (oleic)	3.55
C18:1-OH (ricinoleic)	81.06
C18:2 (linoleic)	5.58
C18:3 n3 (linolenic)	0.50
Others	5.97

After carcass assessment, the *longissimus dorsi* muscle from each left half-carcass was vacuumed, packaged and stored at -18 °C for later determination of fatty acid composition, moisture, protein, ash and ether extract contents.

The moisture and ash contents were quantified according to the AOAC (2000). In addition, the protein determination was carried out based on the sample combustion using a LECO® analyzer (Wiles et al., 1998), model FP 528, with combustion temperature regulated to 835 °C. Meat protein content was obtained by multiplying the total nitrogen content by 5.88 (Baldwin, 1995). The EE was obtained with LECO® analyzer model TFE 2000, using compressed CO_2 as solvent.

To determine meat fatty acid composition, a sample of approximately 2 g, removed from the central part of the *longissimus dorsi* muscle, was used. The frozen sample was homogenized in 20 mL of a chloroform and methanol solution (2:1) using a Turrax homogenizer, disintegrator and emulsifier (Folch et al., 1957). In the next step, the lipid extract aliquot was methylated using the Kramer et al. (1997) method and stored at -18 °C in amber flasks containing nitrogen to avoid oxidation.

Meat fatty acid composition was determined by gas-liquid chromatography (GLC) using an Agilent equipment (7890-A, Agilent Technologies), with flame ionization detector (7683-B, Agilent Technologies) and a 100 m long and 250 µm inner diameter capillary fused silica column (J & W 112-88A7, Agilent Technologies) containing 0.20 µm of cyanopropyl polysiloxane. Data were obtained with the software ChemStation (Agilent Tecnologies).

For fatty acid chromatograph separation, one microliter (µL) of the sample was injected with a 10 µL syringe in the split system at a 50:1 ratio. Hydrogen was used as carrier gas at a flow rate of 1.0 mL/min and nitrogen was used as make-up with the output regulated to 30 mL/min. The synthetic air output was kept at 300 mL/min and the temperatures in the injector and detector were 250 and 255 ºC, respectively.

The initial temperature in the oven was 70 ºC, gradually increased by 5 °C/min until 100 °C and then held for 2 minutes. Afterwards, at a 10 °C/min increase, the oven temperature reached 175 °C and was maintained for 40 minutes. In a third stage the temperature reached 225 °C by a 5 °C/min increase. Next, the oven temperature increased 20 °C/min until a final temperature of 245 °C. The total designated time for the analyses was 87.5 minutes.

Fatty acids were identified by comparing their retention times with the fatty acid methyl standards. A mix standard Supelco® (Sigma Aldrich) of 37 compounds and individual standards to identify fatty acids C18:1 trans-11, C18:2 cis-9, trans-11, C18:2 trans-10, cis-12 (Nu-Chek Prep, Inc.) and C18:1 - OH (Sigma Aldrich) were used.

The experimental design was of completely randomized blocks, and blocks were defined by weight, gender and initial age of animals. Data were analyzed using the PROC MIXED of SAS (Statistical Analysis System, version 9.0), adopting $\alpha = 0.05$.

Results and Discussion

The use of castor oil in the diet did not affect (P>0.05) dry matter intake (DMI) (Table 3). Similar results were found for lambs fed different lipid sources in the diet (Manso et al., 2009; Homem Júnior et al., 2010). However, Solaiman et al. (2009) evaluated different amounts of cottonseed (0; 157 and 327 g/kg of DM) in confined goat diets and found a quadratic effect for DMI.

The conflicting results obtained from the use of lipids in diets for ruminants cannot be attributed only to the type and amount of fat added, but also to the basal diet composition (Manso et al., 2009). In this study, 30 g of oil/kg of DM were used and it should be considered that the EE in the control diet was 39 g/kg of DM and in the diet with addition oil it was 67 g/kg of DM. Normally, a DMI reduction is observed when the EE content in the diet is over 70 g/kg of DM (Palmquist & Jenkins, 1980).

Table 3 - Dry matter and ingredient intakes and performance of goat male kids fed diets with or without castor oil

Item	Diets		Standard error of the mean	P-value
	Control	Castor oil		
Dry matter intake (g/day)	501.4	486.3	25.18	0.673
Dry matter intake (g/kgBW$^{0.75}$)	57.7	56.5	1.77	0.728
Crude protein intake (g/d)	71.9	69.2	3.71	0.618
Neutral detergent fiber intake (g/d)	112.5	107.6	5.15	0.516
Ether extract intake (g/d)	19.3	33.0	2.04	<0.001
Initial body weight (kg)	13.4	13.3	0.41	0.454
Average daily gain (g)	155.0	142.5	11.86	0.518
Final body weight (kg)	21.36	21.23	0.82	0.861
Feed conversion (kg DMI/kg gain)	3.47	3.33	0.11	0.561

BW - body weight; DMI - dry matter intake.

Moreover, castor oil is composed mainly of ricinoleic acid (Table 2), which, in spite of being a long-chain fatty acid (18 carbons), shows only one double bond in its structure, being therefore monounsaturated, which, in turn, when compared with medium-chain and long-chain polyunsaturated fatty acids, is less toxic to ruminal microorganisms (Palmquist & Mattos, 2006) and, thus, has less effect on DMI.

Intakes of crude protein (CPI) and neutral detergent fiber (NDFI) were not affected (P>0.05) by the use of castor oil in the diet, probably because the diets were isonitrogenous and had similar fiber contents, in addition to the fact that DMI did not change. However, due to the oil addition, the EE intake increased (P<0.01) in the treatment with castor oil, which was expected due to the higher diet supplement.

The use of oil in the diet did not alter (P>0.05) the ADG of the goat kids. Therefore, their final weight was not changed (P>0.05). A weight gain in these animals was expected, once the diet with oil had higher energetic density and the DMI was not affected.

Due to the absence of effect on DMI and ADG, feed conversion (kg DMI/kg gain) was not affected as well (P>0.05). Simitzis et al. (2008) found similar data using 1 mL of oregano oil per kg of concentrate fed to lambs. Likewise, Maia et al. (2010) evaluated the addition of 30 g of canola, sunflower and castor oils/kg of DM in diets for lambs and found no changes in animal performance.

The use of castor oil did not influence (P>0.05) slaughter body weight of animals and, therefore, the hot carcass weight, chilled carcass weight, dressing percentage and chilled carcass yield did not change (Table 4).

Marinova et al. (2001) studied the use of sunflower oil (25 g/kg of concentrate, as fed basis) in diets for goats and found no difference for carcass composition. However, the authors suggest that the use of oil in the diet could favor meat quality, once increase in the deposition and better fat distribution in the carcass was reported.

The chilled carcass yield values were similar to those found by Najafi et al. (2012), who reported chilled carcass yield of 43.33% when palm oil, soybean oil or fish oil were used in diets for Mahabadi goat kids.

The higher EE levels in the diets containing oil did not result (P>0.05) in higher deposition of subcutaneous fat. Likewise, Najafi et al. (2012) tested the use of palm oil, soybean oil or fish oil in the diet of Mahabadi kids and did not find difference for this variable, and the SFT average was higher than in this study, probably because of the heavier animals slaughtered (33.9 kg).

The diets did not affect (P>0.05) carcass cooling losses, probably due to the absence (P>0.05) of the SFT difference. Carcass back fat thickness can determine higher or lower cooling loss percentages, once it acts as a thermal insulator, protecting the carcasses against drying caused by cooling (Ribeiro et al., 2001).

The LMA measures aim to evaluate the animal muscle index, i.e., it is a measure that usually estimates the amount of muscle in the carcass. In this study, there was no effect of the treatment (P>0.05) on this variable, which is closely related to the absence of the castor oil effect on hot and cold carcass composition. Likewise, Marinova et al. (2001) did not find LMA difference in goats fed sunflower oil slaughtered at 20 kg of body weight, and the average found was 8.53% for the animals fed oil.

The use of 30 g/kg of castor oil did not affect values of moisture, protein, ether extract and ash in goats (Table 5).

Data found for moisture, protein and ash are in accordance with those reported by Marinova et al. (2001) using 25 g of sunflower oil/kg of concentrate DM and by Najafi et al. (2012), who evaluated the addition of 20 g of palm oil, soybean oil or fish oil/kg of DM in goat kid diets.

The different fat extraction methods and even the variability of the same method among laboratories hamper the comparison of the values regarding fat content in the *longissimus dorsi* muscle.

The fatty acids identified at higher levels in the *longissimus dorsi* muscle of goats (Table 6) were C18:1, C16:0 and C18:0. In a review, Banskalieva et al. (2000) mentioned that values between 28 and 50 g/100 g are found

Table 4 - Carcass characteristics of male goat kids fed diets with or without castor oil

Item	Diets		Standard error of the mean	P-value
	Control	Castor oil		
Slaughter body weight (kg)	25.7	25.6	0.20	0.803
Hot carcass weight (kg)	12.1	12.3	0.13	0.423
Chilled carcass weight (kg)	11.6	11.7	0.12	0.425
Subcutaneous fat thickness (mm)	0.7	0.6	0.06	0.446
Dressing percentage (kg/100 kg)	47.3	48.2	0.66	0.452
Chilled carcass yield (kg/100 kg)	45.0	45.8	0.63	0.455
Shrink after chilling (kg/100 kg)	4.8	5.0	0.22	0.596
Longissimus muscle area (cm^2)	9.6	9.3	0.28	0.669

for C18:1; 15 and 31 g/100 g for C16:0 and values between 6 and 17 g/100 g for C18:0, so these fatty acids are found at higher levels in goat meat.

The use of castor oil in goat diets did not affect concentrations of total saturated, monounsaturated and polyunsaturated fatty acids. Similar response was found for concentration of fatty acid C18:2 cis-9, trans-11(CLA); however, animals fed castor oil showed higher concentrations of C18:2 trans-10, cis-12 (CLA). Because ricinoleic acid (C18:1 - OH) is found exclusively in castor oil, only the animals fed this oil showed this fatty acid.

In ruminants fed high concentrate diets, linoleic acid hydrogenation may be affected, favoring the formation of C18:2 trans-10, cis-12, which is reduced to C18:1 trans-10 (Griinari & Bauman, 1999). In the process, diets with a high concentrate content reduce ruminal pH, which decreases lipolysis and biohydrogenation (Demeyer & Doreau, 1999) and this last reaction may have been reduced in this study, given that an increase of CLA trans-10, cis-12 was found and no change was observed for C18:1 trans. This result shows that the ricinoleic acid did not favor the accumulation of this CLA isomer.

In this experiment, the peaks corresponding to C18:1 trans-10 and its isomer C18:1 trans-11 could not be differentiated; therefore, the peak was interpreted as C18:1 trans (Manso et al., 2009).

The data in this experiment are similar to those obtained by Bessa et al. (2007), where an increase in C18:2 trans-10 cis-12 was observed in lamb meat; however, the authors state that C18:2 cis-9, trans-11 did not alter in response to the use of soy oil in diets with high concentrate. Beaulieu et al. (2002) and Gillis et al. (2004) evaluated the use of unsaturated fat in cattle fed diets with high concentrate and also reported increased CLA trans-10, cis-12 concentration, opposite to CLA cis-9 trans-11, which did not alter.

Castor oil increased the concentrations of long-chain fatty acid C20:4 ω-6, which is synthesized from C18:2 ω-6 through desaturation, chain elongation and new desaturation (Palmquist & Mattos, 2006). Although no difference between C18:2 concentrations was detected in the different treatments, the meat from goats fed castor oil showed almost 20% more of this fatty acid in its composition, which possibly caused higher concentration of C20:4 ω-6.

Table 5 - Chemical composition (g/100 g) of *longissimus dorsi* muscle from goat kids fed diets with or without castor oil

Item	Diets		Standard error of the mean	P-value
	Control	Castor		
Moisture	75.0	74.8	0.26	0.631
Protein	20.4	20.7	0.47	0.472
Ether extract	1.6	1.5	0.11	0.680
Ash	0.9	0.9	0.02	0.976

Table 6 - Fatty acid composition (g/100 g of fatty acids) of *longissimus dorsi* muscle of goat kids fed diets with or without castor oil

Item	Diets		Standard error of the mean	P-value
	Control	Castor		
Saturated	37.02	37.07	0.66	0.923
C12:0 (lauric)	0.88	1.17	0.07	0.060
C14:0 (myristic)	1.16	1.17	0.07	0.951
C16:0 (palmitic)	18.70	18.89	0.43	0.839
C18:0 (estearic)	12.69	13.00	0.53	0.600
Monounsaturated	48.93	46.10	0.74	0.087
C16:1 (palmitoleic)	1.58	1.49	0.06	0.411
C18:1 n9c (oleic)	41.67	38.76	0.88	0.130
C18:1 trans (oleic, isomer)	3.57	2.75	0.27	0.174
C18:1-OH (ricinoleic)	nd	0.58	-	-
Polyunsaturated	14.07	16.84	1.09	0.235
C18:2 ω-6 (linoleic)	8.27	10.19	0.58	0.139
C18:2 c9t11 (CLA)	0.14	0.19	0.02	0.626
C18:2 t10c12 (CLA)	0.10b	0.16a	0.01	0.026
C20:4 ω-6 (arachidonic)	3.81b	5.41a	0.34	0.025
Others	7.53	7.25	0.34	0.713
M:S	1.33	1.25	0.03	0.165
P:S	0.39	0.46	0.02	0.330
ω6:ω3	9.91	9.15	0.73	0.636
(C18:0+C18:1)/C16:0	2.91	2.75	0.07	0.137

M:S - monounsaturated:saturated fatty acid ratio; P:S - polyunsaturated:saturated fatty acid ratio; ω6:ω3 - ω6:ω3 ratio; nd - not detected; CLA - conjugated linoleic acid.

From a nutritional point of view, it is important to determine the ratio between concentrations of unsaturated and saturated fatty acids. Because of this, ratios and proportions between fatty acids of interest have been suggested as a way to evaluate food risk. Castor oil did not alter ratios between fatty acids M:S, P:S, ω6:ω3 or (C18:0+C18:1)/C16:0.

According to Wood et al. (2003), the Health Department of the United Kingdom recommends a P:S ratio higher than 0.4 and ω6:ω3 lower than 4 for beneficial effects against coronary diseases and even cancer.

The values for ω6:ω3 ratio found in this study are above the recommendation stated by Wood et al. (2003). The high values found for this ratio in this study is possibly attributed to the high quantity of grains in the diet, which in turn are rich in fatty acids of the ω6 family (Bessa et al., 2007). According to Wood et al. (2003), ruminant meat may contain low ω6:ω3 ratio when animals consume grass with a high C18:3 content. Talpur et al. (2008) evaluated the composition of fatty acids in goats finished on pasture and found an average ω6:ω3 ratio of 3.38.

Considering that oleic fatty acid (C18:1) decreases the cholesterol level in the blood, while palmitic fatty acid (C16:0) increases it and that stearic acid (C18:0) has no influence (Rhee et al., 2000), it is important to analyze the behavior of these three fatty acids.

Therefore, the (C18:0+C18:1)/C16:0 ratio could possibly better describe the effects of different fatty acids on human health. The values found in this study for this ratio were 2.91 and 2.75 for the control and castor oil treatments, respectively, thus corroborating the data found in the review carried out by Banskalieva et al. (2000), which are between 2 and 3 for goat meat.

Conclusions

The use of 30 g of castor oil/kg of diet DM for confined Boer × Saanen goat kids fed high-concentrate diet does not promote benefits to weight gain, carcass quantitative characteristics, chemical composition and fatty acid profile in the *longissimus dorsi* muscle.

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