



EFFECT OF CURCUMIN DIETARY SUPPLEMENTATION ON GROWTH PERFORMANCE, PHYSIOLOGY, CARCASS CHARACTERISTICS AND MEAT QUALITY IN LAMBS

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Abstract

This study evaluated the effects of curcumin dietary supplementation on growth, physiology, carcass characteristics and meat quality in lambs. Thirty-two male Lacaune lambs (15.6 ± 0.63 kg, 60 ± 2.8 days of age) were randomly allocated in 16 pens (four treatments of four replicates with two lambs each) for 30 days. The animals were assigned to the following treatments: T0, T100, T200 and T300, representing 0, 100, 200 and 300 mg of curcumin/kg of concentrate, respectively. Curcumin dietary supplementation increased ($P=0.02$) weight gain; on regression analysis, 315.1 mg curcumin/kg of concentrate was the dosage that provided the greatest weight gain. T200 and T300 lambs had lower ($P=0.04$) erythrocyte numbers; T100 and T300 lambs had lower ($P=0.01$) leukocyte numbers and T300 lambs had lower ($P=0.04$) lymphocyte numbers, compared to T0 lambs. Globulin levels were significantly greater in the T200 group ($P=0.04$) only on day 15 but not day 30; levels of total protein were significantly higher ($P=0.01$) only in T200 and T300 groups on day 15 and only in T200 group on d 30. Gamma-glutamyltransferase concentrations tended to be lower ($P=0.08$) in T100, T200 and T300 groups on d 15, and only in the T100 group on d 30. Curcumin dietary supplementation increased ($P=0.01$) the serum activity of antioxidant enzymes and reduced ($P=0.01$) levels of reactive oxygen species. In meat samples, T200 and T300 had greater total antioxidant capacity ($P=0.03$) and lower ($P=0.01$) lipoperoxidation rates. In carcasses, T300 lambs had greater ($P \leq 0.02$) cooling weight losses and yields than did T0 lambs. Curcumin dietary supplementation also reduced ($P \leq 0.03$) redness and yellowness. T200 and T300 lambs had fewer ($P=0.01$) cooking losses and T200 lambs had greater ($P=0.03$) water holding capacity than did T0 lambs. These findings suggest that curcumin dietary supplementation improves growth and antioxidant responses, as well as influencing meat quality in lambs.

Key words: antioxidant, biochemistry, *Curcuma longa*, hemogram, sheep

Consumption of sheep meat has increased over the years in Brazil, according to data from Santos and Borges (2019). There has been an increase in the commercialization of the sheep herd of about 50% and a growth in the number of sheep farms by 20%. For these reasons, introduction of technology to this productive sector is necessary to increase productivity by producing more animals in less time, particularly animals that are healthy and that have lower feed conversion rates. According to this concept, an alternative is the fattening of early lambs with improved growth performance and low fat deposition in meat (Bôas et al., 2003). The age at weaning of animals is an important factor that determines the success of lamb fattening, because weaning is a stressful situation for the animals and they are forced to consume only solid feed from this period till slaughter. Moreno et al. (2010) reported that Ile-de-France lambs subjected to weaning at 45 or 60 days did not differ in terms of average daily gain (ADG) or carcass yield, a finding that encouraged early weaning of animals. Early weaning requires some particular premises, of which the most important is in feeding, because the animal must be fully capable to eat solid feed. Therefore, the use of creep-feeding is necessary, because it is a solid energy-rich and palatable feed that stimulates the development of rumen, such that the animals are not totally dependent on pre-weaning breast milk (Bôas et al., 2003).

The consumption of lamb meat is mainly influenced by the purchasing power and habits of the consumer (Almeida Jr. et al., 2004). One of the ways to add value to the product and to increase consumption is the standardization and the production of high-quality meat (Almeida Jr. et al., 2004). In this light, some aspects of meat quality are being considered by breeders to generate increased acceptance by consumers, including fat and fatty acid content, cholesterol levels, softness, juiciness, pH, odor, color and taste (Slukwa, 2014). Early lambs have improved growth performance because they have low feed conversion ratios and low fat deposition; however, they also have rapid development and high average daily weight gain. Animal feed additives have been used to enhance feed efficiency and improve end-product quality (Flachowsky and Meyer, 2015).

One feed additive that has been used with promising results in sheep farming is curcumin, a compound extracted from the *Curcuma longa* L. plant (Jaguezeski et al., 2018). It has demonstrated beneficial effects on animal health and productive performance (Wang et al., 2018; Jaguezeski et al., 2018). According to the literature, *Curcuma longa* contains curcuminoids as active components and these act by modulating the immune and antioxidant systems (Yarru et al., 2009), reducing inflammatory processes and eliminating excess free radical production; as a result, there is less oxidative stress during the growth (Srinivasan and Sambaiah, 1991). Molosse et al. (2019) observed that the addition of curcumin to the diet of lactating lambs increased weight gain, as well as inducing anti-inflammatory and antioxidant effects, all of which are desirable biological benefits that enhance production. The antimicrobial effects of curcumin are also desirable. For example, Jaguezeski et al. (2018) fed lactating ewes with chronic subclinical mastitis with curcumin and found that the disease was cured in most of the cases. However, we are not aware of any study that evaluated the effects of curcumin on growth, physiology, carcass characteristics and meat quality of post-weaning lambs. The effect of curcumin on broiler meat quality

has already been demonstrated (Salah et al., 2019; Galli et al., 2020), as studies show that curcumin dietary supplementation is able to reduce lipid peroxidation, increase antioxidants and thus generate redox stability of meat. Our hypothesis is that something similar occurs in ruminant meat, but as the digestion process is different, it needs to be investigated.

Based on the biological properties of curcumin, the aim of this study was to determine whether the addition of curcumin in the concentrate of post-weaning lambs would improve growth performance, health, carcass and meat quality.

Material and methods

Curcumin

Curcumin was purchased from Shaanxi Jiahe Phytochem Ltda (China), derived from dried extract of *Curcuma longa* (turmeric). The manufacturer guarantees at least 72% of purity.

The purity of curcumin was analyzed using high-performance liquid chromatography (HPLC) following the methodology described by Coradini et al. (2014), described in detail by Jaguezski et al. (2018). The result was similar to that of the manufacturer, i.e., the commercial product contained 74.8% curcumin. Other curcuminoid components as demethoxycurcumin and bisdemethoxycurcumin were identified in low concentrations (1.62% and 0.98% respectively).

Animals, and experimental design

The experiment was conducted on a farm located in Chapecó city (Southern Brazil). Thirty-two male Lacaune lambs [15.6 ± 0.63 kg body weight (BW), 60 ± 2.8 days old] were placed in a shed and randomly allocated into 16 pens ($n = 2/\text{pen}$), where they were fed concentrate and corn silage. The animals were assigned to the following treatments: T0, T100, T200 and T300, representing 0, 100, 200 and 300 mg of curcumin/kg in concentrate, respectively. Concentrate was based on corn and soybean meal, and it was formulated to meet or exceeded the requirements for crude protein, total digestible nutrients and minerals for Lacaune lambs weighing 15 kg and gaining 0.200 kg of BW daily (NRC, 2007; Table 1). The animals received 600 grams of concentrate per day and 1 kg of silage per day. Feed was provided in three similar meals (07:00h, 13:00h, and 18:00h).

Growth performance

Lambs were weighed to verify weight gain and average daily weight gain on days 0, 15 and 30 using a digital scale. This information was used to calculate weight gain (final BW – initial BW) and average weight gain [(final BW – initial BW)/number of the days] in each experimental period.

Sample collections

Blood was collected from the jugular vein on days 0, 15 and 30 of the experiment. Fecal samples were collected directly from the rectal ampulla (days 0 and 30).

Total blood was collected in two tubes: without anticoagulant to obtain serum, and with EDTA as anticoagulant for hemogram. The blood collected without anticoagulant was centrifuged at 3500 rpm for 10 min, and the serum was stored at -20°C until analyses.

Table 1. Ingredients used to formulate the base concentrate of lambs, and chemical composition in diet (silage and concentrate)

Nutrients		Basal concentration (kg)			
Ground corn		66			
Soybean meal		30			
Premix ¹		4			
Total		100 kg			
Chemical composition g/kg	Silage	Concentrate T0	Concentrate T100	Concentrate T200	Concentrate T300
Dry matter (DM)	374	889	889	890	888
Ash (DM)	43.5	49.3	51.6	44.1	49.9
Crude protein (DM)	76.8	198	190	175	185
EE (DM)	35.1	33.5	37.0	37.6	37.1
ADF (DM)	141	33.4	22.4	22.8	26.8
NDF (DM)	263	91.9	84.7	83.3	84.5

¹Premix composition: phosphorus (min 55 g/kg), calcium (min 215 g/kg, max 225 g/kg), sulphur (min 12 g/kg), sodium (min 80 g/kg), cobalt (min 60 mg/kg), chromium (min 12 mg/kg), iron (min 1420 mg/kg); iodine (min 100 mg/kg), magnesium (min 14 mg/kg), manganese (min 1550 mg/kg), selenium (min 22 mg/kg), vitamin A (min 20000 IU/kg), vitamin D (min 40000 IU/kg), vitamin E (min 550 IU/kg), and fluorine (max 550 mg/kg).

DM (dry matter), NDF (neutral detergent fiber), ADF (acid detergent fiber), EE (ether extract).

On day 31 of the experiment (mean age of 91 days of life), the animals were slaughtered in a specialized slaughterhouse for sheep. All slaughtering processes followed current legislation and were conducted under veterinary supervision. Subsequently, the carcasses (hot and cold) were weighed; then was calculated the carcass yield (carcass yield = (cold carcass/pre-slaughter body weight) $\times$ 100). The carcass consists of muscular tissues, fatty tissues, bones, tendons and other connective tissues, large blood vessels; as well as the head and paws are not considered as carcass.

A liver fraction was collected for biochemical analysis. After slaughter, the carcasses were suspended on hooks and kept refrigerated in a cold chamber (6°C for 22 hours). Then, the *longissimus thoracis* muscle was collected for analysis of composition and meat quality assessment. The collected muscle was placed in plastic bags, kept refrigerated (6°C), and after 2 h the subsequent analyses started.

The liver and meat fragments were homogenized (1:10 w/v) in glass Potter homogenizer tubes with Tris-HCl buffer (10 mM, pH 7.4), and centrifuged at $2000 \times g$ for 10 min. The supernatants were stored at -20°C prior to analysis.

Hematological analysis

Erythrocyte and total leukocyte counts, as well as hemoglobin (Hb) content were measured using a semi-automated analyzer Celm[®] 530. Hematocrit was obtained af-

ter capillary centrifugation (1000 rpm for 5 min). Leucocyte differential counts were performed in blood smears stained with commercial dye (*Panótico Rapido*) using a light microscope at 1000 × magnification (Feldman et al., 2000).

Serum clinical biochemistry

Serum levels of total protein (TP), albumin, urea, glucose, triglycerides, cholesterol and aspartate aminotransferase (AST) activity were measured in a semi-automated analyzer (BioPlus 2000®) using commercial kits (Analisa®, Brazil) following the manufacturer's recommendations. Globulin levels were obtained using the formula (total protein – albumin).

Antioxidant capacity against peroxyl radicals (ACAP)

The fluorometric method is based on the thermal decomposition (37°C) of ACAP (2,2'-azobis(2-methylpropionamidine) dihydrochloride that generates peroxyl radicals, as established by Amado et al. (2009) and reported in detail by da Silva Barreto et al. (2018). Serum, liver and meat samples were used to measure fluorescence at 485 nm (excitation) and 520 nm (emission) for 40 min at 37°C. The results were expressed as fluorescence units per mg of protein.

Serum lipid peroxidation

Lipid peroxidation (LPO) levels were measured using serum, liver and meat samples diluted in cold methanol (1:1 v/v) and centrifuged at 1000 x g for 10 min at 4°C (Monserrat et al., 2003; da Silva Barreto et al., 2018). Liver and meat LPO levels were measured in the supernatants using a microplate reader at 550 nm, with cumene hydroperoxide as the standard.

Reactive oxygen species

Serum ROS levels were determined by the DCFH oxidation method described by LeBel et al. (1992) using excitation and emission wavelengths of 485 and 538 nm, respectively, and results were expressed as U DCF/mg of protein.

Glutathione activity

Serum glutathione peroxidase (GPx) activity was measured according to the methodology described by Paglia and Valentine (1967), and was expressed as U GPx/mg of protein. Serum glutathione S-transferase (GST) activity was measured based on the method described by Habig et al. (1974), and was expressed as U GST/mg of protein. Hepatic glutathione reductase (GR) activity was measured according to the methodology described by Carlberg and Mannervik (1985), and was expressed as U GR/mg of protein.

Meat quality assessment

The *longissimus thoracis* muscle was refrigerated at 6°C for 24 h (22 h in carcass, and 2 h after muscle was collected), and was used for the determination of color, water holding capacity (WHC), cooking weight loss (CL) and shear force (SF).

The meat samples were cut according to the methodology of Cañeque and Sañudo (2005), then placed in plastic bags (without vacuum) at 8–10°C. Meat samples were used for each analysis as described below, with the exception of SF that was determined using samples previously used for cooking weight loss. All meat analyses were performed in triplicate and up to 30 h after slaughtering the lambs.

Meat samples were exposed to oxygen for 3 min after cutting. Subsequently, the meat color was assessed on the surface by using a CR-400 Chromameter (Minolta, Osaka, Japan; CIE1976 L* a* b*, with a standard illuminant D65, 2° closely matching the CIE 1931 standard observer ($x_2\lambda$, $y\lambda$, $z\lambda$) and a standard calibration plate (number 1849-701)). Lightness (L*), redness (a*) and yellowness (b*) were measured at three randomly selected meat sample points, i.e. a steak of 2.5 cm thickness.

We used a steak of meat to determine pH using a portable penetration electrode (HANNA, HI 99163). In another steak of meat, we evaluated the WHC using compression according to Hamm's methodology, adapted by Yamamoto *et al.* (2013). To determine CL during cooking, we used a new steak of meat that had been kept refrigerated. It was separated into three samples that were weighed before and after cooking on a portable grill (Grill Mondial Due Grill Smart Pretoforno), preheated to 170°C until achieving 75°C internal temperature using a culinary thermometer inserted in the middle of the sample during cooking.

Cooked samples that were used for CL analysis were cooled and six cylindrical sub-samples, cut in the longitudinal direction of the fiber (1-cm diameter) were removed from each sample using a steel cutter with a cylindrical mold to measure the shear force (SF). The Warner–Bratzler shear force (WBSF) measurement was performed using a texture analyzer (Stable Micro Systems Ltd., TA-XT.plus Texture Analyser, UK), and the test speed was 3.30 mm/s to measure the force necessary to transversally cut each cylinder.

Parasitological exams

Parasitological examination was performed using the McMaster technique described by Gordon and Whitlock (1939) with a saturated sugar solution to quantify the number of eggs per gram of feces (EPG).

Statistical analyses

All dependent variables were tested for normality using Univariate procedure of SAS (SAS Inst. Inc., Cary, NC, USA; version 9.4) and all variables were normally distributed. Then, all data were analyzed using MIXED procedure of SAS, with the Satterthwaite approximation to determine the denominator degrees of freedom for the test of fixed effects. Weight gain, ADG, carcass and meat quality variables, LPO and ACAP levels in liver and meat were tested for fixed effect of treatment using animal(treatment) and animal(pen) as random effects. All other variables were analyzed as repeated measures and were tested for fixed effects of treatment, day, and treatment $\times$ day, using animal(treatment) and animal(pen) as random variables and animal(treatment) as subject. All results obtained on d 0 for each variable were in-

cluded as covariates in each respective analysis, but were removed from the model when $P > 0.10$. The compound symmetric covariance structure was selected for concentration of erythrocytes and lymphocytes and the first order autoregressive covariance structure was selected for all others variables. The covariance structures were selected according to the lowest Akaike information criterion. The weight gain data were subjected to regression analysis to determine the ideal curcumin concentration for lamb diets. Means were separated using PDIF and all results were reported as LSMEANS followed by SEM. Significance was defined when $P \leq 0.05$, and tendency when $P > 0.05$ and ≤ 0.10 .

Results

Growth performance

The results of growth performance are presented in Table 2. Effects of treatment $\times$ day and treatment were detected ($P \leq 0.03$) for body weight (BW) and T100 and T300 animals had greater BW on d 15 than T0 animals. T100, T200 and T300 lambs had greater BW on d 30 than did T0 lambs. T100, T200 and T300 animals had greater ($P = 0.02$) weight gain and ADG from d 0 to 30 than did T0 animals. On regression analysis, the highest dose response of curcumin for weight gain (d 0 to 30) was 315.1 mg/kg of concentrate (Figure 1). The daily feed intake was greater than 95% of the diet offered to all animals.

Table 2. Growth performance of lambs fed curcumin after weaning

Variables	Treatments ^ε				SEM	P-value	
	T0	T100	T200	T300		Treat	Treat $\times$ day
Body weight (kg)						0.01	0.03
d 0	14.47	14.31	14.49	14.24	0.33		
d 15	16.49 b	17.93 a	17.25 ab	17.71 a	0.33		
d 30	20.55 b	22.17 a	22.09 a	22.76 a	0.33		
Weight gain (kg)							
d 0 to 15	2.03	3.62	2.76	3.48	0.48	0.12	
d 15 to 30	4.05	4.24	4.84	5.05	0.54	0.54	
d 0 to 30	6.08 b	7.86 a	7.60 a	8.53 a	0.46	0.02	
Average daily gain (kg)							
d 0 to 15	0.13	0.24	0.18	0.23	0.03	0.12	
d 15 to 30	0.27	0.28	0.32	0.34	0.04	0.54	
d 0 to 30	0.20 b	0.26 a	0.25 a	0.28 a	0.01	0.02	

^εT0, T100, T200 and T300 represents 0, 100, 200 and 300 mg of curcumin/kg of concentrate, respectively. a, b – differs ($P \leq 0.05$) or tends to differ ($P \leq 0.10$) between treatments.

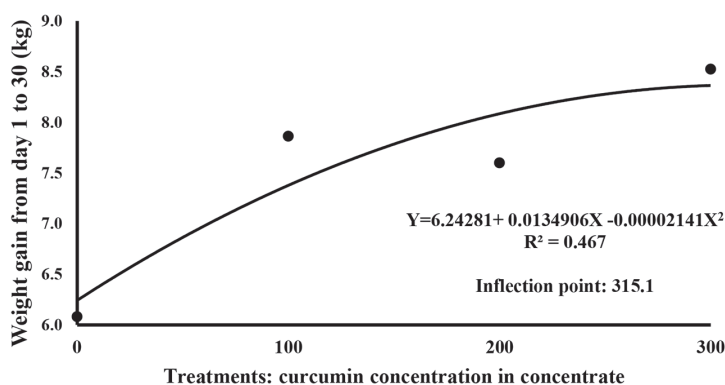


Figure 1. Curve, equation and inflection point obtained via regression analysis of weight gain (d 0 to 30) in lambs fed curcumin after weaning

Hemogram

The results of hemogram are presented in Table 3. Effects of treatment $\times$ day ($P=0.04$) but not of treatment ($P=0.20$) were detected for erythrocytes and T200 and T300 lambs had lower concentrations than did T0 and T100 lambs on d 30. No effects of treatment $\times$ day and treatment were detected ($P \geq 0.13$) for hematocrit, hemoglobin, neutrophils, monocytes and eosinophils. Effects of treatment ($P=0.01$), but not treatment $\times$ day ($P=0.47$) were detected for leukocytes and T100 and T300 animals had lower concentrations than did T0 lambs. Effects of treatment $\times$ day ($P=0.04$) but not treatment ($P=0.33$) were detected for lymphocytes and T300 animals had lower concentration on d 15 and 30 than did T0, T100 and T200 animals.

Table 3. Hematological variables of lambs fed curcumin after weaning

Variables	Treatments [†]				SEM	P-value	
	T0	T100	T200	T300		Treat	Treat $\times$ day
Erythrocytes ($\times 10^6/\mu\text{L}$)						0.20	0.04
d 0	9.41	9.27	9.14	9.36	0.52		
d 15	9.36	9.53	10.54	9.53	0.52		
d 30	10.77 a	10.41 a	8.99b	8.65 b	0.52		
Hematocrit (%)	35.51	35.32	34.86	34.18	0.72	0.61	0.98
Hemoglobin (g/dL)	11.30	10.70	11.15	11.26	0.19	0.13	0.22
Leukocytes ($\times 10^3/\mu\text{L}$)	20.16 a	15.25 bc	17.95 ab	13.77 c	1.12	0.01	0.47
Neutrophils ($\times 10^3/\mu\text{L}$)	7.55	6.07	6.82	5.94	0.43	0.22	0.14
Lymphocytes ($\times 10^3/\mu\text{L}$)						0.33	0.04
d 0	11.48	10.10	10.98	12.09	1.45		
d 15	11.70 a	10.81 a	13.41 a	6.75 b	1.60		
d 30	9.94 a	7.40 a	6.89 a	3.54 b	1.45		
Monocytes ($\times 10^3/\mu\text{L}$)	0.18	0.09	0.33	0.19	0.09	0.33	0.92
Eosinophils ($\times 10^3/\mu\text{L}$)	0.12	0.06	0.06	0.07	0.02	0.29	0.73

[†]T0, T100, T200 and T300 represents 0, 100, 200 and 300 mg of curcumin/kg of concentrate, respectively. a, b, c – differs ($P \leq 0.05$) or tends to differ ($P \leq 0.10$) between treatments.

Serum clinical biochemistry

The results of serum biochemistry are presented in Table 4. No effects of treatment $\times$ day and treatment were detected ($P \geq 0.11$) for glucose, urea, albumin, triglycerides, cholesterol and AST. Effects of treatment $\times$ day ($P = 0.01$) but not of treatment ($P = 0.45$) were detected for total protein. The T200 and T300 animals had greater concentration on d 15, and only T200 animals had greater concentration on d 30, compared to T0 animals. Effects of treatment $\times$ day ($P = 0.04$) but not of treatment ($P = 0.59$) were detected for globulin, and T100, T200 and T300 lambs had greater concentration only on d 15, compared to T0 lambs. Effects of treatment $\times$ day and treatment was not detected ($P = 0.08$) for GGT. The T100, T200 and T300 lambs had lower GGT concentration on d 15, compared to T0 lambs, and only T100 lambs had lower concentration on d 30, compared to T0, T200 and T300 lambs.

Table 4. Serum biochemistry of lambs fed curcumin after weaning

Variables	Treatments ^c				SEM	P-value	
	T0	T100	T200	T300		Treat	Treat $\times$ day
Glucose (mg/dL)	101.62	101.59	102.88	101.68	4.70	0.99	0.30
Urea (mg/dL)	33.02	29.49	31.47	34.73	2.53	0.50	0.82
Total protein (g/dL)						0.45	0.01
d 0	7.84	7.04	7.17	7.63	0.45		
d 15	6.92 c	7.87 bc	9.16 a	8.09 b	0.42		
d 30	6.60 b	6.74 ab	7.71 a	6.98 ab	0.41		
Albumin (g/dL)	3.23	3.07	3.20	3.03	0.11	0.43	0.11
Globulin (g/dL)						0.59	0.04
d 0	4.53	4.23	3.57	3.93	0.40		
d 15	3.55 b	4.63 a	5.41 a	4.82 a	0.38		
d 30	3.70	3.57	4.37	3.78	0.39		
Triglycerides (mg/dL)	41.99	36.87	39.39	41.15	2.54	0.45	0.48
Cholesterol (mg/dL)	62.47	56.71	62.42	60.88	3.80	0.65	0.68
AST (U/L)	141.09	126.49	133.23	138.30	7.63	0.68	0.91
GGT (U/L)						0.08	0.08
d 0	111.90	118.22	118.90	119.98	7.52		
d 15	163.07 x	121.37 y	117.40 y	122.23 y	7.52		
d 30	141.40 x	116.37 y	137.56 x	143.23 x	7.52		

^cT0, T100, T200 and T300 represents 0, 100, 200 and 300 mg of curcumin/kg of concentrate, respectively. AST, aspartate aminotransferase and GGT, gamma-glutamyltransferase.

a, b, c – differs ($P \leq 0.05$) and x, y tends to differ ($P \leq 0.10$) between treatments.

Serum oxidant/antioxidant status

The results of serum oxidant/antioxidant variables are shown in Table 5. Effects of treatment $\times$ day and treatment were detected ($P = 0.01$) for serum concentration of ROS and T100, T200 and T300 lambs had lower concentration only on d 30, compared to T0 lambs, and T200 and T300 had lower concentration than T100 lambs on the same day. Effects of treatment ($P = 0.09$) but not of treatment $\times$ day ($P = 0.11$) tended to be detected for GPx and T300 lambs tended to have greater concentration,

compared to T0 and T100 lambs. Effects of treatment $\times$ day ($P=0.01$) but not of treatment ($P=0.27$) were detected for GST and T100, T200 and T300 lambs had greater concentration only on d 30, compared to T100 animals. Effects of treatment $\times$ day and treatment were detected ($P=0.01$) for GR and T300 lambs had greater concentration only on d 30, compared to T0 animals. Effects of treatment $\times$ day and treatment were detected ($P=0.01$) for serum ACAP. The T100, T200 and T300 animals had greater value on d 15, compared to T0 animals, and T100 animals had the highest value on this day. The T100, T200 and T300 animals had greater value on d 30, compared to T0 animals and T300 animals had the highest value on this day.

Table 5. Serum oxidants and antioxidants variables of lambs fed curcumin after weaning

Variables	Treatments [‡]				SEM	P-value	
	T0	T100	T200	T300		Treat	Treat $\times$ day
ROS (U DCF/mg of protein)						0.01	0.01
d 0	1.35	1.36	1.26	1.29	0.10		
d 15	1.22	1.01	1.37	1.03	0.10		
d 30	1.88 a	0.67 b	1.03 c	0.65 c	0.10		
GPx (U GPx/mg of protein)	2.83 y	3.00 y	3.47 xy	4.83 x	0.51	0.09	0.11
GST (U GST/mg of protein)						0.27	0.01
d 0	6.85	6.03	6.95	6.98	0.49		
d 15	6.93	5.38	6.03	6.02	0.49		
d 30	5.97 b	8.04 a	8.21 a	8.64 a	0.49		
GR (U GR/mg of protein)						0.01	0.01
d 0	3.89	3.63	3.68	3.81	0.35		
d 15	1.96	1.72	1.80	1.36	0.35		
d 30	1.93 b	2.06 ab	2.26 ab	3.12 a	0.35		
ACAP (U F/mg of protein)						0.01	0.01
d 0	0.89	0.93	0.73	0.78	0.24		
d 15	1.55 c	4.28 a	3.45 b	3.37 b	0.24		
d 30	1.61 c	2.95 ab	2.84 b	3.49 a	0.24		

[‡]T0, T100, T200 and T300 represents 0, 100, 200 and 300 mg of curcumin/kg of concentrate, respectively. Oxygen reactive species (ROS), glutathione peroxidase (GPx), glutathione S transferase (GST), glutathione reductase (GR), and antioxidant capacity against peroxyl radicals (ACAP)

a, b – differs ($P\leq 0.05$) and x, y tends to differ ($P\leq 0.10$) between treatments.

Carcass and meat quality

The results of carcass and meat quality are presented in Table 6. No effects of treatment were detected ($P\geq 0.38$) for hot carcass weight, cold carcass weight, pH, lightness, and shear force. The T300 animals had greater ($P=0.01$) cooling weight loss compared to T0 animal. The T300 animals had greater ($P=0.02$) cold carcass yield compared to T0 and T100 animals. T0 animals had higher values for meat redness ($P<0.03$) and yellowness ($P<0.01$) compared to treatments where curcumin was included. The T300 lambs, tended to have lower ($P=0.09$) fat thickness compared to T0 and T200 lambs. The T200 and T300 lambs had lower ($P=0.01$) cooking losses compared to T0 lambs. The T200 lambs had greater ($P=0.03$) water holding capacity compared to T0 lambs.

Table 6. Carcass and meat quality analyses of lambs fed curcumin after weaning

Variables	Treatments [†]				SEM	P-value Treat
	T0	T100	T200	T300		
Hot carcass weight (kg)	9.55	9.81	9.84	10.2	0.46	0.84
Cold carcass weight (kg)	9.04	9.24	9.23	9.50	0.45	0.76
Cooling weight loss (kg)	0.51 b	0.56 ab	0.60 ab	0.73 a	0.03	0.01
Cold carcass yield ¹ (%)	41.60 b	41.50 b	41.40 ab	42.10 a	0.14	0.02
pH	5.63	5.62	5.78	5.69	0.10	0.69
Lightness, L*	39.34	37.40	36.91	38.01	1.67	0.38
Redness, a*	12.26 a	10.0 b	10.4 b	10.0 b	0.53	0.03
Yellowness, b*	7.93 a	6.68 b	6.29 b	6.38 b	0.31	0.01
Fat thickness (mm)	1.13 x	1.07 xy	1.29 x	0.93 y	0.08	0.09
Cooking losses (CL) (%)	22.20 a	21.91 ab	19.80 bc	17.60 c	0.56	0.01
Water holding capacity (WHC) (g water/g dry matter)	0.59 b	0.58 b	0.73 a	0.69 ab	0.03	0.03
Warner–Bratzler shear force (WBSF) (kgf/cm ²)	5.68	5.54	5.77	5.79	0.16	0.75

[†]T0, T100, T200 and T300 represents 0, 100, 200 and 300 mg of curcumin/kg of concentrate, respectively.

a, b, c – differs ($P \leq 0.05$) and x, y tends to differ ($P \leq 0.10$) between treatments.

¹Head and paws were not considered part of the carcass.

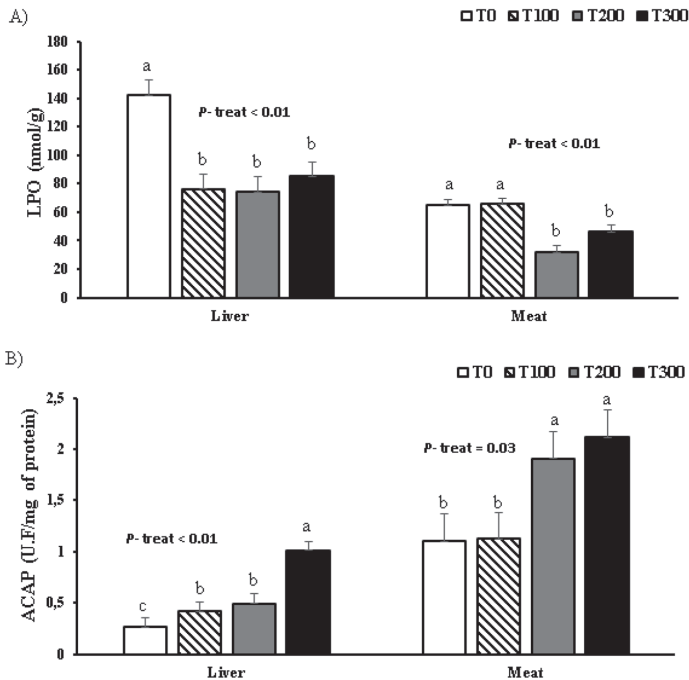


Figure 2. Liver and meat homogenate lipid peroxidation (LPO) levels (A) and antioxidant capacity against peroxyl radicals (ACAP) (B) of lambs fed curcumin after weaning. T0, T100, T200 and T300 represents 0, 100, 200 and 300 mg of curcumin/kg of concentrate, respectively. a, b, c– differs ($P \leq 0.05$) between treatments each respective day. Vertical bars represent the SEM

Liver and meat: lipid peroxidation and total antioxidant capacity

The T100, T200 and T300 lambs had lower LPO in liver ($P<0.01$) compared to T0 lambs (Figure 2). The T200 and T300 animals had lower LPO in meat ($P<0.01$) compared to T0 and T100 animals (Figure 2). The T100, T200 and T300 lambs had greater ACAP ($P<0.01$) in liver compared to T0 animals and T300 had higher levels compared to the other treatments. The T200 and T300 animals had higher ACAP ($P=0.03$) in meat compared to T0 and T100 animals.

Parasitological exams

No parasitic gastrointestinal infection was observed during the experimental period in all lambs: the parasitological examinations were negative for parasite eggs, cysts and oocysts.

Discussion

Curcumin dietary supplementation was associated with increased weight gain in the present experiment, a finding that is possibly related to its anti-inflammatory and antibacterial effects (Jungbauer and Medjakovic, 2012; Fu et al., 2014), increased intestinal villi (Rahmani et al., 2018), higher digestibility of fiber (Jaguezeski et al., 2018) and stimulation of energy metabolism and antioxidant system (Molosse et al., 2019).

Curcumin is thought to be an important additive with anti-inflammatory properties (Jaguezeski et al., 2018; Molosse et al., 2019; de Almeida et al., 2018; Jungbauer and Medjakovic, 2012; Fu et al., 2014). In this study, curcumin reduced the number of total leukocytes, erythrocytes, and lymphocytes, all of which are inflammatory cells that are not desirable for farm animals at high levels, because active inflammatory processes consume large amounts of ATP that are consequently no longer usable for weight gain or production. The anti-inflammatory effect of curcumin occurs via inhibition of neutrophil chemotaxis (Larmonier et al., 2011), leading to decreased pro-inflammatory processes and levels of TNF-alpha (Lu et al., 2008) and cytokines involved in inflammation.

Curcumin dietary supplementation tended to decrease the serum concentration of GGT. This enzyme increases their activity in the case of liver injury or overload (Bavarsada et al., 2019). Previous researchers have stated that curcumin has a hepatoprotective action (Khan et al., 2019) that possibly explains this reduction in liver enzyme. This hepatoprotective effect of curcumin may also have influenced the increase in TP and globulin, because serum levels are determined by liver synthetic capacity (Yoshida et al., 1997; Carvalho and Machado, 2018).

In this study, curcumin dietary supplementation acted as a strong antioxidant, as expected, because it is a molecule thought to be a bifunctional antioxidant (Jaguezeski et al., 2018) that acts against ROS and stimulates antioxidant capacity (Trujillo et al., 2013; Alvarenga et al., 2018; Aparicio-Trejo et al., 2017), as observed in serum and meat samples of the present study. Curcumin also induces the expression of Nrf2, an antioxidant regulator (Tapia et al., 2012) that in turn increases levels of

antioxidant enzymes such as GST, catalase, superoxide dismutase (Cardozo et al., 2013), GPx and GR, as noted here. Taken together, these data support the hypothesis that curcumin is capable of protecting cells and decreasing lipid peroxidation by increasing antioxidant capacity against peroxyl radicals, as previously described in lactating lambs (Molosse et al., 2019).

In the current study, T300 lambs tended to have lower fat thickness in the carcass of lambs. According to the literature, this may be related to curcumin inhibiting adipogenesis (Ejaz et al., 2009; Ahn et al., 2010), because curcumin stimulates activated protein kinase AMP (AMPK), an energy regulator that inhibits lipid accumulation in adipocytes, thereby decreasing adipogenesis as well as angiogenesis (Ejaz et al., 2009; Lee et al., 2013).

The main protein responsible for meat color is myoglobin; however, there are several determining factors that can affect coloration. Despite the fact that pH affects meat coloration, in the present study, different diets did not affect pH. The lower values of redness and yellowness parameters in the meat of lambs treated with curcumin may be related to the lower oxidation of meat caused by the antioxidant effects of curcumin. As opposed to observations in our study, Galli et al. (2020) observed a significant increase of yellowness in broiler chicken fed with 50 mg curcumin/kg diet because of the presence of carotenoids.

According to previous researchers, cooking weight loss is related to meat yield after cooking, as well with water retention capacity (Soares et al., 2017). In the current study, the T200 and T300 lambs had lower cooking losses. This may be explained by the higher water holding capacity, also found in these same groups. The greater water disposal may have affected the juiciness and the flavor of the meat (Soares et al., 2017). It was observed that cold carcass yield was higher in lambs supplemented with 300 mg of curcumin/kg of concentrate, in disagreement to observations by Salah et al. (2019) in broiler chickens supplemented with 100 mg curcumin/kg/diet. This effect can be considered dose-dependent, because 100 mg curcumin/kg diet used in our study did not exert effects on cold carcass yield. Another positive effect of 300 mg curcumin supplementation was the reduction on fat thickness and reduction on cooking losses, representing an interesting result for human consumption. According to the literature, there are other benefits to meat when animals are supplemented with curcumin; for example, a study conducted by Galli et al. (2020) showed that meat of broilers supplemented with curcumin diet has lower content of saturated fatty acids, a class of fatty acids associated with negative effects on human health.

Conclusion

Young lambs supplemented with curcumin had increased weight gain and carcass yield. Lambs fed curcumin showed stimulation of the antioxidant system and consequent reduced serum and meat lipid peroxidation values. The anti-inflammatory action of curcumin may have an indirect effect on lamb weight gain. These results suggest that that curcumin-supplemented lambs had positive changes on meat quality characteristics (primarily lower cooking losses and greater water holding capacity) and antioxidant capacity.

Ethics Committee

This project was approved by the Committee for the Use of Animals in Research (CEUA) of the Universidade do Estado de Santa Catarina (UDESC) under protocol number 9853300918.

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