CRIS LUANA DE CASTRO NUNES

PERFORMANCE, CARCASS TRAITS AND MEAT QUALITY OF LAMBS FED COFFEE HULLS TREATED WITH CALCIUM OXIDE

Dissertation submitted to the Animal Science Graduate Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Magister Scientiae.*

VIÇOSA
MINAS GERAIS – BRASIL
2019

Ficha catalográfica preparada pela Biblioteca Central da Universidade Federal de Viçosa - Câmpus Viçosa

T

Nunes, Cris Luana de Castro, 1992-

N972p Performance, carcass traits and meat quality of lambs fed
2019 coffee hulls treated with calcium oxide / Cris Luana de Castro Nunes. – Viçosa, MG, 2019.

vi, 20 f. : il. ; 29 cm.

Texto em inglês.

Inclui apêndices.

Orientador: Cristina Mattos Veloso.

Dissertação (mestrado) - Universidade Federal de Viçosa.

Referências bibliográficas: f. 12-15.

1. Cordeiros - Alimentação e rações. 2. Resíduos agrícolas como ração. 3. Óxido de cálcio. 4. Cordeiros - Carcaças. 5. Cordeiros - Registros de desempenho. 6. Carne de ovelha - Qualidade. I. Universidade Federal de Viçosa. Departamento de Zootecnia. Programa de Pós-Graduação em Zootecnia. II. Título.

CDD 22. ed. 636.30855

CRIS LUANA DE CASTRO NUNES

PERFORMANCE, CARCASS TRAITS AND MEAT QUALITY OF LAMBS FED COFFEE HULLS TREATED WITH CALCIUM OXIDE

Dissertation submitted to the Animal Science Graduate Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Magister Scientiae*.

APPROVED: February 15, 2019.

Everton Teixeira Ribeiro

Karina Costa Busato

Rasmo Garcia
(Co-adviser)

Mário Luiz Chizzotti
(Co-adviser)

Cristina Mattos Veloso
(Adviser)

ACKNOWLEDGEMENTS

Firstly, to God for guiding my path and for not letting me give up on my dreams.

To the Universidade Federal de Viçosa, especially to the Department of Animal Science, for the opportunity to accomplish my master's degree.

To Fundação de Amparo à Pesquisa do Estado de Minas (FAPEMIG) for the grant support to this project.

To Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the scholarship provided to me during my master's degree.

To my adviser, Cristina Mattos Veloso, for the orientation, teachings and for all time spent. I will always be grateful.

To professor Rasmo Garcia, João Paulo Roseira and Everton Teixeira for guiding me on the project execution.

To all professors of the Department of Animal Science that I had the opportunity to know better through the lectures for helping me in my professional and personal formation.

To my friends Aline Naime, Erica Schultz, Thaís Costa and Willian Rufino, for helping me somehow in the field experiment and for making my life easy far from home.

To the interns Ana Clara, Lázaro Sales, Lorraina Stefanie, Luis Otávio, Naiara Marcos, Thaynara Cunha, for contributing in the field experiment and lab analyses.

Thank you all!

BIOGRAPHY

CRIS LUANA DE CASTRO NUNES, daughter of Carlos Alberto Borges Nunes and Rosangela Gonçalves de Castro Nunes, was born in Rio Verde de Mato Grosso/MS, Brazil, on December 22, 1992.

She started the undergraduate program in Animal Science at Universidade Estadual de Mato Grosso do Sul in 2011. From January 2014 and June 2015, she enrolled at McGill University in Saint-Anne-de-Bellevue/QC, Canada, as part of an exchange program. Back to Brazil, she became a Bachelor of Science in Animal Science in 2016.

In 2017, she started the M.Sc. program with major on ruminant production and physiology at Universidade Federal de Viçosa/MG, Brazil. On February 15th of 2019, she defended her master's dissertation to obtain the *Magister Scientiae* degree in Animal Science.

LIST OF CONTENTS

ABSTRACT

NUNES, Cris Luana de Castro, M.Sc., Universidade Federal de Viçosa, February, 2019. **Performance, carcass traits and meat quality of lambs fed coffee hulls treated with calcium oxide**. Adviser: Cristina Mattos Veloso. Co-advisers: Rasmo Garcia and Mario Luiz Chizzotti.

The objective of this study was to evaluate the effects of replacing corn silage by coffee hulls treated with calcium oxide (CaO) on growth performance, carcass traits and meat quality parameters of lambs. Twenty-eight crossbred, non-castrated male lambs, weaned at three months of age with average initial body weight of 20.24 ± 2.40 kg were housed in individual pens. Lambs were randomly assigned to one of the four experimental treatments, which consisted of different concentration levels of treated coffee hulls (0; 80; 160 e 240 g/kg on DM basis) as a substitute of corn silage. The forage:concentrate ratio of the experimental diets was 50:50 on dry matter (DM) basis and the diets were formulated to supply nutrient requirements of growing lambs with average daily gain of 200 g. After 66 days of experimental period, lambs were slaughtered for further carcass traits and meat quality evaluation. As results, increasing levels of treated coffee hulls in the diets led to a quadratic effect on intake of DM and its components ($P < 0.05$), values were highest at the intermediate addition level. Moreover, as level of coffee hulls increased in the diets, both DM and crude protein (CP) apparent digestibility declined linearly ($P = 0.001$). However, apparent digestibility of neutral detergent fiber corrected for ash and protein contents (apNDF), ether extract (EE) and non-fiber carbohydrates (NFC) were not influenced by treatments ($P > 0.05$). Values of final body weight and average daily gain (ADG) were similar up to 160 g/kg of corn silage replacement. A quadratic effect was observed for shear force (WBSF) ($P = 0.029$), the only meat quality parameter that showed significant effect. Lower values of WBSF were observed at the intermediated levels of corn silage replacement. Coffee hulls treated with CaO can be used as corn silage substitute in levels up to 160 g/kg because lambs' performance and meat quality are not affected.

RESUMO

NUNES, Cris Luana de Castro, M.Sc., Universidade Federal de Viçosa, fevereiro de 2019. **Desempenho, características de carcaça e qualidade de carne de cordeiros alimentados com casca de café tratada com óxido de cálcio.** Orientadora: Cristina Mattos Veloso. Coorientadores: Rasmo Garcia e Mario Luiz Chizzotti.

O objetivo deste trabalho foi avaliar os efeitos da substituição da silagem de milho por casca de café tratada com óxido de cálcio (CaO) sobre o desempenho, características de carcaça e parâmetros de qualidade de carne de cordeiros. Vinte e oito cordeiros machos mestiços, não castrados, desmamados aos três meses de idade, com peso corporal inicial médio de 20,24 ± 2,40 kg foram alojados em baias individuais. Os cordeiros foram distribuídos aleatoriamente em um dos quatro tratamentos experimentais, os quais consistiram de diferentes níveis de inclusão de casca de café tratada (0; 80; 160 e 240 g/kg, com base na matéria seca (MS)) em substituição à silagem de milho. A relação volumoso:concentrado das dietas experimentais foi de 50:50 com base na MS e as dietas foram formuladas para suprir as exigências nutricionais de cordeiros em crescimento com ganho médio diário de 200 g. Após 66 dias do período experimental, os cordeiros foram abatidos para posterior avaliação das características de carcaça e qualidade da carne. Como resultados, os níveis crescentes de casca de café tratada nas dietas levaram a um efeito quadrático sobre a ingestão de MS e seus componentes (P <0,05), os valores foram maiores para os níveis intermediários de adição. Além disso, com o aumento do nível de casca de café nas dietas, tanto a digestibilidade aparente da MS e da proteína bruta (PB) diminuiu linearmente (P = 0,001). No entanto, a digestibilidade aparente da fibra em detergente neutro corrigida para cinza e proteína (FDNcp), extrato etéreo (EE) e carboidratos não fibrosos (CNF) não foi influenciada pelos tratamentos (P> 0,05). Os valores de peso corporal final e do ganho médio diário (GMD) foram similares até 160 g/kg de substituição da silagem de milho. Observou-se efeito quadrático para força de cisalhamento (FC) (P = 0,029), o único parâmetro de qualidade da carne que apresentou efeito significativo. Menores valores de FC foram observados nos níveis intermediários de substituição de silagem de milho. Casca de café tratada com CaO pode ser usada como substituto de silagem de milho em níveis de até 160 g/kg, pois o desempenho dos cordeiros e a qualidade da carne não são afetados.

1. Introduction

The use of alternative feeds on livestock diet, for instance, crop residues and agro-industrial by-products with reasonable nutritive value is an important tool to improve animal production sustainability and profitability. As stated by Shreck et al. (2015), the use of agricultural residue on animal diet decreases feed costs and increases the profit-making of the production system since animals' performance is not affected.

In this context, an agro-industrial residue that can be used on ruminant diet is coffee hulls, which are generated from the processed coffee fruit. According to International Coffee Organization (ICO, 2019), the total production of coffee by all exporting countries in 2018 reached 168.093 million (60 kg) bags. This data show us how huge is the production of coffee hulls since it is produced in a 1:1 ratio, which means that for each 1 kg of processed coffee fruit 1 kg of coffee hulls is produced (Gouvea et al., 2009). Because coffee hulls are considered a poor quality feedstuff due to their high lignin content that affects hemicellulose and cellulose digestion, a great alternative is to submit coffee hulls to alkaline treatment in order to improve microorganism fermentation (Chaudhry, 2000; Shi et al., 2016).

Thus, due to the few studies using treated coffee hulls (TCH) on ruminant diet, we hypothesized that lambs fed diets containing coffee hulls treated with CaO as partial replacement of corn silage would perform similarly to lambs fed a corn silage based diet during finishing phase. Therefore, the aim of this study was to evaluate the effects of replacing corn silage by TCH (0, 80, 160, and 240 g/kg of replacement on DM basis) on feed efficiency, growth performance, carcass traits, and meat quality of lambs fed in feedlot system.

2. Material and methods

2.1. Coffee hulls treatment

Coffee hulls was obtained through dry-processed coffee fruits and a chemical analysis pre-treatment showed contents of 888, 661, 572 and 211 g/kg of DM, neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin, respectively. Then, coffee hulls were hydrated to 50% moisture with a mix of water and CaO, which was added at a concentration of 5% on DM basis as described by Shreck et al. (2015). Subsequently to the CaO dilution into water, the solution was mixed with coffee hulls for 10 minutes to ensure complete incorporation. After treatment, coffee hulls were stored in sealed plastic bags for two weeks to allow the chemical reaction occur before the material is fed to the animals.

2.2. Animals, experimental design and diets

The Animal Care and Use Committee of the Universidade Federal de Viçosa, Brazil, approved all animal handling procedures (protocol number 070/2017).

Twenty-eight crossbred (Santa Inês x Dorper) non-castrated male lambs, weaned at three months of age with average initial body weight of 20.24 ± 2.40 kg were assigned to the trial. The lambs were housed in individual pens with feeders and water suppliers.

The treatments consisted of four concentration levels of TCH (0, 80, 160, and 240 g/kg on DM basis) as corn silage substitute. Firstly, each treatment was assigned to seven experimental units as completely randomized design. Then, an adaptation period of 10 days was performed with the animal's weight being recorded following a 16 h fasting on 10^{th} day.

Experimental diets were composed of 50% corn silage and 50% concentrate on DM basis. Diets were formulated to be isonitrogenous in order to supply nutrient requirements of growing lambs with average daily gain of 200 g according to NRC (2007). A mixture of urea and ammonium sulfate was used to adjust the crude protein content. Proportion and chemical composition of diets are presented in Table 1 and chemical composition of feeds are presented on Table 2.

Throughout the trial, three animals drastically reduced the dry matter intake (DMI) with no apparent reason. Since the other animals from the same treatment were normal feeding, we decided to remove them from the trial to be medicated. Because of that, at the end of the experiment we had the following replicates for each treatment: 0 g/kg (n = 6), 80 g/kg (n = 5), 160 g/kg (n = 7) and 240 g/kg (n = 7).

2.3. Intake and sample collection

Diets were provided *ad libitum* as total mixed ration (TMR) twice daily (08:00 and 16:00 h). The amount of provided TMR and orts were quantified daily to determine DMI and to ensure at least 10% of orts.

Samples of ground corn, soybean meal and concentrates were collected before the beginning of the trial. Samples of corn silage and TCH were taken weekly. Moreover, samples of orts were taken daily, just before feeding, and then a weekly sample for each animal was composed.

The feed efficiency was estimated by the ratio between ADG and DMI, while feed conversion was estimated by the ratio between DMI and ADG.

2.4. Digestibility

Indigestible NDF (iNDF) was used as internal marker to estimate the nutrient digestibility and fecal output. Feces collection were performed as described by Gionbelli et al. (2014). In summary, two periods of fecal spot sampling, with five consecutive days each period, were performed during the trial. The first period was carried out in the middle of the trial (days 38 to 42) and the second during the last week of the experiment (days 59 to 63).

Fecal samples were collected twice daily directly from the lambs' rectum. On the first day of collection, sampling was performed at 06:00 and 13:30 h. Throughout the collection period, 1.5 h was added to the previous day, therefore, at the end of each period we had samples of feces collected throughout the day. Provided feeds and orts were collected daily during digestibility periods.

The fecal excretion of dry matter (FDM) was estimated by the following equation: FDM (g/day) = [g/kg of dietary iNDF / g/kg of fecal iNDF] x 100. Furthermore, total tract apparent digestibility of the nutrients was estimated as follows: (intake – excretion / intake) x 100.

2.5. Chemical analysis

Weekly composite samples of orts and provided feeds were dried at 55 ^{o}C for 72 h and then grounded using a Willey mill with sieve of 1 mm. Samples collected during the digestibility assays were also grounded using a Willey mill with sieve of 2 mm in order to perform iNDF analysis.

Feeds, orts and feces samples were analyzed according to the standard analytical procedures of the AOAC (1990) for

Brazilian National Institute of Science and Technology in Animal Science (INCT-CA; Detmann et al., 2012) for DM (dried overnight at 105 °C; method INCT-CA number G-003/1), ash (complete combustion in a muffle furnace at 600 °C for 4 h; method INCT-CA number M-001/1), CP (Kjeldahl procedure; method INCT-CA number N-001/1), EE (method INCT-CA number G-004/1), iNDF (method INCT-CA number F-008/1) and apNDF (using a heat-stable α-amylase, omitting sodium sulfite, and correcting for contaminant ash and protein; methods INCT-CA F-002/1; N-004/1; and M-002/1).

Acid detergent fiber (method INCT-CA number F-004/1) and lignin (determined by solubilization of cellulose with sulphuric acid and expressed inclusive of residual ash; method INCT-CA number F-005/1) were performed on coffee hulls samples to verify the CaO treatment effectiveness on those parameters (Table 2).

Non-fiber carbohydrates (NFC) of the diets was estimated as described by Detmann et al. (2012) as follows: NFC = 100 – ash – EE – NDFap – (CP – CPu + U); in which: CPu = assuming 260% of CP in the mixture of urea and ammonium sulfate, and U = amount of urea added in each diet.

The total digestible nutrients (TDN) were estimated using the following equation from NRC (2001): TDN (%) = dCP + $dNDF_{ap}$ + dNFC + (2.25 x dEE); in which: dCP = apparent digestible crude protein; $dNDF_{ap}$ = apparent digestible neutral detergent fiber corrected for ash and protein; $dNFC_{ap}$ = apparent digestible non-fiber carbohydrates corrected for ash and protein; and dEE = apparent digestible ether extract.

2.6. Slaughter procedure, carcass evaluation and meat sampling

Lambs were submitted to a total of 66 days of performance evaluation. At the end of the trial, final body weight (FBW) was obtained after a 16 h solid fasting and then the lambs were slaughtered by cerebral concussion followed by jugular and carotid venesection. Immediately after slaughter, carcasses were weighed to obtain the values of hot carcass weight (HCW). Moreover, initial temperature and pH were measured on the left carcass between 12^{th} and 13^{th} rib, using a potentiometer with a glass probe for pH and temperature (SevenGo^{TM}, Mettler Toledo-Schwerzenbach, Switzerland).

All carcasses were refrigerated at 4 °C for 24 h. After this period, carcasses were taken from the cooling chambers and weighed again in order to determine the cold carcass (CCW) weight. In addition, final temperature and pH were measured in the same site of the initial pH. Afterward, the *Longissimus dorsi* muscles were removed from right side of the chilled carcasses, and individually vacuum packaged, frozen and stored at -20 ^{o}C until subsequent meat quality analysis.

Hot carcass yield (HCY) and cold carcass (CCY) yield were calculated using the following equations: HCY = HCW / FBW x 100 and CCY = CCW / FBW x 100.

2.7. Meat quality evaluation

Meat color measurement was performed on three steaks 24 h after thawing at 4 °C. Steaks were exposed to air 30 min prior measurements. Values of L^* (lightness), a^* (redness), and b^* (yellowness) were obtained from five readings performed at different points on the surface of each steak, using a Hunter MiniScan EZ colorimeter (4500L; Hunter Associates Laboratory, Inc., Reston, Virginia, USA).

Thawing loss were estimated by weight difference between frozen and thawed steaks. The same steaks previously thawed for meat color measurements were weighted, vacuum packed and cooked in a water bath at 70 °C for 30 minutes. Then, the steaks were placed in an ice bath for 10 minutes to stop cooking and kept in refrigerator for 24 h. Lastly, they were removed from the package and weighed again to obtain water cooking loss. The results of water loss by thawing and cooking were used to estimate the total loss of water of each steak, using the following equation: Total water loss (%) = [(frozen steak weight – cooked steak weight) / frozen steak weight] x 100.

Warner-Bratzler shear force (WBSF) was determined using the cooked steaks after cooled for 24 h at 4 ºC (AMSA, 1995). Five cylindrical samples with 1.27 cm in diameter were removed from each steak parallel to the long axis of the muscle fibers, using a stainless-steel device for the extraction of samples (AMSA, 1995). Shear force was determined by perpendicular incision of the muscle fibers of each cylinder of meat by Warner-Bratzler shear device (G-R Electrical Manufacturing Company, Manhattan, KS, USA).

Sarcomere length was estimated according to the laser diffraction technique (Cross et al., 1981). Six individual muscle fiber were teased from the muscle bundle and placed on a microscope slide with a drop of 0.2 M sucrose solution (0.2 M glucose and 0.1 M $NaHPO_4$ with pH 7). Sarcomere length was measured by laser diffraction using a 05-LHR-021 laser

(Melles Griot, Carlsbad, CA) and calculated by using the following equation:

Sarcomere length (μm) = [0.6328 x D x $\sqrt{(T/D)^2 + 1}$]/T; in which: D = distance (mm) from the specimen-holding device to the screen (throughout this experiment, D had a constant value of 120 mm) and T = the separation (mm) between the zero and the first maximum band.

2.9. Statistical analysis

Data were analyzed as a completely random design using SAS 9.4 software (2017). The statistical model used was:

$Yij = \mu + Ti + \varepsilon(i)j$; in which: *Yij* = experimental response measured on the treatment *i* and repetition *j*; μ = population mean; *Ti* = treatment effect of treatment *i* (i = 0, 80, 160 and 240 g/kg of coffee hulls replacement); and *ε(i)j* = residual error.

Linear and quadratic effects due to TCH inclusion levels were determined and means were separated using LSMEANS command in SAS. Significant differences were accepted if $P \leq 0.05$.

3. Results

3.1. Intake and apparent digestibility

Increasing levels of TCH in the diets led to a quadratic effect on intake of DM and its components (P < 0.05). Intake values of DM, CP, apNDF, NFC and TDN were highest at the intermediate levels of replacement (Table 3). Moreover, as level of coffee hulls increased in the diets, both DM and CP apparent digestibility declined linearly (P = 0.001). However, apparent digestibility of apNDF, EE and NFC were not influenced by treatments (P > 0.05).

3.2. Performance and carcass traits

Dietary treatments led to a quadratic effect on final body weight (P = 0.026) and ADG (P = 0.001). Values of ADG were highest at the intermediated levels of corn silage replacement by TCH. Moreover, feed efficiency and feed conversion ratio were unaffected by treatments ($P > 0.05$).

Also, a quadratic effect was observed on both hot and cold carcass weight values ($P < 0.05$). Values of carcass weight were highest at 160 g/kg of corn silage replacement by TCH (Table 4). Dietary treatments had no effect on hot carcass yield ($P > 0.05$). However, cold carcass yield increased linearly as addition of TCH increased ($P = 0.047$).

3.3. Meat quality

Although there was no treatment effect ($P > 0.05$) on pH, thawing, cooking and total water loss and sarcomere length values (Table 5), a quadratic effect was observed for WBSF ($P = 0.029$). The lowest value of WBSF were observed with the inclusion of 80 g/kg of TCH.

4. Discussion

4.1. Intake and apparent digestibility

Alkaline treatments are well-known in improving microorganism fermentation of poor quality feedstuffs due to reduction of crystallinity of lignocellulosic structure (Kerley et al., 1985; Zaman and Owen, 1995; Chapple et al., 2015). As expected, contents of NDF, ADF and lignin reduced on TCH compared with untreated coffee hulls (Table 2), while content of NDF on total diets increased because of treatments that consisted of increasing levels of TCH (Table 1). Therefore, the lowest value of feed intake observed at the highest level of corn silage replacement by TCH could be explained by the decrease in DM digestibility as level of TCH increased. Although values of apFDN were higher at the intermediate levels of TCH inclusion, its digestibility remained similar as addition of TCH increased (Table 3), probably due to lignin content present on coffee hulls. Lignin is a phenolic compound that reduces cellulose and hemicellulose digestion by ruminal microorganisms (Kerley et al., 1988).

Although diets were formulated to contain equal amount of CP, coffee hulls have greater proportion of CP linked to fiber than corn silage as observed by the values of NDIP/CP (Table 2). Consequently, it decreases the nitrogen availability to the ruminal microorganisms. Thus, this is a factor that explain the reduction of crude protein digestibility (Table 3) as corn silage replacement by TCH increases.

Moreover, as stated by some authors (Hawkins and Davis, 1970; Brand et al., 2000; Pandey et al., 2000), coffee sub-products also contain organic compounds, such as caffeine and tannins, which are considered anti-nutritional factors that limits animal feed intake and protein digestibility. Lastly, because sheep has the ability to select specific and more palatable ingredients of the diet and we evidenced large amounts of coffee hulls in the orts at the highest level of inclusion, the palatability could be another characteristic of coffee hulls that reduces diet intake.

4.2. Performance and carcass traits

Our results suggest that corn silage can be replaced by TCH at levels up to 160 g/kg on DM basis without compromising animal performance. Lambs fed diet with 240 g/kg of TCH showed impaired performance when compared with other treatments probably because reduction of DMI and digestibility of DM and CP. Previous study of Teixeira et al. (2007) who evaluated the replacement of corn silage by coffee hulls (0, 70, 140 and 210 g/kg DM basis) on performance and digestibility of dairy heifers observed a linearly decrease of ADG, DM intake and digestibility as coffee hulls level increased. Possibly, we obtained better results on animal performance due to effectiveness of the coffee hulls treatment, which allows the improvement of fiber digestibility.

Values of hot and cold carcass weight and carcass yield of the treatments receiving up to 160 g/kg of TCH were similar to values observed by Garcia et al. (2010) in crossbred lambs (Dorper x Santa Inês) receiving a diet composed by 30% of Tifton hay and 70% of ground corn and soybean meal concentrate, while values of carcass weight at the ultimate level of corn silage replacement were similar to lambs managed on extensive system (Garcia et al. 2010).

4.3. Meat quality

Inclusion of coffee hulls in the lambs' diet did not negatively affect meat quality parameters (Table 5). Final pH values were below six, which is recommended to avoid dark-cutting meat. Because the extent of pH decline during *rigor mortis* has major influences on meat quality attributes such as tenderness, color and water holding capacity (Kim et al., 2014), we assume that meat quality parameters remained within desirable ranges.

Meat color can be influenced by species, age, diet and pH (Braden, 2013). In our study, the only parameter that could influence meat color would be the inclusion levels of TCH and since no difference on meat color was observed among the treatments, we can infer that coffee hulls do not affect meat color. Furthermore, our results suggest that the mean values of lightness (L*; 38.43) and redness (a*; 15.65) are considered acceptable by the consumers because according to Khliji et al. (2010) consumers usually consider the meat color acceptable when values of lightness and redness are equal or greater than 34 and 9.5, respectively.

The WBSF is an indirect method used to measure meat tenderness and it is influenced by sarcomere length. Studies of Cross et al. (1981) and Rhee et al. (2004) showed that sarcomere length has a positive correlation with tenderness. According to Penny and Dransfield (1979), short sarcomere is a characteristic of tough meat. In this study, values of WBSF showed acceptable tenderness as classified by Hopkins et al. (2006), which characterize an acceptably tender meat values of shear force less than 49 N.

Since there were no differences on sarcomere length, another characteristic that could explain the differences on values of WBSF is the growth rate. The growth rate is characterized in vivo by the rate of protein synthesis and degradation, known as protein turnover. The protein turnover in vivo can affect the rate of postmortem muscle proteolysis and meat tenderness (Kristensen et al., 2002). Thus, it is possible to assume that lambs fed 80 g/kg of TCH had the lowest average of WBSF, probably because that group presented higher ADG than animals that received 240 g/kg of TCH.

5. Conclusion

Coffee hulls treated with CaO replacing up to 160 g/kg DM of corn silage is a suitable agro-industrial residue for lambs' diet, composed by 500 g/kg of corn silage and 500 g/kg of concentrate, because animal performance and meat quality is not compromised.

Funding

This work was supported by the Fundação de Amparo à Pesquisa do Estado de Minas (FAPEMIG; grant number: APQ–01980-14), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

References

AMSA - American Meat Science Association. 1995. Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. Chicago, IL: American Meat Science Association.

Braden, K.W., 2013. Converting muscle to meat: the physiology of rigor, in: Kerth, C.R. (Ed.), The Science of Meat Quality. John Wiley & Sons, Inc., Iowa, pp. 79-97.

Brand, D., Pandey, A., Roussos, S., Soccol, C. R., 2000. Biological detoxification of coffee husk by filamentous fungi using a solid state fermentation system. Enzyme and Microbial Technology, 27, 127-133.

Chapple, W.P., Cecava, M.J., Faulkner, D.B., Felix, T.L., 2015. Effects of feeding processed corn stover and distillers grains on growth performance and metabolism of beef cattle. Journal of Animal Science, 93, 4002-4011.

Chaudhry, A.S., 2000. Rumen degradation in sacco in sheep of wheat straw treated with calcium oxide, sodium hydroxide and sodium hydroxide plus hydrogen peroxide. Animal Feed Science and Technology, 83, 313-323.

Cross, H.R., West, R.L., Dutson, T.R., 1981. Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. Meat Science, 5, 261-266.

Detmann. E., Souza. M.A., Valadares Filho. S.C., Queiroz. A.C., Berchielli. T.T., Saliba. E.O.S., Cabral. L.S., Pina. D.S., Ladeira. M.M., Azevedo. J.A.G., 2012. Métodos para análise de alimentos. Visconde do Rio Branco: Suprema. 214p.

Garcia, I.F.F., Costa, T.I.R., Almeida, A.K.D., Pereira, I.G., Alvarenga, F.A.P., Lima, N.L.L., 2010. Performance and carcass characteristics of Santa Inês pure lambs and crosses with Dorper e Texel at different management systems. Revista Brasileira de Zootecnia, 39, 1313-1321.

Gionbelli. T.R.S., Veloso. C.M., Gionbelli. M.P., Novais. M.A.S., Silva. A.L., Espechit. C.J.B., Campos. J.M.S., Valadares Filho. S.C., Pereira. O.G., Cunha. C.S., Alcântara. P.H., Virgínio. G.F., Duarte. M.S., 2014. Utilization of castor bean meal treated with calcium hydroxide, fed wet or dry, by lambs. Livestock Science, 168, 76–83.

Gouvea, B.M., Torres, C., Franca, A.S., Oliveira, L.S., Oliveira, E. S., 2009. Feasibility of ethanol production from coffee husks. Biotechnology Letters, 31, 1315-1319.

Hopkins, D.L., Hegarty, R.S., Walker, P.J. and Pethick, D.W., 2006. Relationship between animal age, intramuscular fat, cooking loss, pH, shear force and eating quality of aged meat from sheep. Australian Journal of Experimental Agriculture, 46, 879-884.

International Coffee Organization, 2019. Trade statistics tables. http://www.ico.org/prices/po-production.pdf (accessed 16 February 2019).

Kerley, M.S., Fahey, G.C., Berger, L.L., Gould, J.M., Baker, F.L., 1985. Alkaline hydrogen peroxide treatment unlocks energy in agricultural by-products. Science, 230, 820-822.

Kerley, M.S., Fahey Jr., G.C., Gould, J.M., Iannotti, E.L., 1988. Effects of lignification, cellulose crystallinity and enzyme accessible space on the digestibility of plant cell wall carbohydrates by the ruminant. Food Structure, 7, 59-65.

Khliji, S., Van de Ven, R., Lamb, T.A., Lanza, M., Hopkins, D. L., 2010. Relationship between consumer ranking of lamb colour and objective measures of colour. Meat Science, 85, 224-229.

Kim, Y.H.B., Warner, R.D., Rosenvold, K., 2014. Influence of high pre-rigor temperature and fast pH fall on muscle proteins and meat quality: a review. Animal Production Science, 54, 375-395.

Kristensen, L., Therkildsen, M., Riis, B., Sørensen, M. T., Oksbjerg, N., Purslow, P. P., & Ertbjerg, P., 2002. Dietary-induced changes of muscle growth rate in pigs: Effects on in vivo and postmortem muscle proteolysis and meat quality. Journal of Animal Science, 80, 2862–2871.

NRC, 2001. Nutrient Requirements of Dairy Cattle: Seventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/9825.

NRC, 2007. Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids. Washington. DC: The National Academies Press. https://doi.org/10.17226/11654.

Pandey, A., Soccol, C.R., Nigam, P., Brand, D., Mohan, R., Roussos, S., 2000. Biotechnological potential of coffee pulp and coffee husk for bioprocesses. Biochemical Engineering Journal, 6, 153-162.

Penny, I.F., Dransfield, E., 1979. Relationship between toughness and troponin T in conditioned beef. Meat Science, 3, 135-141.

Rhee, M.S., Wheeler, T.L., Shackelford, S.D., Koohmaraie, M., 2004. Variation in palatability and biochemical traits within and among eleven beef muscles. Journal of Animal Science, 82, 534-550.

SAS (Statistical Analysis Systems Institute Inc.), 2017. User's Guide, Version 9.4. SAS Institute Inc., Cary, NC, USA.

Shi, H.T., Cao, Z.J., Wang, Y.J., Li, S.L., Yang, H.J., Bi, Y.L., Doane, P.H., 2016. Effects of calcium oxide treatment at varying moisture concentrations on the chemical composition, in situ degradability, in vitro digestibility and gas production kinetics of anaerobically stored corn stover. Journal of Animal Physiology and Animal Nutrition, 100, 748-757.

Shreck, A.L., Nuttelman, B.L., Harding, J.L., Griffin, W.A., Erickson, G.E., Klopfenstein, T.J., Cecava, M.J., 2015. Digestibility and performance of steers fed low-quality crop residues treated with calcium oxide to partially replace corn in distillers grains finishing diets. Journal of Animal Science, 93, 661-671.

Teixeira, R.M.A., Campos, J.M.S., Valadares Filho, S.C., Oliveira, A.S., Assis, A.J. and Pina, D.S., 2007. Consumo, digestibilidade e desempenho de novilhas alimentadas com casca de café em substituição à silagem de milho. Revista Brasileira de Zootecnia, *36*, 968-977.

Zaman, M.S., Owen, E., 1995. The effect of calcium hydroxide and urea treatment of barley straw on chemical composition and digestibility in vitro. Animal Feed Science and Technology, 51, 165-171.

Tables

Table 1
Ingredients and chemical composition of experimental diets

	Treatment[a] (g/kg DM)			
	0	80	160	240
Ingredients, g/kg of DM				
Corn silage	500	420	340	260
Treated coffee hulls	0	80	160	240
Grounded corn	293.4	293.4	293.4	293.4
Soybean meal	178.1	178.1	178.1	178.1
Urea:Ammonium Sulfate (9:1)	10.0	9.2	8.4	7.6
Mineral premix[b]	13.5	13.5	13.5	13.5
Sand	5.0	5.8	6.6	7.4
Chemical Composition, g/kg of DM				
Dry matter (g/kg of fresh matter)	603	621	639	653
Organic matter	944	934	925	916
Crude protein	165	158	172	167
Neutral detergent fiber	313	329	346	363
apNDF[c]	282	294	298	308
Ether extract	30	25	26	22
Non-fiber carbohydrates	465	455	428	418

[a] Replacement levels of corn silage by TCH.
[b] Levels of guarantee/kg: Dicalcium phosphate (18.5% P): 500 g; Sodium chloride: 496.4 g; Zinc sulfate: 1.8 g; Copper sulfate: 1.5 g; Cobalt sulfate: 0.1 g; Sodium selenite: 0.1 g; Potassium iodate: 0.1 g.
[c] Neutral detergent fiber corrected for ash and protein content.

Table 2
Chemical composition of ingredients used in the experimental diets.

Analyses, g/kg of DM	Corn silage	TCH	Ground corn	Soybean meal
Dry matter, g/kg	322	532	881	893
Organic matter	950	848	988	930
Crude protein	67	103	79	491
NDF[a]	483	590	158	241
NDIP/CP[b]	152	470	158	70
apNDF[c]	462	513	153	61
Ether extract	27	8	42	29
ADF[d]	-	540	-	-
Lignin	-	207	-	-

[a] Neutral detergent fiber.
[b] Neutral detergent insoluble protein by unit of crude protein.
[c] Neutral detergent fiber corrected for ash and protein content.
[d] Acid detergent fiber.

Table 3
Effect of feeding TCH to replace corn silage on intake and total tract apparent digestibility

Item[a]	Treatment[b] (g/kg DM)				SEM[c]	*P*-value[d]	
	0	80	160	240		Linear	Quadratic
Intake, g/day							
DM	1071a	1121a	1122a	904b	29.8	0.048	0.010
CP	177ab	190a	190a	159b	4.6	0.177	0.010
apNDF	304ab	325a	340a	263b	9.0	0.159	0.002
EE	32a	31a	29a	24b	0.8	0.0001	0.025
NFC	504a	507a	484a	388b	15.0	0.003	0.040
TDN	736a	763a	733a	571b	22.1	0.004	0.007
Total apparent digestibility, g/kg							
DM	673a	680a	655ab	634b	5.2	0.001	0.125
CP	690a	652b	662ab	618c	7.5	0.001	0.630
apNDF	370ab	396a	381ab	344b	8.4	0.217	0.058
EE	843	862	860	842	7.4	0.950	0.230
NFC	874	881	867	863	3.4	0.131	0.503

Means within same row without common letters differ (P ≤0.05).
[a] DM = dry matter, CP = crude protein, apNDF = neutral detergent fiber corrected for ash and protein, EE = ether extract, NFC = non-fiber carbohydrate, TDN = total digestible nutrients.
[b] Replacement levels of corn silage by TCH.
[c] Standard error mean.
[d] P ≤ 0.05.

Table 4
Effect of feeding TCH to replace corn silage on performance and carcass traits

Item	Treatment[b] (g/kg DM)				SEM[c]	*P*-value[d]	
	0	80	160	240		Linear	Quadratic
Animal performance							
IBW, kg	21.49	19.41	21.11	19.41	0.48	0.269	0.986
FBW, kg	37.43a	37.14a	38.49a	32.57b	0.76	0.039	0.026
ADG, kg/d	0.241a	0.269a	0.263a	0.199b	0.01	0.063	0.001
Feed efficiency	0.226	0.241	0.235	0.222	0.01	0.731	0.302
Feed conversion	4.45	4.19	4.27	4.70	0.13	0.482	0.203
Carcass traits							
HCW, kg	17.63ab	17.50ab	18.69a	15.67b	0.40	0.174	0.040
CCW, kg	17.26ab	17.22ab	18.29a	15.46b	0.38	0.184	0.039
HCY, %	47.07	47.09	48.48	48.07	0.29	0.099	0.598
CCY, %	46.09	46.34	47.45	47.42	0.29	0.047	0.722

Means within same row without common letters differ (P ≤0.05).
[a] IBW = initial body weight, FBW = final body weight, ADG = average daily gain, HCW = hot carcass weight, CCW = cold carcass weight, HCY = hot carcass yield, CCY = cold carcass yield.
[b] Replacement levels of corn silage by TCH.
[c] Standard error mean.
[d] P ≤ 0.05.

Table 5
Effect of feeding TCH to replace corn silage on meat quality

Item	Treatment[a] (g/kg DM)				SEM[b]	*P*-value[c]	
	0	80	160	240		Linear	Quadratic
Initial temperature, ºC	31.05	31.68	29.23	29.57	0.44	0.087	0.977
Initial pH	6.65	6.55	6.90	6.72	0.06	0.384	0.630
Final temperature, ºC	8.47b	8.22b	8.81ab	9.69a	0.19	0.008	0.106
Final pH	5.47	5.42	5.43	5.50	0.02	0.694	0.245
Thawing loss, %	2.30	2.69	4.53	3.64	0.52	0.226	0.473
Cooking loss, %	21.91	22.67	22.34	24.35	0.53	0.135	0.501
Total water loss, %	23.72	24.73	25.85	27.07	0.72	0.081	0.943
Color L*	36.86	39.62	39.05	38.19	0.51	0.460	0.094
Color a*	16.21a	16.77a	14.35b	15.25ab	0.34	0.096	0.608
Color b*	14.97	15.90	14.82	14.89	0.25	0.590	0.522
WBSF[d], N	42.18ab	36.89b	41.38b	50.66a	1.77	0.052	0.029
Sarcomere length, µm	2.28	2.29	2.26	2.26	0.01	0.559	0.968

Means within same row without common letters differ ($P \leq 0.05$).
[a] Replacement levels of corn silage by TCH.
[b] Standard error mean.
[c] $P \leq 0.05$.
[d] Warner-Bratzler shear force.