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Quality of Santa Inês × Dorper sheep meat submitted to different levels of inclusion of sunflower cake

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Abstract

Aim of study: To evaluate the physicochemical and sensory quality of meat from Santa Inês × Dorper lambs fed diets with increasing levels of sunflower cake.

Area of study: Rio Grande do Norte (Brazil).

Material and methods: Twenty-four castrated lambs (initial weight of 18.9 ± 2.17 kg) were distributed in a completely randomized design with four treatments (0, 5, 10 and 15% sunflower cake in diet) with six repetitions and kept in confinement until reaching the average body weight of 32.1 ± 2.6 kg. The *Longissimus lumborum muscle* was used for proximate composition and physicochemical analyzes, and the *Semimembranosus* muscle was used for pH (after 24 h of slaughter) and sensory analysis assays.

Main results: The increasing levels of sunflower cake did not affect the composition or physicochemical properties. Sensory analysis also did not reveal significant differences in meat obtained from animals in different diets. Principal Components Analysis indicated that juiciness, color, odor and flavor were positioned opposite to protein, texture, and ash.

Research highlights: The use of sunflower cake in diets for crossbred sheep Dorper × Santa Inês as soybean meal and corn replacer, up to 15% inclusion of soybean meal and corn, does not affect the proximate composition, physicochemical or sensory characteristics of the meat.

Additional key words: sunflower meal; sensory analysis; proximate composition; water holding capacity; shear force.

Abbreviations used: CL (cooking loss); DM (dry matter); PC1 (principal component one); PC2 (principal component two); SF (shear force); WHC (water holding capacity).

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Introduction

Sheep and goat meat are important sources of dietary proteins with high biological value and nutrients (Webb *et al.,* 2005; Ponnampalam *et al.,* 2015). The global production of sheep and goat meat increased from 15 million tons to 16.2 million tons between 2015 and 2019 (FAOSTAT, 2021). Moreover, rearing these animals (largely composed of traditional breeds) has a socioeconomic role in less developed regions by providing occupation, income, and food security for local populations (Lobo, 2019; Morales-Jerrett *et al.,* 2020). Among the many factors involved in meat production, animal feed composition is considered a crucial component to promote the proper animal development and finishing as well as the improvements in meat quality (Knapik *et al.,* 2017). Specifically, meat quality comprises the nutritional value, physicochemical (such as color, water holding capacity, and shear force), and sensory properties that, collectively, govern the suitability of meat for consumption (Elmasry *et al.,* 2012).

Animal diet has also gained another dimension due to the concerns about current practices to produce crops (Salami *et al.,* 2019a). The use of edible crops (food-feed competition) that also have an environmental impact (land-use, soil erosion, and climate change, for instance) is a major component in meat production cost (Peacock & Sherman, 2010; Salami *et al.,* 2019a). Consequently, the search for alternative sources of nutrients for meat animals has become an important aspect to improve the current commercial meat production systems (Salami *et al.,* 2019a). In this sense, the concept of circular economy gained the spotlight. Circularly economy consist in the strategic utilization of resources, reduction of waste generation, and also reutilization of co-products of production chains, which fits in the current trend of sustainable development (Hamam *et al.,* 2021).

Sunflower cake/biomass is the co-product obtained from cold pressing of sunflower seeds for biodiesel production and is considered a rich source of nutrients with high contents of protein, fiber, and minerals (29-61%, 4-45%, and 6-9%, respectively) (Brazil *et al.,* 2019; Subaşı *et al.,* 2021). In this context, the incorporation of sunflower cake in the diet of ruminant has been studied in the last decade. For instance, the use of increasing levels of sunflower cake (up to 30%) in Santa Ines lambs improved the fat content and the fatty acid profile of *Longissimus lumborum* muscle (Lima *et al.,* 2018). Additionally, no significant effects were reported for chemical composition and sensory attributes. Conversely, a similar experiment with sunflower (8, 16 and 24%) in the diet of Boer goats revealed no significant effect in the pH or chemical composition of *Longissimus lumborum* muscle whereas tenderness was reduced (Oliveira *et al.,* 2015).

Considering the utilization potential of sunflower cake in animal feed, this study aimed to evaluate the meat quality (proximate composition and physicochemical characteristics in *Longissimus lumborum* muscle; and pH (24 h) and sensory analysis in *Semimembranosus* muscle) of crossbred lambs (Santa Inês × Dorper) fed with increasing levels of sunflower cake.

Material and methods

Animal, diets, and slaughter

Twenty-four male castrated lambs (Santa Inês × Dorper) with initial mean weight of 18.9 ± 2.17 kg and mean age of 2 months were allocated into individual pens (1.50 m²) located at the Universidade Federal da Paraíba, Brazil.

Table 1. Chemical composition of the main ingredients in the experimental diets (g/kg DM) for Santa Inês × Dorper lamb.

Item	Ingredients			
	Ground corn	**Soybean meal**	**Sunflower cake**	**Tifton hay**
Dry matter (g/kg DM)	876.4	886.1	924.9	899.4
Organic matter	984.5	936.8	952.5	933.6
Mineral matter	15.5	63.2	47.5	66.4
Crude protein	91.1	487.5	345.1	96.5
Ether extract	40.7	17.1	63.1	16.5
Neutral detergent fiber	139.8	146.2	374.8	798.9
Fiber in acid detergent	40.8	98.6	278.6	390.3
Lignin	11.6	13.3	10.7	53.5
Total carbohydrates	852.7	432.2	544.4	820.6
Non-fibrous carbohydrates	712.9	286.0	169.6	21.7
Total digestible nutrients	872.4	815.4	776.6	512.0

DM: dry matter.

Table 2. Percentage of main ingredients and chemical composition of the experimental diets based (% DM) with increasing levels of sunflower cake for Santa Inês × Dorper lamb.

	Level of inclusion (%)			
	0	**5**	**10**	**15**
Ingredients				
Ground corn	40.40	38.95	38.40	36.60
Soybean meal	16.60	13.05	8.60	5.40
Sunflower cake	0.00	5.00	10.00	15.00
Mineral supplement	2.00	2.00	2.00	2.00
Tifton hay-85 (*Cynodon* sp)	41.00	41.00	41.00	41.00
Chemical composition of diets				
Dry matter (% DM)	86.99	87.20	87.39	87.61
Organic matter	93.60	93.61	93.66	93.65
Mineral matter	6.40	6.39	6.33	6.34
Crude protein	15.73	15.59	15.10	15.10
Ether extract	2.60	2.80	3.01	3.20
Neutral detergent fiber	40.82	41.98	43.12	44.28
Fiber in acid detergent	19.28	20.27	21.20	22.20
Lignin	2.88	2.87	2.86	2.85
Total carbohydrates	75.26	75.21	75.54	75.37
Non-fibrous carbohydrates	34.43	33.23	32.42	31.07
Total digestible nutrients	69.77	69.49	69.27	68.97

DM: dry matter

Animals had free access to water and food. After 15 days of adaptation to the facilities, the lambs were fed *ad libitum* twice a day at 08:00 am (60% of the total offered per day) and at 04:00 pm (40% of the total offered per day). Additionally, the quantity supplied (15% of leftovers) was daily controlled. The isoproteic diets (15% crude protein) were provided to animals with a forage: concentrate ratio of 40:60 (using the total-mixed ration method), targeting a gain of 200 g/day according to the recommendations of the NRC (2007). Tifton 85 hay (*Cynodon dactylon* L.) was used as forage and the concentrate was composed of soybean meal, ground corn, mineral supplement (Table 1), and increasing levels of sunflower cake (0, 5, 10 and 15% DM) (Table 2). This study was approved by the *Universidade Federal da Paraíba*`s institutional committee on animal use (protocol no. 2305/14).

All animals were slaughtered (after fasting for 16 h with full access to water) in a single day after achieving 32.1 ± 2.6 kg (p>0.05). The average daily gain (184.9-229.2 g/day, p>0.05) was similar among treatments. Animals were slaughtered at the industrial slaughterhouse Companhia Frigorífica Potengy located at Parnamirim (Brazil) following the Brazilian regulation for humane and sanitary animal slaughter (RIISPOA) (Brasil, 2000). Animals were stunned and sectioned in the carotid and jugular veins for bleeding and the carcasses were skinned and eviscerated. Chilling was carried out in a cold chamber at 4 °C for 24 h. After this period, pH was determined at the *Semimembranosus* muscle with portable a pHmeter (Testo 205, Testo, Spain). Carcasses were longitudinally cut by the backbone to obtain the halves carcasses and cut into commercial cuts. Then, the *Longissimus lumborum* and *Semimembranosus* muscles were identified, packaged, and frozen at -18°C until further analysis.

Chemical and physicochemical analyses

The *Longissimus lumborum* muscle was used for chemical and physical analyses. To analyze the chemical composition, the samples of each animal were thawed in a conventional refrigerator (at 5 °C) for 24 hours. Then, the connective tissue was removed, and the samples were thoroughly homogenized in a domestic blender (Arno, Brazil). The moisture, ash, and protein contents were determined according to the methodology described by AOAC (2000), in protocols 985.41; 920,153 and 928.08, respectively. The quantification of total lipids followed the methodology described by Folch *et al.* (1957). All chemical analyses were performed in triplicates.

Cooking loss (CL) and water holding capacity (WHC) were determined using the methodologies described by

Table 3. Definitions of descriptors used in the sensory analysis of lamb meat (ISO 8586-1, 1993).

Attributes	Definition
Odor[a]	Intensity of odor associated with ovine species
Color[b]	Intensity of color associated with ovine species
Texture[c]	Force needed to compress a piece of meat between the molar teeth, evaluated at the first bite
Juiciness[d]	Perception of the amount of liquid released from the meat sample in the mouth after the 5th chew
Flavor[a]	Intensity of flavor associated with ovine species

[a] 0 = very weak, 9 = very intense; [b] 0 = very clear, 9 = very intense; [c] 0 = very hard; 9 = very soft; [d] 0 = very dry; 9 = very juicy.

Honikel (1998) and Hamm (1961), respectively. For CL assay, the meat was thawed at 5 °C for 18 hours, and then cut into 2.0 cm thick pieces. Six replicates for each sample were weighed, packaged into a heat resistant plastic bag, and placed in a boiling water bath (> 100 °C) until the core temperature reached 75 °C (monitored with a digital thermometer). Upon reaching this temperature, the plastic bag was removed from the water bath and immediately cooled in an ice bath until reaching the internal temperature of 24 °C. CL was expressed as a percentage of the difference between the initial and final weight. The WHC was determined by loss of exudate (%). The meat samples were pressed with a 5 kg weight for 5 min (in triplicate).

The shear force (SF) assay was used to evaluate texture, using the same samples CL evaluation. Meat pieces (fibers oriented perpendicularly to the Warner Blatzer blade) were cut with descent speed of 5 mm/s in a the texturometer (TA.TX. Plus, Estralab, Brazil). The peak of the shear force was recorded and the result was expressed in kgF (Bratzler, 1949).

The color was measured in the *Longissimus lumborum* muscle 24 h after the slaughter (at the end of chilling period). Samples were exposed to air for 50 min at room temperature. A digital colorimeter (model CR-14, Konica Minolta, Europe) was used to obtain L* (brightness), a* (red-green component), and b* (yellow-blue component) values following the Commission Internationale de L'éclairage system (CIE L*a*b*). The instrument was equipped with a light source (illuminant) D65 (observation angle of 10°).

Sensory analyses

The *Semimembranosus* muscle (without salt or seasoning) was wrapped in aluminum foil and cooked at 180 °C in a single plate grill until the core temperature reached 70 °C. Then, external connective tissue and subcutaneous fat were removed and ten portions (2 cm^3) were obtained. Each portion was individually wrapped in aluminum foil, received a random 3-digit code and kept at 55 ºC in a heater. Samples were given to panelists in a random order to avoid any affect related to the order of presentation (Macfie *et al.,* 1989).

Sensory analysis was performed in individual booths with controlled environmental conditions (temperature around 23 °C) (ISO 8589, 2014). Salt biscuits and mineral water were provided to panelists to clean palate between samples. The panel included nine UFPB students who were duly selected and trained according to the protocol ISO 8586-1 (ISO 8586-1, 1993). Briefly, the panelists were selected from a group of habitual consumers of sheep meat that had interest in participating in the study. The process included a selection of panelists based in the sensorial acuity to evaluate sheep meat with a discrimination test. The training was conducted in 10 sessions in order to develop a common vocabulary and agreed upon the list of descriptors and their definitions.

The quantitative descriptive method was used within a complete and balanced block design that included ten

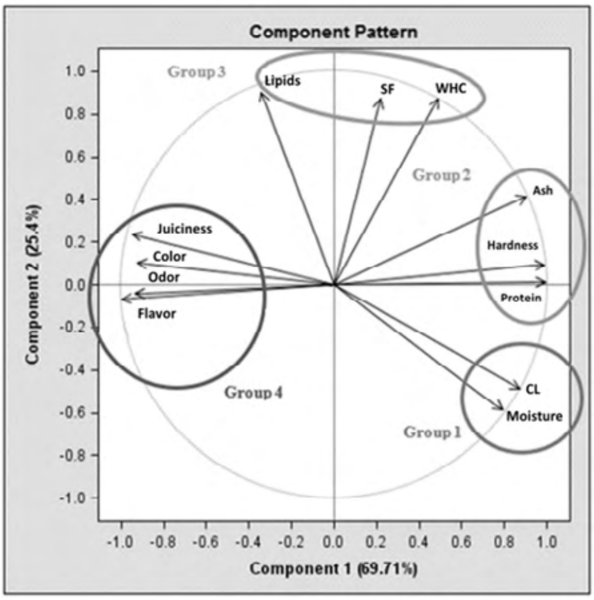

Figure 1. Principal component analysis for the chemical composition, physicochemical parameters and sensory attributes of meat from Santa Inês × Dorper lamb fed with different levels of sunflower cake.

plates containing four samples each. The tests took place in five sessions and two courses per session. Thus, the sensorial analysis included the meat of 24 animals (6 in each treatment) totaling 216 samples analyzed. The analysis was based on 5 sensory descriptors (Table 3), using an unstructured 9-cm scale, anchored at the extremities with terms expressing the intensity.

Statistical analysis

The experimental design was completely randomized (4 treatments and 6 replicates). The obtained data were evaluated through analysis of variance (ANOVA) and the averages were compared by the Tukey test with 5% probability, through PROC GLM of the SAS® program.

The contrast analysis is a practical approach to analyze experimental data regarding the main, interaction and nested effects (Howell, 2010). A contrast is defined as a linear function between treatment means that can be calculated using the equation (1):

$$Y = \sum_{i=1}^{I} c_i \, \mu_i \qquad (1)$$

where Y is the contrast, c_i are the values of coefficients related to each μ_i, and μ_i is the mean of each i treatment.

The contrast analysis can be used on experimental designs that do not fit into defined structures and also to obtain more precise and specific comparisons between groups of means (control *vs.* treatments at different levels, for instance). The significance of the contrast was determined by comparing the $F_{contrast}$ ($F_{contrast} = MS_{contrast}/MS_{error}$) with the $F_{critical}$ at 5% of significance (Howell, 2010). Animal was considered as the experimental unit.

For sensory analysis, the Ryan-Einot-Gabriel-Welsch test was used at a significance level of 5%. Regression analysis (PROC REG) and main component analysis (PROC PRINCOMP) were also performed. All analyses were performed using the Statistical Analysis System (SAS Institute., 2003).

Results

The experimental diets had no effect on the chemical composition or the physicochemical parameters of the meat (Table 4). Moreover, the orthogonal contrast analysis (0% *vs.* 5, 10, and 15% addition of sunflower cake into sheep diet) for these data did not indicate significant differences, except for moisture content. Sensory evaluation of lamb meat revealed that selected descriptors were not affected by increasing levels of sunflower cake (Table 5). The average values found for hardness, juiciness, flavor, aroma, and color were 2.42, 3.90, 4.28, 4.11, and 3.96, respectively.

In order to evaluate the degree of association among the physicochemical composition and the sensorial attributes of the meat of lambs fed different levels of sunflower cake, a Principal Component Analysis (PCA) was carried out. As a result, it is observed that the first two components explained 95.59% of the total variability of meat quality characteristics, 69.71% explained by the first component and 25.88% by the second one (Fig. 1). Protein was the most relevant variable (0.331) in principal component one (PC1) and lipid was the most important factor (0.478) in principal component two (PC2).

Four main groups of variables can be observed in Fig. 1. The group 1 is composed of moisture content and CL; the group 2 is formed protein, hardness, and ash content; the group 3 composed of lipid content, SF, and WHC; the group 4 has juiciness, color, odor, and flavor. Fig. 1 shows that sensory analysis results were mainly distributed in PC1 wherein group 2 (protein, texture, and ash) and 4 (juiciness, color, odor and flavor) were positioned in opposite locations. A similar interpretation can be observed between moisture and lipid content.

Discussion

Our results from chemical composition analysis of *Longissimus lumborum* are in agreement with other studies found in the literature for Santa Inês and their crossbreeds fed with licuri (*Syagrus coronata*) and crambe (*Crambe abyssinica hochst*) cakes, whose percentage values varied between 64 and 76% for moisture; from 14 to 27% for protein; between 1.5 and 7% for lipids; and from 1.0 to 1.2% for ashes (Issakowicz *et al.,* 2017; Costa *et al.,* 2018; Bagaldo *et al.,* 2019). According to these studies, the incorporation of cakes from vegetable oil processing indicated a variable effect in terms of chemical composition of meat. The use of licuri cake (up to 260 g/kg feed) did not cause a significant effect in the composition of lamb meat. It is also relevant to mention that lipid and protein contents varied from 19.7 to 36.3 and from 200 to 189 g/kg feed, respectively, as the level of licuri cake increased in the diet (Bagaldo *et al.,* 2019). Conversely, another study with licuri cake in lamb diet indicated significant increase in moisture content in meat whereas the content of lipids and proteins were reduced due to partial replacing of soybean meal and ground corn by licuri cake (8, 16 and 24% feed in DM) (Costa *et al.,* 2018). In that experiment, increasing levels of licuri cake in the diet resulted in lipid content from 2.6 to 5.1% and protein content around 16%.

The difference in these studies seem to relay in the variations of lipid and protein content in the diet of lambs. High lipid level with reduced protein content has been suggested as the relevant factor that modify the progression of fermentation in the rumen and favor the deposition of fat in body and meat (Bagaldo *et al.,* 2019). Considering this aspect, the results for the chemical composition obtained in our study may be explained by the

Table 4. Chemical composition and physicochemical parameters of *Longissimus lumborum*[a] meat from Santa Inês × Dorper lamb fed with different levels sunflower cake.

Parameter	Level of inclusion				SEM	*p* values	
	0	5	10	15		T	C
Moisture (g/100 g)	73.78	73.63	72.25	72.06	0.94	0.064	0.0191
Protein (g/100 g)	22.67	22.00	21.98	21.41	0.99	0.213	ns
Lipid (g/100 g)	2.62	2.83	2.88	2.98	0.45	0.578	ns
Ash (g/100 g)	1.04	1.01	1.01	1.02	0.04	0.690	ns
pH (24 h) [a]	5.87	5.84	5.84	5.79	0.17	0.782	ns
SF (kgF)	6.43	6.02	5.71	5.22	2.20	0.810	ns
CL (%)	22.97	22.86	23.02	23.14	1.85	0.994	ns
WHC (%)	64.35	63.71	62.94	61.39	4.33	0.670	ns
L*	42.13	42.61	42.84	43.09	1.45	0.708	ns
a*	11.74	10.93	10.83	9.97	1.50	0.265	ns
b*	7.82	7.62	7.12	7.03	0.71	0.189	ns

SF=shear force; CL=cooking loss; WHC=water holding capacity; L=lightness; a=redness; b=yellowness. SEM=standard error of mean. T=treatment; C=Orthogonal contrast: control (0%) *vs* inclusion levels of 0, 5, 10 and 15%. ns = not significant. [a] pH (24 h) assay was determined in *Semimembranosus* muscle.

relatively small variations in lipid and protein contents in diet (Table 2). Moreover, the orthogonal contrast analysis did not indicate significant differences for chemical composition (except for moisture) or physicochemical parameters (Table 4). Although moisture content varied between the meat of animals receiving control and supplemented diet, this effect was not observed in other parameters, indicating a marginal variation derived from diet composition.

A suitable acidification rate in muscles during the 24 hours post-slaughter period leads to pH values between 5.5 and 5.7 in lamb meat (Chauhan *et al.,* 2019). In this experiment, the muscle presented average values higher than this range. This difference may be attributed to pre-slaughter factors such as stress, feeding, and environmental temperature that reduces the glycogen levels in the animal, which limits the pH decay in the post mortem period (Ferguson & Warner, 2008). It is also relevant to mention that our pH values are within the range reported in scientific literature (from 5.68 to 5.96) wherein lambs were fed with licuri cake (Costa *et al.,* 2018), camelina (*Camelina sativa*) meal (Ramírez *et al.,* 2018), and cardoon (*Cynara cardunculus* var. *altilis*) (Salami *et al.,* 2019b).

The effect of agro-food residues in lamb meat varies across studies (L*, a* and b* in the ranges of 35.7-40.00, 14.85-24.4, and 3.12-11.4) (Bezerra *et al.,* 2016; Costa *et al.,* 2018; Bagaldo *et al.,* 2019; Salami *et al.,* 2019b). Similar to our study, Bezerra *et al.* (2016) did not observe significant differences in color of crossbreed (Dorper × Santa Inês) lambs fed with increasing levels of peanut cake (replacing up to 100% of soybean meal). Likewise, Salami *et al.* (2019a), explored the effect of cardoon meal (15% in diet) in Sarda × Comisana lambs meat and reported no significant changes in color. Conversely, the use of licuri cake in lamb feed was associated with significant changes in color (especially redness) of meat (Costa *et al.,* 2018; Bagaldo *et al.,* 2019). For consumers, lamb meats with brightness values below 34 and redness values below 9.5 for a* value are considered dark and unacceptable (Khliji *et al.,* 2010).

Although non-significant differences were obtained for SF among treatments, it is important to note that SF values between 5.0 and 7.9 can be considered tender whereas meat with SF values in the ranges of 8.0–10.9 and above 11 can be classified as acceptable and thought, respectively (Bickerstaffe *et al.,* 2001). Previous studies indicate different results about the effect of sunflower cake and seeds in SF of *Longissimus* muscle of goats and lambs. For instance, a significant reduction SF values (*Longissimus* muscle) was reported by Xazela *et al.* (2012), who compared the effect of two diets (*Medicago sativa vs.* sunflower cake) in the production of autochthonous goats (Boer and Xhosa × Boer cross) of South Africa. However, these authors also indicated similar SF for Xhosa lop eared and Nguni breeds fed with either *Medicago sativa* or Sunflower cake diet. Moreover, a related experiment showed that including 8% of sunflower seeds in diet of Ile de France lamb did not affect the SF in *Longissimus lumborum* muscle (Sales *et al.,* 2013).

The WHC is directly linked to the final quality of the meat because the greater the capacity to retain water, the better the juiciness and the lower the weight loss and CL; which can also be associated to the yield in the preparation for consumption (Warner, 2017). The values of WHC in the present study were close to that reported by Bezer-

Table 5. Sensory analysis of *Semimembranosus* from Santa Inês × Dorper lamb fed with different levels of sunflower cake.

Attribute	Level of inclusion (%)				SEM	*p* values
	0	5	10	15		
Odor	3.71	4.15	4.41	4.16	1.99	0.524
Color	3.73	3.89	3.97	4.25	2.04	0.828
Texture	2.86	2.34	2.12	2.34	1.75	0.396
Flavor	4.09	4.23	4.55	4.25	1.98	0.849
Juiciness	3.41	3.97	4.13	4.10	1.91	0.426

ra *et al.* (2016), who reported non-significant differences (values in the range 63.41-59.86%) among the increasing levels of peanut cake as soybean meal replacer. Similarly, Sales *et al.* (2013) obtained a WHC value of 62.9% in Ile de France lambs fed diets containing sunflower seeds and vitamin E. These authors observed a significant increase in WHC due to sunflower seed supplementation. Additionally, high WHC values were also associated with the retention of water-soluble nutrients in the meat, since these components could be leaked in the exudate. Thus, high values of WHC are indicative of less shrinkage and more soluble myofibrilar proteins (Huff-Lonergan & Lonergan, 2005).

The CL values of lamb meat found in this study were in the range of values found for studies exploring the effect of agro-food residues in lamb feed. In agreement with our results, the inclusion of sunflower seeds (8%) in the diet of Ile de France lambs did not affect the CL of *Longissimus lumborum* muscle (Sales *et al.,* 2013). Other similar studies with agro-food residues indicate a similar outcome. For example, CL mean values between 23.57 and 29.08% were reported for the meat of Dorper × Santa Inês lamb fed with peanut cake (Bezerra *et al.,* 2016), from 25.5 and 29.0% for the incorporation of licuri cake into feed of Santa Inês lamb (Costa *et al.,* 2018), and values in the range of 28.1-31.6% Boer × indigenous lambs with increasing levels of palm kernel cake (7, 14, and 21%) in diet (Ribeiro *et al.,* 2018).

Considering the sensory evaluation data, it was possible to classify the meat as slight hard; with medium to reduced juiciness, flavor, and aroma (all the treatments received scores around the middle of the scale). It is relevant to remember that lamb meat stands out among other meats due to its characteristic and intense odor and flavor. In a similar way to observed in the present study, Ribeiro *et al.* (2018) reported non-significant differences in sensory analysis of lambs fed with palm kernel cake for aroma, flavor, tenderness, and juiciness. A related experiment with Barbarine lambs fed with olive cake did not indicated significant effects in flavor and tenderness whereas significant differences were reported for juiciness (Hamdi *et al.,* 2016).

PCA revealed interesting outcomes regarding the characteristics of meat from animals fed with different levels of sunflower cake. The negative correlation between juiciness and hardness (evaluated by PCA) in lamb and hogget meat was reported in a previous study with animals from two breeds (Norwegian White Sheep and Norwegian Spel) (Bhatti *et al.,* 2020). It is also relevant to mention that this negative correlation between the juiciness and tenderness of meats may occur across different species (Rødbotten *et al.,* 2004). Regarding the negative association between lipid and moisture contents in meat samples from animals with increasing levels of sunflower cake, a recent experiment reported a similar outcome due to the addition of guava processing waste in the feed of lambs (Nobre *et al.,* 2020). Increasing levels of guava (*Psidium guajava* L.) residue in animal feeding were associated with reduced moisture content and increased levels of fat in meat.

Some negative correlations between sensory and chemical composition were also observed in the PCA analysis. Considering the role of proteolysis in the formation of flavor and aroma in meat, a negative correlation between protein content and sensory attributes can be considered. This relation may be explained, at least in part, by a previous study proteomic of meat from Santa Inês × Dorper lambs feed with increasing levels of sunflower cake (5, 10, and 15%) (de Melo *et al.,* 2020). That experiment revealed that the contents of most structural proteins in meat (such as myosin light chain 2, troponin C, tropomyosin beta chain, and actin) were gradually reduced (suggesting intensification of proteolysis) as the level of sunflower cake increased in the diet of animals.

In this context, the inverse relation between protein content and juiciness could be explained by the advance of proteolysis that could affect proteins structure and lead to a reduced capacity to retain water (Pearce *et al.,* 2011). Another consideration related to the progression of proteolysis may explain the inverse relation with the flavor and odor of meat and protein. It is known that proteolysis is a key process for the formation of odor– and flavor–active compounds in meat (Khan *et al.,* 2015).

In summary, sunflower cake when included in feed for lambs (up to 15%) does not interfere with the chemical composition or physicochemical characteristics of *Longissimus lumborum* muscle. Neither pH (24 h) nor sensory characteristics of *Semimembranosus* muscle were affected by the increasing levels of sunflower cake. Therefore, sunflower cake can be used as an alternative source of nutrients in diet of Santa Inês × Dorper sheep with minimal impact in meat quality. Further experiments with a large number of animals are necessary to expand our understanding about the effect of sunflower cake in the meat of Santa Inês × Dorper sheep.

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