

## Effect of breed on meat quality and global acceptance of native lambs and their crosses

R.R.P. Lage<sup>1</sup>, W.H.O. Vega<sup>1#</sup>, H.H.A. Costa<sup>1</sup>, A.C. Costa<sup>1</sup>, L.C.O. Sousa<sup>1</sup>, L.D. Lima<sup>1</sup> & A.V. Landim<sup>1</sup>

<sup>1</sup>Centre of Agrarian and Biological Sciences, Department of Animal Science, State University of Vale do Acaraú -UVA, Betânia, CEP: 62040-370, Sobral, CE, Brazil

<sup>2</sup>Embrapa Goats and Sheep, Fazenda Três Lagoas, PO Box 71, CEP: 62010-970, Sobral, CE, Brazil

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### Abstract

International projections point to the growth in global production of sheep meat, mainly from developing countries. However, the exigencies of consumers on characterization of production systems, nutritional information, and sensorial analysis to target the preferences must be answered. The aim of this study was to characterize the meat quality and the global acceptance of Brazilian native ovine breeds and their crosses, and discuss these aspects on the current basis of human health and wellbeing. Three native breeds (Morada Nova, Rabo Largo, and Santa Inês) that were managed in semi-intensive systems and raised in semi-arid Brazilian regions were used. Chemical composition and fatty acid analysis, sensory evaluation and health indices were accessed. The combined effects of breed, sex and breed by sex interaction produced differentiation in meat fatty acid (FA) profiles. The cholesterol contents ranged between 51 and 59.1 mg/100 g. The Morada Nova lambs showed the lowest lipid content (1.93%). The Morada Nova x Rabo Largo crossbreed breed has the potential to increase the content of conjugated linoleic acid. The high content of  $\alpha$ -linolenic acid, which is considered hypocholesterolemic, was responsible for better health indices. The moderate acceptability obtained in sensory traits is compatible with the requirements of the consumer market. The combination of nutritional and sensory traits associated with human health and wellbeing that is presented by these native ovine breeds qualifies them as a good choice of red meat to be included in a larger proportion in human food.

**Keywords:** fatty acids, healthier meat, semi-arid region, sheep

# Corresponding author: wilortvet@yahoo.es

### Introduction

Red meat is an essential component of the diet in many populations, contributing to reducing malnutrition in developing countries via its supply of protein and key micronutrients (McNeill & Van Elswyk, 2012). There is consensus on the importance of these dietary factors in human health. Ruminant-derived meat fat has received special focus because of its unfavourable relationship with cardiovascular disease and cancer (Stewart & Wild, 2014; Sacks *et al.*, 2017). This is due mainly to its high content of saturated fatty acid (SFA), which is classically related to elevated plasma low density lipoprotein (LDL) and increased cardiovascular risk (Santos *et al.*, 2013). In Brazil, the rapid growth in meat consumption (beef, pork, and poultry) in the last five decades (from 32 kg in the mid-1970s to 91 kg at present), the adoption of a dietary pattern with high saturated fat and sugar, and foods with low fibre content have raised concerns among health agencies (Santos *et al.*, 2013; CONAB, 2017).

On the other hand, compared with beef, sheep meat has higher proportions of omega (n)-3 polyunsaturated fatty acids (PUFAs), and PUFA biohydrogenation intermediates (PUFA-BHI), including conjugated linoleic acid (CLA), which are related to potential beneficial effects on human health and wellbeing (Calder, 2015; Chikwanha *et al.*, 2018). Sheep meat consumption occupies the fourth position among the major livestock species, the world average being about 1.7 kg per capita annually (OECD, 2018). Interestingly, when the international guidelines on health and consumption of animal fats are reviewed,

sheep meat is not included (Santos *et al.*, 2013; Van Horn *et al.*, 2016; Faludi *et al.*, 2017; Sacks *et al.*, 2017).

In contrast to the world average, the pattern of higher consumption per capita in regions such as Northeast Brazil, North Africa, Middle East and India is related to sheep meat being a primary animal-source protein (Montossi *et al.*, 2013; Costa & Gonzalez, 2014). Semi-intensive production systems, locally adapted native breeds, semi-arid climatic conditions, and culinary and socio-cultural aspects give special characteristics to sheep meat that is consumed in these regions (Montossi *et al.*, 2013; Carvalho *et al.*, 2016; Hajji *et al.*, 2016).

International projections point to a growth in global production of sheep meat, mainly from developing countries (FAO, 2011). However, the demands of consumers for characterization of production systems, nutritional information, and sensorial analysis to target their preferences must be answered (Montossi *et al.*, 2013).

The fatty acid (FA) profile of meat in sheep is influenced by aspects such as feed, production system, sex, and breed (Díaz *et al.*, 2005; Rovadoscki *et al.*, 2018). Brazilian sheep meat production derives fundamentally from native breeds that are raised in semi-arid regions. However, their FA profile and sensorial traits have not been completely characterized. The present study was, therefore, conducted to characterize the meat quality and overall acceptance through sensorial analysis in Brazilian sheep native breeds. The discussion of results on the scientific basis associated with human health was part of the main line of work.

## Materials and Methods

Animal handling followed the Brazilian College of Animal Experimentation (COBEA) directives, and approved by the Ethics Committee of State University of Vale do Acaraú (UVA), Ceará, Brazil (n°003.04.015.UVA.504.02). For sensory analysis, written consent was given by all volunteers. The study was conducted at Centre for Research in Nutrition of Small Ruminants at Experimental Farm of UVA, in northeast Brazil.

The experimental design was a completely randomized balanced full factorial design (three genetic groups and two genders) with six treatments and five replications, in which each animal represented an experimental unit. Ten lambs of each breed were used in this study; that is, five males and five females were randomly selected and distributed in the three native breeds (Morada Nova (MN), crossbred Rabo Largo x Morada Nova (RBxMN), and crossbred Santa Inês x Morada Nova (SixMN). Thus, 30 Morada Nova ewes from different properties of region and adapted to the conditions of the experimental farm were mated with three rams of each breed. At birth, the lambs were weighed, identified, and housed until weaning in collective pens with access to solid diet (concentrate based on corn, soybean meal and limestone), in order to meet the requirements and weight gain of 150 g/day (NRC, 2007). Afterwards, and until slaughter, the feeding regime was replicated and all the animals, which were managed in a semi-intensive system (65 days), received supplementation with concentrate as a function of total live weight of the lot (1.5% of the total live weight, adjusted weekly). Briefly, native pasture of thinned caatinga, supplemented with *Canarana erecta lisa* grass (*Echinochloa sp*), was provided ad libitum. The bromatological analyses of diet components are shown in Table 1, and were performed according to procedures described in Mizubuti *et al.* (2009).

All lambs were slaughtered at the same time, at  $24 \pm 3.71$  kg of average weight, following the standard procedure of Brazilian Ministry of Agriculture, Livestock and Supply (MAPA, 2017). After the slaughter, carcasses were identified and refrigerated for 24 hours at 4 °C. Samples of each carcass were provided by a transverse section of the *Longissimus lumborum* (LL) muscle between the 11th and 13th ribs and were frozen at -10 °C for later evaluation. Meat FA composition was determined by chromatographic analysis of methyl esters (FAME) using 3 g of muscle sample (wet) in a gas chromatograph (GCMS-QP5050A, SHIMADZU, Brazil). To calculate the concentration of FAs of muscle sample the intramuscular fat proportion of the trimmed muscle was used. Extraction of intramuscular fat was performed using the methodology of Hartman and Lago (1973). Fatty acid methyl esters were identified based on retention times compared with those of the standard FAME mixture using Sigma® reference standards (Sigma, St. Louis, MO, USA). Data for FA composition were expressed in percentage by weight of total identified FAs, and expressed as mg per 100 g muscle sample.

Each quality parameter was evaluated from the LL muscle sample. The centesimal composition, moisture content (method 930.15), ash (method 920.153) and crude protein (method 928.08) were determined according to the AOAC (2012). Lipids were extracted and quantified following the methodology described by Folch *et al.* (1957) and the cholesterol determination used the high performance liquid chromatography (HPLC) method.

Health indices related to cardiovascular risk such as the hypocholesterolaemic to hypercholesterolaemic ratio (H/H : [(sum of oleic, linoleic, arachidonic, linolenic) / (sum of myristic and

palmitic)] (Santos-Silva *et al.*, 2002) and linoleic to linolenic ratio (C18:2/C18:3) (Díaz *et al.*, 2005) were calculated.

**Table 1** Nutritional analysis of dietary components for finishing lambs

Chemical composition (g/kg DM)	Diet components		
	Canarana grass	Native pasture <sup>1</sup>	Concentrate <sup>2</sup>
Dry matter (DM) as feed	918	906	929
Organic matter (OM)	872	894	945
Crude protein	51.6	155	368
Ether extract	12.8	25.0	40.0
Neutral detergent fibre	758	626	169
Acid detergent fibre	430	306	96
Hemicellulose	325	320	73
Cellulose	347	242	94.3
Lignin	46.1	44.7	3.7
In vitro digestibility DM	310	450	730
In vitro digestibility OM	387	535	813

<sup>1</sup> Main herbaceous species: vassourinha-de-botão (*Borreria verticillata* G.F.W Mayer), marianinha (*Commelina diffusa* Bumm. F), capim-milhã (*Digitaria Sanguinalis* (L.) Scop), forage peanuts (*Arachis pintoi*), algodão de seda (*Calotropis procera*), erva de ovelha (*Stylosanthes humilis*), jitrana lisa (*Ipomea glabra* Choisy), jitrana peluda (*Jacquemontia asarifolia* L. B. Smith), bamburral (*Hyptissu aveolens*), beldroega (*Sesuvium portulacastrum*)

<sup>2</sup> Corn, soybean meal and limestone

The sensorial analysis were performed according to procedures described by Landim *et al.* (2011). The LL muscle at the 13th rib was used. Briefly, samples were cut in 1-cm<sup>3</sup> cubes and roasted in a preheated oven to 170 °C. They remained there until the meat temperature was 71 °C at the geometric centre of the cube. Thirty non-trained judges indicated the intensity of sensation on a 9-cm linear scale. The responses were on a 1 to 9 scale. Each judge received the meat in an individual cabin in plastic containers coded with random three-digit numbers. Between tasting the first sample and the next, each taster received a glass of water at room temperature and a cracker-type biscuit, in order to remove the residual taste from the mouth. Sensations included hardness (perception of force necessary to cut the sample when bitten), succulence (perception of quantity of liquid liberated by the sample of meat in the mouth), taste (sensation of flavour liberated by the sample during chewing), aroma (sensation of smell liberated by the sample during chewing), and overall acceptance (evaluator's opinion of preference and acceptability based on all these attributes). Hardness varied from extremely soft (1) to extremely tough (9); succulence from extremely dry (1) to extremely succulent (9); flavour from bland (1) to extremely tasty (9); aroma from absent (1) to strong (9); and overall acceptance from low (1) to high (9).

To identify the effects of breed and sex on these traits, analysis of variance (ANOVA) was carried out for the chemical composition of meat data, followed by Duncan tests, while two-way ANOVA was performed for sensory and FA data to determine the significance in the breeds (G), sex (S) and interaction of sex by breed (G x S), followed by the Kruskal Wallis and Duncan tests, respectively. A statistical general linear model (GLM) was used. The existence of effect was considered when *P*-value was below 0.05. The results are presented as least square means with standard errors.

To determine the variance components of overall acceptance of a sensorial trait, mixed models of predictive equation using the sensorial attributes and FA acid profile were tested. The restricted maximum likelihood (REML) method was used to estimate the variance components. The effect of the terms in the regression equations was examined by ANOVA for each response. The terms that were found as non-effect were excluded from the initial model, and the experimental data were refitted only to the effect (*P* < 0.05) parameters. In estimating the best regression model, the one with higher values of R<sup>2</sup> and adjusted R-square and lower Bayesian information criteria (BIC) was considered, Pearson's correlation coefficients (*r*) were calculated to identify associations among sensorial attributes and FA composition (in grams and percentage) and meat chemical composition. No more than five variables were analysed at a time, in order not to

compromise the analysis results (Granato *et al.*, 2014). All statistical analysis was conducted using IBM SPSS Statistics 22 for Windows (SPSS Inc., IBM Corporation, NY, USA).

## Results

The chemical compositions of meat in Brazilian native sheep breeds are shown in Table 2. The meat lipids content was higher in RBxMN compared with MN lambs and similar to SlxMN. Moisture, protein, ash and cholesterol components are similar between breeds ( $P > 0.05$ ). Male lambs showed higher moisture content than female.

**Table 2** Chemical composition of meat from native breeds of sheep as affected by sex

Nutrient	Breed			Sex		SE
	MN	RBxMN	SlxMN	Male	Female	
Moisture, g/100g	75.34	74.30	75.29	75.56 <sup>a</sup>	74.48 <sup>b</sup>	0.246
Protein, g/100g	21.23	21.38	21.26	21.37	21.24	0.222
Lipids, g/100g	1.93 <sup>b</sup>	2.81 <sup>a</sup>	2.39 <sup>ab</sup>	2.24	2.50	0.139
Ash, g/100g	1.06	1.13	0.99	1.05	1.07	0.038
Cholesterol, mg/100g	59.14	53.32	53.00	52.39	57.07	2.62

MN: Morada Nova; RBxMN: Rabo Largo x Morada Nova; SlxMN: Santa Inês x Morada Nova

<sup>a,b</sup> Means between breeds and sex in the same row with different superscripts are different ( $P < 0.05$ )

Nutritional contents in human food are generally expressed in mg of nutritional element per gram of tissue analysed. Table 3 shows the effects of various sheep native breeds on the FA content of LL in mg per 100 g of muscle sample by weight of total identified FAs.

The levels of stearic and palmitic SFA were highest in all breeds, followed by margaric and myristic acids in similar amounts. Greater content of myristic acid (30.74) was found in RBxMN lambs compared with other breeds (8.69 in MN and 13.34 in SlxMN). The SlxMN lambs had the lowest content of margaric acid (13.16). The highest value was obtained in MN lambs (35.39). No differences between breeds were found in stearic and palmitic acids. No sex effect in saturated acids was detected by ANOVA. Only margaric acid showed interaction of breed by sex effect ( $P < 0.05$ ).

The monounsaturated oleic FA was found in larger amounts and had effects among all breeds ( $P < 0.01$ ). The RBxMN lambs had the highest value (1476.4), followed by SlxMN (1071.2) and MN (663.5) lambs. Females showed higher values in palmitoleic acid than males ( $P < 0.05$ ). The palmitoleic and oleic FAs showed interaction breed by sex effect ( $P < 0.05$ ). The content of PUFA was led by linoleic acid, followed by arachidonic acid. No breed effect was observed in these FAs. The higher values in linolenic and rumenic FAs were obtained by RBxMN animals. The other two breeds showed similar results. No effects of sex and interaction breed by sex were found in PUFA.

Breed x sex interaction effects (G\*S) on MUFA and PUFA were found. With reference to the sum of total FAs, only MUFA differed between breeds ( $P < 0.01$ ). Here, the crossbred breeds had greater values than MN lambs. A sex effect was detected in total PUFA with males having a significantly greater amount than females.

**Table 3** Means ( $\pm$  SE) of fatty acid content of *Longissimus lumborum* (mg per 100 g of muscle) by weight of total identified fatty acids in sheep native breeds

	Breed (G)			Sex (S)		SE	Significance		
	MN	RBxMN	SlxMN	M	F		G	S	GxS
Total fatty acids									
IFP, %	1.93 <sup>b</sup>	2.81 <sup>a</sup>	2.39 <sup>at</sup>	2.38	2.41	0.14	*	ns	ns
<i>Saturated</i>									
C14:0	8.69 <sup>b</sup>	30.74 <sup>a</sup>	13.34 <sup>b</sup>	18.89	19.522	4.77	*	ns	ns
C16:0	410.38	502.19	485.26	404.47	514.68	32.70	ns	ns	ns
C17:0	35.39 <sup>a</sup>	30.42 <sup>ab</sup>	13.16 <sup>b</sup>	17.10	22.17	4.02	*	ns	*
C18:0	524.15	556.67	592.34	558.20	557.27	27.43	ns	ns	ns
<i>Monounsaturated</i>									
C16:1	9.53	16.68	13.79	7.47 <sup>b</sup>	21.21 <sup>a</sup>	3.30	ns	*	*
C18:1n9c	663.5 <sup>c</sup>	1476.4 <sup>a</sup>	1071.2 <sup>t</sup>	1012.3	1117.3	94.31	**	ns	*
C18:1n9t11	32.46	18.012	24.10	28.88	21.64	2.92	ns	ns	ns
<i>Polyunsaturated</i>									
C18:2c9t11	5.27 <sup>b</sup>	20.44 <sup>a</sup>	9.48 <sup>b</sup>	12.09	13.44	2.35	**	ns	ns
C18:2n - 6c	194.99	155.05	205.51	185.14	183.95	15.73	ns	ns	ns
C18:3n - 3	7.96 <sup>b</sup>	25.71 <sup>a</sup>	8.87 <sup>b</sup>	19.21	9.30	3.17	*	ns	ns
C20:4n - 6c	39.51	63.22	63.33	61.92	46.18	6.00	ns	ns	ns
$\Sigma$ SFA	1018.3	1122.8	1108.3	1100.1	1059.8	60.46	ns	ns	ns
$\Sigma$ MUFA	649.8 <sup>b</sup>	1496.1 <sup>a</sup>	1126.5 <sup>e</sup>	1050.4	1121.1	101.90	**	ns	**
$\Sigma$ PUFA	240.47	192.48	261.24	270.46 <sup>a</sup>	190.21 <sup>b</sup>	17.08	ns	*	*

MN: Morada Nova; RBxMN: Rabo Largo x Morada Nova; SlxMN: Santa Inês x Morada Nova; IFP: percentage intramuscular fat; C14:0: myristic acid; C16:0: palmitic acid; C17:0: margaric; C18:0: stearic; C16:1: palmitoleic acid; C18:1n9c: pleic acid; C18:1n9t11: elaidic acid; C18:2c9t11: rumenic acid; C18:2n-6c: linoleic acid; C18:3n-3: linolenic acid; C20:4n6c: arachidonic acid.  $\Sigma$ SFA: sum saturated fatty acids;  $\Sigma$ MUFA: sum monounsaturated fatty acids;  $\Sigma$ PUFA: sum polyunsaturated fatty acids GxS: breed by sex interaction; ns: non-significant

<sup>a,b,c</sup> Means between breeds and sex in the same row with different superscripts are different (\* $P < 0.05$ ; \*\* $P < 0.01$ )

The results for health indices were calculated, and their effects according to the FA profile in native lambs are shown in Table 4.

**Table 4** Least square means for health indices based on the fatty acid profile of meat from native lambs

Health indices	Breed (G)			Sex (S)		SE	Significance		
	MN	RBxMN	SlxMN	M	F		G	S	GxS
H/H	2.42 <sup>b</sup>	3.34 <sup>a</sup>	2.63 <sup>b</sup>	2.60	2.98	0.14	*	ns	*
C18:2/C18:3	18.49 <sup>a</sup>	7.93 <sup>b</sup>	20.64 <sup>a</sup>	14.01	18.83	2.17	*	ns	ns

MN: Morada Nova; RBxMN: Rabo Largo x Morada Nova; SlxMN: Santa Inês x Morada Nova

H/H: hypocholesterolaemic/hypercholesterolaemic ratio: [(sum of oleic, linoleic, arachidonic, linolenic) / (sum of myristic and palmitic)]; C18:2/C18:3: linoleic/linolenic ratio

<sup>a,b</sup> Means between breeds and sex in the same row with different superscripts are different (\*  $P < 0.05$ ); ns: non-significant.

For the H/H ratio, higher values are more desirable. The RBxMN lambs obtained the highest value (3.34) among the three breeds. The MN and SlxMN lambs obtained similar results (2.24 and 2.63, respectively). Breed interaction by sex was also presented. In the linoleic to linolenic ratio (C18:2/C18:3),

minor values are desired. The minor value was obtained in RBxMN lambs (7.93). The MN and MNxSI lambs obtained similar results (18.49 and 20.64, respectively).

Sensory analysis results of *LL* muscle in native sheep breeds, according to breed and sex are shown in Table 5. There were no differences between breeds and sex in the sensory attributes.

**Table 5** Sensory analysis of meat from the *Longissimus lumborum* of native lambs, by breed and sex

Attributes	Breed			Sex		SE
	MN	RBxMN	SlxMN	M	F	
Aroma	4.42	4.04	3.80	4.20	3.96	0.278
Succulence	3.66	3.80	4.41	3.99	3.93	0.191
Flavour	4.54	4.79	5.10	4.81	4.83	0.140
Hardness	3.80	3.58	3.36	3.93	3.03	0.201
Overall acceptance	4.51	4.85	5.12	4.76	4.90	0.128

MN: Morada Nova; RBxMN: Rabo Largo x Morada Nova; SlxMN: Santa Inês x Morada Nova

Aroma did not present extreme values in any of the breeds. The scores varied between 3.8 and 4.42 were classified as moderate. Meat samples of the breeds also presented medium succulence and moderate flavour. Regarding hardness of the meat, the three breeds were had scores that varied between 3.36 and 3.8. If 4.5 is considered the average value for overall acceptance, all breeds approached this value. Overall acceptance was classified as medium.

Predictive equations for the global acceptance sensorial trait and its succulence and flavour components are shown in Table 6. In this study, succulence and taste were the main sensorial traits that represent variance in the overall acceptance trait ( $R^2 = 0.84$ ). The succulence of meat depends mainly on the percentage content of margaric FA ( $R^2 = 0.77$ ). The lipid and percentage content of margaric FA (C17:0) explain the variations due to taste ( $R^2 = 0.77$ ).

**Table 6** Predictive equation for overall acceptance sensory trait of meat and its component traits in meat from native lambs

Dependent variable	Model	$R^2$	Adj R-Sq	BIC	$P$ -Value <sup>1</sup>
Overall acceptance	$Y = 1.519 + 0.375(\text{SUC}) + \beta_2 0.400(\text{TAS})$	0.84	0.83	27.0	<0.0001
Succulence	$Y = 4.893 + -1.431(\text{C17:0})$	0.77	0.75	16.5	<0.0001
Flavour	$Y = 4.31 + -0.658(\text{C17:0}) + 0.315(\text{Lipid})$	0.77	0.71	7.2	<0.0001

Y: dependent variable, SUC: Succulence, TAS: Flavour, C17:0: margaric acid (%), Lipid: lipid content (%),  $R^2$ : determination coefficient, Adj R-Sq: adjusted R-square, BIC: Bayesian information content (smaller is better)

<sup>1</sup> $P$ -value for the model

Meat with lower succulence and taste was strongly correlated ( $r = -0.88$  and  $-0.80$ , respectively) with a high content of margaric FA ( $P < 0.05$ ). A moderated and negative correlation were found between margaric acid content (%) and overall acceptance ( $r = -0.74$ ) ( $P < 0.05$ ). The content of the PUFA arachidonic acid (C20:4n6c) was associated with harder ( $r = -0.50$ ) and less succulent ( $r = 0.66$ ) meats ( $P < 0.05$ ). The lipid content (%) was moderately and negatively correlated with hardness of meat ( $r = -0.50$ ,  $P < 0.05$ ). Associations between lipid content (%) and taste and overall acceptance were weaker and positive (0.31 and 0.33, respectively) and significant at  $P < 0.09$ . Other associations among sensorial attributes with FA composition (in grams and percentage) and chemical composition were very weak.

## Discussion

Potential to increase affordability and availability of healthier foods relative to less healthy foods in developed and developing countries depends, among others, of validation of past trends and information, with more recent information about quality, consumption and lifestyle patterns (Muchenje *et al.*, 2018).

In the chemical composition, lipid and cholesterol content are primary considerations in discussions of healthy meat. It is now clear that different dietary patterns modulate different aspects of the atherosclerotic process and cardiovascular risk factors. These include plasma lipid levels, insulin resistance and glucose metabolism, blood pressure, oxidative phenomena, endothelial function, and vascular inflammation. Consequently, dietary consumption patterns may lead to inference with regards to atherosclerotic events (Santos *et al.*, 2013).

The lowest value in lipid content, which was obtained in meat from MN lambs (1.93% of muscle) is therefore considered favourable. This difference may be related to the slaughter bodyweight of the MN lambs (17.46 kg) compared with RBxMN and SixMN lambs (20.97 and 21.10 kg, respectively). Despite the clear influence of weight on the lipid composition of carcass, small size and late growth are part of distinguishing breed characteristics of MN sheep.

Lipid content in German, British and Uruguayan (light and heavy) lambs from typical production systems in the respective countries was higher compared with the Brazilian native breeds, reaching values of 4.25, 4.32, 3.05 and 5.94 %, respectively (Díaz *et al.*, 2005). These greater levels of fatness are probably related to the heavier slaughter body weight of these breeds. Recently, de Abreu *et al.* (2019) have shown that Dorper x Santa Inês lambs in Brazilian semi-arid production system have a degree of fatness that approaches the values obtained for meat from the RBxMN and SixMN lambs. The beef lipid content in grass-fed heifers was also greater (4.6%) to that obtained in the current study in the all groups (Berger *et al.*, 2018).

Several international guidelines recommend the restriction of dietary fats and cholesterol, aiming at reducing and controlling plasma cholesterol and plasma LDL (Santos *et al.*, 2013; Sacks *et al.*, 2017). The Brazilian Guideline on Fats and Cardiovascular Health recommends a consuming not more than 300 mg/day of cholesterol (Santos *et al.*, 2013).

The cholesterol content in this study ranged between 51 and 59.1 mg/100 g of muscle. This result contrasts with cholesterol concentrations in mg/100 g muscle in species such as chicken (73.42), beef (70.22) and pork (65.42) (Montalvo-Puente *et al.*, 2018). Muscle cholesterol values in Iranian fat- and thin-tailed sheep native breeds ranged between 62.25 and 82.85 mg/100 g meat (Aali *et al.*, 2017), values that are also higher than those seen in this study. People with diabetes may have abnormalities in the cholesterol transport mechanism and may benefit from a decrease in dietary cholesterol intake (Djousse & Gaziano, 2008). The current results demonstrate the potential of these Brazilian native sheep breeds in reducing dietary cholesterol consumption from red meat.

The influence of FA intake on the risk factors of cardiovascular disease and plasma concentrations of lipids and lipoproteins has been widely demonstrated in experimental and population studies (Billett, *et al.*, 2000; Hamley, 2017). Saturated fatty acids are cited as the main contributors to these harmful effects (Sacks *et al.*, 2017). The greatest proportion of SFAs in this study was found in MN lambs. However, this result should be interpreted with caution. Because of the lower content of lipids (1.93%) in this breed, the final concentrations in 100 g of muscle were not greater than in the other breeds (Table 4). Stearic acid (C18:0) was the main SFA, which contributes 53.5% (in RBxMN lambs) to 57.6% (in MN lambs) of the total SFA, followed by palmitic acid (C16:0) which was 41.3% to 44.8% of total SFA. Myristic acid (C14:0), which is considered more cholesterolemic, represented only 1.5% to 2.5% of total SFAs.

When the native sheep breeds from this study are compared with other sheep breeds and beef (Díaz *et al.*, 2005; Borghi *et al.*, 2016; Feitosa Braga *et al.*, 2017), the distribution of SFA is different with higher concentrations in palmitic and myristic acids and lower content of stearic acid. The potency of individual longer-chain SFA ( $\geq 12$  carbons) in raising low-density lipoprotein-cholesterol (LDL-C) levels diminishes from myristic acid (C14:0) with increasing chain length up to stearic acid (C18:0), which generally has a neutral effect on lipid and lipoprotein levels (Siri-Tarino *et al.*, 2015; Nettleton *et al.*, 2016). Thus, it can be suggested that meat consumption from these native breeds, and particularly SixMN lambs, might be associated with a lower elevation of LDL-C levels if compared with meat from other sheep breeds or beef.

Commonly, most interest has been in reducing the negative health impact of FAs that are related to cardiovascular disease (CVD), but it is now clear that some FAs (MUFA and PUFA) have a positive influence on CVD and a range of other diseases (Chikwanha *et al.*, 2018). Oleic acid, the major cis-MUFA that was found in this study in RBxMN lambs, contributed 52.5% of total FAs in this breed. This FA is associated with beneficial effects on the prevention of cancer, and autoimmune and inflammatory diseases (Sales-Campos *et al.*, 2013) and reduction in LDL-C and triglycerides levels (Van Horn *et al.*, 2016). In MN and SixMN lambs the proportions of oleic acid were 34.7 and 42.9% of total FA, respectively. The results related by Chikwanha

*et al.* (2018) in sheep (32.5%) and beef meat (36.1%) endorse this superiority in this study by the RBxMN breed. There is scientific consensus that high intakes of trans-MUFA (as elaidic acid) are detrimental to heart health (Brouwer *et al.*, 2013; Souza *et al.*, 2015). The proportion of elaidic FA ranged from 0.64% (RBxMN lambs) to 1.7% (MN lambs) of total FA. Higher values were reported in Santa Inês lambs (2.43%) (Lôbo *et al.*, 2013) and Nellore beef (2.9%) (Feitosa- Braga *et al.*, 2017) in this FA. If one considers the MUFA ratios that were found in this study, and the theoretical basis that was supported, it can be suggested that the RBxMN breed shows a health advantage compared with other breeds and species.

A prospective nested case-control study in humans showed that compared with controls, people with total haemorrhagic and ischemic strokes had similar proportions of omega-3 PUFA (such as linolenic acid) and lower proportions of linoleic and arachidonic acids (Iso *et al.*, 2002). In the current study, the PUFA content was led by linoleic acid, followed by arachidonic acid in all breeds. These results were similar to those in Spanish lambs and contrast with German, British and Uruguayan (light) lambs, in which the linolenic acid content also exceeded that of arachidonic acid (Díaz *et al.*, 2005). It is contented that this result is due not only to the breed effect, but also to the semi-extensive management system of natural pastures containing mixed browse/shrubs and grasses (Lourenço *et al.*, 2007). The caatinga plant secondary metabolites affect the PUFA profile as their presence culminates in higher duodenal flow rate compared with forage without these secondary metabolites (Fraser *et al.*, 2004; Pinto *et al.*, 2018). Higher intake of linoleic acid (an essential FA) may protect against ischemic stroke, possibly through potential mechanisms of decreased blood pressure, reduced platelet aggregation, and enhanced deformability of erythrocyte cells (Iso *et al.*, 2002; Calder, 2015). Additionally, linoleic acid is a precursor of docosapentaenoic (DPA) (22:5n-3), eicosapentaenoic (EPA) (20:5n-3) and docosahexaenoic (DHA) (22:6n-3) acids, which are associated with the promotion of cardiovascular, neural and mental health, lipid metabolism and endothelial cell migration and anti-inflammatory properties, which together suggest a strong role for prevention of CVD, inflammatory and metabolic diseases and cancer (Byelashov *et al.*, 2015; O'Connell *et al.*, 2017; Chikwanha *et al.*, 2018). Priority should be given to the consumption of linoleic acid from animal sources due to the low conversion of EPA and DHA acids from vegetable sources (Santos *et al.*, 2013). It is necessary to acknowledge the limitations of the current study that are related to the lack of detection of EPA, DHA, and DPA in the meat although the lipid content was moderate compared with other studies.

A unique characteristic of ruminants is the preferential incorporation of long chain n-3 PUFA into phospholipids as opposed to triacylglycerol, contributing to accumulation of PUFA-BHI, such as conjugated linoleic acid (CLA) (Chikwanha *et al.*, 2018). Rumenic acid (RA) (C18:2c9t11), the main natural isomer of CLA, was found in major amounts in RBxMN lambs in this study (approximately 61.3 mg per serving). Preliminary evidence suggests intakes of RA of about 0.80 g/day (from 0.6 to 3.0 g/d) are helpful in protecting against a range of diseases from cancer to atherosclerosis (Siurana & Calsamiglia, 2016). A portion of meat from RBxMN lambs would contribute 7.66% of the recommended intake. Therefore, its meat would be an opportunity to increase consumption of CLA, principally RA, without requiring major changes to eating habits.

Another n-3 PUFA that is associated with reduced risk of fatal and non-fatal coronary heart disease (CHD) or composite CHD is  $\alpha$ -linolenic acid (ALA) (C18:3n-3) (Wei *et al.*, 2018).  $\alpha$ -Linolenic acid content was also greater in RBxMN lambs (25.71 mg/100 g). This result may be due to the breed effect, since the feed management system was equal among the groups. The results obtained by Díaz *et al.* (2005) showed that lambs reared under intensive conditions, and fed concentrates and cereal straw, had low ALA content (9.72 mg/100 g, in Spanish lambs) as a consequence of the FA composition of the diet, since ALA is the major FA in grass. The ALA content was the trait with greater genomic heritability ( $h^2=0.46$ ) for FA profile in Santa Ines sheep, which would facilitate its genetic improvement through selection (Rovadoscki *et al.*, 2018). Comparatively, sheep meat has more PUFA-BHI than beef, because of the smaller size of the rumen and consequent shorter retention times or higher passage rates of feed from the rumen, with consequent increased duodenal flow, absorption and deposition of PUFA and their BHI into tissues (Chikwanha *et al.*, 2018).

The health indices results are in line with the MUFA and PUFA contents. The meat of RBxMN lambs was shown to be healthier by the H/H and linoleic/linolenic (C18:2/C18:3) ratios. The higher content of FAs that are regarded hypocholesterolemic (oleic, rumenic and linolenic acids) explains these results. In the H/H index, higher hypocholesterolemic FA values result in higher index values. Thus, indices with higher values are desirable. The results in all native breeds in this study (Table 5) were higher when compared with Ile France lambs (1.45) (Borghetti *et al.*, 2016). Despite the advantages of ALA and LA acids, and due mainly to a large number of sources of LA in nature, it is necessary to maintain a balance in the consumption of these two PUFAs. The recommendation of Brazilian Guideline on Fats and Cardiovascular Health is from 5:1 to 7:1 (linoleic/linolenic ratio) of total intake (Santos *et al.*, 2013). The RBxMN breed had this index within the recommended Brazilian guideline (7:1). The other native breeds showed higher values owing to the low

content of linoleic acid. German, British and Uruguayan lambs had values of this ratio that ranged from 1:1 to 3:1. In Spanish lambs (Díaz *et al.*, 2005), this ratio was in line with the other native breeds that were accessed in the present study.

An adequate balance of sensory traits is fundamental to potential consumption of native sheep meat. The results obtained here place these breeds within the range of moderate or medium acceptability based on the scores that were assigned to the sensory traits. Thus, meat from these breeds is seen as being compatible with the requirements of the Brazilian consumer market (Montossi *et al.*, 2013), which supports the use of these sheep breeds. Regression analysis identified margaric FA and lipid content as the main variables explaining variation in overall acceptability of lamb meat, due mainly to their roles in determining succulence and meat flavour. For applications such as the evaluation of sensory data, the coefficient of determination may be considered good if  $R^2 > 60\%$  (Granato *et al.*, 2014). Sensory properties may be improved through genetic selection because of the moderate to high estimates of genomic heritability that were reported for components of the FA profile of meat from sheep (Rovadoski *et al.*, 2018). It is believed that genetic improvement should be directed at decreasing the margaric acid content. An increase in arachidonic acid content in meat is not necessary since the level is already high in concentrate-fed animals. Finally, cross-cultural studies of consumer acceptance could be vital in informing future marketing or regulatory strategies involving these breeds.

## Conclusion

Based on the differences in FA profiles, crossbred Rabo Largo and Morada Nova lambs are thought to represent breeds with potential benefit to human health, mainly because of the MUFA and PUFA distribution and contents. The Morada Nova breed was highlighted because of its low lipid content, thus being indicated in diets in which the lipid intake from animal sources should be lower. All breeds have low cholesterol content, demonstrating their potential to reduce cholesterol consumption. The large effect of margaric FA in the prediction of overall sensory acceptance signals a useful starting point for improving the acceptance of meat from these breeds. This paper contributes to promoting better understanding of the meat quality and potential health benefits of FA profiles in native Brazilian sheep breeds. This information has values that are related to human health and wellbeing. Sheep meat production may benefit by including this health-related information in formulating future information and marketing campaigns.

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## Authors' Contributions

AVL designed the study. RPL collected and analysed the data. WHOV and HEAC drafted and revised the manuscript. LCS and ACC collected the data. WHOV, LDL and AVL analysed the data and revised the manuscript.

## Conflict of Interest Declaration

The authors have no conflicts of interest to declare.

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