

# Physical characteristics of meat from native Brazilian sheep breeds: a systematic review and meta-analysis

## Características físicas da carne de raças nativas brasileiras de ovinos: revisão sistemática e meta-análise

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### Highlights

Meat from native Brazilian sheep has lower fat content.

It meets quality standards according to consumer acceptance criteria.

Meat from native female Brazilian sheep presents less cooking loss.

### Abstract

A systematic review and meta-analysis were carried out to determine current knowledge concerning the physical characteristics of sheep meat from native Brazilian breeds and which of the principal quality indicators were used in the studies following PRISMA guidelines. Exploratory factor analysis was applied, using the iterated principal-factor method. The analysis of variance adopted a completely randomised design using mixed-model methodology. Blood grade and sex were evaluated as a fixed effect, and age at slaughter as a covariate or random effect defined by the parsimony of the mathematical model. pH, carcass fat content and luminosity ( $L^*$ ) showed high values for the coefficient of variation (CV), while

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the moisture and protein content of the carcass showed low CV values. When the effects of the blood grade and sex of the animals were evaluated separately, there were no differences in the variables under analysis. There was interaction between treatment factors for redness, shear force and cooking loss, where redness ( $a^*$ ) and shear force are lower in crossed females and pure males, whereas cooking loss was greater in crossed females and pure males. The quality of the meat from native Brazilian sheep, despite having lower fat levels, is within the parameters described in the literature for consumer acceptability.

**Key words:** Ewe. Lamb. Meat colour. Sex. Shear force. Tenderness.

## Resumo

Uma revisão sistemática e meta-análise foram realizadas para determinar o conhecimento atual sobre as características físicas da carne de ovina de raças nativas brasileiras e quais foram os principais indicadores de qualidade utilizados nos estudos, seguindo as diretrizes do PRISMA. Foi aplicada a análise fatorial exploratória, utilizando o método de fator principal iterativo. A análise de variância adotou um delineamento inteiramente casualizado, utilizando a metodologia de modelo misto. O grau de sangue e o sexo foram avaliados como efeitos fixos, e a idade ao abate como covariável ou efeito aleatório definido pela parcimônia do modelo matemático. O pH, o teor de gordura da carcaça e a luminosidade ( $L^*$ ) apresentaram valores altos de coeficiente de variação (CV), enquanto o teor de umidade e de proteína da carcaça mostraram valores baixos de CV. Quando os efeitos do grau de sangue e do gênero dos animais foram avaliados separadamente, não houve diferenças nas variáveis analisadas. Houve interação entre os fatores de tratamento teor de vermelho, força de cisalhamento e perdas de peso por cocção, onde a teor de vermelho ( $a^*$ ) e a força de cisalhamento foram menores em fêmeas mestiças e machos puros, enquanto a perda por cocção foi maior em fêmeas mestiças e machos puros. A qualidade da carne de ovinos nativas brasileiras, apesar de apresentar menores níveis de gordura, está dentro dos parâmetros descritos na literatura para aceitabilidade do consumidor.

**Palavras-chave:** Cor da carne. Cordeiro. Força de cisalhamento. Maciez. Ovelha. Sexo.

## Introduction

Sheep meat is considered exotic, appealing to specific consumer segments due to its flavour (Ripoll et al., 2018), tenderness and distinctive texture, and features prominently on restaurant menus in both Brazilian and international cuisine (Gonzaga et al., 2018). The meat is characterised as softer and pinker compared to beef, with a firm texture and consistency, and is rich in monounsaturated fatty acids

that help reduce LDL levels in the blood, commonly called 'bad cholesterol' (Madruga et al., 2020; Carneiro et al., 2021). The current demand is for products of organoleptic and sanitary quality, which are achieved through the adoption of modern production systems (Battagin et al., 2021; Gloria-Trujillo et al., 2022) which focus on optimising genetic selection, nutrition and animal welfare, leading to more-uniform and high-quality carcasses with improved flavour, tenderness and juiciness.

Several breeds of sheep are raised in Brazil, particularly in regions with a tropical climate. Some hair breeds, such as Santa Inês, Morada Nova, Brazilian Somalis, Cariri and Rabo Largo are important in the semi-arid region of the northeast (Ribeiro & González-Garcia, 2016). Sheep from these breeds have behavioural, physiological or metabolic characteristics that help them to withstand stressful situations and adapt to hardship (Leite et al., 2018). Santa Inês sheep, under water restriction for up to 72 hours, reduce their dry matter intake with no effect on the weight of commercial cuts or on meat quality (F. M. dos Santos et al., 2019), showing the adaptability of these animals to extreme climates.

The determining factors of meat quality include the chemical composition, the number of fatty components, and the organoleptic properties, which are directly related to the characteristics of flavour or aroma (Madruga et al., 2005). In this respect, for meat production, the use of sheep from native breeds is interesting, because genetically, these animals carry genes that favour growth and production under challenging conditions. From a biological point of view, the genetic material of native breeds is still little known, and requires improvement, especially in terms of carcass quality and the meat produced by these animals (Jucá et al., 2014). The principal aim of research with native sheep is to assess the impact of different diets on the qualitative parameters of sheep meat, making it difficult to divulge accurate information about the product.

Native sheep breeds are more adapted to environmental issues, having gone through a process of natural selection for thousands of years (Saadatabadi et al., 2023). Their genetic variability allows them to be bred in environments with adverse soil and climate conditions (Ramos et al., 2019). In crosses with specialised breeds, they offer gains in productivity while maintaining their robust characteristics (Freitas et al., 2020). Native breeds, in addition to making up part of the local biodiversity, have a valuable genetic pool, often little known, but with potential for the selection of desirable productive traits. Conserving the genetic integrity of local breeds is therefore of great importance, as this can favour breeding studies or add diversity to both inbred lines and pure breeds for commercial purposes (Ođjakova et al., 2023).

In the European Union, agricultural and rural-development policies help to maintain the diversity and genetic types of indigenous sheep breeds with the aim of increasing biodiversity (D'oronzo et al., 2022). For the authors, investigating the population dynamics of native breeds in Southern Italy, regional development policies have helped to protect and increase the number of breeds and, in some cases, have been successful in achieving their objectives. However, opportunities must be created to increase the income of farmers who maintain these native breeds, by diversifying agricultural activities and improving their skills and capacity to introduce innovations and promote the addition of value to such products. Moreover, there is an obvious need for specialised consulting services and improvements in

infrastructure to improve the quality of life of rural communities, in addition to enhancing communication channels to raise awareness of the importance of indigenous races in improving the land and landscape, and in maintaining biodiversity and sustainability (D'oronzio et al., 2022).

Research on native Brazilian sheep is needed to evaluate, in addition to the production systems, the genetic improvement potential of these animals. A number of questions can also be answered through studies that assess pure breeds or industrial crosses, as well as the parameters inherent to meat quality.

In order to elucidate the meat quality of native Brazilian sheep, it is necessary to synthesise the current evidence base. This systematic review and meta-analysis aimed to provide an up-to-date and comprehensive answer to the question: What is known about the physical characteristics of sheep meat from Brazilian native breeds, and what are the main quality indices used in the evaluation?

## Material and Methods

This systematic review was carried out in accordance with the guidelines of the

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). The PICO strategy followed the PRESS guidelines statement (McGowan et al., 2016) and defined: Population - meat sheep; Intervention: meat; Control: diets; and Results: meat quality of sheep from native Brazilian breeds. The PICO strategy was used to arrive at the research question on the quality of sheep meat.

Searches were made based on title and abstract, refining the language, and including articles published in English and Portuguese, as per the PRISMA flow procedure (Figure 1), and included the following databases: Web of Science, Scopus, PubMed, Scielo and Science Direct. The Boolean moderators 'AND' and 'OR' were used to help find as many results as possible. The following set of words was used: (Sheep OR Lamb OR 'Santa Ines' OR 'Santa Inez' OR Bergamácia OR 'Brazilian Bergamácia' OR 'Morada Nova' OR 'Brazilian sheep breed') AND ('Lamb meat' OR 'Sheep meat' OR 'Lamb quality') AND ('Chemical analysis' OR 'Fatty acids' OR 'Instrumental measurement' OR Textures OR Flavour OR pH OR 'Meat Colour' OR Tenderness OR 'Carcass' OR 'Shear force').

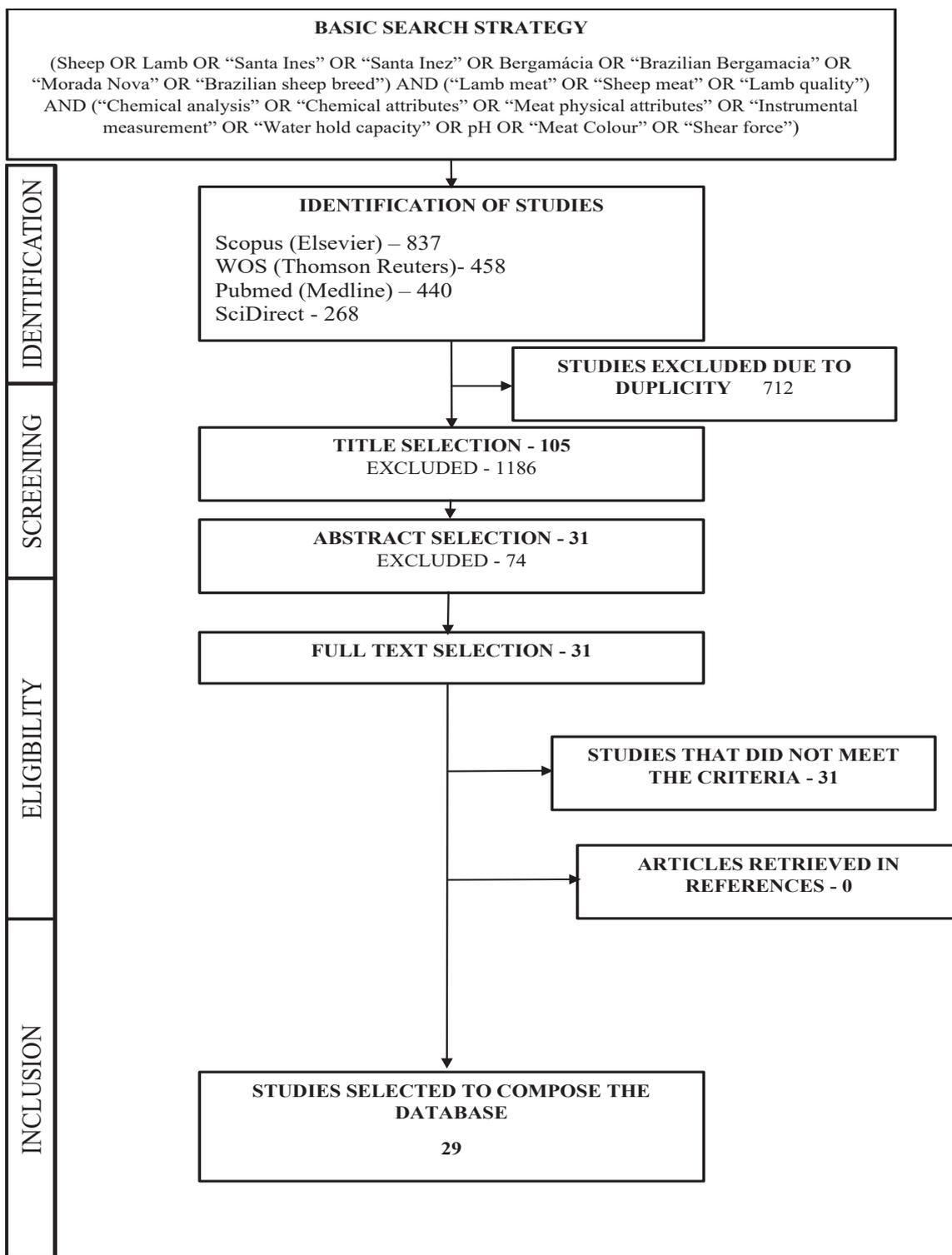


Figure 1. Literature retrieval flow chart - PRISMA.

The references of articles selected for tabulation were reviewed to identify possible additional articles and avoid potential publication bias. Following identification, the studies were critically evaluated based on relevance and quality relative to the aims of the systematic review.

### *Selection of the articles*

After conducting a search of the literature, the articles were sent to the EndNote™ tool, which helped eliminate duplicates and organise the abstracts. The articles were tabulated in an MS Excel file (2019) to be evaluated during the screening process, based on the following information: a) Author, b) Journal, c) Year, d) Title, e) Meets the selection criteria, f) Does not meet the selection criteria, and g) Reason for not meeting the selection criteria. Selection and evaluation of the eligibility of studies for the systematic review was carried out by two reviewers.

The eligibility criteria had been previously defined to select by title, abstract and full text. The titles should specify that the article presented characteristics concerning sheep of native breeds, the abstracts should present data on the quality of sheep meat, while during the final selection phase, the inclusion criteria were as follows: (1) data concentrating on the quality of sheep meat from native Brazilian breeds; (2) presentation of original data; (3) articles published in journals; (4) articles published from the year 2000; (5) articles in English and Portuguese.

### *Data systematisation and coding*

The methodology used to construct and codify the database followed methods previously described in the literature (Sauvant et al., 2008; Lovatto et al., 2007), where the data were introduced and organised on an electronic spreadsheet, with the rows representing the values and the columns designating the variables.

Information relevant to the purpose of this study (meat colour, meat pH, water holding capacity, cooking loss, moisture content, protein content and shear force) and other variables (flavour, odour, texture, tenderness, hardness, juiciness, aroma, softness, firmness) were included to allow a more critical and descriptive analysis of the studies.

### *Overview of the studies*

All of the studies selected for meta-analysis were carried out in Brazil (Table 1), and included the southeast and northeast of the country (Figure 2), regions characterised by a predominantly tropical climate. This resulted in 17 articles from the northeast, six from the southeast and two from the south. The terrain in these regions is varied, with elevated surfaces and coastal plains in the southeast, and coastal plains and plateaus that surround the backlands (sertão) of the northeast, with an average rainfall of 1,500 mm that varies from 300 to 2,000 mm, respectively.

The analysed studies dated from the 2003 to 2022, mostly research published in 2020 and evaluating 'Santa Inês' animals and the influence of different diets (sources of carbohydrates associated with urea, and isonitrogenous and isocaloric diets) on meat quality. The average length of the experimental periods was 68 days, and the

average age of the animals was 100 days at the start of the experiment. As for the sex of the animals used in the selected articles, 1,035 animals were male, and 76 were female. The experimental designs used in the studies were: completely randomised with different treatments and repetitions, randomised block designs, and factorial arrangements.

**Table 1**  
**Overview of the 29 publications included in the data tabulation of the meta-analysis**

Authors	DOI	Breed	Aim of the study
Alba et al. (2021)	<a href="https://doi.org/10.3390/ani11020328">https://doi.org/10.3390/ani11020328</a>	Dorper x Santa Inês	Evaluate the effect of the inclusion of protected or unprotected fats in the diet of feedlot lambs on feeding behavior, productive characteristics, carcass traits and meat quality
S. B. L. Batista et al. (2010)	<a href="https://doi.org/10.1590/S1516-35982010000900021">https://doi.org/10.1590/S1516-35982010000900021</a>	Morada Nova, Santa Inês e Santa Inês x Dorper	Analyse the chemical and sensory quality of lamb meat from native genotypes when submitted to diets with two energy concentrations.
Bezerra et al. (2021)	<a href="http://dx.doi.org/10.4314/sajas.v51i4.1">http://dx.doi.org/10.4314/sajas.v51i4.1</a>	Santa Inês	Determine the effect of increasing the dietary inclusion of spineless cactus ( <i>Nopalea cochenillifera</i> Salm Dyck) on the carcass characteristics and meat quality of confined lambs
H. V. A. Bezerra et al. (2020)	<a href="https://doi.org/10.1016/j.livsci.2019.103882">https://doi.org/10.1016/j.livsci.2019.103882</a>	Dorper x Santa Inês	Evaluate the influence of purified lignin as an additive in high-concentrate diets on performance, ruminal health, meat traits, and oxidative stress control in lambs.
L. S. Bezerra et al. (2016)	<a href="https://doi.org/10.1016/j.meatsci.2016.05.019">https://doi.org/10.1016/j.meatsci.2016.05.019</a>	Dorper x Santa Inês	The effect of the replacement of soybean meal with peanut cake on the proximate composition, physicochemical characteristics and fatty acid profile of meat from crossbred lambs (Dorper x Santa Inês) finished in a feedlot
Campos et al. (2017)	<a href="https://doi.org/10.1016/j.meatsci.2016.10.011">https://doi.org/10.1016/j.meatsci.2016.10.011</a>	Santa Inês crossbreed	Compare diets containing silages from forage plants adapted to semi-arid conditions on the quality of meat from feedlot-finished lambs by determining the physicochemical, proximate and sensory properties of their meat

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C. A. da Costa et al. (2020)	<a href="https://doi.org/10.1016/j.smallrumres.2020.106245">https://doi.org/10.1016/j.smallrumres.2020.106245</a>	Santa Inês	Analyse the effect of increasing levels (0, 6, 12, and 18 %) of crude glycerin to replace maize in the diet of lambs on the chemical composition, physicochemical parameters and fatty acid profile of the meat
E. I. de S. Costa et al. (2021)	<a href="https://doi.org/10.1016/j.livsci.2021.104717">https://doi.org/10.1016/j.livsci.2021.104717</a>	Santa Inês crossbreed	Evaluate the effects of dietary condensed tannins from <i>Acacia mearnsii</i> extract on the performance, carcass traits and meat quality of lambs
J. B. Costa et al. (2018)	<a href="https://doi.org/10.1371/journal.pone.0206863">https://doi.org/10.1371/journal.pone.0206863</a>	Santa Inês	Investigate licuri cake as alternative feed for lambs and the outcome on the sensory and physicochemical characteristics and fatty acid profile of meat from lambs.
R. G. Costa et al. (2017)	<a href="https://doi.org/10.56890/jpacd.v19i.42">https://doi.org/10.56890/jpacd.v19i.42</a>	Santa Inês	Evaluate the physicochemical composition (fatty acid content) and the sensory evaluation of meat from sheep fed with cactus forage in place of buffelgrass.
Fernandes et al. (2021)	<a href="https://doi.org/10.1016/j.livsci.2021.104694">https://doi.org/10.1016/j.livsci.2021.104694</a>	Santa Inês e Dorper	Evaluate the carcass characteristics and meat quality of castrated and non-castrated Santa Inês and Dorper lambs, finished in confinement and slaughtered with different subcutaneous fat thickness.
Lage et al. (2020)	<a href="https://doi.org/10.4314/sajas.v50i1.16">https://doi.org/10.4314/sajas.v50i1.16</a>	Morada Nova; Rabo Largo x Morada Nova; Santa Inês x Morada Nova	Characterise meat quality and overall acceptance through sensorial analysis in native Brazilian sheep breeds.
A. C. V. de Lima et al. (2018)	<a href="https://doi.org/10.1371/journal.pone.0188648">https://doi.org/10.1371/journal.pone.0188648</a>	Santa Inês	Evaluate the effects on meat quality of including sunflower cake in the diet of lambs
Madruga et al. (2006)	<a href="https://doi.org/10.1590/S1516-35982006000600035">https://doi.org/10.1590/S1516-35982006000600035</a>	Santa Inês and Santa Inês x Dorper crossbred	Describe the outcomes of sex and genotype (breed) on the composition and fatty acid profile of the semimembranosus muscle of feedlot sheep
Madruga et al. (2005)	<a href="https://doi.org/10.1590/S1516-35982005000100035">https://doi.org/10.1590/S1516-35982005000100035</a>	Santa Inês	Evaluate the qualitative aspects of lamb meat from Santa Inês sheep when submitted to different feeding systems during the termination phase
Maia et al. (2012)	<a href="https://doi.org/10.1590/S1516-35982012000400022">https://doi.org/10.1590/S1516-35982012000400022</a>	Santa Inês, Ile de France, Ile de France x Santa Inês, Dorper x Santa Inês, Texel x Santa Inês, Suffolk x Santa Inês	Analyse the effects of genotype (breed) on the chemical composition and fatty acid profile of the longissimus dorsi muscle of female feedlot lambs

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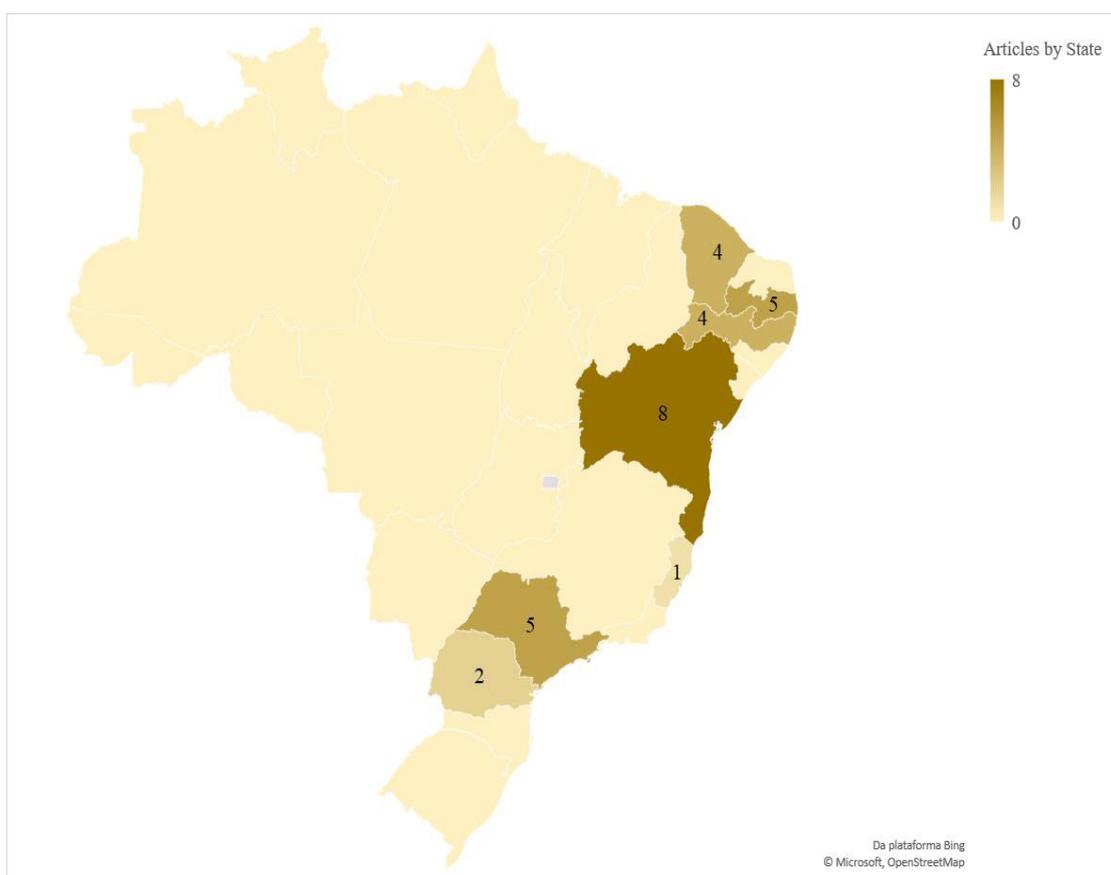
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Menezes et al. (2014)		Santa Inês x Somalis	Describe the influence of diet on sheep of different breeds on the physical, chemical and sensory due his flesh termination
Moulim et al. (2017)		Santa Inês; 3/4 Dorper x 1/4 Santa Inês	Evaluate the composition and fat profile of the meat of pure and crossbred lambs supplemented with protected fat.
Nascimento et al. (2021)	<a href="https://doi.org/10.3390/ani11020267">https://doi.org/10.3390/ani11020267</a>	Santa Inês x Dorper	Assess the addition of whole maize germ as a source of linoleic acid in diets for feedlot lambs on carcass characteristics, physicochemical composition, sensory attributes and fatty acid profile of the meat
Rodrigues et al. (2020)	<a href="https://doi.org/10.1016/j.livsci.2020.104155">https://doi.org/10.1016/j.livsci.2020.104155</a>	Santa Inês x Dorper	Determine whether partial and total replacement of cracked maize grain with soybean molasses modifies the performance and meat quality of feedlot-finished lambs
V. C. Santos et al. (2013)	<a href="https://doi.org/10.4025/actascianimsci.v35i4.20403">https://doi.org/10.4025/actascianimsci.v35i4.20403</a>	Santa Inês	Analyse the effect on carcass and meat characteristics of adding by-products from the processing of oil seeds to the diet of lambs
Senegalhe et al. (2014)		1/2 Dorper x 1/2 Santa Inês); Santa Inês	Investigate genetic group and the thickness of subcutaneous fat at slaughter on the chemical composition and fatty acid profile, slaughtered at 2.0, 3.0 and 4.0 mm of subcutaneous fat thickness
F. J. S. da Silva et al. (2020)	<a href="https://doi.org/10.4067/S0718-58392020000300361">https://doi.org/10.4067/S0718-58392020000300361</a>	Santa Inês	Evaluate whether diets containing maize and soybean meal, maize, cassava ( <i>Manihot esculenta Crantz</i> ) root or spineless cactus ( <i>Opuntia ficus-indica</i> [L.] Mill., SCU) associated with urea modify the performance, carcass characteristics and meat quality of confined lambs
A. C. F. da Silva et al. (2016)	<a href="https://doi.org/10.5433/1679-0359.2016v37n2p911">https://doi.org/10.5433/1679-0359.2016v37n2p911</a>	Morada Nova	Evaluate whether pre- and post-calving feed restriction impairs the quantitative characteristics and lipid profile of meat from Morada Nova sheep
S. V. de Sousa et al. (2022)	<a href="https://doi.org/10.1016/j.meatsci.2022.108734">https://doi.org/10.1016/j.meatsci.2022.108734</a>	Santa Inês x Dorper	Investigate the effect of dietary buriti oil intake on meat quality, fatty acid composition and sensory attributes
D. S. Sousa et al. (2016)	<a href="https://doi.org/10.5433/1679-0359.2016v37n3p1515">https://doi.org/10.5433/1679-0359.2016v37n3p1515</a>	Santa Inês	Evaluate the quality of meat from castrated and non-castrated Santa Ines lambs submitted to food restriction
Torres-Geraldo et al. (2020)	<a href="https://doi.org/10.17533/udea.rccp.v33n2a02">https://doi.org/10.17533/udea.rccp.v33n2a02</a>	Santa Inês	Describe the effect of castration and vitamin E supplementation on the performance, carcass characteristics and meat of lambs slaughtered at 45 kg.

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Urbano et al. (2014)	<a href="https://doi.org/10.1590/S1413-70542014000600007">https://doi.org/10.1590/S1413-70542014000600007</a>	Santa Inês	Assess replacing maize with maize germ meal on the chemical and lipid composition and physicochemical parameters of meat.
Vieira et al. (2010)	<a href="https://doi.org/10.1590/S0101-20612010000200013">https://doi.org/10.1590/S0101-20612010000200013</a>	Santa Inês	Evaluate the effect of termination diets containing increasing levels (0, 20, 30, and 40%) of whole cotton seed ( <i>Gossypium hirsutum</i> ) on the physical and sensory parameters of Santa Ines sheep.



**Figure 2.** Origin of the published studies on meat quality in native Brazilian sheep.

### Meta-analysis

A preliminary analysis of the data was carried out based on graphic analyses. From these analyses, correlation hypotheses were

formulated to define the statistical models (Lovatto et al., 2007). The Mi procedure (Statistical Analysis System Institute [SAS Institute], 2018) was used to impute

incomplete data using the Monte Carlo chain method. Exploratory factor analysis was then applied to verify the latent and underlying variables found in the data set. The iterated principal factor method was applied to decompose the factor correlation matrix.

The commonality and load of each latent variable (factor) were estimated. The Varimax rotation method was used. The factored model was represented in a path diagram. The exploratory analysis was performed using the Factor procedure (SAS Institute, 2018). For the analysis of variance, a completely randomised design was adopted using the mixed-model methodology, incorporating fixed and random effects into the model. The genetic group (pure or crossbred animals) was evaluated as a fixed effect, as was the sex of the animals. Age at slaughter was used both as a covariate

and as a random effect, based on the p-value ( $P=0.05$ ) and the corrected Akaike information criterion – AICc. The Glimmix procedure (SAS Institute, 2018) was then adopted, choosing the best distribution and fit of the model based on the AICc. These data were subjected to analysis of variance, with the addition of the fixed effects (sex and genetic group) and random effects (articles and age at slaughter). The SAS OnDemand software was used for the statistical analysis.

## Results and Discussion

The variables luminosity, pH and fat showed a high coefficient of variation. (Table 2). On the other hand, in the data under study, for moisture and protein content, the coefficient of variation was low.

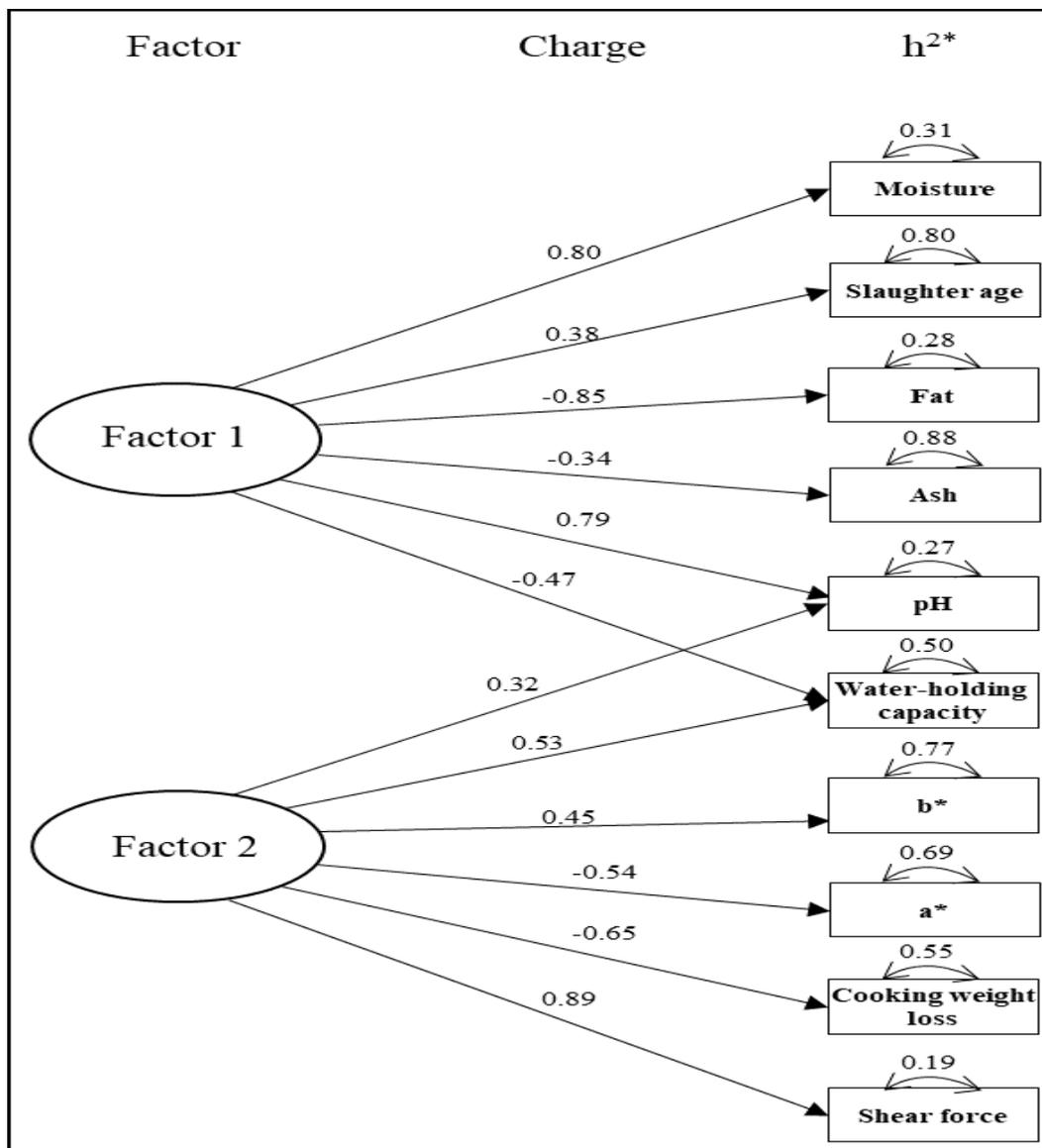
**Table 2**  
**Characteristics of the animal and physical characteristics of the meat from native Brazilian sheep (Ovis aries)**

Variable	N	Mean	Standard error	CV	SD
Age at slaughter (days)	111	197.33	3.66	20.99	41.41
Slaughter weight (kg)	88	32.53	0.07	19.10	6.21
Lightness (L*)	76	46.61	3.51	85.26	39.74
Redness (a*)	71	17.48	0.35	22.57	3.94
Yellowness (b*)	72	7.65	0.19	27.64	2.11
pH (0 hs)	74	5.93	0.56	107.12	6.35
Water holding capacity (%)	28	51.34	2.19	48.28	24.79
Cooking loss (%)	85	27.56	0.68	27.98	7.71
Shear force (kgf/cm <sup>2</sup> )	88	3.06	0.09	34.08	1.04
Moisture (%)	102	74.33	0.18	2.68	1.99
Protein (%)	102	21.65	0.19	9.78	2.12
Fat (%)	102	3.24	0.18	62.18	2.01
Ash (%)	102	1.23	0.04	36.08	0.44

N = number; CV = coefficient of variation; SD = standard deviation.

Eighteen articles reported slaughter weight, with a mean value of 32.53 kg. However, this weight range was used only as a parameter to evaluate animal performance. The primary focus of these studies, however, was meat quality and the fatty acid profile. In this context, the proximate composition of the meat showed an inverse relationship

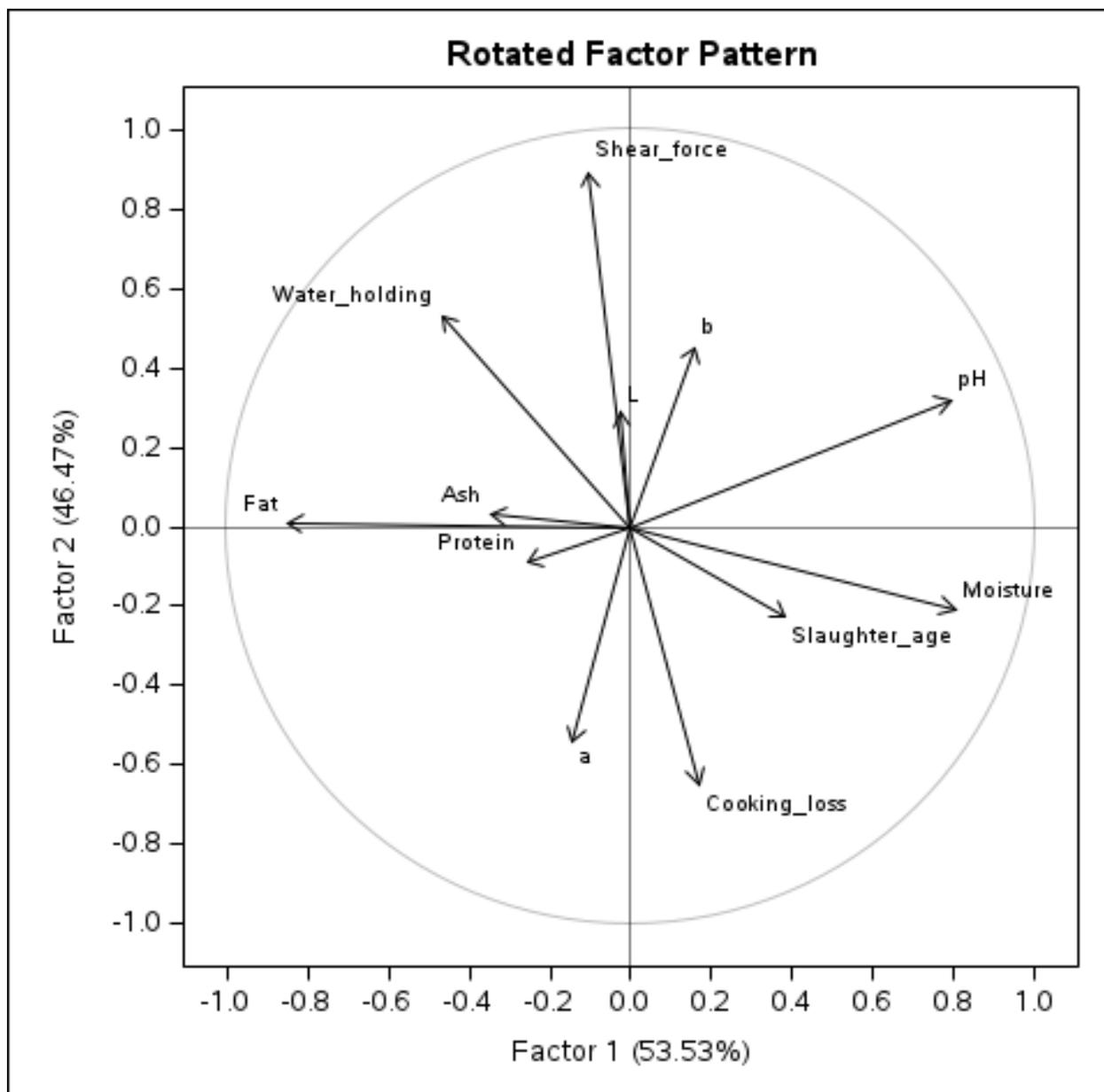
with moisture and pH (Figure 3). Meats with a higher cooking loss had higher  $a^*$  intensity and lower shear force (Figure 3), with luminosity having a low weight in the latent variables. As such, variables with greater weights comprised the factors related to the physical and quality aspects of the meat (Figure 3).



**Figure 3.** Path diagram with factor loadings and commonality of the physical factors; \*Quality factor communality ( $h^2$ ) following Varimax rotation.

Fat, due to its negative correlation with Factor 1, had an insignificant contribution to its formation (Figure 3). The colour intensity of the meat ( $a^*$ ,  $b^*$ ,  $L^*$ ) had the greatest contribution to the formation of Factor 2.

These results demonstrate the relationship of Factor 1 with the physical variables of the meat, and Factor 2 with the variables related to meat quality (Figures 3 and 4).



**Figure 4.** Linear combination of the dimensions related to the physical parameters of sheep meat from native Brazilian breeds

The effect of the genetic group and the sex of the animals when evaluated separately did not differ for the variables under analysis. However, there was interaction between the treatment factors, genetic group and sex

of the animals for redness, shear force and cooking loss. For redness and shear force, the values were lower in the crossed females and pure males (Table 3), which also showed the highest values for cooking loss.

**Table 3**  
**Influence of crosses and sex on the physical characteristics of the meat from native Brazilian sheep (*Ovis aries*)**

Variable	Cross		Pure		P value		
	Female	Male	Female	Male	Group	Sex	Group*Sex
Lightness	37.3+11.99	48.80+6.00	83.30+26.59	43.70+4.26	0.133	0.437	0.051
Redness	15.50+1.79b	18.10+1.16a	18.40+1.79a	16.50+0.99ab	0.480	0.813	0.014
Yellowness	7.53+1.08	7.59+0.55	7.07+1.01	7.24+0.45	0.522	0.898	0.930
pH	5.30+1.18	6.35+1.53	5.58+1.05	6.46+0.44	0.812	0.314	0.909
WHC*	60.60+ 4.10	51.80+6.63	65.80+15.30	43.30+4.79	0.697	0.149	0.372
Cooking loss	27.90+4.38a	23.00+1.98ab	18.90+2.95b	27.70+2.10a	0.261	0.473	0.003
Shear force	2.60+0.41b	3.14+0.25a	2.72+0.34ab	3.41+0.16a	0.314	0.787	0.023
Moisture*	74.50+0.80	73.60+0.38	74.30+0.81	74.80+0.32	0.311	0.790	0.180
Protein	20.90+0.76	21.30+0.48	22.20+0.81	22.30+0.44	0.112	0.766	0.134
Fat*	4.53+0.80	2.98+0.25	3.31+0.60	2.91+0.20	0.142	0.042	0.228
Ash	1.16+0.13	1.29+0.08	1.18+0.17	1.10+0.06	0.285	0.819	0.197

\*Age as covariable: WHC (water holding capacity) = 0.0031; Moisture = 0.0490; Fat = 0.0001  
Values expressed as mean + standard error.

The high values for the coefficients of variation found in the variables allocated to the model are due to the diversity of production systems and the number of variables studied in this systematic review of the physical characteristics of meat from sheep of native breeds. Sheep meat comes from different production systems, ranging from extensive outdoor to intensive indoor systems, with animals slaughtered at different ages (Prache et al., 2022). The age at slaughter ranged from 110 to 280 days, where obtaining smaller carcasses is

conditional on the mean value of this variable (Prache et al., 2022; Montossi et al., 2013), the animal being slaughtered before sexual maturity in the search for meat with less fat deposition (Cartaxo et al., 2017), which is preferred by the consumer.

The inverse relationship of the proximate composition of the meat with moisture and pH shows that firmer meats have a higher water holding capacity and low cooking loss (Warner, 2022). This release of exudate results in a loss of nutritional value,

leading to drier, less-tender meat (Zeola et al., 2007).

The water holding capacity is one of the factors that affect the juiciness of the meat, together with the degree of fat (D. M. Lima et al., 2016). However, meat with a higher fat content usually comes from animals that are older at slaughter or have a longer finishing time (Kopuzlu et al., 2018). For both purebred and crossbred animals, the water holding capacity was higher in the females than in the males, a fact linked to the fat content, which is higher in females, and which relaxes the microstructure of the meat, causing more water to be incorporated into the fat (Watanabe et al., 2018; Adeyemi et al., 2016).

Water holding capacity and meat colour are important visual and sensory characteristics of meat quality for consumer acceptance (Warner, 2022). The colour intensity is determined by the structure and total concentration of myoglobin; this is affected by ante-mortem factors such as the species, sex and age of the animal, and such post-mortem factors as the anatomical region, temperature and pH (Bekhit et al., 2019). This variation in the factors affecting meat colour is probably the cause of the interaction between the sex, group and racial composition of the animals. Meat colour is very similar between native sheep breeds, but can be influenced by the speed of weight gain, as an increase in muscle mass results in better blood flow and a high concentration of pigments (Oliveira et al., 2020).

The intensity of the yellow colour in sheep fat is more pronounced than in beef (Prache et al., 2022). The sexual condition of the animal influences muscle

and fat deposition in the sheep carcass: non-castrated lambs tend to have a higher proportion of muscle and shoulder compared to castrated animals, which deposit more fat (Fernandes et al., 2021). Although the intensity of the yellow colour ( $b^*$ ) is greater in non-castrated animals (D. S. Sousa et al., 2016), this increase may be a result of colour changes that occur during the meat maturation process (Torres-Geraldo et al., 2020).

The use of crosses interferes with fat deposition in the sheep carcass (Prache et al., 2022). There is greater fat deposition in crossbred animals than in purebred animals, a result of the complementarity of the breeds. Native Brazilian sheep have greater musculature for producing meat, but compared to animals from breeds such as Suffolk, Hampshire Down and Dorper, their fat deposition is lower (Monaco et al., 2015). In the search for a better carcass, native breeds (mainly Santa Inês) are crossed with non-native breeds, especially with Dorper, which adapts to tropical regions. However, the crosses result in a greater energy demand on the lamb diet for the formation of adipose tissue (Cartaxo et al., 2017).

Brazilian sheep breeds originated in the northeast of the country, a semi-arid region (Marinho et al., 2023), from traditional family farming which is characterised by the use of bulky feed with thick cell walls, as in the case of the forage cactus (Silveira et al., 2021). Over the years, these animals have consumed diets of low-calorie density and little metabolisable energy, which may have helped in the genetic selection of individuals adapted to these feeding systems. However, adaptation to nutrition of lower energy density does not prevent the

animals from producing meat with more fat when submitted to more energetic diets. The addition of levels of sunflower cake in the diet of Santa Inês sheep had a linear effect on the fat content, which went from 2.81% with no addition to 3.91% with the addition of 30% sunflower cake (A. C. V. de Lima et al., 2018). This shows that even without crossing with foreign breeds, diets with higher levels of metabolisable energy result in a higher fat content in the meat of native Brazilian sheep. In addition, in crossbred and purebred animals, the fat content of the females was higher than that of the males, even though all of the males were castrated in each of the studies, with greater fat deposition in every part of the female carcass (Schumacher et al., 2022). Furthermore, the greater the age at slaughter, the greater the fat content in the carcass of females compared to males (Prache et al., 2022). Sex has a direct influence on weight gain composition, particularly on intramuscular fat deposition and carcass composition. This effect is associated with the action of sex hormones, such as oestrogen, which favour the early stages of intramuscular fat deposition. Paulino et al. (2009) emphasise that, due to their earlier maturity, females reach the peak of fat deposition at a younger age than males.

The observed protein content was higher than the 20% cited by Prache and Bauchart (2015), which is also linked to a lower fat content when compared to animals of non-native breeds, suggesting that sheep meat is a satisfactory source of protein and rich in highly digestible essential amino acids. When evaluating the proximate composition of the Longissimus lumborum muscle in Santa Inês lambs fed on different native grass silages and slaughtered at 210 days of

age, Campos et al. (2017) found mean protein levels of around 24.0%, a similar result to that reported by Carvalho et al. (2015) who included levels of pure glycerine in the diet of sheep of the same breed. However, conflicting reports are found in the literature, with lower levels for the characteristics of sheep meat from cross-bred native breeds (Alba et al., 2021; Brant et al., 2021; F. M. dos Santos et al., 2019).

A final pH of between 5.5 and 5.7 is considered adequate for most species (Matarneh et al., 2017). The mean pH values of the crossbred animals, both male and female, of 5.8 and 6.0, are higher than those reported by Rodrigues et al. (2020) when evaluating high concentrations of soybean molasses on the performance of confined lambs, with a mean final pH of 5.6, showing no effect on colour or tenderness. In Suffolk sheep, the levels of added silage did not change the pH of the meat, which remained around 5.6 when they were creep-fed on three different levels of silage of moist maize grain (Almeida et al., 2004). Sheep meat, when in this pH range, rarely presents problems related to the appearance of DFD meat (dark, firm and dry).

Aksoy et al. (2019), investigating the chemical composition and quality parameters of lamb meat from six different breeds, both native and non-native to Turkey, and bred under intensive production systems, found significant differences ( $p < 0:05$ ) between breeds for the characteristics of drip loss, pH, cooking loss, water holding capacity, colour, dry matter, ash, protein and intramuscular fat of the longissimus dorsi muscle (LD). For the authors, meat from native breeds can be considered healthier due to the low levels of intramuscular fat and cholesterol. Furthermore, drip loss has an

important effect on the quality of fresh meat and meat-based products, and less drip loss was seen in meat from one of the native breeds. Native breeds can therefore make a difference to the sheep meat production systems of that country.

## Conclusion

This study concluded that the meat of native Brazilian sheep can be considered healthier due to its low cholesterol content and, consequently, lower levels of intramuscular fat. Even so, the meat quality of these animals meets the acceptability criteria described in the literature. Factors that influence this quality, such as drip loss, have a significant effect and can be observed in native sheep.

Furthermore, the quality of the meat from native Brazilian sheep, despite having lower fat levels, is within the parameters described in the literature for consumer acceptability of the final product.

Meat from native female Brazilian sheep presents less cooking loss and requires less shear force, albeit having a higher fat content.

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