



# Meat quality physicochemical traits in hair sheep in southeast Mexico

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## ABSTRACT

**Objective.** To quantify some meat quality physicochemical traits in *Longissimus thoracis* from hair sheep in southeast Mexico, and test if any of these traits effectively distinguish between genotypes.

**Materials and methods.** Animals were 18 male lambs from the Dorper (Dp, n=6) and Katahdin (Kt, n=6) breeds, and F1 Dorper sire x Katahdin dam (DpxKt, n=6) crosses. They were slaughtered at  $29.5 \pm 4.2$  kg average weight, at  $6.2 \pm 0.2$  months. Proximate composition and physicochemical analyses were run of *Longissimus thoracis* samples, and a canonical discriminant analysis run to identify traits that distinguished between breeds. **Results.** Genetic group had no effect ( $p > 0.05$ ) on moisture (%), crude protein (% CP) and myoglobin content. It did affect ( $p < 0.05$ ) intramuscular crude fat (% IMF), ash (%) and cholesterol content. IMF (4.05%) and cholesterol (92.63 mg/100 g) were highest in Kt. Ash content (1.01%) was lowest in DpxKt. Values for pH did not differ between genetic groups and were within normal limits. Cooking and drip losses were highest in DpxKt. Chroma, L\* and a\* values were highest in Kt, providing fresh meat from this genotype a desirable bright red color. The distinction analysis identified drip loss, IMF, Chroma and a\* as effectively separating the genotypes. **Conclusions.** Genetic group influenced intramuscular fat, cholesterol and ash contents, and four traits served to distinguish between genotypes. These are important data for producers and marketers as they aim to create fresh meat products with specific meat quality physicochemical traits that meet demand in a diversifying market that includes grilling and gourmet cuts.

**Keywords:** Animals; color; lambs; genotypes; myoglobin; tropics (Source: USDA, CAB).

## RESUMEN

**Objetivo.** Determinar el efecto del grupo genético sobre algunas características físico-químicas asociadas a la calidad de carne en lomos (*Longissimus thoracis*) de ovinos de pelo del sureste mexicano. **Materiales y métodos.** Se evaluaron corderos machos del genotipo Dorper (Dp, n=6), Katahdin (Kt, n=6) y la cruce F1 semental Dorper x madres Katahdin (DpxKt, n=6), sacrificados con un peso promedio de  $29.5 \pm 4.2$  kg, a una edad de  $6.2 \pm 0.2$  meses. Las muestras *L. thoracis* fueron

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analizadas para determinar su composición proximal y sus características físicas. **Resultados.** El grupo genético no tuvo efecto ( $p > 0.05$ ) sobre % de humedad, % proteína cruda (% PC) y el contenido de mioglobina, por el contrario, afectó ( $p < 0.05$ ) al % de grasa intramuscular (% GCI), % de cenizas (% Cen) y el contenido de colesterol, siendo Kt, la que presentó un mayor contenido con 4.05% de GCI y 92.63 mg/100 g de Colesterol y DpxKt con la menor cantidad de cenizas (1.01%). Los valores de pH no mostraron diferencias estadísticas entre grupos genéticos y se encontraron dentro del rango normal. Las mayores pérdidas por cocción y pérdidas por goteo fueron para DpxKt, pero al igual que Kt tuvieron valores mayores de luminosidad ( $L^*$ ), rojo-verde ( $a^*$ ) y Cromaticidad, lo que confiere a la carne un color rojo brillante más deseable. **Conclusiones.** Algunas de las características fisicoquímicas estuvieron influenciadas por el grupo genético y los resultados deben ser considerados por la industria cárnica para incursionar en mercados que demanden cortes (para carne asada o platillos gourmet) con ciertas características fisicoquímicas asociadas a calidad.

**Palabras clave:** Animales; color; corderos; genotipos; mioglobina; trópicos (*Fuentes: USDA, CAB*).

## INTRODUCTION

Sheep production is currently one of the most important socioeconomic activities in Mexico. It occurs in all of the country's agroecological regions and has high potential growth. In 2019, per capita lamb meat consumption in Mexico was 0.567 kg and total lamb meat production was 64030 tons. Even this level of production did not meet domestic demand, and 6,782 tons, that is, 9.6% of apparent national consumption (70812 tons), was imported (1,2).

This growing domestic demand for lamb meat is driving producers in Mexico to increase production. Most (95%) production is used in typical regional dishes (e.g. *barbacoa* or *mixiote*) (3), but there is a growing market (mainly in the tourism industry) for grilling and gourmet cuts (4).

Sheep producers therefore face daunting challenges. They need to increase meat production while meeting consumer expectations for healthier meat products containing less saturated fat, and that are standardized and high quality. In animal carcasses and meat products, "quality" refers to the perceived degree of excellence. Perception of excellence can depend on the interests of a particular segment (e.g. producers, processors, marketers, or consumers). However, certain technological metrics (pH), nutritional characteristics (fat, protein, etc.) and organoleptic properties most directly affect the consumer market. For example, muscle pH can affect meat color, hardness, proteolytic microorganism growth and water-holding capacity (5). Lamb slaughter weight is known to affect meat fattiness and fat percentage; meat from lambs slaughtered at a lower weight are reported to have lower intramuscular fat content, reduced saturated fatty

acids content and improved nutritional quality, making it healthier for humans (6). This is why lambs are often slaughtered at low weights.

Meat quality also involves various physical-chemical traits associated with the quality of meat, although meat marketers tend to concentrate on aspects of visual quality (e.g. meat and fat color, fat proportion and marbling) since final consumers associate these characteristics with meat sensory qualities (7,8).

Meat quality attributes respond to myriad intrinsic and extrinsic factors, but the most important are genetic factors (genetic group) (9,10,11).

Improving genetic factors is frequently done by crossing sheep of known genotypes to create animals adapted to regional conditions that produce meat which fulfills market demands. In Mexico, for example, genotypes such as Dorper and Katahdin have been introduced, particularly in the tropical southeast, and crossed with locally-adapted Pelibuey and BlackBelly genotypes to improve growth rate, carcass yield and specific carcass quality traits (12). The relevant literature contains no research on meat quality in these genotypes raised in the tropics of Mexico. This is especially the case for the production systems used in Mexico's southeast, where purebred supply animals of these genotypes are rare.

Better understanding meat quality traits in hair sheep helps in identifying genetic groups suitable for specific markets. Statistical tools can be applied to classify or discriminate between genetic groups based on these traits, producing data that can be applied to determine the most adequate groups and crosses for the desired

characteristics. This is vital to developing selection and crossbreeding schemes with well-defined improvement objectives focused on meat quality.

The present study objective was to identify the effect of hair sheep genetic group on some physicochemical traits associated with meat quality using Dorper, Katahdin and F1 Dorper sire x Katahdin dam crosses, finished in southeast Mexico. An additional evaluation was done of the possibility of discriminating between these genetic groups based on some of the studied physicochemical characteristics.

## MATERIALS AND METHODS

**Animals and handling.** Rearing and fattening of the animals used in this study was done in a herd of pure Dorper and Katahdin sheep at the Sheep Research Unit of the Technological Institute of Tizimín (Instituto Tecnológico de Tizimín - ITT). The ITT is located in the east of the State of Yucatan, Mexico (21°09'29" N; 88°10'2" W) at 20 m asl. Regional climate is sub-humid tropical with summer rains (AW0), 1105 mm (400-1300 mm) average annual rainfall, 25.8°C (24-28°C) average annual temperature and 78% average annual relative humidity.

Eighteen uncastrated male lambs born in the same week (maximum 5 days' difference) were randomly selected from three different genotypes (n=6 per group): Dorper (Dp), Katahdin (Kt) and F1 Dorper sire x Katahdin dams (DpxKt). All were suckled by their mothers and supplemented with a commercial feed for lactating lambs (creep feeding) until reaching approximately 75 days of age and an average weight of 17 kg. They were weaned and placed in individual pens (1.5 m x 1.0 m) equipped with feeders and drinkers. Prior to beginning the experiment, the animals were identified with ear tags, dewormed (subcutaneous ivermectin) and vaccinated against *Clostridium* spp. and paralytic rabies.

During the fattening stage (90 days), and after 15 days of adaptation, they were provided an ad libitum ration of corn-moringa silage (60-40%), in the morning (0700 h) and afternoon (1700 h). Diet ingredients were balanced to meet the requirements of sheep in growth-fattening stages (13). Diet nutritional content (mean±standard deviation) was 14.02±0.56%

CP; 41.48±2.01% neutral detergent fiber (NDF) and 25.64 ± 1.03% acid detergent fiber (ADF). Its metabolizable energy (ME) was 2.40±0.16 Mcal and dry matter digestibility (DMD) was 78.60±3.90%.

Animal treatment and handling complied with applicable regulations for the production, care and use of laboratory animals (NOM-062-ZOO-1992).

**Slaughter and sampling.** Fattening ended at 6.2±0.2 months of age, when the lambs reached 29.5±4.2 kg average weight. They were transported to the slaughterhouse, fasted for 12 h, and slaughtered by mechanical stunning followed by bleeding out. Animal ethics, care, welfare and management complied with all applicable regulations (NOM-062-ZOO-1999, NOM-051-ZOO-1995 and NOM-033-SAG/ZOO-2014). Experiment techniques followed animal handling procedures approved by the ITT. Slaughter weight was calculated based on commercial slaughter conditions for lambs finished with high forage diets in southeast Mexico aimed at producing small carcasses suitable for sale in the regional market, where the preference is for lean, soft meat, known as "grilled lamb".

After slaughter the carcasses were stored under refrigeration (4°C) for 24 h. The *Longissimus thoracis* muscle was extracted from each carcass from the sixth to the thirteenth thoracic vertebrae. Cuts were taken between the sixth and tenth vertebrae for chemical and water-holding capacity analyses, and between the eleventh and thirteenth vertebrae for pH and color analyses. Samples were stored in hermetically-sealed polyethylene bags, identified and transported in coolers (4°C) to the laboratory at the Calkiní Higher Technological Institute (Instituto Tecnológico Superior de Calkiní - ITESCAM) for immediate processing and analysis.

**Proximate composition, color and pH.** Sample proximate analysis (moisture-AOAC 930.15, protein-AOAC 984.13, fat-AOAC 920.039 and ash-AOAC 942.05) was done in triplicate following established protocols (14). Moisture (%Mst) was quantified by gravimetry, heating the sample in a convection oven (SHELL LAB 1350FX10, USA) at 105°C to constant weight. Ash content (% Ash) was measured by incinerating the sample at 550°C for 8 h in an ECOSHEL muffle furnace (ECO-2L, USA). Crude

protein (%CP) was calculated by multiplying total nitrogen (N) by 6.25. Total nitrogen (N) was measured with the Kjeldhal method, by digesting the sample at high temperatures with subsequent distillation with 50% NaOH (w/v, in distilled water), using a digester (Büchi®, K424) and a distiller (Labconco®, Rapidstill II). Intramuscular crude fat (%IMF) was measured using a Soxhlet-type fat extractor (VELP®, SER-148) with hexane as solvent.

Pigment content was quantified following an established procedure (15), measuring optical density (OD) of a pigment extract using an UV-visible spectrophotometer (Agilent Cary 60, Australia) at 512 nm, with a blank (20 ml acetone + 1 ml distilled water + 0.5 ml 35% HCl). Myoglobin content was expressed in mg/g of meat = OD x 8.82. Cholesterol content (expressed in mg/100 g) was measured by colorimetric assay (16). A potentiometer (HANNA®, HI 99163) was used to measure pH. After calibration to pH 7.0 and 4.0 buffers, the glass electrode was inserted perpendicularly into the *Longissimus thoracis* to 4 cm depth. Both drip loss (DL) and cooking loss (CL), expressed as a percentage, were measured by the method of Behan et al (17). Water activity ( $a_w$ ) was measured at 20°C using a water activity meter (Aqualab, CX-2, USA).

Color was measured based on the CIELAB system (CIE, 1986). Fillets taken from between the twelfth and thirteenth vertebrae were oxygenated for 45 min in a tray covered with transparent, O<sub>2</sub>- permeable polystyrene film, without touching the sample. Measurements were taken on the surface of the fillets using a colorimeter (Hunter Lab 4500L, ColorFlex, USA), previously calibrated with a black and white color standard. Results were expressed in terms of L\* (lightness), a\* (red-green) and b\* (yellow-blue), and hue (H°) and Chroma (C\*) calculated as:

$$H^{\circ} = \tan^{-1}(b^*/a^*), C^* = \sqrt{(a^*)^2 + (b^*)^2}.$$

**Statistical analysis.** Physicochemical analysis results were processed with an analysis of variance, adjusting it to a linear model using the SAS ver. 9.0 software:  $Y_{ij} = \mu + G_i + \varepsilon_{ij}$ ; where:  $Y_{ij}$  is the dependent variable,  $\mu$  is the overall

mean,  $G_i$  is the genetic group fixed effect, and  $\varepsilon_{ij}$  is the random error. Comparison of the means was done with a Tukey test between the levels of the evaluated factor ( $p < 0.05$ ). A canonical discriminant analysis was done by the step-by-step method to identify the physicochemical variables that contributed to discrimination between the evaluated genetic groups. The canonical variables were identified with the DISCRIM, STEPDISC and CANDISC procedures in the SAS ver. 9.0 software package.

## RESULTS

*Longissimus thoracis* chemical composition (Table 1) showed that %Mst, %CP and myoglobin concentration were unaffected ( $p > 0.05$ ) by lamb genetic group (i.e., Dp, Kt and DpxKt). However, a slight trend was observed towards higher %CP in Dp. Fat (%IMF; 4.05%) and cholesterol content (92.63 mg/100 g) were highest ( $p < 0.05$ ) in Kt lambs, while %Ash was lowest ( $p < 0.05$ ) in DpxKt crosses (1.01%).

**Table 1.** Least squared means for lamb *Longissimus thoracis* chemical composition by genetic group.

Variables	Genetic Group			SE	P-Value
	Dp	DpxKt	Kt		
Moisture (%)	73.54 <sup>a</sup>	72.10 <sup>a</sup>	73.71 <sup>a</sup>	0.73	ns
Crude Protein (%)	23.17 <sup>a</sup>	21.89 <sup>a</sup>	22.12 <sup>a</sup>	0.59	ns
Crude Fat (%)	2.99 <sup>a</sup>	3.49 <sup>ab</sup>	4.05 <sup>b</sup>	0.25	**
Ash (%)	1.13 <sup>b</sup>	1.01 <sup>a</sup>	1.09 <sup>b</sup>	0.02	**
Myoglobin (mg/g)	2.84 <sup>a</sup>	3.05 <sup>a</sup>	3.51 <sup>a</sup>	0.31	ns
Cholesterol (mg/100 g)	80.34 <sup>a</sup>	81.75 <sup>a</sup>	92.63 <sup>b</sup>	0.75	*

Dp = Dorper; Kt = Katahdin; DpxKt = F1 Dorper sire x Katahdin dam, SE: standard error; <sup>a,b,c</sup> Different letter superscripts in the same row indicate significant difference: \* ( $p < 0.05$ ); \*\* ( $p \leq 0.01$ ); ns ( $p > 0.05$ ).

Physicochemical analyses identified no effect ( $p > 0.05$ ) of genetic group on pH (Table 2). Cooking loss (CL) and  $a_w$  were highest ( $p < 0.05$ ) in DpxKt and Kt, respectively. Drip loss (DL) differed between all the genetic groups ( $p < 0.05$ ), being highest in DpxKt, followed by Kt and Dp.

**Table 2.** Least squared means for lamb *Longissimus thoracis* physicochemical variables by genetic group.

Variables	Genetic Group			SE	P-value
	Dp	DpxKt	Kt		
pH	5.52 <sup>a</sup>	5.72 <sup>a</sup>	5.69 <sup>a</sup>	0.13	ns
CL (%)	33.61 <sup>a</sup>	34.72 <sup>a</sup>	32.77 <sup>b</sup>	0.20	*
DL (%)	3.65 <sup>a</sup>	8.37 <sup>c</sup>	5.01 <sup>b</sup>	0.19	***
a <sub>w</sub>	0.86 <sup>a</sup>	0.86 <sup>a</sup>	0.91 <sup>b</sup>	0.01	***

Dp = Dorper; Kt = Katahdin; DpxKt = F1 Dorper sire x Katahdin dam; SE: standard error; CL = Cooking loss; DL=Drip loss;

<sup>a,b,c</sup>Different letter superscripts in the same row indicate significant difference: \*(p<0.05); \*\*\*(p≤0.001); ns (p>0.05).

Genetic group affected the evaluated CIELAB color variables. Lightness (L\*) was highest (p<0.05) in DpxKt (43.02) (Table 3). For a\* and b\*, Dp had the lowest (p<0.05) values (11.05 and 10.72, respectively) and KT the highest (14.69 and 14.29, respectively). Based on the estimated L\*, a\*, b\* coordinates, C\* was highest (p<0.05) in DpxKt and Kt, indicating greater bright red color saturation. Hue tone intensity (H°) was unaffected by genetic group (p>0.05).

**Table 3.** Least squared means for lamb *Longissimus thoracis* CIELAB color variables by genetic group.

Variables	Genetic Group			SE	P-Value
	Dp	DpxKt	Kt		
L*	38.52 <sup>a</sup>	43.02 <sup>b</sup>	40.81 <sup>ab</sup>	0.99	*
a*	11.05 <sup>a</sup>	12.69 <sup>a</sup>	14.69 <sup>b</sup>	0.59	***
b*	10.72 <sup>a</sup>	13.55 <sup>b</sup>	14.29 <sup>b</sup>	0.57	***
C*	15.49 <sup>a</sup>	18.59 <sup>b</sup>	20.53 <sup>b</sup>	0.70	***
H°	43.93 <sup>a</sup>	46.88 <sup>a</sup>	44.28 <sup>a</sup>	1.35	ns

Dp = Dorper; Kt = Katahdin; DpxKt = F1 Dorper sire x Katahdin dam; SE: standard error; L\* = Lightness; a\*=green-red; b\* = blue-yellow; C\* = Chroma; H° = Hue ; <sup>a,b,c</sup> Different letter superscripts in the same row indicate significant difference: \*(p<0.05); \*\*\*(p≤0.001); ns (p>0.05).

The discrimination analysis used the evaluated physicochemical variables and employed Wilks F and λ statistics. It identified DL, Chroma, IMF and a\* as the four variables capable of separating individuals into genetic groups at a significant level (p<0.05) (Table 4).

**Table 4.** Physicochemical variables identified in the step-by-step discriminant analysis as effectively separating individuals into genetic groups.

Variable	Partial R-square	F value	Pr>F	Wilks λ	Pr < λ
Drip loss	0.877	118.08	<0.0001	0.0230	<0.0001
Chroma	0.601	10.55	0.0016	0.0092	<0.0001
Intramuscular crude fat	0.261	2.30	0.1390	0.0068	<0.0001
Green-red	0.245	2.11	0.1438	0.0051	<0.0001

Two discriminant functions were estimated and evaluated with the Wilks λ statistic; function 1 had a 0.0051 value and function 2 one of 0.2754 (Table 5). The χ<sup>2</sup> test identified significant values for function 1 (71.19), which explained 95.25% of total variability, and function 2 (17.40), which explained 4.75%.

**Table 5.** Identified canonical functions.

Function	EV	CP	CC	λ	χ <sup>2</sup>	p-value
1	52.7456	95.25	0.988	0.0051	71.19	0.0000
2	2.62993	4.75	0.840	0.2754	17.40	0.0006

EV= Eigenvalues; CC= Canonical Correlation

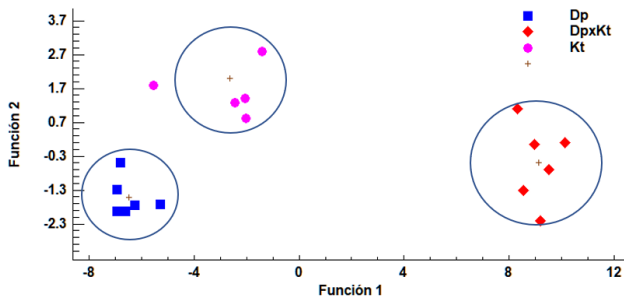
In the analysis of the two Fisher linear discriminant functions, function 1 was found to have the best linear combination because it explained most of the total differentiation between the evaluated genetic groups (Table 6).

**Table 6.** Standardized canonical coefficients for discriminant functions in evaluated genetic groups.

Variable	Function 1	Function 2
DL	1.074750	-0.107494
a*	-0.917881	0.775643
C*	0.874357	0.377888
IMF	-0.053165	0.786071

DL = drip loss; C\* = Chroma; IMF = intramuscular crude fat; a\* = green-red

Graphic representation of the general discrimination between the three evaluated groups based on functions 1 and 2 (Figure 1), shows that cross validation using the discriminant linear function correctly classified and assigned 17 of the lambs (94.6%), with only one Kt incorrectly classified (5.4%).



**Figure 1.** Canonical representation of the three evaluated genetic groups (Dp, DpxKt, Kt) with the discriminant linear function.

## DISCUSSION

Information on food product chemical composition is important to consumers because it allows them to make decisions about the nutrients and energy they ingest. The average proximate chemical composition values for the lamb meat evaluated in the present study are comparable to those reported for lamb meat from arid and dry climates (10,18). This is important data since no data was previously available on the chemical composition of meat from Dorper, Katahdin and F1 Dorper sire x Katahdin dam genotype lambs in tropical systems. Genetic group has a variable effect on meat proximate composition, although moisture and ash contents remain relatively unchanged (18). The meat proximate composition variables which differ between genotypes can vary. For example, in one study comparing meat proximate composition between Morada Nova and Santa Inês hair lambs and their crosses with Dorper, the only difference ( $p < 0.05$ ) was in IMF (19).

Another study of meat proximate composition found KtxDp lambs to have higher CP ( $p < 0.05$ ) and lower IMF than Kt x Charollais lambs (20). In contrast, a report comparing meat from Biellese, Zambucaba and Texel-Merino-Charollais lambs found that CP differed between the genotypes although IMF did not (21). Finally, a study of

proximate composition between Awassi, Harri and Najdi genotypes found no differences ( $p > 0.05$ ) in moisture, CP and IMF (18). The present results differ from these studies in that the tendency towards higher CP and lower IMF (Dp vs. Kt) was not significant ( $p > 0.05$ ), and that intergenotype differences were identified for moisture, CP and IMF.

In Mexico, consumer preference is generally for lean meat ( $< 3\%$  IMF) like that observed here for the Dp genotype (20). However, there are market niches for meat with greater marbling, like those of the Kt and DpxKt genotypes, since this improves meat attributes such as color, aroma, flavor, texture perception and juiciness (22).

The estimated myoglobin content values in the present study were slightly higher (2.84 to 3.51 mg/g) than reported for crosses of Romanov with Suffolk or Charollais (2.15 to 2.18 mg/g) (9), and for the Zwartbles (ZW), Suffolk (SF) and Oxford Down (OD) breeds (2.27 to 2.49 mg/g) (23). Breed affected this variable ( $p < 0.05$ ) in these studies, which differs from the present results ( $p > 0.05$ ).

Variation in lamb meat chemical composition between genetic groups occurs because genotype, in interaction with the environment (nutrition, production system, etc.), determines muscle growth rate and fat deposition sites (intramuscular marbling, subcutaneous, perirenal, etc.) (24).

As a characteristic of meat quality, pH is related to the transformation of muscle to meat (25); post-mortem variation in pH values influences meat organoleptic characteristics. This variable did not differ ( $p > 0.05$ ) between the evaluated genetic groups (5.52 to 5.72), and values were within an appropriate range for meat (5.8 to 6.2), indicating the animals did not suffer significant stress when killed (26). This coincides with previous reports of no differences in meat pH between different sheep breeds (17,18). This is an important characteristic in meat since pH is involved in meat water-holding capacity (27).

Cooking loss (CL) values for the evaluated genetic groups were similar to values reported for the Awassi (34.54%), Harri (33.47%) and Najdi (28.96%) breeds (18). This characteristic is vital to consumer acceptance since meat with greater water-holding capacity during cooking at 75°C is juicier.

The DL values for the Dp and Kt genotypes in the present results were similar to the 3.73 to 4.33% reported elsewhere (18). In contrast, the DL for DpxKt was notably higher (8.37%), which is a distinct disadvantage for this genotype. This difference in DL values may be explained by variability in sarcomere length, ionic strength, osmotic pressure, and protein oxidation, as well as a possible reduction in the distance between myosin and actin filaments in the meat, which can alter cellular and extracellular components that promote water ejection (28).

Drip loss (DL) constitutes the aqueous fraction in muscle proteins expelled from the surface of the meat during storage (29). This variable only quantifies the meat extracellular water fraction, and is used to identify optimum storage conditions. Water loss from carcasses and/or meat represents financial losses for processors and marketers. The consequent weight loss during carcass storage or after processing can reduce sale price, and accumulation of a reddish liquid fraction around the product negatively affects appearance, possibly leading to consumer rejection.

Water activity ( $a_w$ ) in the evaluated lamb meat was lower than the 0.991 reported for meat from eight European lamb breeds (30). Due to its influence on food quality (texture, compaction, etc.) and chemical stability (lipids oxidation and other enzymatic reactions), this variable has become one of the most important intrinsic meat properties in predicting microorganism survival (31). It is also involved in modulating microbial response and determining the type of microorganisms found in foods.

In meat, color is a physical and sensory property, and as such is a quality attribute which can define consumer intention. It is quantified using the parameters of color tone, Chroma and lightness. The color of fresh meat is one of the most important criteria consumers use when making a choice. It is mainly related to the chemical state of myoglobin on the muscle surface but is also influenced by the proportion of intramuscular fat (25).

The  $L^*$  values observed here were similar to those reported for Polish Merino lamb meat (39.8-40.25) (32). As in the present study, differences between genetic groups ( $p < 0.05$ ) have been found (33). Of the evaluated genetic groups,

DpxKt had the highest  $L^*$  value; this is a positive attribute since it improves meat appearance, making it more visually attractive to the consumer (25). However, all the evaluated lamb meat exceeded the 34  $L^*$  value recommended for fresh meat intended for sale (18).

Results for  $a^*$  and  $b^*$  in the present study were similar to those for Kt x Charollais, KtxDp, Kt x Suffolk and Kt x Texel lambs ( $a^* = 8.2$  to 14.4;  $b^* = 6.2$  to 9.1), with differences ( $p < 0.05$ ) between genetic groups (33). In the meat industry,  $a^*$  is the most relevant color coordinate, because it quantifies redness, a vital attribute for consumer perception (25). Of the evaluated genotypes, meat from Kt had the highest  $a^*$  value, suggesting it may enjoy greater consumer preference. Again, it is important to consider that all the evaluated lamb meat exceeded the 9.5  $a^*$  value recommended for fresh meat intended for sale (18).

Finally, Chroma ( $C^*$ ) is the color of a surface evaluated in proportion to its lightness ( $L^*$ ). In the present study, the DpxKt and Kt lamb meat was a paler pink than the Dp meat, possibly making the latter more appealing to consumers.

Overall, the factors that affect color in meat include animal genotype, diet and age (34). As age increases there is a general tendency towards higher pigment content and consequently higher  $a^*$  values and lower  $L^*$  values.

The variables included in the canonical discriminant analysis successfully separated the animals by genotype. This coincides with the discrimination reported between four camel breeds using seven physicochemical variables: color parameters ( $L^*$ ,  $a^*$  and  $b^*$ ), cooking loss, myofibrillar fragmentation index, pH and neck weight (35). Although the present canonical analysis correctly classified over 95% of the animals, there are reports of 100% success rates. One example is a study of lambs from four genetic groups (Morado Nova, Santa Inés and their F1 crosses with Dorper) which used variables related to carcass quality (neck, shoulder and leg proportions) (19). Another is a comparison of two Canarian sheep breeds (hair and wool) slaughtered at different weights, and using meat fatty acid content variables, in which monounsaturated and polyunsaturated fatty acids contents were significant discriminant functions (36).

The physicochemical characteristics evaluated in the present study were significantly influenced by genetic group. In addition, characteristics important to consumer acceptance and the meat industry (e.g. DL, %IMF, Chroma and a\*) effectively discriminated between the evaluated genetic groups. This is promising data for future genetic improvement programs and crossbreeding schemes aimed at developing physicochemical characteristics that ensure product stability, good technological characteristics and a desirable color for markets demanding premium cuts of fresh meat.

Further research is needed to classify different genetic groups based on meat quality

physicochemical characteristics to allow lamb producers in the tropics to generate products for specific purposes, such as grilling meat or gourmet dishes.

### Conflict of interest

The authors declare no conflict of interest.

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