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REGULAR ARTICLES

Histological and physical–mechanical characteristics of the skin of Dorper sheep related to residual feed intake and the confinement environment

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Abstract
The aim was to evaluate the effect of residual feed intake (RFI) on the histological, physical and mechanical characteristics of the sheep skin confined in full sun or shade. Dorper sheep ($n = 64$), male, with an initial bodyweight of 17.8 ± 2.43 kg was confined for 40 days to determine the RFI. After classification, 30 animals with positive RFI and 30 animals with negative RFI were selected, which were distributed in 2 confinement environments. This was a factorial arrangement of 2 (groups of animals—positive RFI and negative RFI) × 2 (environments—full sun and shade), with 15 animals for each combination of factors. The sheep remained in confinement for 60 days. After slaughter, skins were divided in half, and fragments were collected from the right portion for histological sections. The left part of each skin was subjected to tanning. Interaction effect RFI × environment was found in the evaluation of leather fragments in the horizontal direction on elongation at break, leather thickness and tear strength ($p < 0.05$). An isolated effect of the environment was found on elongation at break of leather fragments in the evaluation on the vertical direction ($p = 0.01$) and on the number of secondary follicles during the histological evaluation of the dorsal and lateral regions of the skin ($p < 0.05$). An effect of the interaction RFI × environment was observed for the thermostatic layer of the hip region ($p = 0.03$). Sheep with positive RFI and kept in confinement in full sun have a leather with greater elongation at break and tear strength, important aspects in determining the quality of the product by the leather industry.

Keywords Feeding efficiency · Heat stress · Skin quality · Tanning · Tensile strength

Introduction

In an animal production system, feed represents the largest variable input cost, accounting for about 70% total production costs (Johnson et al. 2019); therefore, continuous efforts to improve feed efficiency are vital for the environment and the economy (Zhang et al. 2021). A viable alternative to reduce animal feed costs is to select animals according to their feed efficiency (González-García et al. 2020). Thus, the identification of animals with low food intake and satisfactory performance would result in greater productive efficiency of the herd (Muir et al. 2018).

Residual feed intake (RFI) is an alternative proposed by Koch et al. (1963) that quantifies feed efficiency of an animal regardless of body weight or production level. RFI can be understood as the difference between the observed dry matter intake and the predicted dry matter intake of an animal as a function of metabolic body weight ($BW^{0.75}$) and average daily gain (ADG) (Ellison et al. 2019). Animals with higher feed efficiency are classified as low RFI and ingest less food than expected for maintenance and production, presenting lower and higher body fat and protein accumulation, respectively, while animals with lower feed efficiency are

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considered to have high RFI, ingesting more food to achieve the same weight gain obtained by the low RFI group (Tortereau et al. 2020). Therefore, selecting animals with higher feed conversion efficiency (low RFI) has the potential to improve productivity, in addition to reducing feed costs, making RFI an economically relevant characteristic for animal production systems (Zhang et al. 2019).

During animal growth, parts of the body change in proportion, including by the skin. The skin is a by-product of meat production and represents about 10 to 12% animal value (Wanyoike et al. 2018). The skin market is very promising, and if they are of high quality and undergo an adequate processing that will add value to this by-product, the skin becomes a product of great economic expressiveness and its value could represent a significant portion of the carcass value (Salehi et al. 2014; Ali et al. 2020).

The quality of sheepskin is influenced by inherent characteristics of the animal (breed and age), as well as by the environment in which it lives. To the best of our knowledge, studies on the effect of RFI on the histological, physical and mechanical characteristics of sheepskin are lacking, considering only skin weighing as one of the non-carcass components (Carneiro et al. 2019).

Thus, the objective was to evaluate the effect of residual feed intake on the histological, physical and mechanical characteristics of the skin of sheep confined in full sun or shade.

Material and methods

Declaration of animal rights

This research was approved by the Ethics Committee on Animal Experimentation (CEUA) of the Federal University of the São Francisco Valley—UNIVASF, with protocol number 0006/131014.

Experimental site and animals

The experiment was carried out at the Federal University of the São Francisco Valley (UNIVASF), in Petrolina, state of Pernambuco, Brazil (09°23′55″ South latitude and 40°30′03″ West longitude, 393 m altitude). The climate, according to the classification of Köppen and Geiger (1928), is hot semi-arid with rainy season (BSh), with an average annual rainfall of 376 mm, unevenly distributed.

Meteorological data were collected using data-loggers. The maximum and minimum temperatures were 34.4 and 28.7 °C and 38.3 and 33.1 °C in the shade and full sun feedlots, respectively. The maximum and minimum values of relative air humidity were 41.9 and 23.1% and 44.0 and 23.6% in the shade and full sun confinements, respectively. Information related to the average temperature and relative humidity during the experimental period is shown in Fig. 1.

Sixty-four intact male Dorper sheep, with 17.8 ± 2.43 kg of average initial body and 70 ± 10 days of average age, were subjected to an adaptation period of 14 days in which they were identified, weighed, dewormed and supplemented with injectable vitamins A, D and E (IVER-VET ADE, Bio-Vet S/A, Vargem Grande Paulista—SP, Brazil). Then, lambs were distributed in individual pens (2.2 m^2) equipped with feeders and drinkers.

Residual feed intake (RFI)

RFI was determined according to the model recommended by Cockrum et al. (2013). For 40 days, animals were given a diet as a complete mixed ration consisting of ground corn, soybean meal, mineral mixture (Guabiphos, Guabi

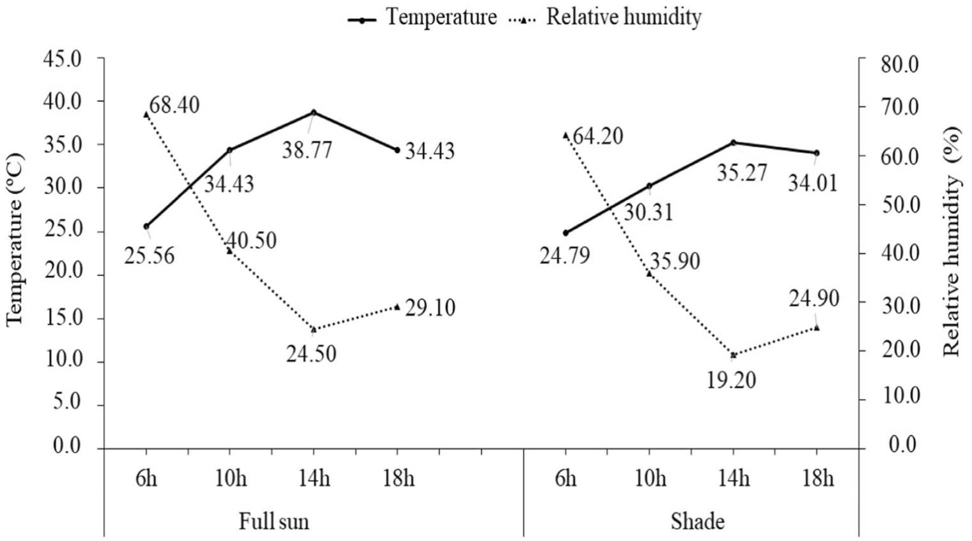

Fig. 1 Averages of air temperature and relative humidity during the experimental period in full sun and shade feedlots

Nutrição e Saúde Animal SA, Campinas—SP, Brazil) and chopped elephant grass (*Pennisetum purpureum*), formulated at a forage:concentrate ratio of 70:30, on a dry matter basis (Table 1) and balanced to obtain a daily gain of 250 g/day, according to the recommendations of the NRC (2007). Elephant grass was harvested daily, and the grass was processed using a stationary forage machine (Nogueira Pecus 9004, Saltinho—SP, Brazil), to particles with an average size of 2.5 cm.

The diet was provided twice a day (08 h and 16 h). The amount of food offered was adjusted daily, considering 15% leftover, based on the previous day's dry matter intake.

At the end of the 40 experimental days, animals were classified into two groups, positive RFI (high feed efficiency) or negative RFI (low feed efficiency), considering the differences in the observed and predicted values of dry matter intake (DMI), based on average daily gain (ADG) and metabolic body weight ($BW^{0.75}$), where (Koch et al. 1963):

$$\text{predicted DMI} = \beta 0 + \beta 1 \times \text{ADG} + \beta 2 \times \text{BW}^{0.75} \quad (1)$$

where: β0 is the regression intercept; β1 is the partial regression coefficient on average daily gain and β2 is the partial regression coefficient on metabolic body weight.

Animals whose standard deviation was greater than 0.5 were classified as positive RFI, while those with standard deviation lower than 0.5 were classified as negative RFI.

Treatments and experimental design

After selection and classification of the animals according to the RFI, they were distributed in two confinement environments (full sun or shade), remaining under this confinement regime for 60 days, totaling a period of 100 experimental days.

Table 1 Ingredients and chemical composition of the experimental diet

Ingredients	g/kg DM
Ground corn	118.6
Soybean meal	164.4
Mineral mixture	17.0
Elephant grass	700
Chemical composition	
Dry matter*	399.9
Mineral matter	99.3
Organic matter	900.7
Crude protein	125.0
Neutral detergent fiber	702.2
Acid detergent fiber	367.8

* in g/kg fresh matter

The experimental design was in randomized blocks (according to animal weight), in a 2×2 factorial arrangement, with two groups of animals (positive RFI and negative RFI) and 2 environments (full sun and shade), with 15 animals for each combination of factors evaluated.

The confinement in the shade was carried out in a hollowed-out shed (without side walls) with a concrete floor, covered with metallic tiles and a ceiling height of 6 m. The animals were confined in pens with dimensions of 1 m×1.5 m and were not exposed to sunlight throughout the experimental period. In full sun confinement, the animals were kept in a shed without a cover, with a dirt floor and a ceiling height of 6 m. The animals were confined in pens measuring 1 m×2 m and exposed to direct sunlight throughout the experimental period.

Slaughter and skin sampling

Animals were slaughtered at the end of the experimental period, after 16h00 of fasting, according to the current rules of the Regulation for Inspection of Industrial Sanitation of Animal Origin Products (Brasil, 2017). Animals were previously stunned by cerebral concussion and bled by section of the jugular vein and carotid artery.

Physical and mechanical analysis

The left halves of sheepskin were salted and kept at 4 °C until tanning, following the steps of soaking, liming, deliming, tanning, lowering, re-tanning and dyeing, applying the methodology of Jacinto et al. (2011). After tanned, leathers were acclimatized at 30 °C for 60 days, before the physical and mechanical tests.

Six specimens were taken from the left side of leather pieces, 3 horizontally and 3 vertically to the dorsal line (the region richest in collagen fibers, responsible for the texture and strength of the leather). The thickness measurements of leather pieces, necessary for the tensile and tear strength calculations, were taken using a leather thickness gauge (Model DM 3 Wolf, Nicawe, Campo Alegre—SC, Brazil) following the ABNT standards (NBR ISO 2589; 2016; NBR 11,114; 2020a).

Tensile strength and percentage extension of leather

To determine the tensile strength and percentage extension, the Universal Testing Machine (Dynamometer; FMS 500 Series, Starrett®, Itu—SP, Brazil), with a load cell of 200 kg was used. The DynaView Standard Software was used to control the equipment. The samples were firmly clamped between two clamps that move apart at a constant speed of ± 100 mm/min. As they move away, the force needed to stretch the leather is automatically measured. At some point, the leather sample breaks. The force required to break the sample is called the tensile strength of the leather and is measured in Newtons. Tensile strength and percentage extension were measured using the ABNT NBR ISO 3376 (2020b) procedure.

Leather tear strength

The leather tear strength involved a rectangular leather sample with a small slit in it. In this sample, a clamp was fixed to its base, and another clamp was inserted through the slit, then the sample was separated. The point at which the crack begins to tear was defined as the tear strength of the leather. Tear strength was expressed in relation to the average thickness of the leather. Tear strength was determined using the test method of the ABNT (2016) and ABNT ISO 3376 (2020b), respectively.

The thickness measurements of the leather pieces, necessary for the tensile and tear strength calculations, were made using a leather thickness gauge (Modelo DM 3 Wolf, Nicawe, Campo Alegre—SC, Brazil) following the ABNT, 2589; 2016; NBR 11, 114; 2020a).

Histological analysis

Immediately after animal slaughtering and skinning, skins were divided in half and samples for histological sections were collected with a trephine (1.0 cm × 0.5 cm) from the dorsal, lateral, ventral, hip and shoulder regions, always on the right half of the skin (Fig. 2) (Tarique et al. 2021).

Skin fragments were individually fixed in buffered formaldehyde at 10% for 18 h, in glasses identified with self-adhesive labels containing the necessary information: animal, treatment, region (skin site where the sample was taken), direction related to the axis and date. Fragments were dehydrated in ethanol, cleared in xylene and embedded in paraffin to form blocks. Sections (5 µm-thick) were made in each block and these were placed on a slide. For each animal, one slide from each of the 5 regions analyzed was counted. Subsequently, sections were deparaffinized and stained with hematoxylin and eosin for microscopic analysis using a Carl Zeiss Polarized light microscope (Tolosa et al. 2003), to evaluate the thickness of the reticular and thermostatic layers, counting of primary follicles and sebaceous glands (Jacinto et al. 2004).

The analysis of the extracellular matrix was performed through the observation of histological sections in photonic microscopy, using as a reference the characteristics of collagen fiber bundles. Measurements were made using photomicrographs using a digital camera (DCM130E, 1.3 M pixels, CMOS chips) and image analysis software (Software Scope-Photo), being taken across the optical field. Everything that could be read in that image field was quantified (3 fields per slide/animal at 4 × magnification: 5 fields per slide/animal at 10 × magnification). The verification of the thickness of the thermostatic and reticular layers was performed using a scale existing in an ocular reticle previously calibrated with a micrometer slide.

Statistical analysis

Data were subjected to the Shapiro–Wilk test to check the normal distribution of residuals and homogeneity of variances using the univariate procedure. Next, they were tested by analysis of variance using the GLM procedure of the SAS 9.2 statistical software (SAS Institute, Cary, NC, USA). The model included the treatment effect (type of confinement and type of residual feed intake). Results were expressed as

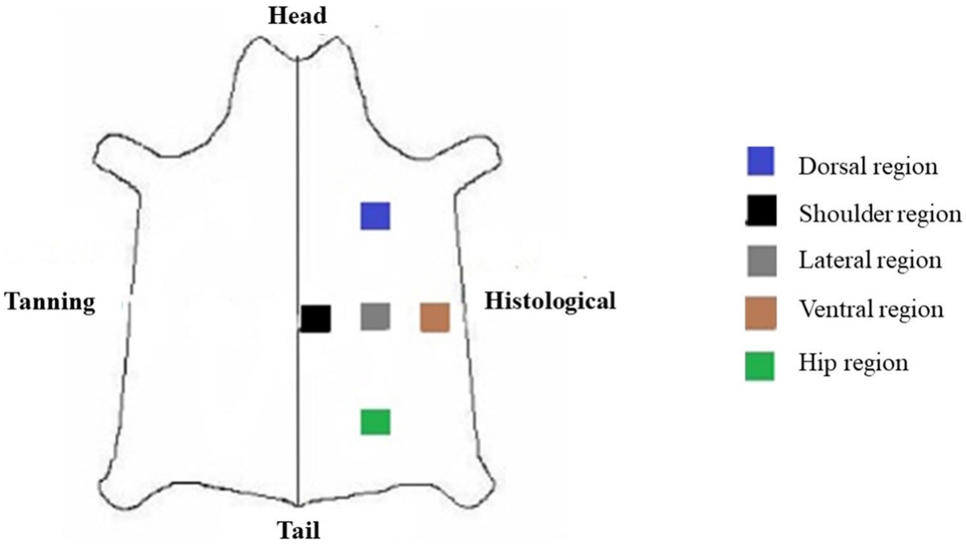

Fig. 2 Sampling regions, view from the surface of the hairs

Table 2 Average values (± standard error) of thickness and percentage extension of leather from Dorper sheep, according to residual feed intake (RFI) and thermal environment ($n = 15$)

Variables	Positive RFI			Negative RFI			SEM	*p* value		
	Full sun	Shade	Average	Full sun	Shade	Average		RFI	E	RFI × E
	Thickness (mm)									
Horizontal	1.15	0.96	1.05	1.03	1.24	1.13	0.05	0.22	0.89	0.07
Vertical	1.17	1.06	1.11	1.10	1.26	1.18	0.03	0.25	0.56	0.09
	Elongation at break (%)									
Horizontal	124.61a	104.83b	114.72A	98.94a	90.50b	94.72B	7.10	0.01	0.02	0.02
Vertical	46.39b	48.17a	48.78A	43.83b	54.94a	49.38A	1.40	0.43	0.01	0.06

Positive RFI positive residual feed intake, *Negative RFI* negative residual feed intake, *Full sun* animals confined to full sun, *Shade* animals confined to shade, *RFI* isolated effect of residual feed intake, *E* isolated effect of thermal environment, *RFI × E* interaction effect between the residual feed intake and thermal environment factors, *SEM* standard error of the mean, *p value* probability value

[a–b] Averages followed by different lowercase letters differ from each other for the purposes of the RFI

[A–B] Averages followed by different capital letters differ from each other for the purpose of environment. Significant at the 5% probability level by Tukey's test ($p < 0.05$)

mean ± standard error of mean, and differences were considered significant when $p < 0.05$ by Tukey's test.

Results

Tensile strength and percentage extension of leather

There was no isolated effect of RFI nor the environment on leather thickness to determine the tensile strength and percentage extension ($p > 0.05$). There was no effect of the interaction RFI × environment on leather thickness to determine the tensile strength and percentage extension ($p > 0.05$; Table 2).

Effect of the interaction RFI × environment was observed in the evaluation of leather fragments in the horizontal direction on the elongation at break ($p = 0.02$; Table 2), in which positive RFI and negative RFI Dorper sheep kept in confinement in full sun had a higher percentage of elongation at break of their leather (124.61 and 98.94%, respectively) in relation to positive RFI and negative RFI animals kept in confinement in the shade (104.83 and 90.50%, respectively) (Table 2; Fig. 3).

For the elongation at break of leather pieces on the vertical direction, an isolated effect of the environment was found, where the sheep confined in the shade presented a greater elongation at break in relation to animals confined in the full sun ($p = 0.01$; Table 2).

Leather tear strength

Effect of the interaction RFI × environment was verified for leather thickness ($p = 0.01$) and for the leather tear strength, when evaluated in the horizontal direction ($p = 0.01$; Table 3). Dorper positive RFI sheep, confined in

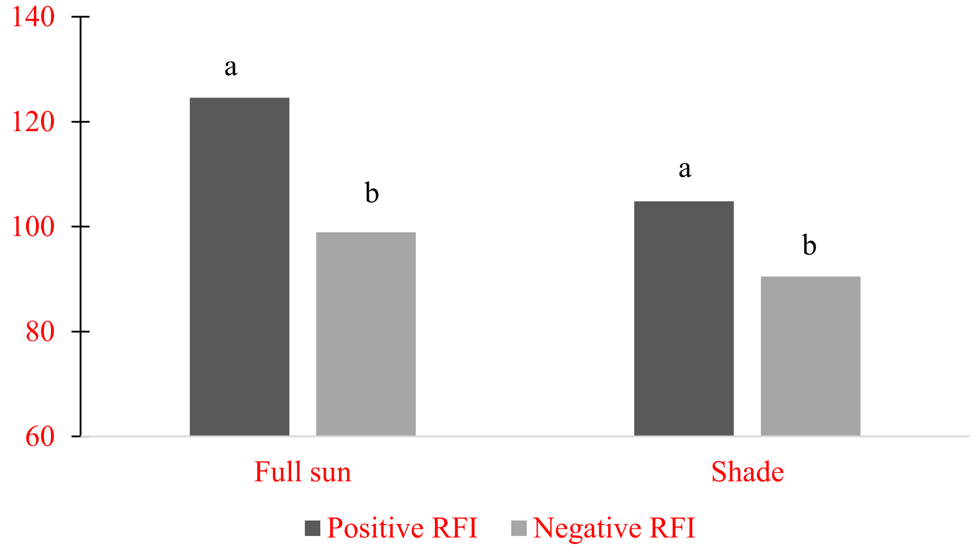

Fig. 3 Interaction effect between residual feed intake and thermal environment in the elongation at break of leather in Dorper sheep, when evaluated horizontally. Negative RFI = negative residual feed intake; Positive RFI = positive residual feed intake; Full sun = animals confined to full sun; Shade = animals confined to shade. [a–b] Averages followed by different lowercase letters differ statistically by Tukey's test ($p < 0.05$)

Table 3 Average values (± standard error) of tear strength—double-end tearing—of Dorper sheep leather according to residual feed intake (RFI) and thermal environment ($n = 15$)

Variables	Positive RFI			Negative RFI			SEM	*p* value		
	Full sun	Shade	Average	Full sun	Shade	Average		RFI	E	RFI × E
	Thickness (mm)									
Horizontal	1.17	1.02	1.09B	1.07	1.33	1.20A	0.03	0.04	0.24	0.01
Vertical	1.16	1.03	1.09	1.06	1.24	1.15	0.04	0.34	0.51	0.08
	Leather tear strength (N/mm)									
Horizontal	44.95a	31.67b	38.31A	34.78a	31.34b	33.06B	2.37	0.01	0.02	0.01
Vertical	33.70	29.30	31.50	25.71	30.04	27.87	2.10	0.20	0.98	0.13

Positive RFI positive residual feed intake, *Negative RFI* negative residual feed intake, *Full sun* animals confined to full sun, *Shade* animals confined to shade, *RFI* isolated effect of residual feed intake, *E* isolated effect of thermal environment, *RFI × E* interaction effect between the residual feed intake and thermal environment factors, *SEM* standard error of the mean, *p value* probability value

$^{a–b}$Averages followed by different lowercase letters differ from each other for the purposes of the RFI

$^{A–B}$Averages followed by different capital letters differ from each other for the purpose of environment. Significant at the 5% probability level by Tukey's test ($p < 0.05$)

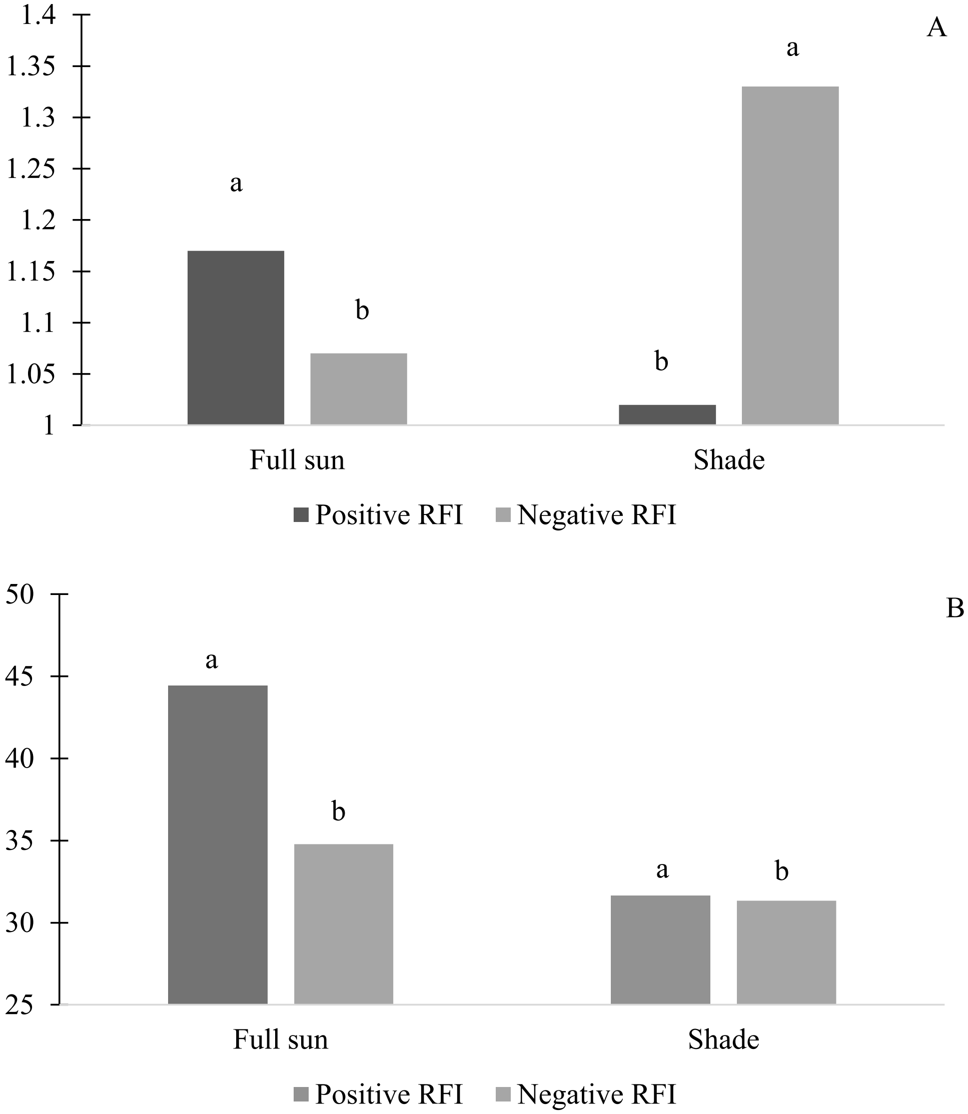

Fig. 4 Interaction effect between residual feed intake and thermal environment on the thickness (**A**) and leather tear strength (**B**) in Dorper sheep, when evaluated horizontally. Negative RFI = negative residual feed intake; Positive RFI = positive residual feed intake; Full sun = animals confined to full sun; Shade = animals confined to shade. $^{a–b}$Averages followed by different lowercase letters differ statistically by Tukey's test ($p < 0.05$)

full sun, presented values of thickness and tear strength of the leather (1.17 mm and 44.95 N/mm, respectively) higher than animals kept in the shade (1.02 mm and 31.67 N/mm, respectively). Negative RFI animals confined in the shade had larger leather thickness (1.33 mm) compared to animals confined in full sun (1.07 mm) (Table 3; Fig. 4). Regarding leather tear strength, negative RFI sheep confined in full sun had higher values (34.78 N/mm) than animals kept confined in the shade (31.34 N/mm) (Table 3; Fig. 4).

There was no isolated effect of RFI nor environment and no effect of the interaction RFI × environment interaction on the thickness and tear strength of leather during the determination of tear force, when evaluated on the vertical direction ($p > 0.05$; Table 3).

Histological analysis

In the structural analysis of the skin, the division into papillary (or thermostatic) and reticular layers was observed, with no defined limits between them. The thermostatic layer represents, approximately, half of the dermis thickness, being observed the proximity in the values of the thermostatic and reticular layers (6.60 mm and 6.11 mm, respectively) (Fig. 5A). It was possible to identify and quantify the presence of primary and secondary hair follicles (Fig. 5B), the primary ones were larger in diameter and usually accompanied by sebaceous glands, while secondary follicles were smaller and without the presence of glands.

In histological sections of the skin, specifically the thermostatic layer of the hip region, it was possible to observe an effect of the interaction RFI × environment ($p = 0.03$; Table 4), in which Dorper sheep with positive RFI and negative RFI confined in full sun showed larger thermostatic layer thickness (0.85 and 0.71 mm, respectively) compared to sheep with positive RFI and negative RFI confined in the shade (Table 4; Fig. 6).

For the reticular layer of the skin of the hip region, no effects of RFI nor the environment were observed, nor any effect of interaction between these factors ($p > 0.05$; Table 4). There was no isolated effect of RFI nor the environment nor an effect of the interaction RFI × environment on the thermostatic and reticular layers of the skin analyzed in the dorsal, shoulder, lateral and ventral regions of Dorper sheep ($p > 0.05$; Table 4).

An isolated effect of the environment was detected on the number of secondary follicles during the histological evaluation of the dorsal ($p = 0.02$) and lateral ($p = 0.04$) regions of the skin of Dorper sheep, where animals confined in the shade presented a higher number of secondary follicles compared to those confined in full sun (Table 5). The number of primary follicles and sebaceous glands were not influenced by the environment ($p > 0.05$; Table 5) in these regions.

The RFI, the type of confinement environment and the interaction RFI × environment did not influence the number of primary follicles, secondary follicles and sebaceous glands in the hip, shoulder and ventral regions of the skin of Dorper sheep ($p > 0.05$; Table 5).

Discussion

The histological structure of the skin and its thickness are different between species or in the same animal, with changes with age as a function of various tissue components, influenced by factors such as nutrition, region from which the specimens are taken, breed, management and exposure to the sun (Urge et al. 2017; Baenyi et al. 2020;

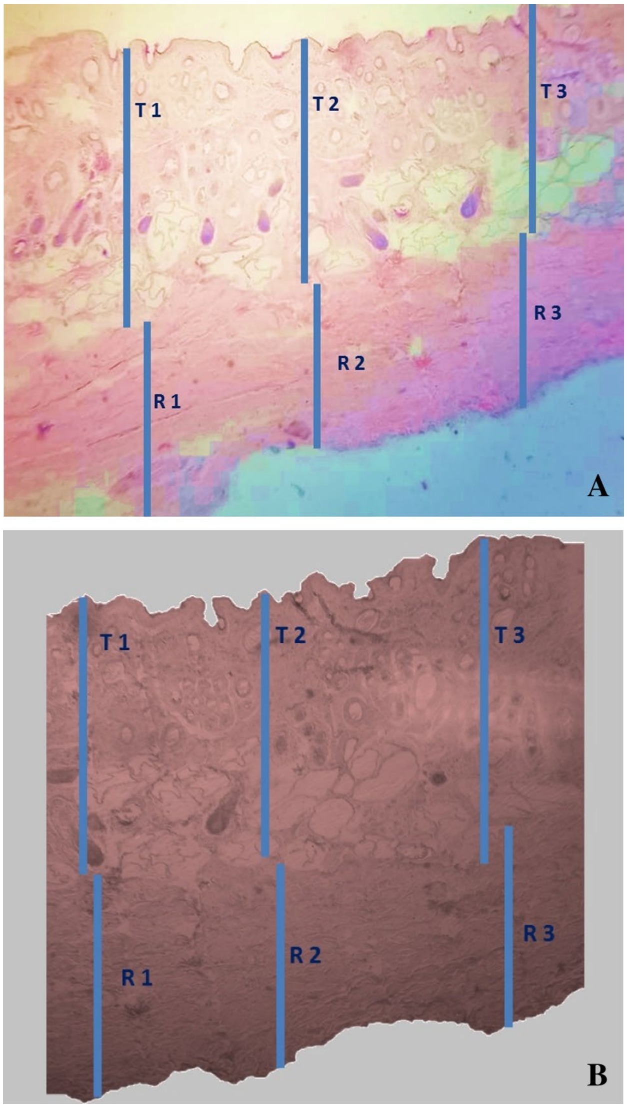

Fig. 5 Photomicrograph of Dorper sheep skin: (**A**) thermostatic layer (T1, T2, T3) and reticular layer (R1, R2, R3), hip region. 40 × magnification. Scale bar 0.1 mm; (**B**) lateral region, (1) primary follicle; (2) secondary follicle; (3) sebaceous glands. 100 × magnification. Scale bar 0.1 mm

Table 4 Average values (± standard error) of thickness of the thermostatic (T) and reticular (R) layers of Dorper sheep skin according to residual feed intake (RFI) and thermal environment ($n = 15$)

Region	Layers (mm)	Positive RFI			Negative RFI			SEM	*p* value		
		Full sun	Shade	Average	Full sun	Shade	Average		RFI	E	RFI × E
Ventral	T	0.85a	0.79b	0.82A	0.71a	0.49b	0.60B	0.03	0.01	0.01	0.03
	R	0.61	0.62	0.62	0.66	0.69	0.68	0.02	0.68	0.25	0.54
Dorsal	T	0.68	0.77	0.73	0.76	0.76	0.76	0.03	0.61	0.69	0.67
	R	0.64	0.51	0.57	0.54	0.56	0.55	0.02	0.28	0.57	0.08
Shoulder	T	0.64	0.56	0.60	0.69	0.68	0.68	0.02	0.51	0.20	0.41
	R	0.55	0.52	0.53	0.56	0.57	0.56	0.01	0.97	0.50	0.55
Lateral	T	0.66	0.62	0.64	0.71	0.59	0.65	0.02	0.70	0.06	0.38
	R	0.56	0.55	0.56	0.62	0.61	0.62	0.01	0.25	0.86	0.92
Hip	T	0.55	0.51	0.53	0.50	0.58	0.54	0.02	0.78	0.19	0.23
	R	0.65	0.71	0.68	0.66	0.72	0.69	0.02	0.85	0.26	0.51

Positive RFI positive residual feed intake, *Negative RFI* negative residual feed intake, *Full sun* animals confined to full sun, *Shade* animals confined to shade, *RFI* isolated effect of residual feed intake, *E* isolated effect of thermal environment, *RFI × E* interaction effect between the residual feed intake and thermal environment factors, *SEM* standard error of the mean, *p value* probability value

$^{\text{a–b}}$Averages followed by different lowercase letters differ from each other for the purposes of the RFI

$^{\text{A–B}}$Averages followed by different capital letters differ from each other for the purpose of environment. Significant at the 5% probability level by Tukey's test ($p < 0.05$)

Fourneau et al. 2020). These facts were observed in the present study, in which Dorper sheep with low feed efficiency (positive RFI) confined in full sun, showed better quality of tanned leather compared to animals confined in the shade. To the best of our knowledge, there are no studies that evaluate the quality of tanned leather from Dorper sheep grouped according to phenotype of RFI subjected to different environmental conditions of confinement (full sun × shade).

Elongation or elasticity has great significance for the leather-based product manufacturing industries (Nalyanya et al. 2018). To obtain a durable product, the leather should have adequate elasticity and, for this purpose, the percentage of elongation at break should be 40–80%, as recommended by BASF (1995). Higher elongation values observed in the present study for positive RFI and negative RFI animals confined to full sun may be related to the arrangement of collagen fibers, given that woolless sheep leather has a greater thickness and greater number of collagen fibers in the thermostatic layer, resulting in greater tensile strength (Salehi et al. 2014). A greater number of collagen fibers is essential for binding the tanning agent to these fibers during the tanning process, promoting better strength and elasticity (Maina et al. 2019).

Regardless of the classification (positive or negative RFI), Dorper sheep confined to full sun were subjected to a higher environmental temperature (Fig. 1) and were exposed to direct solar radiation, that is, they received a high load of thermal energy, a fact that increases the need to dissipate excess heat absorbed by the body. For this, there is an increase in the direction of energy expenditure to maintain body temperature balance (Hill and Wall, 2017). In addition, Dorper sheep have coat characteristics that favor less thermal insulation and greater resistance to solar radiation. Dantas et al. (2020) mention that there is a high correlation between environmental indices and body temperature of sheep, demonstrating the importance of establishing indicative values of thermal discomfort for the adoption of measures that mitigate thermal stress and do not compromise the leather of Dorper sheep.

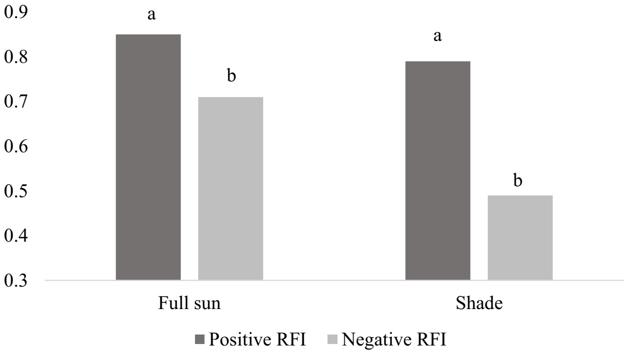

Fig. 6 Interaction between residual food intake and thermal environment on the thermostatic layer thickness (T) of the skin fragment from the hip region of Dorper sheep. Negative RFI = negative residual feed intake; Positive RFI = positive residual feed intake; Full sun = animals confined to full sun; Shade = animals confined to shade. $^{\text{a–b}}$Averages

Table 5 Average number (± standard error) of primary follicles, secondary follicles and sebaceous glands in Dorper sheep according to residual feed intake (RFI) and thermal environment ($n = 15$)

Variables	Positive RFI			Negative RFI			SEM	*p* value		
	Full sun	Shade	Average	Full sun	Shade	Average		RFI	E	RFI × E
	Hip									
Primary	4.26	4.59	4.42	4.72	3.86	4.29	0.22	0.59	0.79	0.24
Secondary	14.19	16.53	15.36	13.66	13.99	13.82	0.78	0.44	0.38	0.56
Glands	7.33	8.06	7.69	8.00	6.92	7.46	0.29	0.79	0.72	0.18
	Dorsal									
Primary	3.42	3.66	3.54	2.66	3.58	3.12	0.19	0.11	0.26	0.34
Secondary	11.91b	14.50a	13.20	8.26b	15.33a	11.79	1.14	0.45	0.02	0.17
Glands	6.83	6.83	6.83	5.87	7.33	6.66	0.34	0.27	0.70	0.30
	Shoulder									
Primary	3.13	3.66	3.39	2.86	3.08	2.97	0.12	0.10	0.11	0.48
Secondary	11.73	13.72	12.72	11.13	10.58	10.85	0.71	0.58	0.29	0.42
Glands	6.13	7.19	6.66	5.99	6.33	6.16	0.24	0.15	0.34	0.52
	Lateral									
Primary	2.99	3.39	3.19	3.53	4.13	3.83	0.16	0.16	0.08	0.70
Secondary	12.26b	16.13a	14.19	12.46b	17.06a	14.76	0.96	0.77	0.04	0.85
Glands	6.46	6.52	6.49	5.52	7.26	6.39	0.28	0.14	0.86	0.17
	Ventral									
Primary	1.66	1.86	1.76	2.32	1.73	2.02	0.11	0.40	0.26	0.10
Secondary	2.40	2.46	2.43	4.59	1.86	3.22	0.38	0.08	0.28	0.07
Glands	5.46	5.46	5.46	5.13	6.19	5.66	0.58	0.62	0.85	0.41

Positive RFI positive residual feed intake, *Negative RFI* negative residual feed intake, *Full sun* animals confined to full sun, *Shade* animals confined to shade, *RFI* isolated effect of residual feed intake, *E* isolated effect of thermal environment, *RFI × E* interaction effect between the residual feed intake and thermal environment factors, *SEM* standard error of the mean, *p value* probability value

$^{a\text{–}b}$Averages followed by different lowercase letters differ from each other for the purposes of the RFI. Significant at the 5% probability level by Tukey's test ($p < 0.05$)

Costa et al. (2020) observed that in an environment exposed to direct radiation, Dorper sheep showed an increase in the area occupied by sebaceous glands in the dermis, due to greater direct contact with sunlight. This may explain the higher elongation values obtained in the tanned leather of animals kept in confinement in full sun compared to those kept in a shaded environment, during the execution of the experiment, since these glands have the characteristics of keeping the skin soft and flexible.

Positive RFI and negative RFI sheep confined to full sun showed greater resistance to leather tearing. However, regardless of feed efficiency and confinement environment, the evaluated leathers showed tear strength values higher than the 20 N/mm recommended by BASF (1995), to obtain a good quality leather. In this sense, when opting for a leather that presents greater resistance to tearing in numerical values, Dorper sheep with positive RFI showed greater resistance to tearing of the leather, in relation to the other groups evaluated. Negussie et al. (2015) reported that the horizontal sampling direction exerts, in numerical terms, greater tensile and tear strength than the vertical sampling direction for the dorsal spine, which could be attributed to the leather fiber arrangement of the dorsal spine according to the sampling direction used.

Secondary follicles provide thermal protection and are found in the skin in greater density than primary follicles and may have only one sebaceous gland (Tuncer et al. 2018; Fourneau et al. 2020). A factor affecting the branching of secondary follicles is related to physiological stress, including high environmental temperature (Badawy 2016; Umar and Atabo 2020), observed in the present study, in which sheep, positive and negative RFI, confined in full sun had a reduced number of secondary follicles in the dorsal and lateral regions.

Studies related to RFI × environment interaction are necessary and relevant, in order to unravel and understand the different forms of action of biological variables on feed efficiency in Dorper sheep raised in tropical regions and what are the impacts on the animals' skin, to obtaining a better quality product to be made available to the market.

Under the experimental conditions, we can infer that Dorper sheep with positive residual feed intake and kept in confinement in full sun have a leather with greater elongation at break and tear resistance, important aspects in determining the quality of the product by the leather industry.

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Data availability Further information on the data and methodologies will be made available by the author for correspondence, as requested.

Declarations

Ethics approval This research was evaluated and approved by the Ethics Committee on the Use of Animals (CEUA) of the UNIVASF, under protocol number 0006/131014.

Consent to participate Not applicable.

Consent for publication All authors declare to agree to the publication of the manuscript.

Competing interests The authors declare no competing interests.

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