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Southern African large frame Indigenous Veld Goat and Boer Goat wether and buck tenderness and colour of six muscles

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Simple Summary: The study describes the meat tenderness and colour attributes of six muscles (*Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), *Semitendinosus* (ST)) from same-aged young wethers and bucks of Boer Goat (BG) and Indigenous Veld Goats (IVG: Cape Speckled and the Cape Lob Ear). IVG is a collective name for the eco-types conserved by the Indigenous Veld Goat Society of South Africa. Muscle tenderness and colour characteristics differed more between wethers and bucks than between IVG and BG. Large frame IVG bucks and wethers produced very similar meat tenderness, juiciness and colour characteristics as the BG bucks and wethers indicating them to be just as suited for meat production. The wethers' meat with its increased intramuscular fat in all six muscles tested would satisfy the consumer segment that prefer juicier and flavorsome meat. Knowledge of muscle characteristics of goat carcasses will help the development of the formal commercial market for goat meat that would benefit smallholder farmers who typically produce most of the goats in the world.

Abstract: Meat tenderness, water holding capacity (WHC) and colour attributes of six muscles (*Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), *Semitendinosus* (ST)) from large frame Indigenous Veld Goats (IVG) and Boer Goats (BG) were studied. Weaner male Boer Goats (BG; n = 18; 10 bucks and 8 wethers) and large frame Indigenous Veld Goats (IVG; n = 19; 9 bucks and 10 wethers) were raised on hay and natural grass, and on a commercial pelleted diet to a live weight of 30 - 35 kg. All goats were slaughtered at a commercial abattoir and the dressed carcasses chilled at 4°C within 1-hour *post-mortem*. The muscles were dissected from both sides 24-hours *post-mortem* and aged for 1-day and 4-days. Variations in meat characteristics such as ultimate pH, WHC, percentage purge, myofibril fragment length, intramuscular fat, connective tissue characteristics, and Warner-Bratzler shear force. Bucks had higher L* and Hue-angle values, whereas wethers had increased a* and Chroma values. The muscle baseline-data will allow informed decisions to support muscle-specific marketing strategies, which may be used to improve consumer acceptability of chevon.

Keywords: Cape Lob Ear, Cape Speckled, meat goat breeds, meat tenderness, meat colour, collagen, chevon

1. Introduction

Indigenous Veld Goats (IVG) are a group of specific pure-bred indigenous eco-types represented by the IVG-Association that define specific standards that a goat must adhere to before it can be classified as one of the eco-types such as the Cape Lob Ear and the Cape Speckled goats [1]. Both of these eco-types have large frames and can compete with the Boer Goat (BG) in terms of meat yield [2], whilst also having additional advantages such as adaptability to harsh climates and disease resistance [3]. The increasing global

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human population and the threat of global warming, makes it important to promote the production of goat meat (chevon) from adapted eco-types such as the IVG. Although chevon is popular amongst the larger population of southern Africa, chevon is not available on the commercial shelves in South Africa, the major reason being that there are insufficient commercial slaughter numbers to ensure a constant supply to the commercial retail market. Although southern Africa has relatively large numbers of meat goats (703,892 head) [4], most are produced in the informal sector and traded within this sector thereby making it challenging obtaining official statistics of the volumes of goat meat produced and traded. Available goats are either sold alive for traditional slaughtering practices or exported to Middle Eastern and Asian countries. Small and emerging southern African farmers are interested in IVGs as they do not require intensive management to be productive. For chevon, quality fresh meat is the most economically profitable, however the scientific knowledge on meat quality of these breed types is scarce, compared to that of the well-known "improved" BG breed and the non-defined "indigenous" goats that are usually used in comparison studies [5, 6, 7, 8, 9, 10].

The term "meat quality" includes many attributes, of these, texture, juiciness and colour are important attributes to consumers, with texture the most important. Tenderness and mechanical properties of meat are influenced by the connective tissue, myofibrils and their interactions which differ between muscles [11, 12]. Compared to sheep and cattle, knowledge of the meat quality of BG and large frame Indigenous Veld Goats (IVG, Cape Speckled and the Cape Lob Ear) of South Africa is limited due to a previous lack of interest. The goat carcass consists of over a hundred different muscles with different properties, which affect processing characteristics and could influence consumer acceptability [13]. There has been a continued trend in the retail sector to separate muscles, based on perceived connective tissue characteristics, to better market them and apply the knowledge in terms of the users' requirements. Notable studies on the physical and compositional traits of BG muscles have been conducted over the years [7]. These range from carcass measurements and commercial yields [14], cooking and juiciness related quality characteristics [15], including studies to understand the impact of carcass handling on the texture, mainly determined by the Warner-Bratzler shear force (WBSF) on different muscles [8, 9, 16, 17]. Most studies evaluating chevon are conducted on the *Longissimus thoracis et lumborum* (LTL) and *Semimembranosus* (SM) muscles in terms of tenderness and sensory quality attributes [5, 6, 9, 10]. To establish a baseline for IVG eco-types, this paper focuses on the effect of breed (IVG vs. BG) and sex (bucks and wethers) on: ultimate muscle pH (pH_u), percentage purge, water holding capacity (WHC), Warner Bratzler shear force (WBSF), myofibril fragment length (MFL), intra muscular fat (IMF), collagen characteristics, and meat colour (CIE L*, a*, b*, Chroma and Hue-angle), in six different muscles (i.e. *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST)) to establish baselines for these eco-types.

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2. Materials and Methods

2.1. Animal and experimental design

This research was approved by the Agricultural Research Council – Animal Production (ARC-AP) Ethics Committee (ref no. APIEC16/021). Weaner Boer Goats (BG; n = 18; 10 bucks and 8 wethers) and large frame Indigenous Veld Goats (IVG; n = 19; 9 bucks and 10 wethers) were purchased from commercial breeders at three months of age (17 kg on average for IVG and 20 kg on average for BG). When bought, the commercial breeder had already castrated the male animals on the farm. The animals were reared at the Small Stock Section of the ARC-AP facility situated in Irene, in the Gauteng province of South Africa where they grazed a natural grass diet supplemented with hay *ad libitum* and an average of 250 g commercial "Ram, lamb and ewe - 13" pellets (protein 130 g/kg, fat 25 - 70 g/kg, fibre 150 g/kg, moisture 120 g/kg, calcium 15 g/kg, phosphorus 3 g/kg, urea 10 g/kg; Meadow Feeds, Lanseria, Gauteng, South Africa) per day per animal. The goats spent on average 6 to 8 months until they attained a live weight (LW) of between 30 and 35 kg. After weighing (LW), the goats were transported for 3 km to the abattoir of the ARC-AP on the day of slaughter. The experimental design is presented in Figure 1 and has been described in more detail in [2]. The carcasses were subjected to electrical stimulation (ES - 20 seconds, 400 Volts peak, 5ms pulses at 15 pulses/second), 10 minutes after stunning and exsanguination where after all the carcasses were placed in the chiller at 4°C within 60 minutes *post-mortem*. After chilling (24 hours, <4°C), the carcasses were removed from the chiller and the specific muscles removed from both sides of the carcass and cut into various steaks for the different meat quality analyses (Figure 2). Temperature and pH values were measured 24 hours *post-mortem* (pH_u) on the same chilled muscles used for colour measurement with a calibrated Crison pH25 meter (Crison Instruments, Barcelona, Spain).

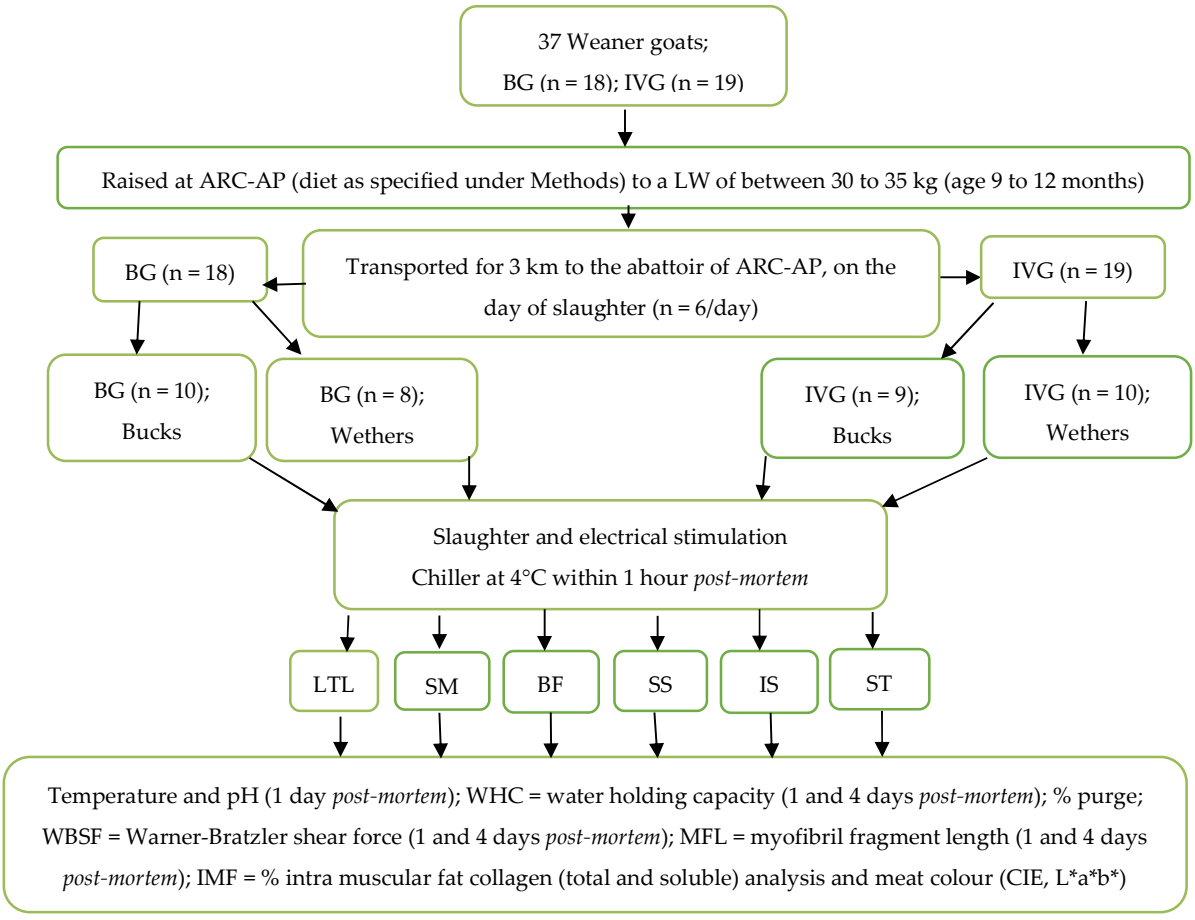

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Figure 1. Experimental design to evaluate the effect of breed; large frame Indigenous Veld Goats (IVG, Cape Speckled and Cape Lob Ear) and Boer Goats (BG) of southern Africa, on tenderness factors, colour attributes and connective tissue characteristic of *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST)). ARC-AP = Agricultural Research Council - Animal Production, Irene, South Africa.

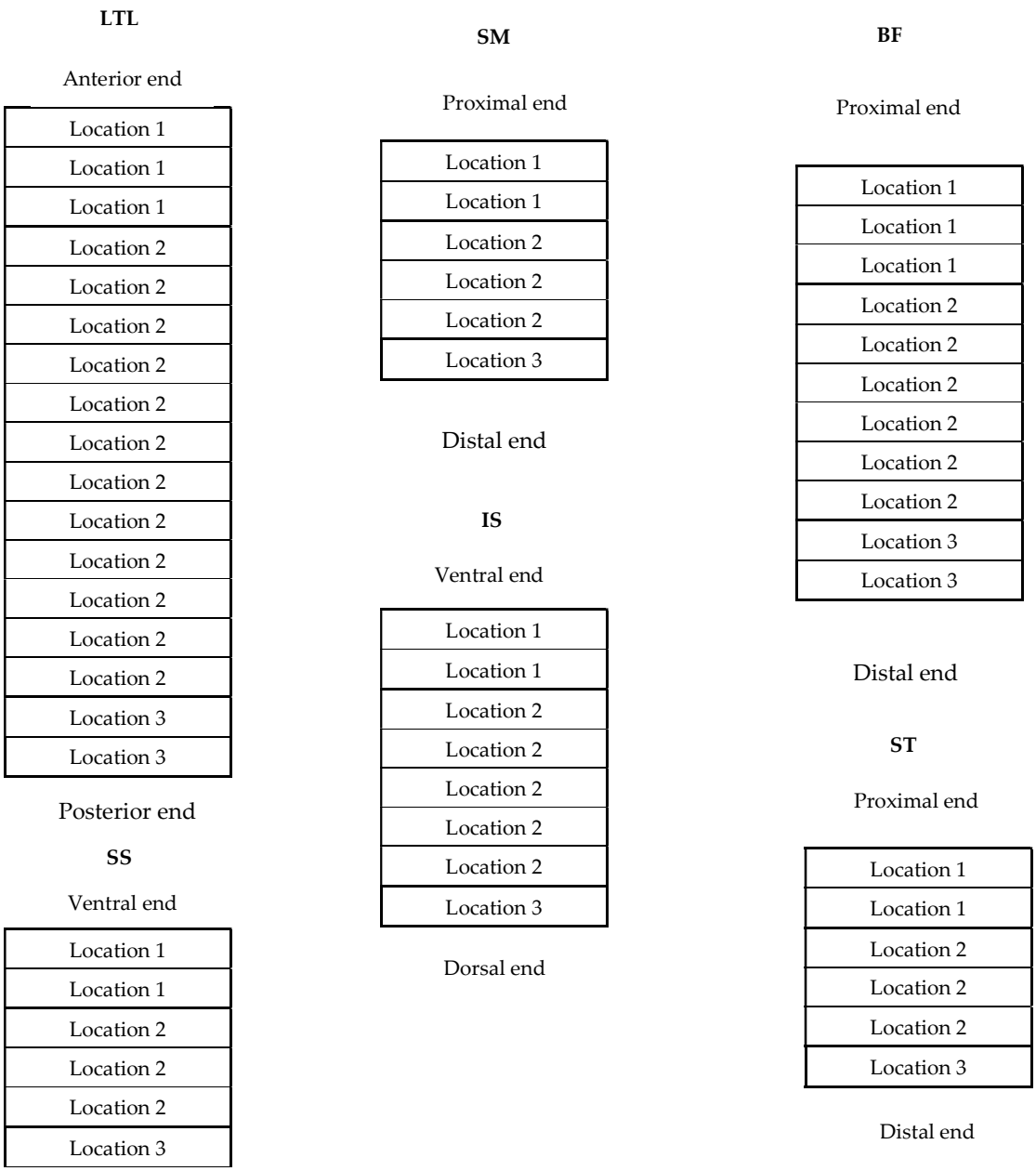

Figure 2. Sampling locations of the six different muscles (i.e., *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST)). Left side of carcass for 1 day samples for location 1 (meat colour (CIE, L*a*b*), water holding capacity (WHC), myofibril fragment length (MFL), location 2 (Warner-Bratzler shear force (WBSF)) and location 3 (collagen (total and soluble) analysis); Right side of carcass for 4 days samples for location 1 (meat colour (CIE, L*a*b*), water holding capacity (WHC), myofibril fragment length (MFL)), location 2 (Warner-Bratzler shear force (WBSF)) and location 3 (collagen (total and soluble) analysis, proximate analysis). Proximal = nearest the vertebral column. Each horizontal section represents a 2.0 cm-thick steak.

2.2. Laboratory analysis

For the chemical and the physical analyses, samples were taken from the various locations of the six muscles *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST) as described in Figure 2. Analyses were either conducted on the fresh samples (purge loss, water holding capacity (WHC), chemical and meat colour analyses) or on vacuum packed frozen (-20°C) and then defrosted (4°C, 24 hours) samples such as Warner-Bratzler shear force (WBSF).

2.2.1. Purge and water holding capacity (WHC)

Purge percentage was measured using a 10 mm thick slice of the six different muscles (LTL, SM, BF, SS, IS, and ST), vacuumed and aged for 4 days at 4°C. The specific muscles were weighed before and after storage and the weight difference indicated as purge loss percentage. Water holding capacity (WHC) of the six fresh muscles were determined using the filter paper press method [18]. Briefly, 400 to 500 mg meat sample was placed on filter paper (Whatman 4), contained between two Perspex plates. Constant pressure was applied using a hand-operated screw for 5 minutes. The borders of meat and fluid expressed were marked out and their areas measured using a video image analyser (Soft Imaging System, Olympus Japan), according to [19]. Water holding capacity was expressed as a ratio of meat area to fluid area.

2.2.2. Warner-Bratzler shear force (WBSF)

The frozen vacuumed packed muscle samples (LTL, SM, BF, SS, IS, and ST) were placed in a cold room at 4°C to thaw for 24 hours before cooking. Whole cuts were prepared according to an oven-broiling method (dry heat cooking) using direct radiant heat [20]. Calibrated electric ovens (Mielé ovens, model H217, Miele & Cie. KG, Gütersloh, Germany) were set on "broil" 10 minutes prior to cooking at 160°C. The samples were placed on an oven pan on a rack and broiled for approximately 20 minutes until they reached an internal core temperature of 70°C. The internal temperature was monitored by placing an iron-constant thermocouple (T-type) (Hand-model Kane-Mane thermometer, Kane International Ltd, Hertfordshire, England) in the approximate geometric centre of each sample. The cooked meat + pan + drip was weighed. The cooked samples were cooled for 2 hours at room temperature (20°C) before shear force measurement. For shear force measurements, six cylindrical samples (12.5 mm core diameter) were bored parallel to the direction of the muscle fibres. Each core was sheared perpendicular to the myofibrils using a Warner-Bratzler device fitted to an Instron Universal Testing Machine (Model 4301, Instron Ltd, Buckinghamshire, England) at a crosshead speed of 200 mm/min with one shear in the centre of each core [21]. The toughness of the meat was the average maximum force (N) required to shear through the cores.

2.2.3. Myofibril fragmentation length (MFL)

Samples used for MFL were aged for 1 day and 4 days *post-mortem*. Sub-samples of ca. 3 g were taken, blended with a blunt blade in cold potassium phosphate extraction buffer at 4°C to arrest any further proteolysis [22], and determined according to [23]. The droplets of extracted MFL solution were mounted on slides, covered with a cover slip, and viewed under a microscope attached to a video image analysis (VIA). One hundred myofibril fragments per sample were examined and measured at a magnification of 40X.

2.2.4. Intra muscular fat (IMF) and collagen characteristics (Total collagen and collagen solubility)

The intra muscular protein and fat (representing chemical determined intramuscular fat – IMF) were analysed using the procedures of the Association of Official's Analytical Chemist [24] at the ARC-AP Analytical Laboratories. Samples (25 g of homogenized meat) were freeze dried according to method 934.01 [24]. The percentage fat content was determined on 5 g of freeze dried sample using a 1:2 chloroform/methanol solution for fat extraction (SOXTEC method) as described in [25]. The total nitrogen content in the defatted muscle samples was determined after samples had been digested in a micro Kjeldahl system (Analytical Laboratory ARC-AP). The nitrogen content was multiplied by a factor of 6.25 in order to obtain the protein content of the sample, which was subsequently converted to a value per gram wet meat (method 922.15) [24]. Soluble, insoluble and total collagen were determined in the same fresh samples.

Total collagen content in the six muscles (LTL, SM, BF, SS, IS, and ST) was determined by measuring the total hydroxyl-proline nitrogen content in hydrolysed samples according to a modified method of [26]. Approximately 1 g of fresh sample was weighed into a hydrolysed tube and mixed with 15 ml of 6 N HCl. The samples were hydrolysed at 120°C for 16 hours, 0.5 g active carbon was added to each tube, stirred, and filtered through Whatman 4 filter paper. The aliquots were collected in a 100 ml volumetric flask and filled up to a volume with distilled water. An aliquot of 50 ml was used for the determination of total collagen described below.

The solubility of the intramuscular collagen (hydroxy-proline nitrogen content of soluble collagen) was determined according to the method of [27] with some modifications. About 2 g of fresh sample was stirred in 10 ml of 1 % NaCl. The samples were heated in a shaking water bath at 78°C for 60 minutes. The cooled samples were centrifuged at 10,000 RPM for 15 minutes. The supernatants were poured into hydrolysing tubes, marked as soluble. The pellet was poured into another hydrolysing tube and marked insoluble. To each tube, 7.5 ml of 6 N HCl (19.2 %) was added and hydrolysed overnight at 120°C. The following day, 0.5 g of active carbon was added to the cooled tubes, stirred, and the homogenates filtered into 50 ml volumetric flasks and filled to the mark with distilled water. Aliquots of 50 ml were used for determination of both soluble and insoluble collagen.

Hydroxy-proline concentrations were determined calorimetrically according to a modified method of [28]. About 1 ml of the final sample was added into the test tubes where 1 ml of 10 % KOH solution was added (to neutralise the acid in the sample). A blank consisting of 2 ml distilled water was prepared. Standard solutions were prepared containing zero to 7.5 µg/ml and 2 ml hydroxy-proline to create a new standard curve for each analyses session.

To each test tube (including standards and blanks), 1 ml of the oxidant solution (1.41 g Chloramine-T in a 100 ml, pH 6.8 buffer solution consisting of: 26 g citric acid monohydrate, 14 g sodium hydroxide, 78 g Anhydrous sodium acetate and 250 ml propan-1-ol) was added. The tubes were vortexed for 5 seconds and left for 20 minutes at room temperature. After 20 minutes, 1 ml of the colour reagent (10 g para-dimethylaminobenzaldehyde, 35 ml perchloric acid solution (60 %), 65 ml propan-2-ol, prepared fresh) was added and the tubes vortexed. The tubes were heated to 62°C ± 5°C for 30 minutes, then vortexed. Thereafter, they were cooled to room temperature (a strong aromatic pink liquid with a white salt residue forms in the tubes). The top transparent pink liquid was pipetted into disposable micro cuvettes and absorbance was read on a spectrophotometer at 558 nm (± 2 nm). Hydroxy-proline content was determined from the standard addition curve.

Total collagen content was determined by calculating hydroxy-proline nitrogen from hydroxy-proline (MM 131.13 and nitrogen atom number 14.0067). Collagen values were expressed as mg collagen/g of muscle sample by using the hydroxy-proline conversion of 7.25 and 7.53 for insoluble and soluble collagen respectively [29].

2.2.5. Minolta meat colour and pH measurements

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Colour of muscle samples (ca. 15 mm thick) were measured fresh at 1 day and 4 days *post-mortem*. The meat samples were allowed to bloom for 60 minutes at ± 4°C before the meat colour values were recorded. A Konica-Minolta 600d spectrophotometer (Konica-Minolta Inc. Osaka, Japan) with the software package Spectra Magic NX Pro was used to measure surface D65 at three different positions on the meat samples. Three components were recorded; lightness, L* (dark [0] to light [100]) and the two chromatic components; a* (green [-60, 180°] to red [+60, 0°]) and b* (blue [-60, 270°] to yellow [+60, 90°]) which represented the myoglobin levels in the meat [30]. The spectrophotometer configuration consisted of illuminate (A), with an observer angle of 10° and the spectral component excluded (SCE) after calibration using a white reference [31]. Chroma (saturation index (S) = $(a^{*2}+b^{*2})^{1/2}$; [32] and Hue-angle (discolouration) = $\tan^{-1(b^*/a^*)}$; [33] were calculated from a* and b* values, Chroma measures colour intensity where the higher values indicate more intense red colour in meat. An increase in Hue-angle between 0° and 90° corresponds to a blending of yellowness or less of redness, probably due to metmyoglobin formation in fresh meat.

2.2.6. Statistical analysis

The data were subjected to analysis of variance (ANOVA) [34] to test the effect of breeds (BG and IVG), and sex-types (bucks and wethers) on six muscles for the following characteristics; pH and temperature (24 hours *post-mortem*, pH_u and T_u), WHC (1 and 4 days *post-mortem*), % DL, WBSF (1 and 4 days *post-mortem*), MFL (1 and 4 days *post-mortem*), connective tissue characteristics, and meat colour (CIE L*, a*, b*, Chroma and Hue-angle,1 and 4 days *post-mortem*) [35]. Statistical significance (Fisher's t-test, least significant difference) was calculated at a 5 % level to compare means. $P \leq 0.05$ was considered statistically significant, although in some instances' data with a $P \leq 0.1$, (10 % level) was considered as a trend worth discussing.

Prior to analyses, a Shapiro-Wilk test for normality was performed on the data [36] and where applicable, outliers (classified as such when the standardized residual for an observation deviated with more than three SDs from the model value) were removed. Where applicable, the closeness of the linear relationships between the measured variables was determined using Pearson' correlation coefficient (r).

3. Results

The results for the carcass characteristics of the experimental animals have been described previously [2] and summarised in Table 1

Table 1. Least square means and standard error (SE) of means for carcass characteristics of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats (adapted from [2]).

	Breed						
	BG		**IVG**		**Significance (P – Values)**		
Carcass characteristics	**Bucks n = 10**	**Wethers n = 8**	**Bucks n = 9**	**Wethers n = 10**	**Breed**	**Sex**	**Breed Sex**
Live weight (kg)	$35.40^{ab} \pm 4.01$	$36.13^{a} \pm 3.02$	$36\ 67^{a} \pm 2.68$	$32.8^{b} \pm 2.39$	0.293	0.118	**0.032**
Cold carcass weight (kg)	15.26 ± 2.31	16.25 ± 1.66	15.88 ± 1.83	14.86 ± 0.97	0.541	0.938	0.094
Dressing (%)	$42.99^{a} \pm 2.44$	$44.95^{b} \pm 1.08$	$43.28^{a} \pm 3.23$	$45.42^{b} \pm 2.49$	0.508	**0.017**	0.912

*^{a,b} Means in the same row per main effect bearing different letters differ ($P \leq 0.05$)**

The choice of the particular six muscles studied; *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST), was to obtain a set of muscles representing a variation in tenderness and other quality parameters due to their different anatomical positions, func-

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tions and commercial value. Means and standard errors of breed and sex on pH_u, T_u, muscle water holding capacity (WHC), percentage purge, Warner Bratzler shear force (WBSF), myofibril fragment length (MFL), intra muscular fat (IMF), collagen characteristics, and meat colour (CIE L*, a*, b*, Chroma and Hue-angle) for each of these six muscles are presented in Tables 2 to 7, respectively.

Large frame IVG presented higher pH_u values ($P \leq 0.05$) compared to that of BG for LTL, BF, and ST muscles, with SM and SS having a tendency ($P \leq 0.10$) to show breed differences. Sex differences for pH_u were more prominent ($P \leq 0.05$) for SM, SS, with ST showing both breed and sex differences and therefor a tendency ($P \leq 0.10$) to have breed x sex interactions. The IS muscle (~6.1) showed on average the highest pH_u, but no differences between breed and sex. In the muscles where pH_u differences were found, the IVG seemed to have the higher pH_u compared to BG. When sex differences arose, the wethers always tended to have higher pH_u than the bucks. On average, the SS measured a pH_u of ~5.9, followed by BF and ST with pH_u between 5.7 and 5.9.

Although there is some tendencies of breed and sex differences at 1 day *post-mortem* for some muscles, it is only after 4 days *post-mortem* that significant differences were observed in pressed out water (WHC). Water holding capacity mostly vary between 0.35 to 0.40 measured at 4 days *post-mortem*, but LTL measured 0.43 to 0.45, respectively for BG and IVG wethers compared to 0.38 and 0.39, respectively for BG and IVG bucks. Significant breed and sex effects for WHC at 4 days *post-mortem* were recorded for SM and SS muscles although the ratio was not as high as for the LTL. Only IS presented a breed difference for percentage purge with that of IVG (0.62% - 0.82%) significantly lower than that of BG (0.97% - 1.20%). It was observed that overall IS and BF seemed to have lower percentage purge than that of the other muscles (>1.5%) (Results not shown).

Tenderness related sex effects were recorded for the BF (MFL 1 and 4 days *post-mortem*) and ST (WBSF 1 day *post-mortem*) muscles, while a tendency ($P \leq 0.1$) for an interaction between sex and breed was recorded for MFL at 1 day *post-mortem* for the SM muscles (Table 3). The BF wether muscle measured shorter MFL than that of the buck muscle (Table 4). Differences were found between the different muscles (results not shown). Some numerical tenderisation from 1 to 4 days *post-mortem* can be observed in each of the Tables 2 to 7, with SM, SS and IS being the most tender after 4 days *post-mortem*.

All the muscles showed a sex-effect ($P \leq 0.05$) for IMF (Tables 2 to 7). Wether muscles overall recorded higher percentage IMF than that of bucks in LTL, SM, BF, SS, IS and ST. IVG bucks recorded the lowest values (1.1%) in the IS muscles (Table 6) and BG wethers recorded the highest values of 4.18% in the BF muscle (Table 4). For most muscles, the bucks had about 1% less IMF than that of the wethers whilst the buck BF muscle had up to 2% less IMF than that of its equivalent wether muscle.

There were no significant effects of breed and sex on any of the collagen characteristics among the six muscles studied (Tables 2 to 7). However, there were tendencies ($P \leq 0.1$) observed for IVG buck LTL and BG and IVG buck ST to have higher collagen solubility levels.

Meat colour differences related to the sex-effect were noted; *L** (lightness) differences were observed in LTL (1 day *post-mortem*), SM (1 and 4 days *post-mortem*), BF (1 day *post-mortem*), SS (1 and 4 days *post-mortem*), and IS (1 day *post-mortem*), with a trend in the ST for a breed x sex interaction. For these muscles wethers recorded lower L* values (darker meat) than the bucks. A sex effect for redness (a*) and Chroma (saturation index) were experienced in LTL (1 day *post-mortem*), SM (1 day *post-mortem*), BF (1 day *post-mortem*), and SS (1 day *post-mortem*). These muscles from wethers seem darker and brighter red than those of bucks especially at 1 day *post-mortem*. At 4 days *post-mortem* the Hue-angles (discoloration) of wether LTL, SM, SS and IS were lower than that of the corresponding buck muscles. Significant breed x sex interactions were observed for the Chroma of the SM and ST and a trend in BF at 4 days *post-mortem* indicating towards a higher saturation index for BG wethers and IVG bucks. No breed or sex differences were detected for b* (yellowness) for any of the muscles.

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Table 2. Least square means and standard error of means for meat tenderness, meat colour and related physiological characteristics of buck and wether Boer Goat (BG) and Indigenous Veld Goats (IVG) of the *Longissimus thoracis et lumborum* (LTL) muscle

	Breed						
	Boer Goat		Indigenous Veld Goat		Significance (p – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed Sex
pH_u	$5.54^{a} \pm 0.18$	$5.60^{a} \pm 0.05$	$5.67^{b} \pm 0.11$	$5.72^{b} \pm 0.18$	**0.011**	0.241	0.944
Water holding capacity							
1 day *pm*[#]	0.41 ± 0.03	0.39 ± 0.06	0.38 ± 0.04	0.37 ± 0.05	0.101	0.384	0.642
4 days *pm*	$0.38^{a} \pm 0.04$	$0.45^{b} \pm 0.08$	$0.39^{a} \pm 0.08$	$0.43^{b} \pm 0.07$	0.979	**0.018**	0.515
Purge (%)	1.71 ± 0.84	1.86 ± 0.78	2.00 ± 1.02	1.96 ± 0.79	0.495	0.836	0.721
Warner Bratzler Shear force							
1 day *pm* (N)	58.5 ± 1.10	59.0 ± 1.17	57.4 ± 1.15	59.5 ± 1.05	0.958	0.752	0.834
4 days *pm* (N)	46.5 ± 1.14	40.5 ± 1.12	43.3 ± 0.88	42.9 ± 1.22	0.842	0.395	0.499
Myofibril fragment length							
1 day *pm* (µm)	37.16 ± 5.46	35.55 ± 4.83	35.26 ± 5.05	37.42 ± 5.04	0.351	0.220	0.319
4 days *pm* (µm)	33.62 ± 6.21	29.63 ± 2.01	30.32 ± 5.07	29.85 ± 6.14	0.471	0.332	0.426
Marbling*							
IMF (% Fat)	$1.97^{a} \pm 1.11$	$2.58^{b} \pm 1.35$	$1.49^{a} \pm 0.94$	$2.59^{b} \pm 0.70$	0.620	**0.017**	0.473
Collagen characteristics							
Collagen solubility (%)	36.68 ± 10.69	37.55 ± 11.25	38.63 ± 9.83	35.49 ± 11.13	0.973	0.722	0.707
Soluble collagen (mg/g[#])	$1.37^{x} \pm 0.58$	$1.40^{x} \pm 0.42$	$1.66^{y} \pm 0.48$	$1.27^{x} \pm 0.38$	0.958	0.501	0.080
Insoluble collagen (mg/g)	2.40 ± 0.54	2.50 ± 0.91	2.71 ± 0.42	2.40 ± 0.71	0.549	0.232	0.229
Total collagen (mg/g)	3.68 ± 0.85	3.80 ± 0.85	4.24 ± 0.39	3.59 ± 0.78	0.566	0.222	0.160
Meat colour characteristics							
L D65 SCE 1 day *pm*	$35.61^{a} \pm 2.12$	$33.50^{b} \pm 1.20$	$35.11^{a} \pm 2.60$	$33.20^{b} \pm 2.47$	0.877	**0.010**	0.545
L D65 SCE 4 days *pm*	36.65 ± 3.18	34.75 ± 2.67	35.28 ± 1.35	34.84 ± 2.79	0.755	0.471	0.238
a*D65 SCE 1 day *pm*	$9.45^{a} \pm 0.84$	$11.25^{b} \pm 0.76$	$9.90^{a} \pm 1.60$	$10.53^{b} \pm 1.27$	0.966	**0.004**	0.139
a*D65 SCE 4 days *pm*	9.75 ± 1.25	10.91 ± 1.12	10.09 ± 0.96	10.43 ± 1.44	0.736	0.168	0.208
b* D65 SCE 1 day *pm*	11.16 ± 1.41	11.26 ± 1.18	11.10 ± 1.81	12.14 ± 1.41	0.371	0.236	0.354
b* D65 SCE 4 days *pm*	13.04 ± 0.94	12.64 ± 0.65	12.52 ± 0.85	12.48 ± 0.91	0.209	0.413	0.499
Chroma D65 SCE 1 day *pm*	$14.66^{a} \pm 1.30$	$15.95^{b} \pm 1.02$	$14.93^{a} \pm 1.96$	$16.13^{b} \pm 1.39$	0.486	**0.015**	0.898
4 Chroma D65 SCE days *pm*	16.34 ± 1.13	16.74 ± 0.06	16.11 ± 1.10	16.18 ± 1.27	0.340	0.577	0.680
Hue angle D65 SCE 1 day *pm*	$49.58^{x} \pm 4.02$	$44.96^{y} \pm 3.51$	$48.76^{x} \pm 6.09$	$47.74^{y} \pm 2.73$	0.388	0.059	0.139
Hue angle D65 SCE 4 days *pm*	$53.36^{a} \pm 3.86$	$49.36^{b} \pm 2.62$	$51.16^{a} \pm 2.39$	$50.16^{b} \pm 3.49$	0.724	**0.026**	0.116

[a,b] Means in the same row per main effect bearing different letters differ (P ≤ 0.05)

[x,y] Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)

[#]pm = post-mortem

**Marbling = chemically determined intramuscular% fat (IMF); L = lightness; a*= redness; b*= yellowness; Chroma = saturation index; Hue angle = discolouration*

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Table 3. Least square means and standard error of means for meat tenderness, meat colour and related physiological characteristics of buck and wether Boer Goat (BG) and Indigenous Veld Goats (IVG) of Semimembranosus (SM) muscle

	Breed						
	Boer Goat		Indigenous Veld Goat		Significance (p – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed Sex
pH_u	5.89^{a} ± 0.27	5.98^{ab} ± 0.11	5.91^{a} ± 0.12	6.17^{b}±0.25	0.092	**0.017**	0.267
Water holding capacity							
1 day *pm*$^{\#}$	0.35^{x} ± 0.03	0.35^{x} ± 0.03	0.35^{x} ± 0.06	0.31^{y} ± 0.04	0.205	0.078	0.165
4 days *pm*	0.35^{ab} ± 0.03	0.35^{ab} ± 0.04	0.36^{a} ± 0.06	0.41^{b} ± 0.03	**0.019**	**0.026**	0.185
Purge (%)	1.89 ± 0.48	2.21 ± 1.12	1.60 ± 1.03	1.92 ± 1.00	0.384	0.306	0.999
Warner Bratzler Shear force							
1 day *pm* (N)	37.6 ± 0.44	37.4 ± 0.60	39.7 ± 0.50	35.8 ± 0.71	0.908	0.415	0.230
4 days *pm* (N)	33.1 ± 0.43	31.9 ± 0.84	34.7 ± 0.49	30.0 ± 0.69	0.968	0.177	0.420
Myofibril fragment length							
1 day *pm* (μm)	41.06 ± 5.85	45.03 ± 5.03	44.08 ± 4.74	42.13 ± 2.73	0.883	0.560	0.066
4 days *pm* (μm)	38.64 ± 6.78	37.85 ± 5.78	40.22 ± 3.62	35.46 ± 4.60	0.803	0.130	0.276
Marbling*							
IMF (% Fat)	1.94^{a} ± 1.09	3.05^{b} ± 1.53	1.76^{a} ± 1.05	2.76^{b} ± 0.80	0.689	**0.008**	0.888
Collagen characteristics							
Collagen solubility (%)	35.19 ± 11.59	27.58 ± 9.62	32.91 ± 5.68	33.03 ± 12.27	0.935	0.236	0.572
Soluble collagen (mg/g$^{\#}$)	2.55 ± 1.30	1.76 ± 0.76	2.09 ± 0.53	2.04 ± 1.01	0.602	0.624	0.388
Insoluble collagen (mg/g)	4.43 ± 0.45	4.60 ± 0.67	4.39 ± 0.56	4.11 ± 0.78	0.647	0.207	0.384
Total collagen (mg/g)	6.82 ± 1.60	6.21 ± 1.03	6.32 ± 0.81	5.99 ± 0.97	0.705	0.175	0.467
Meat colour characteristics							
L D65 SCE 1 day *pm*	35.74^{a} ± 3.03	33.78^{b} ± 1.84	37.24^{a} ± 2.36	33.01^{b} ± 1.47	0.894	**0.0003**	0.199
L D65 SCE 4 days *pm*	36.94^{a} ± 3.22	34.06^{b} ± 2.99	36.33^{a} ± 2.08	34.14^{b} ± 2.72	0.501	**0.012**	0.270
a*D65 SCE 1 day *pm*	10.55^{a} ± 1.40	12.36^{b} ± 1.66	10.30^{a} ± 1.32	11.74^{b} ± 1.72	0.388	**0.003**	0.060
a*D65 SCE 4 days *pm*	9.85^{a}± 2.03	12.30^{b} ± 1.84	11.17^{b} ± 1.63	10.37^{a} ± 2.21	0.066	0.111	**0.018**
b* D65 SCE 1 day *pm*	11.91 ± 1.31	12.06 ± 1.37	12.31 ± 0.67	12.07 ± 1.31	0.318	0.474	0.580
b* D65 SCE 4 days *pm*	12.71 ± 1.21	12.68 ± 0.63	13.26 ± 0.67	12.23 ± 1.38	0.828	0.353	0.512
Chroma D65 SCE 1 day *pm*	15.99^{a} ± 1.49	17.33^{b} ± 1.91	16.12^{a} ± 0.90	16.89^{b} ± 1.84	0.754	**0.018**	0.375
Chroma D65 SCE 4 days *pm*	16.14^{a} ± 2.06	17.71^{b} ± 1.61	17.41^{b} ± 1.43	16.16^{a} ± 1.99	0.078	0.185	**0.024**
Hue angle D65 SCE 1 day *pm*	48.71^{a} ± 4.36	44.49^{b} ± 3.34	50.39^{a} ± 4.10	44.9^{b} ± 2.28	0.395	**0.001**	**0.011**
Hue angle D65 SCE 4 days *pm*	52.71^{a} ± 4.11	46.21 ± 3.61^{b}	50.34^{a} ± 3.46	48.29^{b} ± 4.23	0.215	**0.003**	0.236

^{a,b} Means in the same row per main effect bearing different letters differ (P ≤ 0.05)

^{x,y} Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)

$^{\#}$pm = post-mortem

**Marbling = chemically determined intramuscular% fat (IMF); L = lightness; a*= redness; b*= yellowness; Chroma = saturation index; Hue angle = discolouration*

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Table 4. Least square means and standard error of means for meat tenderness, meat colour and related physiological characteristics of buck and wether Boer Goat (BG) and Indigenous Veld Goats (IVG) of Biceps Femoris (BF) muscle

	Breed						
	Boer Goat		Indigenous Veld Goat		Significance (p – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed Sex
pH_u	$5.74^{a} \pm 0.11$	$5.71^{a} \pm 0.14$	$5.82^{b} \pm 0.13$	$5.91^{b} \pm 0.16$	**0.003**	0.477	0.204
Water holding capacity							
1 day *pm*#	$0.38^{y} \pm 0.04$	$0.38^{y} \pm 0.05$	$0.36^{x} \pm 0.04$	$0.35^{x} \pm 0.05$	0.096	0.550	0.686
4 days *pm*	0.35 ± 0.04	0.41 ± 0.06	0.37 ± 0.04	0.37 ± 0.06	0.647	0.167	0.074
Purge (%)	0.96 ± 0.34	1.00 ± 0.40	0.97 ± 0.27	0.70 ± 0.35	0.182	0.282	0.188
Warner Bratzler Shear force							
1 day *pm* (N)	55.8 ± 1.06	47.1 ± 1.52	49.9 ± 1.09	47.6 ± 1.43	0.444	0.211	0.455
4 days *pm* (N)	44.5 ± 0.82	34.4 ± 0.78	40.9 ± 0.96	42.1 ± 1.36	0.652	0.213	0.102
Myofibril fragment length							
1 day *pm* (µm)	$43.57^{a} \pm 9.93$	$35.01^{b} \pm 5.51$	$40.81^{a} \pm 6.80$	$38.89^{b} \pm 6.50$	0.989	**0.046**	0.188
4 days *pm* (µm)	$35.11^{a} \pm 5.76$	$28.26^{b} \pm 3.54$	$33.29^{a} \pm 7.04$	$32.21^{b} \pm 5.27$	0.724	**0.044**	0.128
Marbling*							
IMF (% Fat)	$2.75^{a} \pm 1.85$	$4.18^{b} \pm 2.46$	$1.88^{a} \pm 1.29$	$3.74^{b} \pm 0.74$	0.345	**0.005**	0.694
Collagen characteristics							
Collagen solubility (%)	37.88 ± 14.34	34.50 ± 7.73	27.93 ± 9.14	37.33 ± 16.13	0.450	0.418	0.143
Soluble collagen (mg/g#)	2.80 ± 1.67	2.46 ± 1.44	1.82 ± 0.78	2.43 ± 1.21	0.218	0.286	0.646
Insoluble collagen (mg/g)	4.27 ± 0.97	4.49 ± 0.87	4.67 ± 0.43	4.09 ± 1.11	0.519	0.505	0.974
Total collagen (mg/g)	6.92 ± 2.22	6.81 ± 2.19	6.33 ± 0.91	6.36 ± 1.25	0.466	0.467	0.938
Meat colour characteristics							
L D65 SCE 1 day *pm*	$37.60^{a} \pm 3.05$	$33.29^{b} \pm 2.18$	$37.11^{a} \pm 2.38$	$34.06^{b} \pm 1.50$	0.744	**<.0001**	0.246
L D65 SCE 4 days *pm*	38.00 ± 2.56	35.83 ± 1.76	36.68 ± 2.09	36.24 ± 2.93	0.965	0.432	0.160
a*D65 SCE 1 day *pm*	$9.95^{a} \pm 1.16$	$12.29^{b} \pm 0.99$	$10.33^{ab} \pm 1.62$	$10.64^{ab} \pm 1.41$	0.267	**0.006**	**0.027**
a*D65 SCE 4 days *pm*	$8.76^{a} \pm 1.17$	$10.84^{b} \pm 1.36$	$9.78^{ab} \pm 1.33$	$9.25^{ab} \pm 1.19$	0.648	0.085	**0.004**
b* D65 SCE 1 day *pm*	11.81 ± 1.33	11.98 ± 1.10	11.89 ± 1.14	12.02 ± 1.52	0.860	0.729	0.997
b* D65 SCE 4 days *pm*	11.71 ± 1.31	12.19 ± 1.15	11.84 ± 1.10	11.99 ± 1.23	0.985	0.445	0.671
Chroma D65 SCE 1 day *pm*	$15.49^{x} \pm 1.40$	$17.16^{y} \pm 1.24$	$15.79^{x} \pm 1.57$	$16.11^{y} \pm 1.67$	0.574	0.056	0.179
Chroma D65 SCE 4 days *pm*	$14.66^{x} \pm 1.62$	$16.39^{z} \pm 1.59$	$15.38^{y} \pm 1.64$	$15.23^{y} \pm 1.29$	0.809	0.143	0.072
Hue angle D65 SCE 1 day *pm*	$49.84^{a} \pm 3.94$	$44.25^{b} \pm 2.98$	$49.21^{a} \pm 4.49$	$47.54^{b} \pm 2.43$	0.243	**0.005**	0.064
Hue angle D65 SCE 4 days *pm*	$53.22^{b} \pm 2.66$	$48.95^{a} \pm 3.26$	$50.56^{ab} \pm 2.33$	$51.84^{ab} \pm 3.73$	0.723	0.398	**0.010**

^{a,b} Means in the same row per main effect bearing different letters differ ($P \leq 0.05$)

^{x,y} Means in the same row per main effect bearing different letters was considered a tendency to differ ($P \leq 0.1$)

#pm = post-mortem

**Marbling = chemically determined intramuscular% fat (IMF); L = lightness; a*= redness; b*= yellowness; Chroma = saturation index; Hue angle = discolouration*

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Table 5. Least square means and standard error of means for meat tenderness, meat colour and related physiological characteristics of buck and wether Boer Goat (BG) and Indigenous Veld Goats (IVG) of Supraspinatus (SS) muscle

	Breed						
	Boer Goat		Indigenous Veld Goat		Significance (p – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed Sex
pH_u	$5.89^{a} \pm 0.27$	$5.98^{b} \pm 0.11$	$5.91^{a} \pm 0.12$	$6.17^{b} \pm 0.25$	0.092	**0.017**	0.267
Water holding capacity							
1 day *pm*#	$0.35^{x} \pm 0.03$	$0.35^{x} \pm 0.03$	$0.35^{x} \pm 0.06$	$0.31^{y} \pm 0.04$	0.205	0.078	0.165
4 days *pm*	$0.35^{ab} \pm 0.03$	$0.35^{ab} \pm 0.04$	$0.36^{a} \pm 0.06$	$0.41^{b} \pm 0.03$	**0.019**	**0.026**	0.185
Purge (%)	1.89 ± 0.48	2.21 ± 1.12	1.60 ± 1.03	1.92 ± 1.00	0.384	0.306	0.999
Warner Bratzler Shear force							
1 day *pm* (N)	37.6 ± 0.44	37.4 ± 0.60	39.7 ± 0.50	35.8 ± 0.71	0.908	0.415	0.230
4 days *pm* (N)	33.1 ± 0.43	31.9 ± 0.84	34.7 ± 0.49	30.0 ± 0.69	0.968	0.177	0.420
Myofibril fragment length							
1 day *pm* (μm)	41.06 ± 5.85	45.03 ± 5.03	44.08 ± 4.74	42.13 ± 2.73	0.883	0.560	0.066
4 days *pm* (μm)	38.64 ± 6.78	37.85 ± 5.78	40.22 ± 3.62	35.46 ± 4.60	0.803	0.130	0.276
Marbling*							
IMF (% Fat)	$1.94^{a} \pm 1.09$	$3.05^{b} \pm 1.53$	$1.76^{a} \pm 1.05$	$2.76^{b} \pm 0.80$	0.689	**0.008**	0.888
Collagen characteristics							
Collagen solubility (%)	35.19 ± 11.59	27.58 ± 9.62	32.91 ± 5.68	33.03 ± 12.27	0.741	0.297	0.202
Soluble collagen (mg/g#)	2.55 ± 1.30	1.76 ± 0.76	2.09 ± 0.53	2.04 ± 1.01	0.697	0.575	0.179
Insoluble collagen (mg/g)	4.43 ± 0.45	4.60 ± 0.67	4.39 ± 0.56	4.11 ± 0.78	0.498	0.359	0.838
Total collagen (mg/g)	6.82 ± 1.60	6.21 ± 1.03	6.32 ± 0.81	5.99 ± 0.97	0.987	0.946	0.128
Meat colour characteristics							
L D65 SCE 1 day *pm*	$35.74^{a} \pm 3.03$	$33.78^{b} \pm 1.84$	$37.24^{a} \pm 2.36$	$33.01^{b} \pm 1.47$	0.649	**0.0003**	0.222
L D65 SCE 4 days *pm*	$36.94^{a} \pm 3.22$	$34.06^{b} \pm 2.99$	$36.33^{a} \pm 2.08$	$34.14^{b} \pm 2.72$	0.991	**0.012**	0.450
a*D65 SCE 1 day *pm*	$10.55^{a} \pm 1.40$	$12.36^{b} \pm 1.66$	$10.30^{a} \pm 1.32$	$11.74^{b} \pm 1.72$	0.558	**0.003**	0.720
a*D65 SCE 4 days *pm*	$9.85^{a} \pm 2.03$	$12.30^{b} \pm 1.84$	$11.17^{ab} \pm 1.63$	$10.37^{ab} \pm 2.21$	0.788	0.224	**0.018**
b* D65 SCE 1 day *pm*	11.91 ± 1.31	12.06 ± 1.37	12.31 ± 0.67	12.07 ± 1.31	0.623	0.885	0.597
b* D65 SCE 4 days *pm*	12.71 ± 1.21	12.68 ± 0.63	13.26 ± 0.67	12.23 ± 1.38	0.853	0.131	0.153
Chroma D65 SCE 1 day *pm*	$15.99^{x} \pm 1.49$	$17.33^{y} \pm 1.91$	$16.12^{x} \pm 0.90$	$16.89^{y} \pm 1.84$	0.934	0.054	0.591
Chroma D65 SCE 4 days *pm*	$16.14^{a} \pm 2.06$	$17.71^{ab} \pm 1.61$	$17.41^{ab} \pm 1.43$	$16.16^{b} \pm 1.99$	0.911	0.811	0.024
Hue angle D65 SCE 1 day *pm*	$48.71^{a} \pm 4.36$	$44.49^{b} \pm 3.34$	$50.39^{a} \pm 4.10$	$44.9^{b} \pm 2.28$	0.351	**0.001**	0.934
Hue angle D65 SCE 4 days *pm*	$52.71^{a} \pm 4.11$	$46.21^{b} \pm 3.61$	$50.34^{a} \pm 3.46$	$48.29^{b} \pm 4.23$	0.800	**0.003**	0.054

a,b Means in the same row per main effect bearing different letters differ (P ≤ 0.05)

x,y Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)

#pm = post-mortem

**Marbling = chemically determined intramuscular% fat (IMF); L = lightness; a*= redness; b*= yellowness; Chroma = saturation index; Hue angle = discolouration*

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Table 6. Least square means and standard error of means for meat tenderness, meat colour and related physiological characteristics of buck and wether Boer Goat (BG) and Indigenous Veld Goats (IVG) of *Infraspinatus (IS)* muscle

	Breed						
	Boer Goat		Indigenous Veld Goat		Significance (p – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed * Sex
pH_u	5.97 ± 0.26	6.11 ± 0.10	6.09 ± 0.24	6.12 ± 0.21	0.324	0.247	0.446
Water holding capacity							
1 day *pm*[#]	0.36 ± 0.05	0.38 ± 0.07	0.34 ± 0.05	0.34 ± 0.05	0.195	0.791	0.606
4 days *pm*	0.35 ± 0.05	0.39 ± 0.06	0.38 ± 0.04	0.37 ± 0.05	0.686	0.419	0.199
Purge (%)	0.97^{a} ± 0.35	1.20^{a} ± 0.57	0.82^{b} ± 0.49	0.62^{b} ± 0.23	**0.015**	0.960	0.129
Warner Bratzler Shear force							
1 day *pm* (N)	33.8 ± 0.63	31.9 ± 0.45	29.9 ± 0.40	30.0 ± 0.68	0.155	0.641	0.588
4 days *pm* (N)	26.9^{x} ± 0.37	28.9^{x} ± 0.42	25.7^{y} ± 0.39	24.8^{y} ± 0.54	0.083	0.726	0.331
Myofibril fragment length							
1 day *pm* (µm)	46.53 ± 6.51	42.70 ± 4.59	44.63 ± 5.51	44.43 ± 8.29	0.886	0.367	0.403
4 days *pm* (µm)	41..41 ± 7.32	39.36 ± 6.25	38.78 ± 4.06	37.46 ± 5.89	0.232	0.407	0.856
Marbling*							
IMF (% Fat)	1.49^{a} ± 0.59	2.70^{b} ± 1.10	1.10^{a} ± 0.66	2.09^{b} ± 0.41	0.092	**<.0001**	0.641
Collagen characteristics							
Collagen solubility (%)	37.05 ± 10.26	39.39 ± 9.81	38.31 ± 11.58	34.79 ± 9.69	0.513	0.873	0.538
Soluble collagen (mg/g[#])	2.83 ± 1.14	2.76 ± 1.22	2.89 ± 1.11	2.33 ± 0.74	0.793	0.396	0.200
Insoluble collagen (mg/g)	4.89 ± 1.06	4.18 ± 1.15	4.67 ± 0.81	4.47 ± 0.81	0.848	0.133	0.733
Total collagen (mg/g)	7.55 ± 1.55	6.79 ± 2.04	7.39 ± 1.21	6.61 ± 0.89	0.891	0.131	0.598
Meat colour characteristics							
L D65 SCE 1 day *pm*	36.96^{a} ± 3.39	34.64^{b} ± 2.57	38.36^{a} ± 2.32	37.0^{b} ± 2.15	0.057	0.048	0.537
L D65 SCE 4 days *pm*	37.61 ± 3.34	36.03 ± 2.64	38.21 ± 2.43	37.19 ± 3.88	0.461	0.221	0.785
a*D65 SCE 1 day *pm*	8.22^{a} ± 1.92	10.28 ^{b}± 1.45	8.43^{a} ± 1.64	9.03^{b} ± 2.18	0.519	0.040	0.244
a*D65 SCE 4 days *pm*	8.86^{a} ± 1.70	10.84^{b} ± 2.08	8.69^{a} ± 1.74	9.60^{b} ± 2.42	0.402	0.039	0.447
b* D65 SCE 1 day *pm*	10.60^{a} ± 1.52	10.89^{a} ± 1.47	12.13^{b} ± 0.71	11.17^{b} ± 0.97	0.042	0.815	0.411
b* D65 SCE 4 days *pm*	12.41 ± 1.28	12.20 ± 1.34	12.46 ± 1.22	11.98 ± 1.02	0.831	0.364	0.712
Chroma D65 SCE 1 day *pm*	13.52 ± 2.18	15.03 ± 1.98	14.53 ± 1.98	14.48 ± 1.84	0.642	0.289	0.254
Chroma D65 SCE 4 days *pm*	15.36 ± 1.67	16.36 ± 2.20	15.32 ± 1.72	15.54 ± 1.86	0.545	0.332	0.508
Hue angle D65 SCE 1 day *pm*	52.73^{a} ± 4.83	47.01^{b} ± 2.23	55.90^{a} ± 4.28	50.57^{b} ± 4.40	0.034	0.001	0.586
Hue angle D65 SCE 4 days *pm*	54.86 ± 5.07	49.16 ± 4.10	55.66 ± 4.87	52.18 ± 7.07	0.409	0.017	0.544

[a,b] Means in the same row per main effect bearing different letters differ (P ≤ 0.05)

[x,y] Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)

[#]pm = post-mortem

**Marbling = chemically determined intramuscular% fat (IMF); L = lightness; a*= redness; b*= yellowness; Chroma = saturation index; Hue angle = discolouration*

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Table 7. Least square means and standard error of means for meat tenderness, meat colour and related physiological characteristics of buck and wether Boer Goat (BG) and Indigenous Veld Goats (IVG) of *Semitendinosus (ST)* muscle

	Breed						
	Boer Goat		Indigenous Veld Goat		Significance (p – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed Sex
pH_u	$5.66^{a} \pm 0.11$	$5.69^{a} \pm 0.06$	$5.71^{b} \pm 0.13$	$5.89^{b} \pm 0.18$	**0.004**	**0.021**	0.091
Water holding capacity							
1 day *pm*[#]	0.37 ± 0.04	0.35 ± 0.05	0.38 ± 0.03	0.37 ± 0.04	0.432	0.394	0.705
4 days *pm*	0.38 ± 0.07	0.39 ± 0.06	0.39 ± 0.04	0.41 ± 0.05	0.265	0.421	0.750
Purge (%)	1.49 ± 0.97	1.62 ± 0.83	1.93 ± 1.53	1.54 ± 0.92	0.624	0.708	0.479
Warner Bratzler Shear force							
1 day *pm* (N)	$50.8^{a} \pm 0.51$	$44.8^{b} \pm 0.48$	$44.8^{b} \pm 0.48$	$44.1^{b} \pm 1.19$	0.440	**0.047**	0.736
4 days *pm* (N)	47.3 ± 0.61	41.4 ± 0.32	43.0 ± 0.64	40.8 ± 1.23	0.288	0.137	0.483
Myofibril fragment length							
1 day *pm* (µm)	46.48 ± 4.56	45.63 ± 3.40	44.06 ± 5.03	46.66 ± 5.38	0.662	0.553	0.274
4 days *pm* (µm)	40.58 ± 5.24	38.44 ± 4.41	40.12 ± 6.19	38.51 ± 8.17	0.864	0.371	0.899
Marbling*							
IMF (% Fat)	$2.12^{a} \pm 1.53$	$2.76^{b} \pm 1.50$	$1.84^{a} \pm 1.07$	$2.93^{b} \pm 0.68$	0.980	**0.040**	0.590
Collagen characteristics							
Collagen solubility (%)	37.09 ± 11.22	33.60 ± 9.82	35.31 ± 7.75	32.94 ± 8.66	0.821	0.404	0.690
Soluble collagen (mg/g[#])	$1.85^{x} \pm 0.52$	$1.41^{y} \pm 0.47$	$1.74^{x} \pm 0.75$	$1.57^{y} \pm 0.55$	0.058	0.059	0.757
Insoluble collagen (mg/g)	3.36 ± 1.07	2.89 ± 0.52	3.10 ± 0.30	3.21 ± 0.47	0.688	0.128	0.136
Total collagen (mg/g)	5.08 ± 1.05	4.20 ± 0.57	4.72 ± 0.10	4.70 ± 0.71	0.823	0.104	0.160
Meat colour characteristics							
L D65 SCE 1 day *pm*	$40.11^{x} \pm 2.05$	$38.73^{y} \pm 1.68$	$39.36^{y} \pm 0.98$	$39.46^{y} \pm 2.62$	0.963	0.882	0.090
L D65 SCE 4 days *pm*	39.89 ± 2.21	39.58 ± 2.99	39.52 ± 1.68	38.28 ± 3.03	0.781	0.849	0.899
a*D65 SCE 1 day *pm*	$7.58^{b} \pm 1.22$	$9.25^{b} \pm 0.94$	$8.17^{b} \pm 0.85$	$7.63^{a} \pm 1.27$	0.342	0.891	**0.005**
a*D65 SCE 4 days *pm*	$7.21^{a} \pm 1.28$	$8.50^{b} \pm 1.63$	$8.09^{a} \pm 1.06$	$8.96^{b} \pm 1.61$	0.347	**0.029**	0.392
b* D65 SCE 1 day *pm*	12.40 ± 0.78	12.79 ± 1.09	12.84 ± 0.89	12.76 ± 0.73	0.428	0.618	0.408
b* D65 SCE 4 days *pm*	12.47 ± 0.91	12.73 ± 0.93	12.80 ± 1.23	13.23 ± 0.80	0.178	0.285	0.785
Chroma D65 SCE 1 day *pm*	$14.64^{a} \pm 0.93$	$15.89^{b} \pm 1.11$	$15.60^{b} \pm 0.82$	$14.79^{a} \pm 1.08$	0.959	0.594	**0.004**
Chroma D65 SCE 4 days *pm*	$14.47^{x} \pm 1.23$	$15.41^{y} \pm 1.33$	$15.19^{x} \pm 1.49$	$15.86^{y} \pm 0.90$	0.110	0.059	0.744
Hue angle D65 SCE 1 day *pm*	$59.04^{ab} \pm 4.34$	$54.45^{a} \pm 3.42$	$58.40^{ab} \pm 3.14$	$59.51^{b} \pm 3.76$	0.236	0.936	**0.029**
Hue angle D65 SCE 4 days *pm*	60.12 ± 4.16	56.94 ± 5.15	58.16 ± 2.41	55.96 ± 5.36	0.671	0.335	0.421

[a,b] Means in the same row per main effect bearing different letters differ (P ≤ 0.05)

[x,y] Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)

[#]pm = post-mortem

**Marbling = chemically determined intramuscular% fat (IMF); L = lightness; a*= redness; b*= yellowness; Chroma = saturation index; Hue angle = discolouration*

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4. Discussion

Compared to extensive studies on the influence of muscle source on meat quality indicators such as pH_u, chemical composition, tenderness, juiciness and colour attributes in other livestock, only limited studies examined these phenomena in chevon (goat) meat; with the focus mainly being on the LTL and SM muscles [8, 37, 38]. The present study investigated the meat quality of six different muscles (i.e. *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST). The different muscles will not show the same values for pH_u, WHC, percentage purge, WBSF, MFL, IMF, collagen characteristics and meat colour measurements, due to their different intrinsic characteristics [39].

Slightly higher pH_u values for LTL and SM were reported by [8] and [40] compared to the present study (LTL and SM muscles showed similar but lower pH_u values from 5.5 to 5.7). On average pH_u of 5.7 to 5.8 are reported [8] for both the LTL and SM with no differences between breeds and treatments, the latter included 30 seconds electrical stimulation (ES) under similar conditions and step wise chilling for non-stimulated (NS) carcasses. A pH_u higher than 5.8 for LTL in goat carcasses were reported by [41, 42, 43], who all concluded that DFD was the cause of this higher pH_u. Interpretation of the results from the present study should consider that all the carcasses were electrically stimulated as a prevention of cold shortening, thereby causing the lower pH_u. Energy supplementation of the animals with commercial "Ram, lamb and ewe - 13" pellets during growth and limited pre-slaughter stress due to short transport distance from the grower facility to abattoir, combined with a short lairage period, probably contributed to a higher muscle glycogen and generally lower pH_u values in certain muscles such as the LTL and SM.

In agreement with results of the current study, a faster rate of deposition for carcass and non-carcass fat and total fat for Jebel Akhdar Omani does and wethers raised under intensive management as compared to bucks have been reported [42, 43]. The present study's % IMF composition ranges are higher than that reported for non-specified indigenous goats [5]. This could probably be due to differences between breed, age, nutritional plane, and sample size (number of animals). Goats tend to deposit most of their fat in the visceral rather than carcass depot and produce leaner carcasses [46] whilst the "indigenous" goat groups usually give inferior results compared to that of Boer Goat [8, 9, 10].

Notable relative high percentage IMF were measured in all the wether muscles compared to those of buck in both IVG and BG. However, this did not seem to have any effect on tenderness. It is speculated that the IMF value of >4% in the BF muscle of the BG wethers combined with higher levels of ageing (low MFL values) may have contributed to a numerically lower WBSF; a difference of 10 N. Despite variation in IMF% levels between sex groups in other muscles, including the BF, the mean IMF value across all muscles was probably too low to show any effect on tenderness. The intramuscular fat is not usually associated with shear force tenderness and [47] could find no effect of % IMF and WBSF for beef with IMF values between 6.8% and 20.9%. Only when % IMF levels reached 33.9%, the effect become significant. An early study [48], showed significant but low correlations with WBSF, which corresponds with the trends in our study. For sensory scores, the effect of % IMF on tenderness experience becomes relevant as a result of the added effect of mouthfeel that is released during chewing. According to [49] marbling levels varying between 1.96% and 3.8% had no effect on consumers scores for beef tenderness (not Warner Bratzler shear force), but scores increased significantly at 5.6% and higher.

Although differences between the different muscles for all connective tissue characteristics were observed (statistical data not shown), which agrees with the findings of [29] for cattle, the differences in tenderness between sex could not be explained by conventional reasons such as differences in connective tissue properties and ageing. On average, the LTL muscles had the most advantageous *post-mortem* proteolytic activity (as

indicated by the myofibril fragment length) and lowest total collagen, and despite the fact that ES was applied during slaughter, The LTL was still tough as indicated by the high WBSF. A possible explanation for the tougher LTL muscles could be the cooking method; the recommended cooking method for LTL is a dry cooking method [50], whilst in this investigation, the LTL and the rest of the muscles were cooked by means of a moisture cooking method (recommended for higher connective tissue cuts for mutton and beef [51]). Chevon LTL might have different physiological characteristics compared to the muscles of other domestic species that requires different cooking methods. This aspect warrants further research to help with the commercialising process and refining post-slaughter procedures that will benefit consumer perceptions of chevon.

The differences in muscle physiology between species could also explain some of the colour differences noted. Reported by [52], muscle-specificity in fresh meat from a medium sized wild ungulate, the blesbok (*Damaliscus pygargus phillipsi*) and observed that the blesbok *Infraspinatus* muscle was more colour-stable than the LTL and BF. This observation is different from that previously reported for fresh beef and suggests that game species have a unique biology and that the influence of muscle source on colour stability is species dependent [53]. These observations may support the idea that goat is a unique species, and that chevon should be approached differently from that of the other better known red meats such as beef and mutton. In general, the rate and extent of *post-mortem* glycolysis and ultimate pH of the muscle are critical factors that determine goat meat quality but more particular WHC and meat colour [53]. Contrary to [54], no breed differences in meat colour characteristics for the various BG and IVG muscles was experienced in this study. For the SM and SS muscles, wethers recorded higher pH_u values, which also coincided with slightly darker muscles, i.e. lower L* values and higher values for redness (a*) and consequently Chroma. Incidentally, there was no differences in purge between breed nor sex; this was to be expected as the animals had ad lib access to feed and were all treated the same ante mortem. This might have been due to the high pH_u in general as all values were above 5.8 suggesting higher stress susceptibility in these specific animals [55].

Meat from intact male animals (bulls and rams) are generally darker compared to females and castrated males [56]. This is in contrast to the present study, where the wethers had darker meat ($L^* < 35.0$) compared to bucks ($L^* > 36.9$). Small and sometimes significant differences were found for other colour parameters where muscles of wethers in most cases tend to show more vivid colours (higher Chroma) and lower discolouration (lower Hue angle values). It is known that energy status immediately after slaughter has an influence on meat colour (lightness) and tenderness [57, 58].

5. Conclusions

Knowledge about meat quality of specific indigenous eco-types is limited as studies usually compare nonspecific "indigenous" goats with Boer Goat (well described). This study alleviates some misconceptions that exist about the potential quality of "indigenous" goat meat. More muscle meat quality differences were found between bucks and wethers than between Boer Goats and large frame Indigenous Veld Goats consisting of a mixture of the different goat eco-types. This study showed that the muscles of IVG large frame goats differed minimally from the same muscles derived from BG when finished off in the same feedlot. This study further showed that goat muscles have different characteristics than that of other red meat animals and warrant further research to understand this species' meat quality characteristics and the factor that influence it, better. More studies should also focus on understanding how to adapt/manage pre- and post-slaughter procedures to produce the best goat meat (chevon) eating experience.

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ble for resources, supervision, project administration and funding acquisition. All authors have read and agreed to the published version of the manuscript.

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