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# Carcass Yields and Physicochemical Meat Quality Characteristics of Namibian Springbok (*Antidorcas marsupialis*) as Influenced by Muscle, Sex and Age[1]

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**Abstract:** This investigation determined the carcass yields of Namibian springbok and compared the physicochemical meat quality characteristics of 6 different muscles (*biceps femoris*, *infraspinatus*, *Longissimus thoracis et lumborum*, *semimembranosus*, *semitendinosus*, and *supraspinatus*) from different sex and age groups. Although the adult male slaughter weights (40.44 ± 1.88 kg) did not differ from that of the adult female slaughter weights (36.61 ± 0.50), the adult males were heavier than both sexes from the sub-adults. No differences were observed for dressing percentages between sex nor age groups. The *infraspinatus* muscle showed the lowest shear force values in adult male springbok and in both sub-adult male and female springbok and can be described as the more tender muscle. The *infraspinatus* and *Longissimus thoracis et lumborum* muscles of the adult male springbok group showed the lowest cooking losses. The *supraspinatus* and *semitendinosus* muscles from the sub-adult groups tended to have the highest L* and thus the lightest meat. No major differences were observed for protein content between the different sex and age groups although the muscles of the different sex and age groups had a noticeably higher fat content (above 3%). Discriminant analysis revealed no differentiation among the different muscle groups for the variables measured. Neither springbok sex nor age influenced any of the meat quality parameters although older animals tended to have heavier carcasses, therefore the decision of which sex and/or age group to cull will depend on the springbok management strategy.

**Keywords:** chemical composition, game meat, muscle profiling, quality, venison
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## Introduction

Springbok (*Antidorcas marsupialis*) is an antelope commonly found in the arid southwestern parts of southern Africa (Skinner and Smithers, 1990). The springbok is the game species most extensively harvested in Namibia and in South Africa (Hoffman and Wiklund, 2006). The springbok population in Namibia amounts to about 750,000. It is also the major game species exported as meat to the European Union and into South Africa. Vegetation type and

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condition associated with different regions are known to influence the chemical composition of springbok and therefore the eating quality of springbok may vary between geographical regions (Hoffman et al., 2007a, 2007b, 2007c, 2007d; Neethling et al., 2016a, 2018a). No scientific information on the chemical composition of springbok in Namibia is available, so it is postulated that Namibian springbok may have a different chemical composition compared to that of South African springbok especially since the live weight of springbok vary geographically (Robinson, 1979; Skinner and Smithers, 1990).

When considering the production of meat from game animals, the same factors applicable to traditionally farmed species, such as yield, chemical composition, and meat quality are important (Hoffman, 2000; Mostert and Hoffman, 2007). According to Von la Chevallerie (1970), carcass weights can give a good indication of the meat production potential of an animal when sufficient data on carcass conformation and composition is available; currently, in Namibia and South Africa game meat producers are asking questions around which springbok age and sex will deliver the most meat of the best quality. Factors such as age, gender, muscle type, and degree of fatness also influence the quality of meat (Sales, 1995; North and Hoffman, 2015, 2017). Some of the most noticeable meat parameters of older animals are a decrease in tenderness (Shorthose and Harris, 1990) and an increase in myoglobin content, which is often accompanied by a darkening in color (Lawrie, 2006; Neethling et al., 2017). Consumers consider tenderness to be the most important factor determining meat quality (Koohmaraie et al., 2003). The tenderness of meat is strongly influenced by the pH and the temperature of the muscle post mortem (Yu and Lee, 1986) due to its effect on the enzymatic tenderization process (North and Hoffman, 2015; North et al., 2015, 2016). The water holding capacity of meat is also affected by pH and decreases post mortem to the iso-electric point of meat proteins which is between pH 5.0 and 5.5, at this point the water holding capacity is at its lowest (Pearson and Young, 1989). When comparing sex classes, differences in fat deposition are often seen, as female animals tend to accumulate more fat. This was explained by Díaz et al. (2003) as the result of variations in protein assimilation efficiency and the difference in composition of weight gain by males and females throughout their growth period. The fact that females also mature at a more rapid rate than males would result in the females being fatter at any given chronological age.

The color and appearance are the first characteristics which the consumer observes when purchasing meat. Neethling et al. (2017) reviewed the factors influencing the color of game meat while Shange et al. (2019) indicated that typical color coordinates for game meat with normal pH (~5.6) could be described as CIE L* (measure of lightness) > 33, a* (the red-green range) > 13, b* (the blue-yellow range) ~10 resulting in calculated chroma (C*) > 17 and hue angles (Hab) > 36. Modern consumers want to be informed about the nutritional composition of the food that they eat (Horbañczuk et al., 1998). Springbok is an attractive meat product for the health-conscious consumer. Several studies indicated that the mean fat content in meat from all age groups of springbok carcasses never exceeded 4% (Jansen van Rensburg, 1997; Skinner and Louw, 1996; Van Zyl and Ferreira, 2004; Hoffman et al., 2007b). To compete with existing meat products, scientifically-based information on the meat quality characteristics of game meat is needed. Species specific research of the physicochemical attributes of game meat and the factors that may influence these attributes need to be researched extensively (Hoffman et al., 2007a). Therefore, the aims of this study were to 1) determine and compare the carcass yields of Namibian springbok from different sex and age groups; and 2) determine and compare the physicochemical characteristics of 6 different muscles (*Longissimus thoracis et lumborum* [LTL], *biceps femoris* [BF], *semimembranosus* [SM], *semitendinosus* [ST], *supraspinatus* [SS], and *infraspinatus* [IS]) from 2 age and 2 sex groups of Namibian springbok.

## Materials and Methods

### *Harvesting and sampling*

Thirty-nine springbok (19 males and 20 females) were harvested from 3 freehold commercial farms, Kleepforte (no. 110), Garibib (no. 275), and Onverwacht (no. 460) in the Dordabis district, east of Windhoek, Namibia, during 10 consecutive days in the dry winter month of July. The 3 different farms managed the game as a large population within the same conservancy (Namatanga) and thus in the same climatic and geographic region. The springbok were harvested using standard techniques (Hoffman and Wiklund, 2006; Van Schalkwyk and Hoffman, 2016).

After being killed with head or upper neck shots, the animals were exsanguinated within 2 to 5 min by cutting the throat and thereby severing the jugular veins and the carotid arteries below the jaw line by means of a deep cut with a sharp sterile knife. The time of death and

placement of the shot on each animal were recorded after which each animal was assigned a unique tag number.

Dentition were used to classify adults and sub-adults, the latter having no permanent teeth. Milk incisors are much smaller than the permanent teeth and replacement is from the front to the rear. At an age of 18 to 24 mo, 1 pre-molar tooth and 3 molar teeth are visible (Rautenbach, 1971). As the harvesting occurred at the onset of the lambing season, and springbok typically have a short 4-wk lambing season, all sub-adults were younger than 12 mo.

Animals were transported to a field abattoir where the full slaughter body weights after exsanguination of the carcasses were recorded. The field abattoir consisted of a hanging frame for hoisting of the carcasses. Adequate lighting was provided for the cutting and evisceration processes (design and procedures followed are described in Van Schalkwyk and Hoffman, 2016). The heads were removed at the junction of the atlas and axis neck vertebrae using a horizontal cut to the back bone. The feet were removed at a point just below the carpus of the front legs and tarsus of the back legs. After evisceration of the stomachs and intestines (white offal), as well as the pluck (red offal), carcasses were hung, with the skin on, from the Achilles tendons, in a cold room on the premises at a temperature ranging from 0 to 5°C.

At 24 h post mortem, carcasses were de-skinned in the cold room on the premises, weighed and the dressing percentages calculated. For the physicochemical analyses, the left LTL muscle from between the 12th and 13th rib to between the 4th and 5th lumbar vertebrae was removed.

The BF, SM, ST, SS, and IS muscles of left side of each carcass were also removed for analyses. Physical measurements were determined on fresh samples. Samples for chemical analyses were cut, vacuum packed in polyethylene bags (80 µm thickness, water vapor transmission rate 7 cc $m^{-2}$ $d^{-1}$, oxygen transmission rate 50 cc $m^{-2}$ $d^{-1}$, carbon dioxide transmission rate 200 cc $m^{-2}$ $d^{-1}$, nitrogen transmission rate 12 cc $m^{-2}$ $d^{-1}$, Multimax, Windhoek, Namibia), labeled, and stored at –18 to –20°C for 30 d prior to analyses.

## Temperature and pH

Initial temperature and pH ($pH_0$) readings at the time of death and ultimate temperature and pH readings ($pH_u$) at 24 h post mortem were taken (Testo model 205, Testo AG, Germany) in the LTL muscle of the carcasses between the last and second last rib (Tarrant and Sherington, 1979).

## Proximate analyses

The moisture, protein, fat, and ash content were determined on muscles (±100 g) cut and ground after defrosting. Moisture content was determined by drying samples at 100 to 105°C for 24 h (AOAC Official method 934.01; AOAC, 2002). Thereafter, the dried samples were placed into an oven (500°C for 6 h) for ash determination (AOAC Official method 942.05; AOAC, 2002).

Samples were homogenized in a blender using chloroform:methanol (2:1) as solvents for fat (g/100 g) determination (Lee et al., 1996).

Protein content was determined according to AOAC official method 992.15 (AOAC, 2002). Dried de-fatted samples were ground with a pestle in a mortar into a fine powder. Approximately 0.15-g sample was weighed and inserted into a foil wrap designed for a Leco protein analyzer (LECO FP-528 Nitrogen Analyzer, Leco Corporation, St. Joseph, MI). An EDTA (ethylene diamine tetra-acetic acid) calibration sample (part number 502–092) was analyzed with each batch of samples to ensure accuracy and recovery rate. The protein content was determined as nitrogen content multiplied by a factor of 6.25.

## Drip loss

Drip loss was determined by suspending a freshly cut and weighed meat sample of ± 60 g (ca. 15 mm thick slice cut perpendicular to the grain of the meat) in an inflated polyethylene bag, without the sample touching the sides of the bag. The bags were hung in a cold room at 1 to 5°C for 24 h before samples were removed, blotted and reweighed. The drip loss was expressed as a percentage of the weight of the fresh sample (Honikel, 1998).

## Cooking loss

Cooking loss of the muscles was determined by placing a freshly cut and weighed meat sample of ± 60 g (ca. 15 mm thickness, cut perpendicular to the grain of the meat) in a polythene bag. Sealed bags were cooked in a water bath at ± 80°C for 1 h. Samples were then removed from the water bath, the fluid purge drained from the bags and the samples cooled under running water, while still in bags. The remaining liquid was decanted afterward; the samples were blotted and weighed again. The cooking loss was expressed as a percentage of the initial weight (Honikel, 1998).

**Table 1.** Mean carcass yields (±SE) for different gender and age groups of springbok from Namibia

| Item | Adult male ($n$ = 12) | Sub-adult male ($n$ = 7) | Adult female ($n$ = 11) | Sub-adult female ($n$ = 9) |
|---|---|---|---|---|
| Slaughter weight, kg | $40.44^{a} \pm 1.88$ | $34.94^{b} \pm 2.25$ | $36.61^{ab} \pm 0.50$ | $29.32^{c} \pm 1.63$ |
| Carcass weight, kg | $24.72^{a} \pm 1.15$ | $19.73^{bc} \pm 1.19$ | $21.25^{b} \pm 0.42$ | $16.80^{c} \pm 1.14$ |
| Dressing, % | $61.6^{a} \pm 1.36$ | $56.0^{b} \pm 2.60$ | $58.1^{ab} \pm 1.31$ | $57.1^{ab} \pm 1.18$ |

$^{a–c}$Values in the same row with different superscripts differ significantly ($P \leq 0.05$)

### *Tenderness*

Tenderness of the muscles was determined by measuring Warner-Bratzler (WBS) shear force values (Universal Testing Machine, Model 4444, Apollo Scientific, South Africa; with a Warner-Bratzler blade, 1.2 mm thick with a triangular opening, 13 mm at the widest point and 15 mm high). Four 1.27 cm diameter (cylindrical core) samples of the cooked muscle were randomly removed parallel with the longitudinal axis of each muscle with a hand corer. Maximum shear force values (kg/1.27 cm ø) at a cross head speed of 33.3 mm/s, were measured and recorded for each of the 4 samples.

### *Color measurements*

Color of the fresh muscles was determined by using a Color-guide 45°/0° colorimeter (CAT no. 6805; BYK-Gardner, Columbia, MD) equipped with 11-mm aperture, illuminant D65, and 10° observer angle. The muscles were allowed to bloom for a period of 30 min before 3 measurements were taken at randomly selected sites on the sample surfaces (Stevenson et al., 1989). CIE L*, a* and b* values were determined where L* indicates lightness, a* the red-green range, and b* the blue-yellow range. The hue angles and chroma values were calculated as hue angle = $\tan^{-1}(b^*/a^*)$ and chroma = $([a^*]^2 + [b^*]^2)^{0.5}$.

### *Statistical analyses*

The experimental design was a completely randomized design. For the carcass yield, pH and temperature measurements, the 2 main factors were sex (male and female) and age (adult and sub-adult springbok). The 3 factors for the remaining physicochemical analyses were sex (male and female), age (adult and sub-adult), and muscle type (LTL, BF, SM, ST, SS, and IS).

An experimental unit was a single carcass. The variables were recorded as interval data and subjected to analysis of variance (ANOVA) using Proc GLM of SAS version 9.1 statistical software (SAS Inst. Inc, Cary, NC). The Shapiro-Wilk test was used to test for normality (Shapiro and Wilk, 1965). Student's *t*-LSD (least significant differences) values were calculated at a 5% significance level to compare treatment means (SAS Inst. Inc.).

Stepwise discriminant analysis (SDA) was used to select a subset of variables from the initial variables for use in discriminating among the different muscles. The SDA is considered a preliminary analysis and the resulting subset was used in the discriminant analysis to describe differences among groups (muscles) and predict or allocate observations to groups. Where appropriate Pearson's correlations were calculated and the data displayed in a discriminate analysis plot.

Due to challenges experienced during field measurements, not all parameters were measured on all animals resulting in differing numbers of animals used during the statistical analyses as depicted in the Tables.

## Results and Discussion

### *Carcass yields*

Sex and age showed an interaction for slaughter weight, carcass weight and dressing percentage (Table 1). Although the adult male slaughter weights did not differ from that of the adult female slaughter weights, the adult males were heavier than both sexes from the sub-adults. The adult females had a similar weight as the sub-adult males, while the sub-adults ewes were the lightest of the 4 groups. Springbok ($n$ = 166) from 4 different regions in South Africa had different ($P < 0.05$) slaughter weights of adult male and female springbok, with means of 31.7 kg and 28.3 kg, respectively (Hoffman et al., 2007a). However, Van Zyl and Ferreira (2004) found no differences ($P > 0.05$) in slaughter weights between male (33.7 kg) and female (27.1 kg) springbok in South Africa, although their sample size was small ($n$ = 8). Similar live/slaughter weight values were reported for springbok in South Africa by Fairall et al. (1990). The springbok in Namibia tend to be larger than those found in South Africa, which can be attributed to better vegetation and a more suitable climate (Furstenburg, 2006) although there is also a debate that these differences might be due to genetics (Robinson, 1979). Differences for carcass weights

**Table 2.** Mean values (±SE) for pH and temperature for different sex and age groups of springbok from Namibia

| Item | Adult male ($n$ = 12) | Sub-adult male ($n$ = 6) | Adult female ($n$ = 11) | Sub-adult female ($n$ = 7) |
|---|---|---|---|---|
| $pH_0$ | 6.3 ± 0.16 | 6.2 ± 0.14 | 6.5 ± 0.09 | 6.2 ± 0.23 |
| $pH_u$ | 5.6 ± 0.062 | 5.5 ± 0.05 | 5.5 ± 0.061 | 5.7 ± 0.05 |
| $Temperature_0$, °C | 37.5 ± 0.5 | 36.9 ± 0.45 | 38.7 ± 0.30 | 38.1 ± 0.56 |
| $Temperature_u$, °C | $10.0^{ab}$ ± 0.39 | $10.9^{a}$ ± 0.80 | $8.5^{b}$ ± 0.63 | $9.7^{ab}$ ± 1.08 |

[a,b]Values in the same row with different superscripts differ significantly ($P \leq 0.05$)

(Table 1) were observed with the adult males being significantly heavier than any of the other sex/age groups. The adult females were significantly heavier than the sub-adult males with the latter being similar in slaughter weight to the sub-adult females. The male and female sub-adult groups did no differ in their carcass weights.

The adult males had significantly higher dressing percentages than the sub-adult males (61.6 and 56.0%, respectively; Table 1), a difference that could be attributed to the former being more sexually mature and showing secondary sexual characteristics (such as thicker neck and shoulders). The dressing percentages for the adult females, sub-adult males, and sub-adult females did not differ significantly. Hoffman et al. (2007a) noted that springbok males ($n$ = 66) in South Africa had a higher dressing percentage ($P \leq 0.05$) of 58.8% than females ($n$ = 83) with 55.8%, while Van Zyl and Ferreira (2004) reported differences ($P \leq 0.05$) for dressing percentages between springbok males and females in South Africa of 64.9% for male springbok and 62.6% for female springboks. The latter are higher values than the values observed in this study.

## *Physico-chemical analyses*

There were no interactions nor differences ($P > 0.05$) for $pH_0$ and $pH_u$ for the main effects of gender and age (Table 2). The $pH_0$ ranged between 6.2 and 6.5 and the $pH_u$ between 5.5 and 5.7. The amount of glycogen available in the muscle for post mortem glycolysis will affect the rate and extent of the pH decline (Bond et al., 2004) and may vary depending on the muscle, species, and nutritional status of the animal (Lawrie, 2006). In normal meat, the pH usually declines gradually from 7.4 in living muscle to roughly 5.6 to 5.7 within 6 to 8 h and at 24 h ($pH_u$) the meat has an ultimate pH of around 5.3 to 5.7, which is close to the iso-electrical point of meat (pH = 5.5; Briskey and Wismer-Pedersen, 1961; North et al., 2016). Several studies confirmed that the production of lactic acid causes the pH decrease during post mortem glycolysis. Muscle which is deficient in glycogen due to stress prior to slaughter produces dark, firm, and dry meat. Such meat is characterized by a high ultimate pH > 6 (Shange et al., 2019). Results from this study indicated that the pH declined to an acceptable range varying between a pH value of 5.5 to 5.7 (Table 2), indicating that the animals were not stressed prior to being harvested. The ultimate pH averaged 5.6. Wiklund et al. (2003) stated that when animals are in a good condition, the muscles contain enough glycogen in order for ultimate pH levels to reach values of 5.5 to 5.7.

An interaction was noted for the LTL muscle temperature measured at $pH_u$ (Table 2). The reason for lower temperatures of the adult females than the sub-adult males is not clear, but may be linked to the hanging position in the chiller rather than to biological reasons. The relatively high temperature at 24 h post mortem (>7°C) could possibly be ascribed to the chilling unit on the farm that was stocked to full capacity. A positive correlation ($r$ = 0.870, $P \leq 0.05$) with live weight was observed. This was possibly the result of the lighter animals cooling down faster than the heavier animals. The interaction between temperature and pH post mortem can lead to protein denaturation and thus influence the physical attributes of meat such as water holding capacity and tenderness (Offer and Knight, 1988).

Although Thomas et al. (2004) found a correlation between ultimate pH post mortem and tenderness of ostrich meat, other researchers found no significant correlation between the 2 characteristics in reindeer (Wiklund et al., 1997). The temperature and pH at the onset of rigor mortis is important for tenderness and it was postulated by Hannula and Puolanne (2004) that pH values should decrease below 5.7 before, or when, muscle temperature reaches 7°C. The findings of this study agreed with this recommendation (Table 2).

Interactions were observed for the proximate analyses (moisture, protein, lipid, and ash) between sex, age, and muscle (Table 3). Although significantly different, the moisture values (%) in the muscles did not differ greatly from each other with the SS muscle of the sub-adult females having the highest (74.7%) and the LTL of the adult females the lowest (72.1%). Hoffman et

**Table 3.** Mean values (±SE) for moisture, protein, fat, and ash values for the *longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM), *Semitendinosus* (ST), *Supraspinatus* (SS), and *Infraspinatus* (IS) muscles from different sex and age groups of springbok from Namibia

| Item | Adult male ($n$ = 12) | Sub-adult male ($n$ = 7) | Adult female ($n$ = 11) | Sub-adult female ($n$ = 9) |
|---|---|---|---|---|
| Moisture, % | | | | |
| BF | $73.2^{efgh} \pm 0.21$ | $73.5^{cdefg} \pm 0.24$ | $73.2^{efgh} \pm 0.35$ | $73.0^{fghi} \pm 0.41$ |
| IS | $73.9^{abcde} \pm 0.32$ | $74.6^{a} \pm 0.26$ | $74.1^{abcd} \pm 0.27$ | $74.2^{abc} \pm 0.23$ |
| LD | $72.6^{ghij} \pm 0.2$ | $72.2^{ij} \pm 0.21$ | $72.1^{j} \pm 0.24$ | $72.6^{hij} \pm 0.27$ |
| SM | $72.9^{fghij} \pm 0.16$ | $73.0^{fghi} \pm 0.27$ | $72.7^{ghij} \pm 0.31$ | $72.7^{ghij} \pm 0.41$ |
| ST | $74.0^{abcde} \pm 0.19$ | $74.4^{ab} \pm 0.16$ | $73.3^{defgh} \pm 0.45$ | $73.6^{bcdef} \pm 0.22$ |
| SS | $74.5^{a} \pm 0.23$ | $74.3^{abc} \pm 0.35$ | $74.1^{abcd} \pm 0.43$ | $74.7^{a} \pm 0.38$ |
| Protein, % | | | | |
| BF | $21.4^{de} \pm 0.30$ | $21.7^{cd} \pm 0.17$ | $21.1d^{e} \pm 0.48$ | $21.3^{de} \pm 0.50$ |
| IS | $21.3^{de} \pm 0.28$ | $20.5^{efg} \pm 0.32$ | $20.8^{e} \pm 0.38$ | $20.7^{ef} \pm 0.27$ |
| LD | $22.6^{bc} \pm 0.20$ | $23.79^{a} \pm 0.24$ | $22.8^{ab} \pm 0.22$ | $22.5^{bc} \pm 0.34$ |
| SM | $22.6^{bc} \pm 0.24$ | $22.7^{b} \pm 0.30$ | $22.8^{ab} \pm 0.31$ | $22.6^{bc} \pm 0.41$ |
| ST | $21.0^{de} \pm 0.15$ | $21.0^{de} \pm 0.47$ | $21.1^{de} \pm 0.30$ | $21.0^{de} \pm 0.32$ |
| SS | $19.6^{h} \pm 0.33$ | $19.4^{h} \pm 0.29$ | $19.8^{gh} \pm 0.36$ | $19.8^{fgh} \pm 0.24$ |
| Fat, % | | | | |
| BF | $2.8^{bcde} \pm 0.19$ | $2.5^{de} \pm 0.22$ | $2.8^{bcde} \pm 0.30$ | $2.7^{bcde} \pm 0.29$ |
| IS | $2.9^{abcde} \pm 0.16$ | $3.1^{abcd} \pm 0.27$ | $3.3^{ab} \pm 0.23$ | $3.2^{abc} \pm 0.17$ |
| LD | $2.9^{abcde} \pm 0.16$ | $2.4^{e} \pm 0.19$ | $2.9^{abcde} \pm 0.21$ | $2.7^{bcde} \pm 0.21$ |
| SM | $2.4^{e} \pm 0.15$ | $2.3^{e} \pm 0.18$ | $2.6^{cde} \pm 0.25$ | $2.4^{e} \pm 0.07$ |
| ST | $2.7^{bcde} \pm 0.16$ | $2.7^{bcde} \pm 0.28$ | $2.8^{bcde} \pm 0.27$ | $2.9^{abcde} \pm 0.26$ |
| SS | $3.2^{abc} \pm 0.19$ | $3.2^{abc} \pm 0.39$ | $3.5^{a} \pm 0.27$ | $3.1^{abcd} \pm 0.28$ |
| Ash, % | | | | |
| BF | $1.2^{abc} \pm 0.00$ | $1.2^{abcde} \pm 0.03$ | $1.2^{abcd} \pm 0.03$ | $1.2^{ab} \pm 0.04$ |
| IS | $1.2^{abcde} \pm 0.02$ | $1.1^{f} \pm 0.02$ | $1.1^{cdef} \pm 0.04$ | $1.2^{abcdef} \pm 0.02$ |
| LD | $1.2^{ab} \pm 0.03$ | $1.2^{abc} \pm 0.02$ | $1.2^{abcdef} \pm 0.04$ | $1.3^{a} \pm 0.02$ |
| SM | $1.2^{abcd} \pm 0.03$ | $1.2^{ab} \pm 0.02$ | $1.2^{abcdef} \pm 0.05$ | $1.2^{abc} \pm 0.02$ |
| ST | $1.3^{ab} \pm 0.04$ | $1.2^{bcdef} \pm 0.07$ | $1.2^{abc} \pm 0.04$ | $1.2^{abcde} \pm 0.04$ |
| SS | $1.2^{bcdef} \pm 0.02$ | $1.1^{ef} \pm 0.04$ | $1.1^{def} \pm 0.03$ | $1.1^{f} \pm 0.03$ |

[a–h]Values in the same subgroup of variables with different superscripts differ significantly ($P \leq 0.05$)

al. (2007b) reported moisture values of 74.2/100 g and 73.4/100 g, respectively, for male and female springbok ($P \leq 0.05$) from 4 different regions in South Africa which agreed with the findings of this study. Similar moisture values varying between 72.2 and 74.2% were reported for springbok muscles by Du Buisson (2006).

There was a larger range in protein content between the muscles from the different aged and sex springbok with the sub-adult males' having the lowest protein in the SS muscle (21.4%) as well as the highest (23.8%) in the LTL (Table 3). Van Zyl and Ferreira (2004) found carcass protein of the springbok to vary between 22.9 and 24.2%. In another study by Hoffman et al. (2007b), the protein content of springbok meat originating from 4 production regions in South Africa varied between 18.8 to 21.2%, which is slightly lower than the findings of this study. This can possibly be ascribed to the fact that the female springbok in those regions ($n$ = 76) were noted to have a higher fat content (3.1%) than the females in this study (Table 3), and this resulted in lower protein values.

Onyango et al. (1998) compared the protein content of game species with beef and observed that beef loin had a slightly lower crude protein content of 19.4%. The highest protein value (23.7%) was observed in the LTL muscle of the sub-adult male group (Table 3). The SS muscle of the sub-adult female group had the lowest protein value (19.4%); this could be ascribed to the specific muscle having a higher fat content. Du Buisson (2006) did not detect any differences ($P > 0.05$) between the BF, LTL, SM, ST, and SS muscles for protein content in springbok from South Africa.

The mean fat values ranged from 3.5% in the SS of the adult females down to 2.3% in the SM of the sub-adult males. Due to the interactions between the main effects it was not clear whether females were fatter than males as reported by Hoffman et al. (2007b) and Van Zyl and Ferreira (2004).

Although there were interactions for the main effects as pertaining to the ash contents, the ash percentage ranged from 1.3% to a low of 1.1% between various muscles from the different age and gender groups.

Tenderness, drip loss, and cooking loss all showed significant interactions (Table 4). Tenderness is an intrinsic meat property and can be measured either with an instrument or by a trained sensory panel. Warner-Bratzler shear force values were used to determine tenderness in this study (Table 4). No distinct trend in meat tenderness were detected between the 2 sexes or age groups for the 6 muscles tested. This is contradictory to the phenomenon that muscles increase in toughness with animal age (Shorthose and Harris, 1990). Nonetheless, the mean shear force value for male and female springbok of all age groups was 3.76 kg/1.27 cm ø, which indicated very tender meat.

Hoffman et al. (2007a) also observed no differences ($P > 0.05$) in tenderness of springbok LTL muscle for different sex and age groups in South Africa. However, animals from different regions in South Africa differed ($P \leq 0.05$) in terms of tenderness with shear force values varying from 2.04 kg/1.27 cm ø to 2.31 kg/1.27 cm ø for different age categories. The values were lower than the values observed for springbok in this study indicating that the meat studied in Hoffman et al. (2007a) was more tender. Even so, when evaluating the different muscles (Table 4), there were some trends worth noting; the IF muscle had the lowest shear force value

**Table 4.** Mean values (±SE) for shear force, drip loss and cooking loss for the *longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM), *Semitendinosus* (ST), *Supraspinatus* (SS), and *Infraspinatus* (IS) muscles from different sex and age groups of springbok from Namibia

| Item | Adult male ($n$ = 12) | Sub-adult male ($n$ = 7) | Adult female ($n$ = 11) | Sub-adult female ($n$ = 8) |
|---|---|---|---|---|
| Shear force, kg/1.27 cm ø | | | | |
| BF | $3.82^{defgh} \pm 0.192$ | $3.82^{defg} \pm 0.290$ | $3.94^{cdef} \pm 0.200$ | $3.80^{defgh} \pm 0.332$ |
| IS | $3.02^{hij} \pm 0.157$ | $2.87^{ij} \pm 0.246$ | $3.53^{efghi} \pm 0.202$ | $2.61^{j} \pm 0.229$ |
| LD | $3.12^{ghij} \pm 0.175$ | $3.13^{ghij} \pm 0.291$ | $2.93^{ij} \pm 0.069$ | $3.04^{ghij} \pm 0.360$ |
| SM | $4.74^{ab} \pm 0.410$ | $4.40^{abcd} \pm 0.381$ | $4.26^{abcde} \pm 0.291$ | $4.21^{abcde} \pm 0.462$ |
| ST | $4.62^{abc} \pm 0.220$ | $4.96^{a} \pm 0.485$ | $4.53^{abcd} \pm 0.232$ | $4.18^{abcde} \pm 0.337$ |
| SS | $3.57^{efghi} \pm 0.191$ | $3.39^{fghij} \pm 0.193$ | $4.00^{bcdef} \pm 0.205$ | $3.37^{fghij} \pm 0.339$ |
| Drip loss, % | | | | |
| BF | $1.4^{bc} \pm 0.12$ | $1.5^{abc} \pm 0.14$ | $1.5^{abc} \pm 0.08$ | $1.4^{abc} \pm 0.18$ |
| IS | $1.5^{abc} \pm 0.20$ | $1.8^{abc} \pm 0.27$ | $1.6^{abc} \pm 0.20$ | $1.9^{ab} \pm 0.24$ |
| LD | $1.3^{c} \pm 0.13$ | $1.9^{a} \pm 0.17$ | $1.9^{ab} \pm 0.14$ | $1.8^{abc} \pm 0.23$ |
| SM | $1.4^{bc} \pm 0.15$ | $1.4^{abc} \pm 0.21$ | $1.5^{abc} \pm 0.10$ | $1.4^{abc} \pm 0.11$ |
| ST | $1.3^{c} \pm 0.15$ | $1.6^{abc} \pm 0.15$ | $1.7^{abc} \pm 0.09$ | $1.6^{abc} \pm 0.18$ |
| SS | $1.5^{abc} \pm 0.22$ | $1.6^{abc} \pm 0.25$ | $1.6^{abc} \pm 0.12$ | $1.7^{abc} \pm 0.19$ |
| Cooking loss, % | | | | |
| BF | $38.1^{fghi} \pm 1.05$ | $38.8^{efg} \pm 0.67$ | $41.3^{bcde} \pm 0.46$ | $38.4^{fgh} \pm 1.45$ |
| IS | $35.3^{ij} \pm 1.35$ | $36.7^{ghij} \pm 2.06$ | $40.5^{cdef} \pm 0.67$ | $35.7^{hij} \pm 0.85$ |
| LD | $35.0^{j} \pm 1.01$ | $36.8^{ghij} \pm 0.86$ | $38.6^{efgh} \pm 0.67$ | $37.4^{ghij} \pm 0.94$ |
| SM | $40.3^{def} \pm 1.11$ | $40.7^{cdef} \pm 0.84$ | $42.1^{bcd} \pm 0.64$ | $40.5^{cdef} \pm 1.40$ |
| ST | $41.9^{bcd} \pm 0.73$ | $43.3^{abc} \pm 0.71$ | $43.8^{ab} \pm 0.42$ | $43.0^{bcd} \pm 1.18$ |
| SS | $43.2^{abc} \pm 1.01$ | $43.8^{ab} \pm 1.02$ | $46.1^{a} \pm 0.40$ | $43.7^{ab} \pm 1.20$ |

[a–j]Values in the same subgroup of variables with different superscripts differ significantly ($P \leq 0.05$)

for all sex and age groups except for adult females. The SM and ST muscles of the springbok tended to have the highest shear force values (lowest tenderness) when compared to the other springbok muscles.

Hoffman (2001) reported impala shear force values similar to that noted in this study. Wiklund et al. (1997) reported Warner-Bratzler shear force values for reindeer (*Rangifer tarandus tarandus* L.) at 3 d post mortem varied between 2.1 to 4.9 kg/cm$^2$, indicating very tender meat. Wiklund et al. (2001) observed a value of 4.9 kg/cm$^2$ for non-electrical stimulated red deer (*Cervus elaphus*) venison at 1 wk post mortem as measured with a MIRINZ tenderometer, while Volpelli et al. (2003) reported a Warner-Bratzler peak shear force value of 4.4 kg/1.27 cm ø for pasture-fed fallow deer (*Dama dama*) and Dhanda et al. (2003) found values of 4.9 kg/1.27 cm ø and 5.7 kg/1.27 cm ø, for elk (*Cervus elaphus*), respectively, which are higher than the values observed in this study (Table 4), reflecting slightly tougher meat.

Locomotive muscles have been reported to be less tender and to vary in tenderness attributes (Segars et al., 1974). Warner-Bratzler shear force values obtained from the springbok muscle tended to be in agreement with this finding as the BF, SM, and ST (locomotory) muscles tended to have higher values and were thus less tender than the LTL, SS, and IS.

As pertaining to the interactions observed for the drip loss, the SM and LTL muscles of the adult male springbok had the lowest drip loss values (Table 4). Drip loss values of 2.0 and 2.9%, respectively, were observed by Du Buisson (2006) for BF and ST muscles for springbok. Hoffman et al. (2007a) reported drip loss values of 2.8 and 3.7% for male and female springbok, respectively.

The values from previous studies are higher than the values observed in this study (Table 4). It is well known that the rate of chilling influences pH decline, which in turn influences water holding capacity and thus the drip loss. The possibility therefore exists that the carcasses in this investigation were chilled more rapidly than those of Du Buisson (2006) and Hoffman et al. (2007a).

Cooking loss is associated with tenderness because the ability to hold water in the meat structure is important for juiciness, another attribute positively correlated to tenderness, and Briskey (1963) found muscles with a low cooking loss to be more tender than muscles with a high cooking loss.

The IF and LTL muscles showed the lowest values (Table 4) for cooking loss of 35.3 and 35.0%, respectively. This agreed with the findings of Hoffman et al. (2009) where the LTL muscle in impala showed the lowest value for cooking loss (31.2%) when compared to the BF, SM, ST, and SS muscles.

All color CIE ordinates (L*, a*, b*, and hue and chroma) showed interactions between the main effects. The means for CIE L*, a*, and b* colorimetric values, as well as hue angle and chroma, for the different muscles as affected by sex and age are represented in Tables 5 and 6, respectively. Game meat has characteristic color measurement properties with Shange et al. (2019) indicating that typical color coordinates for game meat with normal pH could be described as L* > 33, a* > 13, b*~10 resulting in calculated C* > 17 and hue > 36. Color parameters (L*, a*, and b*) are affected by rigor temperature, as these parameters increase with increase in temperature. Usually, after blooming, samples at a higher temperature are lighter and redder that those at a lower temperature (Bekhit et al., 2007).

Due to the interactions, it could not be established whether sex or age had an effect on the L* values. Neethling et al. (2019) also found that sex had no effect on the L*-value of springbok although they did find that

**Table 5.** Mean values (±SE) for CIE L*, a* and b* values for the *longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM), *Semitendinosus* (ST), *Supraspinatus* (SS), and *Infraspinatus* (IS) muscles from different sex and age groups of springbok from Namibia

| Item | Adult male ($n$ = 11) | Sub-adult male ($n$ = 4) | Adult female ($n$ = 8) | Sub-adult female ($n$ = 5) |
|---|---|---|---|---|
| CIE L* | | | | |
| BF | $31.98^{cdef} \pm 0.566$ | $32.54^{bcde} \pm 0.701$ | $30.51^{fg} \pm 0.511$ | $31.50^{cdefg} \pm 1.212$ |
| IS | $33.19^{abc} \pm 0.477$ | $32.92^{abcd} \pm 0.521$ | $31.69^{cdefg} \pm 0.607$ | $24.40^{ab} \pm 0.538$ |
| LD | $30.43^{fg} \pm 0.489$ | $31.15^{defgh} \pm 0.857$ | $29.48^{h} \pm 0.489$ | $29.78^{gh} \pm 0.828$ |
| SM | $30.80^{efgh} \pm 0.359$ | $31.87^{cdef} \pm 1.083$ | $29.83^{gh} \pm 0.434$ | $30.24^{fg} \pm 1.078$ |
| ST | $33.42^{abc} \pm 0.527$ | $34.38^{ab} \pm 1.053$ | $31.68^{cdefg} \pm 0.571$ | $33.24^{abc} \pm 0.713$ |
| SS | $32.66^{bcde} \pm 0.446$ | $33.11^{abc} \pm 0.620$ | $31.02^{defgh} \pm 0.659$ | $34.61^{a} \pm 0.595$ |
| CIE a* | | | | |
| BF | $13.38^{abcd} \pm 0.354$ | $13.17^{abcde} \pm 0.759$ | $12.88^{abcde} \pm 0.706$ | $12.32^{cde} \pm 0.499$ |
| IS | $12.90^{abcde} \pm 0.455$ | $12.69^{bcde} \pm 0.777$ | $12.55^{bcde} \pm 0.575$ | $12.89^{abcde} \pm 0.320$ |
| LD | $12.77^{abcde} \pm 0.431$ | $13.45^{abcd} \pm 0.555$ | $13.33^{abcd} \pm 0.455$ | $12.26^{de} \pm 0.495$ |
| SM | $12.92^{abcde} \pm 0.376$ | $12.86^{abcde} \pm 0.406$ | $12.60^{bcde} \pm 0.529$ | $11.77^{e} \pm 0.664$ |
| ST | $14.30^{a} \pm 0.305$ | $13.89^{ab} \pm 0.388$ | $13.05^{abcde} \pm 0.463$ | $13.59^{abcd} \pm 0.257$ |
| SS | $13.80^{abc} \pm 0.229$ | $13.06^{abcde} \pm 0.816$ | $13.45^{abcd} \pm 0.447$ | $12.96^{abcde} \pm 0.662$ |
| CIE b* | | | | |
| BF | $7.09^{efg} \pm 0.453$ | $8.49^{abcd} \pm 0.468$ | $8.27^{abcde} \pm 0.458$ | $6.81^{fg} \pm 0.612$ |
| IS | $8.11^{abcde} \pm 0.277$ | $8.11^{abcde} \pm 0.456$ | $7.67^{cdefg} \pm 0.390$ | $7.75^{cdefg} \pm 0.314$ |
| LD | $8.52^{abc} \pm 0.338$ | $6.64^{g} \pm 0.131$ | $8.03^{abcde} \pm 0.350$ | $7.14^{defg} \pm 0.637$ |
| SM | $8.16^{abcdef} \pm 0.300$ | $9.37^{a} \pm 0.590$ | $8.71^{abc} \pm 0.508$ | $7.68^{cdefg} \pm 0.658$ |
| ST | $9.25^{ab} \pm 0.420$ | $8.39^{abcde} \pm 0.484$ | $8.51^{abc} \pm 0.436$ | $8.75^{abc} \pm 0.458$ |
| SS | $8.60^{abc} \pm 0.311$ | $8.36^{abcde} \pm 0.461$ | $7.90^{bcdefg} \pm 0.336$ | $8.87^{abc} \pm 0.468$ |

[a–h]Values in the same subgroup of variables with different superscripts differ significantly ($P \leq 0.05$)

**Table 6.** Mean values (±SE) for hue and chroma values for the *longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM), *Semitendinosus* (ST), *Supraspinatus* (SS), and *Infraspinatus* (IS) muscles from different sex and age groups of springbok from Namibia

| Item | Adult male ($n$ = 11) | Sub-adult male ($n$ = 4) | Adult female ($n$ = 8) | Sub-adult female ($n$ = 5) |
|---|---|---|---|---|
| Hue angle | | | | |
| BF | $23.56^{bc} \pm 1.287$ | $25.90^{abc} \pm 2.158$ | $24.57^{bc} \pm 1.307$ | $23.22^{c} \pm 1.106$ |
| IS | $25.41^{abc} \pm 0.895$ | $25.76^{abc} \pm 2.079$ | $22.94^{c} \pm 1.437$ | $24.51^{bc} \pm 0.955$ |
| LD | $26.76^{ab} \pm 0.598$ | $23.16^{c} \pm 1.814$ | $24.82^{abc} \pm 0.822$ | $24.17^{bc} \pm 1.233$ |
| SM | $26.20^{abc} \pm 0.788$ | $28.32^{a} \pm 0.842$ | $27.03^{ab} \pm 0.805$ | $26.10^{abc} \pm 1.863$ |
| ST | $25.73^{abc} \pm 0.830$ | $26.31^{abc} \pm 2.043$ | $26.12^{abc} \pm 0.726$ | $24.67^{bc} \pm 0.857$ |
| SS | $25.17^{abc} \pm 0.760$ | $23.75^{bc} \pm 0.550$ | $23.97^{bc} \pm 1.030$ | $27.04^{ab} \pm 0.980$ |
| Chroma | | | | |
| BF | $15.62^{abcd} \pm 0.563$ | $15.76b^{ac} \pm 0.445$ | $15.41^{bcdef} \pm 0.616$ | $13.89^{f} \pm 0.640$ |
| IS | $15.31^{bcdef} \pm 0.433$ | $15.13^{cdef} \pm 0.603$ | $15.16^{bcdef} \pm 0.464$ | $15.04^{cdef} \pm 0.286$ |
| LD | $15.03^{cdef} \pm 0.386$ | $14.61^{cdef} \pm 0.332$ | $15.56^{abcd} \pm 0.483$ | $13.91^{ef} \pm 0.789$ |
| SM | $15.10^{cdef} \pm 0.405$ | $15.94^{abc} \pm 0.641$ | $14.83^{cdef} \pm 0.465$ | $14.07^{def} \pm 0.746$ |
| ST | $17.08^{a} \pm 0.406$ | $16.78^{ab} \pm 0.665$ | $15.54^{abcde} \pm 0.567$ | $15.32^{bcdef} \pm 0.658$ |
| SS | $16.23^{abc} \pm 0.325$ | $15.38^{bcdef} \pm 0.338$ | $15.63^{abcd} \pm 0.424$ | $15.38^{abc} \pm 0.748$ |

[a–h]Values in the same subgroup of variables with different superscripts differ significantly ($P \leq 0.05$)

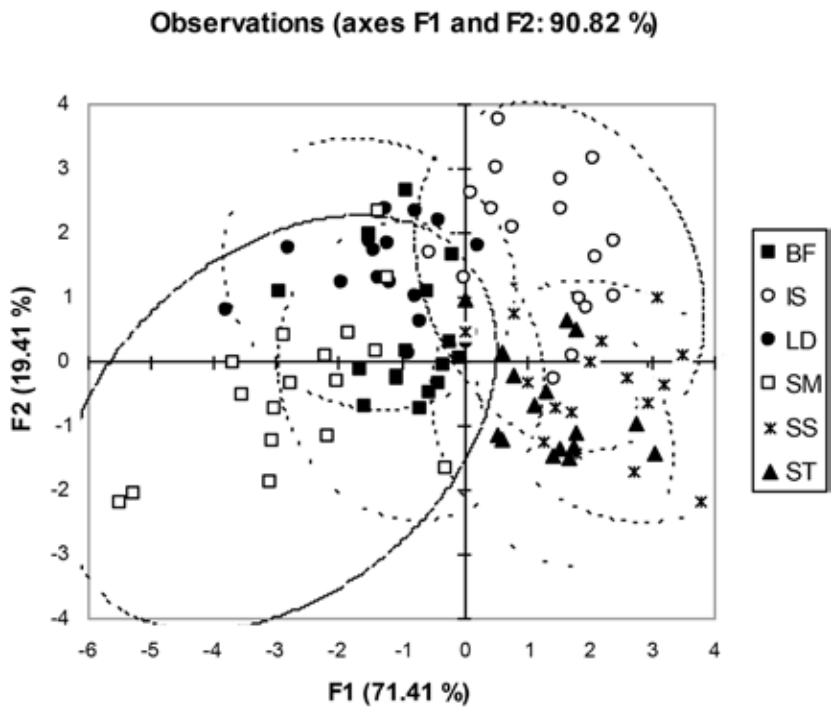


**Figure 1.** Discriminant analysis for the *longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM), *Semitendinosus* (ST), *Supraspinatus* (SS), and *Infraspinatus* (IS) muscles from Namibian springbok.

the IS, LTL, and BF muscles differed from each other; the IS having the lightest and BF the darkest color. This is contradictory to the postulation of Seideman et al. (1982) that the meat from male animals is darker in color due to their greater physical activity.

The SS and ST muscles from the sub-adult groups tended to have the highest L* and thus the lightest meat. The ST muscle (Table 5) had the reddest color with mean CIE a* value of 14.30 for adult and 13.89 for sub-adult male springbok. For the CIE b* (blue-yellow range) values, the ST muscle of adult males had the highest value (9.25) while the LTL muscle of the sub-adult males had the lowest (6.64) value. The color data in this study met the color criteria of Volpelli et al. (2003) and Shange et al. (2019) for normal venison/game meat.

Neethling et al. (2017) reported that a* values and hue angles are good indicators for meat discoloration and it was observed that a* values decreased and hue angles increased, as discoloration increased in deer (Neethling et al., 2018b) and blesbok (Neethling et al., 2016b) and springbok (Neethling et al., 2019). The IS muscle from the female adult group had the lowest mean hue angle (22.94°) with the reddest meat, while the SM muscle of the sub-adult male group had the highest hue angle (28.32°), indicating that it was less red. Hue angle values reported by Hoffman et al. (2007a) for male and female springbok in South Africa were higher than in the present study at 31.47° and 30.31°, respectively.

Du Buisson (2006) reported a mean hue angle of 26.68° in the ST (less red color) and 20.72° in the MLT of springbok in South Africa (more red color). That study also reported that springbok muscles could be divided into 2 significantly different groups when the L* values were considered, with the ST and SS muscles being in one group and the MLT being in the other group, which is in agreement with the findings of this study.

The lowest mean chroma value (13.89) was found in BF muscle of the female sub-adult group while the highest chroma value (17.07) was observed in the ST muscle of the male adult group (Table 6). This agreed with the findings of Hoffman et al. (2007a) who reported mean chroma values between 15.26 and 17.51 for springbok from 4 different regions in South Africa.

Higher chroma values mean higher color saturation levels, which result in muscles appearing brighter in color (Stevenson et al., 1989; Neethling et al., 2016b). A mean chroma value of 25.79 was reported for the ST muscle in springbok by Du Buisson (2006) which is higher than the values in this study.

### *Discriminant analysis*

Consumers want to have the same eating experience every time a certain type of meat is consumed (Issanchou, 1996; Hoffman and Wiklund, 2006). Grouping different cuts of meat with the same physical and sensory properties can be of value to the commercial industry that merchandises different muscles under generic terminology (e.g., springbok steaks) without differentiating between the specific muscles. It is well known that beef muscles differ in their various physical and sensory traits (Jeremiah et al., 2003a) and biochemical measurements have been reported to predict untrained consumer sensory scores across beef muscles (Bonny et al., 2015). Discriminant analysis was used to determine group differences and to predict the likelihood that some of the springbok muscles under investigation could belong to a particular group based on several variables (Fig. 1).

The variables used in this study could not differentiate among the different muscle groups, thus indicating that the industry would most probably be correct in marketing springbok steaks derived from these muscles under the generic name. This result contradicts the research conducted on domesticated animals (Johnson et al., 1988; Jeremiah et al., 2003b; Jones et al., 2004). A possible explanation for this phenomenon could be that springbok muscle has been described as being very fine grained (Von la Chevallerie, 1970; North and Hoffman, 2017), and it was demonstrated by Von la Chevallerie (1972) that springbok had a finer grain (45 μm) compared to red hartebeest (*Alcelaphus buselaphus*; 52.6 μm), eland (*Tragelaphus oryx*; 66 μm), and gemsbok (*Oryx gazelle*; 69 μm) meat, with springbok having the most tender meat (1.2 kg/cm; Warner-Bratzler shear force values) compared to red hartebeest (2.9 kg/cm), eland (3.4 kg/cm) and gemsbok (4.1 kg/cm). Springbok meat is even prone to becoming too soft if aged for too long (Jansen van Rensburg, 1997). This phenomenon is not surprising, as all the measured shear force values were very low. Wiklund et al. (1997) demonstrated the same phenomenon as reindeer (*Rangifer tarandus tarandus* L.) *M. Longissimus* muscles were found to be extremely tender regardless of the ultimate pH.

## Conclusion

This study investigated the carcass yields and quality characteristics of Namibian springbok. Dressing percentages did not differ significantly between the different sex and age groups. Although there were some statistical differences in the chemical composition of the various muscles, these were of a minor nature. The IS muscle had the lowest shear force values in adult male springbok and in both sub-adult male and female springbok and can be described as the more tender muscle. However, all muscles were found to be extremely tender. The IS and LTL muscles showed the lowest values for cooking loss. Discriminant analysis could not differentiate among the different muscle groups for the variables. As neither springbok sex nor age influenced any of the meat quality parameters and older animals tended to have heavier carcasses, the decision of which sex and/or age group to cull will depend on the springbok management strategy. It is suggested that models be developed to predict yield (kg meat) per surface area per time unit as it is becoming the norm to pay a fixed price per kg carcass weight rather than per carcass and these models will indicate whether it is commercially more viable to cull young or older animals.

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