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Muscle-Specific Color Stability of Fresh Meat from Springbok (*Antidorcas marsupialis*)

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Abstract: Springbok (*Antidorcas marsupialis*), a popular South African game species, has significant potential in meat production. Considering the importance of fresh meat color on consumers' purchasing intent, the objective of this study was to evaluate the color stability of 3 economically important springbok muscles, *infraspinatus* (IS), *longissimus thoracis et lumborum* (LTL), and *biceps femoris* (BF). The IS, LTL, and BF muscles from both sides of 12 (6 male and 6 female) springbok carcasses were utilized. The muscles were fabricated (72 h postmortem) into 2.5-cm thick steaks, which were aerobically over-wrapped and stored for 8 d at 2°C. Surface color, myoglobin redox forms, pH, metmyoglobin reducing activity, total iron content, and myoglobin concentration were evaluated. Data were analyzed using mixed model repeated measures ANOVA. The IS exhibited greater ($P < 0.05$) redness, chroma, color stability, pH, oxymyoglobin content, and metmyoglobin reducing activity than its LTL and BF counterparts. Moreover, metmyoglobin formation and total iron content were lower in IS than in LTL and BF. The IS demonstrated stable redness and chroma throughout the storage, whereas the LTL and BF exhibited a steady decline. The results indicated that springbok IS muscle was the most color stable, while the LTL and BF did not differ in color stability from each other. These findings also suggested that muscle-specific processing methods could be utilized to improve retail color stability for fresh meat from springbok.

Keywords: color stability, game meat, muscles, myoglobin, springbok
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Introduction

Springbok (*Antidorcas marsupialis*) is one of the most common game species in South Africa. In addition, it is the most extensively harvested and exported game from South Africa, comprising approximately 70% of the game animals harvested (Eloff, 2001). Consumption of springbok meat is often perceived by tourists as an integral element of the South African safari experience (Hoffman and Wiklund, 2006). A sustainable game meat market can only be achieved through the delivery of products of consistently high quality (Hutchison et al., 2010). The purchasing intent of fresh meat by consumers is based largely on color (Faustman and Cassens, 1990; Mancini and Hunt, 2005; Suman et al., 2014; Neethling et al., 2017), and thus the color and color stability of game meat need to be consistent. Since meat color stability is both species- (Faustman and Cassens, 1990; Mancini and Hunt, 2005; Neethling et al., 2017) and muscle-specific (O'Keeffe and Hood, 1982; McKenna

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et al., 2005; Joseph et al., 2012; Nair et al., 2018), different approaches may be required to improve color stability of whole-muscle cuts from various game species (Neethling et al., 2016; Neethling et al., 2018).

Despite the large potential for a sustainable game meat market, limited research has been undertaken on color stability of game meat (Neethling et al., 2016; Neethling et al., 2018), which indicated that the color stability attributes of muscles from game are very different from those of the same muscles from conventional livestock (Neethling et al., 2017). Therefore, the objective of the present study was to examine the color stability of 3 economically important springbok muscles during refrigerated storage. The springbok muscles studied were *infraspinatus* (IS; from the forequarter), *longissimus thoracis et lumborum* (LTL; from the trunk/mid-section), and *biceps femoris* (BF; from the hindquarter). In commercial practice, most of the game meat is deboned and the muscles are separated; the IS being a low-value muscle is commonly retailed as composite/multi-muscle cut or minced meat, or processed into various products, whereas the LTL and BF being high- and intermediate-value muscles, respectively, are often sold as fresh whole-muscle cuts (North et al., 2015).

Materials and Methods

Animal harvesting and muscle collection

Twelve (6 male and 6 female) mature springbok (older than 3 yr) were harvested (average bled weight 28.6 ± 3.18 kg) on the farm at Brakkekuil, Witsand (Western Cape Province, South Africa). The harvest was done in compliance with the Stellenbosch University Animal Care and Use Committee's standard operating procedure (SU-ACUM14–001SOP). To minimize stress, the animals were harvested at night and were shot in the head using a .308 caliber rifle. The animals were exsanguinated within 2 to 3 min after being shot. The undressed carcasses were transported within 15 min to an on-farm abattoir facility, where the legs, head, skin, and viscera were removed.

The dressed carcasses were hung in a cold room (2°C) for 24 h. Subsequently, the *infraspinatus* (IS), *longissimus thoracis et lumborum* (LTL), and *biceps femoris* (BF) muscles were removed from the left and right sides of each carcass. After removal of visible intermuscular and subcutaneous fat, the muscles were individually vacuum packaged in a composite plastic bag (70 µm polyethylene and nylon; moisture vapor transfer rate of 2.2 g^{-2} 24 h^{-1} 1 atm^{-1}, O_2 permeability of 30 cm^{-3} m^{-2} 24 h^{-1} 1 atm^{-1}, and CO_2 permeability of 105 cm^{-3} m^{-2} 24 h^{-1} 1 atm^{-1}; Freddy Hirsch, Cape Town, South Africa) with a residual pressure of 5 mbar (Multivac, Model C200; Sepp Haggenmuller, Wolfertschwenden, Germany). The vacuum-packaged muscles were transported under refrigeration to the Department of Animal Sciences at Stellenbosch University and were placed in a cold room (2°C) on racks in a single layer to minimize any temperature variations.

Muscle fabrication

The muscles were stored for another 48 h in the cold room prior to the color stability study. The muscles from the left and right sides of each carcass were considered an experimental unit because the variations between the muscles from left and right sides are negligible. The muscles were removed from the vacuum packaging and blotted dry to remove any surface moisture. The anterior and posterior ends of the muscles were removed and were not used. Each muscle was then cut at the center and perpendicular to the muscle fiber direction into 2 halves, and three 2.5-cm thick steaks were cut perpendicular to the muscle fiber direction from each half, providing 6 steaks per muscle and 12 steaks per experimental unit. Steaks from each muscle (IS, LTL, and BF) and carcass were packed in a single layer in polystyrene trays (16 cm × 21 cm; Freddy Hirsch, Cape Town, South Africa) and were overwrapped with low-density polyethylene (LDPE) film (moisture vapor transfer rate of 585 g^{-2} 24 h^{-1} 1 atm^{-1}, O_2 permeability of 25 000 cm^{-3} m^{-2} 24 h^{-1} 1 atm^{-1}, and CO_2 permeability of 180 000 cm^{-3} m^{-2} 24 h^{-1} 1 atm^{-1}; Freddy Hirsch, Cape Town, South Africa).

Refrigerated storage

The color stability study was conducted for 8 d during refrigerated storage at 2°C. The overwrapped steaks were placed in a single layer in the cold room to minimize variations between samples on light exposure, temperature, and gas permeation through the LDPE film. The packaged steaks were stored under fluorescent lights (OSRAM L58W/640, Energy saver, Cool White, 4000 K color temperature, 4600 Lumen) continuously (24 h/d), and the samples were analyzed on d 0, 1, 2, 4, 6, and 8.

Instrumental color evaluation

On d 0, the steaks, overwrapped to prevent surface desiccation, were bloomed for 60 min at 2°C prior to color measurement. The surface color of the steaks was measured instrumentally (American Meat Science Association, 2012) using a color-guide 45°/0° colorimeter (Model 6801, BYK-Gardner, Geretsried,

Germany) equipped with 11 mm aperture, illuminant D65, and 10° observer angle. The overwrap was removed, and the color was measured directly on the steak surface. After the color measurement, the specific sample was removed for biochemical analyses.

Color was measured at 5 different locations on each steak, and the average of the 5 measurements was calculated for statistical analysis. The instrumental color parameters evaluated were *L** (lightness), *a** (redness) and *b** (yellowness) values. Additionally, the hue angle and chroma were calculated (American Meat Science Association, 2012).

The reflectance was measured from 400 to 700 nm at 10 nm increments, and the reflectance data were used to calculate the ratio of reflectance at 630 nm and 580 nm (R630/580), as an indirect estimate of surface color stability (American Meat Science Association, 2012).

Surface myoglobin (Mb) redox forms

The reflectance data, measured at the isobestic wavelengths of Mb (473, 525, 572, and 730 nm), from steak surface were used to calculate Mb redox forms (American Meat Science Association, 2012). Since the colorimeter did not measure 730 nm, a wavelength of 700 nm was used in its place. Reflectance at wavelengths 473, 525, and 572 nm were calculated using integration (American Meat Science Association, 2012). The reflectance values were first converted to reflex attenuance (the logarithm of the reciprocal of reflectance), which was subsequently used to calculate the percentages of the various Mb redox forms (American Meat Science Association, 2012).

Meat pH

The pH of the steaks were determined employing the iodoacetate method (Jeacocke, 1977). The sample (0.5 g) was homogenized in 5 mL of a 5 mM sodium iodoacetate and 150 mM KCl (adjusted to pH 7) solution. The pH of the homogenate was measured in duplicate with a bench top pH meter (Jenway 3510, IJEN351201, Lasec SA, Cape Town, South Africa).

Metmyoglobin reducing activity (MRA)

The MRA was measured on d 0, 4, and 8. A 3 cm × 3 cm × 2 cm sample was removed from the center of each steak. The samples were submerged in 0.3% $NaNO_2$ (w/w) solution for 20 min to induce metmyoglobin (MMb) formation. After 20 min, the samples were removed, blotted dry and vacuum packaged in a composite plastic (70 μm polyethylene and nylon; moisture vapor transfer rate of 2.2 g^{-2} 24 h^{-1} 1 atm^{-1}, O_2 permeability of 30 cm^{-3} m^{-2} 24 h^{-1} 1 atm^{-1}, and a CO_2 permeability of 105 cm^{-3} m^{-2} 24 h^{-1} 1 atm^{-1}; Freddy Hirsch, Cape Town, South Africa) with a residual pressure of 5 mbar (Multivac, Model C200; Sepp Haggenmuller, Wolfertschwenden, Germany). The surface reflectance was measured (400 to 700 nm) immediately after packaging, and the samples were incubated in a water bath at 30°C for 2 h after which the surface reflectance was re-scanned. The %MMb (pre-incubation as well as post-incubation) on the surface was calculated based on the K/S ratios and according to established formulas using the relevant spectral values at 525, 572, and 700 nm (American Meat Science Association, 2012). MRA was calculated using the following equation.

$$\text{MRA} = 100 \times [(\%\ \text{pre-incubation surface MMb} - \%\ \text{post-incubation surface MMb}) / \%\ \text{pre-incubation surface MMb}]$$

Total iron content

Total iron content was determined on d 0 using HNO_3–digested samples analyzed by inductively coupled plasma atomic emission spectroscopy (ICP–AES). Briefly, a 0.5-g sample was pre-digested (allowed to digest at 21°C) in concentrated HNO_3 for 20 min. The samples were then fully digested in a microwave digester (MARS 240/50; CEM Corporation, Matthews, NC) at 1,600 W, 800 psi and 200°C for 10 min (ramp time of 25 min and cool down time of 25 min). The digested samples were diluted to 50 mL (1:100 dilution) with deionized water and were then analyzed in a Thermo ICap 6200 ICP–AES (Thermo Electron Corporation, Milan, Italy) calibrated using NIST traceable standards. The results were corrected for the dilution factor resulting from the digestion procedure.

Myoglobin concentration

Myoglobin concentration was measured on d 0. Myoglobin was extracted according to the method of Tang et al. (2004). Briefly, a 10-g sample was homogenized (P-8; Kinematica, Littau, Switzerland) in 100 mL cold 40 mM potassium buffer (pH 6.8) and allowed to extract for 60 min at 4°C. The extract was then centrifuged (Sigma 2–16 K, Wirsam Scientific, Cape Town, South Africa) for 30 min at 4,000 rpm at 4°C. A small quantity of sodium dithionite (3 to 5 μg) was added to the supernatant to convert all the Mb to

deoxymyoglobin (DMb). The absorbance of the supernatant was measured at 433 nm (A_{433}) spectrometrically (Spectrostar Nano, BMG Labtech, Ortenberg, Germany), and the Mb concentration was calculated as follows (American Meat Science Association, 2012).

$$\text{Mb (mg / g meat)} = A_{433} \times (1\ \text{M Mb} / 114{,}000) \times [(1\ \text{mol / L}) / \text{M}] \times (17{,}000\ \text{g Mb / mol Mb}) \times (1000\ \text{mg / g}) \times \text{dilution factor of } 0.10\ \text{L}/10\ \text{g meat}$$

Statistical analyses

Statistical analysis was performed using STATISTICA 64 Version 13.2 (StatSoft Inc., Tulsa, OK). Mixed model repeated measures ANOVA was used to investigate the differences between muscles, taking into account gender and storage time effects. Gender, muscle, and storage time were treated as fixed effects, whereas animal nested in gender as random effect. For post hoc testing, the Fisher least significant difference (LSD) test was used. Pearson correlation was used for correlation analyses. A 5% significance level ($P < 0.05$) was employed for significant effects and correlations.

Results

The main effects and the interactions between the main effects are presented in Table 1. Only the results for significant main effects ($P < 0.05$) and their interactions ($P < 0.05$) are presented and discussed.

Instrumental color

An interaction ($P < 0.05$) between muscle and storage time was observed for the L^* values, while gender had no effect (Table 1). All three muscles demonstrated a similar trend (Fig. 1), with an initial (from d 0 to d 1) increase ($P < 0.05$) in L^* values followed by a decrease ($P < 0.05$). The L^* values for the LTL and BF plateaued after d 4 and d 6, respectively. Overall, the IS had the highest L^* values ($P < 0.05$) and the LTL the lowest ($P < 0.05$).

A gender, muscle, and storage time interaction ($P < 0.05$) was observed for the a^* values (Table 1). The 3 muscles from male and female carcasses exhibited a similar trend in a^* values (Fig. 2). The a^* values of IS remained relatively constant during the storage, whereas those of the LTL and BF decreased ($P < 0.05$; Fig. 2). The LTL and IS (from both male and female carcasses) did not differ from each other ($P > 0.05$) on d 0, whereas the BF differed ($P < 0.05$) from the other 2 muscles.

Table 1. *P*-values[1] indicating the impact of gender (G), muscle (M), storage time (T), and their interactions on color and biochemical attributes of springbok meat

Attribute	G	M	T	M × T	G × T	G × M	G × M × T
L^* value	0.139	**0.000**	**0.000**	**0.004**	0.116	0.077	0.695
a^* value	0.850	**0.000**	**0.000**	**0.000**	**0.036**	**0.001**	**0.023**
b^* value	0.202	**0.000**	**0.000**	**0.000**	0.567	0.069	0.454
Chroma	0.338	**0.000**	**0.000**	**0.000**	0.154	**0.010**	0.073
Hue	0.521	**0.000**	**0.000**	**0.000**	**0.008**	0.845	**0.011**
R630/580	0.114	**0.000**	**0.000**	**0.000**	**0.022**	0.912	0.399
%DMb	0.084	**0.000**	**0.000**	**0.000**	0.296	0.727	0.090
%OMb	**0.045**	**0.000**	**0.000**	**0.000**	0.431	0.681	0.324
%MMb	0.915	**0.000**	**0.000**	**0.000**	0.322	0.657	0.740
pH	0.637	**0.000**	**0.000**	**0.000**	0.555	0.902	0.442
MRA	0.250	**0.000**	**0.000**	0.336	**0.039**	0.501	0.079
Total iron	0.704	**0.000**	–	–	–	0.370	–
Myoglobin	0.551	**0.024**	–	–	–	0.187	–

[1]*P*-values in bold indicate a significant interaction/difference at $P < 0.05$.

The results for b^* values exhibited a muscle and storage time interaction, while gender had no effect (Table 1). Initially (d 0), the IS had the highest b^* values ($P < 0.05$), whereas the LTL and BF did not differ ($P > 0.05$) from each other (Fig. 3). An increase ($P < 0.05$) in b^* values was observed for the IS and BF from d 0 to d 1, whereas no such increase ($P > 0.05$) was observed in the LTL. A decrease ($P < 0.05$) in b^* values was observed for the LTL and BF from d 1 to d 4, after which the values plateaued ($P > 0.05$). A decrease ($P < 0.05$) was also observed for the IS from d 1, but the b^* values only plateaued ($P > 0.05$) after d 6. All the muscles differed significantly on d 8, with the IS having the highest b^* value ($P < 0.05$) and the LTL the lowest ($P < 0.05$).

The data for chroma values demonstrated gender × muscle as well as muscle × storage time interactions (Table 1). Chroma demonstrated a trend similar to that of the a^* values. Overall, the IS muscle had the greatest chroma values ($P < 0.05$), and it remained relatively constant during most part of the storage (Fig. 4).

A gender, muscle, and storage time interaction ($P < 0.05$) was observed for the hue values (Table 1). Similar overall trends were observed in hue for the muscles from the male and female carcasses (Fig. 5). For IS, an increase ($P < 0.05$) was observed from d 0 to d 1, followed by a decline ($P < 0.05$). In contrast, LTL and BF exhibited an increase ($P < 0.05$) throughout storage.

The R630/580 values exhibited gender × storage time and muscle × storage time interactions (Table 1). The R630/580 values of the muscles from male and female carcasses declined ($P < 0.05$) in a similar pattern

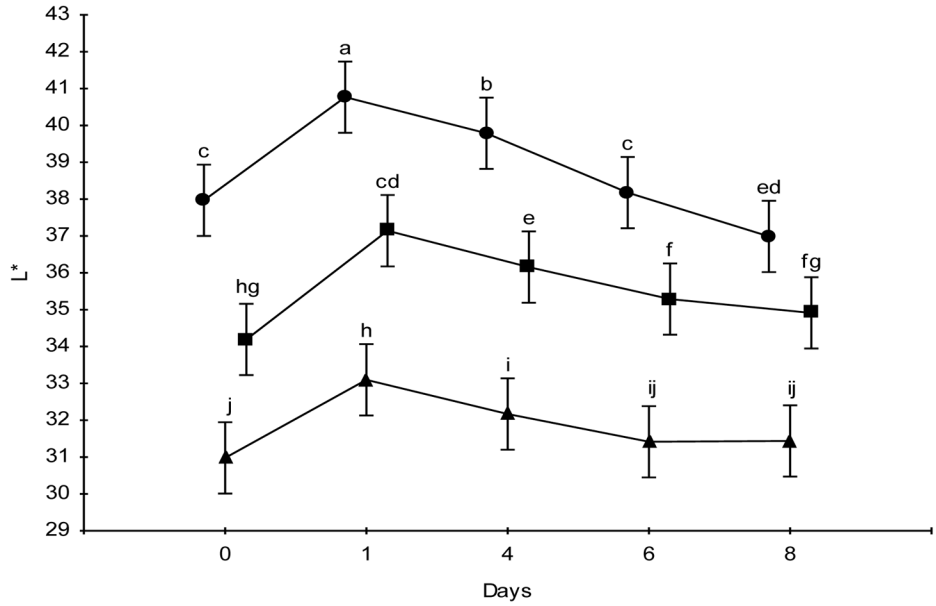

Figure 1. The changes in *L** values (lightness) of 3 springbok muscles, (●) *infraspinatus*, (▲) *longissimus thoracis et lumborum*, and (■) *biceps femoris*, stored at 2°C. [a-j]Means without common letters are different ($P < 0.05$).

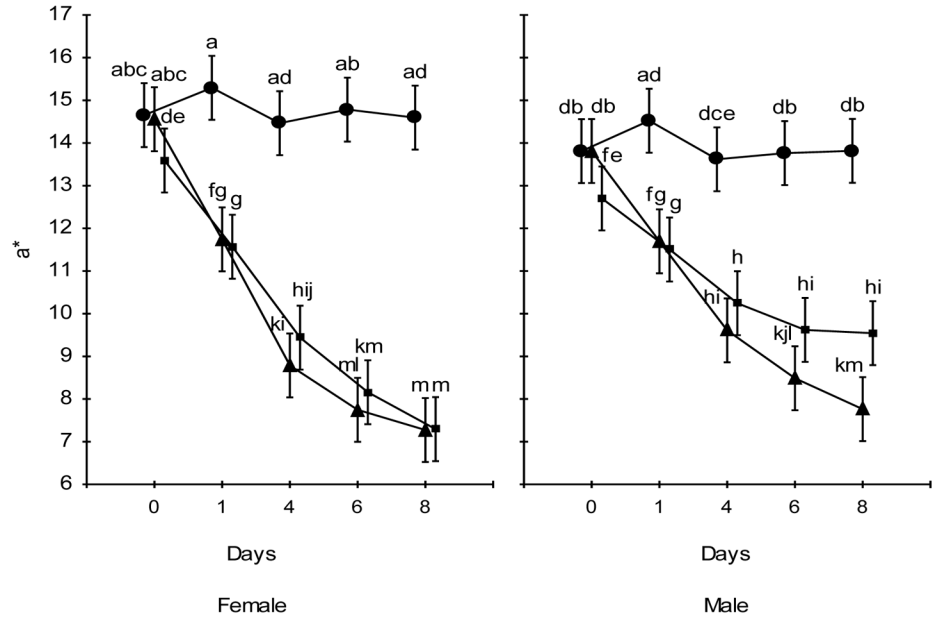

Figure 2. The changes in *a** values (redness) of 3 springbok muscles, (●) *infraspinatus*, (▲) *longissimus thoracis et lumborum*, and (■) *biceps femoris*, from male and female carcasses, stored at 2°C. [a-m]Means without common letters are different ($P < 0.05$).

(Fig. 6A). While a decrease ($P < 0.05$) in R630/580 values was observed for all the muscles (Fig. 6B), the IS maintained the highest R630/580 values from d 1 to d 8.

Surface Mb redox forms

A muscle × storage time interaction was observed for %DMb, while gender had no effect (Table 1). A decrease ($P < 0.05$) in %DMb values was observed for all the muscles (Fig. 7A). While no differences ($P > 0.05$) were observed among the muscles from d 0 to d 4, the IS had the highest %DMb values ($P < 0.05$) from d 6 to d 8.

The results of % oxymyoglobin (%OMb) indicated a muscle × storage time interaction and a gender effect (Table 1). While all the muscles demonstrated a decline in %OMb (Fig. 7B), the decline was slower ($P < 0.05$) in the IS than in the LTL and BF. The IS had the greatest values ($P < 0.05$) from d 1 to d 8. The gen-

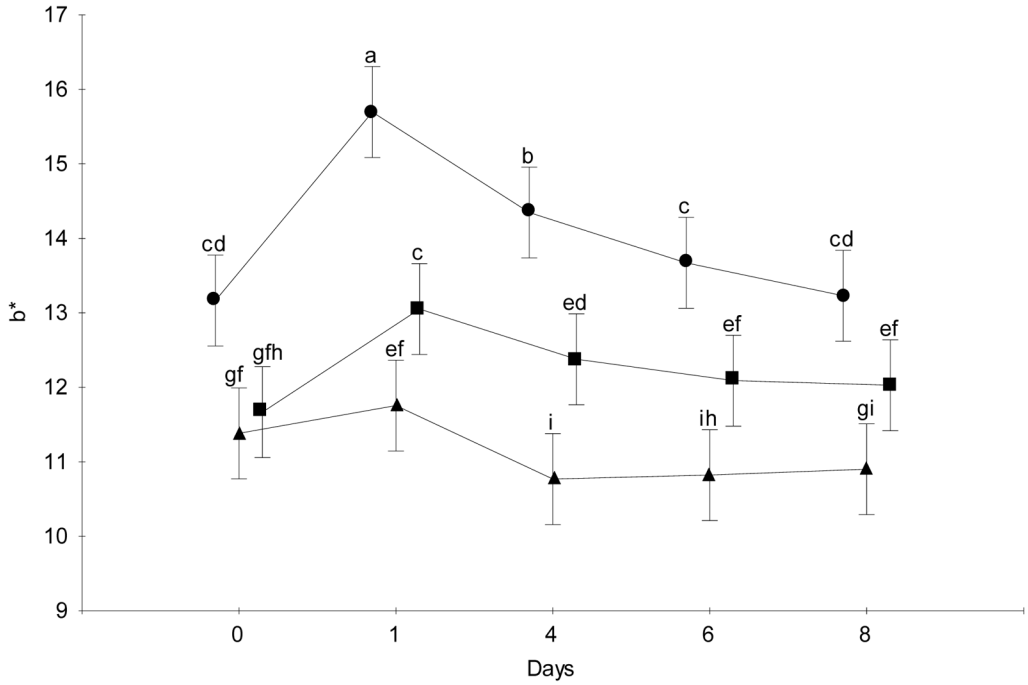

Figure 3. The changes in *b** values (yellowness) of 3 springbok muscles, (●) *infraspinatus*, (▲) *longissimus thoracis et lumborum*, and (■) *biceps femoris*, stored at 2°C. [a-i]Means without common letters are different ($P < 0.05$).

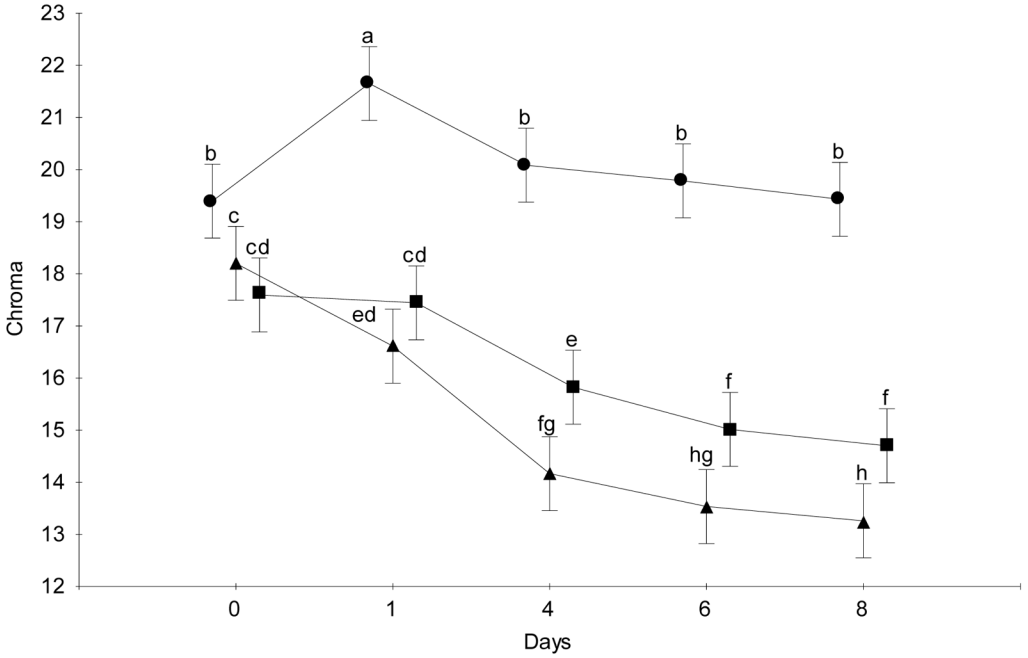

Figure 4. The changes in chroma of 3 springbok muscles, (●) *infraspinatus*, (▲) *longissimus thoracis et lumborum*, and (■) *biceps femoris*, stored at 2°C. [a-h]Means without common letters are different ($P < 0.05$).

der effect indicated that the muscles from females had greater ($P < 0.05$) %OMb (40.85 ± 0.372) in comparison to their counterparts from males (39.65 ± 0.372).

While gender had no effect on %MMb, a muscle × storage time interaction was observed (Table 1). An increase in %MMb values was observed for the 3 muscles (Fig. 7C). The IS had the lowest %MMb values ($P < 0.05$) during the storage, except on d 0. Furthermore, the increase ($P < 0.05$) in %MMb was slower in the IS than in the LTL and BF.

Biochemical attributes

While a muscle × storage time interaction was observed for the pH values, gender had no effect (Table 1). An increase ($P < 0.05$) in pH values during storage was

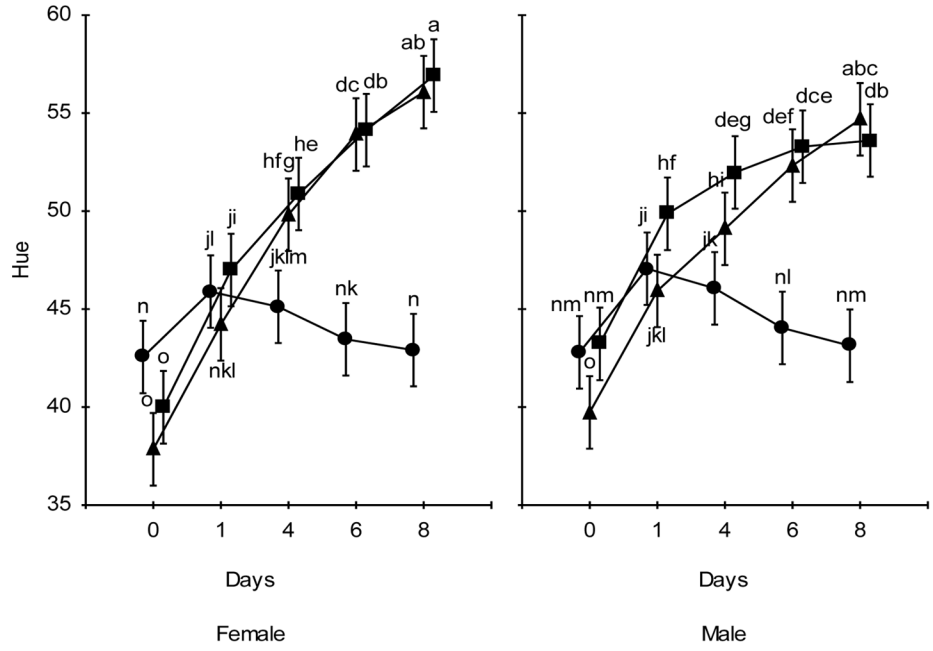

Figure 5. The changes in hue of 3 springbok muscles, (●) *infraspinatus*, (▲) *longissimus thoracis et lumborum*, and (■) *biceps femoris*, from male and female carcasses, stored at 2°C. [a-o]Means without common letters are different ($P < 0.05$).

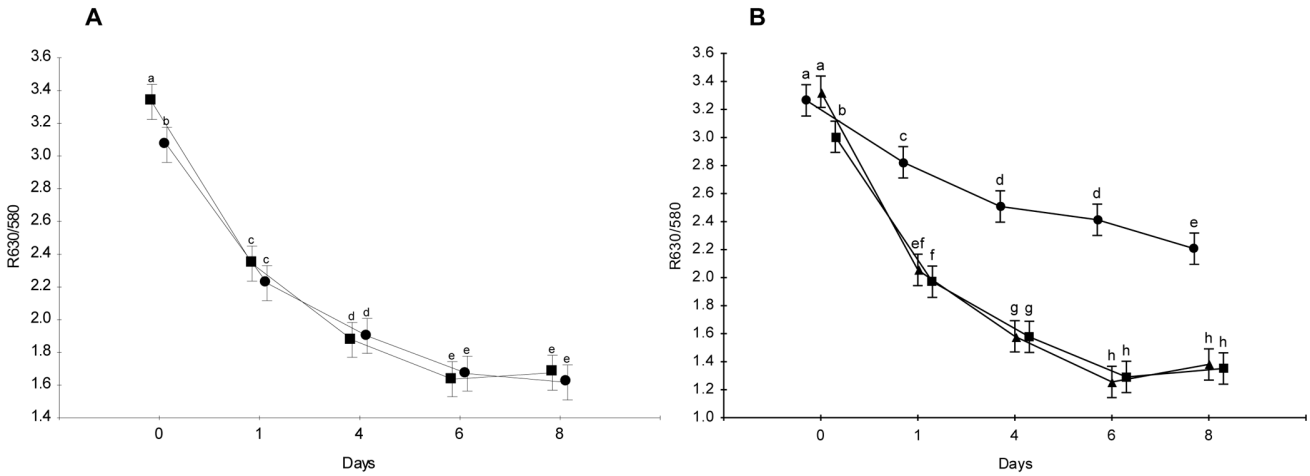

Figure 6. (A) The changes in R630/580 of muscles from (●) male and (■) female springbok, stored at 2°C; (B) The changes in R630/580 of three springbok muscles, (●) *infraspinatus*, (▲) *longissimus thoracis et lumborum*, and (■) *biceps femoris*, stored at 2°C. [a-h]Means without common letters are different ($P < 0.05$).

observed for all the muscles (Fig. 8). The IS had the greatest pH values ($P < 0.05$) throughout the storage, whereas the pH values of LTL and BF did not differ ($P > 0.05$) from each other during the storage.

The data for MRA exhibited gender × storage time interaction and muscle effect (Table 1). Muscles from males demonstrated an initial increase (d 0 to d 4; $P < 0.05$) followed by a decrease (d 4 to d 8; $P < 0.05$) in MRA (Fig. 9); however, no difference in MRA was observed between d 0 and d 8. While the muscles from female carcasses exhibited no initial increase ($P > 0.05$), a decrease ($P < 0.05$) was observed from d 4 to d 8. The muscles from female and male carcasses differed only on d 8. The muscle effect indicated that the IS had the greatest ($P < 0.05$) MRA, whereas the LTL and BF had the lowest ($P < 0.05$) values (Table 3).

Muscle source influenced the total iron content, whereas no effect of gender was observed (Table 1). The LTL and BF had the greatest ($P < 0.05$) and the IS had the lowest total iron contents (Table 3). Data for Mb concentration demonstrated a muscle effect, while no gender effect was observed (Table 1).The LTL and IS differed

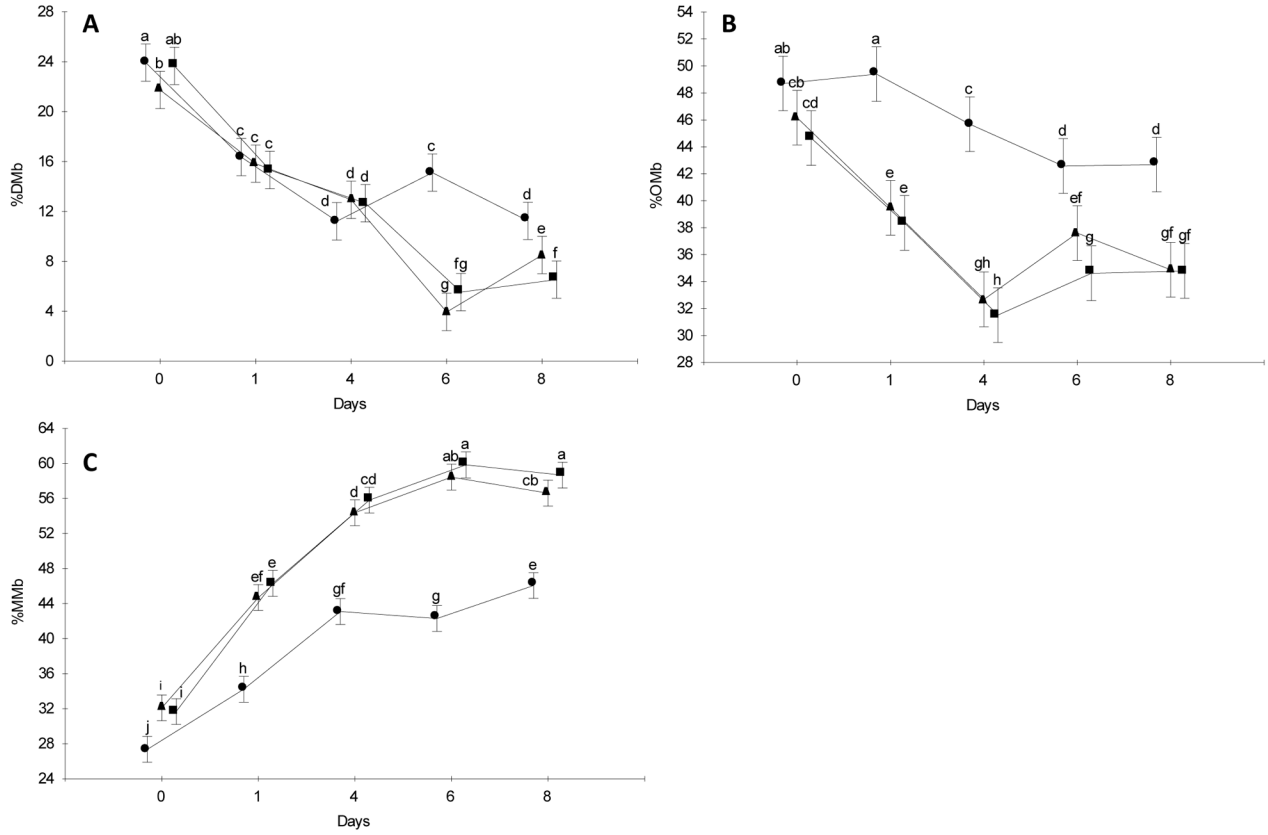

Figure 7. The changes in the (A) %DMb, (B) %OMb, and (C) %MMb of 3 springbok muscles, (●) *infraspinatus*, (▲) *longissimus thoracis et lumborum* and (■) *biceps femoris*, stored at 2°C. [a-j]Means without common letters are different ($P < 0.05$).

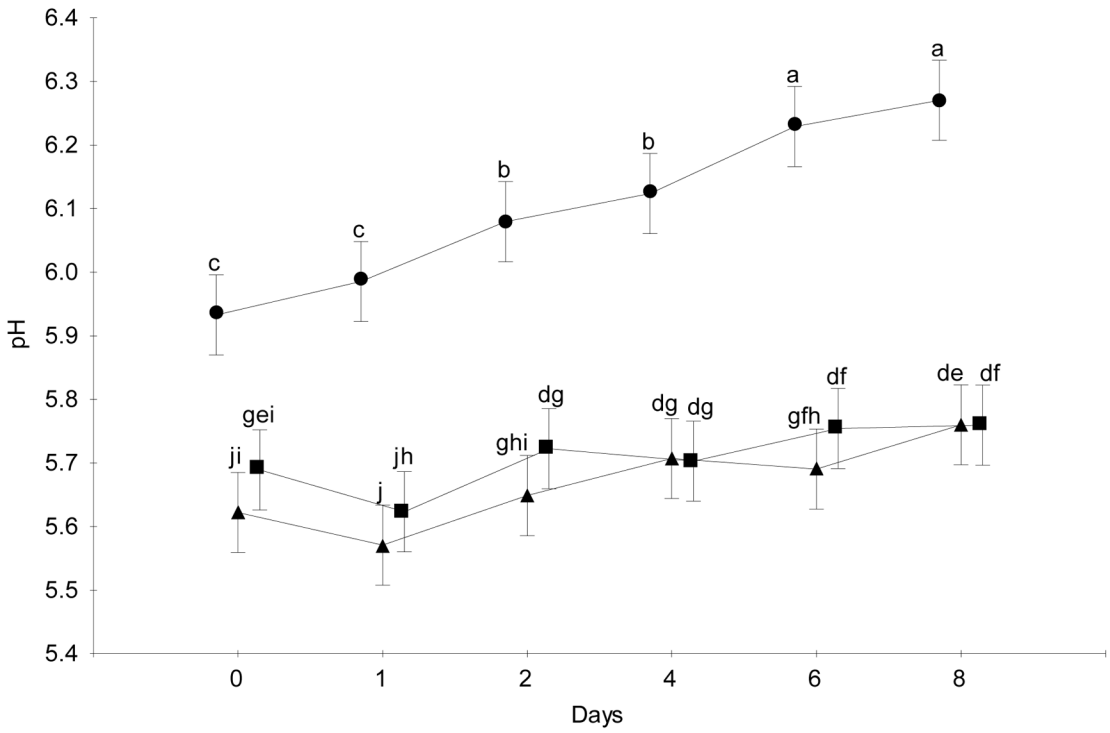

Figure 8. The changes in pH of 3 springbok muscles, (●) *infraspinatus*, (▲) *longissimus thoracis et lumborum*, and (■) *biceps femoris*, stored at 2°C. [a-j]Means without common letters are different ($P < 0.05$).

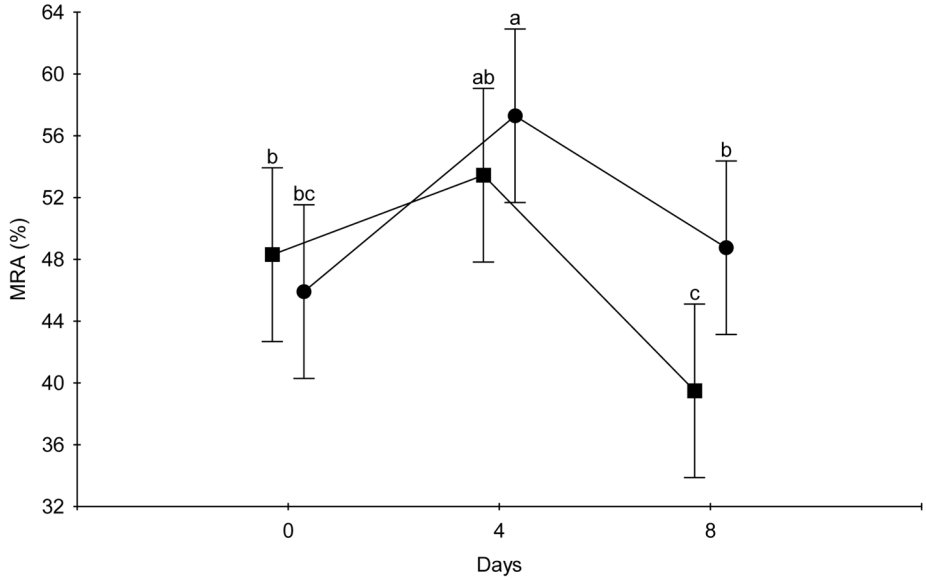

Figure 9. The changes in metmyoglobin reducing activity (MRA) of muscles from (●) male and (■) female springbok. [a-c]Means without common letters are different ($P < 0.05$).

($P < 0.05$) in total Mb, with the LTL having the highest and the IS the lowest values, respectively (Table 3). The BF did not differ ($P > 0.05$) from LTL and IS.

Discussion

Surface color stability

The data for L^* values indicated that the IS was the lightest in appearance, followed by the BF, with the LTL being the darkest (Fig. 1). These results agree with the observations for corresponding blesbok (*Damaliscus pygargus phillipsi*) muscles (Neethling et al., 2016). In partial support, Neethling et al. (2018) reported that the IS muscles of fallow deer (*Dama dama*) were lighter than their BF and LTL counterparts. In beef muscles, King et al. (2011) observed a trend similar to the one in the present study. Moreover, McKenna et al. (2005) reported the lowest L^* values for *longissimus* among 19 beef muscles.

The results for the a^* values (Fig. 2) indicated that the IS was the most color stable among the three muscles from both genders. Similarly, previous studies reported that IS was the most color stable among the 3 muscles (IS, LTL, and BF) from blesbok (Neethling et al., 2016) and fallow deer (Neethling et al., 2018) . The greater color stability of the IS was reiterated by the results of chroma (Fig. 4), hue (Fig. 5), R630/580 (Fig. 6), %OMb (Fig. 7B) and %MMb (Fig. 7C). Overall, based on R630/580 (Fig. 6), %OMb (Fig. 7B) and %MMb (Fig. 7C), the color stabilities of the LTL and BF were similar. Conversely, in fresh beef, McKenna et al. (2005) documented that the IS, BF and LTL had "very low", "low", and "high" color stabilities, respectively. Furthermore, the color stability data on beef IS, LTL and BF reported by King et al. (2011) agreed with the aforementioned categorization. These observed differences between game and beef may be attributed to the species-specificity in meat color (Neethling et al., 2017).

With respect to chroma (Table 2), only BF exhibited an influence of gender, indicating that color stability is not only muscle-dependent, but also gender-specific. On the other hand, gender influenced R630/580 in all the muscles on d 0 (Fig. 6). The R630/580 values (Fig. 6) and %MMb (Fig. 7C) indicated similar overall color stabilities for the BF and LTL. Together, data of a^* values (Fig. 2), chroma (Fig. 4), hue (Fig. 5), R630/580 (Fig. 6), %OMb (Fig. 7B), and %MMb (Fig. 7C) indicated that the color stability of springbok muscles were in the order of IS > LTL = BF. This order is similar to those for the corresponding muscles from fallow deer (Neethling et al., 2018) .

No gender differences were observed in color stability parameters (except %OMb) during the storage in the present study (Table 1). The literature regarding the effect of gender on the color of venison and game varies widely (Daszkiewicz et al., 2012). Several studies on venison have noted no color stability differences between genders (Daszkiewicz et al., 2009; Purchas et al., 2010; Daszkiewicz et al., 2012). In contrast, gender differences in meat color have been observed for gemsbok (*Oryx gazella*), with females having lower L^*, hue and chroma values (Hoffman and Laubscher, 2010). These findings are in contrast to the data from the present study and contradict the theory that male animals have darker meat

Table 2. Chroma of three springbok muscles, *infraspinatus* (IS), *longissimus thoracis et lumborum* (LTL) and *biceps femoris* (BF), from male and female carcasses, stored at 2°C

	Gender		
Muscle	Female	Male	SEM
IS	20.53[a]	19.61[a]	0.356
LTL	14.95[c]	15.36[c]	0.356
BF	15.40[c]	16.83[b]	0.356

[a-c]Means without common superscripts are different ($P < 0.05$).

Table 3. Metmyoglobin reducing activity (MRA), total iron, and myoglobin in *infraspinatus* (IS), *longissimus thoracis et lumborum* (LTL), and *biceps femoris* (BF) muscles from springbok on d 0 of refrigerated storage at 2°C

Attribute	IS	LTL	BF	SEM
MRA (%)	59.65[a]	43.16[b]	43.80[b]	2.184
Total iron (μg/g)	28.04[b]	33.83[a]	31.96[a]	0.854
Myoglobin (mg/g)	8.01[b]	8.59[a]	8.21[ab]	0.202

[a,b]Means in a row without common superscripts are different ($P < 0.05$).

than females. Noticeably, no color stability studies (during storage) have been previously conducted on game meat, and the results only give initial color values and were predominantly on only one muscle (LTL), which may also contribute to the differences in the results.

Biochemical attributes influencing surface color stability

High pH values can delay Mb oxidation resulting in increased color stability, with the opposite being true for low pH values (Gotoh and Shikama, 1974; Ledward, 1985; Gutzke and Trout, 2002). Thus, the significantly higher pH noted for the IS (Fig. 8) may have contributed to its greater color stability (through minimizing Mb oxidation) in comparison to the LTL and BF. Similarly, the low pH values observed for the LTL and BF could contribute to their low color stabilities. Furthermore, the similarities noted in the pH values for the LTL and BF suggest similarities in the color stabilities of these muscles. A similar trend was reported for the pH in the corresponding muscles from blesbok (Neethling et al., 2016). Neethling et al. (2018) also documented that in fallow deer the IS had the highest pH values, while the LTL had the lowest pH values. Although McKenna et al. (2005) noted higher pH values for the beef IS compared to the LTL and BF, the IS exhibited a lower color stability than the LTL and BF, with the LTL having the greatest color stability among the 3 beef muscles. These differences between beef and game meat suggest that the influence of pH on color stability is species-specific.

The relationship between pH and color stability may be linked to MRA, as the MRA increases with an increasing pH (Stewart et al., 1965; Ledward, 1970). Greater MRA leads to an increased color stability in a variety of muscles (Bekhit and Faustman, 2005). In the present study, MRA followed the order of IS > LTL = BF (Table 2), similar to the trend in pH and color stability. These results are in agreement with the observations in blesbok (Neethling et al., 2016) and fallow deer (Neethling et al., 2018) muscles, where the IS demonstrated the highest color stability and correspondingly the highest MRA.

Iron is a prooxidant that serves as a catalyst for lipid oxidation, which in turn accelerates Mb oxidation and consequently decreases meat color stability (Faustman et al., 2010). Both heme and non-heme iron have been implicated in accelerating lipid oxidation (Igene et al., 1979; Chen et al., 1984), and therefore, the total iron content could be a reliable indicator for color stability. In the present study, muscle source influenced the total iron content (Table 3); lower total iron contents were observed in IS (the most color stable) than in LTL and BF, whereas LTL and BF had similar values. This observation further reiterated the relationship between color stability and iron content. Similarly, total iron content correlated with the color stability in the blesbok (Neethling et al., 2016) and fallow deer (Neethling et al., 2018) muscles.

The Mb content of muscles is often implicated in its color stability (Farouk et al., 2007; Purchas et al., 2010), with higher Mb concentrations leading to rapid oxidation and a decrease in color stability in beef muscles (Jeong et al., 2009; King et al., 2011). However, in the present study, the Mb content was not correlated to the color stability; BF, which differed from the IS in color stability, but not from the LTL, did not differ from either in Mb content. Similarly, the Mb content was not observed as a reliable indicator of color stability in blesbok (Neethling et al., 2016) and fallow deer (Neethling et al., 2018) muscles. Other investigators have also noted that the Mb content is not a good indicator of beef color stability (Sammel et al., 2002; McKenna et al., 2005; Canto et al., 2015). In agreement with the observation of the present study that gender did not affect Mb content, Hoffman et al. (2009) reported no differences in the Mb content of meat from male and female kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*).

Conclusions

The results of the surface color parameters, Mb redox forms, and biochemical attributes suggested that the IS was the most color stable among the three springbok muscles. The LTL and BF demonstrated similar color stabilities. Interestingly, Mb content did not appear as a reliable indicator of color stability in springbok meat. The findings of the present study suggested the necessity to develop muscle-specific processing strategies for retailing springbok meat.

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