# Effects of electrical stimulation and age at slaughter on carcass and meat quality of two Sudanese Baggara beef types

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## Abstract

This study aimed to evaluate the influences of electrical stimulation (ES), age at slaughter, and breed type on muscle pH, the decline in carcass temperature, and meat quality attributes of Sudanese indigenous Baggara cattle. Eighty Baggara bulls, representative of Nyalawi (n = 40) and Mesairi (n = 40) breed types, were selected at their typical marketing age of about 4.5 years. Electrical stimulation was applied for 30 seconds at 20 minutes post mortem to 20 randomly selected carcasses from each breed type and compared with 20 carcasses from each type that were not electrically stimulated (NES). Samples of the *Longissimus dorsi* muscle were collected for meat analyses. Breed type showed no significant influence on meat quality characteristics, while ES and age at slaughter did. Electrical stimulation accelerated the carcass pH decline significantly up to 24 hours post mortem. Meat from electrically stimulated carcasses and younger animals resulted in higher L* values, lower a* values, higher hue values, and better tenderness. Older Mesairi animals had darker meat than their younger counterparts. Electrical stimulation reduced water-holding capacity (WHC), although it had no influence on cooking loss (CL). Meat from older cattle showed better WHC compared with meat from younger animals. The ES treatment decreased the variations in meat tenderness between the younger and older bulls. It is concluded that the use of ES and younger bulls produced more tender meat with better colour. Therefore, these practices should be adopted in Sudan to ensure better beef quality management.

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## Introduction

Sudanese indigenous Baggara cattle provide a major source for the domestic and export beef markets. They are generally owned by nomadic Baggara tribes, who always migrate in search of feed and water (Alsiddig *et al.*, 2010). Baggara cattle are maintained on natural grassland, which is characterized by seasonal fluctuations in the quantity and quality of feed in addition to stresses from high environmental temperature and movement on hoof (Rahman, 2007). These cattle are often herded for 35 to 75 days to the local livestock markets, and are generally slaughtered at relatively mature ages (≥ 4 years old). All these factors could affect meat quality negatively, especially meat tenderness. In Sudan, castration of cattle is not practised for beef production, but it is used when the bulls are used for draft purposes.

Beef consumers regard tenderness as a very important quality characteristic (Miller *et al.*, 2001; Verbeke *et al.*, 2010), while colour is the main factor that is observed when purchasing the product (Mancini & Hunt, 2005). The cause of variation in meat quality attributes is complex and depends on factors such as species, breed type, age, bodyweight, gender, nutrition, and pre- and post-slaughter handling (Guerrero, 2013).

Electrical stimulation of carcasses is one of the major practices that is used for improving meat quality (Adeyemi & Sazili, 2014). Electrical stimulation causes muscles to contract, resulting in a high anaerobic

glycolytic rate, and hastens pH decline. This leads to early onset of rigor mortis before the carcass temperature drops to values that cause cold shortening and toughening (Simmons *et al.*, 2008; Devine *et al.*, 2014). Electrical stimulation provides an additional means of increasing tenderness through changes in muscle fibre structures either by physical disruption or by increasing the activity of protease enzymes (Hwang *et al.*, 2003; Kadim *et al.*, 2009). Electrical stimulation of carcasses has been used to improve tenderness and colour in beef (McKenna *et al.*, 2003; Nazli *et al.*, 2010; Mombeni *et al.*, 2013; Agbeniga & Webb, 2014), lamb (Cetin *et al.*, 2012; Pouliot *et al.*, 2014), goat (Biswas *et al.*, 2007; Cetin *et al.*, 2012; Pophiwa *et al.*, 2016), chicken (Kahraman *et al.*, 2011), and pigs (Channon *et al.*, 2003).

However, ES may have negative impacts on WHC in beef by hastening pH decline (Li *et al.*, 2006; Agbeniga & Webb, 2018). The current focus of the meat industry is to produce a product of good quality and consistent supply. Currently, in Sudan, ES is not used at beef abattoirs. Nor is any technology employed at abattoirs to improve beef quality. Therefore, there is a need to investigate new techniques that may help to achieve a more desirable beef quality. The purpose of this study was to determine the effects of ES, age at slaughter, and breed type on muscle pH, the decline in carcass temperature, and meat quality attributes of Sudanese indigenous Baggara cattle.

## Materials and Methods

This research project was approved by the Animal Ethical Committee of the University of Pretoria, South Africa (approval number: EC076-17). The study was carried out at the Animal Production Research Centre (KUKU) in Sudan. A total of 80 Baggara cattle were selected according to breed type and age. They were divided into two equal groups that were representative of the typical white Nyalawi breed type (n = 40) and typical red Mesairi breed type (n = 40). Each breed type was divided into two age groups, namely 20 bulls of about 5–5.5 years old, weighing between 280 and 310 kg, and 20 bulls of about 4–4.5 years old, weighing between 240 and 260 kg. All animals were fed the same diet and slaughtered at the adjacent abattoir of the Animal Production Research Centre. Cattle were fasted and offered only ad libitum water for 12 hours before slaughter. Animals were killed and dressed according to the standard Halal method.

One half of the carcasses in each group were randomly selected and electrically stimulated for 30 seconds at 20 minutes post mortem using an electrical stimulator (110 V) (Jarvis, model ECS-1, South Africa). The ambient temperature of the abattoir was 25–30 °C. Carcasses were moved to a chiller (2–4 °C) at approximately 45 min post mortem and chilled for 24 hours before removing muscle samples. Muscle pH and temperature were recorded with a portable pH/temperature meter (Hanna Instruments, code- HI99163) that is specially designed for the meat processing industry. The values of muscle pH and temperature were measured at a point between the 10th and 11th ribs on the *Longissimus dorsi* muscle. They were measured at 10 min (0.17 hours), 3 hours, 6 hours, 9 hours, 12 hours, and 24 hours post mortem.

*Longissimus dorsi* muscle samples were cut between the 9th and 12th ribs of the left side of each carcass at 24 hours post slaughter for meat quality analysis. Muscle samples were left to bloom at 25 °C (room temperature) for 20 min. Meat colour was taken with a Hunter Lab ColorFlex EZ (Model 45/0 LAV, Hunter Laboratory Associates, Inc., Reston, Virginia, USA) using illuminant D65 at 10° standard observer to determine L* (lightness), a* (redness), and b* (yellowness) values. Chroma (intensity of the red colour/saturation index) and hue angle (meat discoloration) were determined using these formulas: chroma = $(a^{*2}+b^{*2})^{1/2}$, and hue angle = $\tan^{-1}$ (b*/a*) (Hunt *et al.*, 1991). The ColorFlex EZ was calibrated immediately before readings against black and white tiles according to the guidelines of the manufacturer. The mean of three random readings was used for statistical analysis. Each sample was labelled and put in a plastic bag and frozen at − 20 °C until processing.

The frozen beef samples were thawed at 4 °C for 36 hours. Water-holding capacity was determined following the procedure of Babiker & Lawrie (1983), which was based mainly on the evaluation of the amount of water pressed out of the meat under standard conditions. A 0.5 g minced meat sample was placed on humidified Whatman filter paper (No.4), stored in a desiccator over-saturated potassium chloride solution and pressed between two plexiglass plates at 25 kilograms (kg) weight for 2 minutes. The area of the meat was defined with a ballpoint pen, and the paper was dried. Meat and loose water areas (in $cm^2$) were determined with a planimeter to calculate the WHC ratio by the equation "WHC ratio = (loose water area − meat film area) /meat film area". A large WHC ratio indicates a high watery condition of the meat or a diminution in the WHC of muscle. For cooking loss (CL), each sample was weighed and put into a plastic bag and cooked in a water bath at 80 ºC, while the internal temperature of meat samples reached 70 ºC. The cooked samples were chilled overnight at 4 °C. The samples were later blotted dry and weighed. Cooking loss (CL) was calculated as a percentage of the initial weight by the equation "cooking loss (CL) % = ((weight loss after cooking)/ initial sample weight) x 100" (Honikel, 1998).

Beef tenderness was measured by mean of a shear force (SF) test, with a Warner-Bratzler instrument (G-R Elec. Mfg. Co. Manhattan, Kansas 606502). The test was done on the same samples used for cooking

loss measurements. A preliminary investigation was done to decide the best thickness and enough length of the slice of the meat sample to be clamped and sheared by the instrument. Then, rectangular meat samples (cross-section, 1 x 1.5 cm), 10 cm long were removed from the cooked muscles. The single peak force value expressed in kg required to cut the meat samples by shearing perpendicular to the muscle fibres was recorded (Szczesniak, 1963). A mean of 2 single peak force values per sample was recorded for statistical analysis.

Data were analysed as a 2 X 2 X 2 factorial design using SPSS 11.5 for Windows (2003, SPSS version 11.5, SPSS Inc., Chicago, IL, USA). The model used in the analyses of the independent variables (pH, temperature, and meat quality parameters) contained the fixed effects of ES, age at slaughter, and breed type. Appropriate interactions were also estimated, although these were not significant in most cases. Main effect means were thus presented. The results of significant interactions are provided in the text where appropriate. Means of significant interaction were separated by Tukey's test at a 5% significance level using the Statistix 8.0 for Windows (Analytical Software, Tallahassee, FL, USA). Data were expressed as means ± standard deviation (SD).

## Results and Discussion

Breed type had no influence on meat quality traits ($P$ >0.05). Generally, the meat quality traits were not affected by the interaction of breed type × age at slaughter × ES. Electrical stimulation treatment hastened the carcass pH decline ($P$ <0.001) up to 24 hours post mortem. The stimulated carcasses had lower pH values at 1, 3, 6, 9, 12, and 24 hours post mortem compared with the NES carcasses (Figure 1). Mombeni *et al.* (2013) reported results that were similar to what was observed in the present study in terms of the effect of ES on the decline in beef carcass pH up to 24 hours post mortem. In other species, Cetin *et al.* (2012) found that the stimulated carcasses of lamb and goat with different levels of voltage (50, 100, and 250 V) resulted in a significant pH decrease up to 24 hours post mortem compared with non-stimulated ones. However, other studies reported the significant effect of ES on post-mortem pH decline up to 6 hours post mortem (Agbeniga & Webb, 2014; Polidori *et al.*, 2016; Pophiwa *et al.*, 2016; Agbeniga & Webb, 2018).
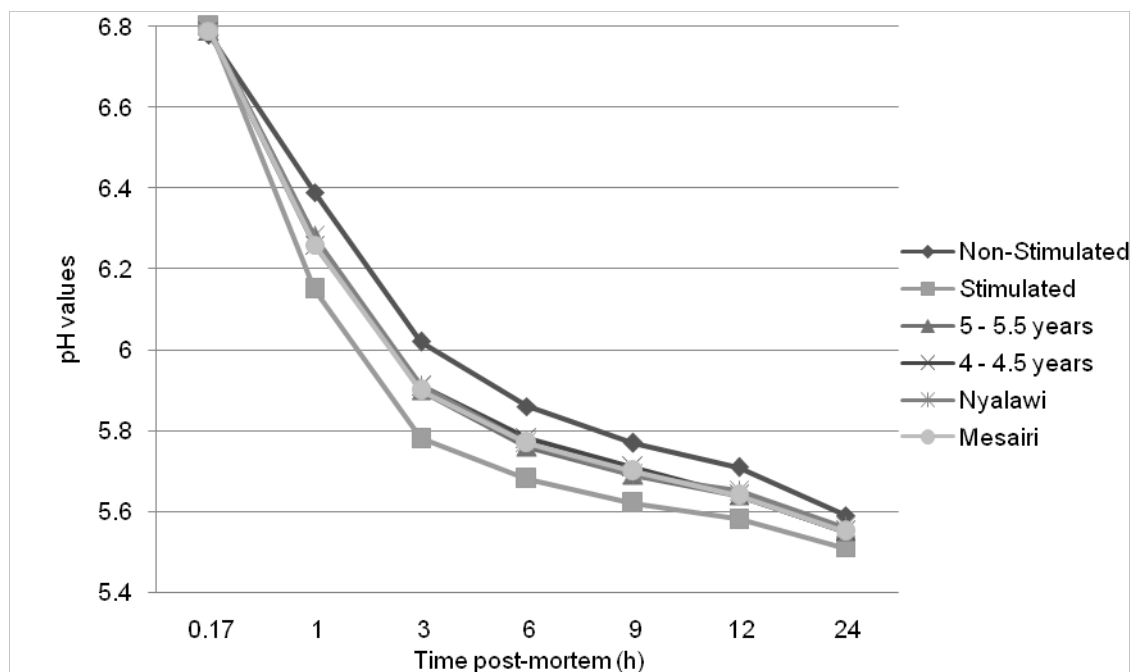


**Figure 1** Graphical illustration of the effects of electrical stimulation, age at slaughter, and breed type on pH decline of Sudanese beef carcasses

The observed effects of ES on the decline in carcass pH up to 24 hours post mortem may be due to factors that influence the amount of glycogen stored before slaughter. In general, the degree of acidification of post-mortem muscle depends on the muscle glycogen concentrations (Pösö & Puolanne, 2005). The results of O'Neill *et al.* (2018) indicate that a short fasting period before slaughter may increase the amount of available muscle glycogen. These authors also found that a short fasting period ante mortem had the

lowest post-mortem muscle pH values for Brahman cattle at 2, 3, and 9 hours post mortem and Nguni cattle at 6, 9, and 24 hours post mortem. In this study, the feed was withdrawn for 12 hours before slaughter, which could result in high muscle glycogen concentration and explain the prolonging effects of ES on pH up to 24 hours post mortem.

The other possible reason for the extended effects of ES on muscle pH could be the lower stress during the ante-mortem period. It is well known that exposure of beef cattle to ante-mortem stress causes low muscle glycogen stores, which eventually results in meat with a high ultimate pH (Njisane & Muchenje, 2017). Kadim *et al.* (2010) reported that ES affected the ultimate pH of the non-transported (less stressed) Dofari goat breed. The authors stated that within the non-transported group the stimulated carcasses had lower significant ultimate pH (5.61) at 24 hours post mortem than the non-stimulated ones (5.75), while the pH at 24 hours in the transported (more stressed) groups was not affected ($P$ >0.05) by ES. The animals in the present study were not exposed to transportation stress and few other stressors because the feedlot is on the same premises as the abattoir. Neither breed type nor age at slaughter had any influence on muscle pH decline ($P$ >0.05) (Figure 1). Similar findings were reported by Schutt *et al.* (2009), Kadim *et al.* (2009; 2010), and Czyżak-Runowska *et al.* (2017).

The present study indicates that ES (110 V) had no significant effect on the carcass temperature decline of Sudanese indigenous Baggara bulls. At 1 hour post mortem, the average temperature value of stimulated carcasses was slightly higher (32.43 ± 1.64) than NES ones (31.89 ± 1.61), but not significant ($P$ >0.05) (Table 1). Similarity, Li *et al.* (2006) reported that the rate of carcass temperature decline was not affected by low voltage electrical stimulation in Chinese Yellow crossbred bulls. Agbeniga & Webb (2014) also reported that carcass temperature decline was not influenced by ES. Breed type did not influence the rates of carcass temperature decline ($P$ >0.05), while age at slaughter was significantly affected by the carcass temperature decline (Table 1). Carcasses from animals of 4–4.5 years old that weighed 240–260 kg chilled faster than those from animals of 5–5.5 years old that weighed 280 to 310 kg, and the subsequent carcass temperature values were significantly different at 3 hours, 12 hours, and 24 hours post mortem (Table 1). Obviously, the carcasses with lower weights and from younger bulls contributed to its faster chilling rate.

**Table 1** Effects of electrical stimulation, age at slaughter, and breed type on muscle temperature decline in beef carcasses (mean ± SD)

| Time | Electrical stimulation | | Age at slaughter (years) | | Breed type | |
|---|---|---|---|---|---|---|
| | NES | ES | 5–5.5 | 4–4.5 | Nyalawi | Mesairi |
| 10 min | 37.83 ± 0.54 | 37.86 ± 0.47 | 37.92 ± 0.45 | 37.77 ± 0.55 | 37.80 ± 0. 47 | 37.90 ± 0.53 |
| 1 h | 31.89 ± 1.61 | 32.43 ± 1.64 | 32.08 ±1.43 | 32.23 ±1.84 | 32.28 ±1.68 | 32.03 ± 1.61 |
| 3 h | 20.81 ± 1.91 | 20.82 ± 1.63 | 21.40[a] ± 1.75 | 20.23[b] ± 1.60 | 20.96 ± 1.76 | 20.67 ± 1.78 |
| 6 h | 11.57 ± 1.14 | 11.66 ± 1.21 | 11.80 ± 0.97 | 11.43 ± 1.33 | 11.75 ± 1.35 | 11.48 ± 0.96 |
| 9 h | 7.60 ± 1.00 | 7.65 ± 1.06 | 7.70 ± 0.94 | 7.55 ± 1.11 | 7.65 ± 1.11 | 7.59 ± 0.95 |
| 12 h | 5.49 ± 0.80 | 5.71 ± 0.91 | 5.92[a] ± 0.84 | 5.28[b] ± 0.76 | 5.53 ± 0.97 | 5.68 ± 0.74 |
| 24 h | 3.84 ± 0.39 | 3.95 ± 0.39 | 4.06[a] ± 0.29 | 3.72[b] ± 0.41 | 3.92 ± 0.44 | 3.87 ± 0.34 |

[a,b] Row means with different superscripts within electrical stimulation, age at slaughter, and breed type differ significantly ($P$ <0.05)
ES: electrical stimulation; NES: non-electrical stimulation

In terms of meat colour, the ES group had a higher ($P$ <0.001) mean value in lightness (L* = 44.61 ± 1.82) and a lower ($P$ <0.001) mean value in redness (a* = 13.74 ± 1.02) compared with the NES group (L* = 41.61 ± 1.46; a* = 14.65 ± 0.88). However, no effect ($P$ <0.05) on meat yellowness (b*) was detected (Figure 2). This shows that electrical stimulation improves meat colour by producing a brighter and better red colour. Similarly, the reports of King *et al.* (2004) and Nazli *et al.* (2010) confirmed that ES-treated beef carcasses had a brighter red colour than untreated ones. Carcasses from the ES group had lower ($P$ <0.05) chroma values (chroma = 20.04 ± 1.01) and higher ($P$ <0.001) hue values (hue = 46.70 ± 2.39) compared with the NES group (chroma = 20.59 ± 1.14; hue = 44.61 ± 1.72) (Figure 2). Low muscle pH values early post mortem combined with high temperature may explain the improvements in meat colour through increased

protein denaturation and consequently increased light scattering properties of meat (Kim *et al.*, 2014; Hughes *et al.*, 2018).
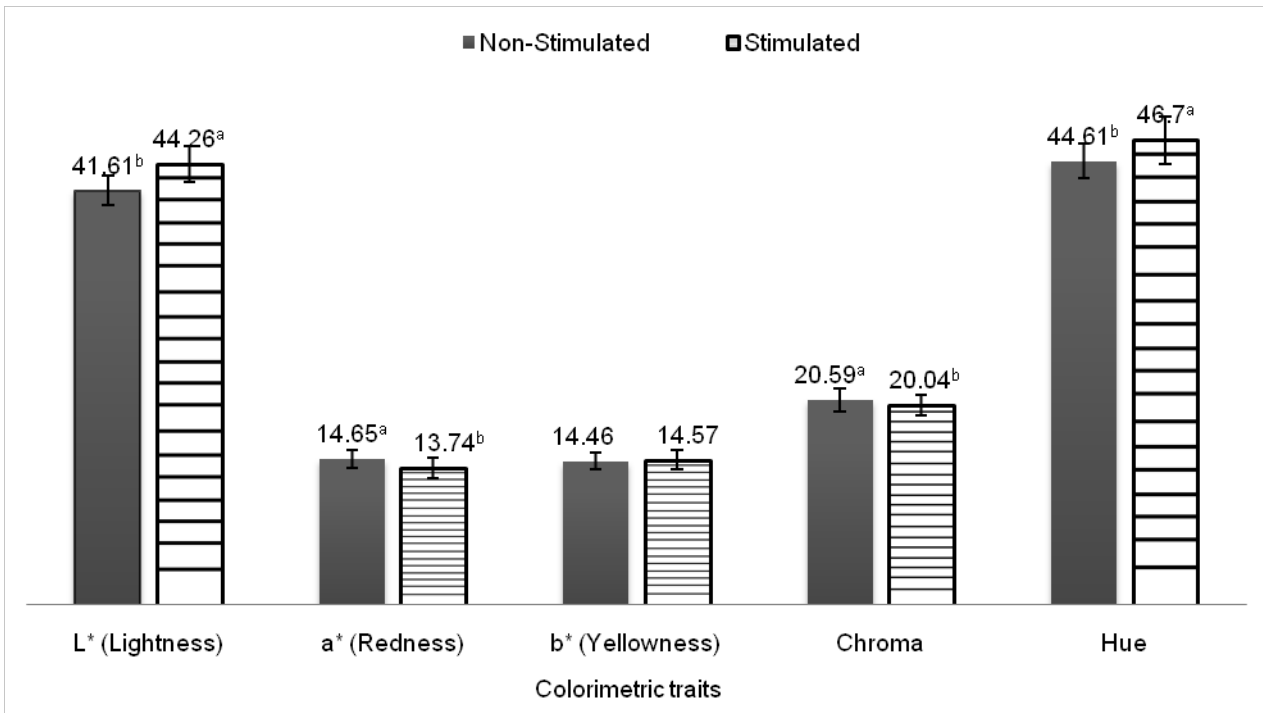


**Figure 2** Colorimetric traits of Baggara beef muscle samples between electrical stimulation groups (stimulated versus non-stimulated)
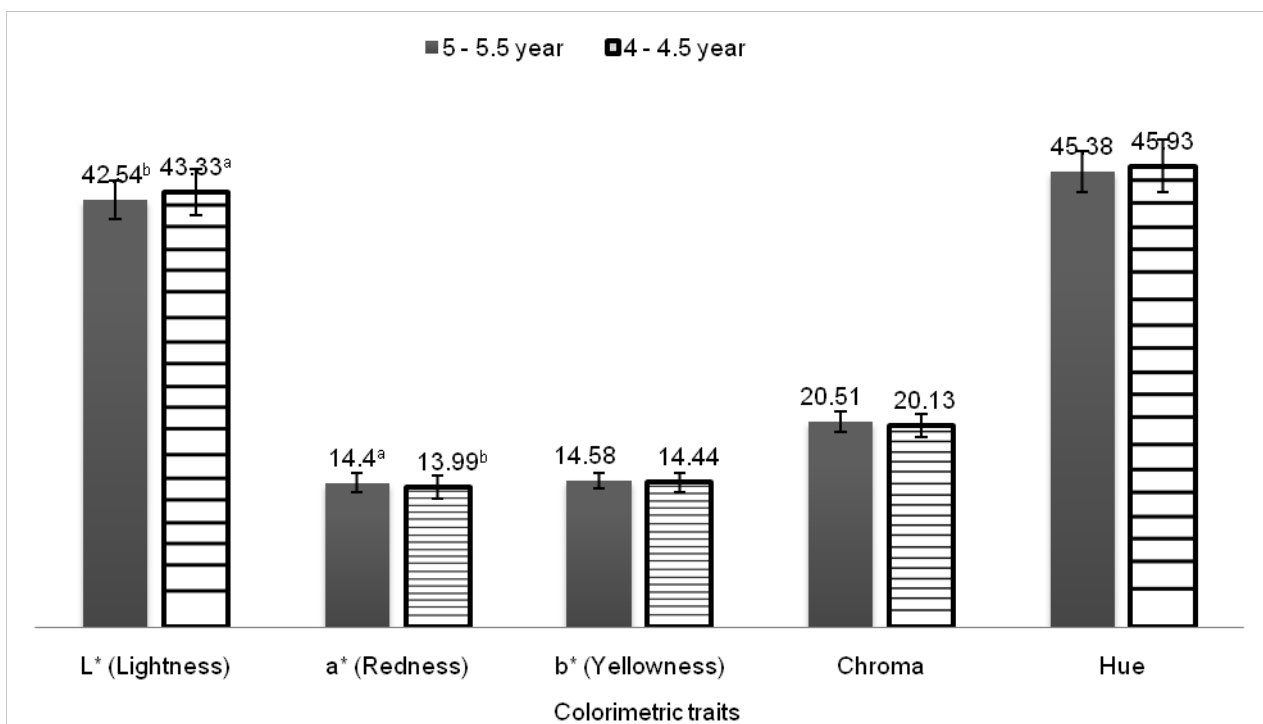


**Figure 3** Colorimetric traits of Baggara beef muscle samples between age groups (5–5.5 versus 4–4.5)

The age group had no influence ($P$ >0.05) on chroma and hue values (Figure 3). Breed type showed no influence on any of the meat colour traits ($P$ >0.05) (Figure 4). However, bulls slaughtered at 4–4.5 years showed the higher ($P$ <0.05) mean value of lightness (L*) and the lower ($P$ <0.05) mean value of redness (a*) compared with animals slaughtered at 5–5.5 years (Figure 3). The observed variations in the L* could be due to the differences in myoglobin content, since dark meat is associated with increased myoglobin concentration (Lawrie & Ledward, 2006). In general, the myoglobin concentration increases as the animal ages (Humada *et al.*, 2014). With this increase, the meat from older animals tends to be higher in a* value (redness) and lower in L* value (lightness) (Ponnampalam *et al.*, 2017). Furthermore, younger animals produce meat with lower a* and chroma values as a result of lower haematin concentration (Vestergaard *et al.*, 2000; Gil *et al.*, 2001; De Palo *et al.*, 2012).

There were only two significant interactions observed for meat colour parameters (Table 2). The first interaction ($P$ <0.05) was between breed type and age at slaughter for the meat lightness (L*) parameter. Older Mesairi animals had the lowest L* value (darker) compared with their younger counterparts. The second interaction ($P$ <0.05) was found between breed, age at slaughter and electrical stimulation for hue. Mesairi bulls slaughtered at younger ages and subjected to electrical stimulation tended to have higher huge values (47.95 ± 2.69) than Mesairi bulls slaughtered at older ages and subjected to electrical stimulation (45.19 ± 1.53).
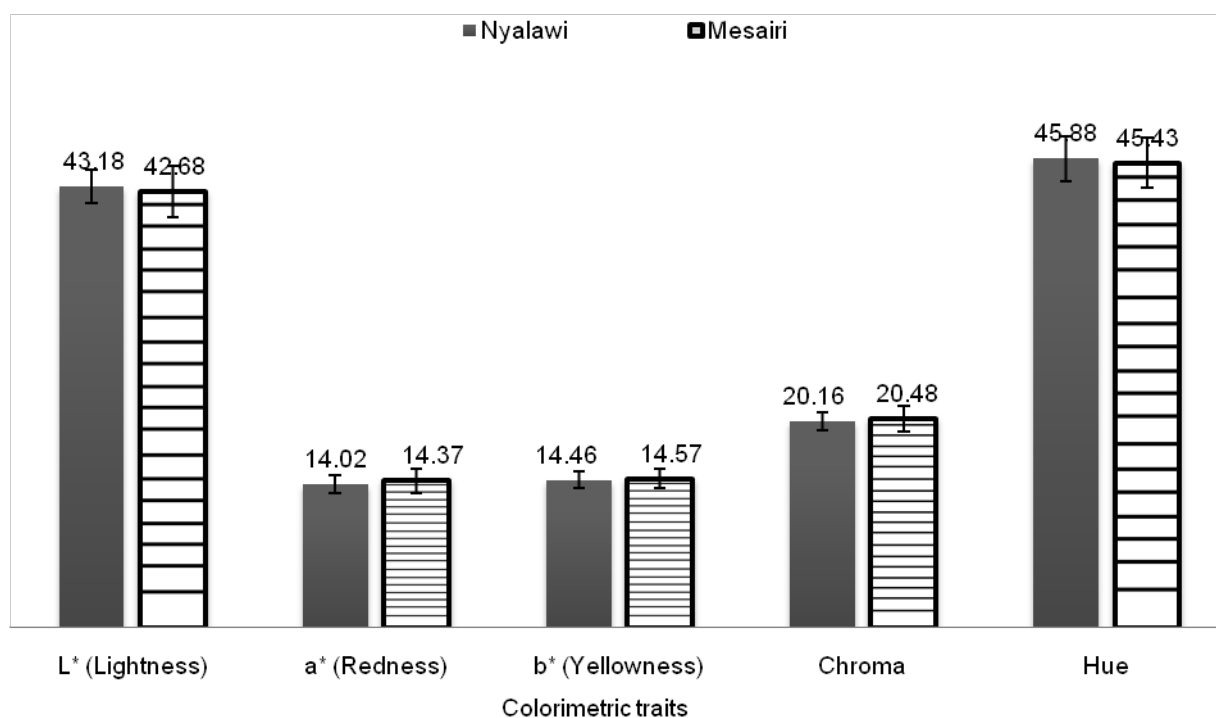


**Figure 4** Colorimetric traits of Baggara beef muscle samples between breed type groups (Nyalawi vs. Mesairi breed types)

Water-holding capacity was affected by ES and age at slaughter (Table 3). Electrical stimulation diminished ($P$ <0.01) WHC, but had no effect on cooking losses ($P$ >0.05). A low carcass pH combined with high-temperature causes myosin denaturation, which contributes to lower WHC and higher drip loss (Kim *et al.*, 2014). In this study, ES carcasses reached a low pH value (5.77), whereas the carcass temperature was still high (21.40 °C). This observation agrees with the reports of Li *et al.* (2006) and Agbeniga & Webb (2018), who found that ES of beef carcasses resulted in a rapid carcass pH fall with a reduction in the WHC. The water-holding capacity of the muscles from older animals was better ($P$ <0.01) than the muscles of the younger group. These findings might be due to a diminution in muscle water content with increasing animal age.

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**Table 2** Effects of electrical stimulation, age at slaughter, and breed type on colorimetric traits of Sudanese beef muscle samples (mean ± SD)

| Treatments | | | Colorimetric traits | | | | |
|---|---|---|---|---|---|---|---|
| Breed type | Age at slaughter | Electrical stimulation | L* (Lightness) | a* (Redness) | b* (Yellowness) | Chroma | Hue |
| Nyalawi | 5–5.5 years | NES | $41.95^{d} \pm 1.19$ | $14.68^{ab} \pm 0.37$ | $14.58 \pm 0.65$ | $20.69 \pm 0.45$ | $44.78^{bc} \pm 1.63$ |
| | | ES | $44.45^{ab} \pm 0.95$ | $13.80^{ab} \pm 1.01$ | $14.84 \pm 0.67$ | $20.27 \pm 1.03$ | $47.11^{ab} \pm 1.78$ |
| | 4–4.5 years | NES | $42.14^{cd} \pm 1.17$ | $14.18^{ab} \pm 0.48$ | $14.24 \pm 1.12$ | $20.10 \pm 1.05$ | $45.06^{bc} \pm 2.05$ |
| | | ES | $44.18^{abc} \pm 1.41$ | $13.44^{b} \pm 0.91$ | $14.18 \pm 0.72$ | $19.56 \pm 0.67$ | $46.57^{abc} \pm 2.74$ |
| Mesairi | 5–5.5 years | NES | $40.89^{d} \pm 1.66$ | $14.83^{a} \pm 1.07$ | $14.54 \pm 1.06$ | $20.78 \pm 1.31$ | $44.43^{bc} \pm 2.11$ |
| | | ES | $42.85^{bcd} \pm 1.73$ | $14.29^{ab} \pm 0.97$ | $14.38 \pm 0.84$ | $20.28 \pm 1.16$ | $45.19^{abc} \pm 1.53$ |
| | 4–4.5 years | NES | $41.45^{d} \pm 1.64$ | $14.93^{a} \pm 1.23$ | $14.48 \pm 1.00$ | $20.80 \pm 1.49$ | $44.15^{c} \pm 1.49$ |
| | | ES | $45.54^{a} \pm 2.07$ | $13.42^{b} \pm 1.09$ | $14.87 \pm 0.93$ | $20.05 \pm 1.08$ | $47.95^{a} \pm 2.69$ |
| ANOVA | | | *P* value | *P* value | *P* value | *P* value | *P* value |
| Breed type | | | 0.15 | 0.10 | 0.59 | 0.18 | 0.32 |
| Age at slaughter | | | < 0.00 | < 0.05 | 0.48 | 0.12 | 0.22 |
| Electrical stimulation | | | < 0.01 | < 0.01 | 0.59 | < 0.05 | < 0.01 |
| Breed type x age at slaughter | | | < 0.05 | 0.91 | 0.08 | 0.26 | 0.13 |
| Breed type x electrical stimulation | | | 0.28 | 0.62 | 0.97 | 0.77 | 0.69 |
| Age at slaughter x electrical stimulation | | | 0.22 | 0.32 | 0.77 | 0.69 | 0.22 |
| Breed type x age at slaughter x electrical stimulation | | | 0.06 | 0.19 | 0.28 | 0.89 | < 0.05 |

[a,b,c,d] Means within the same column with different superscripts differ significantly (*P* <0.05)
ES: electrical stimulation; NES: non-electrical stimulation

There was an interaction (*P* <0.05) between age at slaughter and ES. Meat samples from the electrically stimulated carcasses in the older group had a better (*P* <0.05) WHC (2.70) than meat samples from other groups, followed by ES carcasses in the older group (3.13), NES carcasses in the younger group (3.15) and ES carcasses in the younger group (3.23).

**Table 3** Effects of electrical stimulation, age at slaughter and breed type on water-holding capacity, cooking loss, and shear force of Sudanese beef muscle samples (mean ± SD)

| Treatments | Parameters | | |
|---|---|---|---|
| | WHC ratio | CL % | SF (kg/1.5 cm$^2$) |
| Electrical stimulation | | | |
| NES | 2.92[a] ± 0.43 | 21.72 ± 3.10 | 7.40[a] ± 0.81 |
| ES | 3.18[b] ± 0.34 | 22.26 ± 2.85 | 5.83[b] ± 0.66 |
| Age at slaughter | | | |
| 5–5.5 years | 2.91[a] ± 0.40 | 21.67 ± 2.93 | 6.99[a] ± 1.13 |
| 4–4.5 years | 3.19[b] ± 0.37 | 22.30 ± 3.09 | 6.24[b] ± 0.88 |
| Breed type | | | |
| Nyalawi | 3.01 ± 0.41 | 21.42 ± 2.74 | 6.51 ± 0.91 |
| Mesairi | 3.09 ± 0.41 | 22.56 ± 3.10 | 6.72 ± 1.22 |

[a,b] Column means with different superscripts within electrical stimulation, age at slaughter, and breed type differ significantly (*P* <0.05)
ES: electrical stimulation; NES: non-electrical stimulation

In terms of cooking loss (CL), the main factors (ES, age at slaughter, and breed type) did not influence the percentage of CL (Table 3). However, meat samples from the ES group lost more water as CL (22.26 %) than the NES group (21.72 %), which may be attributed to the variations in WHC and ultimate pH between the two ES groups. Previous studies reported significant losses regarding cooking loss between the ES and NES carcasses (Li *et al.*, 2006; Agbeniga & Webb, 2014). Younger bulls also lost more water as CL (22.30 %) than the older animals (21.67%). High moisture content and lower fat content in meat samples from less mature bulls may result in decreasing water binding ability in younger cattle. Likewise, meat samples from the Mesairi-type bulls lost more water as CL (21.42 %) than those from the Nyalawi type (22.56 %).

Concerning shear force (SF), as expected, the meat tenderness was affected by ES and age at slaughter (Table 3). The ES carcasses had lower (*P* <0.001) SF values (5.83 ± 0.66 kg/1.5 cm$^2$) than those from NES carcasses (7.40 ± 0.81 kg/1.5 cm$^2$). As reviewed by Bekhit *et al.* (2014) and Huang *et al.* (2016), ES accelerates carcass pH decline, causing early activation of protease enzymes and protein degradation, which increases the meat tenderization process. The observed effect of ES on SF agrees with previous works (Li *et al.*, 2006; McKenna *et al.*, 2003; Nazli *et al.*, 2010; Mombeni *et al.*, 2013; Agbeniga & Webb, 2014). As anticipated, the SF values were affected significantly by age at slaughter (Table 3). Meat from younger animals showed lower (*P* <0.001) SF values (6.24 ± 0.88 kg/1.5 cm$^2$) than those from older animals (6.99 ± 1.13 kg/1.5 cm$^2$). However, breed type had no influence on SF.

A second-order interaction (*P* <0.05) was observed between age at slaughter and ES on SF. In the NES carcasses, the younger group had lower (*P* <0.05) SF values (6.88 ± 0.67 kg/1.5 cm$^2$) than the older group (7.91 ± 0.59 kg/1.5 cm$^2$). However, in the ES carcasses, there were no differences (*P* >0.05) between the younger and older bulls in terms of SF values, but younger bulls still had lower values (5.60 ± 0.54 kg/1.5 cm$^2$) compared with older ones (6.06 ± 0.69 kg/1.5 cm$^2$). Therefore, this study showed that ES reduced the differences in SF values between the younger and older carcasses. There was also a two-way interaction (*P* <0.05) between breed type and ES for SF values. Regardless of the factors of ES and age at slaughter, the Nyalawi type cattle had a lower (*P* <0.05) SF value (7.10 ± 0.67 kg/1.5 cm$^2$), compared with the Mesairi type (7.69 ± 0.69 kg/1.5 cm$^2$). However, in the ES group, the Mesairi-type cattle recorded a lower SF value (5.75 ± 0.60 kg/1.5 cm$^2$) than the Nyalawi-type cattle (5.92 ± 0.71 kg/1.5 cm$^2$), but the difference was not significant. Therefore, the Mesairi breed type cattle responded better to ES in terms of tenderness compared with the Nyalawi breed type.

## Conclusion
Breed type did not influence meat quality attributes, but ES and age at slaughter had significant effects. Electrical stimulation accelerated the post mortem pH decline significantly up to 24 hours post mortem. Beef from young animals may help in obtaining high meat quality. This study showed that ES reduced the differences in meat tenderness between younger and older animals. It was also shown that meat from the Mesairi type responded better to ES in terms of tenderness compared with meat from the Nyalawi type. Electrical stimulation of Sudanese Baggara beef carcasses and the use of younger bulls produced more tender meat with better colour. These practices should be adopted in Sudan to improve beef quality.

## Authors' Contributions
ECW and ADAB devised the study and performed data analysis. AMM assisted with the experimental animals and abattoir facilities. ADAB performed data collection and wrote the manuscript. ECW provided guidance and reviewed the manuscript.

## Conflict of Interest Declaration
Authors declare that there is no conflict of interest for this work.

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