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The effect of electrical stimulation on the meat quality of impala *Aepyceros melampus*

By

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Supervisor: Prof EC Webb

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DECLARATION

I, Johannes Hermanus van den Berg declare that the thesis/dissertation, which I hereby submit for the degree **MSc (Agric) Meat Science** at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature: _____

Johannes Hermanus van den Berg

Date: _____

SUMMARY

The purpose of this research was to study the effect of electrical stimulation of carcasses on the meat quality of impala (*Aepyceros melampus*). The impala is one of the most important species in game meat production.

A total of 40 impala (*Aepyceros melampus*) were harvested on Mara Research Station (23° 05' S and 29° 25' E; 961 m.a.s.l.) in the Limpopo province, South Africa. Animals were obtained during daytime by shooting from vehicles and by the walk and stalk method. Animals were shot high in the neck with .308 calibre scoped rifles and were immediately exsanguinated by cutting the jugular veins and carotid arteries with a sharp knife. The harvested animals were then taken to the processing facility at Mara Research Station, electrically stimulated, eviscerated and the carcasses cleaned according to standard South African and Zimbabwean practices. The animals were then hung by their Achilles tendon in a cold room at *ca* 4 ºC and left in the cold room for 24 hours with the skins on after which the skins were removed.

The 40 animals were randomly grouped in the following groups and marked accordingly:

Group 1: Electrical stimulation (ES) group consisting of 20 impala of which 10 were male and 10 were female (Experimental group).

Group 2: Non-electrical stimulation (NES) group consisting of 20 impala of which 10 were male and 10 were female (Control group).

Impala were electrically stimulated within 40 minutes after being shot. ES was applied using a Jarvis BV-80 unit (Jarvis Products Corporation, Middletown, CT) that delivered an electrical charge (230V; 50 Hz for 60 seconds) via a clamp attached to the nose and a steel hook (probe) inserted into the anus.

The live mass (kg) of each animal was recorded and after dressing the carcass, the dressed out percentage (%) was calculated per individual animal. The average live mass of impala males was 55.5 kg which was significantly ($p<0.001$) higher compared to the females with an average live mass of 46.4 kg. The dressing percentage however did not differ significantly between the sexes where males had a 60 % dressing percentage and females a 59.4 % dressing percentage.

ES, sex and muscle group had a significant ($p<0.001$) effect on muscle pH as measured at 45 min. 3, 6, and 12 hours post mortem. ES had a significant ($p<0.001$) effect on the pH of *m. semimembranosus* (SM), *m. semitendinosus* (ST), *m. biceps femoris* (BF) and *m. longissimus dorsi (L1-L6)* (LM) at 45 min., 3,6 and 12 hours post mortem. The pH of *m. triceps brachii* (TB) samples from impala in the ES group did not differ significantly ($p=0.096$) from samples from the NES group, samples from TB had a significantly ($p<0.01$) lower initial rate of pH decline compared to BF, LM, SM and ST. The interaction between ES x sex was significant ($p<0.01$). Muscle pH of samples from male impala in the NES group had lower initial pH values (at 45 min., 3,6 and 12 hours post mortem; $p<0.001$) than samples from the female impala in

the NES group while there was no differences between samples from male and female impala in the ES group.

Electrical stimulation influenced the pH_u-value ($p<0.05$) of *m. semitendinosus*, with muscles from the ES group having a lower pH_u (pH 5.52 ± 0.02) than muscles from the NES group (pH 5.59 ± 0.02). No significant differences were observed between ES and NES for the pH_u-values of *m. semimembranosus*, *m. biceps femoris*, *m. longissimus dorsi et lumborum* and *m. triceps brachii*. Sex had a significant ($p<0.05$) effect on the pH_u-value of the *m. triceps brachii*, with muscles from the male group having a higher pH_u (pH 5.64 ± 0.02) than muscles from the female group (pH 5.58 ± 0.02).

Electrical stimulation had a significant ($p<0.05$) effect on the L^*_{24}-value of the *m. biceps femoris* muscle, with muscles from the ES group (35.8 ± 0.08) being lighter than muscles from the NES group (33.1 ± 0.08). No significant differences were observed between ES and NES for the a^*_{24}- and b^*_{24}-values for all muscle groups. The L*-, a*- and b*-values of *m. longissimus dorsi et lumborum* muscle from ES and NES carcasses declined significantly ($p<0.001$) from 24 hours post-mortem to post freeze-thaw. ES also had no significant effect on the L^*_F- and a^*_F-values of the *m. longissimus dorsi et lumborum* muscle. ES however, had a significant ($p<0.05$) effect on the b^*_F-values. The b^*_F-value for ES meat (7.1 ± 0.1) was higher than NES meat (6.5 ± 0.2).The muscle x ES interaction was not significant. A significant difference ($p<0.01$) was found before and after freezing between the L*-values, a*-

values and b*-values for both the ES and NES groups whereas the NES b*-value ($p = 0.0638$), showed a tendency to differ.

No significant differences were observed between ES and NES for the thaw loss, drip loss, cooking loss, pH_u, sarcomere length and shear force for the *m. longissimus dorsi et lumborum* muscle. Sex of the animal influenced ($p<0.05$) the thaw loss and cooking loss of the *m. longissimus dorsi et lumborum* muscle. No significant differences were observed between male and female for the drip loss, pH_u, sarcomere length and shear force of the *m. longissimus dorsi et lumborum* muscle.

In conclusion, it was found that ES did not have a significant effect on the meat quality of impala *Aepyceros melampus*. ES however decreased muscle pH early post-mortem for impala by accelerating post-mortem glycolysis and hastening the onset of rigor mortis. This decrease in muscle pH probably reduced the possibility of cold shortening especially as impala have leaner carcasses. Thus ES may provide a commercial advantage with a decrease in processing and cooling time and an increase in meat production and shelf life.

OPSOMMING

Die doel van hierdie studie was om die invloed van elektriese stimulasie van rooibok (*Aepyceros melampus)* karkasse op vleiskwaliteit te ondersoek. Die rooibok is een van die mees belangrikste spesies in wildsvleis produksie.

'n Totaal van 40 rooibokke (*Aepyceros melampus*) is uitgedun by Mara Navorsingstasie (23° 05' S en 29° 25' E; 961 m.b.s.) in die Limpopo provinsie, Suid Afrika. Diere is bekom gedurende die dag deur hulle vanaf voertuie te skiet en deur die loop-en bekruip metode. Die diere is hoog deur die nek geskiet met .308 kaliber (trefwydte) geweer en is onmiddelik uitgebloei deur die nekaar (v. jugularius) en nekslagaar (a. carotis) met 'n skerp mes af te sny. Die karkasse is daarna na die prosesseringsfasiliteit by Mara Navorsingstasie geneem waar hulle elektries gestimuleer is en die binnegoed uitgehaal en karkasse skoongemaak is volgens Suid Afrikaanse standaarde en Zimbabwiese praktyke. Die diere is toe opgehang aan hulle Achilles sening in 'n koelkamer by ca 4° vir 24 uur met velle nog aan waarna die velle verwyder is.

Die 40 diere is ewekansig gegroepeer in die volgende groepe en daarvolgens gemerk.

Groep 1: Elektriese stimulasie (ES), die groep bestaande uit 20 rooibokke, 10 manlik en 10 vroulik (Eksperimentele groep).

Groep 2: Nie-elektriese stimulasie (NES), die groep bestaande uit 20 rooibokke, 10 manlik en10 vroulik (Kontrole groep)

Die rooibokke is binne ‘n tydsbestek van 40 minute nadat hulle geskiet is, elektries gestimuleer. ES is toegepas deur die gebruik van ‘n Jarvis BV-80 unit (Jarvis Products Corporation, Middleton, CT) wat ‘n elektriese lading (230V; 50Hz vir 60 sekondes) gelewer het via ‘n klamp aan die neus en ‘n staal haak (voelstafie) wat by die anus ingedruk is.

Die lewendige massa (kg) van elke rooibok is genoteer en na verwerking van die karkas is die uitslag persentasie (%) van elke individuele dier bereken. Die gemiddelde lewendige massa van rooibok ramme was 55.5 kg, wat betekenisvol ($p<0.001$) hoër was in vergelyking met die ooie met ‘n gemiddelde lewendige massa van 46.4kg. Die uitslag persentasie daarenteen het nie betekenisvol verskil tussen die twee geslagte nie aangesien die manlike diere ‘n uitslag persentasie van 60 % en die vroulike diere ‘n 59.4 % uitslag persentasie getoon het.

ES, geslag en spier groep het ‘n betekenisvolle ($p<0.001$) effek op die spier pH gehad by 45 min., 3, 6, 9 en 12 uur post mortem. ES het ‘n betekenisvolle ($p<0.001$) effek op die pH van *m.semimembranosus* (SM), *m semitendinosus* (ST), *m. biceps femoris* (BF) en *m. longissimus dorsi* (L1-L6) (LM) gehad. Die pH van *m. triceps brachii* (TB) van bokke in die ES groep het nie betekenisvol verskil ($p=0.096$) van die van die NES groep nie, maar TB monsters het betekenisvolle ($p<0.01$) laer pH waardes gehad as BF, LM, SM en ST by 45 min., 3, 6, 9 en 12 ure post mortem. Die ES x geslag interaksie was ook betekenisvol ($p<0.01$). Die spier pH van manlike rooibkokke in die ES groep

was laer by 45 min., 3, 6, 9 en 12 ure post mortem ($p<0.001$) as die spier pH van vroulike rooibokke in die NES groep, terwyl daar geen verskil in die aanvanklike spier pH van manlike en vroulike rooibokke in die ES groep was nie.

Elektriese stimulasie het 'n betekenisvolle ($p<0.05$) effek op die pH_u-waarde van *m. Semitendinosus* gehad, waar spiere van die ES groep 'n laer pH_u (pH 5.52 ± 0.02) as spiere van die NES groep (pH 5.59 ± 0.02) gehad het. Geen betekenisvolle verskille was waargeneem tussen ES en NES vir die pH_u waardes van *m. semimembranosus*, *m. biceps femoris*, *m. longissimus dorsi et lumborum* en *m. triceps brachi* nie. Geslag het 'n betekenisvolle ($p<0.05$) effek op die pH_u-waarde van die *m. triceps brachii* gehad, waar spiere van die manlike groep 'n hoër pH_u (pH 5.64 ± 0.02) as spiere van die vroulike groep (pH 5.58 ± 0.02) gehad het.

Elektriese stimulering het 'n betekenisvolle ($p<0.05$) effek op die L^*_{24}-waarde van die *m. biceps femoris* spier gehad, waar spiere van die ES groep (35.8 ± 0.08) ligter was as spiere van die NES groep (33.1 ± 0.08). Geen betekenisvolle verskille was opgemerk tussen ES en NES vir die a^*_{24}-en b^*_{24}-waardes vir alle spier groepe nie. Die L*-. a* - en b* - waardes van die *m. longissimus dorsi et lumborum* spier van diere in die ES en NES groep was laar ($p<0.001$) by 24 uur post-mortem as tydens vries/ontdooiing. ES het nie 'n betekenisvolle effek op die L^*_f- en a^*_f- waardes van die *m. longissimus dorsi et lumborum* spier gehad nie. ES het egter 'n betekenisvolle ($p<0.05$) effek op die b^*_f-waardes gehad. Die b_f-waarde vir vleis (7.1 ± 0.1) van diere in die ES groep was hoër as die van die NES groep (6.5 ± 0.2). Die spier x ES

interaksie was nie betekenisvol nie. ‘n Betekenisvolle verskil ($p<0.01$) was gevind voor en na bevriesing tussen die L*-waardes. a*-waardes en b*waardes vir beide die ES en NES groepe behalwe vir die NES b*-waarde ($p = 0.0638$), wat wel ‘n neiging getoon het.

Geen betekenisvolle verskille was waargeneem tussen ES en NES vir ontvries verlies, drup verlies, kook verlies, pH_u, sarkomeer lengte en sny weerstand/skeurkrag vir die *m. longissimus dorsi et lumborum* spier nie. Geslag het ‘n betekenisvolle ($p<0.05$) effek op die ontvries en kook verliese van die *m. longissimus dorsi et lumborum* spier gehad. Geen betekenisvolle verskille was waargeneem tussen manlik en vroulik vir drup verlies, pH_u, sarkomeer lengte en sny weerstand/skeurkrag van die *m. longissimus dorsi et lumborum* spier nie.

Die gevolgtrekking, is dat ES nie ‘n betekenisvolle effek op die vleis kwaliteit van rooibok Aepyceros melampus het nie. ES veroorsaak egter `n laar pH post mortem in rooibokke deur post-mortem glikolise te versnel en die intree van rigor mortis ook te versnel. Hierdie daling in pH post mortem sal die moontlikheid van koue krimping verminder veral omdat impala maerder karkasse het. Dus verskaf ES ‘n kommersiële voordeel deur ‘n afname in prosessering en verkoeling tyd te verkry en ‘n verhoging in vleis produksie en rak lewe te verkry.

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NOTE

The language and style used in this thesis are in accordance with the requirements of the scientific journal, *Meat Science*.

LIST OF ABBREVIATIONS

ATP	Adenosine Tri-phosphate
BF	*m. biceps femoris*
DFD	Dark, Firm and Dry meat
ES	Electrical Stimulation
LD	*m. longissimus dorsi et lumborum*
LS	Least square
LT	*m. longissimus thoracis*
NES	Non-electrical Stimulation
PSE	Pale, Soft and Exudative meat
SM	*m. semimembranosus*
ST	*m. semitendinosus*
TB	*m. triceps brachii*
TEM	Transmission electron microscopy

CHAPTER 1

GENERAL INTRODUCTION, MOTIVATION AND AIM

Over the past 10 years, the game industry in South Africa has grown rapidly (Tainton, 1999; Radder, 2000). An estimated 5100 ranches were registered in 1995 (Tainton, 1999). In August 1998 an estimated 2300 game ranches existed in the Northern Province, which covered approximately 3.6 million hectares. This represented 26 % of the total area of the Northern Province (Van der Waal & Dekker, 2000). In 1999, approximately 7000 game farms comprising a total of about 11 million hectares were reported in the country (Gouws, 1999). African game species are often perceived as being more productive than domestic livestock due to selection pressure, which has resulted in a high degree of adaptation of these species to their environment (Bothma, 1996; Bothma, 2002). Game species are considered to be more resistant to disease than domestic stock, utilise a broader spectrum of vegetation, produce meat which contains less fat and some species have higher levels of fecundity than domestic stock (Bothma, 1996; Bothma, 2002).

Information regarding the economic aspects of game farming in comparison with livestock is generally lacking, although South African hunters reportedly spend an average of R7080 per year per hunter, with a total turnover of R850 million. If the value of equipment is included, the total game industry's total turnover is approximated at R1236 million per year (Swanevelder, 1997). The export of venison and related products from South Africa and Namibia to Europe amounted to R14 million in 1978 (Van Rooyen, 1990). Davies (2002) reported that 32246 animals was hunted in South Africa during 2001 and that this amounted to a total revenue of

US$ 80 million (R960 million). Impala is quantitatively the most important game animal in the Bushveld areas of South Africa (Fairall, 1983). A study in the KwaZulu-Natal sweetveld revealed a lower income from meat production from impala than that of cattle. However, if the higher input costs for cattle relative to impala are considered, then it must be concluded that impala generate a higher net profit than cattle on a per hectare basis (Collinson, 1979 *In*: Tainton, 1999).

Trophy hunting is considered to be the foundation of the game industry in South Africa (Bothma, 1996; Bothma, 2002). It is estimated that approximately 4000 foreign trophy hunters visited South Africa in 1990 and spend about R26000 each. In 1997, the number of overseas trophy hunters in South Africa increased to almost 5000 and spend on average about R37200 on game, and R11000 on transport and taxidermy costs per hunter (Swanevelder, 1997). The best alternative for the game industry, however, is a combination of various facets of the industry, i.e. venison production, tourism and other aspects in addition to trophy hunting. The game industry cannot rely on trophy hunting alone for its sustainance (Van Rooyen, 1990; Van der Waal & Dekker, 2000).

The tourism industry in South Africa is a growing one, attracting large numbers of visitors (mostly from industrialized countries). Despite all the arguments for and against hunting, one fact remains: game populations' natural migration routes were, and still are, severely restricted by game fences, resulting in the degradation of natural vegetation through overgrazing. The management option is obvious: control game numbers within the ecological capacities of the given farm or sacrifice production potential which would ultimately threaten the financial existence of the farmer. The removal of excess numbers of animals is presently

carried out mainly through live game sales, or cropping for the venison market. A decrease in the demand for stocking animals is inevitable, which will leave the marketing of venison and hunting as an alternative outlet (Hoffman & Bigalke, 1999). Berry (1986) found venison production to be the most profitable followed by live game sales, non-trophy recreational hunting and trophy hunting. Berry (1986) however also reported that all segments of the population should be utilized (e.g. live animal sales, venison production) and not just a single segment (trophy hunting) in any management strategy.

There is a growing demand for meat protein world-wide due to the growth of the human population (Garnier, Klont & Plastow, 2003). The meat production potential of a variety of game species found in southern Africa has long been recognised and has been an important source of high quality protein and low fat content (Ledger, Sachs & Smith, 1967; Ledger, 1968; Von La Chevallerie, 1970; Hanks, Cumming, Orpen, Parry & Warren, 1976; Conroy & Gaigher, 1982; Meissner, 1982; Fairall, 1983; Fairall, 1985; Skinner, Monro & Zimmermann, 1984; Skinner & Smithers, 1990; Van Rensburg, 1992; Pietersen, 1993; Onyango, Izumimoto & Kutima, 1998; Hoffman, 2000a; Ferreira & Hoffman, 2001; Volpelli, Valusso & Piasentier, 2002). The potential of certain ungulates for game farming in Africa has created an increase in awareness in studies such as growth and reproductive rates, meat production and efficiency of feed utilization (Howells & Hanks, 1975; Onyango et al., 1998). Ledger et al. (1967), Ledger (1968) and Onyango et al. (1998) reported that many game species produce a higher proportion of edible animal protein (lean carcass meat) per unit of live mass when compared to domesticated livestock. Anderson (1983) and Van Rooyen (1994) reported that for game ranching the impala are numerically the most important species in the lowveld and bushveld areas of the Limpopo Province, Mpumalanga Province and Kwa-Zulu Natal. Fairall

(1983) reported that impala are 22 % sustainable under a predator regime and 25-30 % under a non-predator regime.

Venison is well known in Europe and New Zealand as a traditional meat product (Forss, Manley, Platt & Moore, 1979; Stevenson, Seman & Littlejohn, 1992; Wiklund, Stevenson-Barry, Duncan & Littlejohn, 2001; Pollard, Littlejohn, Asher, Pearse, Stevenson-Barry, McGregor, Manley, Duncan, Sutton, Pollock & Prescott, 2002). New Zealand currently produces over 800 different product specifications in its venison product range and over 90 % is exported (Pauw, 1993; Bekhit, Farouk, Cassidy & Gilbert, 2007). Venison is seen as a delicacy in highly developed countries (Von La Chevallerie, 1972). According to Von La Chevallerie (1970) the gamey taste in venison is usually caused by a progressed stage of ageing or spoilage with blood and intestine fluid during slaughter. African people readily accept venison, and people opposed to hunting have fewer objections against hunting game for venison than for trophies. Biltong is considered to be a part of South Africa's heritage. In 1991, hunting for venison yielded 68 % of the South African game industry's income (Van Rooyen, Ebedes & Du Toit, 1996). In a study by Brown (1975) it was reported that of 392 black students at the University of Fort Hare, 74.3 % found venison to be acceptable, 25.1 % found venison to be unacceptable and 0.5 % gave no answer. Venison has a very low fat content which is important for a healthy diet (Stevenson et al., 1992; Pauw, 1993; Schönfeldt, 1993).

There appears to be no information available on the effect of electrical stimulation (ES) on the meat quality of the impala *Aepyceros melampus*. The effect of electrical stimulation (ES) on beef, lamb, goat and red deer meat quality has been studied extensively. Electrical

stimulation (ES) prevents the toughening effect of cold shortening and improves tenderness. Electrical stimulation accelerates glycolysis and thereby prevents cold shortening by reducing the concentration of ATP and other high-energy phosphates during rigor development (Gariépy, Delaquis, Aalhus, Robertson, Leblanc & Rodrique, 1995; Tornberg, 1996; Den Hertog-Meischke, Smulders, Van Logtestijn, & Van Knapen, 1997; Lawrie, 1998; Kerth, Cain, Jackson, Ramsey & Miller, 1999; Byrne, Troy & Buckley, 2000; Wiklund *et al*., 2001; Pollard *et al*., 2002).

The increase in human populations and advancing agriculture shows that there is clearly a need for the development of a scientific base of knowledge on which the game industry in South Africa can be firmly established and developed (Von La Chevallerie, 1970; Bothma, 1996; Bothma, 2002). The traditional use of electrical stimulation (ES) in livestock is to stimulate carcasses in order increase the post mortem glycolysis and reduce cold shortening of the musculature. Impala are known to be more stress sensitive compared to livestock and are more prone to ante mortem stress. Ante mortem stress are also common in indigenous goats, but these animals exhibit a high glycolytic potential (Simela, Webb & Frylinck, 2004) and it is postulated that a similar condition occurs in impala. Venison in South Africa is usually seen as a dark unattractive meat with a red colour, which is similar to dark firm and dry (DFD) beef (Hoffman, 2000b; Hoffman & Ferreira, 2000). The effect of electrical stimulation (ES) on the meat colour of venison is an apparent uncertainty. There is currently little information available on the effects of electrical stimulation (ES) in game species. The aim of this research project was to study the effects of electrical stimulation (ES) on the colour and meat quality parameters of impala *Aepyceros melampus*.

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CHAPTER 2

LITERATURE REVIEW

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1. THE IMPALA (*Aepyceros melampus*)

1.1 Taxonomy (Skinner & Smithers, 1990)

Phylum: Chordata

Subphylum: Mammalia

Order: Artiodactyla

Subfamily: Aepycerotinae

Genus: Aepyceros

Species: Melampus melampus

1.2 Description

The name impala is most probably derived from the Tswana name *phala* or from the Zulu name *Impala*, for this species. Impala are medium-sized (males 60-65 kg, females 40-45 kg) antelope that are sexually dimorphic where only the males have lyrate horns that are strongly ridged (Jarman & Jarman, 1973; Lewis, Pinchin & Kestin, 1997; Bothma, 2002). Skinner and Smithers (1990) and Hoffman (200a) however reported that adult males weigh 50 kg and stand about 0.9 m at the shoulder whereas adult females weigh 40 kg. The impala have a reddish-brown upper body with a light brown middle section and a pure white under part (Skinner & Smithers, 1990)

1.3 Distribution and habitat

According to Skinner, Monro and Zimmermann (1984) impala *Aepyceros melampus* evolved along the eastern seaboard of Africa. Impala occur throughout the wooded grassland and open woodland biomes of eastern, central and southern Africa (Jarman & Jarman, 1973; Lewis et al., 1997; Cooper, 1982; Skinner et al., 1984). They occur from northern Kenya south to northern Natal in South Africa and extending westwards towards southern Angola (Skinner & Smithers, 1990). Impala are intermediate mixed feeders. Impala are associated with woodland and will graze on open grassland. Water and cover are essential for impala (Skinner & Smithers, 1990).

1.4 Breeding

Impala are gregarious and are found in small herds from 6 to 20 and larger herds from 50 to 100 animals (Skinner & Smithers, 1990). Hanks, Cumming, Orpen, Parry and Warren (1976), Pettifer and Stumpf (1981), Dunham and Murray (1982), Fairall (1983), Fairall (1985) and Skinner and Smithers (1990) reported that the sexual cycle of the impala in Zimbabwe (South Rhodesia) and South Africa is characterised by a peak of conceptions occurring in May during the rut which, are then followed by a peak in births about six months later. The births usually occur at the start of the new rainy period when environmental conditions are optimal. Impala lambs are born during the months of November to January following a gestation period of 194-200 days (Pettifer & Stumpf, 1981; Skinner & Smithers, 1990; Marais, 1992; Lewis et al., 1997). Impala females can only lamb for the first time at two years of age (Fairall, 1983). According to Fairall (1983) the fecundity of mature impala females is 90-95 %. The fecundity in two-year old ewes is lower and is influenced by climate. Ledger (1963) found that many females attain sexual maturity much earlier than males. Impala males are physiologically

mature at 13 months of age but successful mating has been observed at the age of 17-18 months. Hanks et al. (1976) also found that spermatogenesis starts at 1-5 years on average and continues until about 4 years of age. Females are physiologically mature at 17-18 months of age (Hoffman, 2000a). Fairall (1983) reported that the sex ratio in impala at birth is about equal (51.9 % females out of 765 foetuses), but found that a mature population consisted of 65 % females.

1.5 Body growth

Jarman and Jarman (1973) reported that impala ingest more food in the dry season than in the wet season. Hitchins (1966) and Anderson (1982) reported that adult male impala in Africa has a live mass range of 59 – 73 kg. According to Howells and Hanks (1975); Brooks (1978) and Fairall (1983) impala males reach their asymptotic mass of 56.6 kg at about 4.5-5 years whereas females reach their asymptotic mass of 43.2 kg at about three years using theoretical von Bertalanffy curves. Fairall and Braack (1976) reported that impala from the Serengeti region in Tanzania are heavier and larger in all body measurements compared to impala from other regions in southern Africa. Fat in impala is deposited around the kidney and in an extension of the kidney mesentery anteriorly and posteriorly (Knox, Hattingh & Raath, 1991).

2. MEAT PRODUCTION

2.1 Harvesting methodology

Harvesting is an integral component of a wildlife management program. As land available for wildlife decreases and competition for natural resources increases among wildlife, it requires a high level of active management. Animal numbers therefore need to be reduced and this

can be done on a sustainable basis. Meat production can be one of the positive incentives that results from harvesting wildlife (Lewis et al., 1997). Von La Chevallerie (1970) stated the following: “The requirements of a successful cropping technique are as follows: Humanity, Economy, Efficiency in terms of man hours, Low wounding loss, low disturbance and scattering, selectivity of correct ages and sexes, little damage to meat, ability to bleed carcasses, no association with humans.” Von La Chevallerie and Van Zyl (1971) and Van Rensburg and Zondagh (1993) stated that the harvesting methodology of wild animals for meat production requires urgent development attention and that it can influence the quality of the meat. Veary (1991) reported that helicopter, ground day and ground night harvesting methods were used on springbok and found the ground day method to be most stressful based on pH_{48}.

2.1.1 Ground day harvesting method

This method is also known as conventional hunting whereby animals are shot on foot, from a vehicle or at a waterhole. Rifles or bows can be used for this method. Animals can also be selected by age and sex using this method. This method is very difficult where animals are shot often as they become very cautious (Bothma, 2002). Ledger (1963) shot game animals after first light and the neck shot was preferred in order to minimise meat damage. Von La Chevallerie (1970), Von La Chevallerie and Van Zyl (1971) and Von La Chevallerie (1972) shot animals from hides near waterholes during day hours and found that when the hunter was not seen entering or leaving the hide, the animals did not associate man with the shooting.

2.1.2 Ground night harvesting method

This method requires shooting of animals on dark moonless nights. The animals are blinded by the use of spotlights and are then preferably shot at close distance. Shot placement is critical in preventing meat wastage because of bullet damage. More head and neck shots are possible with night shooting which leads to less wastage of meat. Night temperatures are also cooler which results in better quality carcasses. Night shooting proved to be the best method of harvesting game because the meat damage is limited and the animals suffers the least amount of stress (Von La Chevallerie, 1970; Veary, 1991; Sommerlatte & Hopcraft, 1992; Lewis et al., 1997; Onyango, Izumimoto & Kutima, 1998; Hoffman 2000a; Hoffman 2000b; Bothma, 2002). Kritzinger, Hoffman and Ferreira (2003) compared the effects of day and night harvesting on the meat quality characteristics of impala and found that night-time harvesting does have a beneficial effect on certain meat quality parameters.

2.1.3 Helicopter harvesting method

Animals are usually shot in the head with a 12 gauge shotgun from a helicopter. The ground team then picks up these animals and take them to the processing facilities. This method requires high capital investment and professional expertise. The advantage of this method is that better selection takes place, wounded animals can be followed and an estimate of the population size can be made. The disadvantage of this method is that it is expensive and can lead to poorer meat quality as a result of stress, blood contamination and higher day temperatures (Berry, 1986; Bothma, 2002).

2.2 Meat loss during harvesting

Von La Chevallerie and Van Zyl (1971) and Sommerlatte and Hopcraft (1992) reported that head and neck shots resulted in the lowest meat loss due to damage by bullet damage followed by ribs shots, shoulder shots and back shots respectively. Shoulder shots on game resulted in 20 % carcass damage where neck shots resulted in 3 % carcass damage (Von La Chevallerie, 1970). Von La Chevallerie (1970) found that meat loss during springbok and impala harvesting averaged 10 % of the carcass mass and that this loss can be significantly reduced by shooting animals through the head or neck. Von La Chevallerie and Van Zyl (1971) however, reported that carcass damage due to bullet wounds was 13.9 % of the total carcass mass. Conroy and Gaigher (1982) on the other hand reported that body shots on game results in less than 5 % loss.

2.3 Yield

Dressing percentage is an important factor when taking meat production into consideration (Ledger, 1963; Hanks et al., 1976). Ledger (1963), Hitchins (1966); Von La Chevallerie (1970) and Monro and Skinner (1979) found that the majority of dressing percentages of wild ungulates lie between 55 % and 61 % and that no significant differences between the dressing percentages of male and female animals seem to occur. Hitchins (1966), Hanks et al. (1976), De Bruyn (1993) and Lewis et al. (1997) reported that mature springbok and impala rams dressed out at 58 % which is higher when compared to sheep. Fairall (1983) reported that in his study the mean live mass of impala males was 49.2 kg and the females live mass was 38.3 kg with a dressing percentage of 57 %. Hoffman (2000a) reported that the impala that were harvested in Zimbabwe had a mean dressing percentage of 57.5 % for the males and 58 % for the females. The males had a mean live mass of 49.4 kg and the females

a mean live mass of 33.5 kg (Hoffman, 2000a). Hoffman, Kritzinger and Ferreira (2005) reported higher live masses on mature animals (42-54 months) where males had a mean mass of 62.5 kg on and the females a mean mass of 48.9 kg on Mara Research Station. On Musina Experimental Farm, Hoffman, Kritzinger and Ferreira (2005) reported lower live masses on mature animals (42-54 months) where males had a mean mass of 59.3 kg on and the females a mean mass of 41.9 kg.

Impala require about 18 months to reach an economically harvestable size (Von La Chevallerie, 1970). According to Van Zyl, Von La Chevallerie and Skinner (1969) dressing percentages have been calculated in different ways thus leading to different results. The type and quantity of food intake before the animal is shot also influences live and dressed mass (Van Zyl et al., 1969). Van Zyl et al. (1969) also reported that animals shot after midday showed the least amount of contents in the alimentary tract whereas animals that were shot in the mornings and late afternoon showed the opposite. Van Zyl et al. (1969) reported that the cold carcass mass is 3 % lower than the warm carcass mass.

3. FACTORS THAT AFFECT MEAT QUALITY

3.1 Species

Species is perhaps the most easily appreciated factor that affects the composition of muscle but related intrinsic and extrinsic factors also have an influence. The myoglobin content in different species differs. The low myoglobin content in pig muscle causes the meat to be of a paler colour whereas the myoglobin content in beef and lamb muscle is higher and therefore darker in appearance. The rate of oxygenation of myoglobin is slowest in beef, intermediate in lamb and fastest in pork (Lawrie, 1998). Proximate composition differs to a numerically small

but commercially differs significantly between species (Lawrie, 1998). Long chain fatty acid composition also differs among species (Lawrie, 1998). Species differences in enzymatic activity are also reflected post mortem. This causes different rates of post mortem tenderisation among different species (Lawrie, 1998). Aidoo and Haworth (1995) reported that venison meat contained higher levels of organic nitrogen when compared to the corresponding cuts of beef, lamb and pork. Aidoo and Haworth (1995) also reported that the total fat content of venison meat was significantly lower when compared to the other meat samples, whereas the sodium content was similar.

Although preferences differ among consumers, certain African game species make better eating than other species. In South Africa most people agree that springbuck seems to be the favourite game meat and it is also the African game species most sought after by restaurants in Europe. Eland, reedbuck, kudu, gemsbuck and impala are also other firm favourites depending on the preparation method (Woods, 1999). According to Woods (1999) the *Alcelaphinae* family, which includes the blue and black wildebeest, red hartebeest, tsessebe, blesbuck and bontebok are less palatable as table meat but do make excellent biltong.

3.2 Sex

Males usually have less intramuscular fat than females (Lawrie, 1998). Von La Chevallerie (1970) reported that mature males are heavier than the mature females in most species. Arsenos, Banos, Fortomaris, Katsaounis, Stamataris, Tsaras and Zygoyiannis (2002) reported that female lambs normally yield more desirable meat than males.

3.3 Age

As animals get older the composition of muscles start to change regardless of the species or sex (Gallivan, Culverwell & Girdwood, 1995; Lawrie, 1998; Hoffman & Fisher, 2001; Sookhareea, Taylor, Dryden & Woodford, 2001). An increase in animal age leads to a decrease in meat tenderness, an increase in connective tissue content and an increase in intramuscular fat, saturation of intramuscular lipids and myoglobin concentration (Lawrie, 1998; Hoffman & Fisher, 2001). The connective tissue of young animals has less cross-bonding and with age the chemical composition (solubility) of connective tissue changes whereby it decreases (Lawrie, 1998). Lawrie (1998) reported that intramuscular fat increases with age whereas moisture content decreases with age. In bovine fatty tissue it was found that the ratio of linoleic to stearic acids and the softness of the fat also increased as animal age increased (Lawrie, 1998). Myoglobin concentration also increases with age. In young animals the connective tissue content of muscle is greater compared to older animals. With increasing animal age the concentration of collagen and elastin decreases and this affects meat tenderness tremendously (Lawrie, 1998). Lawrie (1998) reported that the solubility of collagen decreases with age upon heating and that the susceptibility of enzyme attack also decreases with age. Lawrie (1998) also reported that the concentration of collagen is the main determinant of eating quality whereas the solubility of collagen is more associated with the determination of shear force.

3.4 Muscle/fibre type

Muscles can be classified as white (fast-twitch) or red (slow-twitch) according to whether they operate in short bursts or carry out sustained action. The 300 muscles in the mammalian

body however reflect a diversity of activity. The red or white reflects the relative content of red or white myofibres. The white (type II) fibres are wide in diameter and mainly glycolytic in their metabolism whereas the red (type I) fibres are a narrow fibre and have a greater proportion of respiratory activity. Type II fibres are subdivided in two subdivisions, namely: Type IIA and type IIB where the former has a considerable capacity for oxidative metabolism and the latter not. The relative susceptibility of beef to develop dark-cutting characteristics post mortem was positively correlated with the number of slow oxidative fibres in their muscles (Lawrie, 1998). White muscles contain less total lipids, triglycerides, cholesterol and polyunsaturated fatty acids than red muscles. In white muscles the store of initial glycogen and buffering capacity is higher while the ultimate pH is lower compared to red muscles. Tenderisation during ageing in white muscles is clearly greater than in red muscles, which indicates that they contain a greater concentration of proteolytic enzymes. Red muscles are also more susceptible to cold shortening than white muscles (Lawrie, 1998).

The lowest content of connective tissue is found in the fillet (*m. psoas major*) (Lawrie, 1998). Taylor, Labas, Smulders and Wiklund (2002) reported that the psoas muscle is very tender at all times. The collagen content in beef hindquarters is significantly lower compared to the forequarters. The connective tissue content differs between muscles but also the types of collagen molecules that are present differ. The pattern of post mortem glycolysis and the onset of rigor mortis also differ between different muscles (Lawrie, 1998).

Pollard et al. (2002) reported that *m. longissimus dorsi* was less hard and juicier at the first bite and more tender than *m. semimembranosus*. Taylor et al. (2002) reported that reindeer meat has a high content of type IIB fibres and that the fibres are very small and a low collagen

content, which could be responsible for the tenderness. Moose meat is usually tough and is probably the result of not enough I band breaks and normal to large fiber size (Taylor et al. 2002).

3.5 Nutritional history

The effects of nutritional level in growing meat animals are reflected in the composition of their individual muscles. The percentage intramuscular fat tends to increase as the percentage fatty tissue increases in an animal. In a controlled nutritional environment the intramuscular fat content will reflect the plain of nutrition (Lawrie, 1998). The percentage of intramuscular fat increases and percentage moisture decreases in animals on a high plain of nutrition. The opposite happens with under-nutrition and the percentage collagen also increases, which leads to greater toughness in meat (Lawrie, 1998).

Von La Chevallerie (1970) reported that the quantity and quality of vegetation, or in other words the available nutrients influences the live mass of game animals. In another study, the nutritional status and physical condition of reindeer had a significant effect on muscle glycogen content while no differences were found in muscle glycogen content for red deer (Wiklund, Stevenson-Barry, Duncan & Littlejohn, 2001). Woods (1999) stated that diet makes a significant difference on the eating quality of game meat.

3.6 Inter-animal variability

The composition of muscles between individual animals is the least understood intrinsic variable. Differences among individual animals include: percentage intramuscular fat, percentage moisture and percentage nitrogen, live mass, carcass mass and organ mass.

These differences are caused by the position of the embryo in the uterus and the quality of feeding after birth (Lawrie, 1998).

3.7 Season

Ingestion of octadecatrienoic acid during pasture feeding show seasonal fluctuations and affect the degree of unsaturation of ruminant fat depots (Lawrie, 1998). Woods (1999) reported that the time of year makes a significant difference in the quality of game meat. Game shot early (May) in the winter season is tastier and fatter compared to game shot at the end (August) of the winter season. Impala rams that are shot during rut (May/June) are also gamier in taste. During the rut it is advised to rather shoot young “penkop” and “knypkop’ rams, and females (Woods, 1999). Stevenson, Seman and Littlejohn (1992) reported that pre-rut carcass mass were lower than post-rut carcasses mass of red deer stags.

3.8 Region

Woods (1999) reported that game meat quality varies regionally whereby game meat obtained from drier regions is generally better than in wetter climates.). McGeehin, Sheridan and Butler (2001a) reported that the basal metabolic rate of animals in hotter climates is lower than in cooler climates. McGeehin et al. (2001a) also reported that a higher metabolic rate pre-slaughter in lamb continues post mortem and therefore the lower initial pH and subsequent rapid glycolysis.

3.9 Physical exercise

During systematic exercise myoglobin is depleted in the muscle and in inactive muscle the opposite happens. Increased stores of muscle glycogen are depleted because of exercise

and this leads to a lower ultimate pH post mortem. When animals exercise and their muscles work aerobically they rather depend on fat than carbohydrates. Inactive muscle leads to atrophy and this causes total nitrogen, percentage sarcoplasmic proteins and myofibrillar proteins to decrease while the amount of connective tissue proteins increases. Only the diminution of sarcoplasmic and myofibrillar proteins results in moderate inactive muscles (Lawrie, 1998).

3.10 Pre-slaughter handling/stress

Stressed animals have a subnormal content of glycogen in their muscles ante mortem, which leads to a high ultimate pH post mortem, and this attributes to a lower eating quality in meat (Von La Chevallerie & Van Zyl, 1971; Tornberg, 1996; Lawrie, 1998; Vergara & Gallego, 2000; Geesink, Mareko, Morton & Bickerstaffe, 2001a; Pollard et al., 2002). Tornberg (1996), in a study where animals had both long-term and short-term stress, found that long-term stress depletes the glycogen content and results in lower lactic acid production during glycolysis, which leads to a higher ultimate pH. This type of meat appears darker and is called DFD (dark, firm and dry) meat (Von La Chevallerie & Van Zyl, 1971). DFD meat occurs more often in beef. A high ultimate pH negatively affects colour, flavour and keeping quality of meat (Geesink et al., 2001a). Short-term stress just prior to slaughter causes rapid glycolysis and a fast drop in pH, which leads to the denaturation of the muscle proteins especially in combination with a relatively high temperature. This type of meat appears pale and watery and is called PSE (pale, soft and exudative) meat. PSE meat occurs more often in pork (Tornberg, 1996).

Geesink et al. (2001a) reported that an intermediate ultimate pH also caused increased toughness in meat after limited post mortem storage and that minimising pre-slaughter stress could benefit meat quality considerably. Woods (1999) reported that the killing method also affects the quality of game meat. The best game meat was from animals that were shot in either the neck or head while they were unaware of the hunter. The meat of a fearful game animal that runs away before being shot or one that is wounded and needs to be followed-up before killing causes the meat to be tough and also spoils the flavour of the meat. It is therefore of paramount importance that an animal must be killed quickly and clean in order to yield good meat quality. Although head and neck shots are not always possible or advisable the next best “meat quality shot” is the heart shot. A lung shot on the other hand causes the animal to run a distance before dying and this yields meat of lower quality (Woods, 1999). Bond, Can and Warner (2004) reported that exercise and pre-slaughter stress increased drip loss and purge but had no effect on meat tenderness of lamb.

3.11 Bleeding and post-slaughter handling

Blood is an excellent growth medium for micro-organisms and has an unpleasant appearance and therefore it is necessary to remove as much blood as possible. This will enhance the eating and keeping qualities of the meat. Cutting the throat with a sharp knife enhances bleeding by the vasoconstriction of the blood vessels. Bleeding causes the elimination of blood-borne oxygen supply to the muscles, which leads to a fall in oxidation-reduction potential. Only 50 % of the total blood is removed with effective bleeding (Lawrie, 1998). Woods (1999) reported that game animals should be bled immediately after death while the heart is still pumping. The sooner enough blood is removed the better the quality of game meat.

After bleeding the dressing of carcasses takes place. This takes place in a vertical hanging positions rather than supine on the abattoir floor, which helps to effectively drain the blood from the carcass (Lawrie, 1998; Woods, 1999). Faecal contamination during the slaughter and dressing procedures occurs sometimes and this leads to contamination of the carcass with spoilage organisms and micro organisms (Edwards, 1999). Woods (1999) advised that the animal should be gutted before fetid cases in the abdomen taint the meat. Care should be taken when gutting the animals to ensure that no puncturing of the rumen, small intestine takes place. Otherwise the rumen or small intestine fluid will taint the meat. The liver should also be handled with care in order to ensure that the gall bladder is not punctured. The diaphragm, heart and lungs should also then be removed to avoid blood congealing in the chest cavity (Woods, 1999).

3.12 Chilling

Chilling dressed carcasses prior to processing is a commercial practice (Lawrie, 1998). Janz, Aalhus and Price (2001) stated that chilling is the most energy expensive aspect of carcass processing. Woods (1999) reported that chilling temperatures should be between 1 °C and 4 °C. The average air temperature that is used in the commercial refrigeration of lamb carcasses in Ireland is 4 °C, which is also referred to as conventional chilling (Douglas, MacDougall, Shaw, Nute & Rhodes, 1979; Maribo, Ertbjerg, Andersson, Barton-Gade & Møller, 1999; Geesink, Taylor, Bekhit & Bickerstaffe, 2001b; McGeehin et al., 2001a; McGeehin, Redmond, Sheridan & Butler, 2001b; McGeehin, Redmond, Sheridan & Butler, 2001c; Redmond, McGeehin, Sheridan & Butler, 2001; Dhanda, Pegg, Janz, Aalhus, & Shand, 2002; Taylor et al., 2002).

Soares and Arêas (1995), Gariépy, Delaquis, Aalhus, Robertson, Leblanc and Rodrique (1995), Johnson and McGowan (1998), Kerth, Cain, Jackson, Ramsey and Miller (1999) and Rhee and Kim (2001) all used a chilling temperature of 2 °C over 24 hours. Den Hertog-Meischke, Smulders, Van Logtestijn and Van Knapen (1997) used a chilling temperature of 5 ºC overnight. Vergara and Gallego (2000) reported that they chilled carcasses at 6 °C for 24 hours. Devine, Wells, Cook and Payne (2001) placed all the carcasses into a coldroom at 10 °C. Devine, Payne and Wells et al. (2002a) reported that the carcasses were transported to a chiller at 12 ºC immediately after electrical stimulation. Geesink, Mareko, Morton and Bickerstaffe (2001c) reported that the carcasses were held at 8 ºC for 6 hours and 4 ºC for 16 hours. Wiklund et al. (2001) reported that over 90 % of all deer meat produced in New Zealand is exported and that chilling meat in vacuum packages at –1.5 ºC has been developed to store fresh meat for up to 14 weeks.

Chilling temperature has a marked influence on tenderness. Rapid chilling may induce a rapid temperature decline in superficial muscles, which might lead to cold shortening and resultant toughening. The rate of pH decline increases with a high muscle temperature post mortem (Byrne, Troy & Buckley, 2000). Redmond et al. (2001) found that ultra-rapid chilling (-20 °C for 3.5 hours) of lamb carcasses and carcasses chilled at 4 °C for 24 hours produced meat of the same tenderness. The internal temperature of the *Longissimus thoracis* was 4 °C within 5 hours for ultra-rapidly chilled carcasses whereas conventionally chilled carcasses were 14 °C within 5 hours (Redmond et al., 2001).

3.13 Ageing

The holding of unprocessed post mortem meat above the freezing point in the absence of microbial spoilage is known as “conditioning” or “ageing”, and it has long been associated with an improvement in tenderness and flavour (Van Rensburg & Zondagh, 1993; Koohmaraie, 1994; Lawrie, 1998; Woods, 1999; Byrne et al., 2000; Mandell, Maclaurin & Buttenhan, 2001; McGeehin et al., 2001b; Perry, Thompson, Hwang, Butchers and Egan, 2001; Redmond et al., 2001; Rhee, Ryu, Imm & Kim, 2000). The increased tenderness is the result of myofibrillar degradation by proteases endogenous to the skeletal muscle cells and the calpain system causes the most of this myofibrillar degradation (Koohmaraie, 1994; Redmond et al., 2001; Hwang & Thompson, 2002).

Increased meat tenderness is produced at approximately 10-18 °C until completion of rigor mortis (Hwang & Thompson, 2001a; Devine, Payne, Peachey, Lowe, Ingram & Cook, 2002b). Optimal tenderness is accomplished with minimum hot or cold shortening and tight control of processing temperatures is therefore required (Devine et al., 2002b). Farouk and Swan (1998) reported that muscles stored at 10 and 25 °C had significantly lower ultimate pH values compared to muscles stored at 0, 5 and 35 °C. The latter also had similar ultimate pH values. Morton, Bickerstaffe, Kent, Dransfield and Keeley (1999) reported that carcasses were aged according to the following regime: 15 ºC for 8 hours, 10 ºC for 6 hours and 1ºC for 10 hours for the first 24 hours post-slaughter. Wiklund et al. (2001) found that tenderisation was increased with high temperature conditioning (24 hours at 10 ºC) before subsequent ageing (72 h at 0 ºC). Koohmaraie (1996) reported that in order to maximise meat tenderness, beef should be aged for 10-14 days, lamb for 7-10 days, and pork for 5 days. Van

Rensburg and Zondagh (1993) reported that game meat should be aged for the same amount of time as beef.

Muscle aging causes I bands to break, which leads to tender meat. Reindeer and moose have few I band breaks compared to cattle and sheep (Taylor et al., 2002). Taylor et al. (2002) reported that because of the small fibre size in reindeer meat the meat can be consumed without aging. Geesink et al. (2001b) and Hopkins and Thompson (2001) reported that no increase in sarcomere length in ovine *longissimus* muscles during ageing was observed. Hopkins and Thompson (2001) also reported that ageing had an effect on the free calcium concentration, which increased as muscle aged.

Woods (1999) reported that game carcasses should be aged in the case of head and neck shots to increase tenderness and flavour. Body shots tend to give the meat a liver-like flavour when aged. The ageing period depends on factors such as species, sex and age of the animal. A female springbuck or reedbuck can be aged for 10 days whereas a young ram can be aged for about 14 days. Older or gamier animals can be aged for even longer. Game carcasses should rather be aged with the skin on, as the meat tends to dry out. Woods (1999) reported that a skinned impala carcass lost up to 6 kg in mass during a 28 days ageing period.

3.14 Cold shortening

Cold shortening is the phenomenon where the temperature of muscles is reduced below about 10-15 °C while they are still in early pre-rigor condition (pH about 6.0-6.4) (Stevenson

et al., 1992; De Bruyn, 1993; Tornberg, 1996; Lawrie, 1998; Polidori, Lee, Kauffman & Marsh, 1999; Rhee & Kim, 2001; McGeehin et al., 2001a; Geesink et al., 2001a). Lawrie (1998) reported that red muscles are more prone to cold shortening than white muscles. The rate of inorganic phosphate production during post mortem glycolysis is greater in white muscles, which might explain the absence of cold shortening in white muscles. Muscle shortening during exposure to cold is related to tenderness of cooked meat (Dutson, 1979; Lawrie, 1998; Rhee et al., 2000).

Devine et al. (2002a) reported that cold shortening produces the toughest meat and that most of the toughening in commercial processing is related to cold shortening. Hildrum, Solvang, Nilsen, Frøystein and Berg (1999) reported that cold shortening had a major affect on tenderness at lower chilling temperatures. Hwang and Thompson (2001b) reported that the cold shortening carcasses had shorter sarcomeres and higher shear forces. Dikeman (1996) reported that when subcutaneous fat is totally removed from the pre-rigor *longissimus* muscle in beef sides which are then exposed to rapid chilling, it leads to cold shortening. Lawrie (1998) and Devine et al. (2002a) reported that cold shortening is most likely to occur if meat is boned out pre-rigor because of the lack of skeletal restraint.

Dutson (1979) reported that cold shortening can be prevent if the stimulus of cold shortening can be eliminated by holding the carcasses at higher temperatures for certain periods before the onset of rigor mortis. Polidori et al. (1999) reported that post mortem treatments are more important factors affecting palatability than factors such as breed, age and pre-slaughter state. Tornberg (1996) reported that the minimal cold shortening region for beef m. *longissimus dorsi* (LD) is 10 – 15 ºC and for m. semimembranosus (SM) 7-13 ºC. Lawrie

(1998) reported that pelvic suspension of rapidly chilled pork carcasses opposed cold shortening more than suspension by the Achilles tendon.

3.15 Freezing

Freezing prolongs the storage life of meat and also prevent microbial and chemical changes in meat (Lawrie, 1998). Freezing offers a means of preserving meat during imports and exports between different countries (Farouk & Swan, 1998; Lawrie, 1998). Freezing causes ice crystal formation and this leads to structural damage of the muscle fibres. Ice crystals tend to form in I bands and not in the A bands (Lawrie, 1998; Geesink et al., 2001c).

Morton et al. (1999) reported that *longissimus dorsi* samples were frozen at –20 ºC for shear force measurements. Freezing, however, tends to increase drip loss in meat and therefore water-holding capacity is negatively affected (Farouk & Swan, 1998; Lawrie, 1998). Hildrum et al. (1999) and Geesink et al. (2001c) reported that freezing improves tenderness in partially aged or unaged beef.

4. DETERMINATION OF MEAT QUALITY

4.1 Conversion of muscle to meat

According to Koohmaraie, Kent, Shackleford, Veiseth and Wheeler (2002) and Garnier, Klont and Plastow (2003) muscle consists of three protein fractions, which are myofibrillar (salt-soluble), connective tissue (acid soluble), and sarcoplasmic (water-soluble) proteins where myofibrillar proteins are the main protein fraction of the skeletal muscle.

4.1.1 Post mortem glycolysis

At death, oxygen is permanently removed from the muscle and irreversible anaerobic glycolysis occurs. In mammalian muscle the conversion of glycogen to lactic acid will continue until a pH (5.4-5.5) is reached when the enzymes affecting the breakdown becomes inactivated (Lawrie, 1998). Pollard et al. (2002) reported that glycogen breakdown in muscle can occur in response to catecholamine release or through strenuous muscular activity.

Increasing external temperatures above ambient will increase the rate of post mortem glycolysis. Decreasing the temperature from 5 ºC to 0 ºC will also increase the rate of post mortem glycolysis. In muscles, which are slow to cool the rate of post mortem glycolysis tends to be higher (Lawrie, 1998). Post mortem glycolysis rate is a major parameter that influences meat tenderness (Rhee, & Kim, 2001). Rapid glycolysing muscles were superior in tenderness than slow glycolysing muscles (Hwang & Thompson, 2001b; Redmond et al., 2001). Zhu and Brewer (2002) reported that rapid post mortem glycolysis results in an abnormally rapid pH decline with a normal ultimate pH, whereas an abnormal degree of glycolysis leads to a normal rate of pH decline with an abnormally low ultimate pH. Rhee and Kim (2001) reported that higher muscle temperature increased the metabolic rate and resulted in increased meat tenderness due to an increase in enzyme activity. Hwang and Thompson (2001b) on the other hand found that meat toughness resulted from a high rigor temperature. De Bruyn (1993) reported that the post mortem glycolysis process in game is faster when compared to cattle and sheep.

4.1.2 Onset of rigor mortis

The muscle becomes inextensible as post mortem glycolysis proceeds and this stiffening is referred to as rigor mortis. The onset of rigor mortis is correlated with the disappearance of muscle ATP. In the absence of ATP formation of rigid chains of actomyosin occurs. Onset of rigor mortis is accompanied by a lowering in water-holding capacity (Lawrie, 1998).

The rigor process consists of a delay and a rapid phase period. During the delay period, the ATP level is constant and the creatine phosphate (CP) falls rapidly, while there is a slow production of lactate and no onset of rigor development. A rapid decline in the ATP (rapid phase) is initiated when the CP is low enough. A shortening of the muscle and the development of a force under isometric conditions accompany this. Both longitudinal and lateral contraction occurs during rigor development (Tornberg, 1996; Geesink, Bekhit & Bickerstaffe, 2000). Bekhit, Farouk, Cassidy and Gilbert (2007b) reported that the temperature at which muscles enters rigor has an extreme effect on the meat quality of venison because as rigor temperature increases the rate of pH decline increases.

Soares and Arêas (1995) reported that the ATP level and pH can be used to measure the development of rigor in the post mortem period. Devine et al. (2002a) reported that full rigor was taken as the ultimate pH determined through pH measurements every 30 minutes and was achieved at approximately 5 hours. Rigor at temperatures close to 15 °C is optimal to increase meat tenderness without negatively affecting water-holding capacity or colour (Geesink et al., 2000; Devine et al., 2002a). Farouk and Swan (1998) found that beef samples entering rigor mortis at 35 °C had a strong dairy odour.

4.1.3 Proteolysis

After death of the animal ATP is not available and muscle proteins will tend to denature (proteolysis). These denatured muscle proteins are liable to attack by proteolytic enzymes also called proteases (Tornberg, 1996; Lawrie, 1998). The conversion of muscle to meat and the subsequent tenderisation process are complex. Proteolysis of key myofibrillar and associated proteins are responsible for post mortem tenderisation (Koohmaraie, 1994; Koohmaraie, 1996; Tornberg, 1996; Geesink et al., 2001a; Hopkins & Thompson, 2001; Hwang & Thompson, 2001b; Koohmaraie et al., 2002). Koohmaraie et al. (2002) reported that the function of these proteins is to sustain the structural integrity of myofibrils and that the proteolytic degradation of these proteins would lead to the weakening of myofibrils, which would in turn lead to tenderisation. Koohmaraie et al. (2002) stated that these proteins are involved in: "(1) inter-myofibril linkages (e.g. desmin and vinculin), (2) intra-myofibril linkages (e.g., titin, nebulin, and possibly troponin-T), (3) linking myofibrils to sarcolemma by costameres (e.g. vinculin and dystrophin), and (4) the attachment of muscle cells to the basal lamina (e.g. laminin and fibronectin)".

The calpain proteolytic system is responsible for post mortem proteolysis that results in meat tenderisation (Koohmaraie, 1994; Koohmaraie, 1996; Tornberg, 1996; Geesink et al., 2001a; Hopkins & Thompson, 2001; Hwang & Thompson, 2001b; Koohmaraie et al., 2002; Taylor et al. 2002). According to Koohmaraie, (1994) a proteolytic system must have all three characteristics, which is necessary for bringing about post mortem changes that ultimately result in meat tenderisation. Koohmaraie (1994; 1996) reported that the protease must firstly be endogenous to skeletal muscle cell. Secondly, the protease must have the ability to reproduce post mortem changes in myofibrils in an in-vitro setting under optimum conditions.

Thirdly, the protease must have access to myofibrils in tissue. He stated that calpains are the only proteases that have all of the above characteristics.

Certain structural changes occur during proteolysis namely: The loosing up of the intermediate filaments that holds the myofibrils laterally in place; The degradation of titin and nebulin, which connect myosin filaments along their length, which therefore cause weakening of the myofibrillar strength; Z-disk weakening, this leads to myofibril fragmentation (Tornberg, 1996). According to Tornberg (1996) myosin and actin are not affected and that with regard to the connective tissue, no convincing evidence shows the degradation of the collagen during rigor mortis and ageing. Tornberg (1996) also reported that the greatest changes in tenderisation caused by calpains occur within the first 3 or 4 days post mortem. Improved tenderness was reached in meat held at 15 ºC, as compared to 35 ºC (Tornberg, 1996).

Koohmaraie (1994) reported that the differences in the rate and extent of post mortem proteolysis are almost certainly the reason for the differences in meat tenderness from sheep, pigs and between *Bos taurus* and *Bos indicus* breeds of cattle. Koohmaraie (1994) stated that differences in the rate of myofibrillar protein degradation are the main reason for variations in tenderness of meat from animals of similar age.

Lawrie (1998) reported that the β-agonists appear to stimulate the action of the calpain inhibitor, calpastatin and that the rate of post mortem tenderisation in meat correlate inversely with naturally occurring levels of calpastatin. Koohmaraie et al. (2002) reported that the calpain proteolytic system is a major regulator of muscle protein degradation. Koohmaraie

(1996) and Koohmaraie et al. (2002) mentions that the argument against calpain involvement in post mortem tenderisation is that muscle contains an excess of calpastatin (inhibitor) relative to μ-calpain (low calcium requiring enzyme) and that μ-calpain can therefore never be active. In literature m-calpain (high requiring enzyme) is used to quantify calpastatin activity. This point is extremely important because it takes twice as much calpastatin to inhibit μ-calpain as to inhibit m-calpain (Koohmaraie, 1996). Koohmaraie (1994) also reported that pH and temperature have a dramatic effect on the inactivation of μ-calpain during rigor development. Lee et al. (2000) stated that m–calpain and calpastatin activities in electrically stimulated (ES) muscles decreased significantly after 10 hours post mortem.

Callipyge sheep have a high calpastatin activity and a low μ–calpain to calpastatin ratio post mortem. The similarity of very few I band breaks in moose and reindeer to callipyge sheep therefore indicates a low activity of calpain in post mortem meat of reindeer and moose (Taylor et al., 2002).

5. PHYSICAL MEAT QUALITY PARAMETERS

Honikel (1998) stated that there is little consensus among researchers in the methods being used to measure the physical characteristics of meat and that standardization of methods is critical if research carried by different groups are to be directly comparable.

5.1 pH

The amount of lactic acid produced from glycogen during post mortem anaerobic glycolysis determines the pH of meat (Solomon, Lynch & Berry, 1986a; Veary, 1991; Lawrie, 1998;

Byrne et al., 2000). Farouk and Swan (1998) and Karlsson and Rosenvold (2002) reported that the temperature and pH combination at rigor mortis is important in determining the functional properties of muscle protein. Ultimate pH of meat determines the resistance to microbial spoilage. Optimum growth of bacteria is at about pH 7 (Lawrie, 1998). Lawrie (1998) reported that a high ultimate pH in beef and pork causes dark-cutting beef and glazy bacon in pigs respectively. High ultimate pH in venison does not affect the biological status, as is the case with beef and pork (Lawrie, 1998).

Meat quality is influenced by the rate of pH decline in the muscles post mortem and by the ultimate pH (Byrne et al., 2000; Hoffman & Ferreira, 2000; Karlsson & Rosenvold, 2002). Several factors affect the rate of pH decline and include stress, electrical stimulation and chilling temperature (McGeehin et al., 2001a; Karlsson & Rosenvold, 2002; Pollard et al. 2002). Animal factors such as sex, species, breed, season and age also have an affect on the rate of pH decline (McGeehin et al., 2001a).

Savell, Mueller and Baird (2005) reported that the pH in the muscle normally decreases from 7.0 when slaughtered to 5.3-5.8 at 24 hours post mortem. According to Geesink et al. (2001a), an increase in toughness is associated with an ultimate pH of meat between 5.8 and 6.2. Gariépy et al. (1995) reported that a rapid pH drop reduce the activity of the calcium-activated neutral proteases, which leads to decreased Z line degradation. According to Tornberg, Wahlgren, Brondum and Engelsen (2000), a rapid drop in pH (at a high temperature) yield more tender meat than meat with a slower drop in pH although shortening is higher for meat where the pH drop is very rapid. The rapid drop in pH causes the meat to be more tender because a faster and a more significant proteolytic breakdown occurs

compared to meat with a slower drop in pH (Tornberg et al., 2000). Devine et al. (2002b) and Hwang and Thompson (2001a; 2001b) on the other hand reported that slow glycolysis promotes tenderness compared to rapid glycolysis and that muscle temperature early post mortem is much more critical than muscle pH. Hwang and Thompson (2001b) reported that aging days was the major dependant in producing the optimum pH decline for the most tender meat. They also found that the most tender meat in the strip-loin after 14 days of aging was produced with an intermediate pH decline (pH 5.9-6.2 at 1.5 hours post mortem) or rigor temperature (29 - 30 ºC at pH 6.0). Wiklund et al. (2001) found that a low pH and high temperature in meat reduces the water binding capacity because of muscle protein denaturation. Devine et al. (2002b) also found that high rigor temperatures leads to a higher mean cook loss and slightly paler meat. Meat with an ultimate pH > 5.8 has better colour stability than meat with an ultimate pH of 5.6 (Powell, Dickenson, Shorthose & Jones, 1996). Douglas et al. (1979) reported that high pH venison meat is dark in colour and is prone to bacterial spoilage. Aalhus, Janz, Tong, Jones and Robertson (2001) found meat with a high pH at 10 hours to be tough. Pollard et al. (2002) reported that a high ultimate pH adversely affects meat tenderness and meat colour in red deer. Veary (1991) reported that springbok reached a pH from 5.4-5.8 within 12 hours post mortem. Hoffman (2000b) found that impala had a mean pH_{45} of 7.17 ± 0.0674 and a mean pH_u of 5.70 ± 0.068.

Karlsson and Rosenvold (2002) recommended that a buffer and electrode temperature of 35 ºC as a standard procedure for measuring pH early post mortem should be used. According to Byrne et al. (2000) there is a high level of experimental error linked with the use of glass pH electrodes in meat research. Electrical probes have many intrinsic advantages over glass pH electrodes, which include, faster measurement speed, more robust, less destructive, internal

memory for complete automation, water resistant, easy to clean, no constant recalibration and no health hazards.

5.2 Colour

Consumers use meat colour as a quality and freshness indicator (Ferreira, Andrade, Costa, Freitas, Silva & Santos, 2006; Bekhit, Cassidy, Hurst & Farouk, 2007). Meat colour is predominantly determined by the concentration and the chemical states of myoglobin (Zhu & Brewer, 2002). The appearance of the meat surface depends on numerous factors, which includes the quantity of myoglobin present, the type of myoglobin molecule as well as the chemical and physical condition of other components in the meat (Lawrie, 1998; Zhu & Brewer, 2002). Species, breed, sex, age, muscle type and amount of training also effects meat colour (Lawrie, 1998). Moore and Young (1991) reported that electrical stimulation, freezing and thawing, ageing and type of packaging used during ageing are also factors, which affect meat colour. Lawrie (1998) reported that the colour of meat surfaces become brighter when stored at lower temperatures. Most of the visual differences in meat surfaces arise from the chemical state of the myoglobin molecule (Lawrie, 1998). The colour pigments of myoglobin, oxymyoglobin and metmyoglobin are purplish-red, bright red and brown respectively (Lawrie, 1998; Byrne et al., 2000). Lawrie (1998) reported that a high level of muscular activity leads to more myoglobin in the muscle. Impala are more active than livestock and have darker meat which may be attributed to the elevated levels of myoglobin present in the muscle meat. The darker colour of impala meat may also be attributed to the relatively low amount of intra-muscular fat present (Kritzinger et al., 2003).

The bright red colour of oxymyoglobin pigment only occurs on the surface and is the most important chemical form in fresh meat and is the colour most desired by consumers (Moore & Young, 1991; Lawrie, 1998; Byrne et al. 2000). Consumers generally believe that meat red in colour is safe to eat and vice versa (Moore & Young, 1991). Moore and Young (1991) however also reported that choosing meat on the basis of colour is not a very valid method of choosing meat. Consumers will however continue to use colour as the major guide to choose meat because old habits die hard and scientists will preserve the bright red colour in meat for as long as possible (Moore & Young, 1991). Lawrie (1998) reported that metmyoglobin is the most undesirable colour pigment on meat surfaces. De Bruyn (1993) and Thompson (2002) reported that meat with a pH>6.0 is linked to dark, firm and dry meat (DFD) and that this type of meat has a much shorter shelf-life than normal meat of pH<6.0. Buys (1993) reported that meat with pH_{45} < 5.5 is pale, soft and exudative (PSE) in colour.

Scientists mainly express the colour of meat in terms of L*, a* and b* values (Commission International de l' Eclairage, 1976), with L* indicating brightness or reflectance, a* the red-green range and b* the blue-yellow range (Moore & Young, 1991; Farouk & Swan 1998; Lawrie, 1998; Onyango et al., 1998; Maribo et al., 1999; Byrne et al. 2000; Hoffman 2000a; Dhanda et al., 2002). Moore and Young (1991) reported that chilled lamb chops were brighter (Higher L-value), redder (Higher a-value) and more yellow (Higher b-value) than thawed chops. Farouk and Swan (1998) reported that with increasing rigor temperature in both fresh and frozen meat the L-values and a-values tends to increase. They also found that b-values decreased with frozen storage and increased with rigor temperature. Byrne et al. (2000) reported that the redness (a-value) of meat increased during storage over 12 days because of an increase in the oxymyoglobin concentration in the muscle surface. Farouk and

Swan (1998) reported that Hue angle might be a better indicator of the colour in meat after short-term frozen storage or fresh meat compared to Hunter a* and b* values. Hoffman (2000b) found that the CIELAB values of impala *m. longissimus thoracis* were as follows: L* = 29.22 ± 0.590; a* = 11.26 ± 0.319 and b* = 7.36 ± 0.266). The darker muscle colour of venison is because these ungulates are more active than domestic farm animals (Hoffman, 2000b). Von La Chevallerie (1972) reported that impala meat has a typical red-brown brick colour. Bekhit et al. (2007a) reported that venison meat colour is less stable when compared with other species.

5.3 Thaw, drip and cooking losses

Water loss affects the appearance of meat. Most of the water is present in the myofibrils of the muscle between the myosin and actin/tropomyosin. Capillary forces bind this water. Water in the muscle is either bound or free. During the onset of rigor mortis there is little change in bound water whereas the free water in the extracellular region increases while the intracellular water decreases (Lawrie, 1998).

Thaw loss occurs when uncooked meat samples are thawed after being frozen. The meat samples are then blotted dry with paper towels. The change in mass is then recorded and the thaw loss expressed as a percentage. Den Hertog-Meischke et al. (1997) and Geesink et al. (2001a; 2001c) thawed their samples overnight at 2 ºC. Morton et al. (1999) thawed all frozen *longissimus dorsi* samples at 2 ºC. Wheeler, Shackleford and Koohmaraie (1996) and Wheeler, Shackleford, Johnson, Miller, Miller and Koohmaraie (1997) thawed samples at 4 °C for various lengths of time. Hildrum et al. (1999) and Byrne et al. (2000) thawed meat samples

for 18 hours at 4 °C. Aidoo and Haworth (1995) and Dhanda et al. (2002) thawed meat samples for 24 hours at 4 °C.

Drip loss occurs when uncooked/non-frozen meat samples lose moisture over time in a cooler. The meat samples are then blotted dry with paper towels and weighed again. The changes in mass are then recorded and the drip loss expressed as a percentage (Seman, Drew & Littlejohn, 1989; Farouk & Swan 1998). Farouk and Swan (1998) determined drip loss by keeping meat samples for 24 hours, which were then blotted dry with a paper towel and reweighed. Hoffman (2000a) found the drip loss of impala to be 2.55 ± 0.300 %.

Cooking loss occurs when uncooked meat loses moisture after being cooked for a specific time at a specific temperature. After cooking samples are blotted dry with paper towels. The cooking loss are then calculated as total fluid lost, expressed as a percentage of the fresh (uncooked) sample (Hoffman 2000a; Devine et al. 2002b). Babiker and Bello (1986) and Pollard et al. (2002) cooked 2.5 cm thick steaks in plastic bags immersed in a water bath at 80 °C for 1 hour. Hildrum et al. (1999) cooked meat at 70 °C for 50 minutes. Devine et al. (2002a; 2002b) cooked frozen meat to 75 ºC in an 85 ºC water bath. Hwang and Thompson (2001a) cooked meat blocks from the frozen state at 70 °C for 60 minutes in a water bath. Morton et al. (1999) cooked samples in separate plastic bags at 80 ºC in a water bath until an internal temperature of 75ºC was reached. Devine et al. (2001a; 2002b) cooked frozen meat to 75 ºC in an 85 ºC water bath. Devine et al. (2001a; 2001c) cooked meat samples in plastic bags to an internal temperature of 75 ºC in an 80 ºC water bath. Pollard et al. (2002) cooked 2.5 cm thick steaks in plastic bags at 80 °C for 1 hour in a water bath. Hildrum et al. (1999)

vacuum-packed all samples and cooked at 70 °C for 50 minutes in a water bath. Byrne et al. (2000) cooked meat samples in a plastic bag in a 72 ºC water bath to an internal temperature of 70 ºC. Hoffman (2000b) cooked impala meat samples in a plastic bag in a 75 ºC water bath for 50 minutes and found the cooking loss to be 23.98 ± 0.367 %.

5.4 Tenderness (Shear Force)

Tenderness is rated as one of the most important eating quality attributes by which consumers judge meat quality (Von La Chevallerie, 1972; Koohmaraie, 1994; Wheeler, Koohmaraie, Cundiff & Dikeman, 1994; Tornberg, 1996; Wheeler et al., 1996; Wheeler et al., 1997; Lawrie, 1998; Morton et al. 1999; Byrne et al., 2000; Bickerstaffe, Bekhit, Robertson, Roberts & Geesink, 2001; Gerelt, Ikeuchi, Nishiumi & Suzuki, 2002; Koohmaraie et al., 2002; Peachey, Purchas & Duizer, 2002; Davel, Bosman & Webb, 2003; Ferreira et al., 2006; Stolowski, Baird, Miller, Savell, Sams, Taylor, Sanders & Smith, 2006; Toohey & Hopkins, 2006). Koohmaraie (1994), Morton et al. (1999) and McGeehin et al. (2001a) stated that several factors influence meat tenderness such as animal age, sex, rate of glycolysis, ultimate pH, proteolysis, sarcomere length, amount and solubility of collagen and ionic strength. Meat tenderness does not occur equally in all animals (Koohmaraie, 1996). Tenderness decreases with age and male animals also tend to have tougher meat (Lawrie, 1998). A systematic decrease in meat tenderness occurs in beef *semimembranosus* from the proximal to distal end whereas the tenderness increases in beef *biceps femoris* from insertion to origin (Lawrie, 1998). Dikeman (1996) reported that subcutaneous fat does not affect meat tenderness when cold-shortening conditions do not occur.

According to Lawrie (1998) and Thompson (2002) the physical objective methods of assessing meat tenderness are shear force, penetrating, “biting", mincing, compressing and stretching. The empirical method of the Warner-Bratzler shear device is most widely used because this instrumental technique usually yields the best correlation with sensory panel scores for meat tenderness (Von La Chevallerie, 1972; Babiker & Bello, 1986; Vanderwert, McKeith, Bechtel & Berger, 1986; Wheeler et al., 1994; Soares & Arêas 1995; Berry, Joseph & Stanfield, 1996; Tornberg, 1996; Wheeler et al., 1996; Wheeler et al., 1997; Hildrum et al. 1999; Kerth et al. 1999; Polidori et al. 1999; Byrne et al. 2000; Ferguson, Jiang, Hearnshaw, Rymill & Thompson, 2000; Hwang & Thompson 2001a; Hwang & Thompson, 2001b; Janz et al. 2001; McGeehin et al. 2001b; McGeehin et al. 2001c; Perry et al. 2001 ; Redmond et al. 2001; Peachey et al., 2002; Pollard et al. 2002). Wheeler et al. (1994) and Wheeler et al. (1996) reported that meat cores obtained parallel to muscle fibres produced higher mean shear force and greater repeatability than cores obtained perpendicular to the muscle fibres. Wheeler et al. (1996) also reported that five cores per animal were sufficient to have a repeatable mean shear force. The best forecaster for meat tenderness is the peak load (Tornberg, 1996). Wheeler et al. (1997) reported that the shear force measured on an Instron machine with a crosshead speed of 200mm/min should be the same as from a Warner-Bratzler machine.

Inconsistent meat tenderness is a major problem for the meat industry (Koohmaraie, 1994; Koohmaraie, 1996; Koohmaraie et al., 2002). Hildrum et al. (1999) reported that the meat industry focuses more on the overall effects of relevant treatments rather than on each individual effect regarding meat tenderness. The degree of meat tenderness is related to three categories of muscle protein, which are connective tissue, myofibril proteins and

sarcoplasm proteins. According to Lawrie (1998) there is also an indirect correlation between tenderness and muscle fibre diameter as well as connective tissue.

Lawrie (1998) reported that when the pH falls slowly an increase in tenderness occurs. Rhee and Kim (2001) mentioned that meat tenderness in beef was optimum at a pH of 6.1 at 3 hours post mortem and that fast glycolysis (pH_3<5.9) negatively affected beef tenderness. McGeehin et al. (2001a) reported that optimum meat tenderness is associated with an intermediate rate of glycolysis. Koohmaraie (1996) explained that when slow glycolysing occurs in muscles the meat tenderness is highly dependent on shortening whereas muscles with a more rapid pH decline are completely independent of shortening. Optimum meat tenderness in beef and lamb occurs at an ultimate pH of between 5.8 and 6.2 (Lawrie, 1998).

Taylor et al. (2002) found reindeer meat to be very tender within three days post mortem. Moose is the most commonly consumed game meat in Sweden even though the meat is often tough (Taylor et al. 2002). In South Africa the general public perceives game meat to be tough which does not correlate with Warner Bratzler shear values (Hoffman, 2000b). This may be because of slaughtering techniques or lack of knowledge in preparing this meat. Hoffman (2000b) reported that the mean shear value of impala meat to be 3.65 ± 0.293 kg / 1.27 cm diameter.

6. ULTRA STRUCTURAL MEAT QUALITY PARAMETERS

6.1 Sarcomere length

The distance between two adjacent Z-lines is the functional unit of the myofibril, which is known as the sarcomere (Lawrie, 1998). This distance is measured in µm. A muscle becomes

narrower when a muscle is extended passed its rest length. This leads to a tighter hexagonal array of myosin and actin filaments. The opposite occurs when a muscle contracts (Lawrie, 1998). Shortening of muscles occurs during post mortem glycolysis at temperatures between –1ºC and 38ºC. The minimum shortening of muscles occurs at 15ºC to 20ºC (Lawrie, 1998).

Taylor et al. (2002) reported that electron microscopy came into common use in meat science during the 1970s in order to determine ultra structural changes. Den Hertog-Meischke et al. (1997) assessed sarcomere lengths by measuring the first-order laser diffraction bands. Kerth et al. (1999) froze samples in liquid nitrogen and store it at –70ºC and thereafter determined sarcomere lengths by fixing the samples using helium-neon laser diffraction. Geesink et al. (2001a) used the same method as Kerth et al. (1999) in determining the sarcomere length of washed myofibrils. Wiklund et al. (2001) determined sarcomere length using phase contrast microscopy. The image was then analysed using a computer image analysis program (Image Pro-plus V4.0) (Wiklund et al. 2001). Taylor et al. (2002) used transmission electron microscopy to determine sarcomere lengths.

Sarcomere shortening early post mortem results in the toughening of meat (Koohmaraie, 1996; Koohmaraie et al., 2002). Koohmaraie (1996) and Koohmaraie et al. (2002) also reported that sarcomere length (SL) decreased from 2.24 µm (at death) to 1.69 µm (24 hours post mortem) in lamb *longissimus*. Koohmaraie (1996) and Koohmaraie et al. (2002) also reported that shear force increased in this time in which they concluded that sarcomere shortening during rigor mortis is the cause of the decrease in lamb *m. longissimus* tenderness. Within-animal variation accounts for more variation in sarcomere length than between-animal variation (Koohmaraie, 1996).

Mean sarcomere length values of meat samples at 35ºC rigor were significantly shorter than samples at 18ºC rigor (Devine et al. 2002b). Yook, Lee, Lee, Kim, Song and Byun (2001) reported that no sarcomere shortening was observed in gamma-irradiated muscle but that the disappearance of the M-line and of A- and I-bands were visible. The rate of post mortem glycolysis and the temperature change influences the degree of sarcomere shortening. Sarcomere shortening is excessive in slow glycolysing muscles when subjected to rapid chilling whereas the sarcomere shortening is low in fast glycolysing muscle (Koohmaraie, 1996). Lawrie (1998) also reported that the mode of suspension of a carcass also affects the sarcomere length of specific muscles.

6.2 Relationship between sarcomere length and tenderness

Koohmaraie (1996) stated that tenderness decreases with decreasing sarcomere length. He concluded that a decrease in tenderness during the first 24 hour post mortem can be attributed to rigor-induced sarcomere shortening. Thereafter post mortem tenderisation plays a major role in meat tenderness (Koohmaraie, 1996). Lawrie (1998) reported that the decrease in meat tenderness, which is related to short sarcomere lengths, is the result of interactions between myosin filaments and not due to actin-myosin bonds. The meat tenderness of excised pre-rigor muscle that was exposed to cold shortening temperatures and cooked decreased as the pre-rigor shortening increased from 20 % to 40 % of the initial length. As the shortening increases to 60 % the meat tenderness however, increases (Lawrie, 1998).

Tornberg (1996) reported that the Warner Bratzler peak force values of raw meat increased significantly when the sarcomere length of the muscle increased. The opposite was found

when the meat was cooked above 60 ºC. The more shortened the muscle when cooked the higher the number of fibres per unit cross-sectional area, which leads to a higher elasticity and results in higher Warner Bratzler peak force values (Tornberg, 1996; Lawrie, 1998). Tornberg (1996) however, mentions that only 50 % of the decrease in meat tenderness could be attributed to shorter sarcomere lengths. Wiklund et al. (2001) reported that the extent of muscle contraction at rigor also affects meat tenderness because sarcomere length and meat tenderness are related in beef. Lawrie (1998) however, also mentions that collagen might make a more positive contribution to the degree of meat tenderness in shortened muscle

7. ELECTRICAL STIMULATION (ES)

7.1 Effect of electrical stimulation

Benjamin Franklin found in 1749 that electrical stimulation of turkeys immediately post mortem increased their meat tenderness (Lawrie, 1998). Electrical stimulation increases meat tenderness and is used by the meat industries on beef, lamb and goat in New Zealand, England, Australia and the United States (McKeith, Savell, Smith, Dutson & Shelton, 1979; Pauw, 1993; Berry et al., 1996; Lawrie, 1998; Edwards, 1999; Hildrum et al., 1999; Kerth et al., 1999; Roeber, Canell, Belk, Tatum & Smith, 2000; Aalhus et al., 2001; Devine, 2001; Janz et al., 2001; Devine et al., 2002a; Hwang, Devine & Hopkins, 2003). McKeith et al. (1979) also reported that electrical stimulation increases palatability of meat, increased muscle firmness, brighter coloured muscle and decreases the ageing time to attain meat tenderisation. Electrical stimulation accelerates post mortem glycolysis thus decreasing muscle pH, which leads to prevention of cold shortening when carcasses are chilled rapidly (Gariépy et al., 1995; Lawrie, 1998; Ferguson et al., 2000; Devine et al. 2002b; Hwang et al.,

2003). Kerth et al. (1999) and Ferguson et al. (2000) also mentioned that electrical stimulation results in increased fracturing and disruption of the myofibrillar structure.

Lawrie (1998) however, also reported that electrical stimulated muscle is not as useful as non-electrical stimulated muscle for the production of cured and freeze-dried products. These type of products need high levels of ATP (*in vivo*) at time of processing for their high water holding capacity. Ferguson et al. (2000), however also reported that the activities of calpain I and II and their inhibitor, calpastatin generally decreases following electrical stimulation. Wiklund et al. (2001) however reported that electrical stimulation of red deer offered no advantages in the processing of venison for long-term chilled exports. A comparison of the effect of electrical stimulation on meat characteristics was reported by Davel et al. (2003).

7.2 Different methods of electrical stimulation

According to Lawrie (1998) literature on electrical stimulation indicates that the type of current (voltage, frequency of pulse and duration), the electrode system, the pathways (via nerve or direct) and the time of application post mortem have differed significantly between researchers. Many researchers applied the current via the thoracic region of the carcass and used the Achilles tendon as the earth. Lawrie (1998) electrically stimulated beef carcasses that were intact, dressed and split into dressed sides. The electrodes were placed 200 cm apart and the peak voltage was 680 V. It was found that the intact carcasses gave a peak current of 5.2 amps, the dressed carcasses gave a peak current of 3.3 amps and the dressed sides gave a peak current of 2.4 amps. Intact carcasses allow better current flow for the application of a specific voltage because of intrinsic differences in electrical resistance

(Lawrie, 1998). Electrical stimulation should ideally be applied within 30 minutes after slaughter because of a still functioning nervous system (Lawrie, 1998).

Solomon et al. (1986a) used low voltage electrical stimulation on male lambs, which was supplied via a rectal probe with a ground attachment to the lower mandible. On only one treatment Solomon et al. (1986a) used high voltage electrical stimulation, which was supplied via two probes (approximately 0.6 x 20 cm) where one was inserted in the muscles of the leg while the other was inserted in the neck to serve as the ground for the system. The electrodes can also be placed in the nerve centre of the muzzle and earth via the Achilles tendon in the case of low voltage (80 V). When using low voltage it is preferred that the high resistance of the upper leg and shoulder should be bypassed by using the anus or leg as earth (Lawrie, 1998). Hildrum et al. (1999) used low voltage electrical stimulation, which was applied through a clip in the nostrils and by the shackling of one leg. Kerth et al. (1999) used high voltage electrical stimulation on lamb carcasses, which was supplied by inserting one 20 cm probe between the first rib and scapula and another 20 cm probe in the shank of the hind limb. Polidori et al. (1999) also used low voltage for electrical stimulation, which was applied via a rectal probe and a clip to the nostrils. All the animals were suspended by a grounded shackle, which was attached to the hind legs. Hwang and Thompson (2001a) used low voltage (70 V) and high voltage (800 V) electrical stimulation on whole beef carcasses applied 3 minutes post mortem, via electrodes inserted in the nostril and rectum with both legs shackled. Hwang and Thompson (2001a) then used other beef carcasses and halved them into carcass sides. They supplied high voltage via two multi-point electrode probes, which was inserted into the muscles at the lateral aspect of the scapula and the proximal end of the Achilles tendon at 40 minutes post mortem on the left sides and at 60 minutes post mortem on the right sides

respectively. Hwang and Thompson (2001b) used low voltage electrical stimulation to stimulate beef carcasses, via a nostril/rectal probe 3 minutes post mortem. Janz et al. (2001) also used low voltage electrical stimulation, which was delivered via a nose clamp. Wiklund et al. (2001) electrically stimulated red deer carcasses with a battery clip attached to the upper lip of the jaw and a stainless steel hook contacting the anus. Devine et al. (2002a) used high voltage (1130 V) electrical stimulation, which was supplied by electrodes attached to the neck and Achilles tendons of both legs. Pollard et al. (2002) used low voltage electrical stimulation, which was delivered via a rectal probe and mount clip.

7.3 High voltage electrical stimulation versus low voltage electrical stimulation and time duration

Solomon et al. (1986a), Soares and Arêas (1995), Lawrie (1998), Hildrum et al. (1999), Polidori et al. (1999) and Janz et al. (2001) reported that low voltages (<100V) are safer but that the effectiveness is less consistent than voltages of 500-1000 V or even more. Low voltages (<100V) need about double the electrical stimulation time compared to high voltages (Lawrie. 1998). High voltage and low voltage electrical stimulation on beef carcasses was reported to be both effective in improving meat tenderness (Hildrum et al., 1999).

Dutson, Savell and Smith (1982) used high voltage (550 V) to electrically stimulate left sides of beef carcasses. Solomon et al. (1986a) used both low (45 V; 90 seconds) and high voltage (145 V; 90 seconds) to electrically stimulate male lamb carcasses. They used a full-wave rectified pulsating direct-current (DC) source with a frequency of 16 Hz to generate low voltage electrical stimulation while a half-wave rectified DC source with a frequency of carcass stimulation of 12 Hz was used to generate the high voltage electrical stimulation.

Solomon, West and Hentges (1986b) used high voltage (500 V) to electrically stimulate young purebred bull carcasses. Grosskopf, Meltzer, Van Heerden, Collett, Van Rensburg, Mülders and Lombard (1988) used low voltage electrical stimulation to stimulate feedlot beef carcasses. Seman et al. (1989) used low voltage (45 V, 45 mA, 90 seconds) to electrically stimulate deer carcasses. Moore and Young (1991) used high voltage (1130 V peak, 14.28 pulses/second, 90 seconds) to electrically stimulate lamb. Stevenson et al. (1992) used low voltage electrical stimulation (45 V for 90 seconds) immediately after exsanguinations on red deer stags. Uytterhaegen, Claeys and Demeyer (1992) used high voltage electrical stimulation to stimulate beef carcasses. Gariépy et al. (1995) used low voltage (110 V, 60 Hz, 0.25 A) to electrically stimulate beef carcasses at 5 minutes post mortem. Carcasses were split and high voltage (500 V, 60 Hz, 1.5 A) electrical stimulation was then used at 40 minutes post mortem on the split carcasses (Gariépy et al., 1995). Soares and Arêas (1995) used high voltage (1400 V, 2 A, 60 Hz, 30 seconds) to electrically stimulate half carcasses of buffalo (*Bubalus bubalus*). Berry et al. (1996) used high voltage (600 V, 120 seconds) to electrically stimulate beef carcasses. Dikeman (1996) used low voltage to electrically stimulate carcasses. Eilers, Tatum, Morgan and Smith (1996) used high voltage (240 V, 60 Hz) to electrically stimulate beef carcasses. Tornberg (1996) used low voltage (85 V, 14 Hz, 32 seconds) to electrically stimulate carcasses. Den Hertog-Meischke et al. (1997) used low voltage (85V, 14 Hz, 15 seconds) to electrically stimulate eight bulls. Farouk and Swan (1998) used high voltage (1130 V, 15 pulses sec^{-1}, 120 seconds) to electrically stimulate beef carcass sides. Edwards (1999) used an open circuit high voltage (1130 V, 10 ms, 15 pulses/second, 2 A) to electrically stimulate lamb carcasses. Hildrum et al. (1999) used low voltage (90 V, 15 Hz, 32 seconds) to electrically stimulate lamb. Kerth et al. (1999) used high voltage (550 V, 60 Hz, 2 seconds on and 2 seconds off for 15 repetitions) to electrically

stimulate lamb carcasses. Morton et al. (1999) used high voltage (1130 V, 14.3 pulses/second, 1.8 - 2 A, 90 seconds) to electrically stimulate beef carcasses. Polidori et al. (1999) used low voltage (28 V) to electrically stimulate lamb carcasses. Aalhus, Larsen, Dubeski and Jeremiah (2000) used low voltage to electrically stimulate steers. Ferguson et al. (2000) used high voltage (800 V, 14.3 pulses/seconds frequency for 55 seconds) to electrically stimulate split beef carcass sides. Lee, Polidori, Kauffman and Kim (2000) used low voltage (28 V, 60 Hz) electrical stimulation on lamb carcasses. Rhee et al. (2000) used low voltage (50 V, 60 Hz, 20 seconds, impulse duration of 200 µs) to electrically stimulate Korean native cattle carcasses. Roeber et al. (2000) used medium voltage for medium duration, medium voltage for long duration, high voltage for medium duration and high voltage for long duration to electrically stimulate beef carcasses. Devine et al. (2001) used high voltage (1130 V, 2 A, half sine wave, 10 ms duration, alternating pulse frequency of 14.28 $pulses^{-1}$, 90 seconds) to electrically stimulate sheep carcasses. Geesink et al. (2001a) used high voltage (1130 V, 14.3 Hz, 90 seconds) to electrically stimulate lamb. Geesink et al. (2001c) used low voltage (75 V, 15 Hz, 20 or 80 seconds) to electrically stimulate beef carcasses. Hwang and Thompson (2001a) used low voltage (70 V of unidirectional square wave pulses of 7 ms width, 14.3 pulses/second, 40 seconds) and high voltage (800 V of continuous alternating polarity of bi-directional half sinusoidal pulses of 10 ms width, 14.3 pulses/second, 55 seconds) to electrically stimulated beef carcasses. Low voltage electrical stimulation took place at 3 minutes and 40 minutes post mortem and gave an output of 1.4 A and 0.6 A respectively while high voltage electrical stimulation took place at 3 minutes, 40 minutes and 60 minutes post mortem, which gave an output of 7.9 A, 6.5 A and 6.0 A respectively (Hwang & Thompson, 2001a). Hwang and Thompson (2001b) used low voltage (45 V, 100 ms on and 12 ms off, 36 pulses per second, 500 milliamps) to electrically stimulate

beef carcasses. Johnston, Reverter, Robinson and Ferguson (2001) used extra low voltage and high voltage to electrically stimulate beef carcasses. Rhee and Kim (2001) used low voltage (50 V, 60 Hz, 20 seconds, impulse duration of 200 µs) to electrically stimulate Korean native cattle carcasses. Rodbotten, Lea and Hildrum (2001) used low voltage electrical stimulation (90 V, 15 Hz, 20 seconds) on Norwegian cattle. Wiklund et al. (2001) used low voltage (90-95 V, 7.5 ms duration, 55 seconds) to electrically stimulate red deer carcasses. Devine et al. (2002a) and Devine et al. (2002b) used high voltage (1130 V, 2 A, alternating pulse frequency of 14.28 pulses^{-1}, 90 seconds) to electrically stimulate sheep carcasses. Pollard et al. (2002) used low voltage electrical stimulation on deer. Peachey et al. (2002) used low-voltage electrical stimulation immediately following exsanguination on bulls and steers. King, Voges, Hale, Waldron, Taylor and Savell (2004) used high voltage (550 V, 1.8 seconds on, 1.8 seconds off for 2 minutes) and low voltage (20 V, 2 seconds on, 3 seconds off for 2 minutes) electrical stimulation on cabrito carcasses. Strydom, Frylinck and Smith (2005) used high voltage (400 V peak, 5ms pulses at 15 pulses per second for a duration of 45 seconds) electrical stimulation on half beef carcasses. Li, Chen, Xu, Huang, Hu and Zhou (2006) used low voltage (24 V, 50 Hz, for a duration of 30 seconds) electrical stimulation on Chinese Yellow crossbred bulls. Biswas, Das, Banerjee and Sharma (2007) used low and high voltage (35 V, 110 V, 330 V, 550 V, 1100 V with fixed 50 Hz and 10 pulses/second for a duration of 3 minutes) electrical stimulation on tender stretched chevon (goat meat) sides. Casey and Paterson (1991) used high voltage (380 V, 50 Hz, 3 x 15 seconds) electrical stimulation on hide on beef within 10 minutes after stunning.

Polidori et al. (1999) reported that the majority of studies on electrical stimulation in the past involved the use of high voltages but that low voltage electrical stimulation is more practical

and safe under commercial conditions. Farouk and Swan (1998) found that high voltage electrical stimulation did not significantly affect beef pH_u, colour, drip loss, cook yield, protein solubility and sarcomere length as well as rigor temperature and storage condition. Nour, Gomide, Mills, Lemenager and Judge (1994) found that high voltage electrical stimulation improved some tenderness characteristics and reduced some juiciness scores compared to low voltage electrical stimulation. Gariépy et al. (1995) found that high voltage electrical stimulation did not have any positive or negative affects on the processing properties of frankfurters. Hildrum et al. (1999) however found no significant effect on final meat tenderness using low voltage electrical stimulation. Hildrum et al. (1999) reported that the conflicting results on the effects, which low voltage electrical stimulation has on the meat tenderness of beef may be due to the differences in animals, equipment used for electrical stimulation, chilling and ageing conditions, sample preparation and the analysis of meat tenderness. Kerth et al. (1999) found that high voltage electrical stimulation increased loin chop tenderness of lamb from slightly tough to slightly tender. Geesink et al. (2001a) reported that when animals stress and low voltage electrical stimulation are used that this has a toughening effect on meat. This suggests that there must be an interaction between stress and low voltage electrical stimulation. They however did not find the same with high voltage electrical stimulation, which indicates that there was no interaction between stress and high voltage electrical stimulation on meat tenderness (Geesink et al., 2001a). Geesink et al. (2001c) however found that beef carcasses that was electrically stimulated with low voltage for 80 seconds was significantly less tender at 7 days post mortem than carcasses that was stimulated for 20 seconds. Geesink et al. (2001c) stated that low voltage electrical stimulation can adequately stimulate carcasses and that by over stimulating a carcass might have a negative effect on meat quality. Hwang and Thompson (2001a) reported that high voltage

electrical stimulation of beef carcasses is more effective than low voltage electrical stimulation in improving meat tenderness. They however found that the high voltage treatment at 60 minutes post mortem resulted in a significantly lower muscle temperature at pH 6.0 compared to the high voltage treatment at 40 minutes post mortem while both the treatments had similar shear force, adjusted tenderness, juiciness scores and sarcomere lengths. Hwang and Thompson (2001a) also found that the high voltage electrical stimulation treatment at 60 minutes post mortem had a higher rate of meat tenderisation, with a higher initial shear force. The low voltage electrical stimulation at 40 minutes post mortem treatment resulted in a significantly lower shear force, higher adjusted tenderness scores and a tendency towards higher adjusted juiciness scores compared to the non-stimulated control samples (Hwang & Thompson, 2001a). Hwang and Thompson (2001a) reported that their results imply that high voltage electrical stimulation probably leads to a greater acceleration of autolysis and/or proteolytic activity of μ-calpain and calpastatin during stimulation. Janz et al. (2001) reported that High voltage electrical stimulation causes disruption of muscle tissue, which leads to further meat tenderisation. They however reported that low voltage electrical stimulation resulted in lighter coloured meat and a tendency for a decrease in shear force value (Janz et al., 2001). Johnston et al. (2001) found that the mean and variance of the shear force differed among treatment groups. The non-stimulated groups were more variable than the high voltage groups, which was more variable than low voltage groups (Johnston et al., 2001). King et al. (2004) found that high voltage electrical stimulation increased meat tenderness of cabrito carcasses at 1 and 3 days post mortem but not at 14 days post mortem. Biswas et al. (2007) found 330 V (50 Hz and 10 pulses/second) to be the more effective voltage for the meat quality parameters tested when compared with 35 V, 110 V, %50 V and 1100 V.

7.4 Effect of electrical stimulation on post mortem glycolysis and rigor mortis

Electrical stimulation was developed essentially to accelerate post mortem glycolysis and hasten the onset of rigor mortis (Etherington, Taylor, Wakefield, Cousins & Dransfield, 1990; Casey & Paterson, 1991; Soares & Arêas, 1995; Den Hertog-Meischke et al., 1997; Farouk & Swan, 1998; Lawrie, 1998; Polidori et al., 1999; Ferguson et al., 2000; Devine et al., 2001; Hwang & Thompson, 2001a; Janz et al., 2001; Rhee & Kim, 2001; Wiklund et al., 2001; Devine et al., 2002b; Velarde, Gispert, Diestre & Manteca, 2003; Hwang et al., 2003; King et al., 2004; Strydom et al., 2005; Toohey & Hopkins, 2006; Devine, Lowe, Wells, Edwards, Hocking Edwards, Starbuck & Speck, 2006; Biswas et al., 2007). Lawrie (1998) reported that electrical stimulation hastens the time to the onset of rigor mortis through two phases of acceleration of glycolysis, the first during stimulation and the second, less precipitate phase, after electrical stimulation. A high rate of ATP (Adenosine Tri-phosphate) breakdown occurs while the current is flowing, which leads to activation of the contractile actomyosin ATP-ase by released Ca^{++} ions (Lawrie, 1998; Polidori et al., 1999). The latter enhances the titre of phosphorylase a, which increases the rate of post mortem glycolysis even further (Lawrie, 1998).

Polidori et al. (1999) found that their control samples significantly had more ATP than electrically stimulated samples at 3 and 6 hours after electrical stimulation. Wiklund et al. (2001) on the other hand found no significant difference in muscle glycogen content between control and electrically stimulated samples of red deer. Lawrie (1998) and Hwang and Thompson (2001a) reported that electrical stimulation increases the rate of biochemical reactions of the glycolytic pathway by 100-150 times. Soares and Arêas (1995) found that high voltage electrical stimulation produced rigor mortis in buffalo *Longissimus dorsi thoracis*

muscles after 2 hours from slaughter whereas non-stimulated *Longissimus dorsi thoracis* muscles only produced rigor mortis after 15 hours from slaughter.

7.5 Effect of electrical stimulation on cold shortening

The main purpose of electrical stimulation is to avoid cold shortening whereby the use of electrical stimulation leads to a rapid reduction in muscle pH and thus avoiding the possibility of muscle cold shortening (Casey & Paterson, 1991; De Bruyn, 1993; Gariépy et al., 1995; Soares & Arêas, 1995; Taylor, Nute & Warkup, 1995; Powell et al., 1996; Lawrie, 1998; Farouk & Swan, 1998; Polidori et al., 1999; Ferguson et al., 2000; Geesink et al., 2001a; Geesink et al., 2001c; Janz et al., 2001; McGeehin et al., 2001a; Wiklund et al., 2001; Devine et al., 2002a; Devine et al., 2002b; Hwang et al., 2003; Rees, Trout & Warner, 2003a; Rees, Trout & Warner, 2003b; Savell et al., 2005; Devine et al., 2006; Strydom et al., 2005; Toohey & Hopkins, 2006; Biswas et al., 2007). Cold shortening of muscles leads to meat with shortened muscle fibres and a very tough texture (Edwards, 1999). Although muscles are not reactive to cold shortening in this phase of post mortem glycolysis some muscles are still pre-rigor and therefore, thaw-rigor is still a possibility (Lawrie, 1998). Lawrie (1998) stated that pelvic hanging appears to increase muscle tenderness in electrically stimulated carcasses, which are placed into blast freezers within 30 minutes of electrical stimulation. Lawrie (1998) however, advised that only after 6 hours after electrical stimulation should rapid freezing proceed. Hot deboning occurs in a market where abattoirs prepare pre-packaged cuts. These cuts are commercial joints and/or portions for the individual consumer, which are vacuum packed while the cuts are warm. These cuts are induced under very rapid rates of cooling to lessen microbial growth. Rapid cooling of meat pre-rigor ultimately leads to cold shortening.

Therefore with such relatively small portions of meat, electrical stimulation of the carcass or side could prove particularly useful in avoiding cold shortening (Lawrie, 1998).

Tornberg (1996) on the other hand found that cold shortening was not prevented by electrical stimulation but that enhanced proteolysis could be the reason for an increase in meat tenderness on electrically stimulated *longissimus dorsi* muscle. Rhee and Kim (2001) on the other hand also stated that a combination of electrical stimulation and temperature conditioning was more effective in solving the problem related to cold shortening of muscle.

7.6 Effect of electrical stimulation on post mortem proteolysis

The degradation of cytoskeletal proteins is attributed to proteolysis by endogenous enzymes called calpains. Electrical stimulation promotes endogenous proteolytic enzyme activity. This includes μ-calpain, which is instrumental in promoting the ageing effect (Ho, Stromer & Robson, 1996; Lawrie, 1998; Kerth et al., 1999; Rhee & Kim, 2001). Electrical stimulation also increases the frequency of myofibrillar I-band fractures due to mechanical disruption (Ho et al., 1996; Kerth et al., 1999; Kim et al., 2001; Hwang et al., 2003). Geesink et al. (2001a) reported that the effect of electrical stimulation on post mortem proteolysis is either no effect or an accelerated effect. Geesink et al. (2001a) stated that accelerated proteolysis as a result of electrical stimulation occurs when the range of pH decrease is relatively large between electrically stimulated and non-stimulated muscles and when carcasses are cooled slowly. Wiklund et al. (2001) stated that electrical stimulation led to an earlier onset of rigor mortis while the carcass temperatures in the early post rigor mortis period where high. More rapid proteolysis followed because of this and led to accelerate tenderisation of red deer meat (Wiklund et al., 2001). Lawrie (1999), Ferguson et al. (2000), Geesink et al. (2001c) and

Hwang et al. (2003) also reported that electrical stimulation accelerates post mortem proteolysis. Ferguson et al. (2000) and Geesink et al. (2001c) stated that the decrease in calpastatin activity found in the electrically stimulated muscles indicated that the rate of post mortem proteolysis increased.

7.7 Efficacy of electrical stimulation in different species

Electrical stimulation is used in commercial abattoirs to increase meat tenderness in beef, lamb and goat carcasses (Wiklund et al., 2001). Electrical stimulation was applied on three Bos indicus genotypes (0% Hereford, 50% Brahman x Hereford and 100% Brahman) and the differences in shear force between breeds were reduced by electrical stimulation (Ferguson et al., 2000). Ferguson et al. (2000) reported that the magnitude of and breed effect is substantially reduced when electrical stimulation is applied effectively. Kim, Rhee, Ryu, Imm and Koh (2001) found that the combination of electrical stimulation and early short-term temperature conditioning improved the meat quality of Korean native cattle (Hanwoo Beef).

Morton et al. (1999) applied electrical stimulation to lamb and beef carcasses and found that high voltage electrical stimulation decreases the pH of the *Longissimus dorsi* muscle and within 5 hours ultimate pH values was reached. Polidori et al. (1999) and McGeehin et al. (2001a) reported that electrical stimulation applied to lamb carcasses avoids cold shortening and possible toughness when subjected to rapid cooling temperatures.

Pork muscle is more susceptible to cold shortening compared to beef and lamb especially when subjected to extremely rapid rates of cooling. When electrical stimulation is sensibly applied to pork meat it can ensure that meat quality is retained (Lawrie, 1998). Taylor et al.

1995) reported that the use of electrical stimulation (700 V, 12.5 Hz, for 90 seconds at 20 minutes post mortem) on pork carcasses increased meat tenderness of pork and also resulted in a slight increase in drip loss. Maribo et al. (1999) reported that electrical stimulation (700 Volts, 5-7 A and 12.5Hz, continuously applied for 90s) 20 minutes post mortem on pigs caused a rapid drop in pH of 0·3 units in *Longissimus dorsi* and *Biceps femoris*, but had no effect on ultimate pH. Electrical stimulation of pigs caused an increase in muscle temperature of 0.2 ºC and improved the meat tenderness (Maribo et al., 1999). Maribo et al. (1999) however, also reported that electrical stimulation of pigs increased the incidence of PSE meat and that ageing had a better effect on meat quality. Hammelman, Bowker, Grant, Forrest, Schinckel and Gerrard (2003) reported that electrical stimulation (500 Volts, 26 pulses, 2 seconds on and 2 seconds off) creates PSE-like characteristics if applied during the first 25 minutes post mortem. Rees et al. (2003a) however, reported that low voltage (200 mA, 14 Hz for 15 seconds) electrical stimulation improved pork meat tenderness at 1, 2 and 10 days post mortem. Channon, Walker, Kerr and Baud (2003b) and Channon, Baud, Kerr and Walker (2003a) on the other hand reported that low voltage (50mA, 200 mA and 400 mA for 30 seconds) electrical stimulation increased meat tenderness in pork and did not have any impact on PSE incidence.

Bison carcasses are very lean carcasses, which lead to rapid heat dissipation and therefore cold shortening is a major risk when subjected to rapid low temperatures (Janz et al., 2001). Janz et al. (2001) found that low voltage electrical is most effective in preventing cold shortening in Bison carcasses. Electrical stimulation of deer carcasses has been a standard practice since the beginning of the 1980s in New Zealand (Wiklund et al., 2001). Wiklund et

al. (2001) reported that electrical stimulation of male red deer carcasses significantly increases the meat tenderness.

Electrical stimulation in poultry reduces the need for ageing carcasses before deboning. This reduces the decrease in meat tenderness when the meat is deboned immediately after death (Sams, 1999). Etherington et al. (1990) reported that electrical stimulation resulted in more tender chicken meat.

7.8 Effect of electrical stimulation in different sexes

Male animals generally have less intramuscular fat than female animals (Lawrie, 1998). Male animals generally are leaner than females and more at risk to cold shortening than the females. Electrical stimulation therefore might be even more beneficial for male animals in order to prevent cold shortening (Chekanov, Karakozov, Rieder & Zander, 2000). McGeehin et al. (2001a) found that the sex of lamb had no effect on early pH or ultimate pH but that the 4 hour pH of female lambs was lower than the male lamb when no electrical stimulation was applied. In February, April and September male pH values were higher than females when no electrical stimulation was applied (McGeehin et al., 2001a). The pre-slaughter stress effect during the rut/mating season on male animals might be the reason for this.

7.9 Effect of electrical stimulation on age

The intramuscular fat increases with age, which reduces the risk of cold shortening during rapid cooling. The moisture content also decreases with age. Electrical stimulation might not have any beneficial advantage towards preventing cold shortening in older animals but can be beneficial towards meat tenderness of older animals (Lawrie, 1998).

7.10 Effect of electrical stimulation in carcasses with varying fat contents

Lean carcasses have a higher rate of rapid heat dissipation. Game, deer, bison, lean lamb and lean beef carcasses display a natural tendency towards leanness with localised subcutaneous fat deposition and this inherent attribute introduces a risk for cold shortening in the absence of effective electrical stimulation and/or modified chilling (Dikeman, 1996; Lawrie, 1998; Janz et al., 2001; Wiklund et al., 2001). Effective electrical stimulation and optimum cooling conditions minimises differences between the meat tenderness of lean animals and fat animals (Dikeman, 1996). Large quantities of fat have been found to decrease the effect of cold shortening (Stevenson et al., 1992). Game animals therefore are more prone to cold shortening whereas electrical stimulation assists in preventing cold shortening. Heavier carcasses cool down slower than lighter carcasses therefore the heavier carcasses remain longer above the range at which cold shortening occurs (Lawrie, 1998). Dikeman (1996) also found that Warner-Bratzler shear force values increased as subcutaneous fat depth increased from 1 to 15 mm in electrically stimulated carcasses whereas no relationship where found between depth of subcutaneous fat cover and the amount of toughening in the *longissimus* muscle of non-electrically stimulated carcasses. Aalhus et al. (2001) on the other hand found that as *Longissimus* backfat dept increased the proportion carcasses with very high shear force and average shear force decreases. Dikeman (1996), however also stated that subcutaneous fat depth and marbling is a poor predictor of meat tenderness. Aalhus et al. (2001) however also reported that the leaner carcasses had less shrink/mass loss than the fatter carcasses under blast chilling conditions.

7.11 Effect of electrical stimulation on muscle pH and temperature

The use of electrical stimulation maximises the pH decline early post mortem in beef, veal, lamb, deer, chicken, goat and pork (Dutson et al., 1982; Solomon et al., 1986a; Etherington et al., 1990; Uytterhaegen et al., 1992; Gariépy et al., 1995; Soares & Arêas, 1995; Taylor et al., 1995; Berry et al., 1996; Eilers et al., 1996; Powell et al., 1996; Tornberg, 1996; Lawrie, 1998; Hildrum et al., 1999; Kerth et al., 1999; Morton et al., 1999; Polidori et al., 1999; Ferguson et al., 2000; Lee et al., 2000; Vergara & Gallego, 2000; Hwang & Thompson, 2001a; Hwang & Thompson, 2001b; Janz et al., 2001; McGeehin et al., 2001a; Rhee & Kim, 2001; Wiklund et al., 2001; Devine et al., 2002a; Davel et al., 2003; Rees et al., 2003a; Rees et al., 2003b; King et al., 2004; Li et al., 2006; White, O'Sullivan, Troy & O'Neill, 2006; Biswas et al., 2007). All the electrically stimulated carcasses had a more rapid pH drop than the non-electrically stimulated carcasses during the first 3 hours post mortem (Solomon et al., 1986a; Hildrum et al., 1999; Rhee & Kim, 2001). Ferguson et al. (2000) reported that significant differences in ultimate pH were found between the electrically stimulated and the non-electrically stimulated carcasses. Soares and Arêas (1995) found that the ultimate pH was achieved at 2 hours post mortem for the electrically stimulated sides whereas the ultimate pH was only achieved after 24 hours post mortem for the non-electrically stimulated sides. Kerth et al. (1999) reported that the muscle pH of electrically stimulated carcasses were lower than non-electrically stimulated carcasses within 4 hours post mortem but not at 5, 6 and 24 hours post mortem. Uytterhaegen et al. (1992) reported a pH reduction of 0.5 units after using high voltage electrical stimulation. Morton et al. (1999) on the other hand reported that the pH decline for beef *Longissimus dorsi* muscle was reduced by 0.70 units when high voltage electrical stimulation was used at 50 minutes post mortem. Morton et al. (1999) reported that at 5 hours post mortem the *Longissimus dorsi* muscle reached an ultimate pH of 5.7 at a temperature of

15 ºC. Morton et al. (1999) reported that the pH_3 was 6.1 and the pH_7 was 5.64 with a temperature of 18 ºC. Janz et al. (2001) found that an ultimate pH value of 5.6 converged when measurements at 24 hours and 6 days post mortem were taken. Wiklund et al. (2001) reported that the pH of electrically stimulated red deer carcasses were lower than the non-electrically stimulated carcasses at 20 hours post mortem but that this difference disappeared after 1 week of refrigerated storage. Wiklund et al. (2001) reported that these results suggest that the ultimate pH had not been reached in the non-stimulated red deer carcasses within the first 20 hours post mortem. Dutson et al. (1982) also found that there was no difference between the ultimate pH of electrically stimulated carcasses and non-electrically stimulated carcasses. Gariépy et al. (1995) reported that the pH of electrically stimulated carcasses that were exposed to blast chilling were slightly higher at 24 hours and 6 days post mortem, which is consistent with the lower temperatures recorded after 3 hours and 24 hours post mortem. Hwang and Thompson (2001a) reported that when high or low voltage electrical stimulation are applied directly after slaughter (3 minutes post mortem) the pH decline early post mortem is faster compared to 40 minutes post mortem or 60 minutes post mortem. McGeehin et al. (2001a) reported that early post mortem pH is linked to meat tenderness especially where electrical stimulation and/or rapid cooling are used.

Den Hertog-Meischke et al. (1997) reported that electrical stimulation did not affect muscle temperature. Kerth et al. (1999) also reported that muscle temperature was not affected by electrical stimulation at any time post mortem. Morton et al. (1999) reported that the temperature of the electrically stimulated *Longissimus dorsi* muscle was 37 ºC at 1 hour post mortem, 18 ºC at 3 hours post mortem, 18 ºC at 5 hours post mortem and 6 ºC after 23 hours post mortem. Gariépy et al. (1995) and Geesink et al. (2001c) reported that the temperature

profiles of beef and lamb carcasses were not affected after using electrical stimulation. Wiklund et al. (2001) also reported no significant differences in red deer carcass temperature between electrically stimulated carcasses and non-electrically stimulated carcasses. Uytterhaegen et al. (1992) on the other hand reported an increase in temperature of 1 ºC after using high voltage electrical stimulation. Devine et al. (2006) reported that electrical stimulation resulted in a correspondingly elevated temperature in lamb meat.

7.12 Effect of electrical stimulation on muscle colour

Electrical stimulation results in paler meat with an improved bright red colour on cut meat surfaces at 24 hours post mortem (Dutson et al., 1982; Powell et al., 1996; Lawrie, 1998; Kerth et al., 1999; Vergara & Gallego, 2000; Janz et al., 2001; Wiklund et al., 2001; Davel et al., 2003; King et al., 2004). Electrical stimulation results in a rapid decline of muscle pH, which means that the iso-electric point is reach much earlier and thereby “opening up” the structure. This results in reduced oxygenation of myoglobin and therefore the higher concentration of oxymyoglobin in the surface meat layer (Lawrie, 1998; Wiklund et al., 2001). Lawrie (1998) however, reported that the *semimembranosus* muscle of beef looses colour because metmyoglobin increases after the use of electrical stimulation.

Powell et al. (1996) reported that consumers prefer fresh meat with high ultimate pH (> 5.8), which is darker than meat with a normal pH of 5.6. Powell et al. (1996) also reported that meat with pH_u > 5.8 have a better colour stability compared to meat with pH_u of 5.6. Geesink et al. (2001c) and Wiklund et al. (2001) reported that electrical stimulation may reduce the metmyoglobin accumulation rate in the surface layer of meat at both early post rigor and

following ageing. Wiklund et al. (2001) however found no negative effects on meat colour stability of red deer by using electrical stimulation.

Dutson et al. (1982) and Solomon et al. (1986b) reported that electrical stimulation either reduced or eliminated coarse dark band formation on bullock carcasses. Kerth et al. (1999) on the other hand reported that electrical stimulation had no effect on marbling, meat texture, meat firmness, primary and secondary flank streaking and quality grade. Hildrum, Nilsen, Bekken and Naes (2000) found that cooked lamb was lighter in colour because of electrical stimulation. Roeber et al. (2000) also found L*, a* and b* mean values to be higher following electrical stimulation. Aalhus et al. (2001) found that electrical stimulation reduced the slightly darker colour of blast chilled meat. Moore and Young (1991) reported that electrical stimulation produced a more uniform product regarding Hunter colour (L*, a*, b*) values compared to non-electrically stimulated carcasses. Moore and Young (1991) however, also reported that electrical stimulation adversely affected the colour of lamb that was freeze-thawed, which might be due to tissue damage after electrical stimulation and then further worsening by freezing and thawing.

Janz et al. (2001) found that low voltage electrical stimulation had significant effects on all colour measurements until 24 hours post mortem but that only lightness (L*) persistent until 6 days post mortem. Low voltage electrically stimulated samples where lighter (Higher L*) and more of a cherry red colour (chroma and hue) compared to non-electrically stimulated samples (Janz et al., 2001). Janz et al. (2001) stated that carcass grading usually occurs at 24 hours post mortem and that low voltage electrical stimulation therefore be used as a colour enhancing treatment.

Electrical stimulation did not affect a* values of red deer meat at 7 days post mortem, which is in contrast with beef (Wiklund et al., 2001). Wiklund et al. (2001) however stated that earlier measurements at 24 hours or 48 hours post mortem might have indicated an effect of electrical stimulation on venison colour. Bekhit et al. (2007a) also reported that redness (a*) in venison meat was not affected by electrical stimulation.

7.13 Effect of electrical stimulation on thaw, drip and cooking losses of muscle

The rapid decline of pH after electrical stimulation enhances the intracellular osmotic pressure adequately, which leads to the loss of water-holding capacity by the muscle proteins (Lawrie, 1998). Lawrie (1998) however reported that electrical stimulation did not lead to immediate drip loss in bovine muscle but that some eventual drip loss occurred after some time. Moore and Young (1991) found that electrical stimulation did not increase total drip loss from rigor to end of display and that electrically stimulated and non-electrically stimulated loins had similar drip loss. Moore and Young (1991) also found that electrically stimulated loins produced slightly less drip loss compared to non-electrically stimulated loins during ageing and when thawed loins were aged, the opposite was true. Moore and Young (1991) also found that drip from electrically stimulated lamb was clearer than that from non-electrically stimulated lamb. Janz et al. (2001) reported that low voltage electrical stimulation had no significant effect on drip loss of bison meat. Den Hertog-Meischke et al. (1997) on the other hand reported that the use of electrical stimulation resulted in higher drip losses. Geesink et al. (2001c) also reported that electrical stimulation might negatively affect water-holding capacity. Wiklund et al. (2001) also reported that electrical stimulation reduces water-binding capacity in venison. Wiklund et al. (2001) however found no difference in drip loss between electrically stimulated and non-electrically stimulated samples of red deer at any of the storage times measured.

Strydom et al. (2005) on the other hand found that the drip loss at 24 hours post mortem was slightly higher in electrically stimulated carcasses when compared with non-electrically stimulated carcasses. Biswas et al. (2007) reported that electrical stimulation decreased water holding capacity in chevon (goat) meat.

The sarcolemma of pork muscle is more permeable to water compared to that of beef muscle, which results in pork meat being more susceptible to the loss of water-holding capacity (Lawrie, 1998). Lawrie (1998) also reported that PSE pork is even more susceptible to the loss of water-holding capacity. Taylor et al. (1995) reported that high voltage electrical stimulation resulted in a slight increase in drip loss. Channon et al. (2003a; 2003b) and Rees et al. (2003a; 2003b) both reported that low voltage electrical stimulation had no detrimental affect on drip loss and the incidence of PSE pork meat.

Geesink et al. (2001c) reported that the intensity of electrical stimulation had no effect on cooking loss. Devine et al. (2002a) also reported that electrical stimulation had no effect on cooking loss of sheep meat. Gariépy et al. (1995) reported that electrical stimulation had no significant effect on the cooking yield of frankfurters processed from the chuck muscles. Uytterhaegen et al. (1992) and Li et al. (2006) on the other hand reported that cooking losses in beef were increased due to electrical stimulation. Berry et al. (1996) also reported that cooking loss in patties increased that was processed from electrically stimulated beef.

Den Hertog-Meischke et al. (1997) reported that electrical stimulation had no influence on thaw losses.

7.14 Effect of electrical stimulation on ageing of muscle

Ageing changes proceed at twice the rate during the first 24 hours to 30 hours post mortem following the use of electrical stimulation (Lawrie, 1998). Wheeler, Savell, Cross, Lunt and Smith (1990) reported that electrical stimulation reduced the ageing period that was needed to reach a specific level of meat tenderness regardless of breed or breed-type. Soares and Arêas (1995) also found that electrical stimulation accelerated the process of ageing over 3 days. Ferguson et al. (2000) also reported an increase in the rate of ageing following electrical stimulation. Hwang and Thompson (2001a) found that non-electrically stimulated sides proceeded at a higher ageing rate in sensory tenderness compared to electrically stimulated sides. Hwang and Thompson (2001a), however also found that the non-electrical stimulated sides had significantly less tender meat after 14 days of ageing compared to electrical stimulated sides, which might be due to later activation of the enzymatic tenderising process in non-electrically stimulated sides.

7.15 Effect of electrical stimulation on muscle tenderness

The effect of electrical stimulation on meat tenderness produced considerable conflicting results and disagreement among researchers (Solomon et al., 1986a; Stevenson et al., 1992; Tornberg, 1996; Lawrie, 1998; Hildrum et al., 1999; Ferguson et al., 2000; Davel et al., 2003; Hwang et al., 2003). Some researchers reported that electrical stimulation prevents cold shortening. This resulted in sarcomere rest lengths to be longer in electrically stimulated samples compared to non-electrically samples, which resulted in an increase in meat tenderness in the absence of high temperature conditioning. Other researchers reported that early and extensive conditioning results from the combination of low pH with *in vivo* temperatures, which enhances proteolysis and leads to an increase in meat tenderness.

Some researchers on the other hand reported that electrical stimulation does not lead to any significant improvement in meat tenderness (Lawrie, 1998). Lawrie (1998) reported that electrical stimulation do not always lead to a difference in sarcomere length between electrically stimulated and non-electrically stimulated samples even though the electrically stimulated samples are more tender as meat (Lawrie, 1998). Dutson (1979) & McKeith et al. (1979) reported that electrical stimulation of pre-rigor carcasses increases meat tenderness. Dikeman (1996) reported that electrical stimulation decreased Warner-Bratzler shear force values to about 50 % of those for the non-electrically stimulated carcasses. Geesink et al. (2001c) reported that electrical stimulation accelerates post mortem tenderisation but that intense electrical stimulation combined with slow chilling may have an unfavourable effect on meat tenderness.

The use of electrical stimulation on beef carcasses increases the meat tenderness (Solomon et al., 1986b; Ho et al., 1996; Lawrie, 1998; Roeber et al., 2000). Wheeler et al. (1990) reported that electrical stimulation reduced the differences in meat tenderness between four beef breed-types. Uytterhaegen et al. (1992) reported that high voltage electrical stimulation produced lower shear force values in beef *Longissimus dors*i muscle at 1 and 8 days post mortem. Berry et al. (1996) reported that electrical stimulation in combination with hot processing did not lead to improved tenderness in beef patties when compared to beef patties of non-electrically stimulation in combination with cold processing. Eilers et al. (1996) reported that electrical stimulation improved the meat tenderness of beef *Longissimus* steaks but that electrical stimulation had no effect on the tenderness of *Gluteus medius* or *Semimembranosus* steaks. Powell (1996) reported that electrical stimulation is a necessary procedure in order to produce tender beef in rapidly chilled carcasses. Hildrum et al. (1999)

reported that bovine meat tenderness increased but not significantly after the use of low voltage electrical stimulation. Byrne et al. (2000) reported that by electrically stimulating carcasses or sides to yield a pH_3 of 6 produced optimum tenderness in bovine meat. Rhee et al. (2000) reported that the effect of electrical stimulation on the tenderness of Hanwoo beef depends on the succeeding cooling rate as well as post mortem interactions, which include pH, temperature and extension. Hwang and Thompson (2001a) found that low and high voltage electrical stimulation at different times post mortem led to an increase in beef meat tenderness. Johnston et al. (2001) reported that the tenderness effect of electrical stimulation was greater in the *Longissimus dorsi* muscle than the *Semitendinosus* muscle of beef. Kim et al. (2001) reported that shear force of Hanwoo beef was positively influenced by electrical stimulation. McGeehin et al. (2001a) reported that the pH of already rapid glycolysing beef carcasses could be lowered even more rapidly by using electrical stimulation, which leads to a decrease in meat tenderness. Rhee and Kim (2001) reported that electrical stimulation facilitated meat tenderisation in Hanwoo beef. Rodbotten et al. (2001) reported that low voltage electrical stimulation significantly affected meat tenderness of the *Longissimus dorsi* muscle in Norwegian beef. Strydom et al. (2005) reported that electrical stimulation increased meat tenderness in beef after 2 days post mortem but that the effect of electrical stimulation on beef meat tenderness decreased after 14 days post mortem. White et al. (2006) reported that electrical stimulation increased meat tenderness in hot-boned beef.

Electrical stimulation improves the meat tenderness of lamb (Solomon et al., 1986a; Kerth et al., 1999; Morton et al., 1999; Hildrum et al., 2000; Hwang et al., 2003; Devine et al., 2006). Lee et al. (2000) reported that both the *Longissimus thoracis* and *Semimembranosus* muscles of lamb had lower shear force values after electrical stimulation. Geesink et al. (2001a)

reported that electrical stimulation improved meat tenderness of lamb at 2 days post mortem but that meat tenderness decreased after 6 weeks of post mortem storage.

Taylor et al. (1995) reported that high voltage electrical stimulation increased meat tenderness in pork. Rees et al. (2003a, b) found that low voltage electrical stimulation and had also increased meat tenderness in pork. Channon et al. (2003a; 2003b) reported that low voltage electrical stimulation did not increase the meat tenderness of pork significantly but that the eating quality of the meat improved.

McKeith et al. (1979) reported that electrical stimulation improves meat tenderness in goat meat. King et al. (2004) and Biswas et al. (2007) also found that electrical stimulation improved meat tenderness in goat meat. Soares and Arêas (1995) reported that electrical stimulation produced significantly more tender buffalo meat. Janz et al. (2001) found that low voltage electrical stimulation produced tender bison meat after 6 days of ageing and also produced the lowest frequency of tough samples. Stevenson et al. (1992) and Wiklund et al. (2001) reported that electrical stimulation produced significantly lower shear force values in red deer meat from 1 day to 3 weeks. Wiklund et al. (2001) also found that there was no significant difference in shear force values between electrically stimulated and non-electrically stimulated samples of red deer meat at 6 and 12 weeks post mortem.

7.16 Effect of electrical stimulation on different muscles/fibre type

Muscles differ bio-chemically and respond differently to cold shortening and conditioning. Red muscles are relatively susceptible to cold shortening but on the other hand are little affected

by electrical stimulation. White muscles are little affected by the conditions that lead to cold shortening (Lawrie, 1998).

Vanderwert et al. (1986) reported that in the *Longissimus* muscle more differences due to electrical stimulation occurred. Vanderwert et al. (1986) also reported that the *adductor*, *semimembranosus*, *longissimus*, *semitendinosus* and *biceps femoris* muscles were found to be ranked from most tender to least tender respectively. Powell et al. (1996) reported that most researchers examine the effect of electrical stimulation on the *Longissimus dorsi* muscle and that this muscle cannot be considered representative of the *semimembranosus* muscle, one of the large deep muscles.

The effect of electrical stimulation is dependent on fibre type. Type I (high percentage slow-twitch-oxidative) fibres are not responding so intensively to electrical stimulation compared to type IIA (high percentage fast-twitch-oxidative-glycolytic) fibres or type IIB (fast-twitch-glycolytic) fibres. The percentage type I fibres are found to be higher in the *longissimus* muscle than the *semimembranosus* muscle, which therefore results in the different effects of electrical stimulation upon these muscles (Den Hertog-Meischke et al., 1997). Brooks and Savell (2004) reported that perimysium thickness was not significantly affected by electrical stimulation (300 Volts, 2.5 A for 16 pulses).

7.17 Effect of electrical stimulation on sarcomeres and sarcomere length

Conflicting results of the effect of electrical stimulation on sarcomeres and sarcomere lengths are well documented. Some researchers found no histological proof of tissue disruption in electrically stimulated (50-60 Hz) muscles but found that severe breaking and contraction of

sarcomeres occurred. Other researchers on the other hand found that electrical stimulation (50-60 Hz) had no increase in muscle tenderness of high ultimate pH, although the extensive tearing and contraction of sarcomeres occurred (Lawrie, 1998).

Uytterhaegen et al. (1992) found that sarcomere length was not affected by electrical stimulation. Electrical stimulation is not linked with permanently shortened sarcomeres (Lawrie, 1998). Kerth et al. (1999) reported that sarcomere lengths were not affected by electrical stimulation. Yanar (2000) found that electrical stimulation significantly affected sarcolemma disruption, contracture banding, cellular tearing and nuclear disorganization but that sarcomere length was not significantly affected. Devine et al. (2001) found no difference in sarcomere length after electrical stimulation. Wiklund et al. (2001) found that the difference between electrically stimulated *longissimus* samples and non-electrically stimulated *longissimus* samples were negligible.

Bruce and Ball (1990) reported that electrical stimulation increased sarcomere length of the muscles aged at high temperatures. Ho et al. (1996) found that electrically stimulation resulted in stretched congregated sarcomeres and an increase of I-band fractures frequency as wells as a slight accelerated degradation of titin, nebulin, and troponin-T. Geesink et al. (2001c) on the other hand found that intense electrical stimulation resulted in a trend towards shorter sarcomeres. Biswas et al. (2007) reported that electrical stimulation resulted in a trend where sarcomere lengths were longer in chevon (goat) meat.

The use of electrical stimulation results in denaturation of sarcoplasmic proteins (Uytterhaegen et al., 1992; Gariépy et al., 1995; Den Hertog-Meischke et al., 1997; Lawrie, 1998; Rhee et al., 2000). Gariépy et al. (1995) and Sams (1999) found that the use of

electrical stimulation causes physical disruption in the muscle. King et al. (2004) on the other hand found that high voltage electrical stimulation had no effect on myofibril fragmentation or sarcomere length. White et al. (2006) reported that electrical stimulation increased the sarcomere length in hot-boned *Semimembranosus* muscle but not in the hot-boned *Longissimus dorsi* muscle.

8. CONCLUSION

It is evident from this literature review that the traditional use of electrical stimulation (ES) in livestock is to stimulate carcasses in order increase the post mortem glycolysis and to reduce cold shortening of the musculature. Impala are known to be more stress sensitive compared to livestock and are more prone to ante mortem stress. Ante mortem stress is also common in indigenous goats. These animals exhibit a high glycolytic potential and it is postulated that a similar condition occurs in impala. Venison in South Africa is usually seen as a dark unattractive meat with a red colour. The effect of electrical stimulation (ES) on the meat colour of venison is an apparent uncertainty. It is also evident from this literature study that there is currently little information available on the effects of electrical stimulation (ES) in African game species. The aim of this research project was to study the effects of electrical stimulation (ES) on the colour and meat quality parameters of impala *Aepyceros melampus*.

In Chapter 3, the materials and methods of this research project are documented. In Chapter 4, the results of this research project are documented. In Chapter 5, the discussion of this research project is documented. In Chapter 6, the conclusion of the research project is documented.

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CHAPTER 3

MATERIALS AND METHODS

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1. HYPOTHESIS

- H_0: Electrical stimulation (ES) of impala (*Aepyceros melampus*) carcasses will influence the subsequent meat quality parameters.
- H_a: Electrical stimulation (ES) of impala (*Aepyceros melampus*) carcasses will not influence the subsequent meat quality parameters.

2. EXPERIMENTAL PROCEDURES

2.1 Experimental animals and study area

For this study a total of 40 impala *Aepyceros melampus* were harvested on Mara Research Station. Animals were obtained during daytime by shooting from vehicles and by the walk and stalk method. Animals were shot high in the neck with .308 calibre scoped rifles and were immediately exsanguinated by cutting the jugular veins and carotid arteries with a sharp knife (Ledger, 1968; Von La Chevallerie & Van Zyl, 1972; Hanks, Cumming, Orpen, Parry, & Warren, 1976; Babiker & Bello, 1986; Blumenschine & Caro, 1986; Lewis, Pinchin & Kestin, 1997). The harvested animals were then taken to the processing facility at Mara Research Station where they were electrically stimulated, eviscerated and the carcasses cleaned according to standard South African and Zimbabwean practices (Hoffman, 2000a & b). The animals were then hung by their Achilles tendon in a cold room at *ca* 4 ºC and left in the cold room for 24 hours with the skin on after which the skin were removed (Von La Chevallerie &

Van Zyl, 1972; Douglas, Macdougall, Shaw, Nute, & Rhodes, 1979; Johnson & McGowan, 1998; Hoffman, 2000a & b; Dhanda, Pegg, Janz, Aalhus & Shand, 2002; Davel, Bosman & Webb, 2003).

The harvesting of impala *Aepyceros melampus* took place from June 2002 to September 2002 at the Mara Research Station (23° 05' S and 29° 25' E; 961 m.a.s.l.) in the Limpopo province, South Africa. Mara is situated 50 km west of Louis Trichardt, which lies south of the Soutpansberg mountain range. According to Acocks (1988) and Low and Rebelo (1998) Mara is situated in the Arid Sweet Bushveld and is 11 000 hectares (ha) in extent. The vegetation found on Mara includes woody species such as *Acacia tortillis*, *Acacia karroo*, *Ziziphus mucronata*, *Commiphora pyracanthoides*, *Boscia albitrunca*, *Combretum imberbe*, *Rhigozum obovatum* and *Grewia* species. The grass species found include *Eragrostis rigidior*, *Schmidtia pappophoroides*, *Panicum maximum*, *Urochloa mosambicensis* and *Digitaria eriantha*. Almost 80 % of the rainfall at Mara occurs from November to March every year with a long term mean annual rainfall of 452 mm (Du Plessis & Hoffman, 2004). According to Dekker, Kirkman and Du Plessis (2001) and Du Plessis and Hoffman (2004) the mean daily maximum temperature ranges from 22.6 °C in June to 30.4 °C in January. Impala occur naturally in the area and are subject to annual population harvesting because they compete with the cattle for grazing and goats for browsing (Kritzinger et al., 2003).

2.2 Electrical stimulation procedure

Impala were randomly electrically stimulated within 40 minutes after being shot. The reason for this being that the nervous system can only be utilised for transmitting electrical impulses within 40 minutes of death, after which the nervous system is no longer suitable for

transmitting electrical impulses (Van Zyl, 2000). Electrical stimulation was applied using a Jarvis BV-80 unit (Jarvis Products Corporation, Middletown, CT) that delivered an electrical charge (230V; 50 Hz for 60 seconds) via a clamp attached to the nose and a steel hook (probe) inserted into the anus (Janz, Aalhus & Price, 2001; Wiklund et al., 2001).

2.3 Experimental groups

The 40 animals were grouped in the following groups and marked accordingly:

Group 1: Electrical stimulation (ES) group consisting of 20 impala of which 10 were male and 10 were female (Experimental group).

Group 2: Non-electrical stimulation (NES) group consisting of 20 impala of which 10 were male and 10 were female (Control group).

2.4 Carcass measurements

The live mass (kg) of each impala was recorded and after dressing the dressed mass-skin-on (kg) was recorded. The dressed out percentage (%) was then calculated per individual animal. After 24 hours in the cooler the skin was taken off and the cold carcass mass-skin off was recorded.

2.5 Physical meat quality analyses

2.5.1 pH

pH readings were taken in the *m. semimembranosus* (SM), *m. semitendinosus* (ST), *m. biceps femoris* (BF), *m. longissimus dorsi (L1-L6)* (LD) and *m. triceps brachii* (TB) muscles (Kerth, Cain, Jackson, Ramsey & Miller, 1999). These readings were taken at 45 minutes, 3, 6, 12 and 24 hours *post mortem* with pH_u at 24 hours (Polidori, Lee, Kauffman & Marsh, 1999;

Pollard, Littlejohn, Asher, Pearse, Stevenson-Barry, McGregor, Manley, Duncan, Sutton, Pollock & Prescott, 2002). pH were measured using a calibrated (standard buffers at pH 4.0 and pH 7.0) Russel model RL100 portable pH meter equipped with a temperature compensating (25 ºC) meat probe (Russel electrode type: KNIpHE) inserted into the SM, ST, BF, LD and TB muscles (Byrne, Troy & Buckley, 2000). A temperature compensating probe was used since a thermometer was not available. The electrode was rinsed with distilled water between each measurement.

2.5.2 Colour

Initial colour measurement on carcass

The colour of the SM, ST, BF, LD and TB muscles were measured after 24 hours using a tristimilus colorimeter (Minolta ChromaMeter CR-2006) (Velarde, Gispert, Diestre & Manteca, 2003). The meter was calibrated to a white Minolta Calibration Plate. The above muscles of 10 ES and 9 NES carcasses were cut and left to bloom. The 10 ES carcasses were divided into 6 males and 4 females. The 9 NES carcasses were divided into 6 males and 3 females. The colour was measured intra muscle on the carcass after a 30 minutes blooming period in the *m. semimembranosus* (SM), *m. semitendinosus* (ST), *m. biceps femoris* (BF), *m. longissimus dorsi et lumborum* (LD) and *m. triceps brachii* (TB) muscles.

Colour measurement in excised muscle

Samples of *m. longissimus dorsi et lumborum* (LD) muscles were excised 24 hours *post mortem* from the 40 animals. The samples were then vacuum packed, frozen and stored at –20 ºC for physical analyses. The samples were thawed for 24 hours at 4 ºC (Stevenson, Seman & Littlejohn, 1992; Davel, Bosman & Webb, 2003). These samples were freshly cut

into steaks and were left to bloom for 30 minutes where after the colour was measured in triplicate, at random areas intra muscle using a tristimilus colorimeter (Minolta ChromaMeter CR-2006) (Hoffman and Fisher, 2001, Wiklund et al., 2001). The colour were expressed in terms of L*, a* and b* values (Commission International de I' Eclairage, 1976), with L* indicating brightness or reflectance, a* the red-green range and b* the blue-yellow range (Babiker & Bello, 1986; Stevenson et al., 1992; Onyango, Izumimoto & Kutima, 1998; Hoffman, 2000b; Dhanda et al., 2002; Peachey, Purchas & Duizer, 2002). Since there are reports on the adverse effects of freezing on muscle colour (Moore & Young, 1991), this study focussed on the colour of muscle directly after slaughter as well as that of frozen samples.

2.5.3 Thaw, cooking and drip losses

Samples of *m. longissimus dorsi et lumborum* LD muscles were excised 24 hours *post mortem*. The samples were then vacuum packed and frozen at –20 ºC until physical analyses (Douglas et al., 1979; Forss, Manley, Platt & Moore, 1979; Stevenson et al., 1992; Wheeler, Shackleford & Koohmaraie, 1996; Wheeler, Shackleford, Johnson, Miller, Miller & Koohmaraie, 1997; Byrne et al., 2000; Bickerstaffe, Bekhit, Robertson, Roberts & Geesink, 2001; Dhanda et al., 2002; Peachey et al., 2002; Davel, Bosman & Webb, 2003). The samples were weighed and then thawed for 24 hours at 4 ºC (Stevenson et al., 1992; Wheeler, Koohmaraie, Cundiff & Dikeman, 1994; Aidoo & Haworth, 1995; Wheeler et al., 1996; Wheeler et al., 1997; Bickerstaffe et al., 2001; Dhanda et al., 2002; Davel et al., 2003). The samples were then blotted dry with Kimwipes® paper towels. The change in mass was recorded and the thaw loss expressed as a percentage. LD steaks were then cut perpendicular to the longitudinal axis of the muscle and were used to determine the cooking loss and drip loss according to Honikel (1998). These steaks were approximately 15 mm thick

and weighed approximately 50 g. Percentage cooking loss was determined by placing the weighed samples in sealed polythene bags into a Labcon water bath, at 80 ºC for 60 minutes (Babiker & Bello, 1986; Stevenson et al., 1992; Bickerstaffe et al., 2001; Wiklund et al., 2001; Pollard et al., 2002). This ensured sufficient heat penetration without resulting in severe denaturation of collagen present in the meat. The samples were then cooled to *ca* 25 ºC by holding it under running water. The mass of the cooked samples was then determined by draining the liquid in the polythene bags and blotting dry the samples with Kimwipes® paper towels. The cooking loss was calculated as total liquid lost, expressed as a percentage of the fresh (pre-cooked) sample (Hoffman 2000a). The cooked samples were kept for tenderness measurements.

Percentage drip loss was determined by placing the weighed samples in a net within an inflated sealed polythene bag without touching the sides of the bag. These samples were then hang in the cold room for 24 hours at 4 ºC. The samples were then blotted dry with Kimwipes® paper towels and were weighed again. The change in mass was recorded and the drip loss expressed as a percentage (Honikel, 1998).

2.5.4 Tenderness (Shear force)

A minimum of 5 sample cores (1.27 cm diameter) from the centre of each cooking loss LD sample was removed for shear force determination (Wheeler et al., 1996; Byrne et al., 2000; Hoffman 2000a, Kritzinger et al., 2003). The samples were cut parallel to the muscle fibre direction (Stevenson et al., 1992; Wheeler et al., 1994; Wheeler et al., 1996; Wheeler et al., 1997; Honikel, 1998; Byrne et al. 2000; Hoffman, 2000a; Davel et al., 2003; Kritzinger et al., 2003). The shear force measuring was done using an Instron Model 1011 apparatus

equipped with a Warner-Bratzler shear device (V-shaped blade) (Janz et al., 2001; Davel et al., 2003). Each cylindrical core was sheared once perpendicular to the grain at a crosshead speed of 200 mm/min (Wheeler et al., 1997; Honikel, 1998. The maximum shear force value (kg/12.7 mm) for each sample was recorded and a mean was then calculated for individual animals (Hoffman, 2000a).

2.6 Ultra structural meat quality analyses

2.6.1 Sarcomere length

Only 5 samples of each group were processed for transmission electron microscopy (TEM). Bundles of muscle fibres of ca. 2 mm thick and ca. 10 mm long were dissected from the *m. longissimus dorsi et lumborum* (LD) muscles at 24 hours *post mortem*. The muscle fibres were tied at both ends with sutures onto a 3 mm thick wooden skewer stick to prevent the muscle fibre from contracting. The samples were fixed separately in 2.5 percent glutaraldehyde in 0.13 M Millonig's buffer. After fixation in 2.5% glutaraldehyde in Millonig's buffer the samples were washed in the same buffer and post-fixed in 1% osmium tetra-oxide in Millonig's buffer. The samples were washed again in the buffer, dehydrated in graded alcohols up to absolute ethanol and placed in propylene oxide (PO). The samples were infiltrated with a mixture of PO and epoxy resin and embedded in absolute resin (100 %) and polymerized at 60 ^{0}C overnight.

Semi-thin sections were stained with toluidine blue for light microscopy to determine that the muscle fibres were correctly orientated. Ultra-thin sections of representative areas were stained with Reynold's lead citrate and uranyl acetate before being examined in a Philips CM10 TEM operated at 80kV (Ackerman, Reinecke & Els, 1994; Ackerman, Reinecke & Els,

1996; Ackerman, Reinecke & Els, 1997a; Ackerman, Reinecke & Els, 1997b; Van Wilpe, pers. comm.). Electron micrographs of intact sarcomeres as well as of sarcomeres exhibiting myofibrillary loss were recorded at a magnification of 21 000 times. The negatives were inverted into positive images using a Hewlett Packard Scanjet 7400C and its associated software. The magnification of the final image on computer was calculated as 31 196.141 times. The average sarcomere length was calculated by measuring 8 random sarcomeres per animal (in µm) utilising the Olympus Image AnalySIS ® software.

2.7 Statistical analyses

Descriptive statistics including Shapiro-Wilk, Kolmogorov-Smirnov, boxplot and normal probability plot were used to determine the range of normal distribution of variables. Measured variables within treatments were analysed by analyses of variance using the software package Statistical Analyses System (SAS, 1999). The main effects that were included in the model were treatment, muscle group and sex. All second order interactions were also included in the model. Correlations between meat characteristics were also determined.

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CHAPTER 4

RESULTS

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1. CARCASS MEASUREMENTS

Average live mass of impala rams was 55.5 kg which was significantly ($p<0.001$) higher than the ewes (46.4 kg) (Table 1). The dressing percentage however did not differ significantly between the sexes where males had a 60.0 % dressing percentage and females a 59.4 % dressing percentage.

Table 1

LS means (± s.e.) for live mass, hot carcass mass, cold carcass mass and dressing percentage of male and female impala.

Sex	N	Live mass (kg)	Hot carcass mass (kg)	Cold carcass mass (kg)	Dressing (%)
Male	20	55.5 [a] ± 1.1	36.1 [a] ± 0.8	32.0 [a] ± 1.3	60.0 ± 0.6
Female	20	46.4 [b] ± 1.1	29.3 [b] ± 0.8	27.0 [b] ± 0.7	59.4 ± 0.6

[a, b] Column means with different superscripts differ significantly ($p<0.001$)

2. PHYSICAL AND ULTRA STRUCTURAL MEAT QUALITY ANALYSES

2.1 pH

All main effects (treatment, sex and muscle group) had a significant ($p<0.001$) effect on the muscle pH. The pH of muscles samples in male and NES carcasses tended to be higher at

0.75, 3, 6 and 12 hours post mortem compared to carcasses from females and ES carcasses. The treatment x sex interaction (Figure 1) was also significant ($p<0.01$). Numerically higher values where recorded for muscle pH at 0.75, 3, 6 and 12 hours post mortem in NES males compared to NES females. No other second order interaction tested significant.

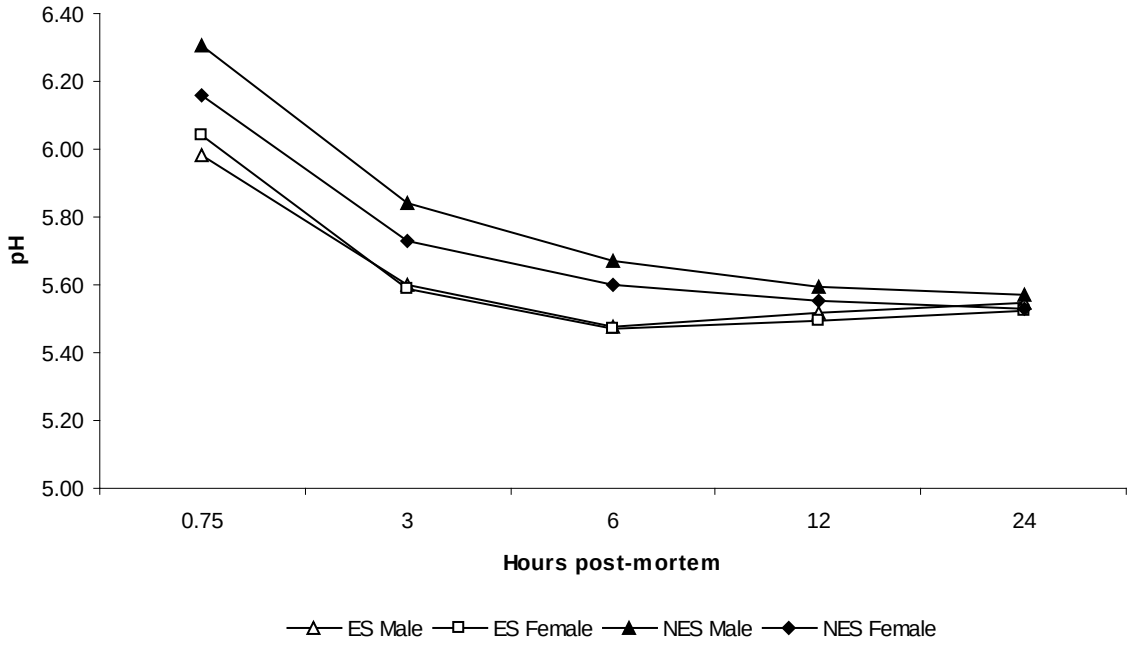

Figure 1 The pH-profile for ES and NES male and female impala.

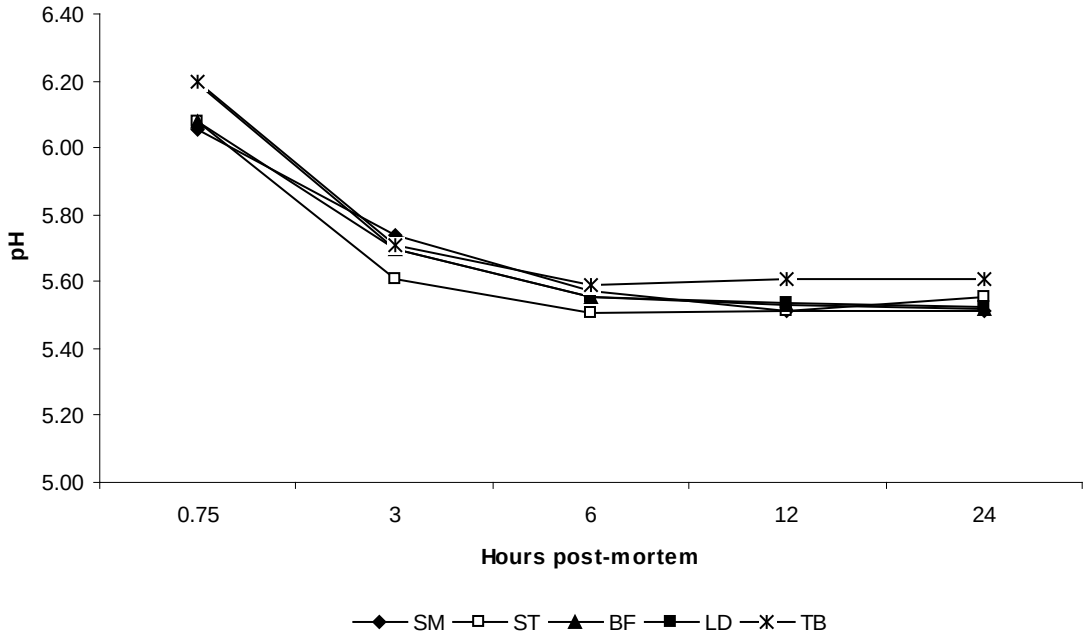

Figure 2 The pH-profile for *m. semimembranosus* (SM), *m. semitendinosus* (ST), *m. biceps femoris* (BF), *m. longissimus dorsi et lumborum* (LD) and *m. triceps brachii* (TB) muscles.

TB had a numerically higher pH_u value than BF, LD, SM and ST (Figure 2). Other comparisons of muscles revealed no significant differences in initial rate of pH decline in relation to each other.

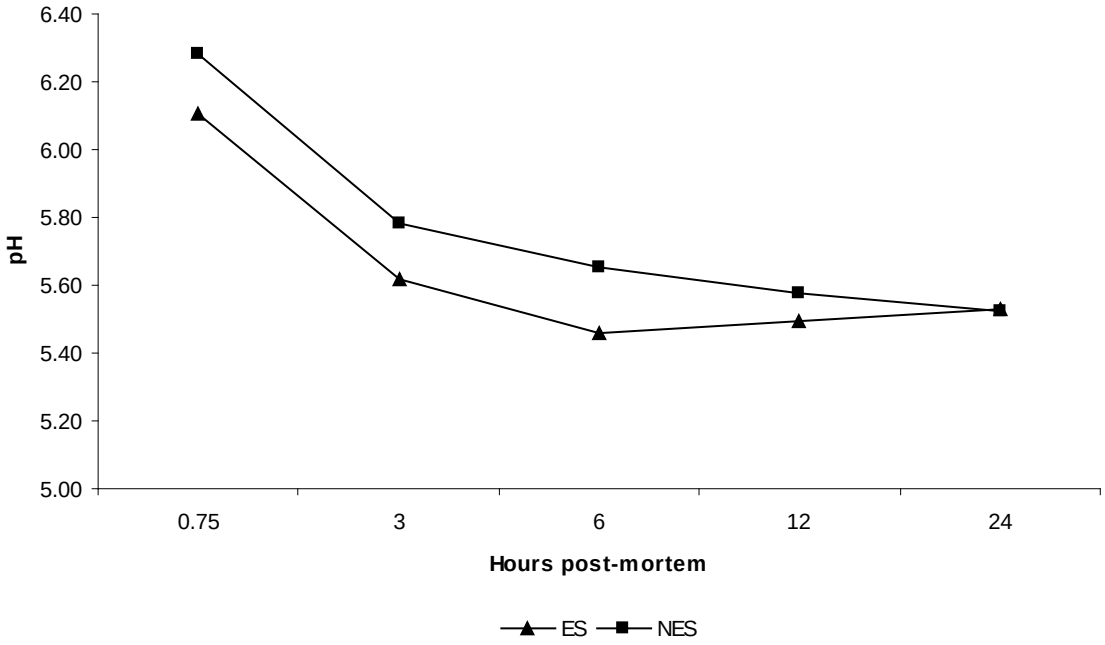

Figure 3 Mean pH profiles in *m. longissimus dorsi et lumborum* (LD) of impala subjected to two treatments; electrical stimulation (ES) and non-electrical stimulation (NES) measured at 0.75, 3, 6, 12, and 24 hours post mortem.

Numerically higher values where recorded for *m. longissimus dorsi et lumborum* (LD) muscle pH at 0.75, 3, 6 and 12 hours post mortem in NES impala compared to ES impala (Figure 3).

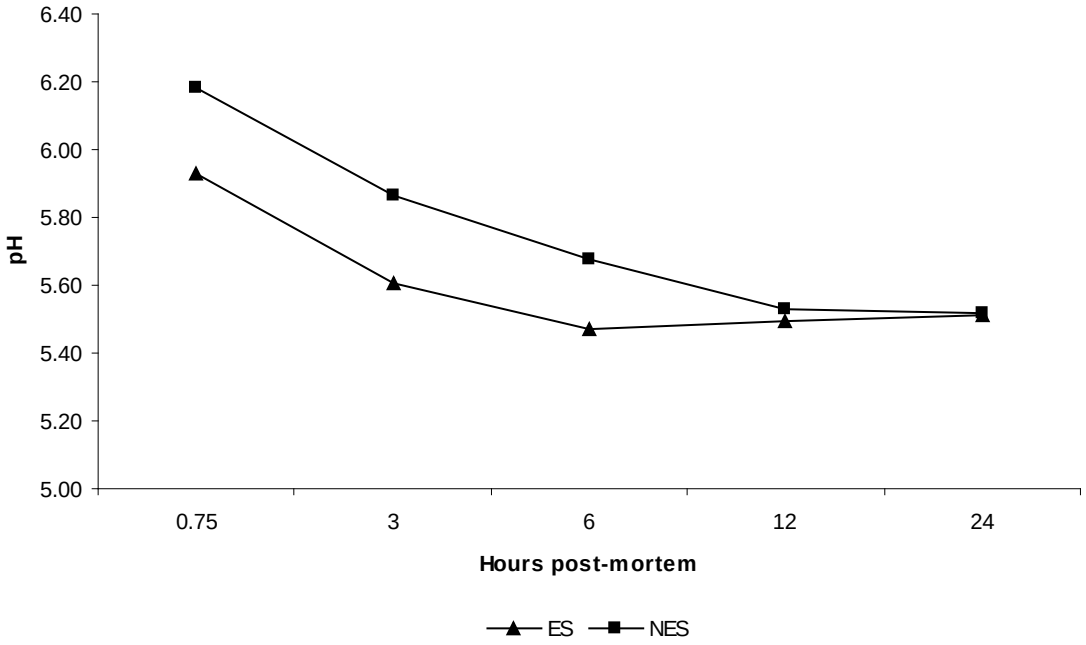

Figure 4 Mean pH profiles in *m. semimembranosus* (SM) of impala subjected to two treatments; electrical stimulation (ES) and non-electrical stimulation (NES) measured at 0.75, 3, 6, 12, and 24 hours post mortem.

Numerically higher values where recorded for *m. semimembranosus* (SM) muscle pH at 0.75, 3, 6, 12 and 24 hours post mortem in NES impala compared to ES impala (Figure 4).

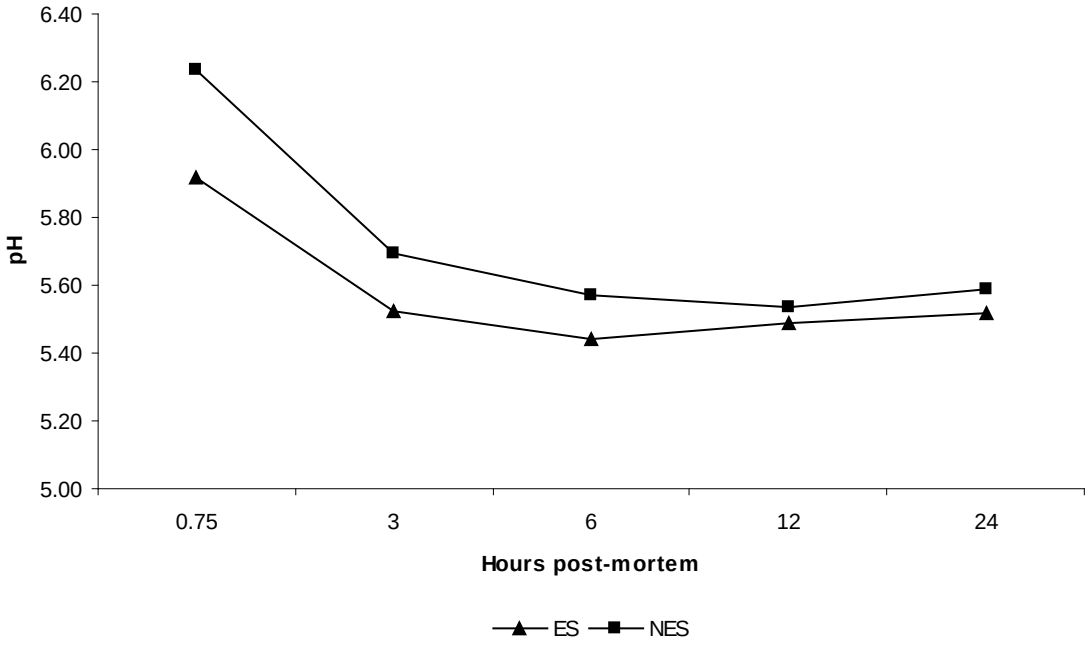

Figure 5 Mean pH profiles in *m. semitendinosus* (ST) of impala subjected to two treatments; electrical stimulation (ES) and non-electrical stimulation (NES) measured at 0.75, 3, 6, 12, and 24 hours post mortem.

Numerically higher values where recorded for *m. semitendinosus* (ST) muscle pH at 0.75, 3, 6, 12 and 24 hours post mortem in NES impala compared to ES impala (Figure 5).

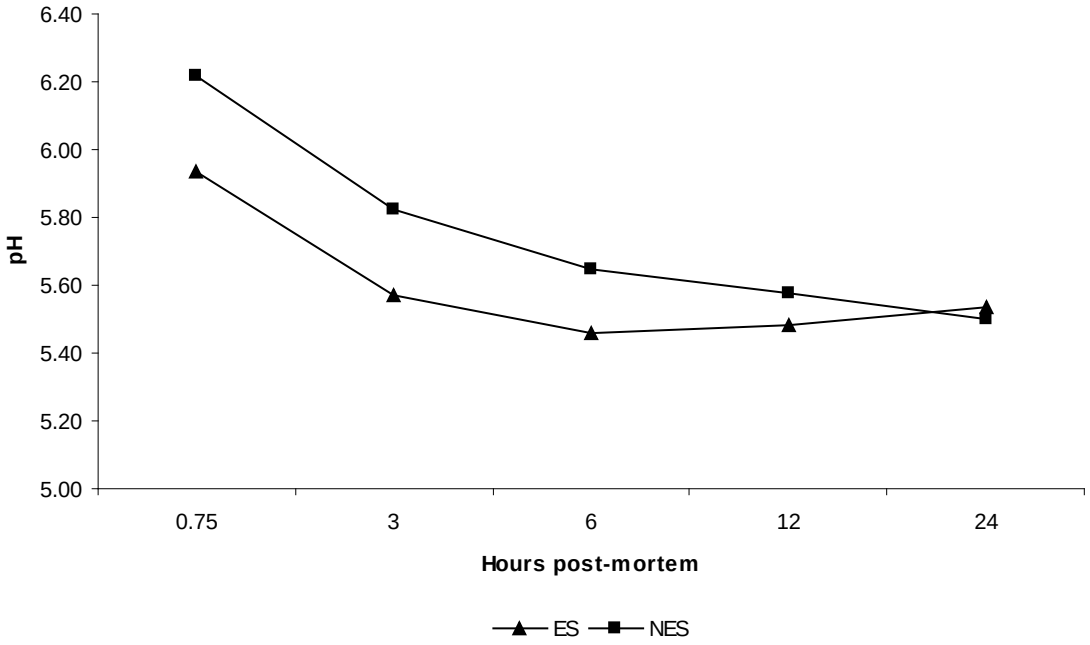

Figure 6 Mean pH profiles in *m. biceps femoris* (BF) of impala subjected to two treatments; electrical stimulation (ES) and non-electrical stimulation (NES) measured at 0.75, 3, 6, 12, and 24 hours post mortem.

Numerically higher values where recorded for *m. biceps femoris* (BF) muscle pH at 0.75, 3, 6 and 12 hours post mortem in NES impala compared to ES impala (Figure 6).

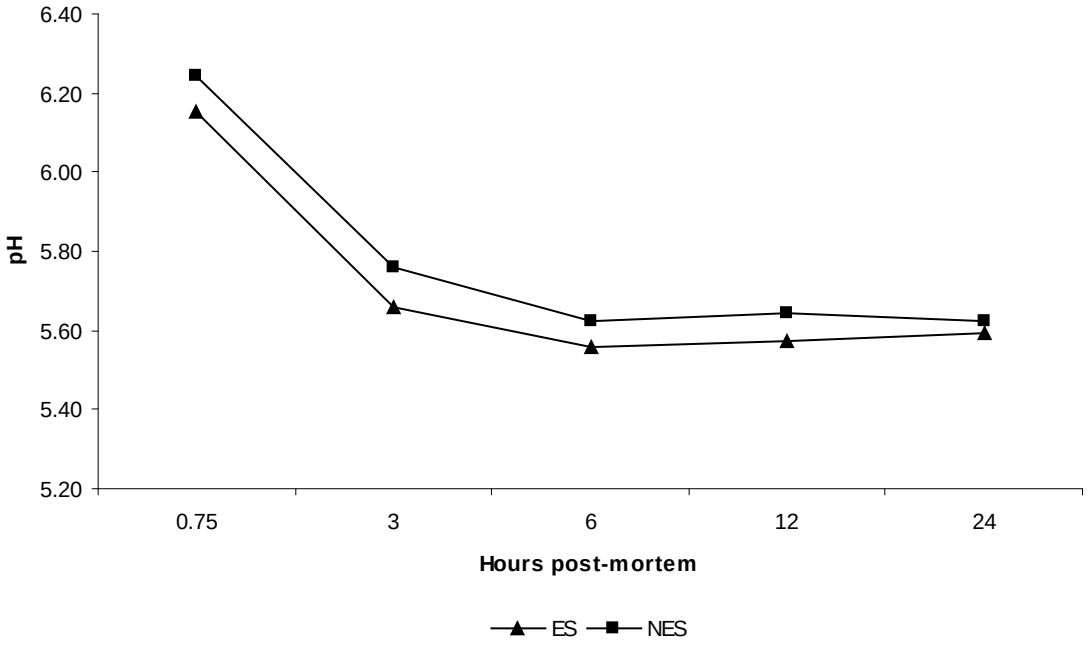

Figure 7 Mean pH profiles in *m. triceps brachii* (TB) of impala subjected to two treatments; electrical stimulation (ES) and non-electrical stimulation (NES) measured at 0.75, 3, 6, 12, and 24 hours post mortem.

Numerically higher values where recorded for *m. triceps brachii* (TB) muscle pH at 0.75, 3, 6, 12 and 24 hours post mortem in NES impala compared to ES impala (Figure 7).

Electrical stimulation only had a significant ($p<0.05$) effect on the pH_u-value of *m. semitendinosus*, with muscles from the ES group having a lower pH_u (pH 5.52 ± 0.02) than muscles from the NES group (pH 5.59 ± 0.02) (Table 2). No significant differences were observed between ES and NES for the pH_u-values of *m. semimembranosus*, *m. biceps femoris*, *m. longissimus dorsi et lumborum* and *m. triceps brachii*. Sex only had a significant ($p<0.05$) effect on the pH_u-value of the *m. triceps brachii*, with muscles from the male group

Table 2

The LS means (± s.e.) of the ultimate pH (pH_u) in *m. semimembranosus* (SM), *m. semitendinosus* (ST), *m. biceps femoris* (BF), *m. longissimus dorsi et lumborum* (LD) and *m. triceps brachii* (TB) muscles for the pertinent sex and treatment groups.

	pH_u SM (n)	pH_u ST (n)	pH_u BF (n)	pH_u LD (n)	pH_u TB (n)
ES	5.51^{a} ± 0.02 (20)	5.52^{a} ± 0.02 (20)	5.53^{a} ± 0.02 (20)	5.53^{a} ± 0.02 (20)	5.59^{a} ± 0.02 (20)
NES	5.52^{a} ± 0.02 (20)	5.59^{b} ± 0.02 (20)	5.50^{a} ± 0.04 (20)	5.52^{a} ± 0.03 (20)	5.63^{a} ± 0.02 (20)
Male	5.52^{c} ± 0.02 (20)	5.58^{c} ± 0.03 (20)	5.51^{c} ± 0.04 (20)	5.55^{c} ± 0.02 (20)	5.64^{c} ± 0.02 (20)
Female	5.51^{c} ± 0.02 (20)	5.53^{c} ± 0.02 (20)	5.52^{c} ± 0.02 (20)	5.51^{c} ± 0.03 (20)	5.58^{d} ± 0.02 (20)

[a, b] Column means between treatment groups with different superscripts differ significantly ($p<0.05$)

[c, d] Column means between sex groups with different superscripts differ significantly ($p<0.05$)

ES = Electrical stimulation NES = Non-electrical stimulation

having a higher pH_u (pH 5.64 ± 0.02) than muscles from the female group (pH 5.58 ± 0.02) (Table 2). No significant differences were observed between males and females for pH_u of *m. semimembranosus*, *m. semitendinosus*, *m. biceps femoris* and *m. longissimus dorsi et lumborum*. The treatment x sex interaction was not significant.

2.2. Colour

Electrical stimulation only had a significant ($p<0.05$) effect on the L^*_{24}-value of the *m. biceps femoris* muscle, with muscles from the ES group (35.8 ± 0.08) being lighter than muscles from the NES group (33.1 ± 0.08) (Table 3). No significant differences were observed between ES and NES for the a^*_{24-} and b^*_{24}-values for all muscle groups. The L*-, a*- and b*-values of the ES and NES *m. longissimus dorsi et lumborum* muscle declined significantly ($p<0.001$) from 24 hours post mortem to post freeze-thaw. However the change in L*-, a*- and b*-values from 24 hours post mortem to post freeze-thaw was similar for ES and NES *m. longissimus dorsi et lumborum* muscle. ES also had no significant effect on the L^*_{F-} and a^*_F-values of the *m. longissimus dorsi et lumborum* muscle. ES however, had a significant ($p<0.05$) effect on the b^*_F-values. The b^*_F-value for ES meat (7.1 ± 0.1) was higher (more blue) than NES meat (6.5 ± 0.2).The muscle x treatment interaction was not significant. A significant difference ($p<0.01$) was found before and after freezing between the L*-values, a*-values and b*-values for both the ES and NES groups except for the NES b*-value ($p = 0.0638$), which however showed a tendency to differ.

Table 3

The LS means (s.e.) for the brightness, red-green, blue-yellow colour range at 24 hours post mortem and post thaw for electrically stimulated and non electrically stimulated *m. semimembranosus* (SM), *m. semitendinosus* (ST), *m. biceps femoris* (BF), *m. longissimus dorsi et lumborum* (LD) and *m. triceps brachii* (TB) muscles.

	n	L^*_{24}	a^*_{24}	b^*_{24}	n	L^*_F	a^*_F	b^*_F
				M. longissimus dorsi et lumborum				
ES	10	$33.7^a \pm 0.8$	$18.5^a \pm 0.8$	$8.5^a \pm 0.6$	20	$29.4^a \pm 0.3$	$13.9^a \pm 0.4$	$7.1^a \pm 0.1$
NES	9	$34.0^a \pm 0.8$	$17.5^a \pm 0.8$	$7.8^a \pm 0.6$	20	$29.2^a \pm 0.3$	$12.9^a \pm 0.4$	$6.5^b \pm 0.2$
				M. biceps femoris				
ES	10	$35.8^a \pm 0.8$	$16.4^a \pm 0.8$	$7.8^a \pm 0.6$				
NES	9	$33.1^b \pm 0.8$	$15.0^a \pm 0.8$	$6.3^a \pm 0.6$				
				M. semimembranosus				
ES	10	$33.8^a \pm 0.8$	$15.9^a \pm 0.8$	$5.9^a \pm 0.6$				
NES	9	$33.2^a \pm 0.8$	$14.0^a \pm 0.8$	$4.9^a \pm 0.6$				
				M. semitendinosus				
ES	10	$40.7^a \pm$	$12.1^a \pm$	$4.1^a \pm 0.6$				

		0.8	0.8	
NES	9	39.3[a] ± 0.8	11.6[a] ± 0.8	3.6[a] ± 0.6
			M. triceps brachii	
ES	10	35.3[a] ± 0.8	20.7[a] ± 0.8	8.9[a] ± 0.6
NES	9	34.3[a] ± 0.8	18.6[a] ± 0.8	7.0[a] ± 0.6

[a, b,] Column means within muscle groups with different superscripts differ significantly ($p<0.05$)

ES = Electrical stimulation

NES = Non-electrical stimulation

L_{24} = Lightness at 24 hours PM

a_{24} = Red-green range at 24 hours PM

b_{24} = Yellow-blue range at 24 hours PM

L_F = Lightness post thaw

a_F = $_{Red}$-green range post thaw

b_F = Yellow-blue range post thaw

2.3 Thaw loss, drip loss, cooking loss, pH_u, Sarcomere length, F-break and tenderness (shear force)

No significant differences were observed between ES and NES for the thaw loss, drip loss, cooking loss, pH_u, sarcomere length and shear force for the *m. longissimus dorsi et lumborum* muscle (Table 4). Sex only had a significant ($p<0.05$) effect on the thaw loss and cooking loss for the *m. longissimus dorsi et lumborum* muscle (Table 4). No significant differences were observed between male and female for the drip loss, pH_u values, sarcomere length and shear force for the *m. longissimus dorsi et lumborum* muscle. The treatment x sex interaction was not significant.

Table 4

The LS means (± s.e.) for thaw loss (%), drip loss (%), cooking loss (%), pH_u values, sarcomere length (µm) and shear force (kg/1.27cm) in *m. longissimus dorsi et lumborum* (LD) muscle for the pertinent sex and treatment groups.

	Thaw loss (%) (n)	Drip loss (%) (n)	Cooking loss (%) (n)	pH_u LD (n)	Sarcomere length (µm) (n)	Shear force (kg/1.27cm) (n)
ES	1.5^{a} ± 0.3 (20)	4.5^{a} ± 0.3 (20)	30.1^{a} ± 0.7 (20)	5.53^{a} ± 0.02 (20)	1.3^{a} ± 0.05 (10)	1.6^{a} ± 0.08 (20)
NES	1.7^{a} ± 0.2 (20)	4.6^{a} ± 0.3 (20)	30.5^{a} ± 0.5 (20)	5.52^{a} ± 0.03 (20)	1.3^{a} ± 0.05 (10)	1.8^{a} ± 0.09 (20)
Male	1.2^{a} ± 0.2 (20)	4.3^{a} ± 0.3 (20)	31.2^{a} ± 0.5 (20)	5.55^{a} ± 0.02 (20)	1.3^{a} ± 0.05 (10)	1.7^{a} ± 0.09 (20)
Female	2.0^{b} ± 0.3 (20)	4.8^{a} ± 0.3 (20)	29.4^{b} ± 0.6 (20)	5.51^{a} ± 0.03 (20)	1.3^{a} ± 0.05 (10)	1.7^{a} ± 0.09 (20)

$^{a, b,}$ Column means different superscripts differ significantly ($p<0.05$)

ES = Electrical stimulation NES = Non-electrical stimulation

pH_u = Ultimate pH at 24 hours PM

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CHAPTER 5

DISCUSSION

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1. Carcass measurements

Impala are medium sized antelope where the live mass of males varies between 60-65 kg for males and 40-45 kg for females (Jarman & Jarman, 1973; Lewis, Pinchin & Kestin, 1997; Bothma, 2002). Hitchins (1966) and Anderson (1982) reported that adult male impala in Africa has a live mass range of 59 – 73 kg. In the present study however, males weighed 55.5 kg and females weighed 46.4 kg which is similar to the male and female mass reported by Fairall (1983); Skinner and Smithers (1990) and Hoffman (2000a). The female mass in this study also correlated with the female mass of Jarman and Jarman (1973); Lewis, Pinchin and Kestin (1997) and Bothma (2002). Hoffman, Kritzinger and Ferreira (2005) however reported higher masses which might be due to the fact that they only used mature (48-54 months) animals in their study. The different live masses reported by researchers might be due to a few factors namely: the type and quality of scale that's been used, the time of the year when the animals are weighed, the age of the animal, quality of habitat and region and if the animals were bled before weighing. All these factors will play a significant role on the live mass that is recorded. Adult male animals that are weighed after the rut season will have a significant lower mass than males that are weighed before the rut season.

Dressing percentage plays a significant role in meat production (Ledger, 1963; Hanks, Cumming, Orpen, Parry, & Warren, 1976). The majority of dressing percentages of wild

ungulates varies between 55 % and 61 % (Ledger, 1963; Hitchins, 1966; Von La Chevallerie, 1970; Monroe & Skinner, 1979). Fairall (1983), De Bruyn (1993), Lewis et al. (1997) and Hoffman (2000a) reported dressing percentage of 57 % to 58 % for male and female impala. In the present study average dressing percentages of 60 % for male and 59.4 % for female impala were found which agrees with the values reported by Kritzinger et al. (2003) in the same study area. The different dressing percentages reported by researchers might be due to different methods in determining dressing percentages. Some researchers leave the skin on and some skin the animal before determining the dressing percentage. This will result in totally different dressing percentages whereby with the skin on will have higher dressing percentages than without the skin. Animals that are left in the chiller with the skin on will also have a lower mass loss over time than an animal that was placed in the chiller without a skin due to the latter being more susceptible to surface drying. Time after dressing the carcass will also have an effect on the dressing percentage in that the more time that elapses after slaughter before the carcass is dressed the more mass the animal will loose due to surface drying and body fluids lost. In the present study the animal was bled immediately after death and the skin was taken off at 24 hours post mortem and this data was used to calculate the dressing percentage. The temperature of the chiller, type of chiller, type of blowers and humidity will also have an effect if animals are placed in a chiller for a certain time before the dressed mass are recorded.

2. pH

It is well documented that the use of electrical stimulation (ES) maximises the pH decline early post mortem in beef, veal, lamb, deer, chicken, goat and pork (Dutson et al., 1982; Solomon et al., 1986a; Etherington et al., 1990; Uytterhaegen et al., 1992; Gariépy et al.,

1995; Soares & Arêas, 1995; Taylor et al., 1995; Berry et al., 1996; Eilers et al., 1996; Powell et al., 1996; Tornberg, 1996; Lawrie, 1998; Hildrum et al., 1999; Kerth et al., 1999; Morton et al., 1999; Polidori et al., 1999; Ferguson et al., 2000; Lee et al., 2000; Vergara & Gallego, 2000; Hwang & Thompson, 2001a; Hwang & Thompson, 2001b; Janz et al., 2001; McGeehin, , Sheridan & Butler, 2001a; Rhee & Kim, 2001; Wiklund et al., 2001; Devine et al., 2002a; Davel et al., 2003; Rees et al., 2003a; Rees et al., 2003b; King et al., 2004; Li et al., 2006; White, O'Sullivan, Troy & O'Neill, 2006; Biswas et al., 2007; Ferreira et al., 2006). Impala are known to be more stress sensitive compared to livestock and are more prone to ante mortem stress. In this study the effects of ES on muscle pH was of particular interest since impala has a high glycolytic potential which is postulated to be similar to indigenous goats, and thus the effects were uncertain. This research provided the answers whereby electrical stimulation also resulted in a significant ($p<0.001$) increase in the rate of pH decline early post mortem for impala. In the five muscles where pH was measured, ES increased the pH decline significantly ($p<0.001$) for *m. semimembranosus* (SM), *m. semitendinosus* (ST), *m. biceps femoris* (BF) and *m. longissimus dorsi et lumborum* (LD). In the *m. triceps brachii* (TB) muscle however, ES only had a tendency ($p=0.0960$) to increase the pH decline. Den Hertog-Meischke et al. (1997) reported similar results for *m. longissimus thoracis* (LT) and *m. semimembranosus* (SM) in bovine but mentioned that the LT muscle was less influenced by ES. Wiklund et al. (2001) on the other hand reported that ES had a significant increase in pH decline for LD, TB and BF in red deer. Species will also have an effect on the initial pH and initial pH decline whereby game animals are normally more active and stressed than domestic animals. Activity and stress of the animal before harvesting will have an effect on the initial pH decline where a stressed and highly active animal will have a higher initial pH

after harvesting. Such an animal will have a lower initial pH decline compared to an animal that was not very active or stressed before harvesting.

In the present study electrical stimulation only had a significant ($p<0.05$) effect on the pH_u-value of ST (pH 5.52 ± 0.02) while no significant ($p>0.05$) differences were observed between ES and NES for the pH_u-values of SM, BF, LD and TB. Wiklund et al. (2001) reported that the ES had a significant effect on the pH_u-value of LD but not for TB and BF. Ferguson et al. (2000) reported that ES had a significant effect on the pH_u-value of beef LD. Dutson et al. (1982) and Ferreira et al. (2006) on the other hand reported that ES had no significant effect on the pH_u-value of beef LD. Kerth et al. (1999) also reported that ES had no significant effect on the pH_u-value of lamb ST, SM, LD, TB and *supraspinatus* (SP). The different results in terms of the effect of ES on different muscles might be due to the response of different muscle fibre types to ES whereby muscles with a higher percentage (type I) fibres respond less to ES and muscles with a higher percentage (Type IIA, Type IIB) respond more to ES (Den Hertog-Meischke et al., 1997; Lawrie, 1998). Another factor which might contribute to this might be the orientation of current-flow to fibre direction as the fibre direction in muscles varies. If ES occurs across the fibre direction then the ES effect is much lower (Lawrie, 1998). During post mortem anaerobic glycolysis, glycogen produces lactic acid which in turn determines the pH of meat. Thus if the initial concentration of glycogen is lower then the amount of lactic acid will also be lower resulting in a higher muscle pH. The different results reported by researchers on the effect of ES on pH_u might be due to the different initial concentrations of glycogen in the animals tested. The effect of ES on pH_u will decrease where the concentration of glycogen is lower in animals (Hammelman et al., 2003). Other factors that also contribute to different results in terms of the effectiveness of ES are type of current

e.g. different voltages, intact carcasses versus split carcasses because of intrinsic electrical resistance, time lapses between slaughter and ES as the ES effect will decrease with an increase in time before stimulation as the pathways decay with time (Lawrie, 1998).

Sex only had a significant ($p<0.05$) effect on the pH_u-value of the TB, with muscles from the male group having a higher pH_u (pH 5.64 ± 0.02) than muscles from the female group (pH 5.58 ± 0.02). No significant ($p>0.05$) differences were observed between males and females for pH_u of SM, ST, BF and LD. The treatment x sex interaction was not significant ($p>0.05$). Males are normally more physically active than females and in doing so deplete more glycogen in the process which will then produces less lactic acid and ultimately a higher pH.

3. Colour

Colour as a visual measure indicates quality and freshness to consumers (Ferreira et al., 2006; Bekhit et al., 2007). The appearance of the meat surface to the consumer depends on numerous factors, which includes the quantity of myoglobin present, the type of myoglobin molecule as well as the chemical and physical condition of other components in the meat (Lawrie, 1998; Zhu & Brewer, 2002). The colour pigments of myoglobin, oxymyoglobin and metmyoglobin are purplish-red, bright red and brown respectively (Lawrie, 1998; Byrne et al., 2000; Ferreira et al., 2006; Bekhit et al., 2007). Bekhit et al. (2007a) reported that venison meat colour is less stable than other species. Species, breed, sex, age, muscle type and amount of training also effects meat colour (Lawrie, 1998). Venison meat colour is darker than domestic animals as they are more active (Hoffman, 2000b).

Electrical stimulation results in paler meat with an improved bright red colour on cut meat surfaces at 24 hours post mortem (Dutson et al., 1982; Powell et al., 1996; Lawrie, 1998; Kerth et al., 1999; Vergara & Gallego, 2000; Janz et al., 2001; Wiklund et al., 2001; Davel et al., 2003; King et al., 2004; Strydom et al. 2005). Impala are more active than livestock and have darker meat which may be attributed to the elevated levels of myoglobin present in the muscle meat (Kritzinger et al., 2003). In the present study ES only had a significant ($p<0.05$) effect on the L^*_{24}-value of the BF muscle and not on the SM, LD, ST and TB muscles. The BF muscle from the ES group ($L^*_{24} = 35.8 \pm 0.8$) was lighter than the NES group ($L^*_{24} = 33.1 \pm 0.8$).

No significant differences were observed between ES and NES for a^*_{24}- and b^*_{24}-values for all muscle groups. Dutson et al. (1982) and Ferreira et al. (2006) reported similar results where ES had no colour improvement on beef LD. Wiklund et al. (2001) and Bekhit also reported that ES had no effect on a*- value of venison LD. Strydom et al. (2005) also reported that ES did not significantly affected the L*-, a*- and b*-values of beef LD.

In this study a significant difference ($p<0.001$) was found in *m. longissimus dorsi et lumborum* muscle before and after freeze-thawing between the L*-values, a*-values and b*-values for both the ES and NES groups except for the NES b*-value ($p = 0.638$), which however showed a tendency to differ. The change in L*-, a*- and b*-values from 24 hours post mortem to post thaw however was similar for *m. longissimus dorsi et lumborum* muscle from ES and NES carcasses. ES also had no significant effect on the L^*_{F-} and a^*_F-values of the *m. longissimus dorsi et lumborum* muscle. ES however, had a significant ($p<0.05$) effect on the b^*_F-values. The b^*_F-value for ES meat was higher ($b^*_F = 7.1 \pm 0.1$) than NES meat ($b^*_F = 6.5 \pm 0.2$).

Moore and Young (1991) reported that ES adversely affected the colour of lamb that was freeze-thawed, which might be due to tissue damage after ES and then further worsening by freezing and thawing. The muscle x treatment interaction was not significant.

Hoffman (2000b) reported impala colour values of L* = 29.22 ± 0.59, a* = 11.26 ± 0.319 and b* 7.36 ± 0.266 on fresh LD in a study in Zimbabwe where the animals was harvested at night. Kritzinger et al. (2003) reported impala colour values of L* = 30.10 ± 1.296, a* = 13.19 ± 1.475 and b* 9.42 ± 1.780 on fresh LD where animals were also harvested at night. The impala Kritzinger et al. (2003) harvested during the day had colour values of L* = 30.53 ± 2.785, a* = 12.52 ± 1.361 and b* 8.75 ± 1.422. Kritzinger et al. (2003) harvested impala in exactly the same area as the present study. The impala harvested in the present study was harvested during the day and in the same area as Kritzinger et al. (2003). The present study recorded different L*-, a*- and b*-values on fresh impala LD on both ES and NES animals compared to the studies of Hoffman (2000b) and Kritzinger et al. (2003). In the present study ES animals had colour values of L* = 33.7 ± 0.8, a* = 18.5 ± 0.8 and b* 8.5 ± 0.6 while NES animals had colour values of L* = 34.0 ± 0.8, a* = 17.5 ± 0.8 and b* 7.8 ± 0.6 for fresh impala LD. The freeze-thawed impala LD in the present study for ES animals had colour values of L* = 29.4 ± 0.3, a* = 13.9 ± 0.4 and b* 7.1 ± 0.1 while the NES animals had colour values of L* = 29.2 ± 0.3, a* = 12.9 ± 0.4 and b* 6.5 ± 0.2. The LD freeze-thawed L*-, a*- and b*-values in the present study are very similar to the L*-, a*- and b*-values reported on fresh LD in the studies of Hoffman (2002b) and Kritzinger et al. (2003). The reason for these different results on fresh LD might be due to different colour meters been used for colour measurements. Both Hoffman (2000b) and Kritzinger et al. (2003) used a Colour-guide $45^0/0^0$ colorimeter (BYK-

Gardener, USA) while a tristimilus colorimeter (Minolta ChromaMeter CR-2006) was used in the present study.

4. Thaw loss, drip loss and cooking loss

The rapid decline of pH after electrical stimulation enhances the intracellular osmotic pressure, which leads to the loss of water-holding capacity by the muscle proteins (Lawrie, 1998; Geesink et al., 2001a; Wiklund et al., 2001). Lawrie (1998) however, reported that electrical stimulation did not lead to immediate drip loss in bovine muscle but that some eventual drip loss occurred after some time. Taylor et al. (1995), Den Hertog-Meischke et al. (1997), Strydom et al. (2005) and Biswas et al. (2007) also found that the use of ES resulted in a slightly higher drip loss when compared with NES carcasses. Janz et al. (2001) and Wiklund et al. (2001), Channon et al. (2003a; 2003b), Rees et al. (2003a; 2003b) and Bekhit et al. (2006) however, found that the use of ES had no difference in drip loss when compared with NES carcasses. Moore and Young (1991) also reported that the drip from ES lamb was clearer than that from NES lamb. The present study also had no significant differences between the drip loss and thaw loss of ES and NES impala carcasses. Den Hertog-Meischke et al. (1997) also reported no difference in thaw loss between ES and NES carcasses. In the present study sex had a significant ($p<0.05$) effect on the thaw loss and cooking loss for the *m. longissimus dorsi et lumborum* muscle but no significant differences were observed between male and female for the drip loss. The treatment x sex interaction was not significant.

Uytterhaegen et al. (1992), Berry et al. (1996) and Li et al. (2006) reported that ES increased cooking losses in beef. Gariépy et al. (1995), Geesink et al. (2001a), Devine et al. (2002a)

and Bekhit et al. (2006) on the other hand, reported that ES had no effect on cooking losses. In the present study no significant difference was observed between ES and NES for the cooking loss.

The different results in drip loss, thaw loss and cooking loss might be due to different species being used. Different methods in determining drip loss, thaw loss and cooking will also lead to different results among researchers. Different methods of ES and different voltages used will also lead to different results among researchers.

5. Tenderness (shear force) and sarcomere length

The effect of electrical stimulation on meat tenderness produced considerable conflicting results and disagreement among researchers (Solomon et al., 1986a; Stevenson et al., 1992; Tornberg, 1996; Lawrie, 1998; Hildrum et al., 1999; Ferguson et al., 2000; Wiklund et al., 2001; Davel et al., 2003; Hwang et al., 2003; Strydom et al., 2005; Bekhit et al., 2006; Stolowski et al., 2006; Biswas et al., 2007). Some researchers report that electrical stimulation prevents cold shortening whilst other researchers report that electrical stimulation increase meat tenderness due to sarcomere rest lengths being longer. Other researchers report that early and extensive conditioning results from the combination of low pH with *in vivo* temperatures, which enhances proteolysis and leads to an increase in meat tenderness. Some researchers on the other hand reported that electrical stimulation does not lead to any significant improvement in meat tenderness (Lawrie, 1998). In the present study ES had no significant effect on the shear force of impala LD.

Conflicting results of the effect of electrical stimulation on sarcomeres and sarcomere lengths are well documented. Some researchers found no histological proof of tissue disruption in electrically stimulated (50-60 Hz) muscles but found that severe breaking and contraction of sarcomeres occurred. Other researchers on the other hand found that electrical stimulation (50-60 Hz) had no increase in muscle tenderness of high ultimate pH, although the extensive tearing and contraction of sarcomeres occurred (Lawrie, 1998). Uytterhaegen et al. (1992) found that sarcomere length was not affected by electrical stimulation. Electrical stimulation is not linked with permanently shortened sarcomeres (Lawrie, 1998). Kerth et al. (1999) reported that sarcomere lengths were not affected by electrical stimulation. Devine et al. (2001) found no difference in sarcomere length after electrical stimulation. Wiklund et al. (2001) found that the difference between electrically stimulated *longissimus* samples and non-electrically stimulated *longissimus* samples were negligible. In the present study ES had no significant effect on the sarcomere length of impala LD. Biswas et al. (2007) however, reported that electrical stimulation resulted in a trend where sarcomere lengths were longer in chevon (goat) meat. White et al. (2006) also reported that electrical stimulation increased the sarcomere length in hot-boned *Semimembranosus* muscle but not in the hot-boned *Longissimus dorsi* muscle.

The reason for the different results among researchers might be due to a few factors namely: Different species used, different sexes and different ages of animals, different ES methods, different voltages and time duration used, fresh versus frozen samples, half carcasses versus whole carcasses, different muscles being used and fat versus lean carcasses.

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CHAPTER 6

CONCLUSIONS

The live mass and dressing percentages of impala in this study agrees with live mass and dressing percentages reported in previous studies.

The use of electrical stimulation (ES) maximises the pH decline early post mortem. In the present study ES also resulted in a significant increase in the rate of pH decline early post mortem for impala. In the five muscles where pH was measured, ES increased the pH decline significantly for *m. semimembranosus* (SM), *m. semitendinosus* (ST), *m. biceps femoris* (BF) and *m. longissimus dorsi et lumborum* (LD). In the *m. triceps brachii* (TB) muscle however, ES only had a tendency to increase the pH decline.

The effect of electrical stimulation (ES) on muscle pH was significant at 0.75, 3, 6 and 12 hours post mortem while no differences where observed at 24 hours post mortem (pHu) for all the muscles except for *m. semitendinosus* (ST). In this study sex only had a significant effect on the pH_u-value of the TB, with muscles from the male group having a higher pHu than muscles from the female group. Males are normally more physically active than females and in doing so deplete more glycogen in the process which will then produce less lactic acid and ultimately cause a higher pH.

The use of electrical stimulation (ES) results in paler meat with an improved bright red colour on cut meat surfaces at 24 hours post mortem. In the present study ES only had a significant effect on the L^*_{24}-value of the BF muscle and not on the SM, LD, ST and TB muscles whereby the BF muscle from the ES group was lighter than the NES group. No significant differences were observed between ES and NES for a^*_{24}- and b^*_{24}-values for all muscle groups.

The rapid decline of pH after electrical stimulation (ES) enhances the intracellular osmotic pressure adequately, which leads to the loss of water-holding capacity by the muscle proteins. In the present study no significant differences between the drip loss, thaw loss and cooking loss of ES and NES impala carcasses were found. Sex however had a significant effect on the thaw loss and cooking loss for the *m. longissimus dorsi et lumborum* muscle but no significant differences were observed between males and females for drip loss.

The effect of electrical stimulation (ES) on meat tenderness produces considerable conflicting results and disagreement among researchers. In the present study ES had no significant effect on the shear force of impala LD. Conflicting results of the effect of ES on sarcomeres and sarcomere lengths are well documented. In the present study ES had no significant effect on the sarcomere length of impala LD.

The effect of ES in combination with ageing at different chilling temperatures on the meat quality of impala should be investigated further.