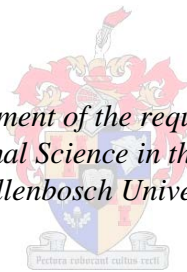# Meat quality of electrically stimulated game under variable harvesting conditions in South Africa

by
Schutz Marais

Thesis presented in fulfilment of the requirements for the degree of Master of Science in Animal Science in the Faculty of AgriScience at Stellenbosch University

Supervisor: Prof LC Hoffman
Co-supervisor: Dr NJ Simmons

March 2013

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained herein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously submitted it, in its entirety or in part, for obtaining any qualification.

Date: March 2013

SUMMARY

In South Africa, game species are harvested throughout the year under variable circumstances, presenting a wide range of temperatures and environmental conditions. The latter can include extremely cold (night harvesting – winter < 5°C) or extremely hot temperature conditions (day harvesting – spring > 35°C). These unique harvesting conditions can negatively affect the game meat quality. Electrical stimulation (ES) has become an important intervention in commercial abattoirs to maintain or improve the meat quality. Electrical stimulation was originally applied to prevent cold shortening (CS) of muscles (i.e. cold induced toughening of muscles) in extremely cold conditions (< 10°C), but ES is also applied to accelerate ageing and to decrease the variation in the quality of meat products. When ES of carcasses is combined with the use of *post rigor* rapid chilling techniques, it can be extremely beneficial to both the supplier and consumer of game meat.

Unfortunately, limited research is available on the use of ES on African game carcasses. The objective of this study was therefore to investigate the effect of ES on the meat quality of South African game carcasses. The latter consisted of two trials: the aim of the first trial was to investigate the effect of ES on the meat quality of commercially harvested springbok *M. longissimus dorsi* (LD) during night harvesting conditions; and the aim of the second trial was to investigate the effect of ES and *rigor* temperature treatment (5°C and 39°C) on the meat quality of blesbok LD muscles over time.

For the first trial, 35 springbok were harvested during commercial night harvesting operations. Electrical stimulation was applied on 16 springbok within 45 minutes *post mortem*, while 19 were non ES animals and therefor used as the control. The pH decline was recorded in the LD muscles until *rigor*, after which general meat quality analyses (pH, tenderness, cooking loss, purge loss and colour) were performed on days 2, 5 and 21 *post mortem*. The ES muscle samples had lower (P ≤ 0.05) initial pH values compared to the non ES samples, however, the pH decline profiles and ultimate pH values (pH_u) were similar for both ES and non ES samples. For each time point and both genders, no differences (P > 0.05) were present in the mean muscle tenderness of the ES and non ES muscle samples. The purge and cooking losses did not differ (P > 0.05) between treatments for days 2 and 5, although on day 21 the storage purge losses were 5.20% ± 0.31 (ES) compared to 4.30% ± 0.31 (non ES). The retail colour stability and regression of the colour measurements over time also did not differ (P > 0.05) between treatments. However, the ES samples had a higher rate of increase in colour sharpness (chroma regression data) (0.567 ± 0.108) compared to the non ES samples (0.224 ± 0.099). It was postulated that ES did not enhance the desired meat quality attributes i.e. tenderness, due to various external factors (animal age, stress and time *post mortem* prior to stimulation) which could have resulted in varying results. In the second trial, 20 mature male blesbok were harvested of which 10 animals were ES within 45 minutes *post mortem* and 10 non ES animals were used as control specimens. Meat quality

analyses (pH, colour, purge loss, cooking loss and tenderness) were also performed during this trial on days 0 (*rigor*), 1, 2 and 5 *post mortem.* Electrical stimulation decreased the initial pH decline as well as the time to the onset of *rigor mortis*. The mean pH of the 5°C ES (5.75 ± 0.07) and non ES muscle samples (5.98 ± 0.06) at *rigor*, were lower (P ≤ 0.05) compared to the ES (5.55 ± 0.14) and non ES samples (5.37 ± 0.03) at 39°C. At 5°C, the ES muscle samples (80.34 ± 5.64) were more tender (P ≤ 0.05) compared to the non ES samples (101.95 ± 4.59) at *rigor*, although no differences (P > 0.05) were present for days 1, 2 and 5. All of the 39°C ES muscle samples (*rigor*, 57.05 ± 5.20; day 1, 48.37 ± 3.68; day 2, 46.06 ± 3.56 and day 5, 39.94 ± 3.46) were more tender (P ≤ 0.05) than the non ES samples (*rigor*, 79.37 ± 9.48; day 1, 74.41 ± 5.40; day 2, 75.52 ± 7.11 and day 5, 66.18 ± 6.14). Electrical stimulation was therefore only successful at increasing the tenderness of the 5°C muscle samples at *rigor*, but ES was very effective at increasing the tenderness of the samples for each time point at the higher temperature treatment (39°C).

The water holding capacity (WHC), cooking loss percentages and bloomed meat surface colour of the blesbok LD muscles were unaffected (P > 0.05) by ES. At each time point the 39°C muscle samples had lower (P ≤ 0.05) mean WHC compared to the 5°C samples. The mean purge losses were higher (P ≤ 0.05) in the non ES (7.13% ± 0.30) compared to the ES (4.89% ± 0.32) muscle samples. However, the mean purge losses were higher in the 39°C (7.31% ± 0.30) compared to the 5°C (4.67% ± 0.29) muscle samples. Additionally, the mean purge losses increased (P ≤ 0.05) over time (day 1, 4.63% ± 0.41; day 2, 5.91% ± 0.34 and day 5, 7.47% ± 0.39), which will possibly have negative affects on consumer perception of blesbok meat quality. The mean cooking loss percentages were higher (P ≤ 0.05) in the 39°C (26.93% ± 1.04) compared to the 5°C (21.33% ± 1.29) muscle samples at *rigor*, although the opposite was true for days 2 and 5 (5°C: day 2, 28.06% ± 0.67 and day 5, 27.72% ± 0.57; 39°C: day 2, 25.60% ± 0.56 and day 5, 25.65% ± 0.72). All of the 39°C bloomed colour measurement values were higher (P ≤ 0.05) compared to the 5°C samples and the former stayed more or less constant over time. Although the 5°C colour measurement values improved over time, it never reached similar values to that of the 39°C samples.

The use of ES under commercial game harvesting conditions requires further investigation; since the expected positive effects on the meat quality parameters were not found to be conclusive in this study. Extremely high temperatures during the harvesting of South African game species will negatively affect most of the meat quality attributes of blesbok LD muscles, while extremely low temperatures will most probably only have a negative affect on muscle tenderness. The application of ES may hold great benefits for the South African game industry, but further research is essential to endorse the application of ES on game species and to manage the factors affecting its effectiveness during different harvesting conditions.

OPSOMMING

Suid Afrikaanse wildsspesies word regdeur die jaar onder veranderlike omstandighede geoes. Daar is dus 'n wye reeks temperatuur- en omgewingstoestande wat tydens die oes van wild 'n rol speel, soos geweldige koue (< 5°C in winter tydens nag oeste) en geweldige warm (> 35°C in lente tydens dag oeste) omgewingstemperature. Die vleiskwaliteit van wildsspesies kan gevolglik negatief beïnvloed word deur dié omgewings toestande. In kommersiële abattoirs het elektriese stimulasie (ES) 'n baie belangrike intervensie geword om vleiskwaliteit te behou of te verbeter. Elektriese stimulasie was oorspronklik vir die voorkoming van kouekrimping (koue geïnduseerde vertaaiing van spiere) van spiere tydens baie koue temperatuurkondisies (< 10°C) toegepas. Verder was ES ook toegepas vir die bespoediging van die verouderingsproses in karkasse asook om die variasie in kwaliteit tussen vleisprodukte te verminder. Die toepassing van ES, in kombinasie met versnelde *post rigor* verkoelingstegnieke, kan dus geweldige voordele vir beide die verskaffer en verbruiker van wildsvleisprodukte inhou.

Daar is ongelukkig beperkte navorsing op die toepassing van ES op Afrika se wildskarkasse. Die doel van die studie was dus om die effek van ES op die vleiskwaliteit van Suid Afrikaanse wildskarkasse te bepaal. Laasgenoemde was vasgestel met behulp van twee proewe: die eerste proef se doelwit was om die effek van ES op die vleiskwaliteit van kommersieël geoesde springbok *M. longissimus dorsi* (LD) gedurende nag oes kondisies te bepaal; en die tweede proef se doelwit was om die effek van ES en *rigor* temperatuurbehandeling (5°C en 39°C) op die vleiskwaliteit van blesbok LD spiere oor tyd te bepaal.

Vyf en dertig springbokke was tydens kommersiële nag oes toestande vir die eerste proef geoes. Elektriese stimulasie was binne 45 minute *post mortem* op 16 van die springbokke toegepas, die ander 19 diere was nie gestimuleer nie (nie ES) en het dus as die kontroles gedien. Die pH daling was in die LD spiere bepaal tot en met *rigor*, waarna die algemene vleiskwaliteit analises (pH, taaiheid, kookverlies, dripverlies en kleur) op dae 2, 5 en 21 *post mortem* bepaal is. Die ES spiere se aanvanklike pH-waardes was laer (P ≤ 0.05) as die van die nie ES spiere, maar die pH dalingsprofiele en die finale pH-waardes (pH$_u$) was min of meer dieselfde (P > 0.05) vir die ES en nie ES spiere. Vir elkeen van die tydpunte en beide geslagte was daar geen verskille (P > 0.05) tussen die gemiddelde spiertaaiheid van die ES en nie ES spiere nie. Daar was ook geen verskille (P > 0.05) in drup- en kookverliese tussen behandelings vir dae 2 en 5 nie. Op dag 21 was die ES spiere se gemiddelde verpakkingsdripverlies persentasies (5.20% ± 0.31) wel hoër (P ≤ 0.05) as die nie ES spiere (4.30% ± 0.31). Daar was ook geen verskille (P > 0.05) in die kleurstabiliteit en die regressie van die kleurmetings oor tyd, tussen behandelings nie. Die ES spiere het wel 'n hoër tempo van toename in die skerphied van die kleur (chroma regressie data) (0.567 ± 0.108) in

v

vergelyking met die nie ES spiere (0.224 ± 0.099) getoon. Elektriese stimulasie het dus nie die verlangde vleiskwaliteit eienskappe (bv. taaiheid) verbeter nie, wat moontlik was as gevolg van verskeie eksterne faktore (die ouderdom van die diere, stress en die tyd *post mortem* voor stimulasie toegepas is) wat variasies in die resultate kon veroorsaak het. Daar kort dus meer navorsing met betrekking tot die toepassing van ES onder kommersiële wildsoeskondisies, omdat die verwagte positiewe effekte van ES op die vleiskwaliteit van wild in die studie nie onomwonde vasgestel is nie.

In die tweede proef is 20 volwasse manlike blesbokke geoes. Daar is op 10 van die blesbokke ES toegepas binne 45 minute *post mortem* en die ander 10 is nie ES en het dus gedien as kontroles. Vleiskwaliteit analises (pH, kleur, dripverlies, kookverlies en taaiheid) is uitgevoer op dae 0 (*rigor*), 1, 2 en 5 *post mortem*. Elektriese stimulasie het 'n afname in die aanvanklike pH daling sowel as 'n afname in die tyd na die aanvangs van *rigor mortis* veroorsaak. The gemiddelde pH-waardes van die ES (5.75 ± 0.07) en nie ES (5.98 ± 0.06) spiere by die 5°C temperatuur behandeling by *rigor* was laer (P ≤ 0.05) as die ES (5.55 ± 0.14) en nie ES (5.37 ± 0.03) spiere by 39°C. By 5°C was die ES spiere (80.34 ± 5.64) sagter (P ≤ 0.05) as die nie ES spiere (101.95 ± 4.59) by *rigor*, maar daar was geen verskille (P > 0.05) in taaiheid tussen behandlings vir dae 1, 2 en 5 nie. Elkeen van die 39°C ES spiere (*rigor*, 57.05 ± 5.20; dag 1, 48.37 ± 3.68; dag 2, 46.06 ± 3.56 en dag 5, 39.94 ± 3.46) was sagter as die nie ES spiere (*rigor*, 79.37 ± 9.48; dag 1, 74.41 ± 5.40; dag 2, 75.52 ± 7.11 en dag 5, 66.18 ± 6.14). Elektriese stimulasie was dus suksesvol om die sagtheid van die 5°C spiere slegs by *rigor* te verbeter, maar die toepassing van ES het die sagtheid van die 39°C spiere by elke tydpunt verbeter.

Elektriese stimulasie het geen effek (P > 0.05) op die waterhouvermoë (WHC), kookverlies persentasies en die vleisoppervlak kleur van die blesbok LD spiere gehad nie. Die WHC van die 39°C spiere was by elke tydpunt laer (P ≤ 0.05) as die van die 5°C spiere. Die nie ES spiere (7.13% ± 0.30) het gemiddeld hoër (P ≤ 0.05) dripverlies persentasies as die ES spiere (4.89% ± 0.32) gehad. Die 39°C spiere (7.31% ± 0.30) het wel beduidend hoër gemiddelde dripverlies persentasies in vergelyking met die 5°C spiere (4.67% ± 0.29) gehad. Die persepsie van die verbruikers van blesbokvleis kan moontlik negatief beïnvloed word deur die toename (P ≤ 0.05) in die gemiddelde dripverlies persentasies van die blesbok LD spiere oor tyd (dag 1, 4.63% ± 0.41; dag 2, 5.91% ± 0.34 en dag 5, 7.47% ± 0.39). By *rigor* was die gemiddelde kookverlies persentasies hoër (P ≤ 0.05) in die 39°C spiere (26.93% ± 1.04) in vergelyking met die 5°C spiere (21.33% ± 1.29), maar die teenoorgestelde was gevind by dae 2 en 5 (5°C: dag 2, 28.06% ± 0.67 en dag 5, 27.72% ± 0.57; 39°C: dag 2, 25.60% ± 0.56 en dag 5, 25.65% ± 0.72). Die vleisoppervlak kleurmetings van die 39°C spiere by elke dag (met tyd) was hoër (P ≤ 0.05) in vergelyking met die 5°C spiere en eersgenoemde het ook min of meer konstant gebly met tyd. Die

vleisoppervlak kleurmetings van die 5°C spiere het wel verbeter met tyd, maar dit was nooit gelyk aan die waardes van 39°C spiere nie.

Die gebruik van ES tydens die kommersiële oes van wild benodig verdere navorsing siende dat die verwagte positiewe effek op die vleiskwaliteit nie gerealiseer het nie. Die meerderheid van die vleiskwaliteit eienskappe van blesbok LD spiere sal negatief beïnvloed word deur die geweldige hoë temperature wat kan voorkom tydens die oes van Suid Afrikaanse wildsspesies. Wanneer geweldige lae temperature oorheers, sal net die taaiheid van die spiere moontlik negatief beïnvloed. Die toepassing van ES kan groot voordele inhou vir die Suid Afrikaanse wildsindustrie, maar verdere navorsing is nodig om die gebruik van ES op wildsspesies te motiveer en om die faktore wat die effektiwiteit van ES tydens die veranderlike oes omstandighede kan beïnvloed te beheer.

ACKNOWLEDGEMENTS

On the completion of this thesis, I would like to express my sincerest appreciation and gratitude to the following people and institutions:

- Prof. L.C. Hoffman (Department of Animal Sciences, Stellenbosch University), my supervisor, for his knowledge, guidance and for his ability to challenge my thinking pattern throughout my study. He made it possible to conduct my research in New Zealand, and for this I am extremely grateful;

- Dr. N.J. Simmons (Carné Technologies, Cambridge, New Zealand), for her friendship, opportunity to work at Carné Technologies, guidance, support and advice throughout my study;

- Dr. C.C. Daly (Carné Technologies, Cambridge, New Zealand), for his incredible knowledge, support and advice throughout my study;

- Prof. M. Kidd (Centrum for Statistical Consultancy, Stellenbosch University) for patiently assisting me in the statistical analysis of the data used in this thesis;

- NRF (National Research Foundation) for the two year scholarship that partly funded this study;

- Camdeboo Meat processors – Arberdeen for facilitating the field trials;

- Lood van Deventer (Brakkekuil Farm) for assistance during field trials;

- Stellenbosch University for providing me with a structure where I could learn and grow;

- My parents (Johann and Chris Marais), for their endless love, encouragement and support;

- Fellow students from Animal and Food Sciences, for their emotional support, patience, advice, encouragement, good humour and friendship;

- The laboratory technical staff (Animal Sciences);

- All my friends and family for their encouragement, humour, friendship and emotional support.

NOTES

The language and style used in this thesis is in accordance with the requirements of the Journal of Meat Science. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some repetition between the chapters was therefore unavoidable.

Results from this study have been presented at the following symposiums:

7ᵗʰ International Wildlife Ranching Symposium (IWRS), 10-14 October 2011, Kimberley, South Africa.

Annual Congress of the South African Wildlife Management Association (SAWMA), 16-19 September 2012, Bela Bela / Warmbaths, Limpopo Province, South Africa.

CONTENTS

CHAPTER 1

General Introduction

Electrical stimulation (ES) is defined as the application of an electrical current to a carcass, under carcass processing regimes, with the aim of ensuring meat tenderness (Devine, Hopkins, Hwang, Ferguson & Richards, 2004). Tenderness is the most important meat quality characteristic for the consumer (Wood, Enser, Fisher, Nute, Richardson & Sheard, 1999) and can be measured either subjectively by consumer panels or by means of objective measurements such as shear force (the force required to cut through a piece of cooked meat) (Strydom, Frylinck & Smith, 2005). Electrical stimulation can improve the tenderness of most commercial animal species (cattle, sheep, goats, deer and some poultry species) currently being farmed with (Devine et al., 2004). Its application can, however, induce certain unfavourable results, but the overall improvement in tenderness generally outweighs these negative effects with the use of this method (Lawrie & Ledward, 2006).

The application of ES causes muscles to reach *rigor* at an earlier stage *post mortem* by making the muscles contract, thereby depleting the stored glycogen reserves through anaerobic glycolysis, resulting in an immediate drop in pH (ΔpH) followed by a change in the rate of the pH decline (dpH/dt) (Devine et al.*,* 2004). Electrical stimulation further ensures that muscles enter *rigor* at a high muscle temperature and cold induced shortening (CS) can thus be avoided; it also allows ageing to start at a higher temperature and consequently the aging process is more rapid (Simmons, Daly, Cummings, Morgan, Johnson & Lombard, 2008). Electrical stimulation also results in other mechanisms being involved in meat tenderisation, such as structural disruptions and enzymatic modifications (Simmons, Singh, Dobbie & Devine, 1996; Devine et al., 2004).

Electrical stimulation has been shown to enhance certain meat quality characteristics, such as lean colour, flavour and tenderness (Devine et al., 2004; Strydom et al., 2005; Lawrie & Ledward, 2006). The use of ES has also shown to have beneficial attributes for organisations involved with packaging and retail of meat products, in terms of costs and reducing variation in product quality. The consumer could therefore benefit if ES is used as an integral part of the process of converting muscle into meat. Electrical stimulation has thus become an important processing technique in modern abattoirs, and when combined with the use of *pre rigor* rapid chilling, it can be extremely beneficial to both the supplier and consumer (Li, Chen, Xu, Huang, Hu & Zhou, 2006).

The question, however, is whether these benefits are just as beneficial when ES is applied to game meat in the South African commercial game meat industry. The circumstance in which game meat is harvested and processed is unique and can have potential negative effects on the eating quality, due to the stress and environmental conditions associated with harvesting of game. The majority

11

of South African game species intended for the export market are harvested at night, as this method is the most efficient (Bothma, 2006; Hoffman & Wiklund, 2006) and ensures the best quality meat (Hoffman & Wiklund, 2006; Laubscher, 2009). Night harvesting, however, presents unique circumstances, as the mean winter ambient temperatures usually drops below zero (Anon., 1986; Mucina et al., 2006). These low temperatures can have unfavourable effects on meat quality (Veary, 1991) as cold induced toughening/cold shortening (CS) occur in meat, if the carcass temperature drops below 10°C while the pH is still above 6.0 (Pearson & Young, 1989; Devine et al., 2004). This fact, coupled with the processing protocol for game meat intended for export to the European markets – creates a situation whereby the use of ES can be employed to maximise quality and customer satisfaction. This theory has already been well implemented by New Zealand abattoirs since the 1980's, where New Zealand deer carcasses are electrically stimulated during slaughtering in commercial venison abattoirs, and after a short period of conditioning/ageing they are frozen and exported. Similar conditions exist in the export of game meat from South Africa and the potential of increasing the product quality thus exist and should be exploited to ensure high quality game meat products.

This study was therefore conducted to ascertain if the use of ES on springbok (*Antidorcas marsupialis*) and blesbok (*Damaliscus pygargus phillipsi*) in the commercial game harvesting operations of South Africa could show any benefits or enhancements of the resulting game meat quality.

REFERENCES

Anonymous (1986). *Climate of South Africa: Climate statistics up to 1984* (pp. 65–66). South Africa: Weather bureau, Department of home affairs.

Bothma, J.Du P. (2006). Harvesting game. In *Game ranch management – completely revised and expanded* (pp. 246–270) (3rd ed.). Hatfield, Pretoria, South Africa: Van Schaik Publishers.

Devine, C.E., Hopkins, D.L., Hwang, I.H., Ferguson, D.M. & Richards, I. (2004). Electrical stimulation. In W.K. Jensen, C. Devine & M. Dikeman (Eds.), *Encyclopedia of meat science* (pp. 413–423) (Vol. 1). Oxford: Academic Press.

Hoffman, L.C. & Wiklund, E. (2006). Game and venison – meat for the modern consumer. *Meat Science*, *74*, 197–208.

Laubscher, L.L. (2009). *The effect of different cropping methods on the meat quality of various game species.* (Unpublished master dissertation). Faculty of Animal Science, University of Stellenbosch, South Africa.

Lawrie, R.A. & Ledward, D.A. (2006). *Lawrie's meat science* (7th ed.). Cambridge, England: Woodhead Publishing Limited.

Li, C.B., Chen, Y.J., Xu, X.L., Huang, M., Hu, T.J. & Zhou, G.B. (2006). Effects of low-voltage electrical stimulation and rapid chilling on meat quality characteristics on chinese yellow crossbred bulls. *Meat Science*, *72*, 9–17.

Mucina, L., Rutherford, M.C., Palmer, A.R., Milton, S.J., Scott, L., Lloyd, J.W., Van der Merwe, B., Hoare, D.B., Bezuidenhout, H., Vlok, J.H.J., Euston-Brown, D.I.W., Powrie, L.W. & Dold, A.P. (2006). Nama-Karoo Biome. In L. Mucina & M.C. Rutherford (Eds.), *The vegetation of South Africa, Lesotho and Swaziland* (pp. 325–345). South Africa: South African National Biodiversity Institute.

Pearson, A.M. & Young, R.B. (1989). *Muscle and meat biochemistry*. San Diego: Academic Press

Simmons, N.J., Singh, K., Dobbie, P.M. & Devine, C.E. (1996). The effect of pre-rigor holding temperature on calpain and calpastatin activity and meat tenderness. In *Proceedings of the 42nd international congress of meat science and technology* (pp. 414–415). Lillehammer, Norway.

Simmons, N.J., Daly, C.C., Cummings, T.L., Morgan, S.K., Johnson, N.V. & Lombard, A.C. (2008). Reassessing the principles of electrical stimulation. *Meat Science*, *80*, 110–122.

Strydom, P.E., Frylinck, L. & Smith, M.F. (2005). Should electrical stimulation be applied when cold shortening is not a risk? *Meat Science, 70*, 733–742.

Veary, C.M. (1991). The effect of three slaughter methods and ambient temperature on the pH and temperature in springbok (*Antidorcus marsupialis*) meat. (Unpublished master dissertation). Faculty of Veterinary Science, University of Pretoria, South Africa.

Wood, J.D., Enser, M., Fisher, A.V., Nute, G.R., Richardson, R.I. & Sheard, P.R. (1999). Manipulating meat quality and composition. *Proceedings of the Nutrition Society*, *58,* 363–370.

CHAPTER 2

Literature Review

GAME RANCHING IN SOUTH AFRICA

In South Africa, game farming has not always been an attractive form of animal husbandry. Prior to the 1950's, South African farmers had little or no interest in farming with game species (Carruthers, 2008). These game species were considered to be unwanted competition for the various vegetation types consumed by domestic livestock (Bothma, 2002; Carruthers, 2008).

After the 1950's, the perceptions towards South African game species changed, since people realised that game animals had "value" and they did not always compete with domestic livestock for the utilisation of the available vegetation (Carruthers, 2008). In addition, the farmers realised that the wild animals were better adapted to harsher environmental conditions and could therefore be an alternative source of red meat during the tougher climatic years (Skinner, 1970). Joubert (1968) also postulated that game species were better adapted to water conservation and feed selection in the more arid environments as well as being adapted to exposure to heat stress and possessed a superior resistance to endemic diseases compared to that of domestic species. These factors initiated general efforts towards conducting research on game species and implementing a more scientific approach towards farming with game species (Carruthers, 2008). This particularly occurred during the last 20 – 25 years when the South African game farming industry had established itself as a thriving business (Higginbottom & King, 2006) and consequently developed into a major part of the South African agricultural industry (Ebedes, 2002).

In the modern era, South African farmers have to compete with social and economic uncertainties. They have to adapt to survive and to make a profit or a success of their businesses. One means of doing this is by increasing the effectiveness of the utilisation of the available resources by the farming enterprises. In South Africa, as little as 23.3% of all agriculture soil has a high production potential. Farmers are therefore searching for more economical methods of enhancing the utilisation of land with a lower agricultural potential, which is an area where game farming has the potential to excel and be very beneficial to the land owner (Dlamini & Fraser, 2010). The latter is attributed to the wider spectrum of vegetation types utilised by game species and not commonly consumed by domestic livestock species, in addition to the utilisation of several plant species which are poisonous to domestic livestock (Liversidge & Gubb, 1994; Prins, 2000; Skinner, 2012).

An added incentive and/or bonus linked to game farming is the support that the game farmers often receive from conservation bodies, in an effort to conserve the wildlife species on their farms (Bothma, 2002, 2010). Additionally, a drop in the profitability of the conventional livestock farming industry and an increase in the demand for game hunting and eco tourism in the last three decades, have led to increased interest into game farming (Erb, 2004).

The growing game industry also resulted in higher numbers of game species in South Africa in 2005 compared to the past 100 years (Eloff, 2002; Bothma & Van Rooyen, 2005). Game farmers have contributed significantly to this recovery over the years, with for example, a total of 19 576 game species sold live at 58 boma and catalogue auctions as early as 2003. Capital is also generated through hunting of surplus game, with for example some 8 900 head of game hunted in the Eastern Cape Province in 2001 (Flack, 2002; Eloff, 2002). Additionally, Du Toit (2007) reported that the number of South African game animals had increased from 575 000 in 1964 to 18.6 million in 2007. Bothma (2010) also reported an almost 40% increase in the South African wildlife numbers between 2003 and 2010. The various methods by which game species populations are managed are: non-trophy/recreational or biltong hunting (53.4%); trophy hunting (18.1%); eco-tourism (4.7%); and harvesting of surplus animals on an annual basis or as required for game meat production (2.7%) (Van den Berg, 2004).

One should, however, distinguish between game ranching and game farming (Skinner, 2012), since *game ranching* refers to the management and extensive production of free-living animals on large fenced and/or unfenced communal land (Bothma, 2002), but *game farming* refers to an intensive approach towards game breeding and production (Skinner, 2012). As the game industry developed/grew, farmers converted from extensive (ranching) systems to more intensive (farming) production systems, so as to increase productivity and control. For the purpose of this study, the focus is on the more intensive form of game husbandry, namely game farming.

Commercial game meat production

As early as the 1960's, the potential value of African ungulates for commercial meat production purposes had already been established (Ledger, 1963; Ledger, Sachs & Smith, 1967; Von la Chevallerie, 1970). The surplus numbers of game animals from commercial game farms are usually females, which are not hunted by the trophy and/or biltong hunters during the hunting season. These animals can then be utilised to supply fresh, frozen and/or processed game meat products to local and/or exclusive international markets (Van der Merwe, 2004). The only downside to the game meat export market is that infectious animal diseases can seriously impact the production of game meat products and their potential fitness for human consumption (Paulsen & Smulders, 2004). The latter is currently the case, since the export of the meat from various

ruminant game species ceased in 2011, due to the outbreak of foot-and-mouth disease in specific South African locations (Anon., 2011).

The feasibility of game farming was further enhanced by estimates made in 2000, in which the gross income generated by South African game meat sales alone was estimated at around R20 million (Eloff, 2002). In 2005, it was estimated that South Africa exported de-boned meat from 160 000 carcasses, the majority of the meat being from springbok (*Antidorcas marsupialis*) (> 80%), followed by blesbok (*Damaliscus pygargus phillipsi*) and kudu (*Tragelaphus strepsiceros*) as well as fewer volumes from other game species such as burchell zebra (*Equus quagga burchellii*), blue wildebeest (*Connochaetes taurinus*), impala (*Aepyceros melampus*) and eland (*Taurotragus oryx*) (Hoffman & Wiklund, 2006). These trends were also visible in the more recent export numbers of 2008 and 2009 (Table 2.1). The value of the game meat industry in South Africa now contributes over R45 million to the national economy per annum (DAFF, 2010).

Table 2.1

The number of animals and the total weights of the meat from the carcasses of the main game species intended for exports from South Africa in 2008, 2009 and 2010 (Anon., 2009, 2010, 2011)

Species	2008		2009		2010	
	[1]Number	[2]Weight	[1]Number	[2]Weight	[1]Number	[2]Weight
Springbok	59969	910.92	63078	957.72	42709	626.05
Blesbok	12022	426.96	7480	268.53	3621	22.69
Oryx	764	74.57	465	44.41	233	125.08
Rhebok	133	2.13	11	0.17	76	1.19
Kudu	3542	279.88	1370	108.43	1254	96.07
Red Hartebeest	300	21.70	251	17.84	241	16.27
Black Wildebeest	2285	160.88	1482	101.94	2494	182.67
Blue Wildebeest	1755	162.07	529	56.68	1330	123.66
Zebra	364	67.47	212	38.51	820	152.96
Impala	3783	86.86	1006	23.70	687	16.61
Duiker	254	2.43	-	-	87	0.76
Fellow deer	146	4.68	66	1.84	13	0.48
Eland	151	26.84	185	28.15	100	18.08
Waterbok	62	5.67	-	-	16	1.37
Bontebok	-	-	-	-	20	0.83
Totals	85530	2233.13	76135	1647.96	53701	1384.85

[1]Number of animals slaughtered per year
[2]Total cumulative carcass weights in tons

In the past, the springbok, blesbok and impala were the three main game species considered for meat production purposes due to their favourable meat attributes and adaptation to the environment (Joubert, 1968). In 2008, 2009 and 2010, the majority of the game meat intended for exports from South Africa was from springbok and to a lesser extent from blesbok (Table 2.1) (Hoffman & Wiklund, 2006; Anon, 2011).

Springbok (Antidorcas marsupialis)

The springbok is the most important game species for commercial game meat production in South Africa (Hoffman, 2002; Skinner & Chimimba, 2005b; Hoffman & Wiklund, 2006; Bothma, Van Rooyen & Du Toit., 2010). The main reason for this is its large distribution area and high reproduction capabilities (Skinner, Von la Chevallerie & Van Zyl, 1971). Springbok is one species consisting of three sub-species (Table 2.2), defined according to their distribution and scull measurements (Peters & Brink, 1992): the Angolan springbok (*Antidorcas marsupialis angolensis*) which predominantly occurs in Angola; the Kalahari springbok (*Antidorcas marsupialis hofmeyri*) which occurs in Botswana, Namibia and the Northern Cape; and the Southern springbok (*Antidorcas marsupialis marsupialis*) found throughout the southern part of the species distribution range in Southern Africa (Skinner & Chimimba, 2005b).

Table 2.2

The taxonomic classification of springbok (Skinner & Chimimba, 2005b)

Taxonomic classification	Springbok
Class	MAMMALIA
Family	BOVIDAE
Subfamily	Antilopinae
Tribe	Antilopini
Genus	Antidorcas
Species	Marsupialis

There are, however, also three colour variants (black, white and copper) excluding the original coloured springbok. These springbok colour variants can frequently be found in low numbers in natural springbok populations; however, they have been intensively farmed with or exploited by selective breeding activities as practiced by some of the commercial game farmers (Van Aswegen, Labuschagne & Grobler, 2012). When these selective breeding practices are continuously performed, it is possible to breed the specific colour variant. However, if a colour variant population was allowed to breed with the normal common springbok population once again the natural colour of the common springbok will once again be favoured in the end (Frustenburg, 2010). Even though the commercial value of these springbok colour variants differ from that of the

17

normal coloured springbok, the colour variants have no added advantages with regards to their adaptation to different environments or production capabilities (Hetem et al., 2009).

Springbok is the only endemic species of antelope that is found extensively in most of the arid regions of southern Africa (with < 450 mm annual rainfall), in particular the western arid regions of South Africa; Namibia and southern Angola (Fig. 2.1) (Skinner & Chimimba, 2005b).

In 1973, it was concluded that the national parks of South Africa alone contained around 369 000 springbok (Skinner, 1973). Then at the turn of the twentieth century it was estimated that the total population of springbok in southern Africa was more than 670 000 (East, 1999), but this was thought to be an underestimate. In 2005, a more recent appraisal for Namibia projected its population alone at around 730 000, but it too was considered to be an underestimate (IUCN, 2008). Springbok numbers for Angola were estimated at around 10 000, the Botswana side of the Kgalagadi Transfrontier Park around 40 000, the rest of Botswana around 60 000, the Free State around 75 000, the former Transvaal Province 75 000, 1 000 000 in the Karoo and around 100 000 in the Cape Province outside of the Karoo. Based on these figures the total springbok population in southern Africa can be estimated at ca. 2 000 000 – 2 500 000 animals (IUCN, 2008).
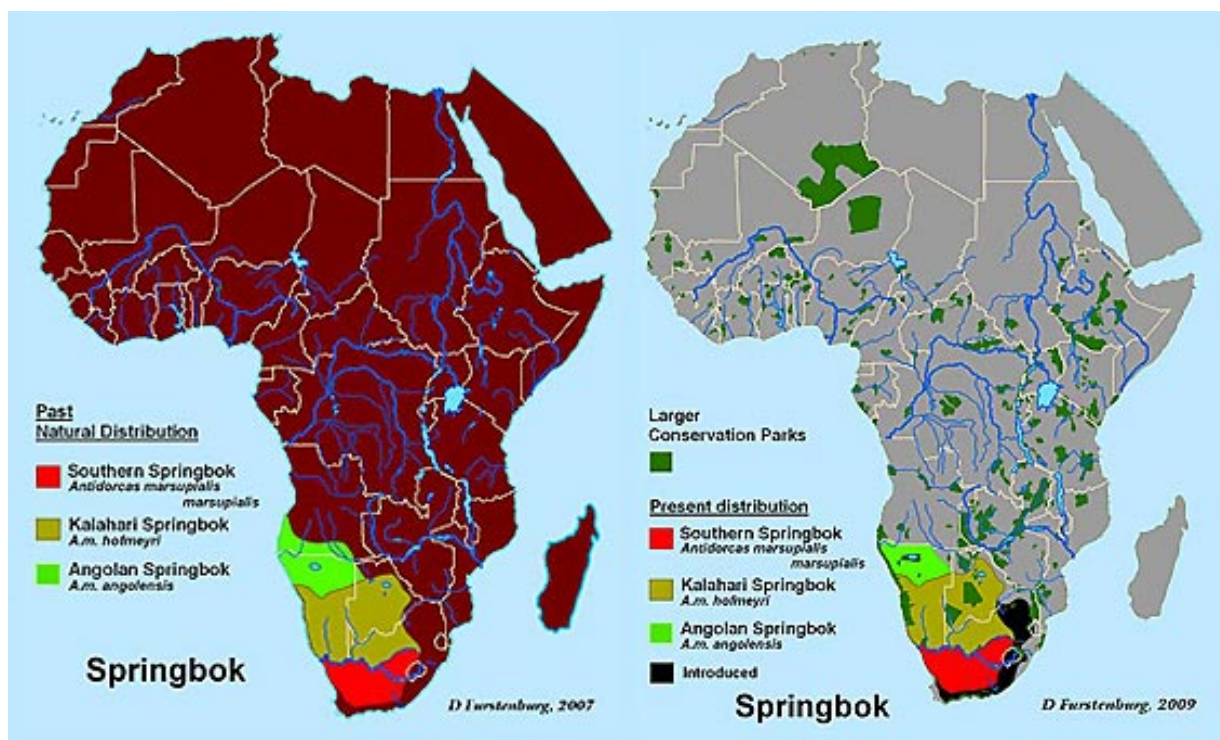

Figure 2.1 The distribution of springbok (Furstenburg, 2010).

Springbok are known for moving in small herds during the dry season in search of better vegetation, however, large herds have also been noted to move across the country (Skinner & Louw, 1996). The primary distribution of springbok is not limited by the amount of rainfall, but

18

rather by the absence of tick-borne illnesses (such as *hartwater* and *babesiosus*) and the availability of suitable habitats (vegetation types) (Conroy, 2005).

The vegetation types characteristically preferred by springbok include the arid environments, dry grassy flats, Karoo scrub, salty pans, dune pathways, dry river beds and semi-desert scrublands. Their only preferences are sandy soil with abundance of short perennial sweet grasses, forbs and dwarf shrubs with a high mineral content and annual rainfall around 50 – 450 mm (Frustenburg, 2010). Areas consisting of dense thicket, closed woodland, rocky surfaces, mountainous areas, forests, tall-grass stands and moist, alluvial clay soils are avoided by and not suitable for springbok populations. Surface drinking water is not essential since the springbok can extract its moisture requirements from the vegetation consumed. Springbok are therefore very well adapted to survive harsh environmental conditions, which make them good to farm with on farms with water scarcities. It has also been postulated that springbok do not compete with sheep for vegetation (Liversidge & Gubb, 1994). Springbok do, however, require a large variety of plant species to sustain their high energy and minerals requirements during the dryer months (Skinner & Louw, 1996).

Springbok have been introduced into the Free State and Eastern Cape Provinces and have adapted to a wider spectrum of marginal habitats. These introductions were of varying success, since springbok populations tend to go through cycles during which they flourish for 3-5 years, followed by a sudden population crash. This phenomenon might be caused by the build-up of internal parasites (*roundworms*, *hartwater* and/or *hairworms*) in the population (Frustenburg, 2010).

Springbok employ a non-fixed reproductive pattern and can adapt to the unpredictable environmental conditions by mating when conditions are more favourable (Skinner et al., 1971). Under favourable conditions, springbok ewes can achieve sexual maturity at six months of age (Skinner & Van Zyl, 1970; Skinner & Louw, 1996; Conroy, 2005). With optimal climatic conditions, a ewe can produce one lamb every eight months or three lambs in two years. This fact coupled with a short gestation period of 25 weeks (Skinner & Chimimba, 2005b), give springbok an uncanny ability to restore their numbers (if conditions are favourable) after a population crash (e.g. due to droughts) (Skinner & Louw, 1996; Conroy, 2005). Springbok populations can have a mean annual growth of around 33%, although this can be increased with the correct sex ratio (one ram: six to eight ewes) in the population (Bothma et al., 2010). Under normal conditions, springbok can therefore have a 100% lambing percentage.

The body weight of springbok can fluctuate between seasons. The latter will be highest near late summer (summer rainfall region), when springbok usually have the best body condition (fatness). Springbok body weight and fatness will usually decline during winter to reach a low in early spring, prior to the start of the rainy season (Skinner, 1973). Harvesting of surplus springbok from a

population should therefore commence when springbok are at their peak body condition (early winter) as well as when the young lambs from the previous season have reached around 60% of their adult body weights. The harvesting of springbok early in winter would also result in colder ambient conditions, a decreased risk for meat spoilage during slaughter and transportation of carcasses (Skinner et al., 1971). Skinner et al. (1971) considered the growth, carcass development, breeding seasons and seasonal feed availability of springbok and taking everything into account, suggested that an optimum age for harvesting springbok is usually around 28 weeks of age.

The harvesting of springbok primarily occurs at night, as it is the most effective method of harvesting large quantities of game in a short period of time (Hoffman, 2002). Although their horns are aesthetically different from one another, it is difficult to distinguish between sexes in large herds during high rate night harvesting. Springbok rely heavily on their eyesight to indentify threats as well as their speed and a safety in numbers policy to evade capture. However, during night harvesting both these factors are used to further improve the effectiveness of the harvesting operation, since a spotlight is used to temporarily blind and immobilize the herd.

The average live weight for a springbok ram is 31.7 kg and 28.3 kg for a springbok ram and ewe respectively (Kroucamp, 2004), while the mean carcass mass is around 22.88 kg for springbok rams and 19.25 kg for springbok ewes (Van Schalkwyk, 2011). Furthermore, the dressing percentage is usually around 58.83% for males and 55.79% for ewes (Kroucamp, 2004), which is similar to the dressing percentages of the majority of African ungulates (55 – 61%) (Von la Chevallerie, 1970).

Blesbok (Damaliscus pygargus phillipsi)

The blesbok (Table 2.3) is closely related to the bontebok (*Damaliscus pygargus pygargus*) and both species are endemic to South Africa, south of the Zambezi River. There has been two additional colour variants (yellow and white) bred for the commercial market. These colour variants are able to interbreed with each other as well as the normal blesbok and bontebok. It is thus important to keep these two species separate as the bontebok/blesbok hybrids are fertile and represents a threat to the genetic purity of both these individual populations (Schmidt, 1999).

Table 2.3

The taxonomic classification of blesbok (Skinner & Chimimba, 2005b)

Taxonomic classification	Blesbok
Class	MAMMALIA
Family	BOVIDAE
Subfamily	Antilopinae
Tribe	Antilopini
Genus	Damaliscus
Species	pygargus

Blesbok were found in large parts of southern Africa. During the 16th to 19th centuries, the blesbok were extensively hunted for their hides and meat, which reduced their population numbers severely. Blesbok have, however, been successfully re-introduced by farmers to re-establish their numbers and they are now commonly found in larger parts of South Africa, Zimbabwe, central and northern central Namibia, but these are marginal habitats compared to their home range (Fig. 2.2). The latter includes the Fynbos, semi – Kalahari, coastal areas and upper bushveld ranges (Skinner & Chimimba, 2005a). Blesbok prefer the large grasslands areas of the upper highlands and central eastern parts of South Africa, with an annual rainfall between 400 – 800 mm. Their preferred habitat must contain short grass veldt with a mix of sweet and sour grass species, a wide range of forbs, non-woody plant species and sandy soils. In contrast to springbok, blesbok rely on water and are therefore heavily dependent on surface water availability, although they can survive in warmer climates but with the presence of larger trees that supply shade to ensure productivity and survival (Skinner & Chimimba, 2005a). In arid regions (lacking surface water), such as the Karoo and Karoo-shrub like vegetation areas, mountainous terrain with no short grass species, karroid veldt without grass stratum, thickets, forests, dense bushveldt, closed woodlands and tall grass veldt are not ideal and should be avoided. Blesbok are highly selective grazers and can adapt their feeding behaviour between seasons, according to the availability of preferred grass species (Du Plessis, 1972). Blesbok are able to survive on sour veldt, but this will decrease their performance. In 1998, approximately 235 000 – 240 000 blesbok were estimated to be present in Africa (East, 1999). Due to the steady increase of South African game ranching in the past three decades, the latter might have increased considerably during the last 15 years.
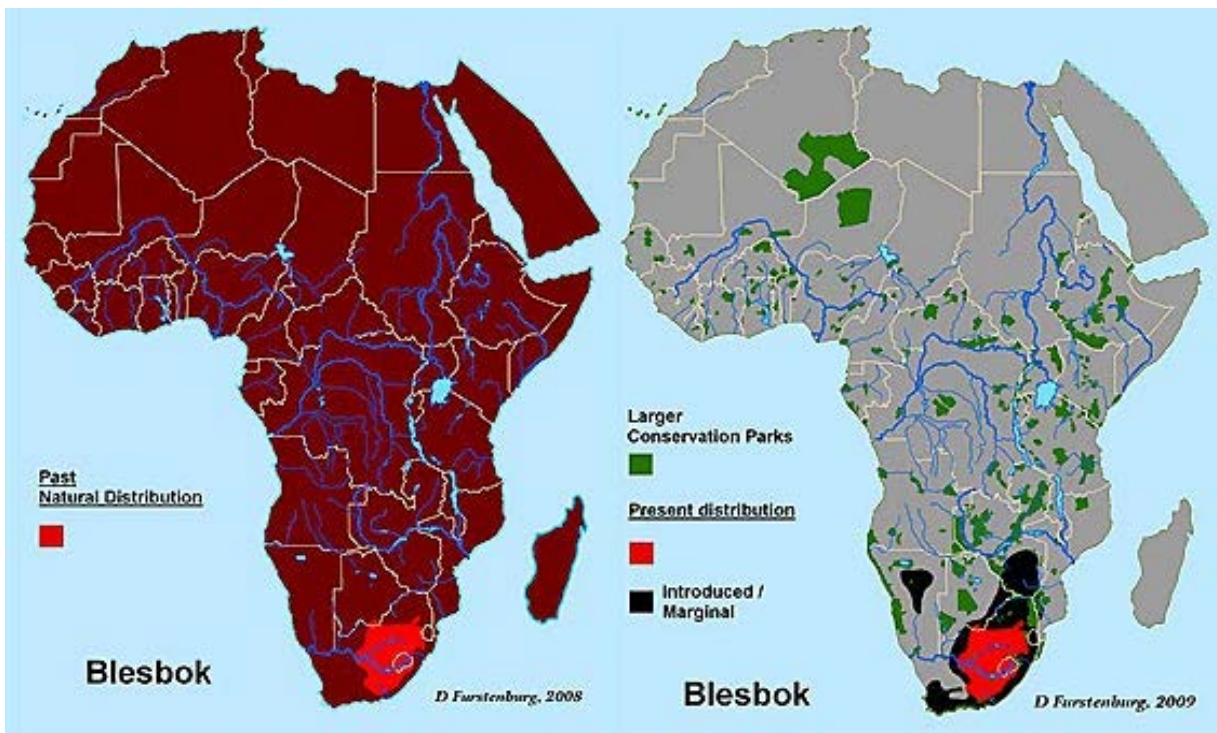
Figure 2.2 The distribution of blesbok (Furstenburg, 2009).

Blesbok are seasonal breeders, with the lambing season generally between November and January (early summer) (Skinner, 1973). Blesbok ewes have to reach a mature age of three years before they are able to breed. This, however, means that mature females must be retained during harvesting so as to establish a breeding herd for future production of animals (Du Plessis, 1972). This, however, presents a problem if animals are harvested at night as well as at a fast take off rate, since male and female blesbok are not easily distinguished from one another. Care must be taken when large numbers are harvested from a single population as to not damage the future fecundity of such a population. A single lamb is born per adult ewe per year, since blesbok has a gestation period around 7.8 – 8 month. The annual yearly mean population growth is estimated to be around 30% and can range between 18 – 55% depending on the rainfall, vegetation conditions and the influence of predation and population dynamics (Bothma et al., 2010). An ideal male to female ratio is one blesbok ram to about eight to 12 ewes, which ensures the largest population growth possible during optimal conditions. However, special note must be made to the presence of predators since young lambs are very susceptible to black-backed jackal (*Canis mesomelas*) predation and this can severely influence the productivity of blesbok populations (Du Plessis, 1972). Blesbok are not renowned for their ability to fend off predators.

After the first winter frost the digestibility of grasses and their feeding value decrease rapidly and the blesbok feeding activity also decrease resulting in up to a 12% decrease in body weight. They do, however, quickly regain this weight with the start of the summer rain season, when the newly formed grass, which is high in nutritional value, sprouts. Blesbok will avoid un-grazed grasses or

moribund grasses as well as grass species with more than one seasons' growth (Du Plessis, 1972). It is best to harvest blesbok before the end of March (if meat production is the main goal) (Bothma et al., 2010) as this is suggested to be the period when they will have the best carcass yield and condition (Du Plessis, 1972).

Blesbok are easily contained by normal livestock fences (Joubert, 1968). They rely on their eyesight to detect threats. When threatened, blesbok tend to bunch up in a group, if the danger persist they will retreat for short distances (200 – 300 m), before stopping and bunching up again (the process is done repeatedly). It is therefore ideal to harvest blesbok at night; however, both the male and females have horns which may present a problem when trying to establish gender at night. The horns of the rams are thicker at the base and are lighter in colour compared to those of the blesbok ewes (Skinner & Chimimba, 2005a).

The mean live carcass masses are between 70 – 80 kg for blesbok rams and between 60 – 70 kg for blesbok ewes. The average carcass weight was calculated for blesbok rams to be 24.9 kg and 28.6 kg for blesbok ewes by Van Zyl and Ferreira in 2004. However, they only tested six animals and such a small samples size may have skewed the results. The dressing percentage is usually around 52.9% (Huntley, 1971), slightly lower than the average dressing percentage found by the majority of African ungulates (55 – 61%) (Von la Chevallerie, 1970). Hoffman, Smit, & Muller (2008) reported a 52.2% dressing percentage for blesbok. The high quality hindquarter cut can comprise around 25.6% of the mature blesbok carcass weight, which is relatively higher in comparison to that of sheep (24.2%), but slightly lower when compared to that of springbok (29%) (Von la Chevallerie & Van Zyl, 1971a). Blesbok meat also contains 81.8% of the total essential amino acids required by humans (Van Zyl & Ferreira, 2004). The chemical composition of blesbok meat indicates that the species could be suitable as an alternative red meat source for consumers wishing to consume more lean meat and that its composition could be a valuable addition to human diets (Hoffman et al., 2008).

Commercial harvesting of game species

Harvesting methods

The efficient and humane harvesting of game species requires the correct harvesting techniques (Bothma, 2010) and will subsequently result in the most efficient and economical means of game meat production (Dlamini & Fraser, 2010). The selection of a harvesting technique will depend on the game species and number of animals to be harvested as well as the habitat of the harvesting region. A variety of harvesting techniques are therefore present and each are adapted to minimise the *ante mortem* stress experienced by game animals. This is crucial as reduced stress positively

influences the final meat quality (Veary, 1991; Hoffman, 2000a; Kritzinger, Hoffman & Ferreira, 2003; Laubscher, 2009).

Von la Chevallerie & Van Zyl (1971b) identified three possible circumstances where the harvesting procedures leads to meat losses from the carcasses: when shot animals are not recovered during harvesting; meat discarded due to wounding and/or bullet damage; and a decline in meat quality due to *ante mortem* stress. Vegetation density or terrain accessibility can affect the efficiency with which shot and/or wounded animals can be traced. The species targeted and/or the harvesting technique can also contribute negatively to the recovery of shot animals (Mostert, 2007). Meat losses due to wounding or misplaced shots can be attributed to the skill of the marksmen; fatigue during harvesting procedures (Ruggeiro & Ansley, 1992) or the use of lighter calibre rifles during strong prevailing wind conditions (Van Schalkwyk, Hoffman & Laubscher, 2011). Skilled marksmen and the correct shot placement can therefore yield the least amount of meat wastage (Bothma, 1996; Laubscher, 2009) as well as ensuring a humane death of the animals (Lewis, Pinchin & Kestin, 1997). When the animals are shot in the head the *ante mortem* stress is minimum, the animals are dead instantaneously (Bothma, 1996), no meat is lost (Hoffman, 2000a, 2000b; Hoffman & Ferreira, 2000) and the meat quality will be at its best (Bothma, 1996). Less than 2% of the carcass meat is lost with a shot in the high neck area (Hoffman, 2000a, 2000b; Hoffman & Ferreira, 2000), but this may result in paralysis and may not render the animal immediately insensible, which leads to stress and poorer meat quality (Lewis et al., 1997).

The success of the harvesting method and therefore the amount of stress experienced by the animals is, however, depended on the marksmanship of the hunters being employed (Joubert, 1968). Inaccurate shooting will increase the costs linked to the harvesting operation, due to higher ammunition costs (can account for up to 30% higher total harvesting costs) and more time needed to achieve the harvesting quota (Bothma, 2002). Furthermore, inaccurate shooting can also result in wounded animals and consequently damaged carcasses (meat losses) as well as more stressed animals (lower meat quality) (Ruggiero & Ansley, 1992). The latter factors therefore results in a loss in profitability of the harvesting operations (Van Rensburg, 1992; Van Schalkwyk et al., 2011).

Four general requirements exist for ensuring the success of the harvesting of game animals: instantaneous death; minimum disturbance of the population; animals being habituated to humans; and a shot in the head or the high neck area to ensure that the game carcasses are fit for meat export purposes (Tinley, 1972). If the population of animals are used to human interactions throughout the year, it will ease the harvesting process since the animals will not be as "wild" and frightened by the presence of the harvesting team. The latter, together with the correct shot placement (instantaneous death) will decrease the amount of *ante mortem* stress experienced by the animals and therefore result in game carcasses of higher quality. The commercial game

industry, however, seeks to make the harvesting of game animals more cost effective. This is done by continuously adjusting the harvesting techniques to reduce the harvesting time and increase the number of animals harvested (Mostert, 2007). Some of these techniques which are frequently employed by the South African game meat industry includes night harvesting, day harvesting, boma en helicopter harvesting.

<u>Night harvesting</u>

Night harvesting is the most popular and commonly used method of cropping/harvesting game animals (Veary, 1991; Lewis et al*.,* 1997; Hoffman, 2000a; Kritzinger et al*.,* 2003; Hoffman & Wiklund, 2006; Le Grange, 2006; Van Schalkwyk & Hoffman, 2010). This method has been proven to be most effective at producing the best quality game meat (Hoffman, 2000a; Hoffman & Ferreira, 2000; Kritzinger et al., 2003; Hoffman & Wiklund, 2006). Night harvesting employs the use of strong spotlights, scoped rifles and modified vehicles on especially dark, moonless nights. The latter makes for more effective immobilisation of animals since the high intensity spotlights are more effective at blinding the animals (Bothma, 1996; Le Grange, 2006). The animals are also less skittish and thus easier to approach, which makes them easier to locate and to harvest higher numbers in a shorter time period. However (depending on the quota for the property), the harvesting usually commences shortly after dark and continues to the break of dawn so as to fully utilise the advantage of the moonless nights (Kritzinger et al*.,* 2003).

The animals are spotted by the reflection of their retinas in the light and are so temporarily immobilised, giving the marksman the opportunity to shoot the animals from relatively close distances (25 – 100 m). The marksman is usually also the driver, so as to eliminate the possibility of confusion or misunderstandings between the driver and marksmen and therefore ensuring the preciseness and efficiency of night harvesting operations (Hoffman & Wiklund, 2006). It is, however, not uncommon to harvest animals at longer distances (40 – 200 m) (Ruggeiro & Ansley, 1992), but when shot distances exceeds 150 m it usually results in missed or unacceptable placements of shots. Furthermore, the firing of shots should only commence if a clear shot is possible (Kritzinger et al*.,* 2003) as to ensure minimum wounded animals. The shots are generally placed in the head or high necks areas (Bothma, 2010; Van Schalkwyk & Hoffman, 2010), as this was found to result in the least amount of carcass damage in springbok and impala (*Aepyceros melampus*) (Von la Chevallerie & Van Zyl, 1971b). Conversely, shots in the shoulder and buttocks regions can account for 20% and 50% of carcass meat wastages, respectively (Bothma, 1996). The use of smaller calibre rifles, good quality telescopic sights and good shot placements ensures minimum carcass losses, accurate shots as well as effective and hygienic harvesting conditions (Bothma, 1996; Le Grange, 2006).

The shot animals have to be collected as soon as possible so that exsanguination can occur preferably within 10 min *post mortem*. This diminishes the chances of not finding the animals, especially where large populations of predators are present as they might become aware of the hunting routine and compete with the harvesting team for the carcasses (Le Grange, 2006). When a sufficient number of animals have been shot or when 120 min have passed, the shot animals are transported to the temporary field abattoir which is usually in close proximity to the harvesting area (Van Schalkwyk & Hoffman, 2010). The animals are partially dressed at the field abattoir and later transported to commercial abattoir facilities where complete processing and packaging of the meat products occur (Anon., 2012).   Although ambient conditions during night harvesting are predominantly cooler and thus meat spoilage is less likely to occur, cooler conditions could also affect the meat quality adversely (see ambient temperatures during harvesting).

Day harvesting

Day harvesting is easily practised on all the common South African game species, since it is easier to spot the animals during the day compared to at night. The setup is similar to night harvesting, with the spotters on the back of a vehicle (without spotlights) and the driver being the marksmen. The marksmen can achieve a higher harvesting success rate since the animals can be clearly spotted and more easily distinguished from the surroundings (Hoffman & Laubscher, 2009). Additionally, the animals can also be selectively cropped as daylight makes it easier to distinguish between age classes, social groups and sexes (even those classes which are sexually similar in appearance) (Bothma, 1996). However, the animals might also be more skittish since they are able to spot the harvesting team easier. With day harvesting the animals can be harvested over longer distances (excess of 150m), however, as with the conventional night harvesting operations the increased distances, together with the more prominent role of wind at these distances, may lead to higher occurrences of wounded animals. It is, however, easier to locate the wounded animals and/or shot animals during the day compared to the night (Hoffman & Laubscher, 2009).

Day harvesting also allows extended harvesting time periods since it is not dependent on the absence of moonlight, but the presence of flies as well as the higher ambient temperatures can negatively affect the harvesting procedures. The harvested animals should thus be placed in cooling facilities as soon as possible, to prevent spoilage (Hoffman & Laubscher, 2009).

Boma harvesting

The boma harvesting method is very adaptable and ideal for use in dense bushveld areas where the terrain and landscape is not as accessible for vehicles (Bothma, 1996). In such terrains the bush is very thick and the off take rate is often limited when using the night or day harvesting

methods (as previously described). This method incorporates similar techniques as used with the mass capture of animals for relocation or live sales.

The boma is artificially constructed in a funnel shape (Fig. 2.3) from a strong, durable, dark coloured material (often best suited to camouflage, matching the type and colour of the vegetation present). The direction from which the wind is blowing plays a critical role in setting up such a boma structure as to not alarm the animals when they are herded towards it, since most ungulates possess a keen sense of smell (Le Grange, 2006). The animals are herded into the boma by use of a helicopter, vehicles or man power and then culled whilst inside (Le Grange, 2006). Herding game animals over long distances could, however, negatively affect the subsequent meat quality attributes by severely stressing the animals, which could lead to mortalities, bruising and other detrimental meat quality affects such as white muscle capture myopathy. Management of such factors is possible, since the success of this technique is based on the design and experience of the team and/or personnel employed (Le Grange, 2006).

The boma material prevents the animals from challenging and escaping out of the boma as they cannot see through it and thus perceive it as being a solid wall or object. The funnel shape channels the animals away from the herding party and into the smallest section of the boma (Figure 2.3). The latter process is further helped by closing the gates behind the animals as they move further into the funnel and closer to the killing complex (Figure 2.3). Once they reach the final narrow section (Ramp crush complex, Figure 2.3), the animals can be separated and kept in different compartments (Le Grange, 2006). Once the animals have reached the last section of the funnel, they should be left to relax for a short period (> 2 hours) (Hoffman & Wiklund, 2006). Le Grange (2006) recommended that the animals be left until night fall before commencing the harvesting operations. The latter, however, requires additional gear (e.g. lighting) which will increase the cost of harvesting, but it can result in less stressed animals and consequently better meat quality (Kritzinger et al., 2003; Laubscher & Hoffman, 2009).

After the "resting period", smaller groups (± 10 animals) of animals are herded into smaller enclosed compartments ("killing acre"), located in the ramp crush section of the boma (Figure 2.3), to be culled with a small calibre silenced rifle (Hoffman & Wiklund, 2006; Le Grange, 2006). The marksmen are usually present at an elevated position and the harvesting of the smaller groups of animals usually takes approximately 60 – 90 s (Hoffman & Wiklund, 2006). Once the animals are all down (killed) the undressed carcasses are removed and exsanguinated at a different location, usually some distance away from the killing block as to not alarm the next group of animals that will be herded into the killing block. The exsanguinated carcasses are then transported to the mobile field abattoir where further processing will commence (Mostert, 2007).

The boma harvesting process allows for the selective harvesting of game animals and thus some individuals (trophy or very young animals) can be selected for breeding purposes and set free. The correct herding and handling of the animals can keep the degree of stress experienced low and thus increase the efficiency of this harvesting method. Boma harvesting allows for a large number of animals to be culled and processed within a relatively short period of time as well as ensuring that no wounded animals are left behind in the processing area, as might be the case with night harvesting methods (Le Grange, 2006). From a meat hygiene perspective this method is ideal since all animals are processed and inspected at a central location, which makes for easier maintenance of hygiene and carcass inspections by authorities (Le Grange, 2006).
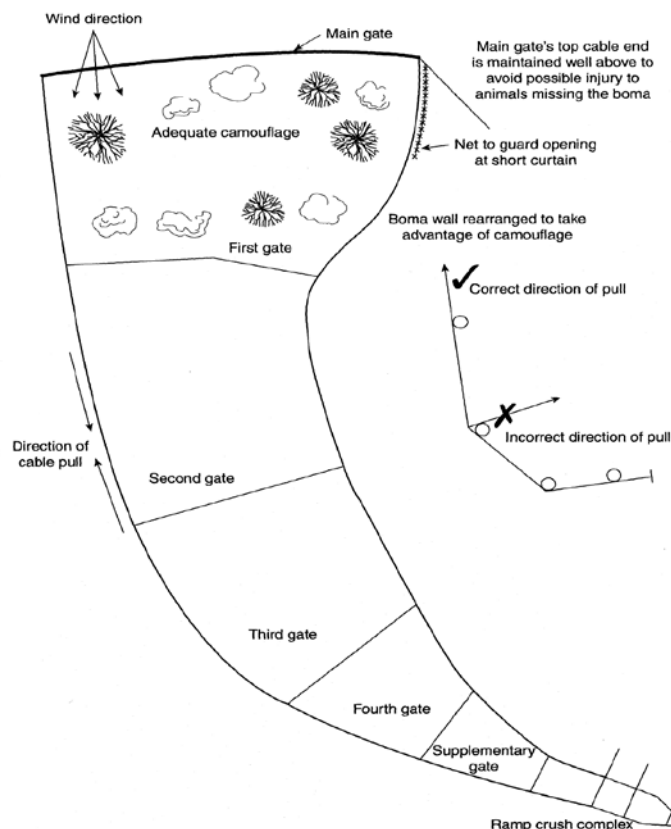

Figure 2.3 Setting up a plastic boma for game capture (Le Grange, 2006).

Care should be taken when animals are harvested during the rutting period, since older male animals might cause the death of younger males (dominance). Animals with horns can also injure other animals during fighting and/or pushing through the boma, which can cause bruising and so negatively affect the meat quality. Nonetheless, most species can be culled using the boma method, although some species require special attention, such as the eland, kudu and waterbuck (*Kobus ellipsiprymnus*) which are known for their jumping ability. Netting can be installed over the top of the boma holding the latter to prevent animals from breaking out and injury. Eland, impala, springbok and blesbok are easily herded and therefore well suited for this method (Le Grange, 2006). Conversely, kudu are difficult to herd and may become extremely nervous (Bothma & Van

28

Rooyen, 2005). Buffalo (*Syncerus caffer*) will not challenge the enclosure or plastic wall of the boma, as long as they are not able to see through the enclosure.

The disadvantages of this method are that the use of helicopters to herd the animals is very expensive and thus large numbers of animals must be targeted to make this method cost effective. It also requires a large well trained and experienced work force, long preparation time and lots of materials. The correct terrain and available camouflage is also essential to design a suitable and efficient workable boma (Bothma & Van Rooyen, 2005; Le Grange, 2006). Boma harvesting may not be the best method when fewer animals should be harvested, the terrain is not suitable and when meat quality is of the highest importance.

Helicopter harvesting

Helicopter harvesting utilises a helicopter and a 12 gauge shotgun with a very tight choke setting. The latter is to minimize the potential of wounding animals by concentrating the spray pattern of the lead shot. The use of a semi-automatic shotgun has shown to give the shooter the ability to shoot as many as six animals in succession (Le Grange, 2006). The animals are shot in the head or upper neck area from an altitude of around 6 m and then collected by the supporting ground personnel (Bothma, 1996; Kroucamp, 2004). Good communication between the pilot and ground crew is also essential so that carcasses can be recovered quickly and bled out efficiently. In many cases the ground crew uses GPS navigational equipment to locate the shot animals rapidly, exsanguinate quickly, to partially dress and place the carcasses in cooling facilities as soon as possible (Le Grange, 2006).

Helicopter harvesting has been successfully practiced in Africa on impala, blesbok, springbok and buffalo as well as in New Zealand on red deer (*Cervus elaphus*) (Le Grange, 2006). However, savannah type vegetation areas are not suited for this method due to the open nature of the terrain (Bothma, 2010). Advantages of helicopter harvesting are the easy access to remote locations or where dense vegetation is present, it is a relatively quick harvesting method; a larger area can be covered as well as being able to selectively harvest game animals. However, collecting and locating the carcasses may still prove to be difficult (Rudman, 1983). A quick population estimate of the available game animals can also be made during the helicopter harvesting operations. This method is, however, the most expensive harvesting method, since it requires high capital investments and professional expertise (Van Rensburg, 1992; Bothma, 2010).

Helicopter harvesting may inflict unnecessarily high stress (due to exercise/fear) and bruising of the animals as well as the possible damaging of fences when larger animals attempt to escape the property (Rudman, 1983; Mostert, 2007). This method will consequently produce lower quality game meat (Bothma, 2010); however, Veary (1991) noted similar muscle ultimate pH values from

29

the animals harvested with helicopters as compared to night harvesting. On the other hand, Le Grange (2006) reported that the body temperature of the animals' increases excessively and together with high levels of adrenaline released during the helicopter harvesting, generally resulted in extremely rapid meat decay.   These carcasses were usually rendered unfit for human consumption, most probably due to high ultimate pH values and the occurrence of dark, firm and dry meat.

Ambient temperatures during harvesting

As mentioned previously, most of the harvesting of game animals occurs at night. The commercial night harvesting operations are usually linked to the South African hunting season, which is generally in the winter months when the crucial reproduction activities (mating; lambing or calving) do not occur (Joubert, 1968).   In South Africa and Namibia, the night harvesting season for commercial meat production usually commences in April and ends in August. This ensures no or little disruption with the mating season of African ungulates which usually occur in late summer (February to March); with the offspring normally being born in late spring (October to November).

Although springbok and blesbok can be harvested all year long, the majority of these species are generally harvested during the winter months (springbok, June; blesbok; April to May) (Anon., 2011). During these harvesting periods, the mean winter ambient night temperatures in the home ranges of springbok (Karoo; Northern Cape) and blesbok (Transvaal; Highveld) can drop to below zero (Anon., 1986; Mucina et al., 2006a, 2006b). The low temperature conditions during night harvesting, together with the minimum subcutaneous fat on game carcasses (Dryden, 1997; Hoffman, Kroucamp & Manley, 2007), usually result in the rapid chilling of game carcasses (Jansen van Rensburg, 1997).   In addition, the harvested game animals are often partially eviscerated (removal of the contents of the abdominal cavities) in the field (Van Schalkwyk & Hoffman, 2010), which would facilitate further heat loss due to exposure to the cold ambient conditions. The latter could result in the even more rapid chilling of game carcasses during the colder night temperatures in winter months and may adversely affect the subsequent meat quality. This can be attributed to a decrease or inhibition of the natural tenderisation brought by the proteolytic enzymes, which are activated by the onset of *rigor mortis* during the conversion of muscle to meat (see proteolysis). In serve circumstance the rapid chilling of game carcasses *post mortem* could result in cold-induced toughening of muscles (see cold shortening).

However, the opposite is found when game animals are harvested during the day. The ambient temperatures can exceed 30°C in the summer months (Mucina et al., 2006a), which necessitates proper cooling facilities and processing standards to prevent microbial spoilage of carcasses (Le Grange, 2006). The draft Meat Safety Act (no.40 of 2000; Anon., 2012) requires that dressed

game carcasses together with the offal must be chilled within the first 12 hours *post mortem*. However, when the ambient temperature exceeds 15°C, the chilling of the dressed game carcasses should commence within four hours *post mortem.* The latter ambient temperature conditions are, however, rarely found in winter during night harvesting conditions. Furthermore, dressed game carcasses should be chilled to a core temperature of 7°C after 24 hours of chilling (Anon., 2012) to be deemed safe for human consumption. However, when higher ambient and therefore carcass temperatures are present, it could result in an increased enzyme activities and proteolysis, since the enzymes responsible for proteolysis will be more efficient (working at a higher rate) with an increase in temperature (Lawrie & Ledward, 2006; Koohmaraie & Geesink, 2006). Such high temperatures during game harvesting may, however, also negatively affect the meat quality by resulting in Pale, Soft and Exudative (PSE) meat. This phenomenon is caused by enzymes (responsible for protein denaturation through proteolysis) which are activated due to an accelerated drop in the muscle pH *post mortem* as a result of higher temperatures affecting *post mortem* glycolysis (Lawrie & Ledward, 2006).

Ambient temperature during harvesting is therefore a very important consideration, since temperature extremes can adversely affect subsequent game meat quality.

PHYSICAL MEAT QUALITY

The physical characteristics of meat influence the consumer's decision to purchase a particular product. Colour, tenderness and juiciness/water holding capacity (WHC) are primary physical factors that influence the consumer's perception on the quality of meat products (Steenkamp, 1997; Wood et al., 1999; Koohmaraie, Veiseth, Kent, Shackleford & Wheeler, 2003). These attributes are affected by both *ante* and *post mortem* elements during slaughter and processing procedures. During these crucial periods, the factors that influences *post mortem* glycolysis (measured as pH) of muscles during its conversion to meat, are of the utmost importance to ensure the final quality of meat products (Lawrie & Ledward, 2006). An understanding of the mechanisms and inner workings of the factors that influences game meat quality is essential for combating inconsistencies in game meat product quality.

Muscle conversion to meat

After exsanguination at slaughter, the blood circulation system of carcasses fail and consequently the supply of oxygen (as well as glucose and free fatty acids) to various tissues in the body is also terminated (Warriss, 2000). The tissues are still able to maintain their metabolisms, but only under local control (Lawrie & Ledward, 2006). The latter includes the individual muscle cells which will still maintain their temperature and organisational integrity, which in turn prevents their spontaneous tendency to break down. This process, however, still requires energy, although the

muscles are not actively contracting (Lawrie & Ledward, 2006). These energy requirements are then met by the available ATP in the muscles at the time of death as well as through anaerobic metabolism. The lack of the blood-borne oxygen circulation system produces a subsequent fall in the oxidation reduction potential, which causes an inability of the cytochrome enzymatic system to function, making re-synthesis of ATP from this source unmanageable (Lawrie & Ledward, 2006).

Consequently, the ATP present in muscle tissue at the time of death is also quickly exhausted, since the muscles have a high ATP turn-over rate and can thus only supply energy for a few twitches of the muscles *post mortem* (Bate-Smith & Bendall, 1949). Additional ATP is thus needed for the muscle tissue to keep its relaxed state. This ATP is supplied by the breakdown of the muscle glycogen reserves (glycolysis), since the normal aerobic process of oxidative decarboxylation and phosphorylation will no longer operate without a source of oxygen (Warriss, 2000). Any subsequent metabolism will thus be anaerobic and muscle glycogen will be degraded (glycogenolysis) and metabolised through anaerobic glycolysis in order to re-phosphorylate ADP to ATP (with the use of creatine phosphate), so as to prevent the permanent formation of actomyosin cross-bridges (Scheffler & Gerard, 2007).

As a result of the breakdown of glycogen, heat and lactic acid hydrogen ions (H^+) are produced and these waste products accumulate in muscles (no blood circulation to remove it), causing an acidification of the environment and a corresponding drop in the pH of the muscles (Warriss, 2000; Lawrie, 2006; Scheffler & Gerard, 2007). As ATP is depleted and *post mortem* anaerobic glycolysis and consequently muscle acidification proceeds, tropomyosin and troponin molecules can no longer prevent the binding of the actin and myosin molecules (Lawrie & Ledward, 2006). The muscles' consequently looses its extensibility due to the formation of permanent actomyosin cross-bridges. This loss in extensibility signals the onset of *rigor mortis*. All factors affecting the levels of glycogen and creatine phosphate at death, will affect the time to onset of *rigor mortis* (Warriss, 2000). The time between death and the onset of *rigor mortis* differs between species and usually coincides with the disappearance of ATP from muscles (Lawrie & Ledward, 2006), which in turn signals the completion of the conversion of muscle to meat (Swatland, 1994).

Muscle pH measurements can be taken at slaughter and during ageing until *rigor.* Muscle pH is one of the most important measurements used in association with meat quality. The pH decline *post mortem* tends to typically begin more or less at a pH of 7.0 and decline to a pH value around 5.5. When *rigor* is obtained, the pH value of the meat is constant and thus referred to as the ultimate pH (pH_u) (Warriss, 2000). The pattern/profile of the pH decline *post mortem* is similar in most animals, although the rate and extent may vary between species and muscles (Lawrie & Ledward, 2006). *Rigor* can take as long as 15-36 hours to develop in un-stimulated beef and 12-24 hours in un-stimulated sheep, 12-24 hours in pig and 4-8 hours in poultry (Dransfield, 1994).

Normal pH_u values of meat are between pH 5.50 and 5.75 although there are times when carcasses have lower glycogen stores, when intermediate (pH 5.75-6.0) or even high pH readings (> 6.0) will be recorded. The pH of meat is, however, affected by *rigor* temperature. The pH will decrease by approximately 0.15 units when the meat is warmed from 20° to 38°C, and it increases by about 0.2 units when the meat is cooled from 20° to 0°C (Bendall, 1973).

Ageing

The next phase of the conversion of muscle into an edible and preferred meat product is known as ageing. It consists of two phases, i.e. the onset of *rigor mortis* (conditioning or toughening phase) and the tenderisation process (ageing or tenderisation) that follows *rigor* (Koohmaraie, 1996). The latter is determined by the pre-slaughter conditions (i.e. stress), *rigor* temperature as well as the ageing temperature (temperature at which meat products are stored) (Devine, 2004).

The toughening phase is depicted by the first 24 hours *post mortem*, it is a result of the amount of sarcomere shortening. Research has shown that the amount of shortening is the cause of the increase in meat toughness, however, the species, pre-slaughtering conditions and the particular animal cause's variation in the extent of shortening of muscles (Koohmaraie, 1996). Nonetheless, all muscles undergo toughening, although the extent of this is determined by the amount of tenderisation that has taken place and the suitability of the conditions during slaughtering and processing for tenderisation (Koohmaraie, 1996).

The process of ageing only starts once each individual muscle cell reaches *rigor*, but until then all of the normal inhibiting mechanisms will still prevent the tenderisation process. Individual muscle fibres, however, do not enter *rigor* at similar time points, since glycogen levels and ATP depletion times differ *post mortem* (Devine, 2004; Warriss, 2000). The latter causes the ageing of muscle fibres to commence at different times in each muscle and therefore results in some fibres ageing quicker than others, since they have entered *rigor* at an earlier stage. However, the instigation of ageing can be altered or affected by the interplay of factors such as rapid pH decline caused by ES or high temperatures that could occur during *rigor* development and storage (Devine, 2004; Warriss, 2000). These factors can drastically change the commencement and rate of ageing and it is clear from the discussion that ageing is not an all or none effect. The enzymes which are involved are also selective in which substrates they bind to and thus the proteolysis of ageing does not affect all the muscle proteins (Devine, 2004).

As previously stated, ageing starts at *rigor* with the disappearance of ATP. The onset of *rigor mortis* causes the endogenous enzymes (calpains and cathepsins) to be activated (Devine, 2004; Lawrie & Ledward, 2006). The latter is a result of the release of calcium ions from the sarcoplasmic reticulum due to its inability to bind calcium and is directed by the temperature at

which the muscle/meat is stored at (Devine, 2004; Lawrie & Ledward, 2006; Warriss, 2000). The proteolysis of key myofribrillar and associated proteins is a result of the activity of the endogenous enzymes which are responsible for the tenderisation process (for a full review; see Koohmaraie, 1996).

Ageing is generally associated with increased tenderness and flavour of meat over time *post mortem* (Lawrie & Ledward, 2006). It is, however, not the elastin and collagen that denature during ageing, but rather the myofibrillar and sarcoplasmic proteins that denature to varying degrees (Lawrie & Ledward, 2006). There is, however, no dissociation of actomyosin during ageing, but rather the actin filaments that are detached from the Z-lines, since they have weaker bondages compared to those between the Z-lines and myosin filaments (Lawrie & Ledward, 2006). The actin filaments then collapse onto the myosin filaments, which lengthens the *A*-bands and weakens the *A-I* junction of the sarcomere (Lawrie & Ledward, 2006).

Furthermore, these enzymes are responsible for the breakdown of structural proteins in muscles (tenderisation), which usually hold the contractile muscle proteins (actin and myosin) together (Devine, 2004). The calpains are enzymes grouped together. They are primarily responsible for the tenderisation process. Calpains consists of two forms, the μ- and m-calpains. These two groups differ in their calcium requirements (μ-Calpain: 1 – 30 μmol and m-calpain: 100 – 750 μmol), but both undergo autolysis (broken down by their own activity) during their operation, which explains why the rate of tenderisation is initially higher and then steadily declines until inhibition of ageing occurs. As the enzymatic activity is increased at higher temperatures, the rate of tenderisation is faster at higher temperatures; however, this is also true for their autolysis activity (Devine, 2004). Moreover, the rate of ageing differs between species as well as between various muscles from the same animal (Lawrie & Ledward, 2006).

The second crucial enzyme group responsible for tenderisation is called the cathepsins. Cathepsins are contained in lysosomes which are found in the sarcoplasm and are shattered *post mortem* (Warriss, 2000). It is believed that they are involved in the long term ageing of meat and are set to degrade troponin-T, some of the collagen cross-links and mucopolysaccharides of the connective tissue ground substance. The cathepsins function at an optimum pH level of 5.4 – 5.6. It has been suggested that the ratio of calpains and cathepsins indicate the extent and speed of tenderisation. However, the *post mortem* tenderisation process is not yet fully understood as the activity of calpastatin and the calpains are also regulated by the pH and temperature of muscles (Devine, 2004; Warriss, 2000).

Calpastatin activity is stimulated by the ß-agonists (Lawrie & Ledward, 2006). The rate of *post mortem* tenderisation in meat is inversely correlated with the naturally present calpastatin (Lawrie

& Ledward, 2006), as calpastatin inhibits the activity of the calpains and thus decrease the extent of the tenderisation process. However, evidence is limited and the relationships may be merely associative, as the latter relationship is also affected by pH values present. The inhibition of calpains by calpastatin is also pH-dependent, since the measured optimal calpastatin activity (pH 7.5) always exceeds the activity of μ-calpain. During prevailing pH conditions in muscles *post mortem* (pH < 5.8), the calpain activity is reduced, but the effective activity of calpastatins are probably reduced to a greater extent. It is postulated that μ-calpain is more active in *post mortem* muscles with an ultimate pH (pHu) of 5.5-5.8, although this does not clarify the rapid tenderisation of meat with a high pH value. There are also a time scale differences between the decline in calpain activity and tenderisation, for example, at storage temperatures between 0° – 2°C the calpain levels are quite low at about two days *post mortem* and a significant amount of tenderisation still occurs after this point (Devine, 2004).

Temperature also plays a crucial role during early *post mortem* tenderisation, as it affects the rate of tenderisation by affecting the enzymatic activity. It is thus crucial to manage the muscle temperature during the processing of meat, so as to ensure low levels of pathogenic and spoilage bacteria on meat products. By controlling the ambient temperature the resulting muscle temperatures are lowered, but this can negatively affect the tenderisation process and should thus be managed along with further processing techniques to maximise the tenderisation of the products, as would be the case if ES was employed to increase pH decline (modification of the glycolytic rate) at a higher temperature. This would cause an earlier onset of *rigor mortis* at a higher carcass temperature, which would result in increased ageing, as the rate of ageing is temperature dependant and the higher temperature would increase the enzymatic activity/process. The use of ES would thus increase the rate of tenderisation as well as prevent cold shortening.

Carcass cooling

Carcasses are cooled to prevent or inhibit microbial growth and so minimise the possible spoilage of the resultant meat products (Warriss, 2000; Lawrie & Ledward, 2006). The carcass chilling temperature (after processing) influences the rate of ageing (enzyme activity) and the shelf-life (storage period) of the potential meat products. This will, however, depend on the product or meat cut being stored as well as the temperature and type of packaging being employed (Lawrie & Ledward, 2006).

Although the market specification or particular product and packaging may influence the ageing of the product, the crucial period is however, during the carcass chilling, before the carcasses are processed further. For example, Xu, Huang, Huang, Xu & Zhou (2012) investigated the impact of different carcass chilling rates (1: conventional chilling method 0° – 4°C; 2: rapid chilling method -20°C for 3 min, then 0° – 4°C; 3: short-duration chilling 0° – 4°C for 30 min, then 25°C) on the meat

quality of pork LD muscles. The rapid carcass chilling method on pork LD muscles significantly increased the WHC and decreased the cooking losses. However, the tenderness was not improved as they found that the rate of pH decline was inversely proportional to the tenderness of the meat.

Rapid carcass chilling can reduce weight loss by evaporation of water from the meat surface (Lawrie & Ledward, 2006). However, cooling too rapidly may lead to less tender meat, either by reducing the activity of the naturally occurring proteolytic enzymes or by inducing cold shortening (Pearson & Young, 1989; Warriss, 2000; Tompson, 2002). The correct balance must be managed between the benefits of rapid carcass cooling compared to the possible negative influences on meat quality (Warriss, 2000). The carcass cooling rates can induce four phenomena in meat: heat shortening, *rigor* shortening; cold shortening; and thaw shortening (Lawrie & Ledward, 2006; Warriss, 2000) (Fig. 2.4).
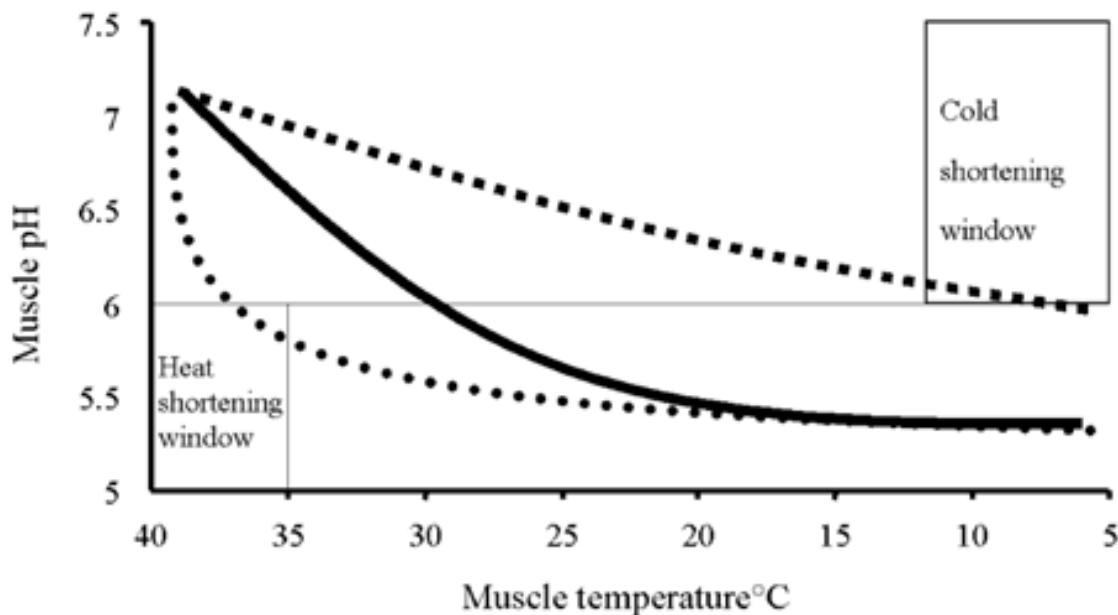

Figure 2.4 The pH/temperature window used by the *Meat Standards of Australia* to optimise the decline in pH relative to the temperature of the muscle. The solid line represents an optimal rate of decline. The dashed line represents the occurrence of cold shortening and the dotted line represents the heat shortening scenario (Thompson, 2002).

Cold shortening

Cold shortening (CS) occurs during rapid chilling of carcasses *pre rigor* when the sarcoplasmic reticulum (SR) loses its integrity and Ca^{2+} are released into and flood the sarcoplasm. Low carcass' temperatures causes a lack in functionally of the SR calcium pump and Ca^{2+} can therefore

not be reabsorbed. The high concentration of Ca^{2+} in the cytoplasm activates the actomyosin ATP-ase, which leads to super contraction of the muscles and subsequent shortening of the myofibrils, since ATP is still present in the muscles (Lawrie & Ledward, 2006; Warriss, 2000). Cold-shortened muscles tend to have lower μ-calpain activity and increased calpastatin levels, which contribute to the toughness of the final meat products. The degree of muscle shortening during *rigor mortis* is furthermore dependent on the temperature conditions *post mortem* (Lawrie & Ledward, 2006). It is, however, important to note that when CS occurs and the toughness increases as a result, it is irreversible. The meat will always be tougher compared to the non CS aged meat and thus there will always be a noted difference between them for all the following time points. However, if two samples differ in their initial tenderness but after a period of aging they no longer differ, cold induced toughing did not occur, but the one sample merely aged quicker than the other (Simmons, Daly, Mudford, Richards, Jarvis & Pleiter, 2006; Simmons, Daly, Cummings, Morgan, Johnson & Lombard, 2008).

The general consensus of the literature states that the conditions needed to induce cold shortening requires the carcass to be in a state of *pre rigor* (with ATP still available for the muscle to be able to contract), while the muscle pH value is greater than 6.0 and the muscle temperature drops below 10°C (Pearson & Young, 1989; Devine, Hopkins, Hwang, Ferguson & Richards, 2004) (Fig. 2.4). The generalisation has already been opposed by Simmons et al. (2008). Their investigation tested a faster chilling rate on beef carcasses; even faster than the chilling rate mentioned for the initiation of CS conditions (Pearson & Young, 1989; Devine et al., 2004). Their results indicated that meat could be cooled at an even faster rate than postulated and not result in cold-induced toughening (Simmons et al., 2008). Simmons et al. (2008) further postulated that CS could not be caused by the cooling regimes of commercial abattoirs, since the conditions stipulated above could not be achieved without freezing the carcass within 24 hours of slaughter.

Some species are more susceptible to the adverse effects of rapid chilling procedures on meat quality. Beef carcasses, for example, are more bulky and they therefore cool down slower under commercial slaughtering conditions, decreasing the chances of inducing CS. However, leaner carcasses or carcasses of smaller build such as springbok and blesbok tend to cool quicker and are thus more susceptible to this phenomenon. Sheep carcasses are also more susceptible to CS, due to their smaller carcass size and therefore have quicker cooling rates, although their well-developed subcutaneous fat layer gives some form of insulation. Game carcasses also fall into the latter category, although they have no or little subcutaneous fat (Hoffman, 2000b) and will therefore cool down rapidly (Jansen Van Rensburg, 1997). In the study by Jansen Van Rensburg (1997) on the effect of temperature treatment on the meat quality of springbok during commercial harvesting, it was postulated that the carcasses would cool down too rapidly if placed in pre-cooled refrigeration trucks. The rapid chilling could cause detrimental effects on resulting game meat

quality. Game animals are thus more susceptible to cooler ambient conditions and processing temperatures, due to their low fat content. The location of the muscle, however, also plays a role since the muscles closer to the surface of the carcass (i.e. *M. longissimus dorsi*) will be more susceptible compared to the muscles located in the deeper regions (*M. psoas*).

Under commercial harvesting conditions in the Karoo, the temperature will frequently drop below 5°C or even below freezing point. These cold circumstances could therefore result in cold shortening of game carcass muscles. In addition, springbok have very little subcutaneous fat (Dryden, 1997; Hoffman et al., 2007) to prevent the rapid rate of heat losses with cold ambient temperatures and this increases the possibility for cold shortening to occur (Smith, Dutson, Hosteler, & Carpenter, 1976; Wood & Warriss, 1992). Carcasses will thus chill more rapidly under these colder ambient conditions, compared to the normal refrigeration conditions used by commercial meat processing facilities (Jansen van Rensburg, 1997; Veary, 1991). For cold shortening to occur, the pH value of the meat should be above 6.1 and the muscle temperature below 10°C (Pearson & Young, 1989; Devine et al., 2004). Cold shortening could thus negatively influence the meat quality attributes of springbok meat, either by decreasing the tenderness and/or leading to inconsistencies or variations in the quality of the products being exported throughout the year.

The question is, however, whether these conditions can induce cold shortening in game meat and whether the use of ES can prevent this from happening and thus ensure game meat quality and favourable game meat tenderness. Even if cold shortening does not occur, the rapid decrease in carcass temperature will influence the activities of the proteolytic enzymes as previously discussed. It is argued that ES will cause a decrease in muscle pH which will stimulate the enzyme activity whilst the muscle temperatures are still high, thus resulting in more tender meat.

ELECTRICAL STIMULATION

Electrical stimulation (ES) is characterised by passing an electric current through a freshly slaughtered carcass, with the aim of ensuring meat tenderness under rapid carcass chilling conditions (Devine et al., 2004). There are three main reasons for the application of ES: the prevention of cold shortening (CS); accelerated ageing; and to decrease variations in the quality of meat products (Simmons et al., 2008).

The meat tenderising attributes of ES was already established in the 1950s, but the process was not yet applied commercially. The commercial application of ES for the prevention of toughness due to CS was first practiced in New Zealand, followed by Australia. Electrical stimulation is now used in various countries with varying parameters (Devine et al., 2004).

The electrical parameters used during ES should consider the type of species, the delay period *post* slaughter, the waveform and pulse frequency, duration and chilling rates (Devine et al., 2004). Electrical stimulation should be applied as soon as possible *post* slaughter, since a relatively low voltage system (< 100 V) can then effectively function via the nervous system (Devine et al., 2004). However, an increased delay *post* slaughter will require higher voltages to directly stimulate the skeletal muscles (Swatland, 1994; Devine et al., 2004; Lawrie & Ledward, 2006). Electrical stimulation has been applied for the improvement of the tenderness of numerous species, such as deer, sheep, cattle, goats and poultry carcasses (Devine et al., 2004).

Initially, New Zealand used ES for the acceleration of *rigor mortis* in cattle and sheep (prior to freezing), however, now ES is also applied to improve the overall meat quality (Devine et al., 2004). Electrical stimulation has been found to significantly increase the rate of pH decline *post mortem* in the muscles of domesticated species (bulls – Li, Chen, Xu, Huang, Hu & Zhou, 2006; lamb – Martin et al., 2006; pork – Zhang, Peng, Zhou, Xu & Wu, 2007; lamb – Toohey, Hopkins, Stanley & Nielsen, 2008; camels and cattle – Kadim et al., 2009; sheep – Abbasvali, Shekarforoush, Aminlari, & Ebrahimnejad, 2012). The muscles of ES carcasses therefore often have significantly lower pH_u values (bovine – White, O'Sullivan, Troy & O'Neill, 2006; camels and cattle – Kadim et al., 2009). Furthermore, it has also been noted that ES increases the rate of glycolysis and ATP depletion (sheep – Abbasvali et al., 2012), decreases the time to the onset of *rigor mortis* (pork – Zhang et al., 2007; sheep – Abbasvali et al., 2012) and significantly improves (longer) sarcomere lengths (camels and cattle – Kadim et al., 2009) and meat tenderness (bovine – White et al., 2006; lambs – Devine et al., 2006; grass-fed steers – Razminowicz, Kreuzer & Scheeder, 2008; camels and cattle – Kadim et al., 2009; sheep – Abbasvali et al., 2012). Research on the effect of ES on the colour and moisture losses from meat, indicated that ES meat was significantly more red (higher CIE a* values) in colour, with higher expressed water and cooking loss percentages (camels and cattle – Kadim et al., 2009). In other studies, however, ES had no significant effect on the above mentioned physical meat characteristics (lamb – Martin et al., 2006; ostriches – Hoffman, Cloete, Van Schalkwyk & Botha, 2009).

Electrical stimulation has been utilised in the commercial game harvesting abattoirs in New Zealand since the start of the 1980s (Wiklund, Stevenson-Barry, Duncan & Littlejohn, 2001). New Zealand exports about 90% of its meat from deer. Assuring the meat quality of the latter is therefore of high priority and a lot of research and funding is allocated to improving techniques and processes to keep their standards high. Nonetheless, there are still mixed opinions about the application of ES to improve game meat quality (Bekhit, Farouk, Cassidy & Gilbert, 2007).

Electrical stimulation accelerates *post mortem* glycolysis (impala – Van den Berg, 2009) and decreases the time to the onset of *rigor mortis* in selected game carcasses (impala – Van den Berg, 2009). Electrical stimulation of game carcasses can also result in significantly lower pH_u values (reindeer (*Rangifer tarandus tarandus*) – Wiklund, Finstad, Johansson, Aguiar & Bechtel, 2008) and improved meat tenderness (red deer – Bekhit et al., 2007; reindeer – Wiklund et al., 2008). However, the improved tenderness of ES game meat samples might not be detected by game meat consumers (Wiklund et al., 2008). Also, in some studies ES had no effect on the pH_u, sarcomere length, tenderness, drip or cooking loss percentages of game meats (impala – Van den Berg, 2009).

Effect of electrical stimulation on muscle conversion to meat

Electrical stimulation induces muscle contractions under anaerobic conditions. Consequently the rate of anaerobic glycolysis in muscles is increased (Devine, Payne, Peachy, Lowe, Ingram & Cook, 2002; Devine et al., 2004), resulting in lactic acid formation due to the breakdown of glycogen for the synthesis of Adenosine Triphosphate (ATP), required during muscle contractions. The application of ES will result in an immediate drop in the pH of the muscles, followed by an increase in the rate of pH decline until the onset of *rigor mortis* (Devine et al., 2004). Electrical stimulation thus results in the earlier onset of *rigor mortis* (Devine et al., 2002, 2004). The degree of the initial decrease in muscle pH is dependent on the muscle fibre type composition, the initial glycogen stores present in the muscles, the muscle temperature, *post mortem* time of ES as well as the electrical characteristics (current, pulse shape, frequency and duration of stimulation). In beef, for example, the fast-twitch *Cutaneus trunci* muscle primarily contains white muscle fibres and consequently has a higher initial pH fall and rate of pH decline with the application of ES. However, in the slow-twitch *Masseter* muscle which primarily consists of red muscle fibres, there is no distinct initial pH fall or increased rate of pH decline (Devine et al., 2004).

Electrically stimulated skeletal muscles thus enter *rigor mortis* at a higher temperature, consequently allowing the earlier activation of proteolytic enzymes and the calpains system and therefore the earlier commencement of ageing (Hwang, Devine & Hopkins, 2003; Simmons et al., 2008). The use of ES at high carcass temperatures (e.g. 35°C) results in a higher rate of pH decline (e.g. 0.6 pH units), while lower carcass temperatures (e.g. 15°C) will result in a lower rate of pH decline (e.g. 0.018 pH units). The ES of warm carcasses (earlier *post* slaughter) will therefore maximise the efficiency of the ES application (Devine et al., 2004). Carcasses are usually cooled to prevent or inhibit microbial growth and so minimise the possible spoilage of the meat (Warriss, 2000; Lawrie & Ledward, 2006). The carcass chilling temperatures after processing influences the rate of ageing and the shelf-life of the potential meat products. However, ES combined with rapid carcass chilling rates, can reduce weight loss through evaporation of water from the meat surface. Cooling carcasses too rapidly may lead to less tender meat, either by

reducing the activity of the naturally occurring proteolytic enzymes or by inducing CS. The correct balance must be managed between the benefits of rapid carcass cooling compared to the possible negative influences on meat quality (Warriss, 2000). The carcass cooling rates can induce four phenomena in meat: heat shortening; *rigor* shortening (see muscle conversion to meat); cold shortening; and thaw shortening (Lawrie & Ledward, 2006; Warriss, 2000).

Electrical stimulation also increases the rate of the ageing process (Simmons et al., 2008). However, there are also other mechanisms involved in meat tenderisation, such as structural disruptions and enzymatic modifications (Simmons, Singh, Dobbie & Devine, 1996; Devine et al., 2004).

Effect of electrical stimulation on meat quality

Meat consumers expect a high-quality product throughout the production year and the most important meat quality factors are colour and tenderness (Wood & Warriss, 1992; Wood et al., 1999; Koohmaraie et al., 2003). Tenderness is the most important meat-quality characteristic for the consumer (Wood et al., 1999) and can be measured either subjectively by consumer panels or by means of objective measurements such as shear force (the force required to cut through a piece of cooked meat) (Strydom, Frylinck & Smith, 2005). Boleman et al. (1997) found that consumers could distinguish between different categories of meat tenderness and were willing to pay a premium price for meat with greater tenderness. Meat tenderness is influenced by the pH and temperature of the muscles *post mortem* due to the effects that both of these parameters have on the activity of the proteolytic enzymes involved in the natural tenderisation process (Yu & Lee, 1986; Hwang & Thompson, 2001a, 2001b). The water holding capacity (WHC) of meat, as an indication of juiciness, is also affected by the pH (Lawrie & Ledward, 2006). Furthermore, meat colour is also important, since it is the first quality characteristic observed by the consumers when they are purchasing meat. Consumers also believe they can judge the "quality" of game meat from its colour (Moore & Young, 2001; Radder & Le Roux, 2005).

Tenderness

Electrical stimulation has become an important processing technique in modern abattoirs. The application of ES was initially employed to prevent cold induced toughening as a result of sarcomere shortening caused by rapid chilling of carcasses during early *post mortem* processing techniques in modern abattoirs (Devine et al., 2004). When ES is combined with the use of *pre rigor* rapid chilling, it can be extremely beneficial to both the supplier and consumer (saving processing time and costs) (Li et al., 2006). The earlier onset of *rigor mortis* and consequently the increased rate of *post mortem* ageing as caused by ES facilitate the earlier deboning of carcasses (Devine et al., 2004). These decrease the costs associated with increased storage of the meat to

reach acceptable tenderness levels as well as facilitating earlier packaging and processing of higher quality products for delivery to the consumer.

Electrical stimulation can further enhance the tenderisation process by increasing the rate of proteolysis as well as altering the protein structure of muscles (Hwang et al., 2003). The rate of tenderisation is enhanced by the earlier onset of *rigor mortis* caused by the rapid pH decline brought about by the application of ES. It causes the proteolytic enzymes to be activated at an earlier stage and at higher temperature *post mortem*, which increases the rate of tenderisation. In addition, ES increases the tenderness by the physical disruption of the muscle structure during stimulation (Lawrie & Ledward, 2006). Electrical stimulation may also cause a temporary rise in free Ca^{2+} which may be an important factor in the activation of calpains and subsequent tenderisation. Furthermore, ES can also be responsible for the ultra-structural changes which result from super contraction nodes and can affect the tenderisation process in addition to those factors that interact with the levels of pH_u (Hwang et al., 2003).

Moisture losses from meat

Water holding capacity (WHC) is considered to be related to juiciness as it refers to the amount of water released during the consumption of meat. Conditions of low pH and high temperatures in *post mortem* muscle reduces the WHC of meat, an effect attributed to the denaturation of muscle proteins, particularly myosin (Offer & Knight, 1988). The rapid rate of glycolysis and subsequent pH decline caused by the application of ES, can cause protein denaturation (especially slow cooling rates) and potentially decrease the WHC and increase the drip losses from meat (Devine et al., 2004). The extent of ES contributing to decreased WHC is determined by the carcass chilling rate. The denaturing conditions usually arise when the pH decline is very rapid, as in the PSE condition in pork, but can also occur when normal rates of pH decline are combined with very slow carcass chilling rates (Babiker & Lawrie, 1983; Offer & Knight, 1988). However, the denaturation of proteins is not always immediate and will generally only occur in the muscle fibres that have not yet entered *rigor mortis* (Devine et al., 2004).

Meat colour

The red colour of game meat is determined by the quantity of primary muscle pigment, myoglobin, present in the meat. The latter is influenced by the species, gender, breed, type of muscle, age and training. In addition, the nature as well as the plane of nutrition can also influence the myoglobin quantity of meat, for e.g. a high plane of nutrition and a diet which is low in iron will both lead to lower quantities of myoglobin in meat (Lawrie & Ledward, 2006). Furthermore, it is not only the quantity, but also chemical state of the myoglobin molecule that determines the colour of meat at purchase. When myoglobin is exposed to oxygen, oxymyoglobin is formed, which is only

present on the surface of meat products, but it gives the meat a preferred bright red colour (Lawrie & Ledward, 2006).

Electrical stimulation brings about the earlier onset of *rigor morti*s and subsequently *post mortem* ageing which generally improves overall meat colour. However, ES had no effect (P > 0.05) on the colour measurements of lamb meat (various muscles) (Channon, Baud & Walker, 2005; Toohey et al., 2008). As mentioned previously, ES is generally applied to improve meat tenderness, but it was found in the United States that ES of carcasses resulted in changes in the meat colour, which could influence consumer perception of such meat products (Devine et al., 2004), since the colour of meat is an important aspect of meat quality (Troy & Kerry , 2010). Consumers often use meat colour at the point of purchase to assure themselves that the meat is "safe to eat" or that the meat is of high quality and therefore not spoiled (Moore & Young, 2001; Radder & Le Roux, 2005). Retailers want this appearance to be maintained for the vital period of retail display, so as to ensure that the meat products are aesthetically pleasing to the consumer and therefore are sold.

CONCLUSIONS

Springbok are the most important game species for commercial game meat production in South Africa (Hoffman, 2002; Skinner & Chimimba, 2005b; Hoffman & Wiklund, 2006; Bothma et al., 2010), although blesbok are also one of the important meat producing game species in South Africa (Anon., 2009, 2010, 2011). These game species are most often harvested during the night (Veary, 1991; Lewis et al.*,* 1997; Hoffman, 2000a; Kritzinger et al.*,* 2003; Hoffman & Wiklund, 2006; Le Grange, 2006; Van Schalkwyk & Hoffman, 2010), since this method has been proven to be most effective at producing the best quality game meat (Hoffman, 2000a; Hoffman & Ferreira, 2000; Kritzinger et al., 2003; Hoffman & Wiklund, 2006). However, during these harvesting periods, the mean winter ambient night temperatures in the home ranges of springbok (Karoo; Northern Cape) and blesbok (Transvaal; Highveld) can drop to below zero (Anon., 1986; Mucina et al., 2006a, 2006b). The low temperature conditions during night harvesting together with the minimum subcutaneous fat of game carcasses (Dryden, 1997; Hoffman, Kroucamp & Manley, 2007), usually result in the rapid chilling of game carcasses (Jansen van Rensburg, 1997). The latter can result in cold-induced toughening of the muscles. When game animals are harvested during the day, especially during hot summer months, the very high temperature conditions can adversely affect the subsequent game meat quality.

Electrical stimulation have been applied commercially on domestic animals for the prevention of cold shortening, to accelerate ageing and to decrease the variation of the quality of meat products. The application of ES can therefore counter the negative affects of the very high and very low ambient temperature conditions during South African game harvesting.

Although some research has been conducted on the use of ES on game animals slaughtered in commercial slaughterhouses (Crystall & Devine, 1983; Drew, Crosbie, Forss, Manley & Pearse, 1988; Wiklund et al., 2001; Bekhit et al., 2007), no work has thus far been published on the use of this technique for African game species slaughtered in the field. The aim of this study was therefore to evaluate the effect of ES on the meat quality of commercially harvested springbok carcasses, as well as blesbok carcasses under two temperature treatments (5°C and 39°C).

REFERENCES

Abbasvali, M., Shekarforoush, S.S., Aminlari, M. & Ebrahimnejad, H. (2012). Effects of medium-voltage electrical stimulation on postmortem changes in fat-tailed sheep. *Journal of Food Science, 71*(1), S47–S53.

Anonymous (1986). *Climate of South Africa: Climate statistics up to 1984* (pp. 65–66). South Africa: Weather bureau, Department of home affairs.

Anonymous (2009). Game numbers and weights exported for 2008. South African Ostrich Business Chamber. Oudtshoorn.

Anonymous (2010). Game numbers and weights exported for 2009. South African Ostrich Business Chamber. Oudtshoorn.

Anonymous (2011). Game numbers and weights exported for 2010. South African Ostrich Business Chamber. Oudtshoorn.

Anonymous (2012). Department of Agriculture, Forestry and Fisheries Act and Regulations. Meat Safety Act no.40 of 2000, draft document. Johannesburg, South Africa: Lex Patria Publishers.

Babiker, S.A. & Lawrie, R.A. (1983). Post-mortem electrical stimulation and high temperature ageing of hot-deboned beef. *Meat Science, 8,* 1-20.

Bate-Smith, E.C. & Bendall, J.R. (1949). Factors determining the time course of *rigor mortis. Journal of Physiology*, *110,* 47-65.

Bekhit, A.E.E., Farouk, M.M., Cassidy, L. & Gilbert, K.V. (2007). Effects of rigor temperature and electrical stimulation on venison quality. *Meat Science, 75,* 564–574.

Bendall, J.R. (1973). Postmortem changes in muscle. In G.H. Bourne (Ed.), *The structure and function of muscle* (pp. 244–309) (Vol. 2). New York: Academic Press.

Boleman, S.J., Boleman, S.L., Miller, R.K., Taylor, J.F., Cross, H.R., Wheeler, T.L., Koohmaraie, M., Shackelford, S.D., Miller, M.F., West, R.L., Johnson, D.D. & Savell, W.J. (1997). Consumer evaluation of beef of known categories of tenderness. *Journal of Animal Science*, *75*, 1521–1524.

Bothma, J.Du P. (1996). The management and utilisation of game. In *Game ranch management* (pp. 223–438) (3rd ed.). Hatfield, Pretoria, South Africa: Van Schaik Publishers.

Bothma, J.Du P. (2002). Some economics of wildlife ranching. In B.L. Penzhorn (Ed.), *Game ranch planning and management* (pp. 23–30). Hatfield, Pretoria, South Africa: Van Schaik Publishers.

Bothma, J.Du P. (2010). Combining wild and domesticated herbivores. In J.Du P. Bothma & J.G. Du Toit (Eds.), *Game ranch management* (pp. 281–288) (5th ed.). Hatfield, Pretoria, South Africa: Van Schaik Publishers.

Bothma, J.Du P. & Van Rooyen, N. (2005). *Intensive wildlife production in Southern Africa*. Pretoria, South Africa: Van Schaik Publishers.

Bothma, J.Du P., Van Rooyen, N. & Du Toit, J.G. (2010). Animals and their characteristics – antelope and other smaller herbivores. In J.Du P. Bothma & J.G. Du Toit (Eds.), *Game ranch management* (pp. 221–239) (5th ed.). Hatfield, Pretoria, South Africa: Van Schaik Publishers.

Carruthers, N. (2008). "Wilding the farm or farming the wild"? The evolution of scientific game ranching in South Africa from the 1960s to the present. *Transactions of the Royal Society of South Africa, 63*(2), 160–181.

Channon, H.A., Baud, S.R., & Walker, P.J. (2005). Modified atmosphere packaging improves retail display life of lamb cuts with variation between loin and knuckle. *Australian Journal of Experimental Agriculture, 45*, 585–592.

Conroy, A.M. (2005). The springbok. In J.Du P. Bothma & N. Van Rooyen (Eds.), *Intensive wildlife production in South Africa* (pp. 214–226). Hatfield, Pretoria, South Africa: Van Schaik Publishers.

Chrystall, B.B. & Devine, C.E. (1978). Electrical stimulation, muscle tension and glycolysis in *bovine sternomandibularis*. *Meat Science*, *2*, 49–58.

Department of Agriculture, Forestry and Fisheries (DAFF) (2010). *Game industry market value chain profile* (pp. 1–13). South Africa: DAFF.

Devine, C.E. (2004). Ageing. In W.K. Jensen, C. Devine & M. Dikeman (Eds.), *Encyclopaedia of meat science* (pp. 330–338). Oxford: Academic Press.

Devine, C.E., Hopkins, D.L., Hwang, I.H., Ferguson, D.M. & Richards, I. (2004). Electrical stimulation. In W.K. Jensen, C. Devine & M. Dikeman (Eds.), *Encyclopaedia of meat science* (pp. 413–423) (Vol. 1). Oxford: Academic Press.

Devine, C.E., Lowe, T.E., Wells, R.W., Edwards, N.J., Hocking Edwards, J.E., Starbuck, T.J. & Speck, P.A. (2006). Pre-slaughter stress arising from on-farm handling and its interactions with electrical stimulation on tenderness of lambs. *Meat Science, 73,* 304–312.

Devine, C.E., Payne, S.R., Peachey, B.M., Lowe, T.E., Ingram, J.R. & Cook, C.J. (2002). High and low rigor temperature effects on sheep meat tenderness and ageing. *Meat Science, 60,* 141–146.

Dlamini, T.S. & Fraser, G. (2010). Economics of meat production from the springbuck in the Eastern Karoo. In *Proceedings of the Joint 3rd African Association of Agricultural Economists* (AAAE) *and the 48th Agricultural Economists Association of South Africa* (AEASA) *Conference*. Cape Town, South Africa.

Du Plessis, S.S. (1972). Ecology of blesbok with special reference to productivity. *Wildlife Monographs, 30*, 3–70.

Dransfield, E. (1994). Tenderness of meat, poultry and fish. In A.M. Pearson & T.R. Dutson (Eds.) *Quality attributes and their measurement in meat, poultry and fish products* (pp. 289–315). London: Blackie Academic and Professional (Chapman and Hall).

Drew, K.R., Crosbie, S.F., Forss, D.A., Manley, T.R. & Pearse, A.J. (1988). Electrical stimulation of carcasses from red, fallow and New Zealand wapiti-type male deer. *Journal of Science and Food and Agriculture*, *43*, 245–259.

Dryden, G.M. (1997). Venison in the human diet – is venison a low-fat meat? *Proceedings of the nutrition Society of Australia, 21*, 44–51.

Du Toit, J.G. (2007). Report: Role of the private sector in the wildlife industry. Tshwane, Wildlife Ranching SA/Du Toit Wilddienste. pp 87. (Cited by Carruthers, 2008)

East, R. (1999). African Antelope Database 1999. Gland, Switzerland and Cambridge, UK: IUCN.

Ebedes, H. (2002). Preface – Game ranching. In H. Ebedes, B. Reilly, W. Van Hoven & B. Penzhorn (Eds.), *Proceedings of the 5th International Wildlife Ranching Symposium Sustainable Utilisation – Conservation in Practice* (pp. 7–9). Port Elizabeth, South Africa: Nelson Mandela Metropolitan University.

Eloff, T. (2002). The economic realities of the game industry in South Africa. In H. Ebedes, B. Reilly, W. Van Hoven & B. Penzhorn (Eds.), *Proceedings of the 5th International Wildlife Ranching Symposium Sustainable Utilisation – Conservation in Practice* (pp. 78–86). Port Elizabeth, South Africa: Nelson Mandela Metropolitan University.

Erb, K.P. (2004). Consumptive wildlife utilization as a land-use form in Namibia. MBa (Business administration) thesis, Stellenbosch University, South Africa.

Flack, P.H. (2002). The conservation revolution. *Game & Hunt, 8*(10), 29–33.

Furstenburg, D. (2009). Blesbok *Damaliscus pygargus phillipsi* (Pallas, 1767). *Wild & Jag, 6,* 6–11.

Furstenburg, D. (2010). Springbok *Antidorcas marsupialis* (Zimmerman, 1780). *SA Hunter 12047, 1,* 46–49.

Hetem, R.S., De Witt, B.A., Fick, L.G., Fuller, A., Kerley, G.I.H., Meyer, L.C.R., Mitchell, D. & Maloney, S.K. (2009). Body temperature, thermoregulatory behaviour and pelt characteristics of three colour morphs of springbok (*Antidorcas marsupialis*). *Comparative Biochemistry and Physiology Part A, 152*, 379–388.

Higginbottom, K. & King, N. (2006). The live trade in free ranging wildlife within South Africa and implications for Australia. In *A report for the Rural Industries Research and Development Corporation*, Australian Government. Publication number 06/046, Project number TA034-56 [Online]. Available from: https:// rirdc. infoservices.com.au/downloads/06-046.

Hoffman, L.C. (2000a). Meat quality attributes of night-cropped impala (*Aepyceros melampus*). *South African Journal of Animal Science, 30*(2), 133–137.

Hoffman, L.C. (2000b). The yield and carcass chemical composition of impala (*Aepyceros melampus*), a southern African antelope species. *Journal of the Science of Food and Agriculture, 80,* 752–756.

Hoffman, L.C. (2002). The effect of different culling methodologies on the physical meat quality attributes of various game species. In H. Ebedes, B. Reilly, W. Van Hoven & B. Penzhorn (Eds.), *Proceedings of the 5th International Wildlife Ranching Symposium Sustainable Utilisation – Conservation in Practice* (pp. 212–221). Port Elizabeth, South Africa: Nelson Mandela Metropolitan University.

Hoffman, L.C., Cloete, S.W.P., Van Schalkwyk, S.J. & Botha, S.St.C. (2009). Effect of bleeding method and low voltage electrical stimulation on meat quality of ostriches. *South African Journal of Animal Science, 39*(3), 206–213.

Hoffman, L.C. & Ferreira, A.V. (2000). pH decline of the *M. longissimus thoracis* of night-cropped grey duiker (*Sylvicapra grimmia*). *South African Journal of Animal Science, 30*(1), 16–17.

Hoffman, L.C., Kroucamp, M. & Manley, M. (2007). Meat quality characteristics of springbok (*Antidorcas marsupialis*). 1. Physical meat attributes as influenced by age, gender and production region. *Meat Science*, *76,* 755–761.

Hoffman, L.C. & Laubscher, L.L. (2009). A comparison between the effects of day v*ersus* night cropping on greater kudu (*Tragelaphus strepsiceros*) meat quality. *South African Journal of Wildlife Research, 39*(2), 164–169.

Hoffman, L.C., Smit, K. & Muller, N. (2008). Chemical characteristics of blesbok (Damaliscus dorcas phillipsi) meat. *Journal of Food Composition and Analysis, 21*, 315–319.

Hoffman, L.C. & Wiklund, E. (2006). Game and venison – meat for the modern consumer. *Meat Science, 74,* 197–208.

Huntley, B.J. (1971). Carcass composition of the mature male blesbok and kudu. *South African Journal of Science*, *1*, 125–128.

Hwang, I.H., Devine, C.E. & Hopkins, D.L. (2003). The biochemical and physical effects of electrical stimulation on beef and sheep meat tenderness. *Meat Science, 65*, 677–691.

IUCN SSC Antelope Specialist Group (2008). *Antidorcas marsupialis*. In IUCN 2011. IUCN Red List of Threatened Species. Version 2011.2. <www.iucnredlist.org>. Downloaded on 11 June 2012.

Jansen van Rensburg, D.M. (1997). The physical, chemical and sensory quality characteristics of springbok (*Antidorcas marsupialis marsupialis*) meat. MSc (Technology: Food and Nutrition) thesis, Pretoria Technicon, South Africa.

Joubert, D.M. (1968). An appraisal of game production in South Africa. *Tropical Science, 10,* 200–211.

Kadim, I.T., Mahgoub, O., Al-Marzooqi, W., Khalaf, S.K., Mansour, M.H., Al-Sinani, S.S.H. & Al-Amri, I.S. (2009). Effects of electrical stimulation on histochemical muscle fiber staining, quality, and composition of camel and cattle *Longissimus thoracis* muscles. *Journal of Food Science, 74*(1), S44–S52.

Koohmaraie, M. (1996). Biochemical factors regulating the toughening tenderization processes of Meat. *Meat Science, 43*, S193–S201.

Koohmaraie, M. & Geesink, G.H. (2006). Contribution of post mortem muscle biochemistry to the delivery of consistent meat quality with particular focus on the calpain system. *Meat Science, 74*, 34–43.

Koohmaraie, M., Veiseth, E., Kent, M.P., Shackleford, S.D. & Wheeler, T.L. (2003). Understanding and managing variation in meat tenderness. In *Consistency of quality: 11th International Meat Symposium*. (pp. 3–13). Pretoria, South Africa.

Kritzinger, B., Hoffman, L.C. & Ferreira, A.V. (2003). A comparison between the effects of two cropping methods on the meat quality of impala (*Aepyceros melampus*). *South African Journal of Animal Science, 33*(4), 233–240.

Kroucamp, M. (2004). Meat quality characteristics of the springbok *(Antidorcas marsupialis).* MSc (Agric) thesis, University of Stellenbosch, South Africa.

Laubscher, L.L. (2009). The effect of different cropping methods on the meat quality of various game species. (Unpublished master dissertation). MSc (Agric) thesis, University of Stellenbosch, South Africa.

Lawrie, R.A. & Ledward, D.A. (2006). *Lawrie's meat science* (7th ed.). Cambridge, England: Woodhead Publishing Limited.

Le Grange, M. (2006). The capture, care and management of wildlife – comprehensive studies on the management, capture and translocation of wildlife from source to final release. Pretoria, South Africa: Van Schaik Publishers.

Ledger, H.P. (1963). Animal husbandry research and wildlife in East Africa. *East African Wildlife Journal, 1*, 18–29.

Ledger, H.P., Sachs, R. & Smith, N.S. (1967). Wildlife and food production. *World Review of Animal Production, 3*, 13–36.

Lewis, A.R., Pinchin, A.M. & Kestin, S.C. (1997). Welfare implications of the night shooting of wild impala (*Aepyceros Melampus*). *Animal Welfare, 6*, 123–131.

Li, C.B., Chen, Y.J., Xu, X.L., Huang, M., Hu, T.J. & Zhou, G.B. (2006). Effects of low-voltage electrical stimulation and rapid chilling on meat quality characteristics on Chinese yellow crossbred bulls. *Meat Science, 72*, 9–17.

Liversidge, R. & Gubb, A. (1994). Feeding competition between springbok and merino sheep. In W. Hoven, H. Ebedes & A. Conroy (Eds.), Wildlife ranching: A celebration of diversity (pp. 87–90). Pretoria, South Africa: Promedia.

Martin, K.M., Hopkins, D.L., Gardner, G.E. & Thompson, J.M. (2006). Effects of stimulation on tenderness of lamb with a focus on protein degradation. *Australian Journal of Experimental Agriculture, 46,* 891-896.

Moore, V.J. & Young, O.A. (2001). The effects of electrical stimulation, thawing, ageing and packaging on the colour and display life of lamb chops. *Meat Science*, *30*, 131–145.

Mostert, R. (2007). Meat quality of kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*). MSc (Agric) thesis, University of Stellenbosch, South Africa.

Mucina, L., Hoare, D.B., Lotter, M.C., Du Preez, P.J., Rutherford, M.C., Scott-Shaw, C.R., Bredenkamp, G.J., Powrie, L.W., Scott, L., Camp, K.G.T., Cilliers, S.S., Bezuidenhout, H., Mostert, T.H., Siebert, S.J., Winter, P.J.D., Burrows, J.E., Dobson, L., Ward, R.A., Stalmans, M., Oliver, E.G.H., Siebert, F., Schmidt, E., Kobisi, K. & Kose, L. (2006a). Grassland Biome. In L. Mucina & M.C. Rutherford (Eds.), *The vegetation of South Africa, Lesotho and Swaziland* (pp. 350–431). South Africa: South African National Biodiversity Institute.

Mucina, L., Rutherford, M.C., Palmer, A.R., Milton, S.J., Scott, L., Lloyd, J.W., Van der Merwe, B., Hoare, D.B., Bezuidenhout, H., Vlok, J.H.J., Euston-Brown, D.I.W., Powrie, L.W. & Dold, A.P. (2006b). Nama-Karoo Biome. In L. Mucina & M.C. Rutherford (Eds.), *The vegetation of South Africa, Lesotho and Swaziland* (pp. 325–345). South Africa: South African National Biodiversity Institute.

Offer, G. & Knight, P. (1988). The structural basis of water holding in meat, Part 2: Drip losses. In R. A. Lawrie (Ed.), *Developments in Meat Science, 4*, (pp. 173–243). London, United Kingdom: Elsevier Science Publishers.

Paulsen, P. & Smulders, F.J.M. (2004). Infectious diseases of meat animals. In W.K. Jensen, C. Devine & M. Dikeman (Eds.), *Encyclopedia of meat sciences* (pp. 649–656).

Pearson, A.M. & Young, R.B. (1989). *Muscle and meat biochemistry*. San Diego: Academic Press

Peters, J. & Brink, J.S. (1992). Comparative postcranial osteomorphology and osteometry of springbok Antidorcas marsupialis (Zimmermann, 1780) and grey rhebok, Pelea capreolus (Forster, 1790) (Mammalia: Bovidae). *Memoirs of the National Museum Bloemfontein, 8*, 161–207.

Prins, H.H.T. (2000). Competition between wildlife and livestock in Africa. In H.H.T. Prins, J.G. Grootenhuis & T.T. Dolan (Eds.), Wildlife conservation by sustainable use (pp. 5–80). Boston: Kluwer Academic Publishers.

Radder, L. & Le Roux, R. (2005). Factors affecting food choice in relation to venison: A South African example. *Meat Science*, *71*, 583–589.

Razminowicz, R.H., Kreuzer, M. & Scheeder, M.R.L. (2008). Effect of electrical stimulation, delayed chilling and post-mortem aging on the quality of *M. longissimus dorsi* and *M. biceps femoris* of grass-fed steers. *Journal of the Science of Food and Agriculture, 88*, 1344–1353.

Rudman, C.E. (1983). Game harvest management as applied to a game ranching program. In S.L. Beasom & S.F. Roberson (Eds.), *Game Harvest Management – Proceedings of the 3rd International Symposium of the Ceasar Kleberg Wildlife Research Institute College of Agriculture* (October). Texas, USA: Kingsville.

Ruggiero, R.G. & Ansley, J. (1992). Factors affecting the cropping efficiency on two Kenyan game ranches. In *3rd International Wildlife Ranching Symposium*. Pretoria, South Africa.

Scheffler, T.L. & Gerard, D.E. (2007). Mechanisms controlling pork quality development: The biochemistry controlling postmortem energy metabolism. *Meat Science, 77*(1), 7–16.

Schmidt, A.G. (1999). Body condition in blesbok x bontebok hybrids in the Oviston Nature Reserve, Eastern Cape Province. *South African Journal of Wildlife Research, 29*(4), 145–147.

Simmons, N.J., Singh, K., Dobbie, P.M. & Devine, C.E. (1996). The effect of pre-rigor holding temperature on calpain and calpastatin activity and meat tenderness. In *Proceedings of the 42nd international congress of meat science and technology* (pp. 414–415). Lillehammer, Norway.

Simmons, N.J., Daly, C.C., Mudford, C.R., Richards, I., Jarvis, G. & Pleiter, H. (2006). Integrated technologies to enhance meat quality – An Australasian perspective. *Meat Science*, *74*, 172–179.

Simmons, N.J., Daly, C.C., Cummings, T.L., Morgan, S.K., Johnson, N.V. & Lombard, A.C. (2008). Reassessing the principles of electrical stimulation. *Meat Science*, *80,* 110–122.

Skinner, J.D. (1970). Game-ranching in Africa as a source of meat for local consumption and export. *Tropical Animal Health Production, 2,* 151–157.

Skinner, J.D. (1973). An appraisal of the status of certain antelope for game farming in South Africa. *Z. Tierzüchtg Züchtgsbiol, 90,* 263–277.

Skinner, J.D. (2012). The real lowdown on ranching with game. In I. Simpson (Ed.), *Mpunzi, dawn of a new era* (pp. 147–158). CTP Printers.

Skinner, J.D. & Chimimba, C.T. (2005a). Blesbok Damaliscus pygargus phillipsi (Pallas, 1767). In J. Du Toit (Ed.), *The mammals of the southern African subregion* (pp. 655–658) (3rd ed.). Cape Town, South Africa, Cambridge University Press.

Skinner, J.D. & Chimimba, C.T. (2005b). Springbok *Antidorcas marsupialis* (Zimmermann, 1780). In J. Du Toit (Ed.), *The mammals of the southern African subregion* (pp. 689–693) (3rd ed.). Cape Town, South Africa, Cambridge University Press.

Skinner, J.D. & Louw, G.N. (1996). The Springbok: *Antidorcas marsupialis* (Zimmerman, 1780). Transvaal Museum Monograph, Pretoria. no 10.

Skinner, J.D. & Van Zyl, J.H.M. (1970). A study of growth of the springbok ewes. *African Wildlife, 24,* 149–154.

Skinner, J.D., Von la Chevallerie, M. & Van Zyl, J.H.M. (1971). An appraisal of the springbok for diversifying animal production in Africa. *Animal Breeding Abstracts, 39*(2), 215–224.

Smith G.C., Dutson, T.R., Hosteler, R.L. & Carpenter, L. (1976). Fatness, rate of chilling and tenderness of lamb. *Journal of Food Science, 41*, 748–756.

Springbok *Antidorcas marsupialis* (Zimmerman, 1780). Retrieved from (http://www.wildliferanching.com/content/springbok-antidorcas-marsupialis)

Steenkamp, J-B.E.M. (1997). Dynamics in consumer behaviour with respect to agricultural and food products. In *Agricultural marketing and consumer behaviour in a changing world*. (pp. 143–189). Kluwer Academic publishers.

Swatland, H.J. (1994). *Structure and development of meat animals and poultry*. Lancaster, Pennsylvania, USA: Technomic Publishing Company Inc.

Thompson, J. (2002). Managing meat tenderness. *Meat Science, 62*, 295–308.

Tinley, C.L. (1972). Cropping techniques. In M.T. Mentis (Ed.), *Ungulate management* (pp. 43–49). Natal, South Africa: Natal Parks Game and Fish Preservation Board.

Toohey, E.S., Hopkins, D.L., Stanley, D.F. & Nielsen, S.G. (2008). The impact of new generation pre-dressing medium-voltage electrical stimulation on tenderness and colour stability in lamb meat. *Meat Science, 79,* 683–691.

Troy, D.J. & Kerry, J.P. (2010). Consumer perception and the role of science in the meat industry. *Meat Science, 86*, 214–226.

Van Aswegen, E., Labuschagne, C. & Grobler, J.P. (2012). Phenotypic differences, spatial distribution and diversity at the Cytb and BMP4 genes in springbok (*Antidorcas marsupialis*). *Mammalian Biology, 77*(6), 391–396.

Van den Berg, G. (2004). The Game Farming Industry in a Nutshell. (Paper read at the Executive Committee meeting of Wildlife Ranching SA, May 28, Pretoria). Unpublished.

Van den Berg, J.H. (2009). *The effect of electrical stimulation on the meat quality of the impala (Aepyceros melampus)*. (Unpublished master dissertation in Meat Science). University of Pretoria, Pretoria, South Africa.

Van der Merwe, P. (2004). Game farms as sustainable ecotourism attractions. (Unpublished doctoral dissertation). Potchefstroom, North West University, South Africa [Online]. Available from: http://dspace.nwu.ac.za/handle/10394/330 [Accessed: 7/5/2011].

Van Rensburg, L.R.J. (1992). A cost evaluation of game cropping methods and certain necessary cost factors in the marketing of venison. In *3rd International Wildlife Ranching Symposium*. Pretoria, South Africa.

Van Schalkwyk, D.L (2011). Investigation into selected parameters required to develop a sustainable Namibian game meat industry. (Unpublished doctorate dissertation). Faculty of Food Science, University of Stellenbosch, South Africa.

Van Schalkwyk, D.L. & Hoffman, L.C. (2010). *Guidelines for the harvesting of game for meat export*. Windhoek, Namibia: AgriPublishers.

Van Schalkwyk, D.L., Hoffman, L.C. & Laubscher, L.A. (2011). Game harvesting procedures and their effect on meat quality: The Africa experience. In P. Paulsen, A. Bauer, M. Vodnansky, R. Winkelmayer & F.J.M. Smulders (Eds.), *Game meat hygiene in focus: Microbiology, epidemiology, risk analysis and quality assurance* (pp. 67–93). The Netherlands: Wageningen Academic Publishers.

Van Zyl, L. & Ferreira, A.V. (2004). Physical and chemical carcass composition of springbok (*Antidorcas marsupialis*), blesbok (*Damaliscus dorcas phillipsi*) and impala (*Aepyceros melampus*). *Small Ruminant. Research, 53,* 103–109.

Veary, C.M. (1991). The effect of three slaughter methods and ambient temperature on the pH and temperature in springbok (*Antidorcus marsupialis*) meat. (Unpublished master dissertation). Faculty of Veterinary Science, University of Pretoria, South Africa.

Von la Chevallerie, M. (1970). Meat production from wild ungulates. *Proceeding of the South African Society for Animal Production, 9,* 73–88.

Von la Chevallerie, M. & Van Zyl, J.H.M. (1971a). Growth and development of the springbok *Antidorcas marsupialis marsupialis* (Zimmermann). *Agroanimalia, 3,* 115–124.

Von la Chevallerie, M. & Van Zyl, J.H.M. (1971b). Some effects of shooting on losses of meat and meat quality in springbok and impala. *South African Journal of Animal Science, 1*, 113–116.

Warriss, P.D. (2000). *Meat science: An introductory text.* New York, USA: CABI publishing, CAB International.

White, A., O'Sullivan, A., Troy, D.J. & O'Neill, E.E. (2006). Effects of electrical stimulation, chilling temperature and hot-boning on the tenderness of bovine muscles. *Meat Science, 73,* 196–203.

Wiklund, E., Finstad, G., Johansson, L., Aguiar, G. & Bechtel, P.J. (2008). Carcass composition and yield of alaskan reindeer (*Rangifer tarandus tarandus*) steers and effects of electrical stimulation applied during field slaughter on meat quality. *Meat Science, 78,* 185–193.

Wiklund, E., Stevenson-Barry, J.M., Duncan, S.J. & Littlejohn, R.P. (2001). Electrical stimulation of red deer (*Cervus elaphus*) carcasses — effects on rate of pH-decline, meat tenderness, colour stability and water holding capacity. *Meat Science*, *59*, 211–220.

Wood, J.D., Enser, M., Fisher, A.V., Nute, G.R., Richardson, R.I. & Sheard, P.R. (1999). Manipulating meat quality and composition. *Proceedings of the Nutrition Society*, *58,* 363–370.

Wood, J.D. & Warriss, P.D. (1992). The influence of the manipulation of carcass composition on meat quality. In P.J. Buttery, K.N. Boorman & D.B. Lindsay (Eds.), *The control of fat and lean deposition* (pp. 331–353). Butterworth & Heinemann Ltd

Xu, Y., Huang, J.-C., Huang, M., Xu, B.-C. & Zhou, G.-H. (2012). The effects of different chilling methods on meat quality and calpain activity of pork muscle *Longissimus Dorsi*. *Journal of Food Science, 71*(1), C27–C32.

Yu, L.P. & Lee, Y.B. (1986). Effects of *post mortem* pH and temperature on bovine muscle structure and meat tenderness. *Journal of Food Science, 51*, 774–780.

Zhang, W.H., Peng, Z.Q., Zhou, G.H., Xu, X.L. & Wu, J.Q. (2007). Effects of low voltage electrical stimulation and chilling methods on quality traits of pork *M. longissimus lumborum. Journal of Muscle Foods, 18,* 109–119.

CHAPTER 3

The effect of electrical stimulation on the physical meat quality of commercially harvested springbok (*Antidorcas marsupialis*)

ABSTRACT

Limited research is available on the use of electrical stimulation (ES) on African game species. The objective of this study was to investigate the effect of ES on the meat quality of springbok. A total of 35 springbok were harvested, of which 16 animals were ES within 45 minutes *post mortem* while 19 non ES animals were used as the control specimens. General meat quality analyses (pH, tenderness, cooking loss, purge loss and colour) were performed on the *M. longissimus dorsi* (LD) on days 2, 5 and 21 *post mortem*. The pH decline was also recorded until *rigor*. The initial pH values were lower ($P \leq 0.05$) in the ES compared to the non ES carcasses, although the pH decline profiles and ultimate pH values (pH_u) were similar ($P > 0.05$) for both groups. The mean muscle tenderness did not differ ($P > 0.05$) between the ES and non ES carcasses at any particular time point or between genders. Purge and cooking losses also showed no differences ($P > 0.05$) for days 2 and 5, however, on day 21 the storage purge losses were 5.20% ± 0.31 (ES) compared to 4.30% ± 0.31 (non ES). No significant differences were found in the retail colour stability or regression over time of the colour measurements, however, the ES samples (0.567 ± 0.108) had a higher rate of increase in colour sharpness (chroma regression data) compared to the non ES samples (0.224 ± 0.099). In general, ES did not enhance the desired meat quality attributes i.e. tenderness. The latter can be attributed to various external factors (animal age, stress, time *post mortem* prior to stimulation) which may have caused variations within the results. The use of ES under commercial game harvesting conditions therefore requires further investigation; since the expected positive effects of ES on meat quality parameters was not found to be conclusive in this study.

INTRODUCTION

Game animals inhabiting the plains of South Africa utilise bushveld resources that deter even the hardiest of cattle breeds and produce a variety of meat types that serve as exotic and novel food alternatives. Consequently, the South African game meat industry not only represents a world leader in the sustainable utilisation of game species, but has more recently also tapped into both the domestic and international meat markets. The value of the game meat industry in South Africa has increased substantially over the past 10 years, now contributing over R45 million to the national economy per annum (DAFF, 2010). Factors that are believed to have led to the growing popularity of game meat among locals and foreigners include its distinctive sensory qualities, its

56

health attributes compared to conventional domestic livestock species, along with the fact that the meat is derived from wild, free-range animals (Hoffman & Bigalke, 1999; Hoffman, Muller, Schutte, Calitz, & Crafford, 2005; Radder & Le Roux, 2005; Hoffman & Wiklund, 2006). The latter aspect has particularly promoted the marketability of game meat, since organically-produced and environmentally-friendly food products are becoming increasingly sought after by modern day consumers (Steenkamp, 1997). Health benefits that are associated with game meat include a high protein, low fat (*ca.* 2 – 3%) and low cholesterol content, as well as a favourable fatty acid profile (Crawford, Gale, Woodford, & Casped, 1970; Von la Chevallerie, 1972; Cordain, Watkins, Florant, Kelher, Rogers & Li, 2002; Van Zyl & Ferreira, 2004; Hoffman & Wiklund, 2006).

The springbok (*Antidorcas marsupialis*) is one of the most commonly farmed game species in South Africa, together with the eland (*Taurotragus oryx*), blesbok (*Damaliscus dorcas phillipsi*) and kudu (*Tragelaphus strepsiceros*) (Conroy & Gaigher, 1982; Jansen van Rensburg, 1997). Springbok is reported to be the most favoured species for recreational hunting purposes, forming 22% of all the game species hunted (Van der Merwe, Scholtz & Saayman, 2011), and is the most extensively harvested species in both South Africa and Namibia (Anon., 2011; Van Schalkwyk, 2011). In terms of local consumption, springbok has been determined to be the most frequently consumed game species by the South African public (Hoffman et al., 2005). In addition, springbok comprised more than 88% of the 168 694 game animals harvested and exported from South Africa in the early years between 1976 and 1980 (Conroy & Gaigher, 1982). More recently, the quantities of springbok that were commercially harvested for export comprised approximately 70%, 83% and 80% of the total wildlife harvest in 2008, 2009 and 2010, respectively (Anon., 2011).

Meat consumers expect a high-quality product throughout the production year and the most important meat quality factors are colour and tenderness (Wood & Warriss, 1992; Wood, Enser, Fisher, Nute, Richardson, & Sheard, 1999; Koohmaraie, Veiseth, Kent, Shackleford & Wheeler, 2003). Boleman et al. (1997) found that consumers could distinguish between different categories of meat tenderness and were willing to pay a premium price for meat with greater tenderness. Meat tenderness is, however, influenced by the pH and temperature of the muscles *post mortem* due to the effects that both of these parameters have on the activity of the proteolytic enzymes involved in the natural tenderisation process (Yu & Lee, 1986; Hwang & Thompson, 2001a, 2001b). The water holding capacity (WHC) of meat, as an indication of juiciness, is also affected by the pH (Lawrie & Ledward, 2006). Furthermore, meat colour is important, since it is the first quality characteristic observed by the consumers when they are purchasing meat. Consumers also believe they can judge the "quality" of game meat from its colour (Moore & Young, 2001; Radder & Le Roux, 2005).

The game meat industry is confronted with the challenge of ensuring a high-quality product (Hoffman, 2002; Hoffman & Wiklund, 2006) and a consistent favourable eating experience throughout the year (Bickerstaffe, Bekhit, Robertson, Roberts & Geesink, 2001; Grunert, Bredahl & Brunsø, 2004). Nonetheless, this presents some difficulty since fluctuating environmental conditions during the year can influence the quality of game meat during harvesting. In addition, harvesting of game species differs from the slaughtering of farmed domestic animals in that the latter are harvested (slaughtered) as young animals, whilst the former are normally harvested without any form of age selection when the animals are mature.

Harvesting of South African game animals normally occurs throughout the year, but peaks during the colder winter months (May to September), prior to a decrease in the quality and quantity of the available vegetation (Hofmann, 2003; Bothma, 2010). The mean temperatures in the Nama-Karoo region, where springbok are abundantly found, are well below zero for the winter months, with a minimum of -3.2°C during July being recorded frequently (Anon., 1986; Mucina et al., 2006). Springbok are generally harvested at night (Hoffman & Wiklund, 2006), which may induce cold shortening (CS) in the muscles due to the extreme temperatures (0° – 5°C) (Veary, 1991).

Cold shortening results when carcasses are chilled very rapidly prior to the onset of *rigor mortis* (before the glycogen in muscles have been converted to lactic acid), leading to irreversible contraction of the muscle and increasing the toughness of the meat (Lawrie & Ledward, 2006). Such a phenomenon is anticipated for springbok meat when considering that the animals have very little body fat and hardly any subcutaneous fat (Dryden, 1997; Hoffman, Kroucamp & Manley, 2007), therefore the carcasses are more susceptible to rapid chilling conditions and to CS (Smith, Dutson, Hosteler, & Carpenter, 1976; Wood & Warriss, 1992). Cold shortening could thus negatively influence the meat quality attributes of springbok meat, either by decreasing the tenderness and/or leading to inconsistencies or variations in the quality of the products being exported throughout the year.

One method that has been suggested to circumvent the occurrence of CS is to maintain the animal carcass temperature above 10°C until the pH of the meat falls below six (Pearson & Young, 1989; Thompson, 2002; Devine, Hopkins, Hwang, Ferguson & Richards, 2004a). The use of ES has also been proposed to minimise the effects of CS by speeding up the onset of *rigor*, so as to allow an increase in the carcass chilling rate without negatively affecting the meat quality (Simmons, Daly, Cummings, Morgan, Johnson & Lombard, 2008). While ES has been applied as a means to deplete energy stores so that super muscle contraction does not occur at low temperatures (Davey, Gilbert & Carse, 1976; Devine et al., 2004a), it is now recognised that this method offers the added advantage of increasing the enzymatic tenderisation of muscles. The latter advantage of ES is associated with cost savings for the meat industry, since less time is needed for

conditioning due to rapid tenderisation that can occur at higher temperatures (Simmons, Daly, Mudford, Richards, Jarvis & Pleiter, 2006; Simmons et al., 2008). The effective control of temperature through chilling and pH declines due to ES *post mortem* can offer the opportunity to not only improve product consistency, but also to tailor the quality attributes to the requirements of specific markets (Simmons et al., 2006).

Although some research has been conducted on the use of ES on game animals slaughtered in commercial slaughterhouses (Crystall & Devine, 1983; Drew, Crosbie, Forss, Manley & Pearse, 1988; Wiklund, Stevenson-Barry, Duncan & Littlejohn, 2001; Bekhit, Farouk, Cassidy & Gilbert, 2007), no work has thus far been published on the use of this technique for African game species slaughtered in the field. The aim of this study was therefore to evaluate the effect of ES on the meat quality of commercially harvested springbok carcasses during the cold winter periods.

MATERIALS AND METHODS

Experimental animals and study area

Forty springbok were harvested during a commercial night harvesting operation in the Aberdeen district (Karoo, South Africa) during August 2009 (cold winter month) using the method described by Van Schalkwyk and Hoffman (2010). The animals where temporarily immobilised by the use of a spotlight and then shot in the head or high neck area with rifles of sufficient calibre equipped with sound suppressors. Exsanguination occurred within 2 – 5 minutes after the animals were shot. During the harvesting exercise, a subjective stress score was assigned to each animal based on the perceived presence or absence of *ante mortem* stress. A score of 1 was given when an animal was not wounded, while a score of 2 was given if the animal was wounded. The stress scores, however, served only as indicators, since the harvesting process is generally a stressful experience for all game animals being harvested (Kritzinger, Hoffman & Ferreira, 2003; Hoffman & Laubscher, 2009a, 2009b; Hoffman & Laubscher, 2011). Gender information and time of death was also recorded.

An exploratory analysis of the recorded data, revealed that five animals were shot a second time to induce death and that the inclusion of these stressed animals caused the data to be skewed. These animals were therefore removed from any further statistical analyses resulting in the data from 16 ES and 19 Non ES animals being further processed to evaluate the effect of ES on meat quality attributes. There were also no difference (P > 0.05) found between the different treatment grouped according to treatment or gender (Table 3.1).

Once a sufficient number of animals were shot to ensure a full load on the hunting vehicle or twenty minutes had passed since the first animal was shot, the carcasses were taken to a

temporary field abattoir, in close proximity to the harvesting area. The abattoir was designed and the slaughtering procedures were conducted as described by Van Schalkwyk and Hoffman (2010). It was essential for the carcasses to be brought to the field abattoir as soon as possible, since ES had to be done within 45 minutes after death. Stimulation conducted after fifty minutes *post mortem* becomes less effective (Bendall, Ketteridge & George, 1976; Lawrie & Ledward, 2006) and the stimulation unit required electrical power from a generator located at the field abattoir.

Table 3.1

Gender groupings and carcass weights (LSMeans ± S.E.M.) of springbok used in the ES experiment

Treatment	Gender			Mean carcass weight (kg)*	
	Male	**Female**	**Total**	**Male**	**Female**
ES[1]	5	11	16	10.88 ± 1.71	11.02 ± 0.67
Non ES[2]	7	12	19	9.80 ± 1.52	10.63 ± 0.74
Total	12	23	35		

[1]ES: Electrically stimulated carcasses
[2]Non ES: Carcasses not electrically stimulated
*The mean weight of the dressed carcass

Electrical stimulation procedure

Once the springbok carcasses reached the field abattoir, these where randomly selected to be either electrically stimulated (ES; n = 16) or non electrically stimulated (non ES: n = 19). Electrical stimulation was performed within 45 minutes post mortem by using a Carné Tech Stimulation unit (Carné Technologies, Cambridge, New Zealand), that delivered a maximum output of 230 V at 15 Hz for a duration of 60 seconds. During stimulation, the carcasses were suspended from their *Achilles* tendons and were insulated from the metal hanging frame by a synthetic strap and rubber pads. The current was applied via an electrical clamp attached to the carcass throat area and a steel hook (probe) placed in the anus. The power was provided by a gasoline generator which provided a steady 230 V output and a maximum current output of one ampere.

Sample preparation

Fourteen hours after the cropping operation was completed, the *M. longissimus dorsi* (loin) on the right side of each carcass was removed between the 5th and 6th rib and the 4th and 5th lumbar vertebrae. The muscle samples were weighed, packaged and refrigerated individually. On day 2 (one day after the muscles were removed from the carcasses), the muscle samples were divided into three sub samples (sub loin samples) and randomly allocated to one of the three time points (2, 5 and 21 days) (Fig. 3.1). The sub loin samples for day 5 and 21 were weighed, and then vacuum packed, labelled appropriately and stored at 5°C until day 5 and 21, respectively.
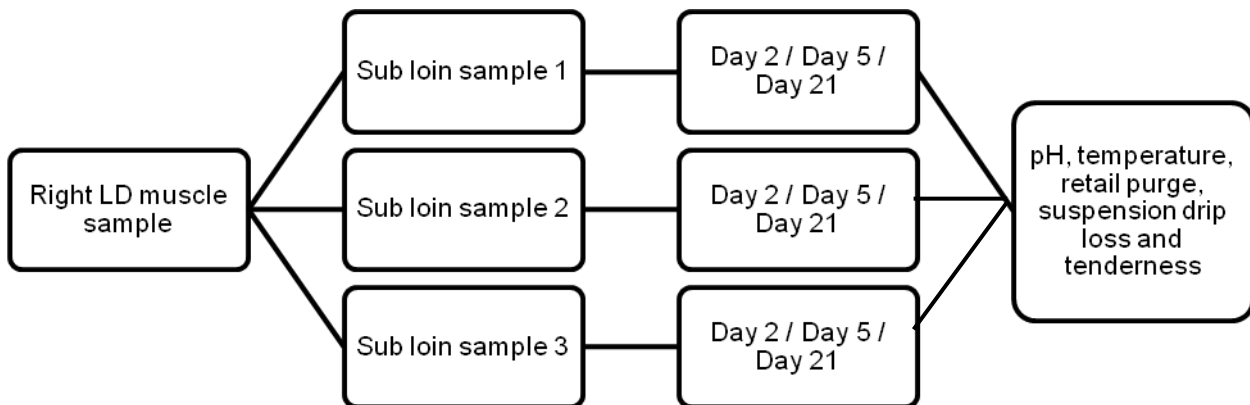
Figure 3.1 Sample preparation (randomly allocated at level three) for physical analysis.

pH and temperature measurements

The initial pH and temperature of all stimulated carcasses was measured and recorded immediately *pre-* and *post-*stimulation in the lumbar region of the LD muscles by means of a small incision in the skin between the last and second last rib. The non ES carcass readings were only recorded one hour *post mortem* and onwards.

Following the stimulation procedure, the carcasses were further processed by the removal of the head and legs and evisceration at the field abattoir. The skin was retained on the carcasses and these were kept at ambient temperature (first five hours *post mortem*), suspended from both their *Achilles* on mobile hanging frames until the harvesting operation for the night was completed. During this period, the pH and temperature readings were recorded in the LD muscles with a portable Crison pH25 meter (Alella, Barcelona). The pH meter was calibrated before each set of measurements. After evisceration, all the pH and temperature measurements were taken in the LD muscles every two hours between the last and second to last rib on the inside of the carcasses through the abdominal cavity (Tarrant & Sherrington, 1980). After eight hours *post mortem*, further pH measurements at 12 and 14 hours *post mortem* were taken to establish the ultimate pH value (pH$_u$) of the LD muscles of all the carcasses. The last three readings were recorded on the muscle itself after it had been removed from the carcasses during processing at a commercial abattoir. Additional Ebro (EBI-6) temperature data loggers (Ebro electronics, Ingolstadt, Germany) were inserted in the centre of the LD muscles and *M. biceps femoris* (BF) of four of the animals to record temperature readings every 15 minutes. Similar temperature loggers were also used to record the ambient temperature during the harvesting operation until 01:15 (Fig. 3.2) when all of the carcasses were suspended in the refrigeration truck that was running at 5°C.
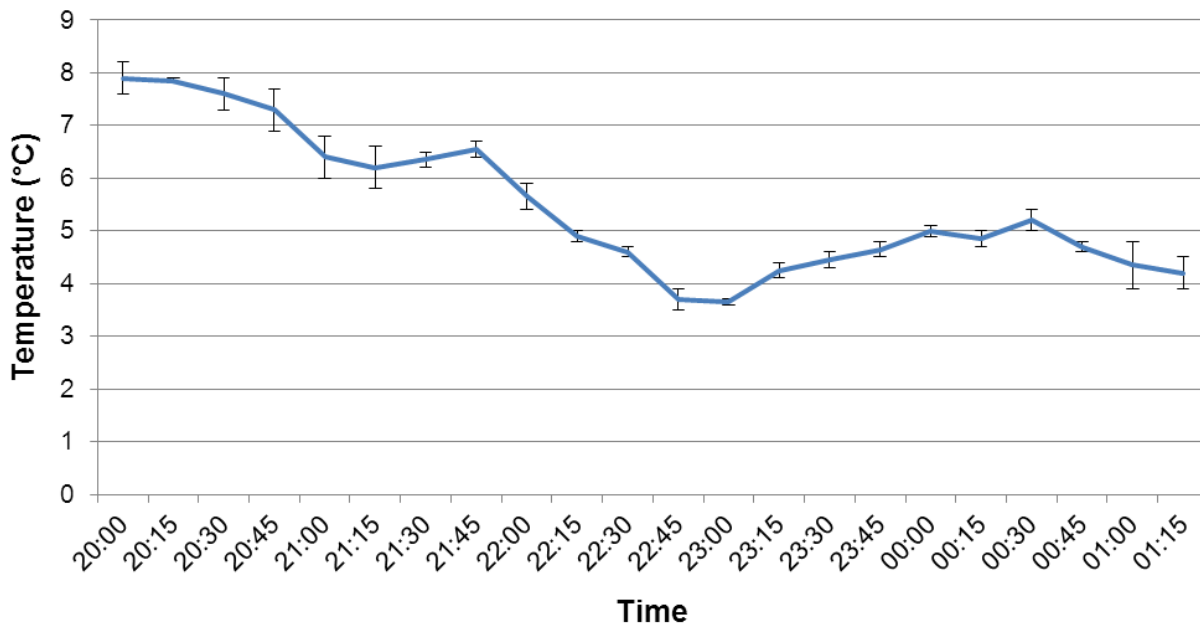
Figure 3.2 Mean ambient night temperatures during the harvesting operation.

Physical meat quality analyses

The analysis of the physical meat quality was divided into two sections. In the first, the pH and meat quality was assessed on day 2, 5 and 21 *post mortem* and in the second, a colour stability trial was initiated on day 2 *post mortem*.

Physical analyses of the sub loin samples on the designated date consisted of pH, temperature, colour (time point day 2 only), retail purge, suspension drip loss and tenderness measurements (Honikel, 1998). The retail purge loss for day 2 was calculated as the purge loss of the whole LD muscle, by weighing the LD muscle after it was removed from the carcass and recording the weight (after blotting dry with disposable absorbent paper towels) and again on the second day after slaughter.

Once the specific time point was reached (day 5 and 21, respectively), samples were removed from the vacuum packaging, blotted dry and weighed (Honikel, 1998). The purge loss for day 5 and 21 loin samples were calculated by dividing the initial weight (recorded on day 2 during sub sampling) by the final weight after packaging and blotting dry and then expressing the difference as a percentage of the initial weight (Honikel, 1998).

After the sub loin samples for a particular time point were blotted dry and weighed (on day 2), these were cut perpendicularly to the longitudinal axis into three equal-sized portions (1.5 cm). These three portions were used for different physical analyses (1: purge loss; 2: pH, tenderness; 3: colour). One of the steaks was randomly selected for drip loss determination and weighed and

placed in an inflated non-permeable plastic bag, ensuring that the sample did not make contact with the inside of the bag. The steaks were held at ± 4°C for 24 hours, then were removed from the bags, blotted dry and weighed to determine the percentage drip lost during storage (Honikel, 1998).

The second group of physical analyses was conducted on the other portion of the sub loin samples. Measurements included weighing the sample and measuring the pH and temperature. Thereafter, the samples were placed in a clearly marked thin-walled plastic bag with a small weight inside (to keep sample submerged in the water bath) and placed in a 100°C water bath and cooked until the internal temperature reached 75°C as measured by an Ebro (TFN 530, Ingolstadt) handheld thermometer. When this temperature was achieved, the sample was placed in an ice-slurry and cooled down to prevent over cooking. Once the sample had cooled below 5°C, the sample was blotted dry with a paper towel and weighed to determine cooking loss (Honikel, 1998). The cooled cooked samples (4°C) were then used to measure shear force values. The Shear force measurements were conducted using an electronic MIRINZ Tenderometer (MacFarlane & Marer, 1966), featuring a pneumatically-driven blunt wedged shape tooth and load cell to measure the force needed to cut through the prepared samples, perpendicular to the grain of the fibers. For the aforementioned measurements, the meat samples were cut into 10 x 10 mm cross sections (n = 10) and these were placed into a tray inserted into the machine for testing. Care was taken to avoid cutting into visible connective tissue as this is known to adversely affect the measurements.

Bloomed meat colour

Meat colour measurements were conducted on the remaining steak from the sub loin sample (Honikel, 1998). The sample was cut into three equally-sized steaks, approximately 1.5 – 2.0 cm thick. These steaks were placed on a flat surface and left to bloom for a period of 40 minutes before conducting colour measurements in triplicate with a colour-guide 45°/0° colorimeter (Cat no. 6805, BYK-Gardner, USA). These measurements were used to determine the colour of the fresh muscle samples in terms of CIE L* (brightness), CIE a* (red-green range) and CIE b*-values (blue-yellow range). The hue angles and chroma values were calculated using the formulae:

$$\text{Hue-angle (°): } h^{ab} = \tan^{-1}(\text{CIE } b^*/\text{CIE } a^*);$$
$$\text{Chroma value: } C^* = [(\text{CIE } a^*)^2 + (\text{CIE } b^*)^2]^{1/2}$$

The same steaks were then placed in a polystyrene tray and overwrapped with clear film of 10 micron Versafilm (Crown National, Cape Town, South Africa) with a moisture vapour transfer rate of 585 g/m^2/24 h/1 atm, O_2 permeability of 25 000 cm^3/m^2/24 h^1/1 atm and CO_2 permeability of 180 000 cm^3/m^2/24 h/1 atm. Thereafter, the sample were placed in a 4°C storage refrigerator with

triplicate colour measurements being recorded each day at the same time for the following 9 days to determine the retail colour stability of the product.

Statistical analyses

The results of the pH and temperature decline and the corresponding meat quality for day 2, 5 and 21 were analysed together, followed by the colour stability of the muscle samples packaged and refrigerated on day 2 and evaluated over 9 days.

Meat quality

The differences between the treatment methods ES and non ES were tested by means of the null hypothesis (H_o), with H_o: $\mu_1 = \mu_2$ and the alternate hypothesis (H_a) is H_a: $\mu_1 \neq \mu_2$.

H_0: ES of springbok (*A. marsupialis*) carcasses under commercial harvesting conditions does not influence (does not differ from control) the subsequent meat quality parameters.
H_a: ES of springbok (*A. marsupialis*) carcasses under commercial harvesting conditions influences (differs from control) the subsequent meat quality parameters.

The experimental design was completely randomized. An experimental unit was either a single carcass or the LD muscle of a single carcass. For the assessment of the physical analyses, the pH and temperature measurements of each carcass were recorded as interval data, with the two main factors being the treatment (ES and non ES) and gender (male and female). However, there were no significant difference in the ph or temperature data as a result of gender. Two-way analysis of variance (ANOVA) was performed on all the meat quality variables (commercial purge and suspension drip loss, colour purge loss, ultimate pH, cooking loss and tenderness) with treatment and gender included as main effects using Proc GLM of SAS version 9.1 (SAS, 2006). Bonferonni post hoc tests were done to obtain the least square mean and standard error of the mean. Differences were considered significant if p-values were less than 0.05. The pH decline profiles were further analysed by fitting a logarithmic trend line to the ES and non ES pH data. The tenderness (N) data were analysed with a repeated ANOVA using Proc Mixed of SAS to determine the mean tenderness value for each time point. For this purpose, the six "best grouped" measurements for each individual carcass were selected out of the original 10 measurements for each of the particular time points so as to decrease the variation within an experimental unit.

Bloomed meat colour

Bloomed meat colour measurements were assessed in a similar manner to the meat quality parameters by comparing the mean measurements for each time point for each particular attribute and treatment. Proc Reg of SAS was used to compare slopes of the colour stability measured

during the 9-day trial for each animal and a comparison of slopes for the treatments was carried out with Proc GLM.

RESULTS

pH and temperature

The mean pH values (n = 35 animals) for the treatments are presented in Table 3.2, whilst the data fitted with log trend lines is illustrated in Fig. 3.3. Electrical stimulation led to a small but immediate pH drop (a mean of 0.21 units) in the springbok meat and even though the average pH values did not differ (P ≤ 0.05) per time point, the initial pH values were lower in the ES carcasses and both groups of pH values decreased steadily to their ultimate values (Table 3.2). Although the mean temperature of the ES carcasses at two hours *post mortem* was higher (P ≤ 0.05) than the non ES carcasses (Table 3.2), the rest of the carcass temperatures did not differ (P ≤ 0.05) between treatments at any specific time point.   There was, however, a gradual decline in carcass temperature with time.

Table 3.2

The pH and temperature measurements (LSMeans ± S.E.M.) of springbok *M. longissimus dorsi* recorded during *post mortem* pH decline

Hours *post* slaughter	Non ES		ES	
	pH*	Temp. (°C)**	pH*	Temp. (°C)**
Pre ES	-	-	6.62 ± 0.068	31.1 ± 0.8
Post ES	-	-	6.41 ± 0.065	30.0 ± 0.7
1	6.59 ± 0.052	27.9 ± 1.0	6.48 ± 0.058	29.2 ± 1.1
2	6.29 ± 0.057	22.8[b] ± 0.4	6.12 ± 0.063	24.1[a] ± 0.4
4	5.94 ± 0.064	16.9 ± 0.6	5.84 ± 0.070	16.7 ± 0.6
6	5.69 ± 0.044	11.4 ± 0.5	5.65 ± 0.048	11.3 ± 0.5
8	5.67 ± 0.027	7.8 ± 0.3	5.64 ± 0.030	7.8 ± 0.3
12	5.63 ± 0.025	6.1 ± 0.3	5.60 ± 0.028	5.7 ± 0.3
14	5.56 ± 0.025	5.2 ± 0.3	5.56 ± 0.028	6.3 ± 0.4

- No Measurements were taken
*significant differences (P ≤ 0.05) between pH values per time unit
**significant differences (P ≤ 0.05) between temperature values per time unit
[a-b]Means with different superscripts in the same row within parameters differ significantly (P ≤ 0.05)

$$y = -0.397\ln(x) + 6.5365$$
$$R^2 = 0.7091$$

● pH non-stimulated

● pH stimulated
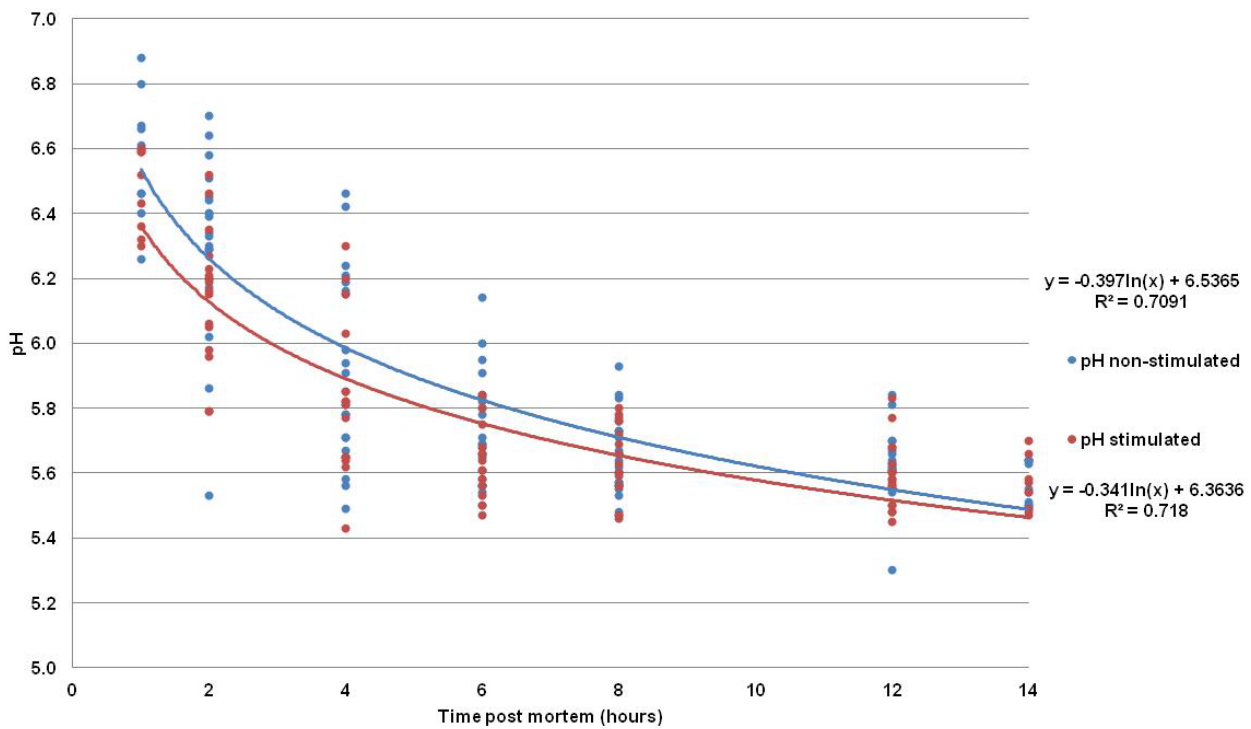
$$y = -0.341\ln(x) + 6.3636$$
$$R^2 = 0.718$$

Figure 3.3 Mean pH profiles of the *M. longissimus dorsi* of the stimulated (n = 16) and non stimulated (n = 19) springbok.

For cold shortening (CS) to occur, the conventional parameters of the muscle temperature dropping below 10°C before the pH drops below six was used (Pearson & Young, 1989; Devine et al., 2004a). Utilising the equation fitted in Fig. 3.3, it was predicted that the pH of an ES carcass will reach the value of 6 after 2.9 hours and a non ES carcass after 3.9 hours. For both these time periods, the muscle temperatures were still above 10°C, in fact after six hours *post mortem* the muscles for both treatments were still above 11°C (Table 3.2). Thus no CS could have occurred in either the ES- or non ES carcasses according to the parameters commonly set in the literature (Pearson & Young, 1989; Devine et al., 2004a). The same conclusion can be drawn when examining the BF muscles (Fig. 3.4). Being a deeper-lying muscle, the BF muscle serves as a good indicator of the core temperature of the carcass and it is clear from Fig. 3.4 that the mean temperature of this muscle for the entire group of carcasses did not reach the critical 10°C within six hours after the animal's death. This can further be emphasised when observing Fig. 3.5, which depicts the typical pH and temperature declines in the LD muscles of a non ES carcasses. The carcass pH value dropped to below six (2.9 hours *post mortem*) before the carcass temperature reached 10°C, in fact the carcass temperature was still above 20°C (Fig. 3.5). This illustrates that CS was theoretically not possible under the slaughtering conditions observed in this trial and thus CS of the LD muscles and its irreversible toughening should not occur.
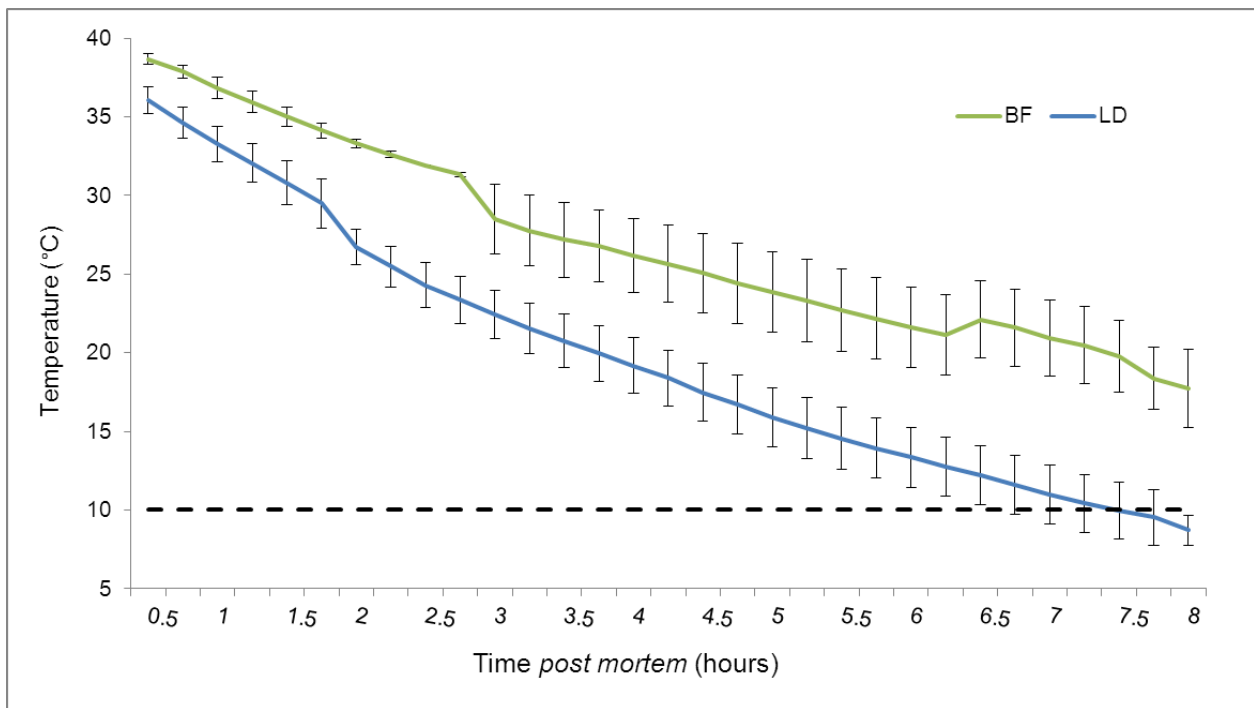
Figure 3.4 Pooled mean temperature decline *post mortem* (with standard error bars) in the LD and BF muscles of springbok (dashed line indicating critical cold shortening temperature).
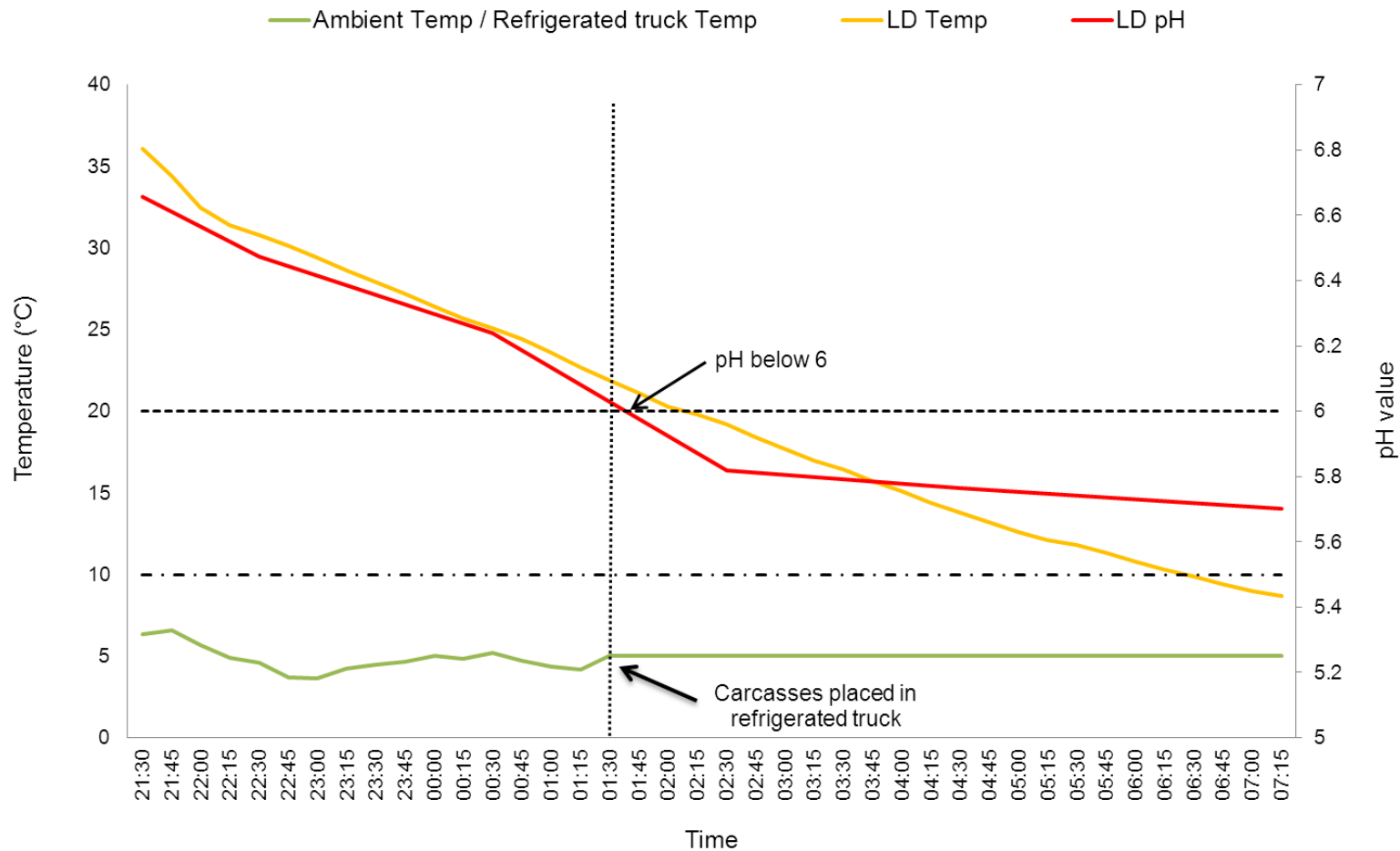
Figure 3.5 Temperature and pH profiles of an average non ES springbok carcass for the duration of the trial. The vertical dashed line indicates the time at which the carcasses where placed inside the cooling truck and the horizontal dashed lines indicates the classical circumstance inducing cold shortening, temperature (10°C) and the critical pH value (6), respectively.

Meat Quality

The mean values (± standard errors of the mean) of the physical attributes of the springbok LD muscles are presented in Table 3.3 according to the two main effects (stimulation and gender) per time (day).

Water holding capacity (WHC)

The WHC of the springbok muscles can be assessed by examining the three purge loss measurements in Table 3.3 (purge loss during storage, suspension drip loss, cooking loss). Neither stimulation nor gender differed (P > 0.05) for any of the three WHC measurements at any of the three time points, except for storage purge loss (%) on day 21, where the ES samples (5.2% ± 0.31) exhibited higher purge loss during storage (5°C) compared to non ES samples (4.3% ± 0.31). However, the water loss of the three measured attributes increased as the trial progressed. The samples used for colour determinations and purge loss (%) also indicated no differences (P > 0.05) between the ES or non ES or between the male or females animals (Table 3.3).

Tenderness

The mean tenderness measurements indicated that no differences (P > 0.05) occurred between the ES or non ES carcasses or between the different genders (Table 3.3). The variation (standard error values per treatment) in the tenderness measurements also did not indicate a decrease in tenderness for the ES group when compared to the non ES group (Table 3.3). Cold shortening did, however, not appear to occur since the conditions which induce CS were not observed in the temperature and pH data collected. This was further emphasised by the meat quality data, which also indicated that no irreversible toughening occurred in any of the carcasses (Table 3.3).

Table 3.3

The physical meat quality parameters of ES and non ES springbok *M. longissimus dorsi* (LSMeans ± S.E.M.)

Time point day 2	Treatment				Gender		
	Non ES[1]	ES[2]	P ≤ |t|		Female	Male	P ≤ |t|
Storage purge loss (%)	1.20 ± 0.13	1.50 ± 0.14	0.146		1.20 ± 0.11	1.50 ± 0.16	0.190
Suspension drip loss (%)	1.70 ± 0.09	1.60 ± 0.10	0.705		1.70 ± 0.08	1.50 ± 0.11	0.159
Cooking loss (%)	18.90 ± 0.72	18.40 ± 0.80	0.986		17.80 ± 0.64	19.50 ± 0.90	0.134
pH_u	5.51 ± 0.02	5.52 ± 0.02	0.757		5.50 ± 0.01	5.54 ± 0.02	0.093
Tenderness (Newton)	36.75 ± 2.86	32.15 ± 3.16	0.276		36.57 ± 2.55	32.32 ± 3.54	0.336
Colour purge loss (%)	11.90 ± 0.34	12.10 ± 0.38	0.681		12.20 ± 0.30	11.80 ± 0.42	0.389
Time point day 5	**Treatment**				**Gender**		
	Non ES[1]	ES[2]	P ≤ |t|		Female	Male	P ≤ |t|
Storage purge loss (%)	2.80 ± 0.25	2.80 ± 0.28	0.946		2.80 ± 0.22	2.70 ± 0.31	0.807
Suspension drip loss (%)	2.60 ± 0.15	2.30 ± 0.17	0.293		2.40 ± 0.14	2.50 ± 0.19	0.844
Cooking loss (%)	18.30 ± 0.61	17.20 ± 0.68	0.219		18.00 ± 0.55	17.60 ± 0.76	0.695
pH_u	5.56 ± 0.02	5.56 ± 0.02	0.776		5.54 ± 0.02	5.58 ± 0.02	0.136
Tenderness (Newton)	25.27 ± 1.90	23.80 ± 2.10	0.598		26.11 ± 1.70	22.97 ± 2.36	0.287
Time point day 21	**Treatment**				**Gender**		
	Non ES[1]	ES[2]	P ≤ |t|		Female	Male	P ≤ |t|
Storage purge loss (%)	4.30 ± 0.31	5.20 ± 0.31	0.044		5.00 ± 0.26	4.50 ± 0.37	0.298
Suspension drip loss (%)	2.10 ± 0.10	2.10 ± 0.10	0.922		2.00 ± 0.08	2.10 ± 0.13	0.670
Cooking loss (%)	21.70 ± 1.01	23.20 ± 1.13	0.312		22.20 ± 0.87	22.70 ± 1.31	0.745
pH_u	5.39 ± 0.02	5.40 ± 0.02	0.660		5.38 ± 0.02	5.41 ± 0.03	0.320
Tenderness (Newton)	24.80 ± 1.02	23.25 ± 1.09	0.294		24.09 ± 0.88	23.96 ± 1.27	0.847

[1]Non ES: Carcasses not electrically stimulated
[2]ES: Electrically stimulated carcasses
pH_u: ultimate pH value

Bloomed meat colour

No differences (P > 0.05) were found between the mean colour measurements of the treatments for days 1 and 9 of the colour stability trial (Table 3.4). The CIE a* values (redness) displayed a value below 12 even after 24 hours of being packaged. The data in Table 3.5 also indicates no differences (P > 0.05) between the calculated colour linear regression gradients for the ES and non ES treatments. Nonetheless, the ES samples presented higher colour intensity gradients (chroma values, P ≤ 0.05) than non ES samples.

Table 3.4

The mean colour measurement values for day 1 and 9 for ES and non ES springbok *M. longissimus dorsi* stored under refrigerated conditions (LSMeans ± S.E.M.)

	Day 1		Day 9	
	Non ES[1]	**ES[2]**	**Non ES[1]**	**ES[2]**
CIE L*	33.29 ± 0.52	32.96 ± 0.56	31.63 ± 0.47	32.81 ± 0.51
CIE a*	12.04 ± 0.17	11.64 ± 0.18	5.94 ± 0.22	5.52 ± 0.24
CIE b*	12.52 ± 0.22	12.30 ± 0.24	7.15 ± 0.14	7.37 ± 0.16
Chroma[3]	17.46 ± 0.17	16.99 ± 0.19	9.38 ± 0.19	9.34 ± 0.20
Hue-angle (°)[4]	46.07 ± 0.70	46.40 ± 0.76	50.61 ± 1.17	53.85 ± 1.27

[1]Non ES: Carcasses not electrically stimulated
[2]ES: Electrically stimulated carcasses
[3]chroma and [4]hue-angle (°) values were calculated
[a-b]Means with different superscripts in the same row within parameters differ significantly (P ≤ 0.05)

Table 3.5

The gradient values of the colour measurements linear regression lines (y = a +bt) of springbok *M. longissimus dorsi* over time (t) with treatment (ES and non ES) (LSMeans ± S.E.M.)

	Regression Gradient (b)		
	Non ES[1]	**ES[2]**	**P ≤ |t|**
CIE L*	-0.298 ± 0.039	-0.244 ± 0.042	0.349
CIE a*	-0.701 ± 0.027	-0.778 ± 0.030	0.065
CIE b*	-0.604 ± 0.020	-0.594 ± 0.022	0.739
Chroma[3]	0.224 ± 0.099	0.567 ± 0.108	0.026
Hue-angle (°)[4]	-0.934 ± 0.028	-0.960 ± 0.030	0.528

[1]Non ES: Carcasses not electrically stimulated
[2]ES: Electrically stimulated carcasses
[3]chroma and [4]hue-angle (°) values were calculated
[a-b]Means with different superscripts in the same row within parameters differ significantly (P ≤ 0.05)

DISCUSSION

pH and temperature

Indications from scientific literature suggests that the low ambient temperatures prevailing during the night harvesting of springbok in the winter months, coupled with their small size and low levels of subcutaneous fat, could lead to the rapid chilling of the carcasses and consequently CS and decreased tenderness of the resultant meat (Anon., 1986; Veary, 1991; Jansen van Rensburg, 1997; Hoffman et al., 2005; Hoffman & Wiklund, 2006; Mucina et al., 2006). It has generally been accepted that CS is promoted when the muscle temperature drops below 10°C while the pH thereof remains above six (Pearson & Young, 1989; Devine et al., 2004a), although it should be noted that Simmons et al. (2008) reported that cold-induced toughening did not occur in beef carcasses chilled at a faster rates than those cited as initiating CS conditions in the muscle.

Electrical stimulation has been utilised to circumvent CS by accelerating the rate of glycolysis and therefore the onset of *rigor* (Devine et al., 2004a; Lawrie & Ledward, 2006). It has been reported that ES results in a 1.5 to 2-fold increase in the rate of muscle pH decline after stimulation compared to a non ES muscles and its effectiveness is demonstrated by the immediate drop in pH caused by the stimulation (Chrystall & Devine, 1978; Carballo, Garcia-Matomoros & Jiménez-Colmenero, 1988).   Such a rapid pH decline was, however, not observed in the current investigation since a 0.2 unit decrease was only detected in the initial pH (pH_0) value *pre-* and *post*-stimulation (Table 3.2). The results of this study (Fig. 3.3, 3.4 and 3.5) also indicated that CS did not appear to occur in any of the tested samples and no negative effects on tenderness were observed in the subsequent quality assessments (Table 3.3). A small increase in pH decline was noted in the LD muscle samples of the ES compared to the non ES carcasses during *rigor* development. The latter is most probably due to the pH_0 value being lower in the stimulated carcass group *post* ES (Fig. 3.3, Table 3.2), although the resulting meat tenderness and quality attributes were not observed to be significantly ($P > 0.05$) improved by ES (Table 3.3).

A possible explanation for the lack of substantial increase in the rate of *post mortem* muscle pH decline due to ES, might be found in the studies conducted on lamb muscle by Carballo et al. (1988). When the lamb carcasses were stimulated shortly after death, the muscles were more reactive (at a higher temperature with more glycogen reserves present) causing the stimulation to be more effective in increasing the rate of glycolysis. A study conducted on lamb stimulated at 45 minutes *post mortem* also achieved a 0.81 pH drop with stimulation, but 500 V was used as the peak voltage, which is more than double the voltage used in this investigation (250 V peak voltage). High voltage (500 – 1000 V) was initially used for ES in commercial abattoirs, since it was more consistent at initiating effective acceleration of glycolysis when stimulation was conducted on the carcass for only a brief one to two minutes (Hwang & Thompson, 2001a). A

72

longer period of stimulation was, however, needed to achieve the same results when using a 100 V system (Lawrie & Ledward, 2006) or the stimulation had to be conducted immediately *post mortem* when the central nervous system could still be utilised (Simmons et al., 2008). Consequently, it appears that the period between the animal's death and stimulation is an important factor in accelerating the rate of pH decline, since the lower voltage system uses the central nervous system to spread throughout the carcass and can thus still improve tenderness if applied after 30 minutes *post mortem*. Simmons, Gilbert & Cairney (1997) also concluded that the effectiveness of low voltage ES in lamb carcasses can be variable.

The aforementioned factors might have played a crucial role in the effectiveness of the stimulation conducted in this trial. Lawrie and Ledward (2006) advised that the stimulation of lamb (which is similar in size as the springbok carcass) should be conducted within 30 minutes of death. The commercial harvesting of springbok at night is, however, conducted at a high pace to ensure efficiency and economic success; thus the implementation of ES within 30 minutes *post mortem* is hampered by the unique circumstances and the medium voltage stimulation (250 V peak) utilised in this study was applied within 45 minutes *post mortem*. The effect of ES might therefore have been improved by conducting this sooner after death when there was a larger amount of residual energy present in the muscle.

When comparing the pH decline of the non ES carcasses with other studies conducted on game species (Chrystal & Devine, 1983; Drew et al., 1988), the initial pH values of the non ES carcasses were lower and the pH decline profile more rapid in the springbok muscles evaluated in this study (Fig. 3.3). While Wiklund et al. (2001) and Bekhit et al. (2007) reported similar results in the pH_0 values in the muscles of commercial produced and slaughtered New Zealand deer, the latter required a longer period (> 10 hours) to drop to a pH value of six. Van den Berg (2009) evaluated the pH decline of ES impala (*Aepyceros melampus*) carcasses harvested during the day and noted a faster decrease in the pH readings of the LD muscles when compared to this investigation. Nonetheless, the pH values of the ES impala LD muscles fell below six within 1.5 hours *post mortem*, but no significant differences were observed in the resulting meat quality. The pH decline profile of impala harvested at night (Hoffman & Laubscher, 2009b) was, however, the most comparable to the results obtained in the current investigation, as well as gemsbok (*Oryx gazella*), even though the latter has a larger carcass than springbok (Hoffman & Laubscher, 2010).

Meat quality

Tenderness

The tenderness of meat is reported to be strongly influenced by the pH and temperature of the muscle *post mortem* (and their interaction) due to the effect of these parameters on the enzymatic-induced tenderisation process (Marsh, Lochner, Takahashi & Kragness, 1981; Yu & Lee, 1986; Offer & Knight, 1988; Lawrie & Ledward, 2006; Simmons et al., 2008). Nevertheless, various factors may influence meat tenderness, such as pH_0 (initial pH), pH_u (ultimate pH) and the rate of pH decline (Hoffman et al., 2007). The ability of ES to increase the tenderness of meat has been linked to the faster onset of *rigor*, meaning that the muscle reaches *rigor* at a higher temperature and thus the tenderisation process is initialised at a higher temperature. The proteolytic enzymes which are responsible for the tenderisation process, mainly the calpains and lysosomes, are more efficient at higher temperatures and thus cause the tenderisation process to be shortened or intensified (Devine et al., 2004a, 2004b; Lawrie & Ledward, 2006; Simmons et al., 2008). In particular, ES has been shown to increase the calpain activity and thus rate of tenderisation during *pre rigor* conditions (Hwang & Thompson, 2001a, 2001b), which causes an increase in tenderness if the chilling conditions are appropriate.

It has been suggested that proteolytic activity and thus tenderisation in the early *post mortem* period decreases at pH 5.8 – 6.3 (Yu & Lee, 1986). The results of this investigation, however, indicated that both groups (ES and non ES) had reached a pH value of below 6.3 within 2 hours *post mortem* (Table 3.2, Fig. 3.3), possibly explaining why such small differences were observed between the groups (Table 3.3). A previous study conducted by Hoffman et al. (2007) on the pH_u values and tenderness of springbok LD muscles indicated a positive correlation (P ≤ 0.001) between pH_u values and tenderness. Conversely, the results of the current investigation did not appear to support the aforementioned findings, since very little variation was observed to exist in the pH_u values measured in the muscles of both the ES and non ES groups (Table 3.3). Only a slight increase in the tenderness (2 – 4 N) of the ES samples was found throughout the trial period (Table 3.3), possibly attributed to the minor increase in the temperature of the LD muscles *post* stimulation (two hours *post mortem*, Table 3.2) due to the heat generated by muscle contraction during stimulation. The shear force value of the ES meat at 21 days was, however, only ca. 1.5 N lower than that of the non ES muscles at the same time point. This small increase in tenderness would most probably not be detected by meat consumers. Bekhit et al. (2007) also found that ES was not effective in significantly increasing the tenderness of red deer (*Cervus elaphus*) after prolonged storage and while initial tenderness values were increased on day 1, these authors noted that little improvement in tenderness could be perceived after 21 days of storage.

The pH data suggest that the ES treatment did deplete the glycogen reserves to some extent and caused the initial drop in the pH value (

Table **3.2**). It did, however, not produce a significant effect on the subsequent meat quality attributes (Table 3.3). This may be attributed to the species differences, as the springbok is known to be extremely tender (Von la Chevallerie, 1972; Veary, 1991; Hoffman & Wiklund, 2006; Hoffman et al., 2007). Consequently, the tenderness measurement were already well below what is considered as very tender (shear force < 49 N; Bickerstaffe, Bekhit, Robertson, Roberts, & Geesink, 2001) within two days of slaughter (Table 3.3). When compared to the tenderness values of other trials conducted on springbok the values are marginally higher, as Hoffman et al. (2007) found an average of 20 – 23 N at 24 hours *post mortem*, compared to this trial 32 – 36.8 N on day 2 (48 hours *post mortem*). Yet when compared to other game species, impala 32.1 – 40.8 N (Hoffman, 2000) or impala and kudu 40 – 42 N (Hoffman, Mostert, Kidd & Laubscher, 2009); gemsbok 41.09 N ± 0.138 (Hoffman & Laubscher, 2010), the tenderness of the meat in this trial was similar. However, comparisons between different studies are complicated by a lack of standardisation in, amongst others, sampling techniques and cooking methods between laboratories. In the aforementioned studies, core samples were used for tenderness measurements that were conducted at 24 hours *post mortem*, whereas in this investigation square sample were cuts following the grain of the meat fibres were used and these were tested at 48 hours after death.

Water holding capacity and purge loss

The amount of 'weep' or 'drip' will depend on the quantity of fluid released (also known as purge loss) from its association with the muscle proteins on shrinkage of the framework of thin and thick filaments during the development of *rigor* (Lawrie & Ledward, 2006). *Post mortem* glycolysis in a typical muscle will normally proceed to a pH_u of 5.5 (*rigor*), which is also the iso-electric point of the principal proteins in the muscle. The rapid decline of the pH *post* stimulation enhances the intracellular osmotic pressure, which leads to the loss in WHC by the muscle proteins (Geesink, Mareko, Morton & Bickerstaffe, 2001; Wiklund et al., 2001; Devine et al., 2004a; Lawrie & Ledward, 2006). In this investigation, the higher (P ≤ 0.05) storage purge loss on day 21 for the ES muscles may have been caused by a sampling error, since the quality attributes such as tenderness conforms with an increase in time and do not differ. Nonetheless, Lawrie and Ledward (2006) noted that ES does not necessarily cause an immediate increase in purge loss but that there is a tendency for increased purge loss over time. This is in accordance with the results from this study for day 21 (Table 3.3). There were, however, no differences (P > 0.05) in any of the other measurements (suspension loss, cooking loss) measuring WHC on day 21. There is no clear understanding of why an increased purge loss could be caused by ES as time progresses. Only if the ES causes abnormal low pH values under high temperature conditions (e.g. pale, soft,

75

exudative (PSE) meat in pork, Lawrie & Ledward, 2006), would protein denaturation increase and the subsequent purge loss values be affected. However, no PSE like conditions occurred in the springbok LD muscles. Both the purge loss (2.5 – 3%) and cooking loss (27 – 32%) values were lower than those reported by Hoffman et al. (2007) for springbok muscles, who tested their samples at 24 hours *post mortem*. In this trial Hoffman and co-authors investigated whether the region had an influence on the quality parameters. Although, they did not incorporate the use of ES during slaughtering, they found differences in terms of purge, cooking loss and tenderness, but not in terms of pH decline. They postulated that region or stress induced during harvesting could induce DFD type condition (high ultimate pH) and explain the results, but that the springbok species possess a high rate of pH decline. Overall, researchers have found mixed results in terms of whether ES increases (Devine et al., 2004a) or had no effect (e.g., game, Wiklund et al., 2001; Bekhit et al., 2007; lamb, Moore & Young, 1991) on purge loss in meat. All results are nevertheless in agreement with regards to the fact that cooling of the carcass has a major influence on the effect of ES on purge loss and should be taken into account when trying to prevent an increase in purge loss (Devine et al., 2004a; Lawrie & Ledward, 2006). In this investigation there were however, no difference (P > 0.05) in the temperature decline between the non ES and ES samples, except at two hours *post mortem* when the ES carcasses (24.1 ± 0.4) were marginally warmer that the non ES carcasses (22.8 ± 0.4).

Bloomed meat colour

Reports on the ability of ES to promote an enhanced flavour and a brighter red colour on the surface of freshly cut meat (Savell, Dutson, Smith & Carpenter, 1978; Lawrie & Ledward, 2006; Simmons et al., 2008) are likely attributed to the rapid pH decline in ES carcasses and the fact that the muscles reach their isoelectric point earlier, opening their structure and aiding in myoglobin oxidation. The marked effect of ES on the redness of meat does, however, become less significant when the meat is cut 48 hour *post mortem* (Lawrie & Ledward, 2006). It is plausible to presume that both ES and non ES muscles would have reached their pH_u in 48 hours *post mortem* and thus would be equally 'open' to residual oxygen utilisation. Reports have also emerged in the past suggesting that ES increases metmyoglobin formation in certain muscles (*M. semimembranosus* in beef), which produces a brown colour in meat (Ledward, Dickinson, Powell & Shorthose, 1986). The redness (CIE a*-value) is generally used by consumers as an indication of "quality" or "safety" of meat, and there is a perception that if the meat is not red, that it may be of dubious quality. Most research show an increase in redness with the use of ES, but the shelf-life stability of the colour depends on the packaging and chilling/storage regimes used (Moore & Young, 1991; Devine et al., 2004a; Simmons et al., 2008). Bekhit et al. (2007) found that the application of ES did not influence (P > 0.05) the colour stability of venison over time under refrigerated storage. The current study also indicated no consistent trend in the colour parameter measurements (P ≤ 0.05) between the treatments, although some of the mean measurements for particular colour co-

ordinates did differ (P ≤ 0.05) during the 9-day trial. It is postulated that these differences were found due to measurement variation and not due to biological reasons or influences by the treatment. Only the calculated chroma regression gradient indicated a slight increase (0.34) in the sharpness of the colour of the ES samples, which could be explained by the higher oxidation rate caused by opening of the structure to binding with oxygen.

CONCLUSIONS

Electrical stimulation was applied with the aim of preventing CS and increasing the quality of springbok meat. It was concluded that CS could not have occurred in the springbok LD muscles during the commercial game harvesting conditions evaluated in this study. It was further assessed that ES did not significantly increase the quality attributes of the springbok meat. While ES did lead to increases in the sharpness of the colour during the display life of the meat and in the storage purge loss after three weeks of ageing, it did not appear to increase the tenderness of the LD muscles, nor decrease the variation in the quality attributes. The lack of significant differences between the ES and non ES (control) springbok muscles in this investigation could be the result of a number of extrinsic factors arising due to the random sampling procedure related to commercial harvesting, including variations in the size, gender and age of the animals. The process of slaughter or harvesting further complicated the use of ES and the evaluation thereof, especially since in this study animals had to be located, shot and transported to the mobile abattoir to be stimulated. It is postulated that the relatively long time between death and stimulation (*ca.* 45 minutes *post mortem*) could also have led to a decrease in the effectiveness of the stimulation. If the pH decline had been more pronounced, there may have been a more profound difference in quality parameters (especially tenderness) as has been indicated in similar investigations. Suggested modifications to the present study could be to sample a larger and more controlled/homogenous group of carcasses, thus making variation due to the aforementioned extrinsic factors smaller, as well as to assess the effect of ES and its influence on meat quality in other primal muscles of the carcass. Additional modifications could be to evaluate different stimulation parameters (frequency, voltages, current), which could increase the effectiveness of the stimulation and result in a more significant difference between treatments, as could a decrease in the period between death and stimulation. Overall, future work should thus be focused on quantifying and controlling potential factors (stress, carcass size, time between death and stimulation, controlled temperature treatment) that could have played a crucial role in confounding these results, which should then provide a better indication of the ability of ES to enhance the quality of game meat.

REFERENCES

Anonymous (1986). *Climate of South Africa: Climate statistics up to 1984*. (pp 65–66). South Africa: Weather bureau, Department of Home Affairs.

Anonymous (2011). *Game numbers and weights exported for 2010*. Oudtshoorn: South African Ostrich Business Chamber.

Bekhit, A.E.E., Farouk, M.M., Cassidy, L. & Gilbert, K.V. (2007). Effects of rigor temperature and electrical stimulation on venison quality. *Meat Science, 75,* 564–574.

Bendall, J.R., Ketteridge, C.C. & George, A.R. (1976). The electrical stimulation of beef carcasses. *Journal of Science of Food and Agriculture, 27*, 1123–1131.

Bickerstaffe, R., Bekhit, A.E.D., Robertson, L.J., Roberts, N. & Geesink, G.H. (2001). Impact of introducing specifications on the tenderness of retail meat. *Meat Science, 59,* 303–315.

Boleman, S.J., Boleman, S.L., Miller, R.K., Taylor, J.F., Cross, H.R., Wheeler, T.L., Koohmaraie, M., Shackelford, S.D., Miller, M.F., West, R.L., Johnson, D.D. & Savell, W.J. (1997). Consumer evaluation of beef of known categories of tenderness. *Journal of Animal Science*, *75*, 1521–1524.

Bothma, J.Du P. (2010). Harvesting wild animals. In J.Du P. Bothma & J.G. Du Toit (Eds.), *Game ranch management* (pp. 489–490) (5th ed.). Pretoria: Van Schaik Publishers.

Carballo, J., Garcia-Matomoros, E. & Jiménez-Colmenero, F. (1988). Influence of low voltage electrical stimulation and rate of chilling on post-mortem glycolysis in lamb. *Food Chemistry*, *29*, 257–267.

Chrystall, B.B. & Devine, C.E. (1978). Electrical stimulation, muscle tension and glycolysis in *bovine sternomandibularis. Meat Science*, *2*, 49–58.

Chrystall, B.B. & Devine, C.E. (1983). Electrical stimulation of deer carcasses. *New Zealand Journal of Agricultural Research*, *26*, 89–92.

Conroy, A.M. & Gaigher, I.G. (1982). Venison, aquaculture and ostrich meat production: Action 2003. *South African Journal of Animal Science*, *12*, 219–233.

Cordain, L., Watkins, B.A., Florant, G.L., Kelher, M., Rogers, L. & Li, Y. (2002). Fatty acid analysis of wild ruminant tissues: evolutionary implications for reducing diet-related chronic disease. *European Journal of Clinical Nutrition*, *56*, 181–191.

Crawford, M.A., Gale, M.M., Woodford, M.H. & Casped, N.M. (1970). Comparative studies on fatty acid composition of wild and domestic meats. *International Journal of Biochemistry*, *1*, 295–305.

Department of Agriculture, Forestry and Fisheries (DAFF) (2010). *Game industry market value chain profile* (pp. 1-13). South Africa, DAFF.

Davey, C.L., Gilbert, K.V. & Carse, W.A. (1976). Carcass electrical stimulation to prevent cold shortening toughness in beef. *New Zealand Journal of Agricultural Research*, *19*, 13–18.

Devine, C.E., Hopkins, D.L., Hwang, I.H., Ferguson, D.M. & Richards, I. (2004a). Electrical stimulation. In W.K. Jensen, C. Devine & M. Dikeman (Eds.), *Encyclopaedia of meat science* (pp. 413–423) (Vol. 1). Oxford: Academic Press.

Devine, C.E., Hopkins, D.L., Hwang, I.H., Ferguson, D.M. & Richards, I. (2004b). Ageing. In W.K. Jensen, C. Devine & M. Dikeman (Eds.), *Encyclopaedia of meat science* (pp. 330–338) (Vol. 1). Oxford: Academic Press.

Drew, K.R., Crosbie, S.F., Forss, D.A., Manley, T.R. & Pearse, A.J. (1988). Electrical stimulation of carcasses from red, fallow and New Zealand wapiti-type male deer. *Journal of Science and Food and Agriculture*, *43*, 245–259.

Dryden, G.M. (1997). Venison in the human diet – is venison a low-fat meat? *Proceedings of the nutrition Society of Australia, 21,* 44–51.

Geesink, G.H., Mareko, M.H.D., Morton, J.D. & Bickerstaffe, R. (2001). Electrical stimulation – when more is less. *Meat Science*, *57*, 145–151.

Grunert, K.G., Bredahl, L. & Brunsø, K. (2004). A review: Consumer perception of meat quality and implications for product development in the meat sector. *Meat Science*, *66*, 259–272.

Hoffman, L.C. (2000). Meat quality attributes of night-cropped impala (*Aepyceros melampus*). *South African Journal of Animal Science, 30*(2), 133–137.

Hoffman, L.C. (2002). The effect of different culling methodologies on the physical meat quality attributes of various game species. In H. Ebedes, B. Reilly, W. van Hoven & B. Penzhorn (Eds.), *Proceedings of the 5th international wildlife ranching symposium sustainable utilisation – conservation in practice* (pp. 212–221). Port Elizabeth, South Africa: Nelson Mandela Metropolitan University.

Hoffman, L.C. (2003). Can South Africa produce meat according to European Union standards? The springbok & impala story. Consistency of quality*: 11ᵗʰ International meat symposium* (pp. 257–268). Perth, Australia.

Hoffman, L.C. & Bigalke, R.C. (1999). Utilizing wild ungulates from Southern Africa for meat production: potential research requirements for the new millennium. *Congress of the Wildlife Management Association of South Africa* (pp. 1–14). George, South Africa.

Hoffman, L.C., Kroucamp, M. & Manley, M. (2007). Meat quality characteristics of springbok (*Antidorcas marsupialis*). 1. Physical meat attributes as influenced by age, gender and production region. *Meat Science*, *76,* 755–761.

Hoffman, L.C. & Laubscher, L.L. (2009a). A comparison between the effects of day v*ersus* night cropping on greater kudu (*Tragelaphus strepsiceros*) meat quality. *South African Journal of Wildlife Research, 39*(2), 164–169.

Hoffman, L.C. & Laubscher, L.L. (2009b). Comparing the effects on meat quality of conventional hunting and night cropping of impala (*Aepyceros melampus*). *South African Journal of Wildlife Research*, *39*(1), 39–47.

Hoffman, L.C. & Laubscher, L.L. (2010). A comparison between the effects of day and night cropping on gemsbok (*Oryx gazella*) meat quality. *Meat Science, 85,* 356–362.

Hoffman, L.C. & Laubscher, L.L. (2011). A comparison between the effects of day v*ersus* night cropping on the quality parameters of red hartebeest (*Alcelaphus buselaphus*) meat. *South African Journal of Wildlife Research*, *41*(1), 50–60.

Hoffman, L.C., Mostert, A.C., Kidd, M. & Laubscher, L.L. (2009). Meat quality of kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*): Carcass yield, physical quality and chemical composition of kudu and impala *Longissimus dorsi* muscle as affected by gender and age. *Meat Science, 83*, 788–795.

Hoffman, L.C., Muller, M., Schutte, De W., Calitz, F.J. & Crafford, K. (2005). Consumer expectations, perceptions and purchasing of South African game meat. *South African Journal of Wildlife Research*, *35*(1), 33–42.

Hoffman, L.C. & Wiklund, E. (2006). Game and venison – meat for the modern consumer. *Meat Science*, *74*, 197–208.

Honikel, K.O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science*, *49*, 447–457.

Hwang, I.H. & Tompson, J.M. (2001a). The effect of time and type of electrical stimulation on the calpain system and meat tenderness in beef *longissimus dorsi* muscle. *Meat Science*, *58*, 135–144.

Hwang, I.H. & Tompson, J.M. (2001b). The interaction between pH and temperature decline early post mortem on the calpain system and objective tenderness of electrically stimulated beef *longissimus dorsi* muscle. *Meat Science*, *58*, 167–174.

Jansen van Rensburg, D.M. (1997). *The physical, chemical and sensory quality characteristics of Springbok (Antidorcas marsupialis marsupialis) meat*. (Unpublished master dissertation). Technology: Food and Nutrition. Pretoria Technicon: Pretoria, South Africa.

Koohmaraie, M., Veiseth, E., Kent, M.P., Shackleford, S.D. & Wheeler, T.L. (2003). Understanding and managing variation in meat tenderness. In *Consistency of quality: 11th International Meat Symposium*. (pp. 3–13). Pretoria, South Africa.

Kritzinger, B., Hoffman, L.C. & Ferreira, A.V. (2003). A comparison between the effects of two cropping methods on the meat quality of impala (*Aepyceros melampus*). *South African Journal of Animal Science, 33*(4), 233–240.

Lawrie, R.A. & Ledward, D.A. (2006). *Lawrie's meat science* (7th ed.). Cambridge, England: Woodhead Publishing Limited.

Ledward, D.A., Dickinson, R.F., Powell, V.H. & Shorthose, W.R. (1986). The colour and colour stability of beef *longissimus dorsi* and *semimembranosus* muscles after effective electrical stimulation. *Meat Science*, *16*, 245–265.

MacFarlane, P.G. & Marer, J.M. (1966). An apparatus for determining tenderness of meat. *Food Technology*, *20*, 134–134.

Marsh, B.B., Lochner, J.V., Takahashi, G. & Kragness, D.D. (1981). Effects of early post-mortem pH and temperature on beef tenderness. *Meat Science*, *5*, 479–483.

Moore, V.J. & Young, O.A. (2001). The effects of electrical stimulation, thawing, ageing and packaging on the colour and display life of lamb chops. *Meat Science*, *30*, 131–145.

Mucina, L., Rutherford, M.C., Palmer, A.R., Milton, S.J., Scott, L., Lloyd, J.W., Van der Merwe, B., Hoare, D.B., Bezuidenhout, H., Vlok, J.H.J., Euston-Brown, D.I.W., Powrie, L.W. & Dold, A.P. (2006). Nama-Karoo Biome. In L. Mucina & M.C. Rutherford (Eds.), *The vegetation of South Africa, Lesotho and Swaziland* (pp. 325–345). South Africa: South African National Biodiversity Institute.

Offer, G. & Knight, P. (1988). The structural basis of water holding in meat, Part 2: Drip losses. In R. A. Lawrie (Ed.), *Developments in Meat Science, 4*, (pp. 173–243). London, United Kingdom: Elsevier Science Publishers.

Pearson, A.M. & Young, R.B. (1989). *Muscle and meat biochemistry*. San Diego: Academic Press

Radder, L. & Le Roux, R. (2005). Factors affecting food choice in relation to venison: A South African example. *Meat Science*, *71*, 583–589.

SAS (2006). SAS/STAT User's Guide. Version 9.1.3 , 1st Edition, Volume 2. SAS Institute Inc., SAS Campus Drive, Cary, North Carolina.

Savell, J.W., Dutson, T.R., Smith, G.C. & Carpenter, Z.l. (1978). A research note: Structural changes in electrical stimulated beef muscle. *Journal of Food Science, 43*, 1606–1607.

Simmons, N.J., Daly, C.C., Cummings, T.L., Morgan, S.K., Johnson, N.V. & Lombard, A.C. (2008). Reassessing the principles of electrical stimulation. *Meat Science*, *80*, 110–122.

Simmons, N.J., Daly, C.C., Mudford, C.R., Richards, I., Jarvis, G. & Pleiter, H. (2006). Integrated technologies to enhance meat quality – An Australasian perspective. *Meat Science*, *74*, 172–179.

Simmons, N.J., Gilbert, K.V. & Cairney, J.M. (1997). The effect of low voltage stimulation on pH fall and meat tenderness in lamb. In *Proceedings of the 43rd international congress of meat science and technology* (pp. 610–611). Auckland, New Zealand.

Smith G.C., Dutson, T.R., Hosteler, R.L. & Carpenter, L. (1976). Fatness, rate of chilling and tenderness of lamb. *Journal of Food Science*, *41*, 748–756.

Steenkamp, J-B.E.M. (1997). Dynamics in consumer behaviour with respect to agricultural and food products. In *Agricultural marketing and consumer behavior in a changing world*. (pp. 143–189). Kluwer Academic publishers.

Tarrant, P.V. & Sherington, J. (1980). An investigation of ultimate pH in the muscles of commercial beef carcasses. *Meat Science*, *4*, 287–297.

Thompson, J. (2002). Managing meat tenderness. *Meat Science, 62*, 295–308.

Van den Berg, J.H. (2009). *The effect of electrical stimulation on the meat quality of the impala (Aepyceros melampus).* (Unpublished master dissertation in Meat Science). University of Pretoria , Pretoria, South Africa.

Van der Merwe, P., Scholtz, M. & Saayman, M. (2011). National profile and economic impact of biltong hunters in South Africa. *Published by Tourism research in economic environs and society (trees)*, Potchefstroom campus.

Van Schalkwyk, D.L. (2011). *Investigation into selected parameters required to developed a sustainable Namibian game meat industry*. (Unpublished doctoral dissertation). Department of Consumer Science. University of Stellenbosch: Stellenbosch.

Van Schalkwyk, D.L. & Hoffman, L.C. (2010). *Guidelines for the harvesting of game for meat export*. Windhoek, Namibia: AgriPublishers.

Van Zyl, L. & Ferreira, A.V. (2004). Physical and chemical carcass composition of springbok (*Antidorcas marsupialis*), blesbok (*Damaliscus dorcas phillipsi*) and impala (*Aepyceros melampus*). *Small Ruminant. Research, 53,* 103–109.

Veary, C.M. (1991). *The effect of three slaughter methods and ambient temperature on the pH and temperature in Springbok (Antidorcus marsupialis) meat*. (Unpublished doctoral dissertation). Faculty of Veterinary Science, University of Pretoria, South Africa.

Von la Chevallerie, M. (1972). Meat quality of seven wild ungulate species. *South African Journal of Animal Science*, *2*, 101–103.

Wiklund, E., Stevenson-Barry, J.M., Duncan, S.J. & Littlejohn, R.P. (2001). Electrical stimulation of red deer (*Cervus elaphus*) carcasses — effects on rate of pH-decline, meat tenderness, colour stability and water holding capacity. *Meat Science*, *59*, 211–220.

Wood, J.D. & Warriss, P.D. (1992). The influence of the manipulation of carcass composition on meat quality. In P.J. Buttery, K.N. Boorman & D.B. Lindsay (Eds.), *The control of fat and lean deposition* (pp. 331–353). Butterworth & Heinemann Ltd

Wood, J.D., Enser, M., Fisher, A.V., Nute, G.R., Richardson, R.I. & Sheard, P.R. (1999). Manipulating meat quality and composition. *Proceedings of the Nutrition Society*, *58,* 363–370.

Yu, L.P. & Lee, Y.B. (1986). Effects of *post mortem* pH and temperature on bovine muscle structure and meat tenderness. *Journal of Food Science, 51*, 774–780.

<div align="center">

CHAPTER 4

**The effect of electrical stimulation and *rigor* temperature on the meat quality of blesbok
(*Damaliscus pygargus phillipsi*)**

</div>

ABSTRACT

This study investigated the effect of electrical stimulation (ES) and temperature treatment (5°C and 39°C) on the meat quality of blesbok *M. longissimus dorsi* (LD) over time. Twenty mature blesbok blesbok were harvested; of which 10 animals were ES within 45 minutes *post mortem* and 10 non ES animals were used as control specimens. Meat quality analyses (pH, colour, purge loss, cooking loss and tenderness) were performed on days 0 (*rigor*), 1, 2 and 5 *post mortem.* Electrical stimulation increased the initial pH decline and decreased the time to the onset of *rigor mortis.* The mean pH at *rigor* was lower (P ≤ 0.05) in the ES (5.75 ± 0.07) and non ES (5.98 ± 0.06) muscle samples at 5°C, compared to the ES (5.55 ± 0.14) and non ES (5.37 ± 0.03) samples at 39°C. The 5°C ES muscle samples (80.34 ± 5.64) were more tender (P ≤ 0.05) than the non ES (101.95 ± 4.59) samples at *rigor*, but no differences (P > 0.05) were present for days 1, 2 and 5. The 39°C ES muscle samples (*rigor*, 57.05 ± 5.20; day 1, 48.37 ± 3.68; day 2, 46.06 ± 3.56 and day 5, 39.94 ± 3.46) were all more tender (P ≤ 0.05) compared to the non ES samples (*rigor*, 79.37 ± 9.48; day 1, 74.41 ± 5.40; day 2, 75.52 ± 7.11 and day 5, 66.18 ± 6.14). Electrical stimulation therefore increased the tenderness of the 5°C muscle samples only at *rigor*, but ES was much more effective at the higher temperature treatment (39°C). Electrical stimulation had no effect (P > 0.05) on the water holding capacity (WHC), cooking loss percentages and bloomed meat surface colour of blesbok LD muscles. The mean WHC was lower (P ≤ 0.05) in the 39°C LD muscle samples from each time point, compared to the 5°C samples. The purge losses were higher (P ≤ 0.05) in the non ES (7.13% ± 0.30) compared to the ES (4.89% ± 0.32) muscle samples. The mean purge losses were higher (P ≤ 0.05) in the 39°C (7.31% ± 0.30) compared to the 5°C (4.67% ± 0.29) muscle samples. The mean purge losses increased significantly over time (day 1, 4.63% ± 0.41; day 2, 5.91% ± 0.34 and day 5, 7.47% ± 0.39), which can negatively affect consumer perception on blesbok LD muscle quality. The mean cooking losses were higher (P ≤ 0.05) in the 39°C (26.93% ± 1.04) compared to the 5°C (21.33% ± 1.29) muscle samples at *rigor*, but the opposite was true at days 2 and 5 (5°C: day 2, 28.06% ± 0.67 and day 5, 27.72% ± 0.57; 39°C: day 2, 25.60% ± 0.56 and day 5, 25.65% ± 0.72). The bloomed colour measurement values of the 39°C muscle samples for each time point were higher (P ≤ 0.05) compared to the 5°C samples. The bloomed colour measurement values of the 39°C samples were more or less constant with time, whereas the values of the 5°C samples improved over time, but never reached similar values to the 39°C samples. The extreme high temperature treatment negatively affected most of the meat

quality attributes of blesbok LD muscles, while the extreme low temperature treatment only negatively affected the tenderness.

INTRODUCTION

In South Africa, game animals are harvested under variable circumstances by the use of specialised rifles, personnel and equipment. It is not possible to slaughter game animals by the conventional methods as practised in commercial domestic abattoirs (Hoffman & Wiklund, 2006; Van Schalkwyk & Hoffman, 2010). However, the game meat industry is confronted by similar challenges as the domestic livestock industry, such as ensuring high quality meat products (Hoffman, 2002; Hoffman & Wiklund, 2006) and a repeated favourable eating experience throughout the year (Bickerstaffe, Bekhit, Robertson, Roberts, & Geesink, 2001; Grunert et al., 2004). The production of a continuous high quality product is difficult, since the stress associated with harvesting cannot be easily controlled or decreased and consequently negatively affects the final meat quality (Von la Chevallerie & Van Zyl, 1971; Veary, 1991; Hoffman & Ferreira, 2000; Kritzinger et al., 2003; Laubscher, 2009; Van Schalkwyk & Hoffman, 2010). The stress, along with environmental conditions fluctuating during the year, could also severely affect game meat quality (Hoffman, 2002, 2003). Veary (1991) noted that the ambient temperatures during night harvesting and processing must be taken into account, as the correct manipulation or management thereof could improve game meat quality. The conditions are, however, specific to the species, the environment or region and the time of year they are being harvested. Even though some game species are harvested throughout the year, there is usually a peak during the optimum period (April to August) when ambient conditions are most favourable and animal reproduction will not be affected by the harvesting operations. In South Africa and Namibia, the optimum period for night harvesting of game species for commercial game meat production usually commences in April and ends in August, the winter period in southern Africa (Hoffman 2003; Bothma, 2010; Van Schalkwyk, 2011).

Blesbok (*Damaliscus pygargus phillipsi*) are one of the most commonly farmed game species in South Africa (Conroy & Gaigher, 1982; Jansen van Rensburg, 1997) and consequently one of the most harvested and exported game species (Hoffman & Wiklund, 2006). The chemical composition of blesbok meat indicates that this species could be suitable as an alternative red meat source for consumers wishing to consume more lean red meat (Hoffman et al., 2008). Mean blesbok live weights are usually between 70 – 80 kg for rams and 60 – 70 kg for ewes, with a dressing percentage around 52.9% for both (Huntley, 1971; Hoffman et al., 2008).

Blesbok populations are predominantly found and harvested throughout the year in the upper highlands and central eastern parts of South Africa. In these regions the ambient temperatures can drop to below 0°C in winter (Anon., 1986; Mucina et al., 2006) and rise to above 30°C in

summer (Mucina et al., 2006). Since blesbok are harvested throughout the year, both of these extreme environmental conditions, namely very high (> 25°C) and very low (< 10°C) ambient temperatures, can be found during blesbok harvesting operations. The latter two extreme temperature conditions can severely affect the quality of the game species being harvested. The low temperature conditions, together with the little or no subcutaneous fat present in game carcasses (Dryden, 1997; Jansen van Rensburg, 1997; Hoffman et al., 2007), may result in the rapid chilling of game carcasses (Veary, 1991; Jansen van Rensburg, 1997). The latter could in turn prevent or slow down the normal tenderisation process of meat *post mortem* and this could have severe affects on the initial meat tenderness (Lawrie & Ledward, 2006).

The opposite would be true with the harvesting of game in the middle of summer, when the warmer temperature conditions would result in carcasses having to be cooled by the use of refrigeration trucks to prevent meat spoilage. Moreover, the higher ambient temperatures can also result in the carcasses being over tenderised and this could possibly result in PSE type meat. The latter condition results in unfavourable meat quality attributes, due to the formation of discoloured/pale soft, watery meat. This was the result of the pH value dropping too quickly *post mortem* and initialising protein denaturation at a higher temperature, causing the muscle cell structure to disintegrate.

In addition to the rate of pH decline, the temperature at which a muscle enters *rigor mortis* can also severely affect game meat quality (Chrystall & Devine, 1983; Devine et al., 2002). The temperature and pH of meat *post mortem* can both influence the subsequent meat quality parameters, especially the meat tenderness, through their involvement in determining the activity of the proteolytic enzymes involved in the natural tenderisation process of meat (Yu & Lee, 1986; Hwang & Thompson, 2001).

To ensure high final game meat quality, it is crucial to consider the rate of pH decline during the conversion of muscles to meat. The latter can be manipulated by: decreasing *ante mortem* stress; ES of game carcasses; and temperature control *post mortem* (Lawrie & Ledward, 2006). Temperature control during meat processing, combined with the use of ES, can produce meat of acceptable tenderness levels at an earlier stage *post mortem*, while still possessing favourable meat quality characteristics (Simmons et al., 2006; Bekhit et al., 2007; Simmons et al., 2008). Furthermore, the effective management of the temperature (chilling) and pH decline (through the use of ES) *post mortem* can improve meat product consistency (Simmons et al., 2006).

The use of ES commercially, was developed to prevent cold shortening (CS) caused by rapid chilling of carcasses during processing (Chrystall & Devine, 1983; Devine, et al., 2004). Electrical stimulation causes an accelerated rate of pH decline in muscles, consequently manipulating the

glycogen reserves and stimulating muscle enzyme activities and causing the onset of *rigor mortis* at an earlier stage and higher temperature *post mortem* (Simmons et al., 2008). The latter results in the initiation of the natural tenderisation process at an earlier stage and higher temperature, resulting in rapid meat tenderisation (enzymes more effective at higher temperatures), thereby saving costs as less time is needed for conditioning (Simmons et al., 2006, 2008). The latter can improve overall meat quality attributes through the improved meat colour and tenderness (Lawrie & Ledward, 2006).

Meat quality improvements have been proven successful for most domestic species such as beef, lamb, pork, poultry and ostriches. However, limited studies have been conducted on the application of ES on game meat and specifically on its application on African game species. More controlled environmental conditions are, however, needed to test the feasibility of the use of ES and its possible affects (positive or negative) on meat quality and the prevention of CS. This was the case during a trial conducted in New Zealand to test the possible improvements of venison meat quality upon the application of ES and under different temperature regulated conditions during *rigor* development (Bekhit et al., 2007). Bekhit et al. (2007) established that an increased *rigor* temperature decreased the water holding capacity (WHC) and improved the colour of venison meat, while the tenderness increased with time *post mortem.* They also concluded that an acceptable level of venison tenderness can be achieved earlier *post mortem* by manipulating the *rigor* temperature, without negatively affecting the meat colour stability.

Although some research has been conducted on the use of ES on venison slaughtered in commercial slaughterhouses (Chrystall & Devine, 1983; Drew et al., 1988; Wiklund et al., 2001; Bekhit et al., 2007), no work has thus far been published on the use of ES on African game species slaughtered in the field. By electrically stimulating game carcasses at both the extreme cold and hot temperature conditions (as they might occur during harvesting conditions) it is possible to investigate whether ES of blesbok carcasses can positively affect the subsequent meat quality. The aim of this study was therefore to investigate the effect of ES and *rigor* temperature on blesbok meat quality during simulated extreme harvesting conditions.

MATERIALS AND METHODS

Experimental animals and study area

During October of 2009, twenty male blesbok were harvested and slaughtered over a four week period on Stellenbosch University's farm, Brakkekuil (S34 1752.7 E20 4920.0), near Witsand in the Heidelberg district of South Africa. Blesbok were harvested early in the morning using standard game day harvesting techniques as described by Van Schalkwyk and Hoffman (2010). The animals were harvested individually allowing the use of ES under controlled conditions.

Stress Score

A subjective stress score was assigned to each animal by an objective observer (Table 4.1), similar to the descriptions by Hoffman & Laubscher (2009). Blesbok were scored on the perceived *ante mortem* stress experienced. The stress scores were quantified by the amount of exercise prior to being shot (i.e. whether animals were pursued prior to being shot or whether fighting with other animals occurred), wounding and the elapse of time between the shot and subsequent death of the animal. Accordingly, a stress score of 1 to 5 was allocated to each animal indicating the amount of stress experienced by the animal prior to death (Table 4.1). The placement of the shot/s, time of the day of harvesting, wounded prior to killing, shot placement, time of death and live weight were also recorded. The blesbok were taken to the field laboratory (in close proximity to the harvesting area) after harvesting, where electrical stimulation was applied within 15 minutes *post mortem*.

Table 4.1

Stress scale animals as pertaining to perceived *ante mortem* stress experienced (adapted from Hoffman & Laubscher, 2009)

Value	Stress experienced
1	No stress: animal died immediately after being shot
2	*Ante mortem* exercise: animal was chased for up to 15 minutes prior to being shot and died immediately after being shot
3	Stressed: shot once and death was not instantaneous – animal moved a short distance (up to 50 m) after being shot before death
4	Stressed: animal fatally wounded – shot a second time after moving a short distance
5	Severely stressed: wounded, although not fatally – animal ran for a long time before being killed by a second or third shot

Carcasses which are not killed instantly with a head or high neck shot are not permitted to be exported and thus the inclusion of such data would not be representative of the commercial harvesting industry. The inclusion of these wounded/stressed animals may also obscure the data or affect the subsequent statistical analysis. However, an exploratory analysis of the stress scores and data indicated that five animals were shot a second time to induce death (3 ES; 2 non ES). Subsequently, a one way analyses of variance (one-way ANOVA) was conducted on all 20 carcasses. The results indicated that stress did not differ between the different treatment groups and that stress was evenly distributed. Consequently, the wounded or stressed animals' datasets did not influence the conclusions. The data from these animals were therefore included in all

further statistical analyses resulting in the dataset of 10 ES and 10 non ES carcasses (Table 4.2). The effect of treatment (ES/non ES) and temperature treatment (*rigor* temperature) was thus investigated without including stress in the model as a co-factor.

Table 4.2

Mean carcass and sample (*M. longissimus dorsi*) weights of blesbok used for ES, non ES and temperature treatments (LSMeans ± S.E.M.)

Treatment	N	Mean Live weight (kg)[3]	Mean carcass weight (kg)[4]	Left LD (g)	Right LD (g)
ES[1]	10	61.67 ± 1.71	31.18[a] ± 1.01	760.87 ± 31.19	769.28 ± 34.34
Non ES[2]	10	54.98 ± 2.11	27.99[b] ± 1.24	671.41 ± 35.06	658.83 ± 27.71
Total	20	58.33 ± 1.52	29.59 ± 0.87	716.14 ± 25.04	714.06 ± 24.94

[1]ES: Electrical Stimulated carcasses
[2]Non ES: Carcasses not electrically stimulated
[3]Mean weight of blesbok immediately *post mortem* after exsanguinations. Note that the mean carcass weights of the two treatments differed (P=0.05)
[4]Mean weight of the dressed blesbok carcass
LD: *M. longissimus dorsi*

Electrical stimulation procedure

Once the blesbok reached the field laboratory/abattoir, they were randomly selected to be either electrically stimulated (ES; n = 10) or not stimulated (non ES: n = 10). Electrical stimulation was performed using a Carné Tech Stimulation unit (Carné Technologies, Cambridge, New Zealand), that delivered a maximum output of 230 V at 15 Hz (Pulse with of 1 ms; Pulse interval of 66 ms) for a duration of 60 seconds. During ES, the undressed blesbok carcasses were suspended from their *Achilles* tendons and were insulated from the ground by being suspended from a synthetic strap and rope attached to a tree. The current was applied via an electrical clamp attached to the carcass throat area and via a steel hook (probe) in contact with the anus. After ES was applied, the undressed blesbok carcasses were further processed with the removal of the head, legs, skin and intestines.

Physical meat quality analyses

Both the *Longissimus dorsi* (LD) muscles were removed entirely within 50 minutes *post mortem* (n = 40). The end sections of each LD muscles were removed, since these are highly variable in terms of meat quality characteristics. The area between the 4th rib and 5th *lumbar vertebrae* was therefore used for further analyses. Consequently, each LD muscle was cut into two, equal sized portions and each portion was weighed (Figure 3.1). The four halved LD muscle samples were then placed in a plastic bag and marked with the corresponding animal identification number and randomly allocated to a temperature treatment (5°C n = 2 and 39°C n = 2) (Figure 3.1). Within

approximately 60 minutes *post mortem* the samples were suspended in the corresponding temperature controlled water baths (5°C or 39°C), until the onset of *rigor*. Each temperature treatment therefore contained 10 ES and 10 non ES halved LD muscle samples. In this study *rigor* is defined as the point at which three consecutive pH readings were similar during the pH profile measurements. The samples were also each fitted with an Ebro (EBI-6) temperature data logger (model 214002, Ebro electronics, Ingolstadt, Germany) that monitored that the temperature was maintained at the correct constant temperature (temp. treatment: 5/39 ± 1°C).
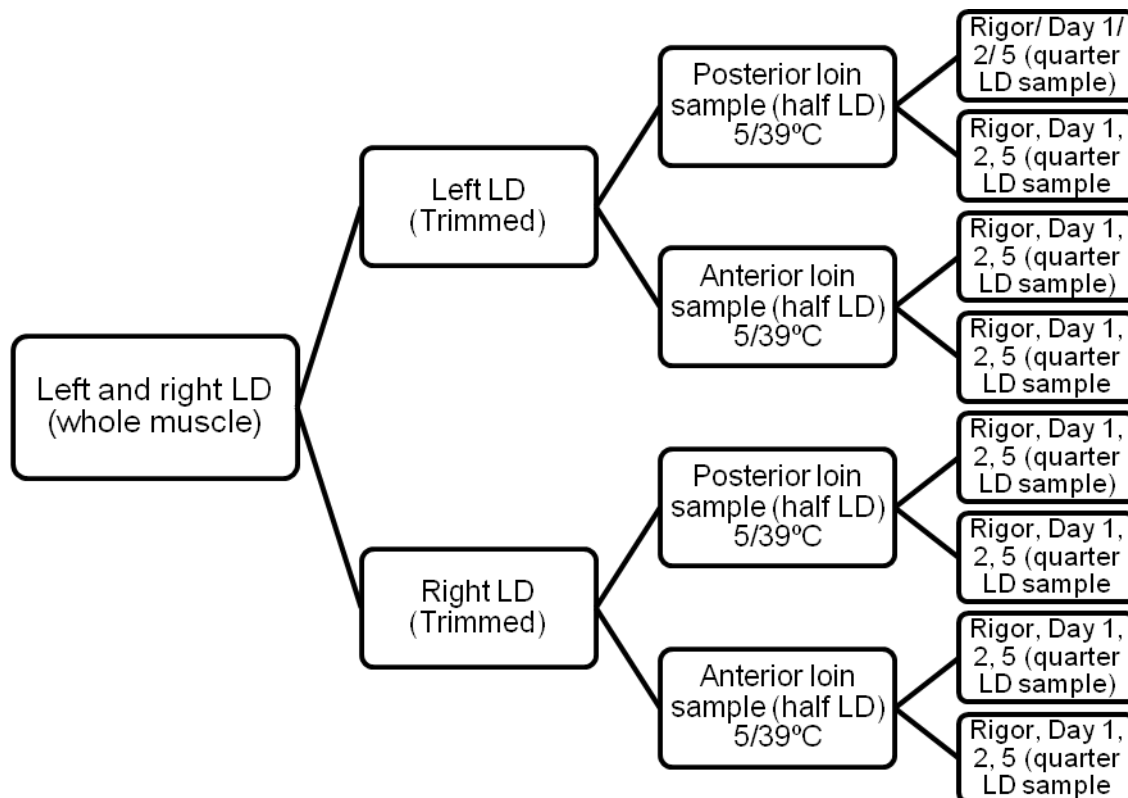

Figure 4.2 Muscle sample preparation for physical analysis.

pH and temperature measurements

The pH and temperature measurements were carried out by use of a Crison - pH25 electrode and meter (Alella, Barcelona). The pH meter was calibrated before each set of measurements. The initial pH and temperature measurements were taken through a small incision in the skin and LD muscles between the last and second last rib. For the non ES undressed blesbok carcasses, the initial pH measurements were recorded approximately 15 minutes *post mortem*, where after the pH measurements were taken at 30 minute intervals starting from one hour *post mortem* onwards to four hours *post mortem* (after three hours of immersion in the water baths). For the ES undressed blesbok carcasses, the pH and temperature measurements were recorded *pre* and *post* ES (10 – 15 minutes *post mortem*) in the same region as described above.

After four hours *post mortem*, the pH measurements were recorded every hour until *rigor* occurred (when three consecutive pH measurements were similar). After 12 hours *post mortem* another pH measurement was taken to establish the ultimate pH values (pH$_u$) and temperatures of the LD muscles of all the carcasses, before continuing with further meat quality assessments (1, 2 and 5 days *post mortem*).

Once the LD muscle samples reached *rigor*, they were blotted dry and transferred to a 4°C refrigerator until further processing could commence. Once both the muscle samples for a particular temperature treatment had reached *rigor*, they were divided into four sub samples (sub loin samples) and randomly allocated to one of the four time points (*rigor*, 1, 2 and 5 days) (Fig. 4.1). The sub loin samples for day 1, 2 and 5 were weighed, vacuum packed, labelled appropriately and stored at 4°C until the respective time periods have passed. The physical analyses of the sub loin samples included pH; temperature; bloomed muscle surface colour, retail purge loss, water holding capacity (WHC) and tenderness measurements (Honikel, 1998).

Commercial purge loss

Once the specific time points were reached (day 1, 2 and 5, respectively), the samples were removed from the vacuum packaging, blotted dry and weighed (Honikel, 1998). The commercial purge loss for the sub loin samples were calculated for day 1, 2 and 5, by dividing the initial weight (recorded at *rigor* during muscle sub sampling) by the final weight (recorded after packaging for the respective days and blotting dry). The final weight was therefore expressed as a percentage of the initial weight sample (Honikel, 1998). The commercial purge loss at *rigor* was not calculated, as water treatment could have hindered the results.

Water holding capacity (WHC)

The WHC of the sub loin samples were determined at *rigor* and day 1, 2 and 5 of *post mortem* packaging at 4°C. Following the determination of the commercial purge losses, small samples were cut off of each sub loin sample to determine the WHC. The filter paper press method was developed to measure the amount of expressible water from meat when pressure is applied as for example during chewing (Trout, 1988). The amount of expressed water is inversely proportional to the meat's WHC. A 0.5 g sample was taken out of the centre of each of the un-oxidized portions of sub loin samples. These samples were finely sliced up with a scalpel in a standardised manner and placed on Whatman filter paper Nr. 2, between two perspex plates, after which a pressure of 1 kg was applied for 1 minute (Irie et al., 1996). Subsequently, the pressed samples were removed and a photo was taken of each of the filter papers using a fixed camera and standardised camera settings. The pressed meat and expressed water areas on the filter papers were calculated (in cm^2) using the *ImageJ* software analysis program (ImageJ, Version 1.41, Maryland, USA, 2009).

The WHC was then expressed as the ratio of the pressed meat area over the expressed water area (Trout, 1988).

Cooking loss

The sub loin samples were weighed and then placed in a clearly marked thin walled plastic bag with a small weight inside (to keep the samples submerged in the water bath). These samples were cooked at 100°C until the internal temperature reached 75°C, as measured by an Ebro (TFN 530, Ingolstadt) handheld thermometer. The samples were then removed from the water bath and placed in an ice-slurry to cool down rapidly and thus prevent over cooking. Once cooled to below 5°C, the samples were blotted dry with a paper towel and weighed. The final weight was then expressed as a percentage of the initial weight (Honikel, 1998).

Tenderness

The tenderness of the sub loin samples was determined objectively by measuring the force required to shear through a cooked sample. The cooled cooked loin samples were firstly prepared by cutting them into 10x10 mm square cross-section (n = 10) portions and then placing them on a tray for the insertion into the machine. Care was taken to avoid cutting into visible connective tissue as this adversely affects the shear force measurements. An electronic MIRINZ Tenderometer was used to measure the shear force (N) values (MacFarlane & Marer, 1966; Chrystall & Devine, 1991). This Tenderometer features a pneumatically driven blunt wedge shaped tooth and a load cell to measure the force needed to cut (perpendicular to the grain of the fibers) through the cooked 10x10 mm muscle samples.

Bloomed meat colour

Bloomed meat colour measurements were conducted on the same muscle samples (1.5 – 2.0 cm thick) cut from the sub loin samples before the latter was used for the tenderness assessments (Honikel, 1998). These un-cooked steak portions were placed uncovered on a flat surface and left to bloom (oxygenate) for a period of 40 minutes before being measured in triplicate with a colour-guide 45°/0° colorimeter (Cat no: 6805; BYK-Gardner, USA). The three colour measurements were taken at randomly selected sites on the sample surfaces (Stevenson et al., 1989). These measurements were used to determine the colour of the fresh muscle samples: CIE L* – (indicating brightness), CIE a* – (indicating the red-green range) and CIE b*-values (indicating the blue-yellow range). The hue angles and chroma values were calculated from these formulae:

$$\text{Hue-angle (°):} \quad h^{ab} = \tan^{-1}(CIE\ b^*/CIE\ a^*);$$
$$\text{Chroma value:} \quad C^* = [(CIE\ a^*)^2 + (CIE\ b^*)^2]^{1/2}$$

Statistical analyses

The pH and temperature decline and corresponding meat quality data for day 0 (*rigor*); day 1, 2 and 5 were analysed together. The four treatment combinations were:

1. no electrical stimulation and *rigor* temperature 5°C (non ES, 5°C);
2. electrical stimulation and *rigor* temperature 5°C (ES, 5°C);
3. no electrical stimulation and *rigor* temperature 39°C (non, ES 35°C); and
4. electrical stimulation and *rigor* temperature 39°C (ES 39°C).

The main Hypotheses tested were:

H_0: Electrical stimulation of blesbok (*Damaliscus pygargus phillipsi*) carcasses will influence the subsequent meat quality parameters during controlled temperature conditions (ES ≠ non ES).

H_a: Electrical stimulation of blesbok (*Damaliscus pygargus phillipsi*) carcasses will not influence the subsequent meat quality parameters during controlled temperature conditions (ES = non ES).

H_0: Temperature treatment of blesbok (*Damaliscus pygargus phillipsi*) *Longissimus dorsi* muscles will influence the subsequent meat quality parameters (5°C ≠ 39°C).

H_a: Temperature treatment of blesbok (*Damaliscus pygargus phillipsi*) *Longissimus dorsi* muscles will not influence the subsequent meat quality parameters (5°C = 39°C).

Stress / no stress

Stress was initially included as a co-factor in the preliminary analyses, but it was concluded that stress had no significant interaction (P > 0.05) or influence (P > 0.05) on the variation. Stress was thus not included in the model for further analyses.

Carcass weight

It was also observed that the treatment groups showed a significant (P = 0.05) difference in terms of carcass weights (Table 4.2). Therefore carcass weight was included as a co-variant in the statistical model.

Interactions

There was however significant 3rd order and 2nd order interactions found between the time point *post mortem*, *rigor* temperature and or treatment (ES vs. Non ES).

Meat quality: The differences between the treatment methods: stimulated (ES) and non stimulated (non ES) and *rigor* temperature treatment (5°C and 39°C), were tested by means of the null hypothesis (H_o), with H_o: $\mu_1 = \mu_2$ and the alternate hypothesis (H_a) being H_a: $\mu_1 \neq \mu_2$.

The experimental design was a completely randomized design. An experimental unit was half a LD muscle of a single carcass. For the assessment of the physical analyses, pH and temperature measurements of each carcass were recorded as interval data, the two main factors were treatment (ES and Non ES; 5 and 39ºC) and time *post mortem*.

Two-way analysis of variance (ANOVA) was performed on all the meat quality variables (commercial purge, bloomed colour, ultimate pH, WHC, cooking loss and tenderness) with treatments (ES, Non ES; 5°C, 39°C) included as main effects, using STATISTICA version 10 (STATISTICA, 2011). Fisher LSD post hoc tests were done to obtain the least square mean and standard error of the mean. Differences were accepted as being significant if p-values were less than or even to 0.05.

The pH decline profiles were further analysed by fitting a logarithmic trend line using the drc package in R (Analysis of dose-response curves, Christian Ritz, ritz@bioassay.dk) to further asses the ES and non ES pH data.

The tenderness (N) data was analysed with a repeated ANOVA analyses using Proc Mixed of STATISTICA version 10 (STATISTICA, 2011) to determine the mean tenderness value for each time point, after each individual carcass' "best grouped" six measurements were selected out of the original 10 measurements for each of the particular time points so as to decrease the variation within an experimental unit.

Colour: The colour measurements were assessed in a similar manner by comparing the mean measurements for each of the time points for each of the particular attributes and grouped according to treatments and significant interactions.

RESULTS

pH and temperature decline profiles

Figure 4.2 indicates the pH and temperature profiles of the ES and non ES blesbok LD muscles over time *post mortem* at 5°C. Without the application of ES the pH decreased gradually in the LD muscle samples over time, but when the muscles were electrically stimulated there was a more prominent decrease in the pH values. The average temperature of all muscle samples held at 5°C dropped to below 10°C at approximately two hours *post mortem*. The non ES muscle samples reached a pH of 6.0 after seven hours, while the ES samples achieved this in one hour.
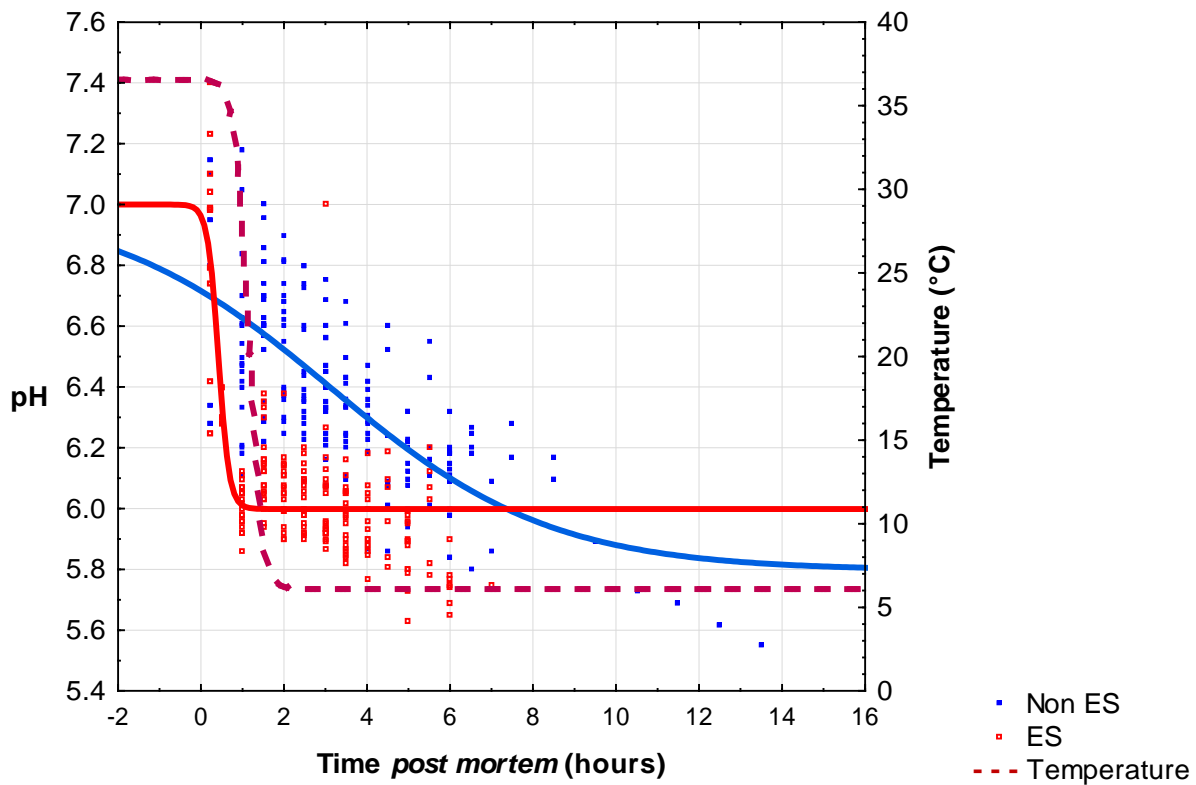
Figure 4.2 Mean pH profiles of the electrically stimulated (ES; n = 10) and non electrically stimulated (Non ES; n = 10) blesbok *M. longissimus dorsi* samples held at 5°C until *rigor*.

pH non ES: y = 5.796032471 + (7.0 - 5.796032471)/((1 + 10^(0.163448469 * (x -3.120445483)))^1). R^2 = 0.71

pH ES: y = 5.998613673 + (7.0 - 5.998613673)/((1 + 10^(3.343610749 * (x -0.420795317)))^1). R^2 = 0.71

Figure 4.3 depicts the pH and temperature profiles of the ES and non ES blesbok LD muscles over time *post mortem* at 39°C. The mean pH regression lines for the non ES and ES muscle samples showed a standard S-shape. The non ES muscle samples reached a pH of 6.0 after 1.75 hours, while the ES samples achieved this in just over an hour.
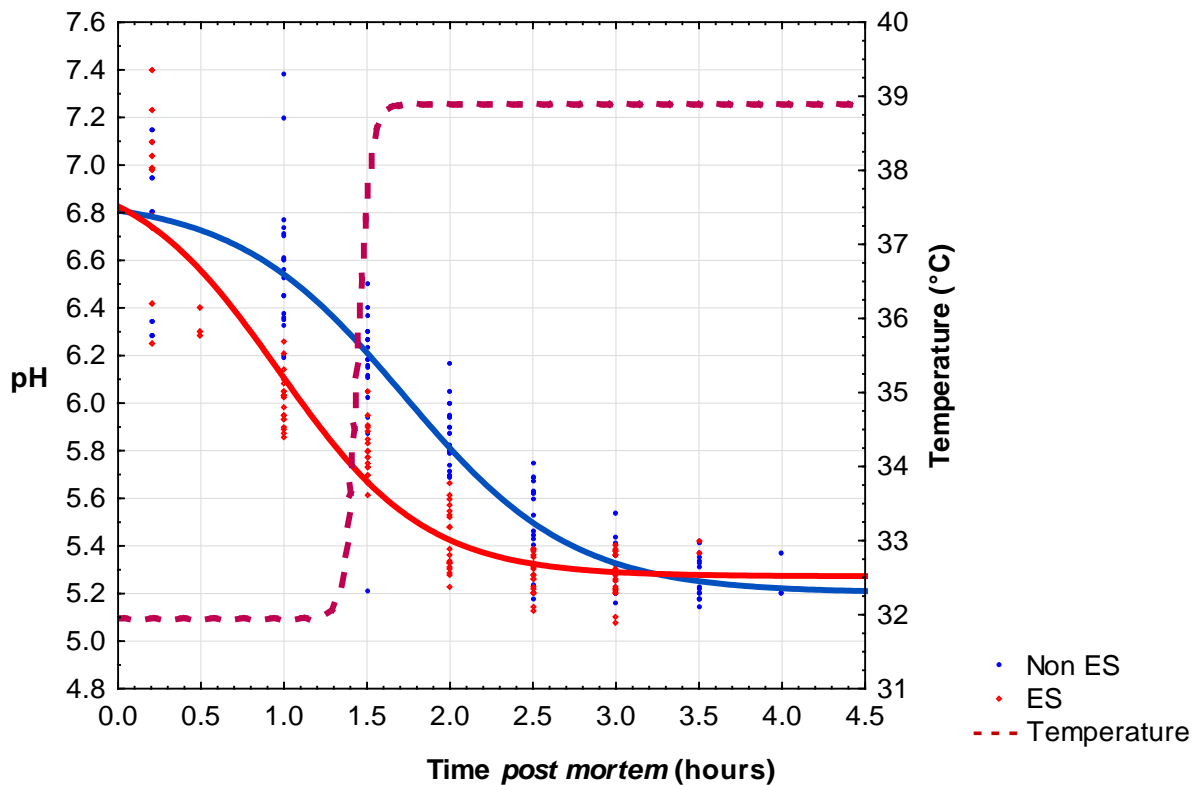
Figure 4.3 Mean pH profiles of the electrically stimulated (ES; n = 10) and non stimulated (Non ES; n = 10) blesbok *M. longissimus dorsi* samples held at 39°C until *rigor*.

pH non ES: y = 5.203608552 + (6.862072115 - 5.203608552)/((1 + 10^(0.857199155 * (x -1.721748773)))^1). R^2 = 0.93

pH ES: y = 5.272682981 + (7.0 - 5.272682981)/((1 + 10^(0.984802897 * (x -0.968537066)))^1). R^2 = 0.93

Meat quality

pH

There was a third order interaction (P = 0.0008) between the treatments (ES vs. non ES), *rigor* temperatures (5°C vs. 39°C) and time *post mortem* for the pH values of blesbok muscle samples (Fig. 4.4). For the 5°C temperature treatment the mean pH of the ES muscle samples (5.75 ± 0.07) was lower (P ≤ 0.05) than the average pH of the non ES samples (5.98 ± 0.06) at *rigor*. The mean pH values of the ES and non ES muscle samples at the 5°C temperature treatment did not differ (P > 0.05) for days 1, 2 and 5 (Fig. 4.4a). With the 39°C temperature treatment the ES muscle samples had higher (P ≤ 0.05) mean pH values (5.55 ± 0.14) compared to the non ES samples (5.37 ± 0.03) at *rigor*. Similar to the 5°C temperature treatment, the mean pH values of the ES and non ES muscle samples from the 39°C temperature treatment did not differ (P > 0.05) for days 1, 2 and 5 (Fig. 4.4b). The mean pH values of the ES and non ES muscle samples at 5°C and *rigor* (Fig. 4.4a)*,* was higher (P ≤ 0.05) compared to the mean pH values of both at 39°C and *rigor* (Fig. 4.4b). The mean pH values of the ES and non ES muscle samples at days 1, 2 and 5 did not differ (P > 0.05) between the two temperature treatments (Fig. 4.4).
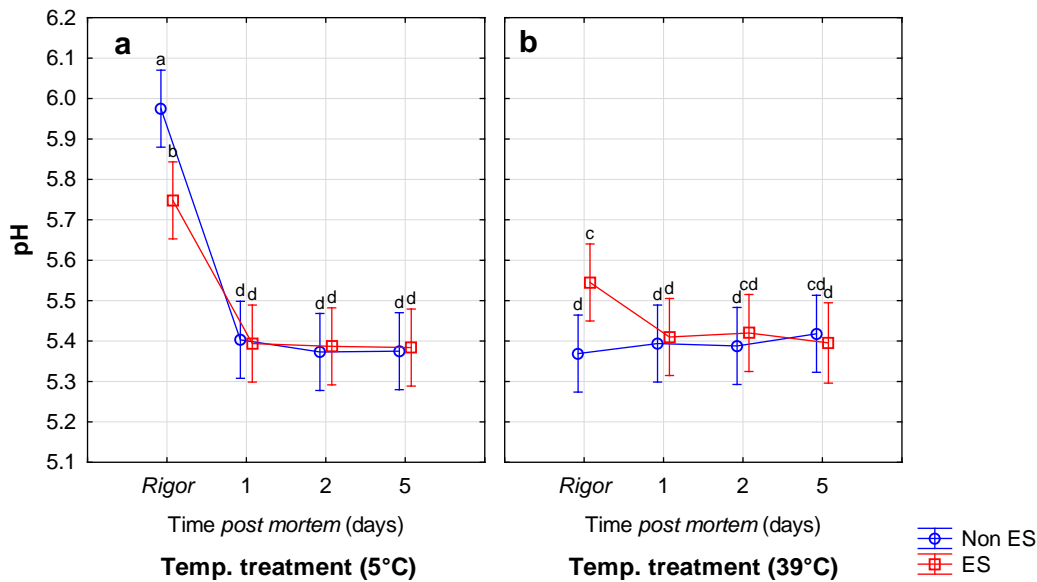
Figure 4.4 Mean pH values of the electrically stimulated (n = 10) and non stimulated (n = 10) blesbok *M. longissimus dorsi* samples at four time points (*rigor,* days 1, 2 and 5) and two temperature treatments (5°C vs. 39°C). [a-d]Means with different superscripts differ significantly (P ≤ 0.05) and the vertical bars indicate 0.95 confidence intervals.

Tenderness

There was a third order interaction (P = 0.02) between the treatments (ES vs. non ES), *rigor* temperatures (5°C vs. 39°C) and time *post mortem* for the shear force values (N) of the blesbok LD muscle samples (Table 4.3, Fig. 4.5). The results in Table 4.3 are illustrated in Fig. 4.5.

Electrical stimulation had no (P > 0.05) impact on the day 1, 2 and 5 muscle samples from the 5°C temperature treatment, although at *rigor* the non ES muscle samples had higher (P ≤ 0.05) mean shear force values compared to the ES samples (Table 4.3). However, with the 39°C temperature treatment and at each of the time points, the non ES muscle samples had higher (P ≤ 0.05) mean shear force values compared to the ES samples (Table 4.3).

The temperature treatment had an effect (P ≤ 0.05) on the shear force values of both ES and non ES muscle samples for all time points tested (Fig. 4.5). All muscle samples from the 5°C temperature treatment had higher (P ≤ 0.05) mean shear force values compared to the samples from the 39°C temperature treatment (Fig. 4.5). Furthermore, the 39°C temperature treatment caused the mean shear force value at *rigor* to already be lower (P ≤ 0.05) than that of the mean shear force value for the 5°C treatment at 5 days *post mortem* (Table 4.3). At 5°C, the ES and non ES muscle samples had lower (P ≤ 0.05) mean shear force values at *rigor*, which increased throughout days 1 and 2 and then decreased slightly to day 5 (Fig. 4.5a). This trend was,

98

however, different for the ES and non ES muscle samples from the 39°C temperature treatment, since the mean shear force values decreased from day 0 (*rigor*) to day 5 (Fig. 4.5b).

It can also be noted that the standard error values of the 39°C non ES samples are double that of the ES samples at all the time points (Table 4.3). This, however, is not evident with the mean shear force values of the 5°C temperature treatment values (Table 4.3).

Table 4.3

Impact of ES, temperature treatment (5°C vs. 39°C) and time *post mortem* (*rigor*, days 1, 2 and 5) on shear force values (N) of blesbok *M. longissimus dorsi* samples (LSMeans ± S.E.M.)

Temperature		Time *post mortem*			
		Rigor (Day 0)	Day 1	Day 2	Day 5
5°C	ES[1]	80.34[de] ± 5.64	128.93[a] ± 3.85	126.46[a] ± 4.08	110.32[cb] ± 3.46
	non ES[2]	101.95[c] ± 4.59	124.21[ab] ± 2.92	121.82[ab] ± 5.55	114.04[ab] ± 4.60
39°C	ES	57.05[fg] ± 5.20	48.37[hg] ± 3.68	46.06[hg] ± 3.56	39.94[h] ± 3.46
	non ES	79.37[d] ± 9.48	74.41[de] ± 5.40	75.52[de] ± 7.11	66.18[fe] ± 6.14

[1]ES: Electrically Stimulated carcasses
[2]Non ES: Carcasses not electrically stimulated
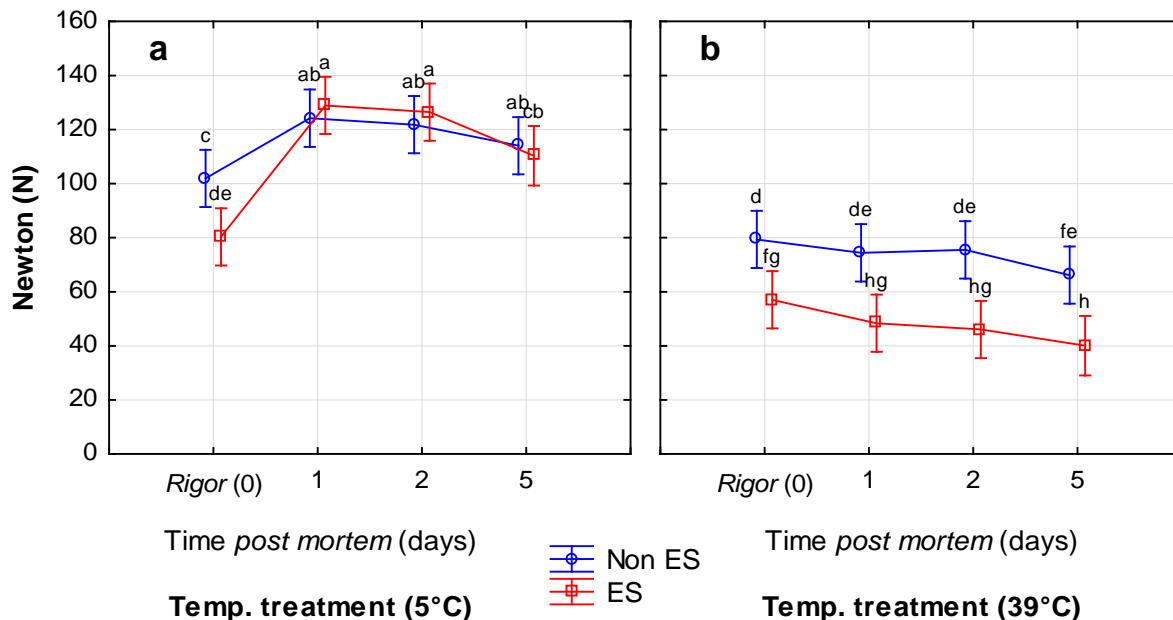[a-h]Means with different superscripts differ significantly (P ≤ 0.05)

Figure 4.5 Interaction between the treatments (ES vs. non ES), temperature treatments (5°C vs. 39°C) and time *post mortem* (*rigor*, days 1, 2 and 5) for the shear force values of blesbok *M. longissimus dorsi* samples.   [a-h]Means with different superscripts differ significantly (P ≤ 0.05).

99

Commercial purge loss

There was no significant interaction (P > 0.05) between the treatments (ES vs. non ES), *rigor* temperature (5°C vs. 39°C) and time *post mortem* for the commercial purge loss values of the blesbok muscle samples. The mean purge loss values differed (P ≤ 0.05) between treatments (ES, 4.89% ± 0.32 and non ES, 7.13% ± 0.30), temperature treatments (5°C, 4.67% ± 0.29 and 39°C, 7.31% ± 0.30) and time points *post mortem* (day 1, 4.63% ± 0.41; day 2, 5.91% ± 0.34 and day 5, 7.47% ± 0.39).

Cooking loss

Table 4.4 shows the cooking loss percentages of the LD muscle samples from the two temperature treatments (5°C vs. 39°C) and days 0 (*rigor*), 1, 2 and 5. Electrical stimulation had no effect (P = 0.428) on the cooking loss percentages of the LD muscle samples. However, there was an interaction (P ≤ 0.05) between the temperature treatments and time *post mortem*. With the 5°C temperature treatment the mean cooking loss percentage of the LD muscles was significantly lower at *rigor* and then increased to significantly higher values at days 1, 2 and 5. The opposite was true with the 39°C temperature treatment, where the mean cooking loss percentages for *rigor* and the different days did not differ (P > 0.05) from each other (Table 4.4). The mean cooking loss percentage of the LD muscles at *rigor* was significantly higher for the 39°C temperature treatment compared to the 5°C treatment, while the mean cooking loss percentage of the 5°C temperature treatment samples were higher for days 2 and 5 than the corresponding two days for the 39°C treatment. No significant differences were present between the temperature treatments on day one (Table 4.4).

Table 4.4

Mean cooking loss percentages (LSMeans ± S.E.M.) of blesbok *M. longissimus dorsi* samples from two temperature treatments (5°C vs. 39°C) and four time points (*rigor*, days 1, 2 and 5)

	Time *post mortem*			
Temperature	***Rigor* (Day 0)**	**Day 1**	**Day 2**	**Day 5**
5°C	21.33[c] ± 1.29	27.64[ab] ± 0.53	28.06[a] ± 0.67	27.72[a] ± 0.57
39°C	26.93[ab] ± 1.04	26.66[ab] ± 0.57	25.60[b] ± 0.56	25.65[b] ± 0.72

[a-c]Means with different superscripts differ significantly (P ≤ 0.05).

Water holding capacity (WHC)

Electrical stimulation had no significant impact on the WHC of blesbok muscle samples. There was a significant interaction (P = 0.0000) between temperature treatment and time *post mortem* (Fig. 4.6). With the 5°C temperature treatment the mean WHC ratio was significantly higher at day

0 (*rigor*). The opposite was true with the 39°C temperature treatment where the mean WHC ratio was significantly lower at day 0. The mean WHC ratio of all of the 5°C muscle samples was significantly lower compared to the 39°C samples (Fig. 4.6).
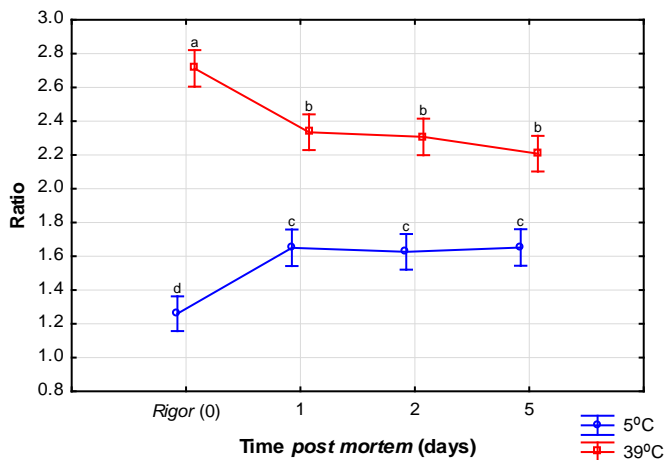

Figure 4.6 Mean WHC ratio of blesbok *M. longissimus dorsi* samples from two temperature treatments (5°C vs. 39°C) and four time points *post mortem* (*rigor*, days 1, 2 and 5). [a-d]Means with different superscripts differ significantly (P ≤ 0.05).

Bloomed meat colour

Electrical stimulation had no significant impact on the mean colour measurements, chroma and hue-angle values. A significant interaction (P = 0.0000) was present between the temperature treatments and time *post mortem* (Table 4.5). All colour measurement, chroma and hue-angle values were higher (P ≤ 0.05) at each time point for the 39°C temperature treatments. With the 5°C samples, the mean colour measurement, chroma and hue-angle values increased from day 0 (*rigor*) to day 5. With the 39°C samples, the mean CIE L* and hue-angle values did not differ (P > 0.05) between the different time points. The mean CIE a*, CIE b* and chroma values were significantly lower at day 0 (*rigor*) for the 39°C muscle samples, although no significant differences were present for days 1, 2 and 5 (Table 4.5).

Table 4.5

Mean colour measurements, chroma (C*) and hue-angle (°) values (LSMeans ± S.E.M.) for blesbok *M. longissimus dorsi* samples from two temperature treatments (5°C vs. 39°C) and four time periods (*rigor*, days 1, 2 and 5)

	Time *post mortem*							
	Rigor (Day 0)		Day 1		Day 2		Day 5	
	5°C	39°C	5°C	39°C	5°C	39°C	5°C	39°C
CIE L*	25.37[d] ± 0.29	37.87[a] ± 0.50	29.10[c] ± 0.43	37.33[a] ± 0.52	30.38[b] ± 0.41	38.14[a] ± 0.36	29.89[bc] ± 0.42	38.33[a] ± 0.39
CIE a*	10.79[d] ± 0.14	16.28[b] ± 0.34	13.39[c] ± 0.37	17.94[a] ± 0.59	13.38[c] ± 0.36	17.78[a] ± 0.62	15.72[b] ± 0.57	17.99[a] ± 0.57
CIE b*	5.59[e] ± 0.22	13.99[b] ± 0.29	9.06[d] ± 0.26	14.98[a] ± 0.43	9.33[d] ± 0.29	15.30[a] ± 0.46	11.01[c] ± 0.43	15.71[a] ± 0.62
Hue-angle (°)[*]	27.37[c] ± 0.84	40.66[a] ± 0.62	34.16[b] ± 0.69	39.93[a] ± 0.84	34.94[b] ± 0.87	40.83[a] ± 0.68	34.99[b] ± 0.79	40.99[a] ± 1.25
Chroma[*]	12.23[e] ± 0.18	21.53[b] ± 0.37	16.24[d] ± 0.41	23.44[a] ± 0.65	16.41[d] ± 0.39	23.52[a] ± 0.72	19.27[c] ± 0.66	24.01[a] ± 0.68

a-e Means with different superscripts differ significantly (P ≤ 0.05)

* Values were calculated

DISCUSSION

pH and temperature

To form a better understanding of the feasibility of ES and its application in game harvesting its effect on meat quality during harvesting conditions had to be evaluated. By placing the LD muscle samples in a temperature controlled water bath, it is possible to simulate the extreme ambient temperature conditions (5°C and 39°C) found during the commercial harvesting of blesbok.

Electrical stimulation of carcasses causes an immediate initial drop in the pH value of the muscles (Chrystall & Devine, 1978; Carballo et al., 1988; Devine et al., 2004), followed by an increase in the rate of pH decline *post mortem*. The application of ES therefore increases the rate of anaerobic glycolysis, resulting in a higher rate of pH decline and the earlier onset of *rigor mortis* (Devine et al., 2002, 2004)*. Electrical stimulation was originally used to protect skeletal muscles against cold shortening (CS), by depleting the muscle energy stores to ensure that super muscle contraction could not occur at the low carcass processing temperatures (Davey et al., 1976; Devine et al., 2004). However, ES now also has the added advantage of saving costs, since less time is required for the conditioning of carcasses, the latter being due to increased enzymatic tenderisation of muscles at a higher temperature (Simmons et al., 2006, 2008). This enables the meat processor to increase the carcass chilling rate without negatively affecting the meat quality (Simmons et al., 2008). When the temperature and pH decline *post mortem* are effectively controlled (through chilling and ES, respectively), it results in improved product consistency (decrease in variation) as well as tailored meat quality attributes (according to market requirements) (Simmons et al., 2006).

A larger initial pH decline can be observed in the pH profiles of the ES muscle samples at both temperature treatments (5°C and 39°C), compared to the pH profiles of the non ES muscle samples (Fig. 4.2 & 4.3). For both treatments (ES and non ES) and temperature treatments (5°C and 39°C) the time *post mortem* at which the muscle samples reached an average pH of 6.0, was calculated from the respective pH regression plots (Fig. 4.2 & 4.3). The ES samples from both temperature treatments attained a pH of 6.0 at around one hour *post mortem* (Fig. 4.2 & 4.3)*. However, the non ES samples attained a pH of 6.0 after seven hours at 5°C and after 1.75 hours at 39°C. The differences in the pH decline of the ES and non ES muscle samples was therefore larger at 5°C. This is important as a pH value of 6.0 is used as a guide to ensure CS does not occur in modern abattoirs. However, the temperature at which the muscle samples are kept is also of concern as CS or cold-induced toughening is set to transpire when the carcass temperature drops to below 10°C, whilst the pH is still above 6.0 (Pearson & Young, 1989; Devine et al., 2004). The latter was the case in the non ES samples held at 5°C (Fig. 4.2) and it was therefore

postulated that CS occurred in these muscle samples. The application of ES was, however, successful in decreasing the pH value of the ES samples to below six before the muscle temperature dropped to below 10°C.

Meat quality

Tenderness

Meat tenderness is not only a function of the extent of sarcomere shortening or cold-induced toughening but it is also determined by the enzymatic tenderisation. The latter is in turn influenced by the pH_u and temperature *post mortem*. In this investigation the pH values for the non ES blesbok samples held at 5°C, were significantly higher than the ES samples at *rigor* (Fig. 4.4a). The shear force values of the non ES samples held at 5°C was also significantly higher compared to the ES samples at *rigor* (Fig. 4.5a, Table 4.3). This was similar for the pH and shear force values at *rigor* for the non ES and ES samples at 39°C (Fig. 4.4b; Fig. 4.5b; Table 4.3). This positive relationship between the pH and tenderness was also noted by Hoffman et al. (2007) in springbok (*Antidorcas marsupialis*) LD muscles (P ≤ 0.05).

At the 5°C temperature treatment both the ES and non ES muscle samples had significantly higher shear force values (less tender) compared to the 39°C samples at *rigor* (Fig. 4.5a, b, Table 4.3). It was postulated that the 5°C treatment decreased or inhibited the enzymatic tenderisation process in these muscle samples. Wheeler and Koohmaraie (1994) measured the tenderness of ovine LD muscles over time *post mortem* and found that the shear force values increased during the toughening phase (sarcomere shortening) and subsequently decreased as a result of the natural tenderisation process. The tenderness of both the ES and non ES samples decreased from *rigor* to day one, where the tenderness did not increase again (Fig. 4.5a, Table 4.3). This can therefore be attributed to the absence of the natural enzymatic tenderisation process. Electrical stimulation had a significant effect on the tenderness of the 5°C muscle samples at *rigor*, since the ES samples were significantly more tender (Fig. 4.5a, Table 4.3). Similar results were found by Bekhit et al. (2007) upon testing the effect of ES and *rigor* temperature on the tenderness of venison LD muscles. However, during this investigation ES did not deliver a significant effect as time progressed *post mortem*. Electrical stimulation was therefore believed not to be effective at preventing cold-induced toughening or counteracting the effect of very low ambient temperatures in this study.

Electrical stimulation had a significant effect on the tenderness of the 39°C muscle samples, since the ES muscle samples were all significantly more tender for each time point (Fig. 4.5b, Table 4.3). The ES muscle samples had less variation in shear force values compared to the non ES samples. The latter is attributable to the additional benefit (i.e. decreased variation in meat quality attributes)

that coincides with the application of ES (Simmons et al., 2008). The calpains are the main proteolytic enzymes responsible for the tenderisation of meat during the conditioning period (Koohmaraie, 1996). These enzymes are more efficient at higher carcass temperatures and consequently the rate of tenderisation is faster (Hertzman et al., 1993; Simmons et al., 2008). All muscle samples of the 39°C temperature treatment (with the exception of non ES at *rigor*) were significantly more tender compared to the 5°C samples (with the exception of ES at *rigor*). However, Bekhit et al. (2007) found no effect (P ≤ 0.05) of the *rigor* temperature on the tenderness values of venison *M. longissimus dorsi* at *rigor*, but this contradiction may be attributed to differences between species. The results from this study emphasises the effect of ambient temperature on the natural tenderisation process. However, the application of ES is known to only be effective at attaining optimum meat tenderness values if the correct management of the temperature, pH decline and processing regime is implemented (Simmons et al., 2008).

Consumers consider the tenderness of meat products as an important meat quality characteristic (Koohmaraie, 1996; Tornberg, 1996; Boleman et al., 1997). Consumers are able to distinguish between different categories of meat tenderness and are willing to pay a premium price for meat with greater tenderness (Boleman et al., 1997). In addition to affecting meat tenderness, ES is also known to have an effect on the WHC (Lawrie & Ledward, 2006; Simmons et al., 2008), meat surface colour and the colour stability of meat products (Simmons et al., 2008).

Water holding capacity (WHC) and purge loss

The WHC of meat will determine the juiciness of the final meat products, since WHC is inversely proportional to the amount of expressed water and it is directly affected by the pH_u (Honikel, 2004; Lawrie & Ledward, 2006). At *rigor*, the pH of both the ES and non ES muscle samples at 5°C (5.75 ± 0.07 and 5.98 ± 0.06, respectively) (Fig. 4.4a) were significantly higher compared to the 39°C samples (5.55 ± 0.14 and 5.37 ± 0.03, respectively) (Fig. 4.4b). The latter differences possibly resulted in the higher (P ≤ 0.05) mean WHC in the 5°C muscle samples compared to the 39°C samples (Fig. 4.6). Bekhit et al. (2007) also found a decrease (P ≤ 0.05) in the WHC of venison LD muscles, with an increase in *rigor* temperature. Low pH values and high temperature conditions reduces the WHC of the muscles, which can be attributed to the denaturation of the muscle proteins (especially myosin) (Offer & Knight, 1988). The WHC of meat generally decreases with the development of *rigor*, due to the formation of actomyosin (Honikel, 2004).

A low WHC will usually result in a higher purge loss percentage (Warriss, 2000; Lawrie & Ledward, 2006), since the structure of the meat is then unable to retain the water when cut. Electrical stimulation should increase the amount of purge loss due to its effect on increasing the pH decline, which results in the loss of WHC of the muscle proteins (Geesink et al., 2001; Wiklund et al., 2001; Devine et al., 2004; Lawrie & Ledward, 2006). However, in this study the ES muscle samples had

a lower percentage purge loss of 4.89% compared to the non ES samples at 7.13%. The reason for this is unknown.

The amount of purge loss increased with an increase in *rigor* temperature, since the 39°C samples (7.31%) had a significantly higher mean purge loss percentage (5°C, 4.67%). However, Wiklund et al. (2008) did not find differences in the drip loss percentage of reindeer (*Rangifer tarandus tarandus*) LD muscles due to the application of ES. Bekhit et al. (2007) also found that drip loss was not affected by *rigor* temperature, but rather by the species and fibre type or muscles tested. However, as stated previously higher *rigor* temperatures decreases the WHC of meat and thus results in higher purge loss. The time period *post mortem* also had an effect by increasing the amount of purge loss over time (day 1, 4.63%; day 2, 5.91%; day 5, 7.47%). The total amount of purge loss is high when compared to other studies conducted on kudu (*Tragelaphus strepsiceros*) (day one, 1.40%), impala (*Aepyceros melampus*) (day one, 1.20%) (Hoffman et al., 2009) and springbok (day one, 3.16%) (Hoffman et al., 2007). Although it should be noted that different techniques were used in these studies and thus could result in variation between results. The presence of purge loss in packaging, negatively affects consumer perception of meat products (Troy & Kerry, 2010). Although the increments between time points (days) in this investigation were significant, they might not be detected by consumers.

Cooking loss

The cooking loss percentage of the 39°C muscle samples was significantly higher compared to the values of the 5°C samples at *rigor* (Table 4.4). Bekhit et al. (2007), however, found no significant effect of *rigor* temperature on the resultant cooking loss percentages of venison LD muscles. In this study, the higher cooking losses at 39°C can again be attributed to the denaturation of muscle proteins at the high *rigor* temperature, resulting in decreased WHC (Offer & Knight, 1988) and water losses upon cooking. The cooking losses did not differ between temperature treatments on day one and although the differences on day 2 and 5 were significant, the latter were not of biological relevance. It can also be postulated that the lower purge losses of the 5°C samples at *rigor*, consequently allowed for higher amounts of water to be lost during cooking on day 2 and 5 (compared to the 39°C samples) (Table 4.4).

Bloomed meat colour

Meat colour is a very important meat quality characteristic, since it is the first quality characteristic observed by consumers when purchasing fresh meat (Troy & Kerry, 2010). Furthermore, consumers also believe that they are able judge the "quality" of meat from its colour (Moore & Young, 2001; Radder & Le Roux, 2005). Electrical stimulation has been found to improve   meat colour (Devine et al., 2004), as a result of the increased rate of pH decline which causes an increase in protein denaturation and the onset of ageing. Electrical stimulation had no significant

affect on any of the bloomed colour measurements collected during this investigation. This was also concluded by Bekhit et al. (2007). They postulated that the effect of ES on enhancing the colour measurements, were superseded by the effect of *rigor* temperature treatment. This could therefore also have been the case in this study.

The individual colour measurements (CIE a*, CIE b* and CIE L*) as well as the calculated values for the chroma and hue-angle were significantly higher for the 39°C muscle samples throughout the time points (Table 4.5). A higher temperature therefore had a favourable affect on the bloomed meat surface colour of blesbok LD muscles. Bekhit et al. (2007) also found a significant effect of *rigor* temperature on the colour parameters (CIE L*, CIE a* and CIE b*) of venison LD muscles. The higher *rigor* temperature treatment (42°C) in their study resulted in more red and lighter meat surface colours and the lower temperature treatment (0°C) conversely resulted in darker and less red bloomed meat colours (Bekhit et al., 2007). The denaturation of muscle proteins as well as a reduction in the enzyme activities responsible for the depletion of oxygen (Bekhit et al., 2007) are possible reasons for the lighter and more saturated red meat surface colour of the 39°C samples (Table 4.5).

The colour measurements of the 5°C muscle samples significantly increased over the time periods to the highest values on day 5. This might suggest that meat held at a low *rigor* temperature will have a better bloomed surface colour after extended storage time. The CIE a* and CIE b* values significantly increased from day 0 to day 1 (and consequently also the chroma value), but from there the bloomed colour measurements for each time period was constant (P > 0.05). The muscle samples held at a higher *rigor* temperature therefore had a more constant bloomed meat surface colour with storage time.

CONCLUSIONS

Electrical stimulation had no significant effect on the WHC, cooking loss percentages and bloomed meat surface colour of blesbok muscles. This investigation did, however, indicate that ES increased the rate of the initial pH decline and so decreased the time to the onset of *rigor mortis* in the blesbok LD muscles of both temperature treatments (5°C and 39°C). This brought about a clear increase in tenderness. *Rigor* temperature had a greater effect on the subsequent tenderness of the blesbok LD muscle samples. The high *rigor* temperature treatment (39°C) negatively affected the WHC of these muscle samples and resulted in higher purge loss with time and higher cooking losses at *rigor*. There was also an increase in the amount of purge loss with time, which will negatively affect the consumer perception on meat products from blesbok LD muscles. The 39°C muscle samples had an improved bloomed colour which was more or less constant with time, while the bloomed colour of the 5°C muscle samples increased with time. The 39°C extreme temperature treatment therefore negatively affected most of the meat quality

attributes of blesbok LD muscles, while the 5°C extreme temperature treatment negatively affected the tenderness of the muscle samples.

At both temperature treatments, the ES muscle samples had significantly lower mean pH_u values and consequently significantly higher tenderness at *rigor*. Electrical stimulation was only effective at increasing the tenderness of the 5°C muscle samples at *rigor*, whereas all of the 39°C ES muscle samples had significantly higher tenderness. The use of ES can thus increase the tenderness of blesbok LD muscles, especially if the muscles are to be frozen within 48 hours of slaughter for export purposes as is the scenario with lamb and deer carcasses from New Zealand. It can, however, be concluded that ES was not as effective in preventing the adverse affects of a low *rigor* temperature on the natural tenderisation process.

REFERENCES

Anonymous (1986). *Climate of South Africa: Climate statistics up to 1984* (pp. 65–66). South Africa: Weather bureau, Department of home affairs.

Bekhit, A.E.E., Farouk, M.M., Cassidy, L. & Gilbert, K.V. (2007). Effects of rigor temperature and electrical stimulation on venison quality. *Meat Science, 75,* 564–574.

Bickerstaffe, R., Bekhit, A.E.D., Robertson, L.J., Roberts, N. & Geesink, G.H. (2001). Impact of introducing specifications on the tenderness of retail meat. *Meat Science, 59,* 303–315.

Boleman, S.J., Boleman, S.L., Miller, R.K., Taylor, J.F., Cross, H.R., Wheeler, T.L., Koohmaraie, M., Shackelford, S.D., Miller, M.F., West, R.L., Johnson, D.D. & Savell, W.J. (1997). Consumer evaluation of beef of known categories of tenderness. *Journal of Animal Science, 75,* 1521–1524.

Bothma, J.Du P. (2010). Harvesting wild animals. In J.Du P. Bothma & J.G. Du Toit (Eds.), *Game ranch management* (pp. 489–490) (5th ed.). Hatfield, Pretoria, South Africa: Van Schaik Publishers.

Carballo, J., Garcia-Matomoros, E. & Jiménez-Colmenero, F. (1988). Influence of low voltage electrical stimulation and rate of chilling on post-mortem glycolysis in lamb. *Food Chemistry, 29,* 257–267.

Chrystall, B.B. & Devine, C.E. (1978). Electrical stimulation, muscle tension and glycolysis in bovine sternomandibularis. *Meat Science, 2,* 49–58.

Chrystall, B.B. & Devine, C.E. (1983). Electrical stimulation of deer carcasses. *New Zealand Journal of Agricultural Research, 26*, 89–92.

Chrystall, B.B. & Devine, C.E. (1991). Quality assurance for tenderness. Meat Industries Research Institute of New Zealand, Hamilton. Publication no. 872.

Conroy, A.M. & Gaigher, I.G. (1982). Venison, aquaculture and ostrich meat production: Action 2003. *South African Journal of Animal Science, 12*, 219–233.

Davey, C.L., Gilbert, K.V. & Carse, W.A. (1976). Carcass electrical stimulation to prevent cold shortening toughness in beef. *New Zealand Journal of Agricultural Research, 19*, 13–18.

Devine, C.E., Hopkins, D.L., Hwang, I.H., Ferguson, D.M. & Richards, I. (2004). Electrical stimulation. In W.K. Jensen, C. Devine & M. Dikeman (Eds.), *Encyclopedia of meat science* (pp. 413–423) (Vol. 1). Oxford: Academic Press.

Devine, C.E., Payne, S.R., Peachey, B.M., Lowe, T.E., Ingram, J.R. & Cook, C.J. (2002). High and low rigor temperature effects on sheep meat tenderness and ageing. *Meat Science, 60,* 141–146.

Drew, K.R., Crosbie, S.F., Forss, D.A., Manley, T.R. & Pearse, A.J. (1988). Electrical stimulation of carcasses from red, fallow and New Zealand wapiti-type male deer. *Journal of Science and Food and Agriculture, 43,* 245–259.

Dryden, G.M. (1997). Venison in the human diet – is venison a low-fat meat? *Proceedings of the Nutrition Society of Australia, 21,* 44–51.

Geesink, G.H., Mareko, M.H.D., Morton, J.D. & Bickerstaffe, R. (2001). Electrical stimulation – when more is less. *Meat Science, 57,* 145–151.

Grunert, K.G., Bredahl, L. & Brunsø, K. (2004). A review: Consumer perception of meat quality and implications for product development in the meat sector. *Meat Science, 66,* 259–272.

Hertzman, C., Olsson, U. & Tornberg, E. (1993). The influence of high temperature, type of muscle and electrical stimulation on the course of rigor, ageing and tenderness of beef muscles. *Meat Science, 35*, 119–141.

Hoffman, L.C. (2002). The effect of different culling methodologies on the physical meat quality attributes of various game species. In H., Ebedes, B., Reilly, W., Van Hoven & B., Penzhorn (Eds.), *Proceedings of the 5th international wildlife ranching symposium*

sustainable utilisation – Conservation in practice (pp. 212–221). Port Elizabeth, South Africa: Nelson Mandela Metropolitan University.

Hoffman, L.C. (2003). Can South Africa produce meat according to European Union standards? The springbok and impala story. In *Consistency of quality – the 11th international meat symposium* (pp. 257–268). Perth, Australia.

Hoffman, L.C. & Ferreira, A.V. (2000). pH decline of the *M. longissimus thoracis* of night-cropped grey duiker (*Sylvicapra grimmia*). *South African Journal of Animal Science, 30*(1), 16–17.

Hoffman, L.C., Kroucamp, M. & Manley, M. (2007). Meat quality characteristics of springbok (*Antidorcas marsupialis*). 1. Physical meat attributes as influenced by age, gender and production region. *Meat Science*, *76,* 755–761.

Hoffman, L.C. & Laubscher, L.L. (2009). A comparison between the effects of day v*ersus* night cropping on greater kudu (*Tragelaphus strepsiceros*) meat quality. *South African Journal of Wildlife Research, 39*(2), 164–169.

Hoffman, L.C., Mostert, A.C., Kidd, M. & Laubscher, L.L. (2009). Meat quality of kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*): Carcass yield, physical quality and chemical composition of kudu and impala *Longissimus dorsi* muscle as affected by gender and age. *Meat Science, 83,* 788–795.

Hoffman, L.C., Smit, K. & Muller, N. (2008). Chemical characteristics of blesbok (Damaliscus dorcas phillipsi) meat. *Journal of Food Composition and Analysis, 21*, 315–319.

Hoffman, L.C. & Wiklund, E. (2006). Game and venison – meat for the modern consumer. *Meat Science*, *74*, 197–208.

Honikel, K.O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science, 49*, 447–457.

Honikel, K.O. (2004). Conversion of muscle to meat/glycolysis. In W.K. Jensen, C. Devine & M. Dikeman (Eds.), *Encyclopedia of meat sciences* (pp. 314–318) (Vol. 1). Oxford: Elsevier Academic Press.

Huntley, B.J. (1971). Carcass composition of the mature male blesbok and kudu. *South African Journal of Science*, *1*, 125–128.

Hwang, I.H. & Tompson, J.M. (2001). The effect of time and type of electrical stimulation on the calpain system and meat tenderness in beef *longissimus dorsi* muscle. *Meat Science, 58,* 135–144.

Irie, M., Izumo, A. & Mohri, S. (1996). Rapid method for determining water-holding capacity in meat using video image analysis and simple formulae. *Meat Science, 42*(1), 95–102.

Jansen van Rensburg, D.M. (1997). *The physical, chemical and sensory quality characteristics of springbok (Antidorcas marsupialis marsupialis) meat.* Unpublished MSc thesis, Pretoria Technicon, South Africa.

Koohmaraie, M. (1996). Biochemical factors regulating the toughening tenderization processes of Meat. *Meat Science, 43*, S193–S201.

Kritzinger, B., Hoffman, L.C. & Ferreira, A.V. (2003). A comparison between the effects of two cropping methods on the meat quality of impala (*Aepyceros melampus*). *South African Journal of Animal Science, 33*(4), 233–240.

Laubscher, L.L. (2009). *The effect of different cropping methods on the meat quality of various game species.* Unpublished MSc thesis, University of Stellenbosch, South Africa.

Lawrie, R.A. & Ledward, D.A. (2006). *Lawrie's meat science* (7th ed.). Cambridge, England: Woodhead Publishing Limited.

MacFarlane, P.G. & Marer, J.M. (1966). Research note: An apparatus for determining tenderness of meat. *Food Technology, 20*, 134–134.

Moore, V.J. & Young, O.A. (2001). The effects of electrical stimulation, thawing, ageing and packaging on the colour and display life of lamb chops. *Meat Science, 30*, 131–145.

Mucina, L., Hoare, D.B., Lotter, M.C, Du Preez, P.J., Rutherford, M.C., Scott-Shaw, C.R., Bredenkamp, G.J., ...Kose, L. (2006). Grassland Biome. In L. Mucina & M.C. Rutherford (Eds.), *The vegetation of South Africa, Lesotho and Swaziland* (pp. 350–431). South Africa: South African National Biodiversity Institute.

Offer, G. & Knight, P. (1988). The structural basis of water holding in meat, Part 2: Drip losses. In R.A. Lawrie (Ed.), *Developments in meat science* (pp. 173–243) (4th ed.). London, United Kingdom: Elsevier Science Publishers.

Pearson, A.M. & Young, R.B. (1989). *Muscle and meat biochemistry*. San Diego: Academic Press

Radder, L. & Le Roux, R. (2005). Factors affecting food choice in relation to venison: A South African example. *Meat Science, 71,* 583–589.

Simmons, N.J., Daly, C.C., Cummings, T.L., Morgan, S.K., Johnson, N.V. & Lombard, A.C. (2008). Reassessing the principles of electrical stimulation. *Meat Science*, *80*, 110–122.

Simmons, N.J., Daly, C.C., Mudford, C.R., Richards, I., Jarvis, G. & Pleiter, H. (2006). Integrated technologies to enhance meat quality – An Australasian perspective. *Meat Science*, *74*, 172–179.

Statistica (2011). STATISTICA Version 10.0.228.2 (data analysis software system). StatSoft Inc., Tulsa, United States of America (www.statsoft.com).

Stevenson, J.M., Seman, D.L., Weatherall, I.L. & Littlejohn, R.P. (1989). Evaluation of venison colour by an objective method using CIELAB values. *Journal of Food Science, 54*, 1661–1662.

Tornberg, E. (1996). Biophysical aspects of meat tenderness. *Meat Science, 43*(S), S175–S191.

Troy, D.J. & Kerry, J.P. (2010). Consumer perception and the role of science in the meat industry. *Meat Science, 86*, 214–226.

Trout, G.R. (1988). Techniques for measuring water-binding capacity in muscle foods – a review of methodology. *Meat Science, 23*, 235–252.

Van Schalkwyk, D.L. (2011). *Investigation into selected parameters required to develop a sustainable Namibian game meat industry*. Unpublished PhD thesis, Stellenbosch University, South Africa.

Van Schalkwyk, D.L. & Hoffman, L.C. (2010). Guidelines for the harvesting of game for meat export. Windhoek, Namibia: AgriPublishers.

Veary, C.M. (1991). The effect of three slaughter methods and ambient temperature on the pH and temperature in springbok (*Antidorcus marsupialis*) meat. (Unpublished master dissertation). Faculty of Veterinary Science, University of Pretoria, South Africa.

Von la Chevallerie, M. & Van Zyl, J.H.M. (1971). Some effects of shooting on losses of meat and meat quality in springbok and impala. *South African Journal of Animal Science, 1*, 113–116.

Warriss, P.D. (2000). *Meat science: An introductory text*. New York, USA: CABI publishing, CAB International.

Wheeler, T.L. & Koohmaraie, M. (1994). Prerigor and postrigor changes in tenderness of ovine longissimus muscle. *Journal of Animal Science, 72,* 1232–1238.

Wiklund, E., Finstad, G., Johansson, L., Aguiar, G. & Bechtel, P.J. (2008). Carcass composition and yield of alaskan reindeer (*Rangifer tarandus tarandus*) steers and effects of electrical stimulation applied during field slaughter on meat quality. *Meat Science, 78,* 185–193.

Wiklund, E., Stevenson-Barry, J.M., Duncan, S.J. & Littlejohn, R.P. (2001). Electrical stimulation of red deer (*Cervus elaphus*) carcasses — effects on rate of pH-decline, meat tenderness, colour stability and water holding capacity. *Meat Science*, *59*, 211–220.

Yu, L.P. & Lee, Y.B. (1986). Effects of *post mortem* pH and temperature on bovine muscle structure and meat tenderness. *Journal of Food Science, 51*, 774–780.

CHAPTER 5

General Conclusions

Electrical stimulation (ES) is typically applied to a carcass with the aim of ensuring meat tenderness. The application of ES has shown to prevent cold shortening (CS) and improve meat quality in the commercial slaughtering of domestic animals and selected game species. Electrical stimulation has thus become an important processing technique in modern abattoirs, and when combined with the use of *post rigor* rapid chilling, it can be extremely beneficial to both the supplier and consumer.

Its application can, however, induce certain unfavourable results, but the overall improvement in tenderness generally outweighs the negative connotations with the use of this method. However, it has not been employed in the South African game meat industry as its application is restricted by the unique harvesting conditions that prevail. Game animals are harvested throughout the year in South Africa, which present a range of temperatures and environmental conditions. These comprise of both extremely cold (night harvesting – winter < 0°C) and hot summer conditions (day harvesting – summer > 35°C). These unique harvesting conditions have the potential to negatively affect game meat quality.

Since night harvesting is the most popular method of harvesting game in South Africa, the first trial consisted of the application of ES on springbok carcasses during night harvesting conditions in winter, with the aim of preventing CS and increasing the quality of springbok meat. Cold shortening could have occurred in the springbok muscles from this study, due to the extremely low temperatures associated with the night harvesting (0°C) of springbok from the study area. However, it was deduced that CS did not occur in the springbok *Longissimus dorsi* muscles during the commercial game harvesting conditions evaluated in this study as ES had no significant effect on the quality attributes of the springbok meat. Electrical stimulation did not increase the tenderness of the LD muscles, nor decreased the variation in the quality attributes. The lack of significant differences in meat quality between the ES and non ES (control) springbok muscles in this investigation could be the result of a number of extrinsic factors (size, gender and age) arising due to the random sampling procedures related to commercial harvesting. Moreover, a delay in the time between death and the application of ES as well as the ES parameters used, could have resulted in the lack of significant meat quality differences between the ES and non ES springbok muscle samples. These results therefore contradict what has been found in the domestic industry. However, to evaluate the potential benefits of the use of ES in the game industry, one must test its application in a more controlled environment thereby controlling some of the factors that could

potentially influence the results so as to ensure that the true effect of ES on the meat quality can be evaluated.

Temperature during the *post mortem* conversion of muscle to meat plays a crucial role with regards to the pH decline and efficiency of ES. Thus during the second trial (blesbok) the application of ES in two simulated extreme temperature conditions (5°C and 39°C, found during commercial harvesting of South African game species) was investigated. In addition the time between death and ES was shortened according to suggestions by literature and the lack of significant results in the preceding springbok trial. The results showed that ES had no significant effect on the WHC, cooking loss percentages and bloomed meat surface colour of blesbok muscles. However, *rigor* temperature did influence the meat quality parameters. The higher moisture losses at the 39°C temperature treatment will negatively affect consumer perception of game meat. The 39°C extreme temperature treatment negatively affected most of the meat quality attributes of blesbok *M. longissimus dorsi* with the exception being tenderness. The opposite was observed with the 5°C extreme temperature treatment, since it mainly negatively affected the tenderness of the muscle samples and improved the overall meat quality attributes when compared to the 39°C results. It can be postulated that the tenderness of the 5°C samples were influenced by CS and that ES was not as effective in preventing the adverse affects caused by the occurrence of CS. Electrical stimulation was therefore effective at increasing the tenderness of the blesbok muscle samples at the 39°C temperature treatment, however, ES was not as effective in preventing the adverse affects of a low *rigor* temperature on the natural tenderisation process.

Although the difference between the ES and non ES was more profound at 39°C *rigor* temperature, the application of ES was originally applied to prevent CS occurring in extremely cold conditions (< 5°C). However, it would seem as if CS was not induced as the prescribe guidelines for CS (pH > 6.0 before carcass temperature drops < 10°C) was not met. However, the sarcomere lengths were not measured and to categorically state that CS did or did not occur, this needs to be investigated/tested along with an increased trial period to prove that sustained toughness has occurred and not just a delay in tenderness. Furthermore, more research is needed to test whether ES parameters must be adapted to suite different situations or game species being harvested.

However, potential benefits of ES include an increase in quality (tenderness) of the game meat – without causing adverse effects on the other meat quality attributes. The practical integration of the ES technology in the unique harvesting conditions is, however, still a case of concern. So as to be effective, ES must be applied within 15 minutes of death. For this to be achieved it would imply that a mobile stimulator must be fitted to the harvesting vehicles; this stimulator would still have to be designed and tested. Furthermore the application of this technology would have to be

streamlined so as not to influence the rate at which game is harvested, since this would jeopardise the economical success of ES application. To further maximise the potential benefit of the utilisation of ES in the commercial game industry, the carcasses should be ES and after a short period of conditioning/ageing the muscles could be frozen. Electrical stimulation would have no benefit if the carcasses/cuts were aged at an appropriate temperature before being sold as fresh meat.