THE EFFECT OF DIFFERENT CROPPING METHODS ON THE MEAT QUALITY OF VARIOUS GAME SPECIES

by

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any other university for a degree.

Date: ______________________________

SUMMARY

The production and especially the export of game meat from Southern African are steadily increasing and with this growth, it is inevitable that more emphasis is being placed on the quality of game meat. Research regarding the effect of different cropping methods on *ante-mortem* stress, and as a result, on meat quality in wild ungulates, is lacking and thus the purpose of this study was to investigate the effect of some of the commonly used cropping methods on the meat quality of red hartebeest, impala, gemsbok and kudu. *Ante-mortem* stress was measured using serum cortisol levels (nmol/L), a subjective stress score allocated to each animal as well as the rate and extent of pH decline in the *M. longissimus dorsi*. Special emphasis was also placed on the meat quality parameters drip loss, cooking loss, colour and Warner-Bratzler shear force (kg/1.27 cm diameter).

The effect of day and night cropping on the meat quality of red hartebeest, gemsbok and kudu was investigated. An exponential decay model, $y = a + b^{-ct}$, was fitted to the pH data of the gemsbok and red hartebeest, and pH_u measurements taken at 24 hours *post-mortem*. Only pH_u readings taken at 48 hours *post-mortem* were analysed in the kudu. Day-cropped kudu had a lower mean pH_u (5.40 ± 0.030) than night-cropped kudu (5.48 ± 0.041). No differences in pH_u were found for the red hartebeest although night-cropped gemsbok had a higher mean pH_u (5.54 ± 0.013) than day-cropped gemsbok (5.49 ± 0.014). None of the constants of the exponential decay model differed for the red hartebeest although day-cropped gemsbok produced a lower constant than night-cropped gemsbok. Mean stress scores and cortisol levels were found to be higher in day-cropped animals for both the gemsbok and kudu while only cortisol levels were higher in die day-cropped red hartebeest. Stress score and cortisol levels were found to be correlated in all three species (red hartebeest: r = 0.51; gemsbok: r = 0.786; kudu: r = 0.823). No treatment differences in drip loss or cooking loss were found for either the red hartebeest or gemsbok, while day-cropped kudu had a higher mean drip loss % (2.76 ± 0.261%) than night-cropped kudu (1.36 ± 0.361%). Night-cropped gemsbok and kudu produced higher mean shear force values (gemsbok = 4.19 ± 0.138; kudu = 4.06 ± 0.237 kg/1.27 cm diameter) than day-cropped animals (gemsbok = 3.57 ± 0.154; kudu = 3.45 ± 0.171 kg/1.27 cm diameter). Colour differences indicated that day-cropped gemsbok and kudu produced lighter meat than night-cropped animals. The results indicate no difference in the effects of day and night cropping in red hartebeest although day-cropped gemsbok and kudu experienced more *ante-mortem* stress than their night-cropped counterparts.

The effect of conventional hunting during the day and night cropping on impala meat was also investigated. No differences were found in pH_{45} or pH_u (taken at 45 minutes and 24 hours *post-mortem* respectively) although the exponential decay model, $y = a + b^{-ct}$, fitted to the pH data revealed differences in all the constants (day: a = 5.424 ± 0.039, b = 1.405 ± 0.034, c = -0.385 ± 0.022; night: a = 5.295 ± 0.033, b = 1.556 ± 0.029, c = -0.184 ± 0.019). No differences were found for drip loss, cooking loss or shear force although day-cropped animals produced higher a* and chroma values. The results indicate that, although conventional hunting caused a faster and more severe *post-mortem* pH decline, both treatments produced meat of similar quality.

OPSOMMING

Die produksie en veral die uitvoer van wildsvleis vanuit Suidelike Afrika is gedurig aan die toeneem en met hierdie groei is dit onvermydelik dat meer klem op die gehalte van wildsvleis gelê word. Daar is ’n tekort aan navorsing oor die uitwerking van verskillende oesmetodes op *ante mortem* stres en gevolglik ook vleisgehalte van verskillende wildspesies en dus was die doel van dié studie om die uitwerking van sommige van die gewildste oesmetodes op die vleisgehalte van rooihartebees, gemsbok, koedoe en rooibok te ondersoek. *Ante mortem* stres is gemeet deur die gebruik van serum-kortisolvlakke (nmol/L), ’n subjektiewe strestelling wat aan elke dier gegee is asook die tempo en vlak van pH-daling in die *M. longissimus dorsi*. Spesiale klem is gelê op die vleisgehalteparameters drupverlies, kookverlies, kleur en Warner-Bratzler-skeurwaarde (kg/1.27 cm deursnee).

Die uitwerking van dag- en nag-oes op die vleisgehalte van rooihartebees, gemsbok en koedoe is ondersoek. ’n Eksponensiële vervalkurwe, $y = a + b^{-ct}$, is aan die pH-data van die gemsbokke en rooihartebeeste gepas en pH_u-metings is op 24 uur ná dood geneem. Net pH_u-lesings op 48 uur ná dood in die koedoe is geanaliseer. Koedoes wat in die dag geoes is, het ’n laer pH_u (5.40 ± 0.030) gehad as koedoes wat in die nag geoes is (5.48 ± 0.041). Daar was geen verskille in pH_u vir die rooihartebeeste nie, alhoewel die gemsbokke wat in die nag geoes is, ’n hoër pH_u (5.54 ± 0.013) gehad het as gemsbokke wat in die dag geoes is (5.49 ± 0.014) . Geeneen van die konstantes van die eksponensiële vervalkurwe het verskil in die geval van rooihartebeeste nie terwyl gemsbokke wat in die dag geoes is ’n hoër konstante a en ’n laer konstante c getoon het as gemsbokke wat in die nag geoes is. Gemiddelde strestellings en kortisolvlakke was hoër in die geval van gemsbokke en koedoes wat in die dag geoes is terwyl net die kortisolvlakke hoër was in die rooihartebeeste wat in die dag geoes is. Daar is ook bevind dat die strestelling en kortisolvlakke gekorreleer was in al drie spesies (hartebees: $r = 0.51$; gemsbok: $r = 0.786$; koedoe: $r = 0.823$). Geen verskille in drupverlies of kookverlies is aangetref vir die rooihartebeeste of gemsbokke nie, alhoewel koedoes wat in die dag geoes is ’n hoër gemiddelde drupverlies % (2.76 ± 0.261%) getoon het in vergelyking met koedoes wat in die nag geoes is (1.36 ± 0.361%). Gemsbokke en koedoes wat in die nag geoes is, het ’n hoër gemiddelde skeurwaarde gehad (gemsbokke = 4.19 ± 0.138; koedoes = 4.06 ± 0.237 kg/1.27 cm deursnee) as diere wat in die dag geoes is (gemsbokke = 3.57 ± 0.154; koedoes = 3.45 ± 0.171 kg/1.27 cm deursnee). Kleurverskille het aangedui dat gemsbokke en koedoes wat in die dag geoes is, ligter gekleurde vleis geproduseer het as diere wat in die nag geoes is. Die resultate dui aan dat daar by rooihartebeeste geen verskil is tussen die uitwerking van dag-oes en nag-oes nie, maar dat die dag-oes van gemsbokke en koedoes meer voordoodse stres veroorsaak het as nag-oes.

Die uitwerking van konvensionele jag gedurende die dag- en nag-oes op die vleisgehalte van rooibokke is ook ondersoek. Geen verskille is aangetref in pH_{45} of pH_u (geneem op 45 minute en 24 uur ná dood onderskeidelik) nie, alhoewel die eksponensiële vervalkurwe, $y = a + b^{-ct}$, wat gepas is aan die pH-data verskille getoon het in al die konstantes (dag: $a = 5.424 \pm 0.039$, $b = 1.405 \pm 0.034$, $c = -0.385 \pm 0.022$; nag: $a = 5.295 \pm 0.033$, $b = 1.556 \pm 0.029$, $c = -0.184 \pm 0.019$). Geen verskille is aangetref ten opsigte van drupverlies, kookverlies of skeurkrag nie. Diere volgens die konvensionele maniere geoes het wel hoër a*-

en chroma-waardes getoon. Die resultate dui daarop dat, alhoewel konvensionele jag ŉ vinniger en meer ekstreme pH-daling veroorsaak het, albei behandelinge tot dieselfde vleisgehalte gelei het.

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LIST OF ABBREVIATIONS

pH_u	Ultimate pH
pH_{45}	pH taken at 45 minutes *post mortem*
PSE	pale, soft and exudative
DFD	dark, firm and dry
S.E.	standard error
LSMean	least squared mean
ANOVA	analysis of variance
WHC	water-holding capacity
HPA	hypothalamic-pituitary-adrenocorticoid
L*	lightness
a*	red-green colour range
b*	blue-yellow colour range
H_{ab}	hue angle
C*	chroma

NOTES

The language and style used in this thesis are in accordance with the requirements of the scientific journal, *Meat Science*. This thesis represents a compilation of manuscripts, where each chapter is an individual entity and some repetition between the chapters has, therefore, been unavoidable.

Results of this study have been represented at the following symposiums:

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Chapter 1

INTRODUCTION

In Africa, indigenous wildlife species have been used for centuries as a good quality protein source. In recent years, the potential of game meat production from African ungulates as a viable enterprise has become increasingly popular amongst local farmers. Barnett (2000) states that since the pioneering work of Dassman and Mossman in the early 1960s, game meat production systems through wildlife ranching and cropping has been heralded as a more suitable land use option within the semi-arid and unproductive areas of Africa. Indeed, during the droughts of the 1940s and 1950s, farmers in the arid and semi-arid areas of South Africa realised that springbok was not as badly affected by the dry years as their conventional livestock counterparts and the springbok began to be harvested for the first time as a source of meat for local consumption (Beinart, 2003 as cited by Carruthers, 2008). Although it is difficult for wild ungulate species to compete with domesticated species for meat production, since the latter has been specifically bred for this purpose, there are certain niches that can be filled by game meat. For example, game meat is distinguishable from venison in that, unlike many of the cervids found in Europe, Australia and New Zealand that are used for venison production, the African ungulates used for game meat production are not farmed and occur as free-roaming animals in large enclosures owned either by the state or by private landowners (Hoffman & Wiklund, 2006). As a result, these animals can invariably also be classified as free-range and the meat from these animals as organic, i.e. free of antibiotic and feed additives. Game meat has also been shown to be much lower in fat than many domesticated species with the average fat content of most game species reported as being lower than 3% (Hoffman & Wiklund, 2006). With these facts as marketing tools, game meat production has expanded dramatically, not only for local consumption but also for export to markets such as the European Union.

As game meat consumption increases, the drive to increase quantity has been accompanied by measures to improve its quality (Cooper, 1995). The wild behaviour and extensive nature of game species mean that inevitably the mechanics of game meat production are infinitely more complex than those of domestic production systems where stock can be driven to a central meat production facility (Ledger, Sachs & Smith,, 1967). Unlike with domestic animals, good management practices that minimise stress during pre-slaughter handling are difficult to employ with wild ungulates since factors such as terrain, time limitations, weather and the behaviour of specific species will hinder the efficiency of the slaughtering process. As noted by Skinner (1984), the same quality criteria apply in the case of meat from wild ungulates as would be the case in domesticated species and because of this, it is becoming vitally important that wild ungulates are slaughtered in a way that causes minimal *ante-mortem* stress and maximises the full meat quality potential of the animal. Because African ungulates are ruminants, they have the potential of having the same meat quality defects as domestic ruminants to such an extent that the occurrence of dark, firm and dry (DFD) meat has the potential of becoming an escalating problem. In fact, South African game meat is often perceived as being dark and dry, according to Hoffman (2001), this may in part be due to the fact that most game animals tend towards DFD as a result of the stress of the cropping process. Accompanied with this defect is a decrease in shelf life, thereby hindering the export of such fresh meat products (Wiklund *et al.*, 2001; Gill & Newton, 1981).

In order to minimise *ante-mortem* stress in African ungulates, adequate research is required on the efficiency and effectiveness of the various cropping methods. With limited research on the effect of commercially used cropping methods on stress in wild ungulate species (Kritzinger, Hoffman & Ferreira, 2002; Hoffman & Ferreira, 2000; Veary, 1991; Von La Chevallerie & Van Zyl, 1971), opinions within the game meat industry vary on which cropping methods work best. The effect of species is also often neglected so that, for example, night cropping is often assumed to cause the least amount of stress to the animals over a wide range of species. This may not necessarily be the case and it is thus important that recommendations on the cropping of different species be based on sound scientific knowledge. It is also important that the full effect of such cropping methods on the meat quality be investigated since what may seem stressful to the observer may not necessarily adversely affect the meat in any way. Other factors such as age, gender and region, the latter of which not only denotes the environmental effect but also the effect of hunting practices in a certain area, should also always be taken into consideration since, as has been established in many domesticated meat-producing species, these will unavoidably have an effect on the meat quality and even the stress susceptibility of the animal and therefore on the effect of the cropping methods.

This study was therefore conducted to determine the effect of a number of different cropping methods on the meat quality of four different ungulate species as specifically pertaining to *ante-mortem* stress. Day and night cropping from a vehicle by a professional cropping team were compared in the case of the red hartebeest, gemsbok and kudu since these two methods are commonly used during the commercial production of game meat for local and export markets. In the case of the impala, a species that is commonly hunted locally by sport and biltong hunters, night cropping from a vehicle was compared with conventional ethical hunting on foot. The reason for this comparison was the fact that the latter method is considered as causing minimal stress to the animals and because much of the game meat consumed by local people originates from this type of hunting activity. With all the species investigated, other extrinsic factors such as age, gender and region were also taken into account where applicable.

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Chapter 2

LITERATURE REVIEW

2.1. GAME RANCHING IN SOUTHERN AFRICA

Although farmers have shot and marketed game in Southern Africa for decades (Veary, 1991), it is only in the last 20-25 years that game ranching has grown tremendously and was shown to be an increasingly commercially viable enterprise (Bothma & Van Rooyen, 2005). According to Van der Walt (2002), only 23.3% of all the agricultural land in South Africa has a high production potential so that, during the latter half of the previous century, much of the agricultural focus has been on alternative land use options. Therefore, even though game ranching has developed as a relatively new agricultural industry, it has become well established in Southern Africa (Ebedes, 2001). Game ranching can be defined as those enterprises that set out to utilise herds of wild game on extensive tracks of (marginal) land for the production of food and utilities (Barnett, 2000; Ledger, Sachs & Smith, 1967). This is in contrast to game farming, which is the concentrated breeding and intensive management of wildlife species on a sustainable basis in smaller, fenced enclosures (Mostert, 2007; Bothma, 2002a; Barnett, 2000). The latter is especially suitable to those species that are relatively easily "domesticated", and has been successful with many cervids, as is the case in New Zealand, where intensively managed deer herds and their products are sold internationally (Bothma, 2002a). In Southern Africa, the wildlife ranching industry initially developed as a result of the desire of ranch owners to have a wildlife retreat for their own enjoyment (Bothma, 2002b). Poor profits realised from beef and other conventional farming operations later resulted in an increase in the conversion of conventional farms to game ranches. The surface area under wildlife ranching in South Africa increased by 2.5% in both 1998 and 1999, representing an increase of some 300 000 ha per year (Bothma, 2002b). According to Van Niekerk (2002), there were 5 000 game ranches and more than 4 000 mixed game and stock ranches in South Africa in 2002, covering some 13% of the country's total land area. Before 1960, little to no economic value was attached to game whereas in 2001, the total gross income from all spheres of activity relating to game ranching, was estimated at more than R1 billion (Van der Walt, 2002). This indicates that the game ranching industry has grown to such an extent that it is now an important and viable form of income generation from agricultural land (Van Niekerk, 2002). Accompanying this increase, game ranching has also spawned new scientific disciplines within animal husbandry with much of the scientific research based on the work of Dassman and Mossman during the 1960s in that species of ungulates are managed on large tracks of land at a level that can be harvested for the production of meat (Carruthers, 2008).

2.1.1. Production of game meat

For the purpose of this research, it was important to distinguish between the terms "venison" and "game meat". According to Hoffman and Wiklund (2006), venison produced in Australia, New Zealand, Europe and America is distinguishable from the game meat produced in Africa since in the former countries, the cervids used to produce venison are becoming increasingly domesticated, whereas African game meat originates from wild, free-running animals. Bothma (2002b) also noted that in the development of a market for wildlife meat in Southern Africa, the term "venison" should be avoided, especially when attempting to compete with true venison produced elsewhere, such as in New Zealand. He noted that “venison” generally refers to the meat of cervids used as food, and the only indigenous cervids occurring in Africa are the red deer, *Cervus elaphus*, which are found in extreme North Africa (Grubb, 1993).

One of the aspects of utilisation on a wildlife ranching enterprise that is playing an increasingly critical role in the overall financial viability of many ranches is meat production (Barnett, 2000). The potential for the production of game meat as a legitimate form of wildlife utilisation has been recognised for a long time (Skinner, 1984; Von La Chevallerie, 1972). In the 1950s, owing to the meat rationing after the war and the droughts of the 1940s and 1950s, consumption of game meat in Southern Africa increased (Carruthers, 2008). During the 1970s, international demand for game meat increased such that in 1972, the first game meat was exported from South Africa (Conroy, 1976 as cited by Carruthers, 2008). Berry (1986) found that in three ranching areas of South Africa, when considering total wildlife populations, game meat production could result in the greatest overall profit as such production utilises all species as well as the whole range of adult animals within a species. In addition, game meat production is associated with smaller set-up costs in comparison with safari hunting (Barnett, 2000). In order to be profitable, game ranchers need to consider diversification into other areas of production and game meat production shows increasing potential as a profitable enterprise. As noted by Skinner (1984), when producing game meat from wild ungulates, the same criteria apply as those applying to meat production from domestic livestock. These include carcass yield, chemical composition and meat quality (Issanchou, 1996). Although wild ungulate species cannot compete with domestic livestock in terms of productivity under intensive farming conditions (Skinner, 1984), their greatest potential lies in their ability to adapt to the harsher environments of extensive stock-farming areas so that they are competitive with domestic stock in these areas (Fairall, 1984). Indeed, much of the research focused on the comparison between the production of domestic livestock and game was originally based on the view that the latter could survive in areas where poisonous plants were abundant and where there was a shortage of drinking water (Carruthers, 2008). Marketing of game meat also holds advantages over that of domestic livestock since the animals used for game meat production are essentially wild and can thus be marketed as free-range. As a result of their inherent wildness, such animals also produce organic products free of hormones, antibiotics or any artificial additives usually added to the diets of domestic animals (Hoffman & Bigalke, 1999). According to Steenkamp (1997), consumers are becoming increasingly concerned about the environment and are consequently becoming more interested in buying free-range and organic products. Other health benefits of game meat include lower cholesterol, lowered fat content and higher protein content. Nyala meat, for example, contains 10.0% more protein per unit weight than beef and is significantly lower in energy (kJ) and cholesterol than beef (Bothma, 2002b). According to Van Zyl and Ferreira (2004), Hoffman (2000a), Schönfeldt (1993) and Von La Chevallerie (1972), game meat has a fat content of 2-3%, which is lower than most other domestic species.

2.1.2. Suitability and sustainability of game species for meat production

The potential of African ungulates for meat production has long been recognised (Von La Chevallerie, 1972 Ledger *et al.*, 1967; Ledger, 1963) and in 2000, it was estimated that the gross income generated by game meat sales in South Africa alone was R20 million (Eloff, 2001). In 2005, it was estimated that South Africa exported de-boned meat from 160 000 carcasses, predominantly from springbok (*Antidorcus marsupialis*, >80%), blesbok (*Damaliscus pygargus phillipsi*) and kudu (*Tragelaphus strepsiceros*). Other species such as zebra (*Equus burchelli*), blue wildebeest (*Connochaetes taurinus*), impala (*Aepyceros melampus*) and gemsbok (*Oryx gazella*) were also exported in smaller numbers (Hoffman & Wiklund, 2006).

The productivity of different game species is dependent on various factors and in order to make a viable contribution to a game rancher's income, a number of these factors need to be comparable to domestic livestock production. Skinner (1984) investigated eight different wild ungulate species suitable for game farming, including the springbok and blesbok, which are easily enclosed in paddocks on a farm, as well as kudu, eland and impala, which are browsers and therefore do not compete with cattle. He found that the smaller species, for example the springbok, reached mature weight much faster than the larger species, for example kudu, so that the former species produced similar dressing percentages as their larger counterparts, at an earlier age. Similar to the findings of Ledger *et al.* (1967), Skinner found the dressing percentages of these ungulates to range from 51.3% (male eland, *Taurotragus oryx*) to 61.9% (male giraffe, *Giraffe camelopardalis*). These values are comparable if not higher than the dressing percentages of most domesticated livestock species and unlike domesticated species, the higher carcass yields of wild ungulates do not result from the laying down of mainly subcutaneous fat but from the presence of high amounts of muscular tissue (carcass lean meat) in the carcasses (Ledger *et al.*, 1967). Cognisance must be taken of the fact that other factors such as fleece weight and gut fill bias the results in favour of game (Hoffman, 2001). On an animal-to-animal basis, wildlife cannot compete with domesticated herbivores for meat production since the latter has been bred for centuries specifically for this purpose. Furthermore, the diets of domesticated stock are easily controlled and manipulated while most game species are very specific about their grazing/browsing selection. Moreover, while domestic animals have been intensely selected for fecundity and productivity, the natural selection of wildlife has been focused principally on survival (Carruthers, 2008). The main advantage of wildlife lies in the diversity of its products. Furthermore, there are at least 45 types of wild herbivores in Southern Africa, many of which occur in the same ecosystem (Bothma, 2002b). In South Africa, springbok is presently the game animal most extensively cropped with most of the research relating to South African game meat having been done on this species (Hoffman, 2001). The reason for this is most likely the relative abundance of the species throughout Southern Africa, its high reproductive capacity as well as the fact that it reaches maturity within less than one year of age. Van Zyl, Von La Chevallerie and Skinner. (1969) also showed that, when compared to impala and Dohne Merino sheep, springbok produced the highest dressing percentage, at about the same proportion as cattle. From Table 1 it can be seen that kudu and blesbok were respectively the second and third most utilised species for game meat production in South Africa between 2002 and 2004, even though the amount of meat produced from these two species were far less than that produced from springbok (Patterson & Khosa, 2005).

Table 1

Species and numbers of game harvested commercially for meat production in South Africa for the period 2002 to 2004 (Patterson & Khosa, 2005)

Species	2002		2003		2004	
	Number	**Weight (tons)***	**Number**	**Weight (tons)***	**Number**	**Weight (tons)***
Springbok	19 252	287 956	25 133	322 030	20 664	307 374
Kudu	733	64 572	256	21 155	646	51 869
Blesbok	811	29 755	31	1 002	1 379	49 241
Black Wildebeest	285	22 460	0	0	222	18 744
Zebra	84	14 240	337	64 914	88	16 633
Eland	14	3 282	0	0	82	16 343
Gemsbok	29	2 491	7	820	139	13 537
Impala	117	3 616	28	794	169	4 296
Deer, Fallow	51	1 519	1	33	65	1 733
Bushbuck	6	190	1	32	0	0
Blue Wildebeest	29	3 005	1	72	0	0
TOTAL	21 457	433 771	25 816	411 080	23 455	479 783

* Weight of the animal comprises of carcass and skin

An important factor to consider when utilising game species for meat production is their suitability as well as the sustainability of such species for utilisation. The game ranching industry in Southern Africa operates from a sustainable utilisation ethic, and Thompson (1992) states that the best way to conserve wildlife is to establish controlled and sustained yield harvest schemes. Off-take rates for each species should be calculated so as to maintain a healthy genetic base for maximum production potential as well as for the conservation of the species (Kritzinger, 2002). As an example, Table 2 shows the number of game in the Eastern Cape as well as the percentage recommended utilisation and the actual percentage utilisation, as found by Van Niekerk (2002).

Table 2

Sustainability of game utilisation in the Eastern Cape (Van Niekerk, 2002)

Species	Game numbers	Annual numbers utilised	% of total utilised	% recommended utilisation
Kudu	18 077	2 683	14.84	19
Springbok	**32 501**	**12 674**	**39**	**33**
Blesbok	**7 322**	**1 780**	**24.3**	**28**
Mountain Reedbuck	22 697	2 635	11.6	29
Warthog	2 502	476	19	120
Oryx (Gemsbok)	**541**	**80**	**14.79**	**15**
Black Wildebeest	1 728	226	13.08	30
Impala	5 638	790	14.01	30
Bushbuck	5 004	439	8.77	20
Bontebok	253	23	9.09	25
Eland	581	48	8.26	20
Blue Wildebeest	658	57	8.66	30
Nyala	293	33	11.26	28
Deer, Fallow	4 211	684	16.24	35-60
Lechwe	**401**	**86**	**21.45**	**25**
Zebra	425	64	15.06	25
Red Hartebeest	**445**	**91**	**20.45**	**23**

*The species in bold are those species which were harvested in numbers close to the recommended percentage utilisation

From the table, it is evident that springbok were harvested at a rate 6% greater than is recommended. This could be detrimental to the genetic base of the population as well as to the population growth, which will affect future availability of the species. When dealing with the sustainable utilisation of game it is important to consider the recommended off-take rates and also to take into account factors such as age and sex ratios (Fairall, 1985).

2.1.3. Legislation regarding game meat

Although the market for venison/game meat has fluctuated sporadically for many years, it has the potential to be one of the wildlife industry's largest sources of income (Bothma, 2002b). On the whole, the game meat market within South Africa is relatively small since many South African consumers consider game meat to be dry and they dislike its 'gamey' flavour (Patterson & Khosa, 2005). Nevertheless, the export market has grown tremendously over the last decade, and currently around 350 tons of game meat is exported annually, consisting of springbok (45 000 animals), kudu, blesbok and a small number of zebra (Patterson & Khosa, 2005). Game meat production is regulated under the Meat Safety Act, Act No. 40 of 2000. Under this Act, game meat can only be sold for human consumption if it has been inspected by a meat inspector and has passed through an abattoir specifically accredited for handling game meat. Biltong hunters and hunting for own consumption are excluded from the requirements of the Act. The EU holds one of the largest export markets for Southern Africa, with stringent controls governing the handling of game meat enforced by the EU, hampering this export. Some of these requirements include that meat has to be at one of only a few EU approved abattoirs within 36 hours of being cropped and that cropping teams have to be registered with the National Veterinarian Department. Strict regulations regarding the cutting and evisceration of carcasses must also be adhered to, and during such operations, workers have to be divided into groups performing "dirty" duties (i.e. workers who perform tasks that will lead to a greater possibility of contamination of hands, protective clothing and equipment) and groups performing "clean" duties (i.e. workers who perform tasks on the clean carcasses, such as weighing of carcasses and placing of carcasses into cooling facilities). Traceability of the meat is a prerequisite and all farms that supply game animals for export, as well as game depots, need to be registered with the Controlling Authority (a person or body that, under a law of the country or province, has statutory responsibilities for game meat hygiene). The South African Standard for the Export of Game Meat also has an intensive residue-monitoring programme as well as complete health and hygiene requirements (Hoffman & Wiklund, 2006). As a result of these regulations, only a few suitable abattoirs exist and only three companies export game meat to the EU from South Africa. Of the latter, Camdeboo Meat Processors cropped 65 000 head of wildlife in 2001 which represented about 80% of all wildlife professionally cropped in and exported from South Africa that year, generating a turnover of about R28 million (Flack, 2002 as cited by Patterson & Khosa, 2005). Animals such as springbok are best suited to the strict regulations of the EU market since they occur in open areas and are easily cropped (mainly at night), whereas species such as impala live in woodlands which makes it difficult for the cropping team to operate (Patterson & Khosa, 2005).

2.2. GAME CROPPING TECHNIQUES

With the advent of fencing and zoning of large areas of land for use as game ranches, cropping of wildlife populations has invariably become an integral component of the management of such ranches. According to Bothma (1996), there are only three broad types of management options for wildlife populations on a game ranch:

- Conservation: the manipulation of a small or reduced population to increase its density;
- Sustained harvest: the utilisation of a population through sustained yield over a long time; and

- Control: the manipulation of a population whose numbers are too high or which has an unacceptably high growth rate, to stabilise the population or to reduce its numbers.

The type of management option followed will depend on a number of factors, including the definitive objectives for the use of the ranch as well as the population dynamics of the species being considered (Bothma, 1996). For the purpose of this research, the focus was placed on the sustainable yield of game for meat production, which is accomplished by regular cropping. Maximum sustained yield assumes a certain constancy of environmental conditions seldom realised in Africa, particularly in arid regions (Skinner, 1989). For this reason, harvesting or cropping programmes should follow the feedback principles of Stocker and Walters (1984), taking into account vegetation and also ungulate population numbers as well as age and sex ratios. The cropping technique applied depends on the species, its habitat and the vegetation of the area, and cropping techniques are continuously being adjusted so as to harvest the most animals in the least amount of time (Mostert, 2007). Cropping of ungulates can either be contracted, in which case professional cropping teams are brought in, or a farmer may choose to crop the animals himself. In the former case, abattoir facilities are customarily provided by the contractor and there is little flexibility in the scheduling of such activities. If, for example, an opportunity for cropping is missed, it may be some time before a contractor is available again (Skinner, 1989). The use of contractors is also a necessity if the meat is to be exported or sold on the local market, whereas meat for own use is exempt from such regulations. In this case, the ranch owner is most likely to do the cropping himself. For meat to be of export quality, only head or neck shots are acceptable (Hoffman, 2003). The use of a specific cropping technique is also important with regard to the stress placed on the animal prior to death since *ante-mortem* stress has been shown to have deleterious effects on the meat quality of domestic livestock as well as on that of game (Hoffman & Wiklund, 2006; Kritzinger, 2002; Hoffman, 2000a; Wiklund, Andersson, Malmfors, Lundström & Danell, 1995; Veary, 1991; Smith & Dobson, 1990; Judge, 1968;). Inefficient cropping techniques also lead to higher labour costs while inaccurate shooting wastes ammunition and may result in excessively damaged carcasses. Inefficient cropping may also lead to lower game productivity as a result of injured and stressed animals (Ruggiero & Ansley, 1992). The cost of cropping has been shown to affect the price of game meat directly (Van Rensburg, 1992). According to Tinley (1972), there are four general requirements for successful cropping:

1. Instantaneous death: from humanitarian considerations and also because *ante-mortem* stress causes inferior meat quality.
2. Minimum disturbance to the population, e.g. if a number of animals have been cropped from one herd, it is unwise to continue chasing the same herd as they become excitable and later unapproachable.
3. Throughout the year, daily human activity on foot, frequent passage of motor vehicles and spotlighting at night without hunting will accustom animals to the rancher’s presence and activities and ultimately facilitate cropping.
4. If carcasses are required for consumption of fresh meat, they are required to be in an unspoilt condition, obtainable only with head and neck shots.

In Southern Africa, the following cropping techniques are most commonly employed.

2.2.1. Night cropping

Night cropping in the field is undoubtedly the most popular method employed in large-scale game cropping operations (Le Grange, 2006; Kritzinger, 2002; Hoffman, 2000a; Hoffman & Wiklund, 2006; Lewis, Pinchin & Kestin, 1997; Veary, 1991). As early as 1964, Dassman reported that this method had the greatest success rate. Hunting commences after dark and usually on moonless nights since animals are difficult to approach in moonlight and because the moonlight reduces the efficiency of the spotlights used to blind the animals (Le Grange, 2006; Bothma, 1996). Strong spotlights are used to detect and blind the animals and hunting may continue until dawn the following day to take maximum advantage of the moonless conditions (Kritzinger, 2002). The spotlights immobilise the animals so that they can be shot from distances ranging from 25 to 100 m. Ruggeiro and Ansley (1992) found that shots in excess of 150 m, on average, resulted in unacceptable accuracy. The latter is especially true when light calibre rifles are used and there is a strong prevailing wind – conditions frequently found out on the South African plains (Karoo) when plains game species are cropped. During large-scale operations, several hunters may be employed at one time, each with a quota of animals to shoot. The hunters each proceed in open chase vehicles and often the shooter may also be the driver so as to avoid delayed reactions from communication errors between drivers and shooters. One or two people are usually equipped with spotlights. They stand on the back of the vehicles, sweeping the light over the terrain to detect the animals. Animals are spotted by the reflection from their retinas and firing should only commence if clear shots are possible (Kritzinger, 2002). Head and neck shots are preferred, using high-velocity, small calibre rifles, since these reduce carcass loss to a minimum (Bothma, 1996; Le Grange, 2006). Von La Chevallerie and Van Zyl (1971) found that these shots resulted in the least amount of carcass damage in springbok and impala, while shots in the shoulder and buttocks can contribute up to 20% and 50% of carcass weight loss, respectively (Bothma, 1996). According to Le Grange (2006), good-quality telescopic sights are also a necessity, since open sights do not provide the accuracy required, especially at ranges as far as 100 m. A study by Lewis *et al.* (1997) noted that, with a single marksman, the average time that lapsed between the culling of impala in a herd was 28 seconds, with the maximum time being 3 minutes and 18 seconds and the minimum time being 2 seconds. It must be noted that in this study there was a high density of animals and the animals had been, as suggested by Tinley (1972), habituated to humans. Animals need to be collected as soon as possible after being shot since the darkness may impede the finding of the animals and in areas that harbour large populations of predators, these animals may compete with the cropping team in recovering the carcasses as they become aware of the hunting routine (Le Grange, 2006).

Studies conducted by Hoffman and Ferreira (2000), Kritzinger, Hoffman and Ferreira (2002), Veary (1991) and Von La Chevallerie and Van Zyl (1971) indicated that the least amount of *ante-mortem* stress is experienced during night cropping so that as a result, the use of night cropping holds beneficial effects on certain meat quality parameters. Other advantages of night cropping include the fact that animals in a herd are less disturbed by the cropping (Bothma, 1996; Ledger *et al.*, 1967) and lower night temperatures may allow for better meat quality as well while it also results in the absence of flies (Bothma, 1996). Disadvantages, on the other hand, are that wounded animals are more difficult to recover and in the absence of moonlight, the method is unsuitable in areas of dense bushveld where the vegetation makes it difficult to see the animals. Night cropping may also be more expensive than cropping methods employed during the day, since labour costs at night tend to be one and a half times those of day costs (Van Rensburg, 1992). Another disadvantage is that the culling is limited to moonless nights (two weeks per month) and with the growth in the export market, insufficient numbers are taken off resulting in alternatives such as day shooting having to be implemented (Le Grange, 2006). In addition, night cropping can prove disadvantageous if shooters and drivers are unfamiliar with the terrain since navigation is more difficult at night and this in turn may hinder the predictability of animal movement.

Night cropping is also limited in its suitability to certain species. In the case of species that are not sexually dimorphic, red hartebeest, for example, the sexes are difficult to tell apart (Bothma, 1996; Ruggeiro & Ansley, 1992). Animals like the kudu are also not suitable for this method as they are predisposed to look away from the spotlight or to close their eyes (Joubert, 1983; Mostert, 2007). This is in contrast to springbok and impala, which are ideal since they have a tendency to remain still once they have been caught in the spotlight (Conroy, 2005; Lewis *et al.*, 1997). According to Ruggeiro and Ansley (1992), the territorial nature and relative tameness of gazelles may reduce their flight distance, whereas the more skittish temperament of wildebeest and zebra, as well as their habit of running in tight groups, makes them more difficult targets when using this method. These authors also found that the dark grey colour of wildebeest made finding its head in the telescopic sight more difficult and the zebra's stripes made distinguishing one individual from another more difficult, particularly when moving in a tight group. During night cropping, cropping teams also tend to get tired so that accuracy tends to decline after 23:00 (Ruggeiro & Ansley, 1992) and more errors are made the longer the cropping sessions proceed.

2.2.2. Day cropping

There are a number of different cropping methods employed during the daytime, and these will be discussed in detail later. A method commonly applied in commercial cropping operations is that of hunting from a vehicle in a method similar as described under night cropping. Unlike night cropping, this method can be used at any time of the month and animals are spotted by two or more people on the back of the vehicle. A definitive advantage of cropping during the day, is that marksmen are able to distinguish sexes (even when species are not sexually dimorphic) as well as age classes and social groupings so that selective cropping is possible (Bothma, 1996). This method is easily used with most species of game since sighting of the animals is less complicated during the daylight hours. Shots can also be fired at distances in excess of 150 m since animals are more easily distinguishable from each other and their surroundings than at nighttime, although it then becomes increasingly important for marksmen to be well trained in shooting at such distances. These distances also inevitably increase the chances of prevailing winds blowing the bullet off course and animals being wounded although during the day, wounded animals as well as carcasses are more easily located than at night thereby decreasing the risk of shooting losses.

Another method employed during the day although not commonly used, involves the herding of animals towards shooting lines using scrambler motorcycles, pick-up vehicles or horsemen. Marksmen position themselves either in camouflaged bunkers or behind bushes where they are unseen by the approaching animals (Kritzinger, 2002). Veary (1991) found that this method caused the largest amount of stress to the animals and he reported final pH values for springbok, cropped using this method, that were similar to a value reported by Hoffman (2000a) for a single severely stressed impala ram. According to Kritzinger (2002), this method also causes severe sub-dermal abrasions and bruising as a result of the animals bumping into each other and falling. The effect of the *ante-mortem* stress on the *post-mortem* pH of the muscle also causes several deleterious meat quality attributes. From personal observation, this method is also not suited to small, agile species such as warthog, since they tend to lie down and hide in the thicket when being chased, making it impossible for the marksmen to spot them. Bothma (1996) observed similar behaviour in bushbuck and nyala, which tend to run in any direction and try to hide.

2.2.3. Hide cropping

This method is employed during the daytime and animals are lured to either a drinking hole or feeding point. Animals are then killed from a nearby hide, using a silenced rifle (Hoffman & Wiklund, 2006). The method may be used in areas with dense bush where animals are difficult to locate on foot or by vehicle. It works well with species such as kudu that are prone to approaching feeding points although it does not work well with other species such as impala (Hoffman & Wiklund, 2006). This method may be used by ranchers for meat for own consumption although it is not commonly used in commercial operations since the off-take rate is very slow.

2.2.4. Boma cropping

The technique employed in this method is similar to that of the mass boma capture of animals for relocation. Game is herded by a helicopter into a large capture boma, where they are then shot with a light caliber rifle from the ground (Bothma, 1996). Bomas are usually constructed from dark coloured plastic since animals are reluctant to challenge an apparently solid wall and because the animals are unable to see through the plastic. This also ensures that as the animals proceed forward to “escape”, they can be moved into separate compartments (Le Grange, 2006). Figure 1 illustrates the general set-up of a capture boma. Bomas used for cropping are very similar, with slight modifications. For cropping, the ramp crush complex is removed and the crush is rounded off so that the animals can be shot in this area. The area beyond the third gate can alternatively be made parallel, with several gates to provide compartments for individual groups of animals. Wind direction plays a critical role in setting up the boma so that the position of the front gate must be downwind from the direction from which the animals will approach (Le Grange, 2006). Once the animals are herded into the main area of the boma, it is recommended that they stand for a short period, usually less than 2 hours (Hoffman & Wiklund, 2006). After this, they are broken up into smaller groups (± 10 animals per group) and moved into smaller compartments. It is in these smaller bomas that they are shot and this activity usually takes approximately 60-90 seconds (Hoffman & Wiklund, 2006). According to Le Grange (2006), it is best if animals are moved into the smaller bomas during the day and left until night, when shooting commences. This allows them to settle down and accept the enclosure as well as the intrusion of the light and the hunter later on, and the animals can then be dispatched of relatively quickly. From there, the animals are removed from the boma to a transport truck where they are hung (head hanging down) and exsanguinated. The carcasses are then transported to a mobile abattoir set up in the veld (Mostert, 2007).

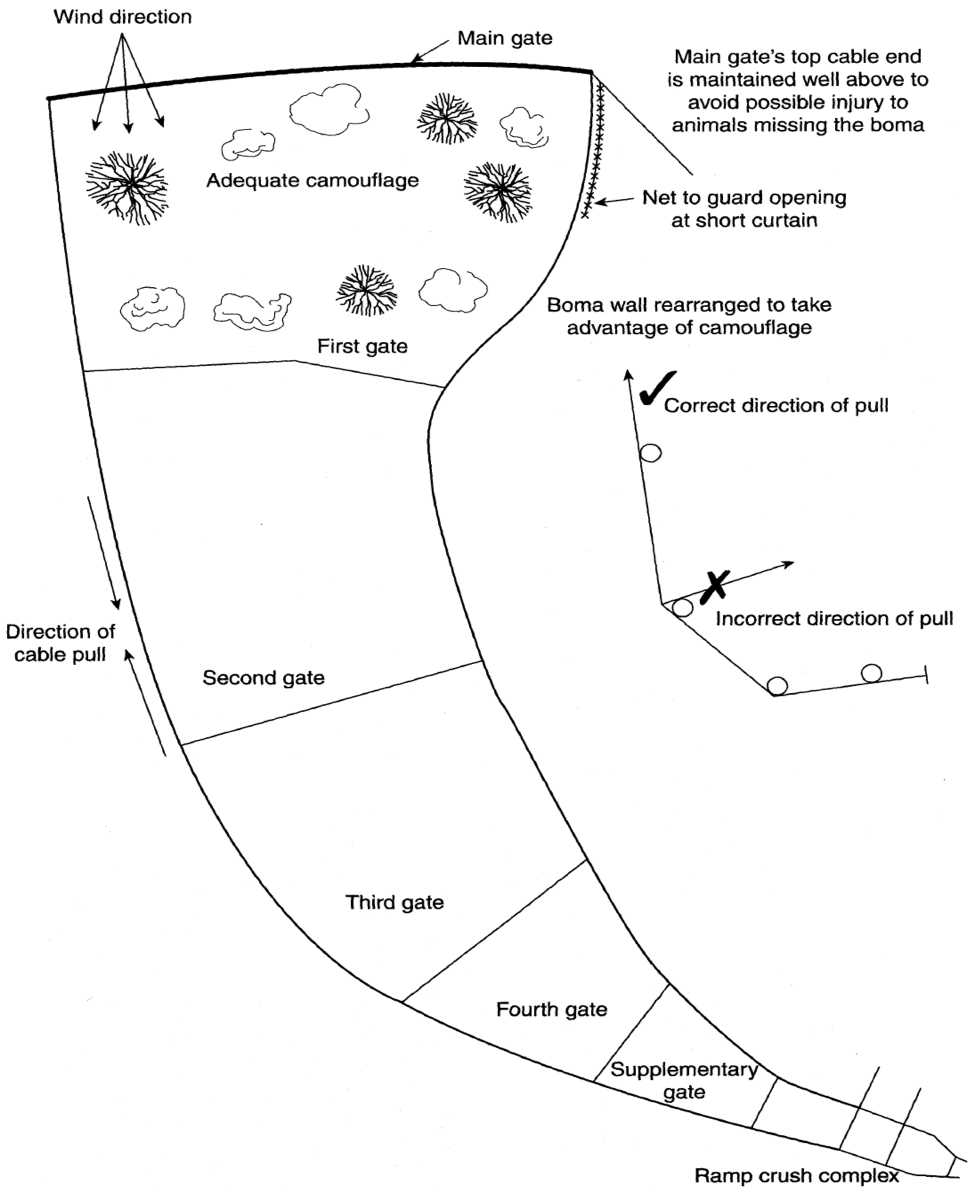

Fig. 1. Setting up a plastic boma for game capture (Le Grange, 2006)

This method of cropping has a practical advantage for dense bushveld areas where the landscape is inaccessible to vehicles. In these areas, the animals can be driven to areas which are accessible to trucks and refrigeration vehicles (Bothma, 1996). It allows for a large number of animals to be cropped and processed within a very short amount of time and ensures that no wounded animals are left behind. It also allows for a certain level of selectivity in terms of which animals are cropped thus allowing animals of trophy status or specific breeding animals or very young animals to be selected and set free. Animals are processed on the spot and this allows for easy maintenance of hygiene and easier inspection of the carcasses by the relevant authorities (Le Grange, 2006). The use of light calibre rifles also causes less damage to the carcass. No research has been done with regard to the effect of this cropping method on meat quality and according to Hoffman and Wiklund (2006), dominant males in a herd may start fighting with submissive males and may even kill submissive males. This is in agreement with Bothma (1996) who found that males of certain species, for example impala, kudu, waterbuck, gemsbok, blue and black wildebeest, red hartebeest and eland, often fight with one another or with the females soon after being captured and may need to be separated to prevent injury. Care should also be taken with those species that have horns since panicked animals may cause serious injuries to those around them. Fighting and pushing between animals may result in bruising which will negatively affect meat quality. Capture myopathy, which will be discussed in detail later, may also become a problem if animals were herded over long distances and for prolonged periods of time. Certain species such as eland bulls, kudu and waterbuck may cause problems when held in the boma since they are excellent jumpers and may jump out if they become overly nervous. This is normally overcome by placing of shade net over the specific boma area. Buffalo do not challenge the plastic at all unless they can see out or through it (Le Grange, 2006). Certain species are also more amenable to being driven, for example eland and blesbok, while others, such as the kudu, easily become nervous and difficult to herd (Bothma & Van Rooyen, 2005; Ledger *et al.*, 1967). Because species such as impala are naturally large-herd animals, they are also easily herded and captured in a boma (Furstenburg, 2005). Other methods of cropping may be preferred over this method since its set-up may be more costly and labour needs to be trained in an assembly line-type approach to process the carcasses as quickly as possible (Bothma, 1996; Le Grange, 2006).

2.2.5. Helicopter cropping

This method consists of shooting animals from a helicopter during the daytime (from an altitude of around 6 m) using a 12-bore shotgun while a ground team follows in a vehicle to collect the dead animals (Bothma, 1996; Kroucamp, 2004). Hunting may be carried out with semi-automatic shotguns so that as many as six animals can be shot in succession as they run in a line (Le Grange, 2006). Shooting from a helicopter has the advantage of selective culling as well as being practical in dense bushveld areas where it is difficult to locate animals on the ground (Rudman, 1983). A quick estimate of the game population can also be made during the cropping operation and cropping can take place over a larger area than would be possible with boma cropping (Bothma, 1996). According to Van Rensburg (1992), this method is the most expensive when compared to boma cropping and cropping from a vehicle and is usually only employed in large scale commercial operations since it requires high capital investment. This method has been successfully used for impala, blesbok, springbok and buffalo in Africa as well as red deer in New Zealand (Le Grange, 2006). Veary (1991) noted similar muscle ultimate pH values as those obtained during night cropping, although according to Le Grange (2006), experience in Zimbabwe has shown that the high levels of adrenaline released in the animals during shooting and the excessive increase in body temperature result in extremely rapid meat decay (probably due to high ultimate pH values and the occurrence of dark, firm and dry meat), usually rendering the carcasses unfit for human consumptions. A high success rate is also dependent on the skill and accuracy of the shooter as well as the open nature of the terrain so that only head and neck shots can be utilised. According to Mostert (2007), this may not always be the case and broken legs can sometimes be observed in species such as springbok that tend to jump when fleeing. Good communication between the pilot and ground crew is also essential so that carcasses can be recovered quickly. In many cases, it may be necessary for the ground crew to use hand-help GPS navigational equipment for locating the carcasses. Carcasses also need to be gutted as soon as possible to cool the carcasses and reduce decay (Le Grange, 2006). Another disadvantage to this method is that is may inflict unnecessarily high stress (due to exercise) and bruising on the animals as well as damage to fences when larger animals attempt to escape the property (Rudman, 1983).

Capture myopathy may also become a problem if animals are chased for extended periods before being shot. This occurs because of over exertion since wild animals are generally not equipped to run fast over long distances or for long periods of time. Overexertion results in increased plasma glucose levels and the oxidative capacity of the mitochondria is exceeded with the intense simultaneous involvement of the majority of the animal's muscles. In the resultant hypoxia, anaerobic metabolism in increased, lactate levels rise dramatically, cell membrane permeability is increased and various intracellular enzymes are released with a simultaneous reduction in blood pH, i.e. blood acidification (Veary, 1991). Following a number of chemical changes in the blood, reactions take place in the damaged tissues and the kidneys become affected as well. The resulting physiological and chemical effects interfere with the normal functioning of several vital organs. Animals then die either as a result of kidney degeneration or heart failure (Bothma, 1996). The high acidification in the muscles of such animals will hold detrimental effects for the meat quality since a high ultimate pH in meat results in meat with a high spoilage potential and a resulting short shelf-life (Newton & Gill, 1981).

2.2.6. Conventional hunting

This method is suited to all game species and can be applied either on foot, from a hide or from a vehicle. Cropping should be done during the daytime, preferably in the early morning or late afternoon if there are no cooling facilities available (Tinley, 1972). It is advantageous as it causes little disturbance, specifically if done on foot which prevents the animals associating vehicles with hunting, and game do not run much and consequently yield a higher quality of game meat. Selective cropping can also take place with regard to age, sex and social grouping (Bothma, 2006). Although it is unethical to hunt game at waterholes, it is effective for game which occurs in small groups, for example warthogs, for timid game such as bushbuck and nyala and in dense bushveld areas where walking is virtually impossible (Bothma, 2006). According to Tinley (1972), it is preferably that all shots be either head shots, side, frontal or rear shots (Figure 2). In the case of zebra, which seldom present frontal shots, the use of dogs may be advantageous since zebras are inquisitive and dislike dogs and will present themselves for a frontal shot if approached by dogs (Tinley, 1972). This method is usually only used when game is cropped on a small scale, for own consumption by the ranch owner or in the case of paid hunting safaris since the off-take rate is very slow.

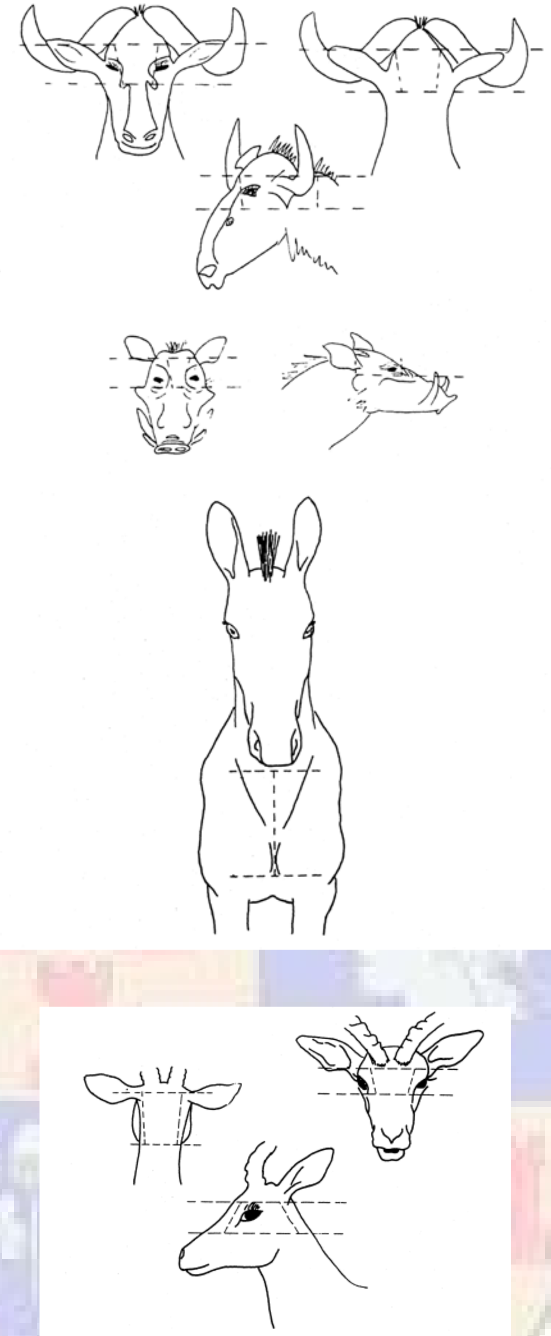

Fig. 2. Shot placement on different species of game which will result in immediate death (Tinley, 1972)

2.2.7. Cropping losses

According to Von La Chevallerie and Van Zyl (1971), cropping losses are usually the result of three factors:

a) Loss of meat unfit for human consumption because of bullet damage;

b) Animals shot and not recovered;

c) A decline in meat quality because of *ante-mortem* stress to which hunted and wounded animals are subjected.

This last factor will be discussed in more detail later. Wastage of meat due to bullet damage may be prevented by the right placement of shots (Table 3) as well as by ensuring good marksmanship of the hunter beforehand since the more difficult shots such as head and neck shots are also the most preferred shots (Bothma, 1996). Studies conducted by Hoffman (2000a, 2000b) and Hoffman and Ferreira (2000) found that head shots resulted in no wastage of meat and high neck shots resulted in less than 2% wastage of meat. In the meat trade, the neck is also classified as a lower value joint (Hoffman, 2001) so that the damage done with regards to carcass value by shots through this region is almost negligible. On welfare grounds, head shots are preferred since they usually result in instantaneous death while neck shots may result in paralysis and may not render the animal immediately insensible (Lewis *et al.*, 1997).

Traditionally, hunters prefer to shoot animals through the shoulder rather than through the head or neck since it gives the shooter a larger and more stationary target area and less chance of missing. This type of shot is usually placed at the top of the crease at the back of the foreleg, in the position where large vital organs such as the heart and lungs can be found as well as major blood vessels and nerves. A bullet in this area will either hit the heart, resulting in massive haemorrhage or will hit the lungs and large blood vessels, resulting in lung collapse and a “quick” death (Hoffman, 2001). Although this shot can result in up to 20% carcass damage (Table 3), it is the type of shot that is most likely to result in death since, even if the exact target area is not hit, most shots in this shoulder area will either result in death (even if not instantaneous) or at least severe wounding of the animal causing no or poor mobility. In the latter case, a second shot should be enough to kill the animal. According to Van Rooyen *et al.* (1996), gut shots should also be avoided since contamination of the carcass from the stomach and intestinal contents may occur, which is unacceptable.

The behaviour of the animals may also affect cropping losses and Lewis *et al.* (1997) found that males generally respond more actively to disturbances than females and show an increase in response when in breeding herds, leading to a higher percentage of animals being wounded.

Table 3

Bullet damage from shots at various localities as a percentage of total carcass weight (adapted from Von La Chevallerie *et al.*, 1971)

Locality of the bullet wound	**Percentage of carcass damaged**
Neck	3.18
Neck and shoulder	15.66
Shoulders	20.58
Shoulder and ribs	22.22
Ribs	5.47
Back	12.47
Other (e.g. stomach, hind quarters)	15.61

Rifle calibre is also important and light calibres are preferred where possible since they cause the least amount of damage (Hoffman, 2001). An impala should, for example, preferably not be shot from a short distance with a 7 mm Remington Magnum but rather with a 7 x 75 mm or a .30–06 with a heavy bullet (Bothma, 1996).

2.3. PHYSICAL CHARACTERISTICS OF MEAT

The physical characteristics of meat are important since they are very often those characteristics that drive consumer purchasing decisions. These characteristics include colour, water-holding capacity (WHC) and tenderness and are affected by both *ante-mortem* and *post-mortem* factors, which most notably influence the pH of the muscle during its conversion to meat (Lawrie, 1998).

2.3.1. Conversion of muscle to meat

At the moment of death of an animal, its various tissues maintain their particular types of metabolism under local control, and although the muscles are not actively contracting, energy is still required to maintain the temperature and organisational integrity of the cells (Lawrie, 1998). ATP production is required to keep the muscle in a relaxed state and *post-mortem* muscle has a high rate of ATP turn-over (Bate-Smith & Bendall, 1949 as cited by Lawrie, 1998). Cessation of blood flow causes the elimination of the blood-borne oxygen supply to the muscles, a subsequent fall in the oxidation reduction potential and an inability of the cytochrome enzyme system to resynthesise ATP (Lawrie, 1998). Any subsequent metabolism will be anaerobic and muscle glycogen will be degraded (glycogenolysis) and metabolised through anaerobic glycolysis in order to rephosphorylate ADP to ATP (with the use of creatine phosphate) to prevent the permanent formation of actomyosin cross-bridges (Scheffler & Gerard, 2007). The break-down of glycogen causes the formation of lactic acid and hydrogen (H^+) and since there is no circulation to remove these waste products, it accumulates in the muscle, causing a drop in pH (Figure 3). Since the supply of glycogen *post-mortem* is finite, ATP production can only be maintained for a short period. Glycolysis usually ceases before the glycogen stores are depleted and it is thought that this may either be because some of the glycolytic enzymes cannot function at the resultant low pH values or because the conversion of adenine nucleotides to inosine derivatives may halt the glycolytic flux (Greaser, 2001). The pattern of pH decline *post-mortem* is similar in most animals (Figure 3), although the rate and extent may vary between species and muscles and can be affected by a number of intrinsic and extrinsic factors. The pH fall *post-mortem* tends to typically begin at around pH 7 and decline to around pH 5.5, referred to as the ultimate pH (Warriss, 2000).

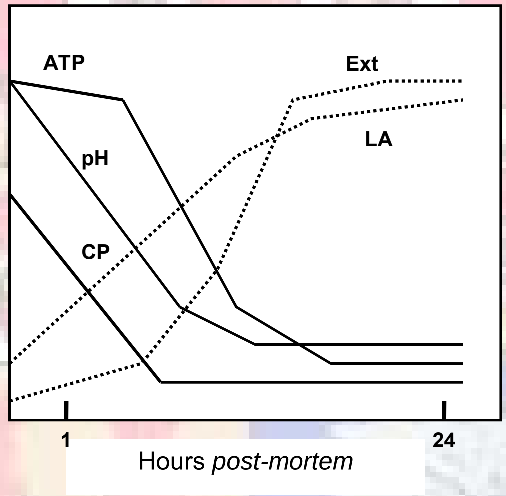

Fig. 3. Chemical and physical changes in muscle *post-mortem*. The pattern shown would be typical for pig muscle undergoing normal metabolism. Abbreviations: ATP – adenosine triphosphate; CP – creatine phosphate; LA – lactic acid; Ext – extensibility (adapted from Greaser, 2001).

As *post-mortem* anaerobic glycolysis proceeds, the muscle starts to lose extensibility, referred to as the onset of *rigor mortis*. The time to onset of *rigor mortis* may differ between species and usually coincides with the disappearance of ATP from the muscle (Figure 3) (Greaser, 2001; Lawrie, 1998). Any factors affecting the levels of glycogen and creatine phosphate at death, will affect the time to onset of *rigor mortis* (Warriss, 2000). This loss of extensibility is due to the formation of permanent actomyosin cross-bridges, since in the absence of ATP, tropomyosin and troponin molecules can no longer prevent the binding of the actin and myosin molecules of the thin and thick filaments (Swatland, 1994). The loss of extensibility begins with a delay phase, where after it proceeds very slowly at first, followed by the fast phase, during which it proceeds rapidly until complete extensibility is attained throughout the muscle, at which point ATP is completely exhausted (Lawrie, 1998). This signals the completion of the conversion of muscle to meat (Swatland, 1994).

2.3.2. Colour

The colour and appearance of meat is the first quality taken into account by consumers when purchasing meat, with a brown colour being synonymous with contamination for consumers (Ouali *et al*, 2006). Meat that is either too dark or too light may also be discriminated against (Issanchou, 1996). Carpenter, Cornforth and Whittier (2001) established that there was a close relationship between colour preference and a consumer's decision to purchase beef and that consumers preferred bright red beef instead of purple and brown. The colour of meat is affected by a variety of factors, including the rate of pH fall *post-mortem*, muscle-fibre type and the type of myoglobin molecule primarily present in the meat (Honikel, 1998; Lawrie, 1998).

The meat of most land mammals has a characteristically red colour, primarily caused by the protein myoglobin. This protein is chemically very similar to the blood protein haemoglobin and consists of a globular protein of about 153 amino acids surrounding a porphyrin ring structure held in a pocket of the protein (Greaser, 2001). As early as 1932, it was determined that, although muscle does contain some haemoglobin, haemoglobin does not affect the colour of meat unless bleeding was faulty because haemoglobin is mainly restricted to the fine vascular supply permeating the muscle (Lawrie, 1998). The function of myoglobin in the live animal is to temporarily bind oxygen intermediate to haemoglobin in the blood and thus allow it to be reduced by respiration in the mitochondria. Due to this, its concentration may vary between muscles according to their specific function in the body so that the most active muscles, i.e. those requiring the largest supply of oxygen, contain more myoglobin than those less often used (Greaser, 2001). This same generalisation carries over into other areas such as age, sex, species and breed. Shorthose and Harris (1990) have suggested that free-range animals have higher concentrations of myoglobin than feedlot animals since the former receive more exercise. According to Hoffman (2000a), game meat in South Africa is often perceived as being of a dark, unattractive colour and some argue that this is due to the increased activity of game animals when compared to that of domestic livestock, which results in higher concentrations of myoglobin in the muscles of the former. Differences between game species have also been observed by Onyango, Izumimoto and Kutima (1998), who found that zebra meat had higher concentrations of myoglobin than meat from cattle, oryx and red hartebeest, resulting in a noticeably darker colour. It is important to note that the colour of the surface of meat is determined not only by the quantity of myoglobin present in the meat, but also by the type of myoglobin molecule and its chemical state, as well as the physical and chemical condition of other components in the meat (Lawrie, 1998).

The most important chemical form of myoglobin in fresh meat is oxymyoglobin. Because of its role of storing oxygen, the iron in the porphyrin ring of myoglobin is able to bind molecular oxygen, converting myoglobin into oxymyoglobin (Greaser, 2001). Although this reaction is limited to the surface of the meat only, the oxymyoglobin pigment is of major importance since it causes the appealing bright red colour of meat preferred by consumers (Lawrie, 1998). On the meat surface, prolonged exposure to the atmosphere causes the oxidation of the haem iron from a ferrous (Fe^{2+}) to a ferric (Fe^{3+}) state, giving rise to brown metmyoglobin (Ouali *et al.*, 2006). Metmyoglobin is the most commonly occurring undesirable pigment on meat surfaces and Carpenter *et al.* (2001) have found that, once metmyoglobin reaches 30-40% of the total amount of pigments on the meat surface of fresh beef, consumers will decide not to purchase the meat. Conditions which accelerate the production of metmyoglobin include low pH values, heat, salts and ultraviolet light. Desiccation of the meat surface, as happens in the case of prolonged chilled storage, can increase the salt concentration on the meat surface and thus promote metmyoglobin formation (Lawrie, 1998). According to Wiklund, Johansson and Malmfors (2003), colour stability is determined by the rate of metmyoglobin accumulation in the surface layer of meat.

The colour changes that occur on the meat surface can be described either subjectively or objectively. Since colour perception between people may be variable, the objective description of meat colour may be difficult and problematic. For this reason, instrumental colour measurements are accepted as more objective and reproducible and a number of options are available for these types of measurements. For the purpose of this study, the CIElab colour system (Commission International de L'Eclairage, 1976) will be used with the three measurements L*, a* and b*. Stevenson, Seman, Weatherall and Littlejohn (1989) noted that the CIELab colour scale is an appropriate measure for venison meat colour. The L* value indicates lightness, the a* value indicates the red-green range and the b* value indicates the blue-yellow range. From these values, hue angle (which defines the colour) and chroma (which defines colour intensity) can be calculated (Honikel, 1998). According to Volpelli, Valusso, Morgante, Pittia and Piasentier (2003), the L*, a* and b* values characteristic of the dark red colour of venison are L* < 40, high a* values and low b* values. This is in agreement with various other authors who have reported L*, a* and b* values of 30.53, 12.52 and 8.75 respectively for impala, 30.71, 13.39 and 8.73 respectively for springbok and 31.79. 11.04 and 8.70 respectively for kudu (Kritzinger *et al.*, 2002; Hoffman, Kroucamp & Manley, 2007; Mostert, 2007).

2.3.3. Water-holding capacity

Water is one of the major constituents of muscle and as much as 75% of lean muscle consists of water (Honikel, 2004). According to Huang and Nip (2001), the bulk of water within the muscle can be found in three locations, namely within the filament, in the interfilamental space and in the extracellular space. This water can be classified as either "bound" or "immobilised", or "free" according to their form of binding. "Bound" water is found within the filament and is strongly associated with myofibrillar proteins through hydrogen bonding. Since the total concentration of protein in the muscle is approximately only 200 mg/g, this bound water makes up less than a tenth of the total water found in muscle (Huff-Lonergan & Lonergan, 2005). "Immobilised" water is thought to be held either by steric effects and/or by attraction to bound water, and although not bound to muscle protein per se, it is held within the structure of the muscle. It is this "immobilised" water that is most affected by the rigor process during the conversion of muscle to meat (Huff-Lonergan & Lonergan, 2005; Lawrie, 1998). 'Water-holding capacity' (WHC) refers to the ability of meat to bind its own water or, under the influence of external forces such as pressure and heat, to bind added water (Honikel, 2004; Swatland, 1994). Water-holding capacity is an important feature of meat quality since it influences essential aspects such as the appearance of meat prior to cooking, and its tenderness and juiciness during eating.

Interfilament spacing is one of the major determinants of the WHC of muscle (Lawrie, 1998), and lateral expansion or contraction of the filament lattice will determine the uptake or expulsion of water from the muscle. This expansion and contraction is a function of long-range electrostatic forces, which affect the interaction between myosin and actin (Warriss, 2000). During the conversion of muscle to meat and the development of rigor, the pH of muscle declines towards the isoelectric point of the major proteins within the muscle. At this point, the positive and negative charges of the proteins are essentially equal so that the positive and negative groups within the protein are attracted to each other (Huff-Lonergan & Lonergan, 2005). Repulsion structures within the myofibril are also reduced so that these structures pack more closely together, and, as the lattice shrinks, water is expelled from the muscle fibres into the extracellular space (Warriss, 2000). This expelled water will be manifested as exudate or “drip” and, as a result, there will always be some water loss from the muscle after death. Drip formation is a function of the WHC of meat and can be measured as such. It is most notably affected by the pH of the muscle, and Bouton, Harris and Shorthose (1971) showed that WHC correlated significantly with pH in both whole and minced muscle samples.

Another measure of the WHC of meat is cooking loss, which is measured as the amount of moisture lost from the meat during cooking. During heating (at temperatures ranging from 36°C to 75°C), the meat proteins denature and the cellular structures are disrupted so that extra- and intracellular water is released from the meat (Honikel, 2004). Some of the structural changes that occur include transverse and longitudinal shrinkage of the muscle fibres, cell membrane destruction, shrinkage of the connective tissue and aggregation of sarcoplasmic proteins. The extent of cooking loss may vary according to time, temperature and method of cooking, and, according to Lawrie (1998), time-temperature measurement curves of meat during cooking reveal a plateau at about 70°C and then a further increase between 107°C to 155°C. At temperatures above 64°C, collagen in the perimesium and endomesium shrinks, which also affects the cooking loss (Sims & Bailey, 1981). The most important pre- and post rigor factor affecting the cooking loss of individual muscle is the pH, and the work of Marsh, Ringkob, Russell, Swartz and Pagel (1987) shows a linear relationship between cooking losses and pH.

2.3.4. Tenderness

According to Koohmaraie, Veiseth, Kent, shackleford and Wheeler (2003), consumers consider tenderness to be the most important factor determining meat quality. In a review of factors influencing the consumption, selection and acceptability of meat purchases, Jeremiah (1982) concluded that the most common cause of unacceptability in beef was toughness (this was also a common problem in pork and lamb). An example of the importance of tenderness over other factors such as flavour and juiciness is the tenderloin (*M. psoas major*). Savell and Shackelford (1992) found that, although this cut is one of the least flavourful and least juicy cuts of meat, it is the most highly valued retail cut due to its supreme tenderness. A common perception of game meat is that it is tougher than meat from conventional livestock, although results from a study conducted by Von La Chevallerie (1972) found that the Warner-Bratzler shear force values of seven wild ungulate species did not bear out this perception. This correlates with the findings of Hoffman (2001) who found shear force values for impala meat that were similar to those of pork.

Meat tenderness is a function of three factors, namely background toughness, the toughening phase and the tenderisation phase. While the toughening and tenderisation phases take place during *post-mortem* storage, background toughness is already in place at the time of slaughter and does not change during storage (Koohmaraie & Geesink, 2006). The degree of background toughness is related to muscle connective tissue, which includes those proteins that support and maintain the integrity of the muscle. Olsson, Hertzman and Tornberg (1994) stated that background toughness refers to the quality and maturity of the connective tissue in meat. According to Young and Gregory (2001), compared to bony fish, land mammals are subject to greater gravitational stress, which leads to a greater proportion of and more robust mucoskeletal connective tissue. As a result, toughness is a greater problem in meat from these animals than in fish. According to Lawrie (1998), the two main types of connective tissue found in animal tissue are collagen, which is straight, inextensible and non-branching, and elastin, which is elastic, branching and yellow in colour. The latter is generally only a minor constituent of the connective tissue in muscle; however, it shrinks and toughens on heating so that its contribution to meat toughness cannot be completely ignored. Collagen, on the other hand, plays a major role in determining the toughness of meat and constitutes as much as 25% to 30% of the total protein in mammals. Collagen causes toughness in meat caused due to the formation of non-reducible cross-links between collagen molecules whereby a three-dimensional network is generated and a high tensile strength is developed (Lawrie, 1998; Young & Gregory, 2001). These cross-links are formed over prolonged periods of time, which means that the older an animal gets, the more cross-linkages are formed and the tougher the meat will be. Cross-linked collagen is also less soluble than non-cross-linked collagen and tends to endure over long periods of *post-mortem* storage. Furthermore, a fraction of these cross-links is heat-stable so that the links persist in cooked meat (Young & Gregory, 2001). Light, Champion, Voyle and Bailey (1985) found that a higher amount of heat-stable collagen cross-links resulted in tougher meat and concluded that these collagen cross-links were important in determining meat toughness.

The toughening phase of meat occurs during rigor development, when sarcomere shortening occurs. This shortening is also a major factor contributing to the toughness of meat and usually occurs within the first 12 to twenty-four hours after death. As the muscle enters rigor and ATP is depleted, overlapping occurs between the contractile proteins, actin and myosin, resulting in a decrease in the width of the A-band within the sarcomere and a consequent increase in toughness. The relationship between sarcomere shortening and meat toughness was first reported by Locker (1960), and it was later shown that there is a strong negative relationship between sarcomere length and toughness when sarcomere lengths are shorter than 2 µm (Bouton *et al.*, 1978; Herring *et al.*, 1967). The degree of overlap between the contractile proteins can be influenced by temperature, with extreme contraction occurring under low temperatures, a process known as "cold shortening" (Hopkins & Thompson, 2002).

While the muscle enters *rigor mortis*, an opposing effect is already taking place within the muscle, known as *post-mortem* tenderisation. Most of the reduction in toughness is attributable to changes in the myofibrillar proteins, although there is some evidence that intramuscular connective tissue does show signs of degradation (Hopkins & Thompson, 2002). This process of tenderisation is known as *post-mortem* proteolysis and the mechanisms that drive it have been the subject of significant debate. It is known that a number of endogenous enzymes are involved in *post-mortem* tenderisation and it is thought that of these enzymes, the calpains and cathepsins play the most significant roles. The calpain family is thought to be primarily responsible for the tenderisation of meat and, in the living animal, is involved in protein turn-over in cells (Young & Gregory, 2001). They are activated by calcium ions and are known to have maximum activity in neutral to alkaline conditions. The cathepsins, on the other hand, show maximum activity in mildly acidic conditions and, although thought to be more important in the *post-mortem* tenderisation of fish muscles, are most likely less involved in the tenderisation of red meat under normal conditions (Warriss, 2000).

In skeletal muscle, the calpain system consists of at least three known proteases, namely μ-calpain, m-calpain and skeletal muscle-specific calpain, as well as a μ- and m-calpain inhibitor, known as calpastatin (Koohmaraie & Geesink, 2006). Calpastatin has a helical sequence that prevents the calpains from binding to membranes, and its action is pH-dependent, with minimal activity at a pH below 6.5. Calpastatin is also a substrate to the calpains and when the pH drops below 5.5, calpastatin is proteolysed by the calpains in the presence of calcium (Lawrie, 1998). Although the calpains have no effect on actin and myosin per se, known substrates of the calpain system include troponin T and I, C-proteins, Z-lines (desmin), connectin, M-line proteins and tropomyosin (Lawrie, 1998). Koohmaraie (1996) found that μ-calpain is responsible for the proteolysis of some of the key myofibrillar proteins in muscle and indicated this as the underlying mechanism responsible for the tenderisation of meat during storage at low temperatures. Other studies have found that the activity of μ-calpain decreased significantly during the onset of rigor, while the activity of m-calpain was largely unaltered for up to 3 days *post-mortem* (Hopkins & Thompson, 2002). In the latter case, it may be that insufficient calcium is available to activate m-calpain, which would suggest significant tenderisation potential remains in the muscle in the form of non-activated m-calpain. Koohmaraie (1990) found that the addition of calcium to the muscle *post-mortem* was successful in shortening the time necessary for ageing to occur in beef. The third calpain, skeletal muscle-specific calpain, is not well studied since its close association with the myofibrillar protein, titin, makes it difficult to extract from skeletal muscle tissue. Although it is not inhibited by the calpain inhibitor, calpastatin, its expression in vitro is hampered by rapid autolysis of the enzyme at physiological levels of calcium (Koohmaraie & Geesink, 2006).

2.3.5. The relationship between pH and the physical characteristics of meat

The acidification of muscle is one of the most fundamental changes that occurs during the conversion of muscle to meat, and the rate and extent of this acidification has a particular influence on the colour, WHC and tenderness of the meat. The acidification is measured in terms of the pH of the muscle, which is a measure of the amount of hydrogen ions in a solution (Warriss, 2000). Measuring pH also allows for the assessment of glycolysis in the muscle since *post-mortem* anaerobic glycolysis results in lactic acid build-up in the muscle and thus, muscle acidification. As the muscle enters rigor, hydrogen ion production decreases with the diminishing rate of anaerobic glycolysis and myosin ATPase activity as the muscle is cooled. This leads to a deviation in pH decline from a linear function so that it is best represented by an exponential decay curve (Bruce, Scott & Thompson, 2001).

As muscle pH decreases *post-mortem*, the muscle proteins tend to denature and this change in the proteins increases the light-scattering properties of the contractile elements of the muscle fibre (Warriss, 2000). According to Swatland (2004), the myofilament lattice shrinks as the pH decreases so that the myofibrillar refractive index increases, eventually exceeding that of the sarcoplasm, and this increases light scattering. Strong scattering shortens the light path through the meat, which reduces selective absorbance and the observer sees a minimal myoglobin effect. Although influenced by the rate of glycolysis, it is the ultimate pH of the meat that has the most notable effect on meat colour. Guignot, Touraille, Ouali and Renerre (1994) found that the lightness, redness and reflectance of veal were negatively correlated with ultimate pH, so that these measurements decreased as the ultimate pH increased. According to Lawrie (1998), if the ultimate pH of meat is high, the muscle proteins will be considerably above their isoelectric point so that much of the water in the muscle will still be associated with them and the fibres will be tightly packed together, presenting a barrier to diffusion. Moreover, the surviving activity of the cytochrome enzymes will be greater so that, as a result of these two factors, the bright-red oxymyoglobin becomes diminishingly small and the purplish-red colour of myoglobin will dominate, making the meat appear darker. The opposite is true for a low ultimate pH, which causes the protein structures of the muscle to “open” and scatter light, also exposing the myoglobin to conditions which cause its oxidation to bright-red oxymyoglobin.

The WHC of meat is also affected by pH and drops from a high of around pH 10 to a low at the isoelectric point of the meat proteins between pH 5.0 and 5.5 (Swatland, 1994). At this isoelectric point, the net charge of the myosin and actin molecules is at a minimum so that the WHC is at its lowest (Pearson & Young, 1989). During *post-mortem* pH decline, the filamental lattice also shrinks so that the amount of water held by capillarity diminishes and will be released to the exterior if the meat is cut (Lawrie, 1998). According to Hamm (1986), in the pH range 5.0 to 6.5, any alteration of pH will have a great influence on the WHC of meat. This effect is most likely related to the ionisation states of histidine and, to a lesser extent, glutamic acid and, although changes in the WHC at this pH range are completely reversible, at a pH above 10 or below 4.5, irreversible changes occur. Bouton, Harris and Shorthose, (1971) found that the WHC of both minced and whole meat samples was positively correlated with pH so that WHC increased as pH increased. This is in agreement with Thomas, Gondoza, Hoffman, Oosthuizen and Naudè (2004), who found that drip-loss percentage and pH followed opposite trends so that an increase in pH resulted in a decrease in drip loss (which results from the increase in WHC). Guignot *et al.* (1994) found that drip loss, cooking loss and roasting loss were negatively correlated with pH, most significantly with the ultimate pH. The latter is in agreement with Offer and Knight (1988), who found that high temperature conditions and low pH in *post-mortem* muscles lead to protein denaturation and, consequently, a decrease in the WHC of the meat.

As mentioned previously, tenderness is a function of a number of factors and, because of this, its relationship with pH is not straightforward. While some authors have found a linear relationship between pH and tenderness (Purchas & Aungsupakorn, 1993; Jeremiah, Tong & Gibson, 1991), others have found a curvilinear relationship, with minimum tenderness between pH values 5.8 and 6.2 (Silva, Patarata & Martins, 1999; Watanabe, Daly & Devine, 1996). Although the reason for this curvilinear relationship has not been fully explained, Yu and Lee (1986) suggested that there is less proteolytic activity at the intermediate pH values of 5.8 to 6.2, because this range lies outside the pH optima of the two main proteolytic enzyme systems. As a result, it can be expected that tenderness should increase at an ultimate pH of 6 to 7 since calpain activity is maximal at these neutral pH values, while tenderness should also increase if the pH falls below 6, where cathepsin activity is maximal. Alternatively, it has been suggested that sarcomere length may play a role since it has been shown that sarcomere length decreases as the ultimate pH decreases below 6.2 (Purchas, 1990; Purchas & Aungsupakorn 1993). Bouton *et al.*, (1971) found a curvilinear relationship between the ultimate pH of beef and sensory toughness, with peak toughness occurring in meat with an ultimate pH of about 6. In contrast, Silva, *et al.*, (1999) found that beef tenderness increased linearly with increasing ultimate pH (5.5 to 6.7), even after one, six and thirteen days of ageing. What is clear from these findings is that the rate and extent of glycolysis *post-mortem* has an effect on the pH and temperature of the muscle and will therefore have a definite effect on the rate and extent of proteolytic enzyme activity and thus the *post-mortem* tenderisation process (Koohmaraie, Schollmeyer & Dutson, 1986).

2.4. THE EFFECT OF STRESS ON MEAT QUALITY

2.4.1. Defining stress

As cited by Dantzer and Morméde (1983), the stress response was originally defined by Selye (1956) as a nonspecific reaction regardless of the nature of the stressor. With reference to Selye's concept, these authors explained stress as follows: exposure to nocuous environmental factors (stressors) which elicit a nonspecific reaction. During the stress response, the constancy of the internal environment of an organism is threatened and it therefore follows that any agent that elicits such a change can be classified as a "stressor". Such stressors may overtax the animal's ability to cope so that the animal is forced to respond with physiological and behavioural changes that are designed to be adaptive or to promote survival (Warriss, 2000). According to Dantzer and Mormède (1983), interactions between these physiological and behavioural changes are essential and, although given physiological responses are somewhat nonspecific to the stressor, behavioural responses are specific to particular stressors and aimed at controlling the threatening stimulus. The nature of the stressor will determine the amount and extent of the physiological and behavioural changes that will occur upon exposure to it.

2.4.2. Endocrine response of animals to stress

All mammals respond to various stresses in a very characteristic way. For the sake of simplicity, this response can be described under two main headings:

(1) A rapid, short-term "alarm" response (commonly referred to as the fight-or-flight response), and
(2) A response that occurs after the "alarm" response and persists over a longer period of time (commonly referred to as the general adaptation syndrome).

The fight-or-flight response was first studied by Cannon (1935) and involves the activation of the sympathetic nervous system and the adrenal medulla (often referred to as the sympatho-adrenal system). It has a short latency response involving the secretion of the catecholamine hormones, epinephrine and norepinephrine, that enables the subject to mobilise its resources quickly for the metabolic requirements of fight or flight (Dantzer & Mormède, 1983).

The general adaptation syndrome was originally described by Selye (1956) and involves the hypothalamic-pituitary-adrenocorticoid system (HPA axis), which is characterised by the secretion of adrenocorticotropic hormone (ACTH) from the anterior pituitary which, in turn, activates the release of corticosteroids from the adrenal cortex. Figure 4 gives a generalised overview of the functioning of the two endocrine systems.

The nervous system of mammals comprises the autonomic nervous system and the central and peripheral nervous system. The main function of the autonomic nervous system is to maintain the body's homeostasis and it too has two components, namely the parasympathetic nervous system and the sympathetic nervous system (Warriss, 2000). The sympathetic nervous system promotes responses that prepare the animal for strenuous physical activity in the face of stressful situations and, as already mentioned, this response is often termed the fight-or-flight response (Sherwood, Klandorf & Yancey, 2005). The sympathetic nervous system innervates the adrenal glands and when an animal is subjected to a stressful stimulus, the adrenal medulla is stimulated to release both catecholamines: epinephrine and norepinephrine. This response can occur within less than a minute and although these adrenomedullary hormones are not essential for life, virtually all the organs in the body are affected by them. Norepinephrine functions mainly as a neurotransmitter in the sympathetic nervous system, while epinephrine mainly brings about such changes as are necessary to maintain homeostasis. The release of the cathecholamines triggers increased heart and respiration rates, increased break-down of glycogen and fat stores to release extra fuel into the blood, dilation of the bronchial airways to allow for better airflow into the lungs, arousal of the central nervous system and alertness, among other things. Both epinephrine and norepinephrine inhibit insulin secretion and stimulate glucagon secretion from the islets of Langerhans, which ensures plentiful glucose in the blood to fuel physical exertion and maintain brain function (Hill, Wyse & Anderson, 2004). Measurement of the catecholamines immediately prior to slaughter may give a good indication of possible acute stress experienced by the animal as well as the expected meat quality, since the release of catecholamine prior to slaughter could be expected to lead to increases in the rate of *post-mortem* glycolysis through the activation of phosphorylase and thus to affect meat quality (Shaw & Tume, 1992). Lowe, Devine, Wells and Lynch (2004) found that bulls from the same farm that were grouped together prior to slaughter (termed 'non-mixed' bulls) had lower levels of urinary epinephrine levels than bulls from different farms that were grouped together prior to slaughter (termed 'mixed' bulls). It was concluded that this was due to the agonistic interaction between animals from different origins, which resulted in pre-slaughter stress. The bulls with the higher epinephrine levels also tended to have higher muscle ultimate pH values. Lay, Friend, Randel, Bowers, Grissom and Jenkins (1992) also found a significant increase in epinephrine in blood from calves that had been hot-iron branded, and it has been found in both horses and cattle that intense spurts of exercise can result in increased levels of plasma epinephrine and norepinephrine (Martinez, Godoy, Naretto & White, 1988; Blum and Eichinger, 1988).

The actions of the sympatho-adrenal system and the HPA axis are not independent of each other and are, in fact, interlinked through the functioning of corticotropin-releasing hormone (CRH). CRH is produced by the hypothalamus and, although it acts as a neurohormone that stimulates the secretion of ACTH, it has a secondary role as a neurotransmitter, stimulating the sympathetic nervous system (Figure 4). It is also known that CRH and norepinephrine have many connections in the brain, and it appears that epinephrine may function together with CRH to stimulate the secretion of ACTH from the pituitary gland (Hill *et al.*, 2004). Once ACTH is released into the blood stream, it stimulates the cortex of the adrenal gland to secrete the corticosteroid hormones (also known as glucocorticoids), cortisol and corticosterone. Although most animals produce both hormones, cortisol predominates in primates, dogs, cats, pigs, sheep and cattle, while corticosterone predominates in rodents and chickens (Warriss, 2000). Glucocorticoids have catabolic (proteolytic and lipolytic) activity in the peripheral tissues and anabolic activity in the liver, including gluconeogenesis and protein synthesis (Mormède *et al.*, 2007). The glucocorticoids reinforce the actions of the sympathetic nervous system, and, unlike epinephrine and norepinephrine, they are able to stimulate protein break-down in the muscle to provide amino acids for gluconeogenesis in the liver and for tissue repair. The liver then releases the newly-formed glucose into the blood as an immediate energy source for the body (Hill *et al.*, 2004). Apart from its effect on the secretion of glucocorticoids, there is also evidence that ACTH suppresses the release of growth hormone (GH), thyroid stimulating hormone (TSH) and gonadotropins, effectively suppressing growth, metabolism and reproduction so that energy can be diverted towards the body’s stress needs (Sherwood *et al.*, 2005). The glucocorticoids also play a role in regulating the immune system, and studies have found that prolonged glucocorticoid elevation due to stress can result in the suppression of the immune system, making animals more susceptible to infection and disease. Glucocorticoids also function to regulate the HPA axis through a negative feedback mechanism. High levels of glucocorticoids tend to suppress the secretion of CRH by the hypothalamus and also reduce the responsiveness of the ACTH cells in the anterior pituitary to CRH. As a result, the pituitary secretes less ACTH, and the adrenal cortex receives less of a stimulus to secrete glucocorticoids (Hill *et al.*, 2004).

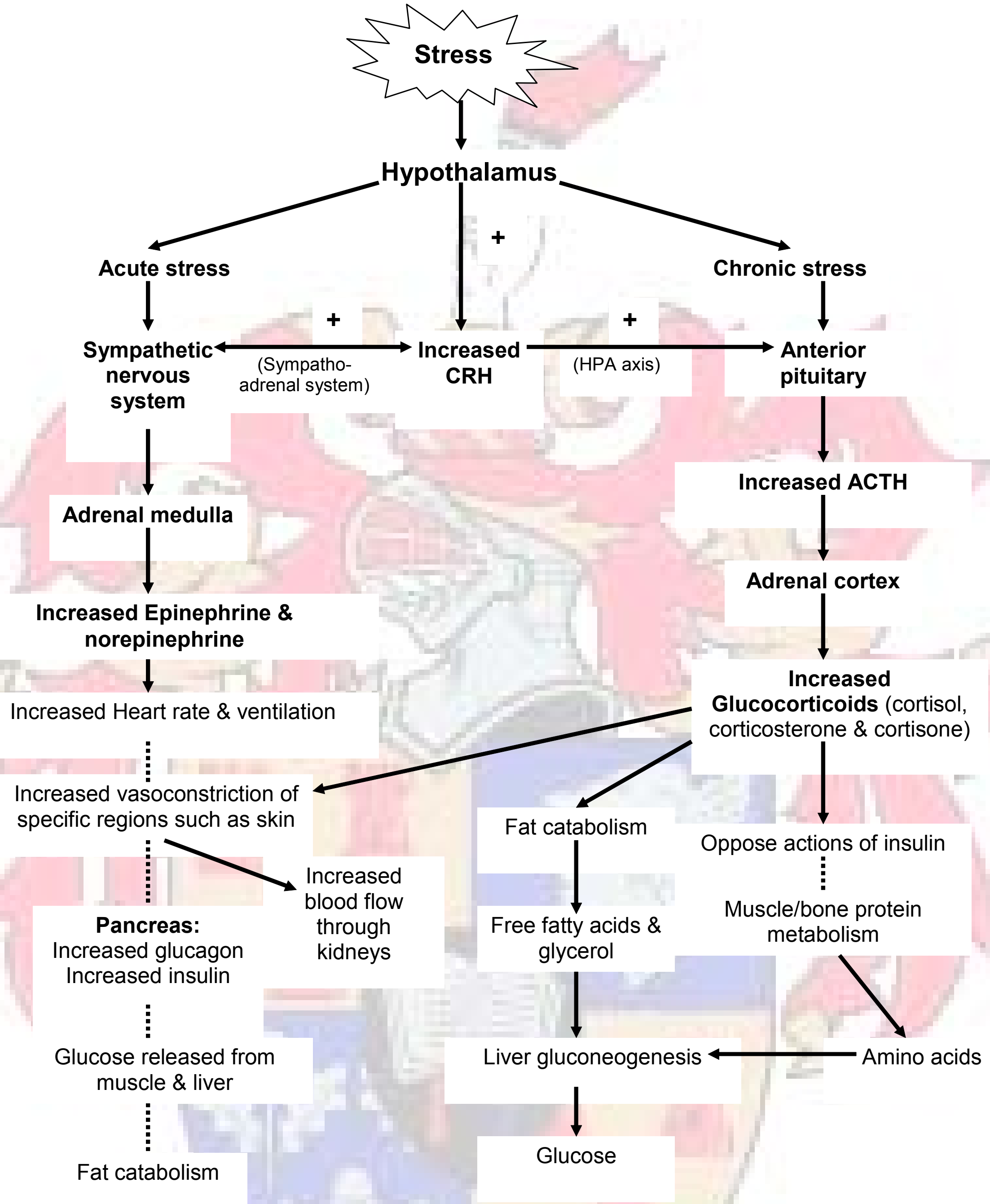

Fig. 4. A generalised overview of the mammalian stress response (adapted from Hill *et al.*, 2004; Sherwood *et al.*, 2005)

Many studies have used cortisol to assess the effect of various pre-slaughter treatments on animal welfare. Knights and Smith (2007) found increases in the transport time of cattle prior to slaughter resulted in increased levels of plasma ACTH and cortisol and that these levels remained high for up to 6 to 8 hours. In a study by Rhodes, Nippo and Gross (1994), it was found that tail docking in lambs had a significant chronic endocrine effect so that cortisol levels were consistently higher in docked animals versus the control animals and remained high for up to three days after docking. In pigs, Shaw, Trout and McPhee (1995) found that animals that produced dark, firm and dry meat as a result of pre-slaughter stress had significantly higher cortisol levels than those animals that produced normal meat. These authors also concluded that cortisol may be a better measure of *ante-mortem* stress since, unlike catecholamines, the act of stunning and exsanguination has little effect on the level of cortisol in the blood. Although the HPA axis is highly sensitive to the emotional response of an animal to an environmental stimulus, care must always be taken when using glucocorticoids as a measure of stress in animals since their secretion may be subject to a diurnal cycle. In diurnal species, including most farmed animals, a peak in glucocorticoid secretion is observed in the morning and a trough during the evening and at night (Mormède *et al.*, 2007).

2.4.3. Other measurable metabolites as indicators of *ante-mortem* stress

According to Shaw and Tume (1992), there are at least two ways of quantifying stress in animals: (1) behavioural response; and (2) measurements of animal tissues and fluids. The measurement of catecholamines and glucocorticoids is a popular method, although there are a number of other plasma and muscle constituents that may also give good indications of the type and amount of stress experienced by an animal.

Firstly, other hormones that may give an indication of stress in animals include CRH, ACTH as well as the thyroid hormones T_3 and T_4. CRH is secreted by the hypothalamus in response to any stress that threatens homeostasis and, in turn, it stimulates both the sympatho-adrenal system and the HPA axis (Figure 4). CRH should be measured in conjunction with either the glucocorticoids or the catecholamines to determine whether the stressor is acute or chronic. ACTH is secreted in response to chronic stress and stimulates the secretion of the glucocorticoids. Its measurement will give an indication of whether a stressor was severe enough to elicit the response of the glucocorticoids. The thyroid hormones assist in lipid and carbohydrate metabolism and their actions are intimately interrelated with those of the catecholamines (Shaw & Tume., 1992). Their measurement will thus give the same indication as that of the catecholamines, although T_3 is a much stronger hormone than T_4, which may make its measurement much easier.

Aspartate aminotransferase (ASAT) and urea are also often measured in plasma samples, along with either cortisol or the catecholamines (Wiklund, Rehnbinder, Malmfors, Hansson & Danielsson-Tham, 2001; Wiklund *et al.*, 2003). ASAT activities have been shown to provide an indication of muscle degeneration and, in reindeer, has been found to increase when the animals are herded, driven and handled manually (Rehbinder, Edgvist, Lundström & Villafañe, 1982). According to Wiklund *et al.* (2001), an increase in urea concentration may be seen in connection with stress-induced muscular lesions and has also been reported as an indicator of the catabolism of proteins due to mal- or under-nutrition or stress. Care should be taken when relating plasma urea levels to stress since urea concentrations may also reflect alterations in dietary protein intake (Säkkinen, 2005).

Muscle glucose, glycogen and lactic acid can also be measured and used to calculate glycolytic potential (GP) according to the formula proposed by Monin and Seller (1985), where brackets indicate concentration expressed as micromoles of lactate equivalents per gram of fresh muscle:

$$GP = 2([\text{glycogen}] + [\text{glucose}] + [\text{glucose-6-P}]) + [\text{lactate}],$$

The GP expresses the muscle’s potential for lactate production which is related to the pH decline of the muscle *post-mortem*. Since the rate and extent of pH decline *post-mortem* is affected by *ante-mortem* stress, amongst others, the GP may be used as an indication of such stress. According to Shaw and Tume (1992), glucose and glycogen by themselves may also provide an indirect indication of stress since their relationship with stress is mediated via the catecholamines and/or glucocorticoids.

Hattingh (1988) and Hattingh and Petty (1992) used the concentrations of eight variables in the blood of animals that have been exposed to acute stress to determine an objective measure of the stress response, based on the percentage maximal change of the eight variables. These variables included lactate, glucose, cortisol, catecholamines, blood haemotocrit, protein, lipids and osmolarity and were used to calculate a species-specific experimental response to stress (SSERTS), which is time- and procedure dependent. This method takes into account the species-specificity of the stress response and is based on changes in the concentration of variables which reflect the (general) hormonal and neuroendocrine balance of an animal at a given time. The authors suggest that the SSERTS measurement is of greater value for measuring the responses of animals to stressors than is the measurement of the concentration of a single blood variable.

2.4.4. The effect of stress on muscle pH *post-mortem* and its implications for meat quality

Meat quality is affected by a number of intrinsic and extrinsic factors and, as mentioned previously, the acidification of muscle *post-mortem* is one of the most fundamental features during the conversion of muscle to meat and will have a profound influence on the quality of the meat. The amount of glycogen available in the muscle for *post-mortem* glycolysis will affect the rate and extent of the pH decline and may vary considerably, depending on the muscle, species and the nutritional status of the animal (Lawrie, 1998). One of the factors that has the largest effect on *post-mortem* muscle glycogen levels is the pre-slaughter stress experienced by the animal. Acute stress activates the release of catecholamines and these have often been implicated in contributing to low ultimate pH values, based on their action of rapid mobilisation of glycogen prior to slaughter (Tarrant, 1988). The release of glucocorticoids caused by prolonged stress may result in the depletion of muscle glycogen stores prior to slaughter, which may result in a higher-than-normal ultimate pH. Smith and Dobson (1990) found that deer shot in the field or penned without handling had low average plasma cortisol concentrations (<7 ng/ml) and muscle pH values less than 5.74, whereas deer that had been herded on the farm or transported to the slaughterhouse had high plasma cortisol concentrations (>20 ng/ml) and muscle pH values above 5.74.

The two most notable quality defects in meat resulting from poor *ante-mortem* handling is pale, soft and exudative (PSE) meat and dark, firm and dry (DFD) meat (Lawrie, 1998). Indeed, these two defects have been a major concern to meat producers world wide since they are unacceptable to consumers, and meat that is classified as either PSE or DFD also has poor processing characteristics (Warriss, 2000). Both phenomena relate to the rate and extent of acidification *post-mortem*. Figure 5 represents an idealised pattern of acidification for PSE, DFD and normal meat. In practice, these patterns may vary enormously, but tend to have similar shapes as those illustrated below:

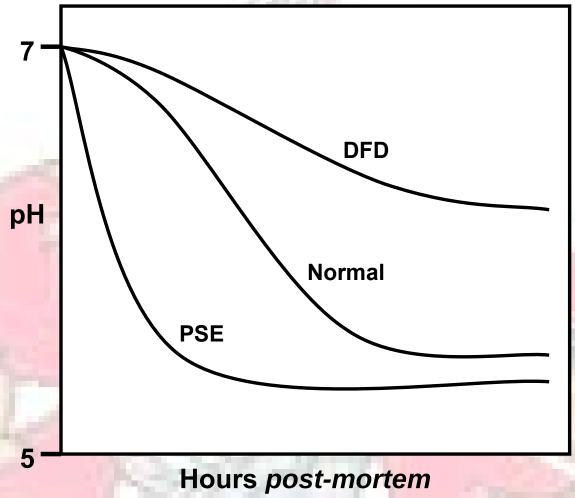

Fig. 5. The pattern of acidification in PSE, normal and DFD meat illustrated schematically (adapted from Warriss, 2000)

In normal meat, pH usually declines gradually from pH 7.4 in living muscle to roughly pH 5.6-5.7 within 6-8 hours *post-mortem* and at 24 hours (pH_u) has an ultimate pH of about 5.3-5.7 (Briskey & Wismer-Pedersen, 1961). In cases of acute stress immediately prior to slaughter, glycogen stores in the body are mobilised so that there is a large amount of glycogen available for *post-mortem* glycolysis, resulting in the large build-up of lactic acid and a rapid rate of muscle acidification characteristic of PSE meat. This hastens the onset of *rigor mortis* while the carcass temperature is still relatively high, resulting in the denaturation of approximately 20% of the sarcoplasmic and myofibrillar proteins (Honikel & Kim, 1986 as cited by Lawrie, 1998). According to Offer (1991), myosin denaturation is the decisive event in determining the soft and exudative state of PSE meat. Upon denaturation, water previously held by the muscle proteins is released and the proteins also become more reflective so that the meat appears paler. Many of the proteins responsible for gel formation in cooked meat are also denatured so that PSE meat is unsuitable for use in comminuted meat products. PSE meat is commonly defined as having a pH at 45 minutes (or 1 hour) *post-mortem* of < 6 (Warriss, 2000). Van der Wal Boling and Merkus. (1989) found that PSE pork loins had a poorer water-holding capacity, higher cooking loss and paler colour compared to normal pork loins. Among meat animals, PSE occurs most commonly in pork and has also been reported in game species such as warthog and buffalo (Hoffman, 2001; Hoffman and Sales, 2007. Although not a major problem, it is also known to occur in beef, especially in double-muscled breeds, as well as turkeys and highly active fish such as tuna (Young & West, 2001).

If animals experience long-term (chronic) stress prior to slaughter, it may lead to the formation of meat that is dark, firm and dry (DFD). DFD meat is characteristically defined as having higher than normal pH values measured at 24 hours *post-mortem*. According to Young and West (2001), the usual pH criterion defining DFD meat is an ultimate pH above 6.0, although this value is arbitrary and the properties of DFD meat evolve as a continuum from pH 5.6 upwards. Prolonged exposure to stress prior to slaughter can result in glycogen depletion in the muscle so that *post-mortem* anaerobic glycolysis becomes very limited. As a result, very little lactic acid is produced *post-mortem* with a resultant higher than normal ultimate pH. As a result of this high pH, very little protein denaturation occurs and water is tightly bound to the proteins. This causes DFD meat to have a very high water-holding capacity to the extent that little if any water is released during mastication, making the meat appear dry. There is little or no shrinkage of the filamental lattice and the refractive indices of the myofibrils and the sarcoplasm are reduced. The muscle presents a closed, translucent structure that absorbs rather than reflects light, making the meat appear much darker. This closed structure also reduces the diffusion of oxygen from the surface into the muscle, and any oxygen that does reach the interior is used up by the high cytochrome activity encouraged by the high pH. This results in only a very thin surface layer of bright red oxygenated myoglobin (MbO_2) allowing the purple colour of the underlying reduced myoglobin (Mb) to show through (Warriss, 2000). DFD meat has a poor appearance as well as having a high ultimate pH which results in a reduced shelf-life, especially if the meat is vacuum-packed. This is because DFD meat contains very small amounts of glucose, the spoilage bacteria's main substrate, and the high pH promotes bacterial growth. As a result, bacterial proteolysis will occur and spoilage odours will arise, even at quite low bacterial concentrations (Wiklund *et al.*, 1995; Gill & Newton, 1981).

DFD is a significant problem in beef, and Tarrant (1981) reported that some 1-5% of steers and heifers, 6-10% of cows and 11-15% of all young bulls produce DFD meat. The major cause of DFD in beef appears to be the mixing of unfamiliar animals prior to slaughter (in lairage) which promotes agonistic behaviour, particularly in young bulls (Warriss, 1990). DFD has also been found to be a problem in venison. According to Wiklund and Malmfors (2004), the traditional reindeer selection technique of using a lasso is the most glycogen-depleting event yet studied in reindeer, resulting in a very high incidence of DFD. Game meat sold in Southern Africa is frequently perceived as being very dark in colour as well as being dry and it has been suggested that this may be the result of poor cropping techniques that place immense stress on the animals, so that DFD meat results. Hoffman (2000a) reported that wounded impala often show meat quality attributes similar to that classified as dark, firm and dry meat.

2.5. OTHER EXTRINSIC FACTORS THAT AFFECT MEAT QUALITY

2.5.1. Species

Species is a genetic aspect and influences a number of factors such as muscularity, muscle activity, growth and muscle composition. The behaviour of an animal is also related to the species since every species has evolved its own unique behaviour in accordance with its environment and its survival needs (Hattingh, 1988). It can thus be expected that the meat from different species will differ in a number of ways.

Muscular activity can vary greatly between species and wilder species or less-domesticated species can be expected to perform a greater amount of exercise. According to Lawrie (1998), higher muscular activity evokes the elaboration of more myoglobin and, as is evident in game meat, this causes the meat to have a darker appearance. Onyango *et al.* (1998) have found that zebra and red hartebeest meat has significantly higher myoglobin contents than beef and, as a result, had lower CIEL* values. Hoffman, Kritzinger and Ferreira (2005) also found that the myoglobin levels of impala were higher than those reported for beef and chicken and concluded that this may account for the darker colour of impala meat compared to that of the latter two species. In the case of mammals like seals and whales, where the need to store oxygen and oxymyoglobin is important in deep dives, myoglobin content in the meat may also be much higher than that of many other land mammal species (Young & West, 2001). Exercise may also reflect differences in fat deposition between species and fat deposition may, in turn, affect the flavour, juiciness and tenderness of meat as perceived by consumers. According to Talbot, Payne, Ledger, Verdcourt and Talbot (1965), game animals tend to deposit more fat around the visceral organs and have virtually no intramuscular fat, so that their meat may be perceived as dry and tough.

The pH decline in muscle *post-mortem* may also be affected by species differences (Pearson & Young 1989). The pH drop in pig muscle, for example, declines by 0.64 pH units/hour, while beef, sheep and rabbit muscles have pH decline rates of about 0.27-0.40 pH units/hour at a temperature of 37°C. Since rate of pH decline *post-mortem* is a major determinant of many meat-quality parameters, it stands to reason that this difference between species may partly account for the species differences in meat quality (Lawrie, 1998).

2.5.2. Gender

The most notable carcass difference between the sexes is that of differing levels of fat deposition. Female animals tend to display a greater tendency to accumulate fat. According to Diaz, Velasco, Perez, Lauzurica, Huidoro and Caneque (2003), differences in fatness between the sexes are associated with variations in protein assimilation efficiency and the different composition of weight gain displayed by males and females throughout their growth. This is in agreement with the findings of Hoffman (2000b) who reported significantly higher levels of lipid content in female impala (33.9 g/kg) than in the males (24.5 g/kg). These differences in fat content will invariably affect the tenderness of the meat and, in accordance with this, Jeremiah *et al.* (1991) found that in cattle, male animals produce tougher meat that female animals. Of the research conducted on wild ungulates, Mostert and Hoffman (2007), Hoffman, Kritzinger and Ferreira (2005) and Hoffman *et al.* (2007) all found no significant differences in shear force between the genders in kudu, impala and springbok meat.

According to Aberle *et al.* (2001), bulls and rams also produce slightly darker meat than that of steers and wethers of similar ages, and this may be the result of higher concentrations of myoglobin as well as the tendency towards stress-induced DFD meat in male animals. The latter is in contrast with the findings of Voisinet, Grandin, O'Connor, Tatum and Deesing (1997) who found that females had a more excitable temperament and that a higher incidence of "borderline" DFD was produced by heifers. Scanga, Belk, Tatum, Grandin and Smith (1998) also found that intact heifers produced higher mean percentages of DFD meat than both steers and spayed heifers.

2.5.3. Age

As an animal age (or as animals ages), many changes occur in the body that will have varying effects on the meat quality. According to Lawrie (1998) the most notable change is the increase in intramuscular fat as well as the increase in myoglobin content of the muscle as animal ages, which is often accompanied by a darkening of the muscle colour. Of greater consequence are the changes in connective tissue that occur with increasing age, so that one of the most notable parameters influenced by age is tenderness (Bouton, Harris, Shorthose, Ratcliff and Morgan 1978; Shorthose & Harriss, 1990). Tests conducted on the meat from animals of various ages have shown that tenderness varies with age, indicating differences in connective tissue content and form (Hill, 1966). Shorthose and Harriss (1990) measured tenderness in 12 muscles from eight beef groups and found that the tenderness of the muscles decreased with age. Although the quantity of connective tissue apparently changes little after sexual maturity, the number of intermolecular cross-links in the collagen fibres increases (Aberle *et al.*, 2001). In young animals, most of these cross-links are reducible, although, after sexual maturity is reached, they are gradually replaced by thermally stable linkages (Shimokomaki, Elsden & Bailey, 1972). Changes in tenderness that occur with age are not linear. During rapid growth phases, tenderness increases with time because the rapid increase in muscle-fibre size “dilutes” the existing connective tissue. Once the growth phase starts to level off, there is an increased toughening with an increase in collagen fibre cross-links as the animal ages (Aberle *et al.*, 2001).

2.5.4. Plain of nutrition

In the case of conventional livestock, animals receive complete or supplementary feed, so that farmers are in absolute control of the feed intake of their animals. In the case of wild game, it is unlikely that farmers provide supplementary feed, so that animals are subjected to any environmental or seasonal changes that may occur; as a result, their plane of nutrition may be variable throughout the year. The two most notable effects that the plane of nutrition will have on meat quality is its effect on the animal’s physical condition, i.e. its fat reserves, and on its muscular energy reserves. The fatness of the animal influences tenderness as well as quality and price since malnourished animals will produce lighter carcasses (Diaz *et al.*, 2003). Any malnutrition in the immediate *ante-mortem* period will alter the quantity of glycogen stored in the muscle and as a result, will influence the ultimate physical quality of the meat. Wiklund, Anderson, Malmfors and Lunström (1996) found that the nutritional status and physical condition of reindeer had a considerable effect on their muscle glycogen content. Any alteration in the muscle glycogen content *post-mortem* will affect the rate and extent of the pH decline which will in turn affect the meat quality characteristics. It can thus be concluded that animals that are cropped during periods of nutritional shortages, are likely to produce meat of inferior quality.

2.5.5. Season

Seasonal changes that are most likely to affect meat quality are related to food availability and quality, as well as breeding. Domesticated livestock are least affected by these changes since their diets and breeding are most likely controlled by the farmer. The opposite is true for wild game and winter live weight gains are generally considerably lower than summer live weight gains. According to Drew (1985), animals have been noted to undergo a 25% weight loss and lose more than 80% of their body energy over six weeks during a period of insufficient nutrition. Gallivan, Culverwell and Girdwood, (1995) reported that the majority of studied impala were in poor condition at the end of the dry season, and their study also found that adult males and yearlings did not regain optimum condition after the spring rain. The rutting season can have similar effects, and Hoffman (2000a) reported that male impala had a lower body lipid content during the rutting season due to strenuous activities such as fighting for and maintaining a harem. The study also found that the rate of pH decline (though not the ultimate pH) *post-mortem* was higher in male impala than in female impala and it was concluded that this was because the males had just finished their rutting season and were therefore more excitable. Stevenson, Seman, and Littlejohn, (1992) found that the percentage soluble collagen is also significantly greater in red deer during the pre-rut period compared to the post-rut period. This causes post-rut samples to be less tender and to have lower flavour intensity.

CONCLUSION AND OBJECTIVES

As the export and local consumption of game meat in Africa increases, it is becoming increasingly important to maximise its quality in order for it to compete with that of domestic species. One of the major quality aspects that can be controlled through proper management is the use of cropping methods suited to the specific species being cropped and efficient in minimising *ante-mortem* stress. Relating this *ante-mortem* stress to the meat quality of wild ungulates is also essential in understanding the importance of the cropping process when it comes to the quality of the product being produced.

The objective of this study was to supply sound scientific research regarding the following aspects:

- Comparing the effects of different cropping methods on *ante-mortem* stress in red hartebeest, kudu, gemsbok and impala as measured by cortisol and *post-mortem* muscle pH decline so as to determine the least stressful cropping method in the case of each individual species
- Comparing the effects of different cropping methods on the meat quality of red hartebeest, kudu, gemsbok and impala so as to determine which cropping method results in the highest meat quality for each particular species
- Determining the contribution of other factors such as age, gender, region and carcass weight or live weight to the effects of cropping methods on the meat quality of red hartebeest, kudu, gemsbok and impala.

Where applicable, correlations were verified between meat quality parameters and those factors which are known to influence them such as ultimate pH_u and rate of pH decline. Subjective stress scores were also given to each animal and correlations between these and plasma cortisol levels were verified, since the latter is a known and generally-used measure of stress which means that these correlations would be indicative of the accuracy of the stress scores.

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Chapter 3

MATERIALS AND METHODS

3.1. CROPPING

The purpose of this study was to evaluate the effect of day and night cropping by vehicle on commercially harvested species that occur predominantly in rangeland areas, since these two methods are two of the most commonly applied cropping methods during the commercial production of game meat. For comparison reasons, night cropping from a vehicle was also weighed against conventional ethical hunting on foot, impala hunting in this case. The reason for this was largely due to the fact that the former hunting method is generally considered to cause minimal animal stress and is the method most commonly used by sport or biltong hunters and as a result, much of the game meat consumed locally is produced by this type of hunting activity. It was thus of interest to compare this method to a method commonly employed to produce game meat on a larger commercial scale. Since the behaviour of each species is unique enough to affect its physiological response to stress and thus its response to the cropping methods employed, the animals used in this study were grouped according to species. Studies conducted on domesticated meat-producing species have also indicated that species differences do exist with regard to animal responses to slaughter (Gregory, 2008; Lawrie, 1998). This idea was carried forward into the current study and species were investigated separately. The segregation of the species studied was also important since most of the research conducted on the effects of cropping methods on game meat quality to date were conducted on smaller species such as springbok and impala. It is, therefore, of interest to compare the results of the three larger species in the current investigation, namely red hartebeest, gemsbok and kudu, with the former results. For this study, two commercially utilised cropping methods were evaluated per species and animals within a species were grouped according to cropping method (i.e. treatment). With the exception of the impala, which were cropped in Kwazulu-Natal, all the other species, namely the red hartebeest, gemsbok and kudu were cropped in Namibia.

The animals that were cropped at night were cropped according to the method described by Lewis, Pinchin and Kestin (1997) with animals being detected and temporarily immobilised with spotlights before being shot. One-million candlelight spotlights were used and animals were sighted either directly or by the reflection of light from their retinas. At nighttime, animals were cropped at distances not exceeding 150m to ensure maximum accuracy as well as ensuring that carcasses were easily recovered. In the case of the red hartebeest, gemsbok and kudu, a professional cropping team, consisting of three sharpshooters and eight assistants, was contracted from Farmer's Meat Market in Windhoek. During each hunting session, the sharpshooters each had their own vehicle and a minimum of two assistants. A single shooter per vehicle fired all the shots using either a .22-50 or .234 rifle, fitted with a telescopic sight and silencer. Each hunter was allocated a different area of the farm and all vehicles were in constant radio contact with each other to prevent any overlapping of shooting areas between hunters, thereby decreasing the risk of accidents. This also ensured that a larger area of the farm was covered so that the required number of animals could be detected and cropped in the minimum amount of time. As per the method described by Hoffman and Wiklund (2006), both sharpshooters were also the drivers, thereby eliminating a potential misunderstanding between the hunter and the driver during the cropping operation. Each hunting vehicle was equipped with a loading ramp at the back, angled at 45 degrees as well as side railings with numerous hooks from which the carcasses of smaller species, such as springbok, could be hung. There were also numerous hooks at the top of the loading ramp from which larger carcasses could be hung (head downwards towards the back of the vehicle), and each vehicle was equipped with a winch to load the carcasses of larger species such as gemsbok.

During the day, the same procedure as that used in the night cropping was followed, although animals were sighted and shot from the vehicles at distances ranging from 50 to 300m. This increase in shooting distance was due to increased visibility during the day, allowing for head and neck shots at these distances as well as increasing the ease and speed of carcass recovery.

In the case of the impala in this study, a similar method of night cropping as that used with the red hartebeest, gemsbok and kudu was employed, and any deviation from this method will be fully discussed in chapter 7. In the second shooting methodology used for the impala, normal ethical hunting practices were utilised i.e. hunting on foot, shooting and waiting for the herd to move away before approaching the downed animal. This method will be referred to as “hunting during the day” and consisted of shooting in the daytime, utilising a flank shot, which is a shot commonly used by hunters. Normally, the shot is aimed at the top of the crease at the back of the foreleg. Underlying this area are large vital organs, such as the lungs and the heart, major blood vessels and important nerves (Hoffman, 2001). A bullet in this area will result in massive haemorrhaging, lung collapse and a “quick death”. This is a relatively large target area and is often more stationary than the head. A shot hitting a point slightly forward of the point of impact might miss the heart, but can still hit lungs and large blood vessels. Such a shot will also most probably result in the bullet hitting and breaking the femur – an action that causes the animal to fall down immediately – which is of particular importance when a lighter-calibre rifle is used (a light-calibre rifle is normally used, as it causes the least meat wastage). A shot slightly behind the intended point of impact will still hit the lungs (and possibly the liver). A slightly low shot may still hit the point of the heart and both lungs, whilst a shot that is too high can hit large blood vessels or even the spinal column. Not all these shots resulted in immediate death. Animals that were still breathing when approached were immediately euthanised with either a second shot or by exanguination. A single shooter fired all the shots using a .243 Winchester, fitted with a telescopic sight and silencer.

Once an animal was shot, all data regarding the animal’s behaviour prior to death as well as the cropping process were recorded by an independent observer. This data included the activity of the animal (i.e. whether it was chased prior to being shot, whether it was fighting with other animals etc.), the placement of the shot, the time of day and whether or not the animal had been wounded prior to being killed. Accordingly, a stress score of 1 to 5 was allocated to each animal indicating the amount of stress perceived to have been experienced by the animal prior to death (Table 1). All carcasses were tagged with blue, white or red plastic tags (each colour representing the specific sharpshooter that had killed the animal), which were attached to incisions made through the Achilles tendon of one of the back legs of the carcass. Each plastic tag contained an individual number so that animals could be distinguished from each other and for traceability purposes. For HACCP purposes, which are a requirement for the export of game meat to the European Union, the time of death, placement of the shot and corresponding tag number of each animal was recorded on a separate data sheet.

Within a few minutes after being killed, animals were exsanguinated and duplicate blood samples collected in clean gel centrifuge tubes for later determination of serum cortisol levels. These samples were marked and kept on ice until reaching the lab.

Once blood samples were collected, viscera and stomachs were removed by cutting open the underbelly of the animal with a clean knife. These were then placed in plastic bags and weighed from a hanging scale which hung from the railing on the back of the hunting vehicle. The viscera and stomachs were discarded in the field. Trachea and organs remained attached and inside the carcasses and were only removed and weighed once carcasses were offloaded at the research laboratory. Cuts were made through the Achilles tendon on one of the back feet of each carcasses from which it was then hung from a hook on the back of the hunting vehicle. Once enough carcasses (usually between four and six) were loaded onto the vehicle, the vehicle would return to the research laboratory where two workers remained to receive the carcasses. Carcasses never remained in the field for longer than three hours.

Once the carcasses arrived at the research laboratory, they were offloaded and each carcass weighed with head, feet and skin on and the lungs, trachea and organs still inside the carcass. Live weight was then calculated as the sum of this carcass weight and the weight of the viscera and stomach weighed in the field. Carcass weight would be determined once the carcasses were skinned, and the heads, feet and organs removed. pH and temperature readings were then taken with a Testo 205 meter (Testo AG, Germany) in the *M. longissimus dorsi* (LD) on the left-hand side, between the last and second last rib (Tarrant & Sherrington, 1979). The pH meter was calibrated when switched on, before taking a set of readings, using the following steps:

1. The “calibration” option was selected on the instrument
2. The acidic calibration point (pH 4) was selected on the instrument and the probe immersed in a pH 4 buffer solution
3. Once a stable reading was available (change less than 0.02 pH in 20 seconds), the calibration point was calibrated and the instrument automatically changed to the next calibration point
4. Step 2 was then repeated, the basic calibration point (pH 7) selected and the probe immersed in a pH 7 buffer solution
5. Once a stable reading was available, the calibration point would be calibrated and the calibration of the instrument would be complete.

After each use, the Testo 205 meter was cleaned with distilled water and dabbed dry with a paper towel. The probe would then be stored in a storage cap filled with electrolyte gel.

After the initial weighing, heads and feet were removed and weighed separately. The heads were removed at the junction of the atlas- and axis-neck vertebrae using a horizontal cut to the back bone. The feet were removed at a point just below the carpus of the front legs and tarsus of the back legs. The carcasses were then hung from their Achilles tendons in a cooling truck, at a temperature ranging from 0 - 5°C and left to cool with the skin still in place. The time of hanging in the truck as well as the position of each carcass in the cooling truck were recorded. pH readings were taken at intervals of two to three hours for 24 hours *post-mortem* with the first pH readings being taken as soon as the carcasses were off-loaded, usually between 1 to 3 hours *post-mortem*. Further pH readings were taken at 48 hours *post-mortem*.

The handling of the impala carcasses differed from the methods described above and will thus be discussed in detail within chapter 7. Any deviation from the above methods will also be discussed within each chapter.

3.2. BLOOD SAMPLES

The collected and cooled blood samples were centrifuged at ambient temperature for ten minutes at the research laboratory, after which the serum was aliquot into clean tubes and frozen within twelve hours after collection. The frozen serum samples were brought back to Stellenbosch and sent to the Pathcare (Drs. Dietrich, Voight, Mia Partners) veterinary laboratories, Pathcare Park, N1 City, Goodwood, Cape Town (Practice No.: 5200539), where they were analysed for serum cortisol levels (nmol/L), using an Access Cortisol assay. This assay is a competitive binding immunoenzymatic assay. A sample is added to a reaction vessel containing rabbit antibody to cortisol, cortisol-alkaline phosphatase conjugate and paramagnetic particles coated with goat anti-rabbit capture antibody. In the sample, cortisol competes with the cortisol-alkaline phosphatase conjugate for binding sites on a limited amount of a specific anti-cortisol antibody. Resulting antigen-antibody complexes bind to the capture antibodies on the solid phase. After incubation in a reaction vessel, materials bound to the solid phase are held in a magnetic field, while unbound materials are washed away. Then, the chemiluminescent substrate Lumi-Phos* 530 is added to the vessel and light generated by the reaction is measured with a luminometer. The light production is inversely proportional to the concentration of cortisol (nmol/L serum) in the sample. The amount of analyte in the sample is determined from a stored, multi-point calibration curve.

3.3. STRESS SCORE

A subjective stress score was assigned to each animal (Table 1) in a similar fashion as described by Von La Chevallerie and Van Zyl (1971). Animals were scored on the perceived stress they experienced *ante-mortem* as related to exercise, wounding and elapsed time between being shot and death.

Table 1

Stress scale animals as pertaining to perceived ante-mortem stress experienced

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

3.4. PHYSICAL ANALYSIS

After 48 hours, the complete *M. longissimus dorsi* (LD) muscle from the right-hand side of each carcass was removed and these muscles were then placed in plastic bags and numbered with the corresponding animal's number. At the research laboratory, two sub-sample steaks (1.5 – 2.0 cm thick) were cut perpendicular to the longitudinal axis from the mid-section of each LD muscle. The steaks were then left to bloom for 30 minutes, after which colour measurements were taken using a Colour-guide 45°/0° colorimeter (Cat no: 6805; BYK-Gardner, USA). Three measurements were taken at randomly selected sites on the sample surfaces (Stevenson, Seman, Weatherall & Littlejohn, 1989). The colour was measured in terms of L*, a* and b* values with L* indicating lightness or reflectance, a* indicating the red-green range and b* indicating the blue-yellow range. These values were then also used to calculate the hue angles (h_{ab}) and chroma values (C*), using the following equations:

Hue angle: $h_{ab} = \tan^{-1}(b^*/a^*)$

Chroma value: $C^* = [(a^*)^2 + (b^*)^2]^{1/2}$

After the colour measurements were taken, the steaks were used to determine drip loss and cooking loss (Honikel, 1998). Drip loss was determined by suspending individually-weighed samples (ranging between 50g and 100g, depending on the species) in inflated polythene bags (taking care that samples did not touch the sides of the bags) for 24 hours at ± 4°C. After 24 hours, samples were removed and weighed, and drip loss was calculated as the percentage of weight lost. To determine cooking loss, weighed samples were cooked in polythene bags in a water bath at ± 80°C for 50 minutes. Samples were then removed from the water bath, the water drained from the bags and the samples (still in the bags) cooled under running water to ± 20°C after which they were then patted dry with tissue paper and weighed. Cooking loss was calculated as the percentage of weight lost by each sample.

The cooled cooking-loss samples (± 20°C) were then used for the Warner-Bratzler shear force test. Five 1.27cm diameter cylindrical core samples were cut parallel to the muscle fibre direction of each cooked piece of muscle at randomly chosen sites and an average shear force value (kg/1.27cm) calculated (Voisey, 1976). Care was taken to avoid cutting into visible connective tissue.

3.5. STATISTICAL ANALYSIS

The differences between cropping methods were, where appropriate, tested separately by means of the null hypothesis (H_o), with H_o: $\mu_1 = \mu_2$ and the alternate hypothesis (H_a) being H_a: $\mu_1 \neq \mu_2$. Analysis of variance (ANOVA) was first performed on all the variables (colour, shear force, drip loss and cooking loss) within the two treatments, using SAS version 8.2 (SAS, 2002). Analysis of variance (ANOVA) was also performed on the pH taken at 24 hours *post-mortem* (pH_u) as well as on serum cortisol levels and stress scores. Very little of the variation in the data was explained by the treatments ($R^2 < 0.1$) alone, so gender, age (where measured) and carcass weight or live weight were included in the model as main effects (live weight was included if species were not sexually dimorphic, while carcass weight was included if species were sexually dimorphic since horn weight would affect gender differences in live weight). Analysis of variance (ANOVA) was performed using SAS version 8.2 (SAS, 2002), with age, gender and treatment (Table 2) being included as classification variables and carcass weight/live weight being included as a quantitative variable. Differences within the main effects were accepted as being significant if the probability of rejection of H_o was less than 5 % ($P < 0.05$). Pearson correlation coefficients were also calculated for the following, using the linear regression procedure:

1. Stress score and cortisol level
2. Stress score and meat quality parameters
3. Cortisol level and meat quality parameters
4. pH_u and the meat quality parameters
5. pH_u and stress score
6. pH_u and cortisol level
7. Carcass/live weight and the meat quality parameters

All these correlations were calculated for each population as a whole and, where applicable, discussed.

An exponential decay model, $y = a + b\,e^{(-ct)}$, was fitted to the temperature data for each carcass, using the non-linear regression procedure of SAS (2002). The function of this model was:

$$y = a + b\,e^{(-ct)}$$

Where:

y = the dependent variable (temperature) at time t; a = ultimate pH; e = base of natural logarithm and b and c are the function parameters describing the shape of the curve.

An ANOVA was then performed on the constants a, b and c of this model with carcass/live weight and hanging position in the cooling truck (Table 2) as main effects using SAS version 8.2 (SAS, 2002). The results of the ANOVA indicated differences in the rate of temperature decline between the carcasses, such that the rate of temperature decline increased as carcass/live weight decreased as well as increased where carcasses were loaded closer to the fans in the cooling truck. The results of the ANOVA are discussed in detail within each chapter.

Table 2

Symbols allocated to each carcass according to location in cooling truck

Symbol	Description
a	Close to fan, at the front of the truck
b	Middle of the truck
c	Close to doors, at the back of the truck

As a result of the differences in temperature decline between carcasses, the pH readings were standardised at 4°C using the formula of Bruce, Scott and Thompson (2001):

$$pH_{\text{adjusted at } t} = \text{measured } pH_t + \{ (T_t - T_{\text{adjusted}}) * 0.01 \}$$

Where:

pH_t is the actual pH measured at time = t; T_t is the muscle temperature at time = t; and T_{adjusted} is the muscle temperature (4°C) to which the data is being adjusted.

The same exponential decay model, $y = a + b^{-ct}$, that was fitted to the temperature data was fitted to the pH data (both adjusted and unadjusted) of each carcass. The a, b and c constants of the unadjusted and adjusted model of the pH decline data were then analysed by analysis of variance (ANOVA) using SAS version 8.2 (SAS, 2002) with treatment (cropping method), age and gender as main effects.

3.6. CONCLUSIONS

The results of the statistical analysis will be discussed in detail within each chapter. Each chapter includes a short descriptive summary of the materials and methods used, with reference to Chapter 3. The purpose of this chapter is to prevent repetition between the chapters that follow. However, inevitably there will be slight differences between the species and any deviation from the materials and methods described above will also be discussed within each chapter.

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Chapter 4

A COMPARISON BETWEEN THE EFFECTS OF DAY AND NIGHT CROPPING ON RED HARTEBEEST (*Alcelaphus buselaphus*) MEAT QUALITY

ABSTRACT

Ante-mortem stress is known to adversely affect the meat quality of animals, and cropping methods that induce the least amount of stress are thus key in ensuring acceptable meat quality from wild ungulates. The purpose of this study was to compare day and night cropping on the quality of red hartebeest meat. Forty animals were cropped, 19 during the day and 21 at night. There was no significant difference in stress score or serum cortisol (nmol/L) between treatments. Since the rate of temperature decline varied between animals, all pH measurements were adjusted to 4°C. Treatment had no significant effect on the adjusted pH$_u$. None of the constants of the exponential decay model of the adjusted pH data ($y = a + b\ e^{(-ct)}$) differed (mean $a = 5.49 \pm 0.096$; $b = 1.86 \pm 0.272$; $c = -0.21 \pm 0.023$). No significant differences were found in drip loss, cooking loss or shear force between treatments. Significant correlations were found between drip loss ($r = -0.322$) and cooking loss ($r = 0.323$) and pH$_u$. A significant difference was found for a* and chroma between day (a* = 13.42 ± 0.236; C* = 16.12 ± 0.231) and night (a* = 12.71 ± 0.219; C* = 15.36 ± 0.215) cropped animals. All colour ordinates, except hue angle, were found to be significantly correlated to pH$_u$. The results of this study indicate that if an experienced cropping team is used, neither of the two cropping methods has any adverse effect on the meat quality of red hartebeest.

INTRODUCTION

The potential of African ungulates for meat production has long been recognised (Ledger, 1963; Ledger, Sachs & Smith, 1967; Von La Chevallerie, 1972) and during the past 20-25 years the commercial utilisation of wildlife has grown tremendously in South Africa (Mostert & Hoffman, 2007). As game meat consumption increases, consumers are becoming increasingly aware of and concerned with the quality of meat products as well as with the health aspects associated with these products. It has been found that, in addition to yielding greater amounts of edible protein per unit of live weight than domestic animals, meat from wild ungulates is also nutritionally superior and contains far less fat (Ledger *et al.*, 1967). There are still, however, quality aspects that can affect a consumer's choice of domesticated-animal meat over that of game meat. In South Africa, game meat is often perceived as having a dark, unattractive colour and as being dry. This may be attributable mainly to either pre-slaughter stress resulting in dark, firm and dry (DFD) meat, or to the fact that wild ungulates are more active than domesticated animals, which means that their meat contains a higher amount of myoglobin and much less intramuscular fat (Hoffman., Muller, Schutte, Calitz & Crafford, 2005). The former is a problem that could be addressed by minimising the *ante-mortem* stress experienced by the animals, through proper and efficient cropping methodologies. For the purpose of this study, cropping will be defined as the killing of animals for meat-production purposes by a sharpshooter from a vehicle utilising only head and neck shots. The plains game species (springbok, impala, blesbok, red hartebeest, etc.) in southern Africa are usually cropped during either the day or at night, using vehicles, helicopters or with the use of boma capture (Hoffman & Wiklund, 2006). Although relatively little research has been done on the effect of these different cropping methods on the meat quality of specific wild ungulate species, many authors have found night cropping to be the method least stressful to wild animals (Hoffman, 2001a, 2001b; Hoffman & Ferreira, 2000; Kritzinger, 2002; Lewis, Pinchin & Kestin, 1997; Veary, 1991; Von La Chevallerie & Van Zyl, 1971) and this notion is generally accepted by most game meat producers. Most of the studies quoted were conducted on impala (*Aepyceros melampus)*, or springbok (*Antidorcas marsupialis*), two smaller species whose behaviour (they are found in herds and tend to stand facing the spotlight) is such that they are suitable for night cropping. Very little research has been conducted on the larger wild ungulate species exported from South Africa and Namibia into the European Union, such as red hartebeest (*Alcelaphus buselaphus*), gemsbok (*Oryx gazelle*) and kudu (*Tragelaphus strepsiceros*).

Red hartebeest are a gregarious species and predominantly occur in small herds of up to twenty, although there have been documented cases of larger herds of several hundred (Stuart & Stuart, 1997). Harem herds usually consist of females with their offspring, a dominant bull and young bulls, while bachelor herds consist of males of all ages. Dominant bulls are very territorial and will defend their territories against intruding males. Red hartebeest are most active in the morning and late afternoon; during the day, they may seek out shade in hot weather or lie in the sun in winter. They have acute senses of smell and hearing, even though they have poor eyesight. Rutting usually starts at the beginning of March and may last until the end of April. Calves are born in October/November or at the onset of rains (Smithers, 1983). Red hartebeest behaviour is such that they tend to move away at a slow canter as soon as danger is spotted – this behaviour is exacerbated during the daytime, when humans are in close proximity to these animals. A typical flight reaction when humans are observed is for these animals to move away to distances over 200m before coming to a standstill and facing the threat. Although this distance is such that it will test the capabilities of the average hunter, it is a prerequisite for a trained and registered sharpshooter (culling operator) to be able to kill an animal at such a distance with a headshot. The authorities responsible for ensuring that the requirements for export of game meat are met, are under the impression that day cropping of this species will cause severe stress and have thus decided that it will not be allowed. Day cropping has numerous advantages over night cropping, such as a better selection of suitable animals (males versus females, young versus old, etc) for cropping. It also allows the operators better manoeuvrability in the African bush, as they have better visibility, and allows for the faster exsanguination and gutting of the shot animal, etc. It is therefore important for the game meat export industry to have scientific data available to support their recommendations with regard to the cropping times for export of game meat.

This study was conducted to determine the effect of day and night cropping on the meat quality parameters of red hartebeest (*Alcelaphus buselaphus*) meat. To our knowledge, this is the first study conducted on red hartebeest with regard to cropping methodology. This species is currently becoming an increasingly popular species for export from both Namibia and South Africa to the European Union and, even though there are currently no protocols regulating the use of specific cropping methods, it is essential that the cropping method not adversely affect the meat quality if this species is to compete with other game meat species on the European market.

MATERIALS

Animals

For this study, forty red hartebeest (*Alcelaphus buselaphus*) were cropped in Namibia, twenty at Neudamm Agricultural College and twenty at Progress Guest Farm. Both these properties were within a 30 km proximity of one another and their terrains did not differ. The terrain was moderately hilly with a medium-to-dense cover of shrubs and small trees, particularly acacias. Of the 40 animals, 19 were shot during the day and 21 at night. Table 1 gives the distribution of the animals with regard to gender, region and cropping method.

Cropping took place at Neudamm Agricultural College at the end of March (during the rutting season), during which time the summer rains were coming to an end and the bush was lush and green. Cropping at Progress Guest Farm took place towards the end of July, during winter, when rainfall was at a minimum and daytime temperatures ranged from 12°C to 15°C while nighttime temperatures dropped to between 2°C and 5°C. Hunting and cropping activities at Neudamm Agricultural College are limited to one annual staff hunt a year, while Progress Guest Farm is a commercial trophy-hunting farm where hunting activities occur throughout the year and cropping is done on a regular basis, depending on the farm's requirements. Thus, region denotes the effect of environment as well as the effect of hunting practices at each particular farm since both factors will affect the behaviour and stress susceptibility of the animals.

Table 1

Distribution of cropped red hartebeest (*Alcelaphus buselaphus*) according to gender, region and cropping method

Region	**Day**		**Night**		**Total**
	Male	**Female**	**Male**	**Female**	
Neudamm	4	6	7	3	20
Progress	5	4	2	9	20
Total	9	10	9	12	40

Cropping

The same sharpshooters and cropping techniques were used as described in the material and methods (Chapter 3) section of this thesis.

All the shots taken were either head or neck shots, with the exception of six animals that were wounded either in the shoulder, neck or stomach and shot a second time – this second shot was normally conducted within 60 to 120 seconds of the first. After being shot, all animals were exsanguinated by cutting the throat. A stress score was allocated to each animal as per Table 2.

Table 2
Stress scale animals as pertaining to perceived *ante-mortem* stress experienced

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

Stomachs and viscera were removed in the field and weighed before being discarded. Trachea, lungs and organs were left in the carcasses and removed once carcasses were offloaded at the research laboratory. These were then tagged, covered with plastic and hung with the carcasses in the cooling truck at 0-5°C. Once carcasses were offloaded, they were weighed again with heads and feet intact and live weight was calculated as the sum of this weight and the weight of the stomach and viscera.

Carcasses remained in the field for no longer than three hours before being loaded into the cooling truck, where pH and temperature readings were taken at two- to three-hour intervals on all the animals for the first twenty-four hours *post-mortem*. Ultimate pH measurements (pH_u) were taken at twenty-four hours *post-mortem*. Cropping was done on the first and second days. On the third day, the cooling truck returned with the carcasses to Farmer's Meat Market in Windhoek where the red pluck was removed for health inspection, the carcasses were skinned and then weighed again (this weight was used as the carcass weight); all organs were then weighed. Muscle sub-samples were subsequently removed from the *Longissimus dorsi* between the first and fourth lumbar vertebrae from one side of each carcass for use in the various physical measurements.

Blood samples

Blood samples were collected during exsanguination, kept on ice for approximately three to four hours and then centrifuged for ten minutes, after which the serum was aliquot into clean tubes and frozen. The serum samples were then used to test for cortisol, as per the procedure described in the materials and methods section (Chapter 3) of this thesis.

Physical analysis

Two sub-samples, 1.5 cm to 2.0 cm thick, were taken from the *M. longissimus dorsi* of each carcass and used to determine drip loss, cooking loss and Warner-Bratzler shear force and to take colour measurements (full procedures described in the materials and methods section of Chapter 3).

Statistical analysis

The statistical analysis used was the same as that described in the materials and methods section of this thesis (Chapter 3). Analysis of variance (ANOVA) was used to test for differences in meat quality, stress scores, cortisol levels as well as pH_u, with treatment, region, gender and live weight (since red hartebeest are not sexually dimorphic) as main effects. Pearson correlation coefficients were calculated, where applicable.

RESULTS AND DISCUSSION

The species used in South Africa for game meat production are inherently wild and hence even more pre-disposed to the effects of *ante-mortem* stress than many of the domesticated species (Hoffman & Wiklund, 2006). The development of cropping methods that minimise such *ante-mortem* stress is thus important from a welfare point of view as well as with regard to the adverse effects of stress on meat quality. Various authors (Tinley, 1972; Veary, 1991; Hoffman, 2001a; Von La Chevallerie & Van Zyl, 1971) have reviewed different methods of cropping, and the method most commonly used is that of night cropping. Red hartebeest are least active at night and at mid-day, and adopt an investigative posture when caught in the spotlight at night (Smithers, 1983). This makes them well-suited to night cropping. However, one advantage of cropping during the day is that the this method would allow the cropping team to be more selective in the animals that they shoot; it will also be easier for the team, as they can better see where they are driving, etc. Selectivity is especially important with regard to selective gender cropping since red hartebeest are not sexually dimorphic, making it difficult to distinguish between the sexes at night. The nature of red hartebeest – when disturbed, they tend to move away at a slow trot until reaching a safe distance (approximately 150 m to 200 m), where they then stop and face the perceived threat – the possibility exists that this species could be cropped in the daytime. The typical professional sharpshooter in a culling team is comfortable with shooting animals at this distance.

Only six animals were wounded during the cropping operation; they were shot a second time (within 60-120 seconds of the first shot) before dying. Three animals were shot twice in the high neck region before falling and no animals were lost after being wounded (100% killing rate). A possible reason for this could be the fact that a fairly strong wind was blowing, which may have caused the bullets to veer slightly; at these distances, this would be sufficient for the light bullet to miss the intended target. This phenomenon has also been observed in the Karoo when springbok are cropped. According to Lewis *et al.* (1997), expected losses of ≤ 8% are not unusual for most cropping operations. Seventy five per cent of all the red hartebeest died after only one shot, with 92.5% of the shots being either head or neck shots, resulting in very little wastage of meat (Von La Chevallerie & Van Zyl, 1971). Since cropping methods accounted for very little of the variation in the data, ($R^2 < 0.2$), gender, region, hanging position in the cooling truck and live weight were also included in the model and will be briefly discussed where applicable.

Stress score

The effect of *ante-mortem* stress on meat quality in domesticated animals (Bond, Can & Warner., 2004; Judge, 1968; Mounier, Dubroecq, Andanson & Veissier, 2006; Pollard *et al.*, 2002; Scanga, Belk, Tatum, Grandin & Smith, 1998; Shorthose, 1977) and deer species (Wiklund & Malmfors, 1996; Wiklund, Andersson, Malmfors, Lündstrom & Danell, 1995; Wiklund, Andersson, Malmfors & Lundström, 1996) has been well documented; however, very little research is available on the effects of stress on meat quality in African game species. In general, the conditions established immediately prior to slaughter have been implicated as important parameters affecting water-holding capacity and the tenderising process in meat (Bond *et al.*, 2004). This is specifically related to the effects of these conditions on the rate and extent of post-mortem pH decline (Watanabe, Daly & Devine, 1996), which is also an accepted measure of *ante-mortem* stress in meat-producing species. Since the measurement of stress in game is confounded by their wild behaviour, a subjective stress score was assigned to each animal in a similar fashion as that described by Von La Chevallerie and Van Zyl (1971). Animals were scored on the perceived stress they experienced *ante-mortem* as it related to exercise, wounding and the time elapsed between being shot and death. The stress scores were intended as an additional validation of the known stress measurement, namely serum cortisol level and pH, and were in no way intended to be conclusive indicators of stress.

Mean stress scores did not differ ($P = 0.501$) between day-cropped red hartebeest (mean stress score = 2.32 ± 0.27) and night-cropped red hartebeest (mean stress score = 2.57 ± 0.26). Mean stress scores were also not found to differ between any of the other main effects. It must be cautioned that, since the stress scores are subjective, this may not be an accurate indication of differences in stress experienced between animals. Stress scores were found to be correlated ($P = 0.0007$; $r = 0.51$) to cortisol levels, thereby indicating relative consistency between the two measurements of stress.

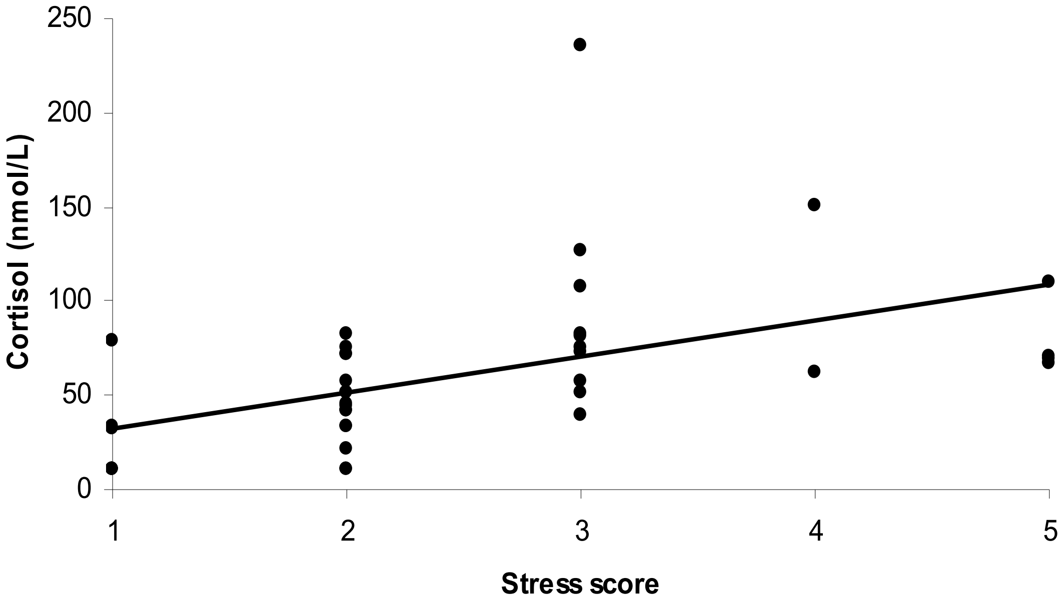

Fig. 1. Linear correlation (P = 0.0007; r = 0.51) between stress score and serum cortisol level (nmol/L) for day- and night-cropped red hartebeest

Cortisol

Cortisol is a major adreno-cortical hormone, secreted in response to the release of adreno-corticotrophic hormone (ACTH) by the pituitary gland (Shaw & Tume, 1992). Cortisol is primarily a measure of psychological stress and, although circulating levels respond less rapidly to stressful stimuli than other indices, cortisol levels recover more slowly, making sampling easier (Warriss, Brown & Adams, 1994). Both salivary and serum cortisol levels have been used as measures of stress in cattle, sheep, pigs, goats and deer (Greenwood & Shutt, 1992; Kannan, Kouakou, Terrill & Gelaye, 2003; Smith & Dobson, 1990; Warriss, 1984; Warriss *et al.*, 1994). In response to stressful stimuli, cortisol release results in elevated plasma glucose concentrations through glycogenolysis and gluconeogenesis, coupled with protein catabolism.

No differences (P = 0.405) were found for serum cortisol level (nmol/L) between day-cropped (65.84 ± 8.92 nmol/L) and night- cropped (55.45 ± 8.52 nmol/L) red hartebeest, indicating that both cropping methods elicited similar stress levels in the animals. Levels ranged between < 11nmol/L to 236 nmol/L, which are within the range of values that have been reported for reindeer (Shaw & Tume, 1992). A difference (P = 0.001) was found between regions so that those animals cropped at Neudamm had lower mean cortisol levels (38.11 ± 8.70 nmol/L) than those animals cropped at Progress (83.18 ± 8.90 nmol/L). This may be a result of the fact that the red hartebeest at Progress tend to be more aware and more nervous of vehicles and hunters because of the year-round hunting that occurs on the property, as opposed to the red hartebeest at Neudamm who are not use to vehicles or hunters since hunting infrequently occurs there.

Temperature

Bruce, Scott and Thompson (2001) found that *post-mortem* pH values should be adjusted to a constant temperature to remove the variations introduced by the effect of muscle temperature on the measured pH value. In the current investigation, non-linear regression analyses of the temperature decline for the animals revealed that the temperature decline could be represented by an exponential decay model ($y = a + b^{-ct}$), with R^2 values ranging from 0.788 to 0.973. The model showed that there was a difference ($p < 0.001$) in the rates of temperature decline between treatments (n = 40; Figure 2: Day: c = -0.217 ± 0.016; Night: c = -0.356 ± 0.011). This is most likely due to differences in ambient temperature, such the nighttime temperature tended to be lower than daytime temperatures. This was especially true during the cropping at Progress which, took place in the middle of winter and where daytime temperatures tended to range between 12°C and 15°C and nighttime temperatures dropped to as low as 2°C to 3°C. Temperature-decline differences ($p < 0.001$) were also found between regions, with those animals cropped at Progress having the fastest decline rate (c = -0.325 ± 1.336) and those cropped at Neudamm having the slowest decline rate (c = -0.249 ± 0.011). This is to be expected, since the cropping at Progress took place during the winter and ambient temperature reached as low as 2°C, which would inevitably affect the carcasses temperatures. Temperature decline also differed between carcasses hung at different positions inside the cooling truck ($P < 0.0001$) so that carcasses that hung close to the fans (n = 13) cooled at a mean rate of -0.338 ± 0.015 units per hour, those hung in the middle of the cooling truck (n = 12) cooled at a mean rate of -0.287 ± 0.014 units per hour and those hung close to the doors (n = 14) cooled at a mean rate of -0.235 ± 0.014 units per hour. This is most probably due to the fact that the doors were constantly being opened as carcasses were loaded in throughout the cropping operation so that carcasses hanging close to the doors were more exposed to outside temperatures, which tended to be warmer than the temperatures close to the fan. Live weight was also found to be correlated to the rate of temperature decline, namely constant c ($P = 0.004$; $r = 0.462$) such that larger carcasses cooled at a slower rate than smaller carcasses. As a result of these differences in cooling rates, all pH values were adjusted to a constant temperature of 4°C (Bruce *et al.*, 2001).

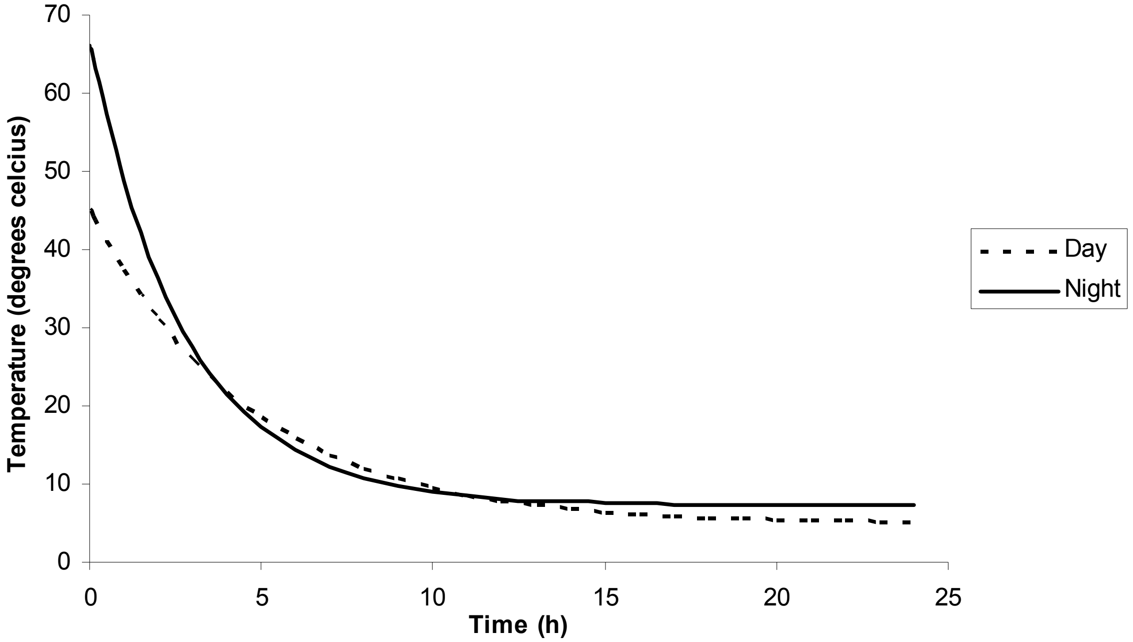

Fig. 2. Mean *M. longissimus dorsi* temperature profiles for day (n=8) and night (n=10) cropped red hartebeest

pH

The rate and extent of pH decline *post-mortem* is a generally accepted measure of pre-slaughter stress (Mounier *et al.*, 2006) and, therefore, differences are important when comparing different slaughtering procedures as well as different pre-slaughter treatments. Ultimate pH (pH_u) was taken at 24 hours *post-mortem* and the mean ultimate pH (pH_u) values are depicted in Table 3 for both cropping methods. Even though there was a difference in non-adjusted pH_u between the treatments (P = 0.046) (since temperature decline differed between treatments), only adjusted pH_u values will be taken into consideration. There was no difference in adjusted pH_u between treatments (P = 0.231). This is in contrast to the findings of Kritzinger (2002) and Veary (1991) who both reported differences in pH_u between day- and night-cropped impala (*Aepyceros melampus*) and springbok (*Antidorcus marsupialis*) respectively, with a higher mean pH_u in the day-cropped animals. A difference (P = 0.0006) was also found in the adjusted pH_u between regions, with those animals cropped at Neudamm having higher mean pH_u values (5.75 ± 0.038) than those cropped at Progress (5.54 ± 0.039). Since cortisol levels indicated that those animals cropped at Progress may have experienced more *ante-mortem* stress than those cropped at Neudamm, it could be that the higher cortisol levels of the former elevated blood glucose levels so that *post-mortem* lactic acid production was increased, resulting in greater muscle acidification and thus a lower pH_u, although it must be noted that no linear correlation was found between either cortisol levels and stress scores and pH_u. The red hartebeest found at Progress also occurred in much larger herds found over a smaller area than those at Neudamm, where small herds of red hartebeest were scattered across the entire property (which consisted of 10 300 ha of land). As a result, the red hartebeest at Progress were cropped in less than half the time it took to crop the same number of red hartebeest at Neudamm and, more often than not, numerous animals were shot within the same herd. This intensified the cropping process at Progress which may have caused increased stress in these animals. No gender differences were found for pH_u.

Table 3
Mean pH_u values (LSMean ± s.e.) measured at 24 h *post-mortem* for day and night-cropped red hartebeest

Treatment	**Non-adjusted pH_u**	**P < │t│**	**Adjusted pH_u**	**P < │t│**
Day	5.56 ± 0.038	0.046	5.61 ± 0.039	0.231
Night	5.67 ± 0.037		5.68 ± 0.037	

The rate and extent of pH decline is dependent on the amount of residual glycogen remaining in the muscle *post-mortem*, since the break-down of glycogen will result in lactic acid build-up and thus muscle acidification. *Ante-mortem* stress causes muscle glycogen break-down which, in turn, increases the risk of a high ultimate pH (pH_u) (Gregory, 1996). The relationship between elevated pH_u and physical activity or stress in deer has been observed in several studies (Macdougall, Shaw, Nute & Rhodes., 1979; Wiklund *et al.*, 1995; Wiklund, Johansson & Malmfors., 2003; Kay, Sharman, Hamilton, Goodall, Pennie & Coutts, 1981) and may result in dark, firm and dry (DFD) meat. Although pale, soft and exudative (PSE) meat has been documented in warthog and buffalo (Hoffman, 2001a), DFD is a larger problem in game meat (Hoffman & Wiklund, 2006). This is because the replenishment of glycogen after stress does not readily occur in the muscle of ruminants because of the distinctive ruminant metabolism, which has little direct access to dietary glucose and must rely on gluconeogenesis (Lister, 1989). Intermediate DFD meat is generally defined as meat with a pH_u that ranges between $5.8 \leq pH_u \leq 6.2$ and DFD with a $pH_u \geq 6.2$ (Wiklund *et al.*, 1995), although many authors believe it to develop from any pH from 5.8 and higher. One animal in this investigation exhibited a pH_u value within the range considered to produce DFD meat, with a pH_u of 6.30. Although this animal was killed by a single head shot, it was part of a larger herd of which six other animals had been cropped prior to it being killed. The increased activity within the herd could, therefore, have caused an increase in *ante-mortem* stress in this particular animal. Five other animals exhibited pH_u values associated with intermediate DFD meat with these pH_u values ranging from 5.81 to 6.14. The occurrence of intermediate DFD pH_u values for these animals may be explained by looking at the individual animals and their behaviour before dying. Two of these animals were males that were fighting with each other prior to being shot. This could be because these animals were being cropped during the end of March and beginning of April, which coincides with the two month red hartebeest rut (Roberts, 1951). The remaining three animals had been chased for quite some time prior to being shot which could have depleted glycogen reserves and thus limited lactic acid production *post-mortem*. Bond *et al.* (2004) found that exercise stress resulted in a higher pH_u in lambs when compared to controls.

Rates of pH decline in *post-mortem* muscle have been estimated with the regression of muscle pH values onto time *post-mortem* (Bendall, 1978). It must be noted, however, that the pH decline of *post-mortem* muscle deviates from a linear regression since it slows as the muscle enters *rigor*. This phenomenon is due to two reasons: Firstly, when the muscle enters *rigor*, hydrogen ion production is decreased as the rate of anaerobic glycolysis and myosin ATPase activity slows during the muscle cooling. The pH decline is further slowed by the buffering effect of ammonia generated from the deamination of adenosine monophosphate (Bruce *et al.*, 2001). Because of this slowed decline rate, the natural decline of pH in post-mortem muscle may be best characterised by an exponential decay model. Table 4 illustrates the constants of the two treatments for the exponential decay model fitted to the data in the current study.

Table 4

The calculated constants (LSMean ± s.e.) for the exponential equations fitted to the pH decline under normal temperature conditions and under adjusted standard temperature (4°C) for day (n = 10) and night (n = 10) cropped red hartebeest

$Y = a + be^{-ct}$	**Treatment**	**Non-adjusted pH**		**Adjusted pH**	
Constants		**Mean ± s.e.**	**P < │t│**	**Mean ± s.e.**	**P < │t│**
a	Day	5.49 ± 0.067	0.797	5.59 ± 0.131	0.265
	Night	5.51 ± 0.063		5.39 ± 0.128	
b	Day	1.62 ± 0.240	0.127	2.22 ± 0.390	0.214
	Night	1.11 ± 0.227		1.54 ± 0.380	
c	Day	-0.21 ± 0.035	0.877	-0.23 ± 0.033	0.413
	Night	-0.20 ± 0.033		-0.19 ± 0.032	

The exponential decay model, $y = a + b^{-ct}$, fitted the pH data well with R^2 values for non-adjusted pH ranging from 0.905 to 0.994 and those for adjusted pH ranging from 0.797 to 0.985. There were no differences between treatments in any of the constants of the exponential decay model for either the adjusted or non-adjusted pH data. This is in contrast to the findings of Kritzinger, Hoffman and Ferreira (2002) who fitted an exponential decay model to the pH data (adjusted to a constant temperature of 4°C) of day and night-cropped impala and found that all the constants were higher in day-cropped animals (a = 5.46 ± 0.006; b = 2.90 ± 0.086; c = -0.58 ± 0.027) than in night-cropped animals (a = 5.42 ± 0.004; b = 2.47 ± 0.057; c = -0.45 ± 0.018). The author concluded that this was because night cropping was less stressful to the animals because of their relative unawareness of the croppers.

There was a difference between regions for constant a, both for the adjusted (P = 0.041) and non-adjusted (P = 0.001) pH data. Constant a gives an indication of the final pH reached and, therefore, the model indicated that animals cropped at Neudamm (n = 20) reached a higher adjusted final pH (5.69 ± 0.129) than those cropped at Progress (5.29 ± 0.133; n = 20). This is in agreement with the earlier findings that the Neudamm animals had higher pH_u values than those cropped at Progress.

Water-holding capacity and tenderness

The water-holding capacity of muscle is an aspect related to important organoleptic properties such as juiciness and tenderness (Hamm, 1960). The term describes the ability of meat to retain water, which is held in the spaces between the thick and thin filaments (Offer & Knight, 1989). Previous work by Warner, Bond and Kerr (2000) has shown that exercise stress alone can cause higher drip loss and cooking loss in the LD muscle of lambs, as a result of its effect on pH. Table 5 gives the mean values of the water-holding capacity and the other physical meat quality parameters for the two cropping methods in this study

Table 5

Mean values of the physical meat quality parameters (LSMean ± s.e.) as measured in the *M. longissimus dorsi* of day and night-cropped red hartebeest.

Meat quality parameter	**Cropping technique**		
	Day	**Night**	**P < │t│**
Drip loss (%)	1.34 ± 0.284	1.76 ± 0.255	0.315
Cooking loss (%)	35.35 ± 0.578	34.94 ± 0.520	0.635
Shear force (kg/1.27cm diameter)	4.09 ± 0.131	3.76 ± 0.123	0.098

There were no differences in drip loss or cooking loss between the day- and night-cropped red hartebeest (Table 4). Kritzinger *et al.* (2002) found a difference in drip loss between day-cropped (4.15 ± 2.339%) and night-cropped (2.93 ± 1.597%) impala, although the authors also found no difference in cooking loss. The mean drip-loss values (1.53 ± 0.197%) are lower than have been reported for springbok, impala, kudu (*Tragelaphus strepsiceros*), and blue wildebeest (*Connochaetes taurinus*) (Hoffman, Kroucamp and Manley, 2007; Kritzinger *et al.* 2002; Hoffman, 2000; Mostert & Hoffman, 2007; Van Schalkwyk, 2004) while mean cooking losses (34.89 ± 0.427%) are very similar to those reported for these species.

A difference (P = 0.048) was found in drip loss between the two regions, with animals cropped at Neudamm having a lower mean drip loss (1.01 ± 0.297%) than those cropped at Progress (2.08 ± 0.327%). This is consistent with the fact that the former also had a higher mean pH_u than those cropped at Progress, since an increase in pH_u has been shown to cause an increase in WHC and thus a decrease in drip loss (Bouton, Harriss & Shorthose, 1971). The pH_u of the animals was also found to be correlated with both drip loss and cooking loss (Table 5). Offer and Knight (1988) showed that drip loss is formed primarily from extracellular space and that the amount of drip loss increases with decreasing pH_u. This is in agreement with the findings of Hoffman, *et al.* (2007), who found that pH_u was correlated (P < 0.01; r = -0.26) to drip loss in springbok. The authors explained that although the correlation was not strong, it was significant due to the large sample size and that the effects of all other main effects on drip loss were directly affected by the pH_u of the meat. Mostert (2007) and Hoffman *et al.* (2007) also found similar correlations between pH_u and cooking loss in kudu and impala (r = -0.277; P = 0.0234) and springbok (r = -0.42; P < 0.001) respectively. No differences were found for drip loss and cooking loss for any of the other main effects. It must also be mentioned that WHC may be influenced by age, as was found by Ziauddin, Rao, Ramesh and Amla (1994) in buffalo. These authors found that older animals had higher cooking losses than younger animals. Since age was not measured in this study and thus not included as a main effect, it may account for the some of the variation in WHC within the groups.

Tenderness is invariably one of the most important factors relating to meat quality. The relationship between tenderness and pH is controversial. Some authors have found that meat with a high pH_u may be more tender than normal because the reduction in glycolytic substrate availability causes more rapid ATP depletion and early rigor, and thus allows prolonged activity of proteases (Maltin, Baleerzak, Tilley & Delday, 2003). On the other hand, some studies have reported that DFD meat (high pH_u) has higher shear force values than normal meat (Wulf, Emnett, Leheska & Moeller 2002). Other authors have suggested a curvilinear relationship between pH and tenderness, with minimum tenderness between pH 5.8 and 6.2 (Silva, Patarata & Martins., 1999), which may explain why no linear correlation was found between pH_u and tenderness in this study (Table 5). There were only five animals in this study that had pH_u values that fell within the pH 5.8 to 6.2 range. The mean shear force values of these animals ranged from a 3.65 to 5.71 kg/1.27 cm diameter, which is within the range of those animals with the highest (6.986 kg/1.27 cm diameter) and lowest (2.331 kg/1.27 cm diameter) mean shear force values. In Table 5, it can be seen that there were no differences in shear force values between day- and night-cropped red hartebeest. This may partly be explained by the fact, as previously mentioned, that there was also no difference in pH_u between day- and night-cropped red hartebeest. Also, since the muscles were only excised 48 hours *post-mortem*, the effect of ageing may have influenced shear force values, so that minor differences in these values, as related to the two cropping methods, may have been compromised. Koohmaraie (1996) found that after 24 hours *post-mortem*, differences in shear force measurements could be related to the effect of the enzymatic degradation of muscle tissue.

There was a gender difference in shear force (P = 0.008) although the ANOVA revealed an interaction between live weight and gender, which can easily be explained by the fact that males (mean live weight = 123.38 ± 4.850 kg) were heavier (P = 0.04) than females (mean live weight = 110.01 ± 4.39 kg). This is in agreement with Smith (2004) who found the mean live weight of male red hartebeest (126.36 kg) to be higher than that of female red hartebeest (99.31 kg). The ANOVA indicated that males weighing between 160-169 kg produced meat with the highest mean shear force (5.54 ± 0.466 kg/1.27 cm diameter) while females weighing between 70 kg and 79 kg produced meat with the lowest mean shear force (2.04 ± 0.467 kg/1.27 cm diameter). A Pearson correlation coefficient was calculated and indicated that shear force was positively correlated with live weight (r = 0.317; P = 0.0013) so that shear force increased as live weight increased. Although age was not measured in the red hartebeest, it may be that this correlation between shear force and live weight may also be related to the known increase in shear force as an animal ages

(Bouton, Ford, Harris, Shorthose, Ratcliff and Morgan 1978) since live weight is known to increase with age. The shear force values ranged from a minimum of 3.88 to a maximum of 4.86 kg/1.27 cm diameter, which is a little higher than the shear force values of red hartebeest reported by Smit (2004), which ranged from 2.65 to 3.87 kg/1.27 cm diameter. One reason for this may be the effect of cold shortening. Although the effect of cold shortening varies between species and between muscles, Bendall (1978) recommended that beef carcasses not be cooled to below 12°C in less than 15 hours, i.e. before the completion of rigor mortis, while others have suggested carcasses not be cooled below 10°C within 10 hours *post-mortem* (Hannula & Puolanne, 2004). Most of the carcasses in this study were cooled to below 10°C within 12 to 15 hours *post-mortem* and thus could have undergone mild cold shortening, resulting in slightly tougher meat.

Colour

Meat colour is one of the most important criteria used by consumers to select meat (Ouali *et al.*, 2006). Consumers tend to discriminate against meat that is either too pale or too dark (Issanchou, 1996; Viljoen, De Kock & Webb, 2002). South African game meat is often perceived as being dark-brown to red-brown in colour (Von La Chevallerie, 1972). There may be a number of reasons for this. Firstly, the dark colour may be caused by the stress experienced by the animals during hunting, so that meat becomes dark, firm and dry (DFD) (Scanga *et al.*, 1998). Alternatively, the dark colour of venison may be a result of the fact that these ungulates are more active than traditionally-farmed animals and, as a result, there is a higher level of myoglobin found in their muscles (Hoffman, 2000; Lawrie, 1998). The fact that game meat has less intramuscular fat than most domestic species may also account for the darker meat colour (Kritzinger, 2002). According to Volpelli, Valusso, Morgante, Pittia, and Piasentier (2003), the L*, a* and b* values that are characteristic of the dark-red colour of venison are L* < 40, high a* values and low b* values.

Table 6 shows all the mean colour ordinates for both treatments. The only differences were between a* and chroma with day-cropped animals having both higher mean a* and chroma values than the night-cropped animals. This indicates that the day-cropped animals produced meat that was redder and, most likely as a result of this, had higher colour intensity than those cropped at night. All mean values (L* = 32.59 ± 0.184; a* = 13.03 ± 0.166; b* = 8.55 ± 0.179) were similar than those found for red hartebeest by Smit (2004). Four of the animals produced meat with mean CIELab values below the total sample means (L* = 32.59 ± 0.184; a* = 13.03 ± 0.166; b* = 8.55 ± 0.179; H_{ab} = 33.18 ± 0.611; C* = 15.69 ± 0.181). The mean CIELab values of these animals ranged from 28.40 ± 0.184 to 29.45 ± 1.073 for L*, 11.08 ± 0.510 to 11.35 ± 0.166 for a* and 5.68 ± 0.479 to 6.18 ± 1.076 for b*. All four of these animals had pH_u values ranging from 5.8 to 6.3, indicating that they had most likely produced meat with DFD characteristics, although the CIELab values of these animals were still higher than those reported by Hoffman (2000) for an impala male that had been wounded and stressed for at least ten minutes prior to being killed and had subsequently produced DFD meat (L* = 25.44; a* = 9.13; b* = 4.88). It is of importance to note, however, that species differences in meat colour do occur and that the mean L* values in this study were higher than those found for impala (L* = 29.66 ± 2.745 to 28.78 ± 1.985) (Hoffman, 2000).This is in keeping with the findings of Von La Chevallerie (1972) who found that, analogous to a comparison between cattle and sheep, larger game species tend to produce meat that is lighter in colour than that of smaller game species, such as springbok and impala. Von

La Chevallerie (1972) also noted that the meat from impala had a red-brown, brick colour, whilst that of red hartebeest had a characteristic bright, cherry-red colour, as is also evident by the high a* values found in this study. Animals in both cropping methods produced meat characteristic of game meat with high a* and low b* values.

Table 6

Mean (LSMeans ± s.e.) of L*, a*, b*, hue-angle (H_{ab}) and chroma values (C*) of red hartebeest *M. longissimus dorsi* (LD) for both cropping methods

Colour ordinates	**Cropping technique**		
	Day	**Night**	**P < │t│**
L*	32.59 ± 0.235	32.80 ± 0.219	0.555
a*	13.42 ± 0.236	12.71 ± 0.219	0.048
b*	8.74 ± 0.272	8.44 ± 0.253	0.461
C*	16.12 ± 0.231	15.36 ± 0.215	0.032
H_{ab}	33.02 ± 1.026	33.42 ± 0.955	0.795

There were also negative correlations between L*, a*, b* and chroma values and ultimate pH (Table 7), indicating that an increase in pH_u would result in a decrease in these values. This is not unusual, since a high ultimate pH would result in very dark meat (DFD) with low L*, a* and b* values as well as decreased colour intensity (chroma). The dark colour of venison in general may also make it difficult to measure subtle colour differences that may have arisen as a result of marginally stressful conditions (Kritzinger, 2002). This may explain why very few differences were detected between the two cropping methods. There was a correlation between live weight and L*, a*, hue angle and chroma values, although the ANOVA indicated an interaction (P = 0.0002) between live weight and gender; this may partly be due to the higher mean live weight of the males (123.6 ± 2.747 kg), even though the mean live weight difference between the genders was not significant (P = 0.077; mean live weight females = 112.9 ± 2.613 kg). The ANOVA indicated that females weighing between 70 kg and 79 kg produced the lowest L* (28.40 ± 0.928), a* (11.08 ± 0.914), b* (6.75 ± 1.084) and chroma (13.42 ± 0.961) values. There was only one such animal cropped in this study, a female weighing 71 kg, and although it only received a stress score of 2 and had a cortisol level of 83 nmol/L, it had an adjusted pH_u of 6.30. This was the same animal previously discussed and was the only animal to be classified as DFD according to its pH_u. Because this was the female with the lowest live weight in the data set, it may more than likely be the interaction between live weight and gender together with the fact that the lightest male, weighing 50 kg, produced meat with the lightest colour (L* = 36.38 0 ± 928) and highest hue angle (39.13 ± 0.371). No regional differences were found for any of the colour ordinates.

Table 7

Pearson linear correlation coefficients (r) between pH_u and the physical attributes of the day and night-cropped red hartebeest

Characteristic	r	P < |t|
Cooking loss	-0.323	0.042
Drip loss	-0.322	0.031
Shear force (kg/1.27 cm diameter)	0.138	0.051
L*	-0.501	< 0.0001
a*	-0.514	< 0.0001
b*	-0.467	< 0.0001
Chroma	-0.640	< 0.0001
Hue	-0.135	0.141

CONCLUSIONS

The results of this study show that there is no difference in the rate and extent of pH decline *post-mortem* between day-cropped and night-cropped red hartebeest. Similarly, no differences in drip loss, cooking loss or shear force was found between treatments, although the colour ordinates indicated that day-cropped animals produced redder meat with greater colour intensity. These results are in contrast to the findings of other authors who have found that night cropping had a significantly better effect on meat quality because of a reduction in stress (Veary, 1991; Hoffman, 2000, 2001a; Kritzinger *et al.* 2002; Lewis *et al.*, 1997). These authors concluded that wild ungulates were less active at night and less aware of the hunting vehicles, so that they experienced less stress during night cropping than during day cropping. It may be that this effect is species-specific since most of the studies mentioned were conducted on smaller species such as impala or springbok. Alternatively, it may be that meat quality was not adversely affected by the cropping method due to the experience (accuracy) and efficiency of the cropping team. This is evidenced by the fact that only wounded animals or those chased for long periods of time before being killed produced meat with DFD characteristics. Some regional differences were found, which indicated that animals that were frequently hunted were more easily stressed during cropping than those that were unaccustomed to vehicles and hunters. The effect of day- and night-cropping on the meat quality of other large antelope is an aspect that requires further research.

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Chapter 5

A COMPARISON BETWEEN THE EFFECTS OF DAY AND NIGHT CROPPING ON GEMSBOK (*Oryx gazella*) MEAT QUALITY

ABSTRACT

As the production of game meat increases, the use of efficient cropping methods that induce the least amount of stress in animals becomes all the more important. The purpose of this study was to compare the effects of day- and night cropping on the quality of gemsbok meat. Day-cropped animals were found to have significantly higher mean stress scores and cortisol levels (stress score: 3.5 ± 0.423; cortisol: 136.88 ± 2.731 nmol/L) than night-cropped animals (stress score: 2.1 ± 0.378; cortisol: 64.1 ± 1.633 nmol/L) while night-cropped animals had a significantly higher mean pH_u (5.54 ± 0.013) than day-cropped animals (5.49 ± 0.014). Stress scores were significantly correlated with cortisol levels (r = 0.786). The exponential decay model, $y = a + b^{-ct}$, fitted to the pH data indicated a significant difference in constant a only (day = 5.45 ± 0.006; night = 5.51 ± 0.006). Night-cropped animals had significantly higher mean shear force values (4.19 ± 0.138 kg/1.27 cm diameter) than day-cropped animals (3.57 ± 0.154 kg/1.27cm diameter). All CIELab values except a* differed significantly between treatments (day: mean L* = 45.40 ± 0.833, b* = 13.65 ± 0.405, chroma = 19.27 ± 0.521 and hue = 45.43 ± 1.078; night: L* = 35.11 ± 0.745, b* = 9.70 ± 0.362, chroma = 16.51 ± 0.467 and hue = 36.22 ± 0.965). The results indicate that day cropping may have elicited more *ante-mortem* stress although this did not necessarily affect the meat quality adversely.

INTRODUCTION

According to Conroy and Gaigher (1982), the most common game species ranched within Southern Africa are springbok (*Antidorcus marsupialis*), eland (*Taurotragus oryx*), blesbok (*Damalicus pygargus phillipsi*), impala (*Aepyceros melampus*) and kudu (*Tragelaphus strepsiceros*). Gemsbok has become a popular species in the game-ranch industry, and Van der Waal and Dekker (2000) estimated that the number of gemsbok equals the number of eland found in the Northern Province. In recent years, the former species has come under consideration for commercial game meat production because of its size, distribution, year-round reproduction and population numbers. This species is also well suited to survive in hot, dry, arid conditions where the environment is unsuited for conventional livestock, thereby providing an alternative form of income for these areas (Hudson, Drew & Baskin, 1989). Gemsbok essentially occur in open, arid country, usually in open grasslands, open bush savanna and in light, open woodland (Smithers, 1983). This species is a large, extremely thick-necked antelope with long straight horns and a distinguishing thick, black tail. Males usually stand about 1.2 m tall at the shoulder and have a mass of up to 240 kg, while females are slightly smaller with a mass of up to 210 kg. The average percentage carcass yield of gemsbok is around 57% (Conroy & Gaigher, 1982). Gemsbok are gregarious and occur in mixed herds, nursery herds and as solitary males. Mature males are territorial, although they will temporarily join mixed herds containing adult females, their calves and non-territorial males of up to five years old (Apps, 1992). They are grazers, although they will browse on bushes and forbs in the absence of grass. Gemsbok are aseasonal breeders and mate at any time of the year. It has been noted that they have low-level aggressive behaviour that is more sustained and continuous than in other oryx species (Kingdon, 1997).

According to Onyango, Izumimoto and Kutima (1998) utilising such a species is also key to solving the dual problem of desertification and the need for high-quality proteins. Since the pre-slaughter handling of game animals is much less controlled than that of conventional livestock, it may be much harder to control meat quality defects with regard to pre-slaughter stress. In light of this, the use of effective cropping methods, well suited to the species being cropped, becomes important since it is one management issue in the production of game meat that can, to a certain extent, be controlled. The plains game species in South Africa are commercially cropped during either the day or night with the use of vehicles, helicopters or by means of boma capture by professional cropping teams (Hoffman & Wiklund, 2006). The use of these cropping methods are determined by the natural terrain and costs involved as well as by the species being cropped, since natural behaviour and response to cropping will differ between species. Although the commercial cropping of game species in southern Africa has been practiced for a number of years, very little research has been done on the effects of commercial cropping on the meat quality of these species. Many authors believe night cropping to be the least stressful and thus the method preferred to optimise meat quality (Hoffman, 2001; Kritzinger, Hoffman & Ferreira, 2002; Lewis, Pinchin & Kestin, 1997; Tinley, 1972; Veary, 1991; Von La Chevallerie & Van Zyl, 1971). It must be noted though that much of the research has been done on smaller species such as impala and springbok and information on the cropping of larger ungulates is sorely lacking.

Therefore, the purpose of this study was to determine the effects of day and night cropping with the use of vehicles on the meat quality of gemsbok (*Oryx gazelle)*, a species which has been identified as viable for commercial game meat production (Patterson & Khosa, 2005). To our knowledge, this is the first study that has been conducted on gemsbok meat with regard to cropping methodology.

MATERIALS AND METHODS

Animals

For this study, eighteen gemsbok (*Oryx gazella*) were cropped in Namibia, eight during the day and ten at night. Table 1 gives the distribution of gender as well as age group according to cropping methods. The age of the animals was determined based on horns, tooth wear and live weight. Gemsbok horns are straight, cylindrical and ringed for about one third of their length. As the animal ages, the rings condense towards the base of the horns, with juveniles having larger spacing between the rings. Tooth wear also increases with age, so that young animals will have relatively long teeth compared to adults, who will have shorter, worn-down teeth with straight, even edges. The animals were classed as juveniles, with live weights below 90 kg, sub-adults, with live weights between 100 kg and 150 kg, and adults, with live weights between 170 kg and 220 kg, after horn structure and tooth wear were taken into account.

Table 1

Distribution of the gemsbok (*Oryx gazella*), according to gender, age and cropping method

Age	**Day**		**Night**		**Total**
	Male	**Female**	**Male**	**Female**	
Juvenile	0	1	0	2	3
Sub-Adult	3	1	0	2	6
Adult	3	0	1	5	9
Total	6	2	1	9	18

Cropping

The same sharpshooters and cropping techniques were used as those described in the material and methods (Chapter 3) section of this thesis.

Daytime ambient temperatures ranged between 12°C and 15°C while nighttime ambient temperatures ranged between 2°C and 3°C. All the shots taken were either head- or neck shots, with the exception of five animals that were wounded in either the stomach or the rear, or shot through the nose. Four of the wounded animals were shot during the day, and wounding usually occurred when shots were taken at distances in excess of 250 m with the animals standing as part of a larger herd. All four of these animals were recovered and killed within a couple of minutes after being shot.

A stress score was allocated to each animal as per Table 2.

Table 2

Stress scale for the Gemsbok (*Oryx gazella*) as pertaining to perceived *ante-mortem* stress experienced

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

Stomach and viscera were removed in the field and weighed before being discarded. Trachea, lungs and organs were left in the carcasses and removed once carcasses were offloaded at the research laboratory. These were then tagged, placed in plastic bags and hung in the cooling truck at 0°C to 5°C. Once carcasses were offloaded, they were weighed again with heads and feet intact, and live weight was calculated as the sum of this weight and the weight of the stomach and viscera.

Carcasses remained in the field for no longer than three hours before being loaded into the cooling truck, where pH and temperature readings were taken at two- to three-hour intervals on all the animals for the first 24 hours *post-mortem*. Ultimate pH measurements (pH_u) were taken at 24 hours *post-mortem*. Cropping occurred over a three-day period. Ten gemsbok were shot during the first evening and another six gemsbok the following day. These animals were all shot at Neudamm Agricultural College, South of Windhoek. The remaining two gemsbok were shot on the third day at Progress Guest Farm, thirty kilometers east of Neudamm. All the carcasses were cooled with skin on in a cooling truck at 0°C to 5°C. On the fourth day, carcasses were transported to Farmer's Meat Market in Windhoek, where the red pluck was removed for health inspection and weighed; the carcasses were skinned and then weighed as well. This weight was used as the carcass weight. Sub-samples were then taken from the *M. longissimus dorsi* between the first and fourth lumbar vertebrae from one side of each carcass for the various physical meat quality measurements.

Blood samples

Blood samples were collected during exsanguination, kept on ice for three to four hours and then centrifuged for ten minutes, after which the serum was aliquot into clean tubes and frozen. The serum samples were then used to test for cortisol as per the procedure described in the materials and methods section (Chapter 3) of this thesis.

Physical analysis

Two sub-samples, 1.5 cm to 2.0 cm thick were taken from the *M. longissimus dorsi* of each carcass and used to determine drip loss, cooking loss, Warner-Bratzler shear force and colour measurements. The same procedures were followed as described in the materials and methods section (Chapter 3) of this thesis.

Statistical analysis

The same statistical analysis was used as described in Chapter 3. Analysis of variance (ANOVA) was used to test for differences in meat quality as well as the constants of the exponential decay model, with treatment, age, gender and live weight (since gemsbok are not sexually dimorphic) as main effects. Where applicable, Pearson correlation coefficients were calculated.

RESULTS AND DISCUSSION

The cropping of game is an integral component of wildlife management and is also important for the production and utilisation of game meat and other animal products. As noted by Skinner (1984), when producing meat from wild ungulates the same criteria apply as those applying to meat production from domestic stock. According to Bakula and Kedzior (2001), sensory characteristics are the most important quality attributes of meat and meat products. Issanchou (1996) also found that consumers discriminate against meat during purchasing, based on the colour and the amount of exudates. These two factors are strongly influenced by two meat quality defects known as pale, soft and exudative (PSE) meat and dark, firm and dry (DFD) meat. In South Africa, game meat is normally perceived as being of a dark, unattractive red colour, somewhat similar to beef that has been classified as DFD (Scanga, Belk, Tatum, Grandin & Smith, 1998). DFD is the result of “extreme” *ante-mortem* stress and, in the case of wild ungulates, can be prevented through the use of proper and efficient cropping methods.

In the current study, eighteen gemsbok were cropped during the day and at night. Seventy-two per cent of all the animals shot in the current study were shot in the head or neck, which, according to Von La Chevallerie and Van Zyl (1971) causes the least amount of meat wastage due to bullet damage. Five animals were wounded, four of which were cropped during the day, and then shot a second time (within ten minutes of the first shot).

Stress score

Pre-slaughter stress can result in a variety of physiological responses that will invariably affect meat quality, mainly because of its effect on muscle glycogen stores and thus the *post-mortem* pH of muscle. Measuring pre-slaughter stress may be confounded by a number of factors, including the animal’s evolutionary past and past experience (Hattingh, 1988). Although the rate and extent of pH fall *post-mortem* is a generally accepted measure of pre-slaughter stress in conventional livestock, other methods are also commonly used, such as documenting bruising as well as behaviour and the consumption of feed and water. In the case of free-living wildlife physiological and emotional stress may be harder to observe since these animals tend to hide symptoms that could make them appear vulnerable to predators or attack (Jordan, 2005). Since animal behaviour prior to slaughter was difficult to document in the current study, stress scores were allocated according to the perceived experience of the animal during cropping (as indicated in Chapter 3 of this thesis). These scores are not meant to be conclusive indicators of *ante-mortem* stress and are rather a measure complementary to other accepted measures, i.e. hormonal changes and changes in pH *post-mortem*.

Stress scores differed (p = 0.025) between treatments, with the mean stress score for day-cropped animals being 3.5 ± 0.423 and the mean stress score for night-cropped animals being 2.1 ± 0.378. This difference is most likely due to the fact that four animals were wounded during the day, whereas none of the recovered animals were wounded during the night cropping. The stress scores were all found to be highly correlated (p = 0.0001; r = 0.786) with cortisol (nmol/L) levels measured in the blood serum of the animals (Figure 1).

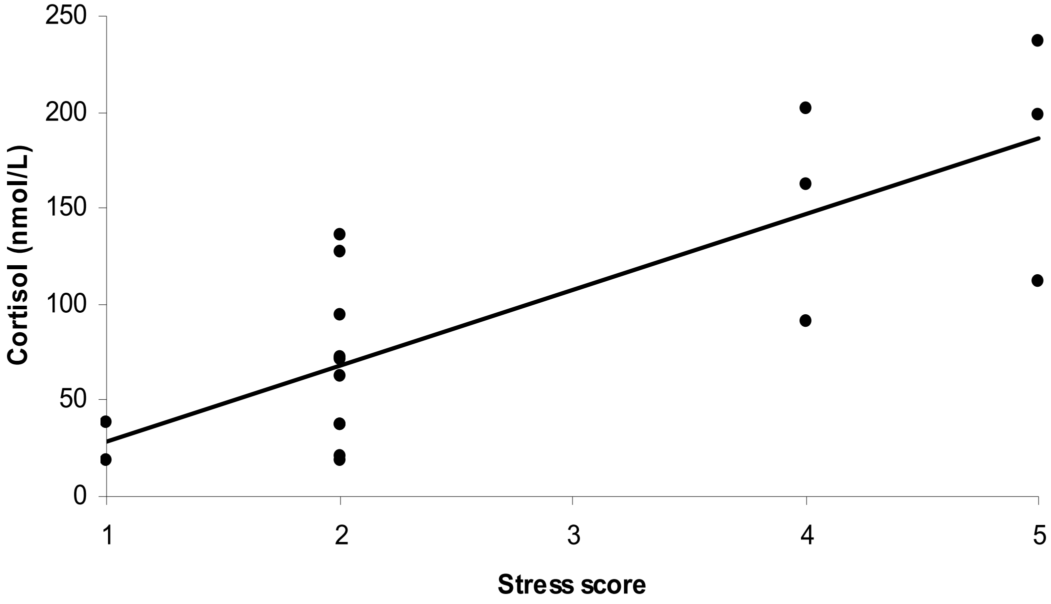

Fig. 1. Linear correlation (P = 0.0001; r = 0.786) between stress score and serum cortisol level (nmol/L) for day and night-cropped gemsbok

Cortisol

Stress activates the hypothalamic-pituitary-adrenal axis (HPA axis) which, in turn, causes the secretion of cortisol from the adrenal cortex. This response is often used as an indicator of stress in animals, and the release of cortisol results in an elevated plasma glucose concentration through increased hepatic glycogenolysis and gluconeogenesis coupled with increased protein catabolism (Shaw & Tume, 1992). Petty, Hattingh, Ganhao and Bezuidenhout (1994) used serum cortisol levels (nmol/L) along with other blood variables to compare the amount of *ante-mortem* stress experienced by cattle during three types of slaughter. These authors found cortisol levels ranging between 88.12 and 207.57 nmol/L. In the current investigation, serum cortisol levels were quite variable between animals, ranging from a minimum of 19 to a maximum of 237 nmol/L. This is similar to the findings of Hattingh (1988), who documented cortisol levels in impala ranging from 19.4 to 148 nmol/L, in roan antelope ranging from 23 to 135 nmol/L, in elephants ranging from 111.4 to 1141 nmol/L and in buffalo ranging from 38.9 to 181 nmol/L.

Serum cortisol levels differed ($p = 0.019$) between treatments, with animals shot during the day having a mean cortisol levels of 136.88 ± 2.833 nmol/L and those shot at night having a mean cortisol level of 64.1 ± 1.833 nmol/L. These results may indicate that day cropping caused a higher amount of *ante-mortem* stress than night cropping and is in agreement with the findings of Kritzinger *et al*., (2002), Veary (1991) and Hoffman (2000), who found that night cropping was the least stressful cropping method and concluded that this was due to the fact that the animals were less active and less aware of the hunters at night. It is of interest to note that the mean cortisol level of those animals wounded before being killed with a second shot was 177.5 nmol/L, which is more than twice the mean cortisol level of those not wounded (73.29 nmol/L). Since no animals were wounded during the night cropping, these values would cause the mean day values to be skewed and may explain the differences in serum cortisol level between day and night-cropped animals.

Temperature

The pH decline in muscle *post-mortem* has been found to be affected by temperature because of the effect that temperature has on the main buffers in the muscle, namely carnosine, anserine and histidine. The effect of temperature on these buffers causes measured pH increases of about 0.1 pH units for every 10^{o}C decrease in temperature (Bruce, Scott & Thompson, 2001; Bendall & Wismer-Pederson, 1962). Bruce *et al.* (2001) therefore suggested that pH values should be adjusted to a constant temperature in cases where there are differences in temperature decline between carcasses. In the current study, an exponential decay model ($y = a + b^{-ct}$) was fitted to the temperature data of the carcasses, with an R^2 value ranging between 0.877 and 0.997. The rate of temperature decline (Figure 2) differed ($p < 0.0001$) between treatments (Day: $c = -0.126 \pm 0.005$; Night: $c = -0.197 \pm 0.004$) and a likely explanation for this was the differences in ambient temperatures, with daytime temperatures ranging from 12°C to 15°C and nighttime temperatures ranging from 2°C to 3°C. This large difference in ambient temperatures also affected the efficacy of the cooling system inside the cooling truck, so that the opening and closing of the doors at night had little or no effect on the cooling truck temperature while it caused warmer air to leak into the truck during the day, As a result, there was a larger fluctuation in temperature inside the cooling truck during the day. Rates of temperature decline also differed ($p < 0.0001$) between the different hanging positions in the cooling truck with those carcasses hanging close to the fan ($n = 8$; $c = -0.202 \pm 0.004$) cooling more rapidly ($p < 0.0001$) than those hanging in the middle ($n = 5$; $c = -0.136 \pm 0.007$) and those close to the doors ($n = 5$; $c = -0.121 \pm 0.006$). Carcass weight also affected the rate of temperature decline, such that, although no correlation was found between carcass weight and rate of temperature decline, differences were found when carcasses were divided into weight classes. The lightest carcasses, weighing between 40 kg and 49 kg ($n = 2$), cooled at a rate of -0.291 ± 0.006 units per hour. The heaviest carcasses, weighing between 130 kg and 139 kg ($n = 2$), cooled at a rate of -0.154 units per hour. These findings are in agreement with the findings of other authors who have found that heavier carcasses have more fat cover (although most game species do not have this) which acts as insulation, as well as having proportionally smaller surface areas from which to lose heat

(Johnson, Bidner, McMillin, Dugas & Hembry, 1989; Lochner, Kauffman & March, 1980). As a result of these differences in temperature decline, all pH values were standardised to 4°C (Bruce *et al.*, 2001).

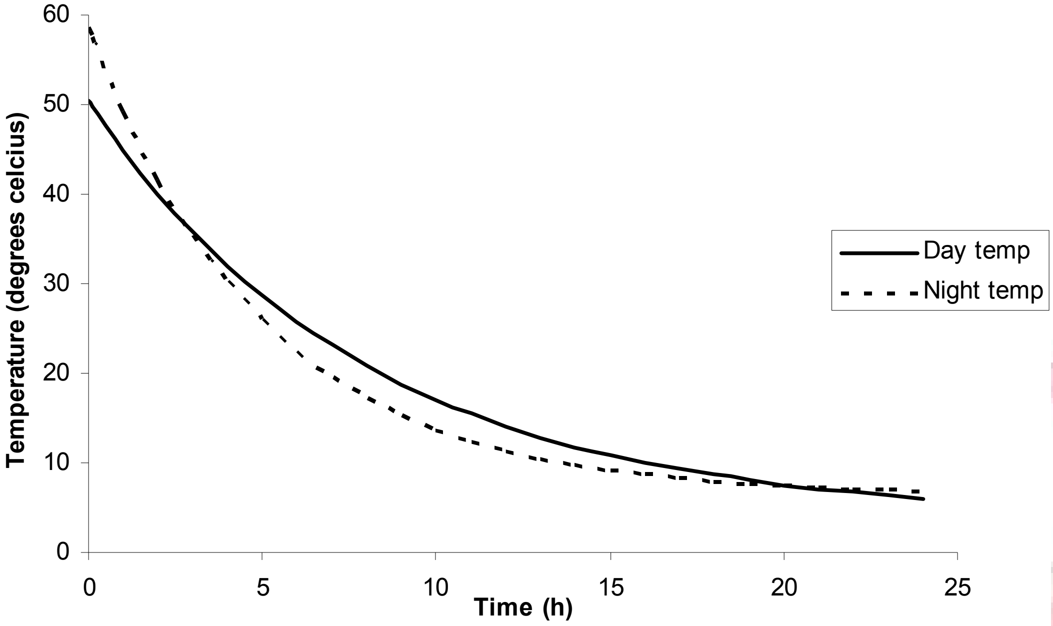

Fig. 2. Mean *M. longissimus dorsi* temperature profiles for day (n=8) and night (n=10) cropped gemsbok

pH

Ultimate pH (pH_u) is often used as an indicator of DFD, which is found in all species although it is more common in ruminants. It is usually the result of chronic stress, where glycogen reserves are depleted prior to death with the result that lactic acid production *post-mortem* is minimal, causing a high ultimate pH (Mounier, Dubroeucq, Andanson & Veissier, 2006). DFD meat is generally defined as having an ultimate pH (pH_u), measured at 12 to 48 hours post-mortem, of > 5.8 (Hoffman, 2001; Warriss, 2000; Wiklund, Andersson, Malmfors, Lündstrom & Danell, 1995). In the current study, pH_u was measured at 24 hours *post-mortem* and none of the animals exhibited pH_u values > 5.8 (Table 3). There was no difference ($P > 0.05$) for non-adjusted pH_u between treatments, although night-cropped animals produced a higher mean adjusted pH_u than day-cropped animals. Since temperature decline differed between carcasses, only the latter will be discussed. It must also be noted that although the mean pH_u differed statistically between treatments, biologically, these values may not necessarily differ significantly with regard to their effect on meat quality. It could therefore be argued that the statistical difference may have become insignificant if the sample size had been larger. The findings of this study are in contrast to the findings of Veary (1991) who reported that the pH_u of springbok was consistently higher in day-cropped animals than in night-cropped animals. Kritzinger *et al.* (2002) similarly found that day-cropped impala had higher pH_u values than night-cropped impala. It may be that the increased *ante-mortem* stress experienced by the day-cropped animals, as indicated by the stress scores and serum cortisol levels, could have caused the mobilisation of the animals' glycogen stores immediately prior to slaughter, resulting in an increased rate of lactic acid production and a decreased pH_u, even though no correlation was found between stress score, cortisol level and pH_u. The results of the current investigation also indicated correlations between pH_u and shear force, L* and hue angle (Table 7).

When gender and age were included as main effects, no difference was found between age groups or live weight, although females were found to have a higher ($P = 0.035$) mean pH_u (5.54 ± 0.013) than males (5.49 ± 0.016). Although there was no interaction between gender and treatment ($P = 0.315$), since only one male was cropped at night while six were cropped during the day, this may have skewed the data, such that night-cropped animals produced a higher mean pH_u.

Table 3
Mean pH_u values (LSMean ± s.e.) measured at 24 h *post-mortem* for day and night-cropped gemsbok

Treatment	**Non-adjusted pH**	**P < │t│**	**Adjusted pH**	**P < │t│**
Day	5.46 ± 0.022	0.121	5.49 ± 0.014	0.013
Night	5.51 ± 0.020		5.54 ± 0.013	

The rate of pH decline in muscle has been found to deviate from a linear function in a curvilinear manner (Bate-Smith & Bendall, 1956; Bendall, 1973; Bruce *et al.*, 2001; Pearson & Young, 1989; Warriss, 2000). This is because, as the muscle enters rigor, the rate of pH decline slows due to the decrease in myosin ATPase activity and anaerobic glycolysis as the muscle cools and the buffering effect of ammonia generated by the deamination of AMP (Bruce *et al.*, 2001). As a result of this, the exponential decay model, $y = a + b^{-ct}$, was fitted to the pH data in the current study. The model fit the data well with R^2 values ranging from 0.874 to 0.989 for the non-adjusted pH data and from 0.857 to 0.987 for the adjusted pH data. Table 4 depicts the constants of the exponential decay model for the two treatments.

Table 4

The calculated constants (LSMean ± s.e.) for the exponential equations fitted to the pH decline under ambient temperature conditions and under adjusted standard temperature (4°C) for day- (n = 8) and night- (n = 10) cropped gemsbok

$Y = a + be^{-ct}$	**Treatment**	**Non-adjusted pH**		**Adjusted pH**	
Constants		**Mean ± s.e.**	**P < │t│**	**Mean ± s.e.**	**P < │t│**
a	Day	5.40 ± 0.007	< 0.0001	5.45 ± 0.006	< 0.0001
	Night	5.45 ± 0.005		5.51 ± 0.006	
b	Day	1.03 ± 0.287	< 0.0001	0.90 ± 0.081	0.1021
	Night	3.16 ± 0.237		1.08 ± 0.080	
c	Day	-0.21 ± 0.034	< 0.0001	-0.18 ± 0.011	0.2020
	Night	-0.43 ± 0.028		-0.21 ± 0.010	

The results of this investigation show that there is only a difference ($p < 0.0001$) between treatments for constant a for the adjusted pH. Since there were differences in the rate of temperature decline between carcasses, only adjusted pH values will be discussed. These values indicate that the night-cropped animals reached a higher final pH ($p < 0.0001$) than the day-cropped animals although the rate of pH decline (constant c) did not differ (Figure 3). These findings are in contrast to those of Kritzinger *et al.* (2002) who found that day-cropped impala had higher ($p < 0.01$) rates of pH decline (Day: $c = -0.58$; Night: $c = -0.45$) as well as higher final pH values than night-cropped animals (Day: $a = 5.46$; Night: $a = 5.42$). Hoffman (2000) reported slightly higher values in night-cropped impala than were found in this study, with constants of a ranging from 5.67 to 5.79, constants of b ranging from 2.10 to 3.10 and constants of c ranging from -0.45 to -0.71. Similarly, Hoffman, Kroucamp and Manley (2007) reported values for constant a ranging from 5.47 to 5.57, constant b ranging from 3.14 to 3.39 and constant c ranging from -0.77 to -0.97 for springbok (it must be noted that these authors also adjusted all pH values to a constant temperature of 4°C). They suggested that the high c-values could be the result of a species effect, resulting in a very fast pH decline. It has been found that a lower final pH may be indicative of a greater amount of acute *ante-mortem* stress since, in such a case, glycogen stores in the body are mobilised so that there is a large amount of glycogen available for *post-mortem* glycolysis, resulting in a large build-up of lactic acid and a greater extent of muscle acidification. In the case of the gemsbok, this may be the case, since both stress score and cortisol levels indicated a greater amount of *ante-mortem* stress in the day-cropped animals. This increased extent of muscle acidification is usually accompanied by an increase in the rate of acidification, which was not the case in the current investigation since there was no difference in constant c of the exponential decay model between treatments when adjusted for a constant temperature.

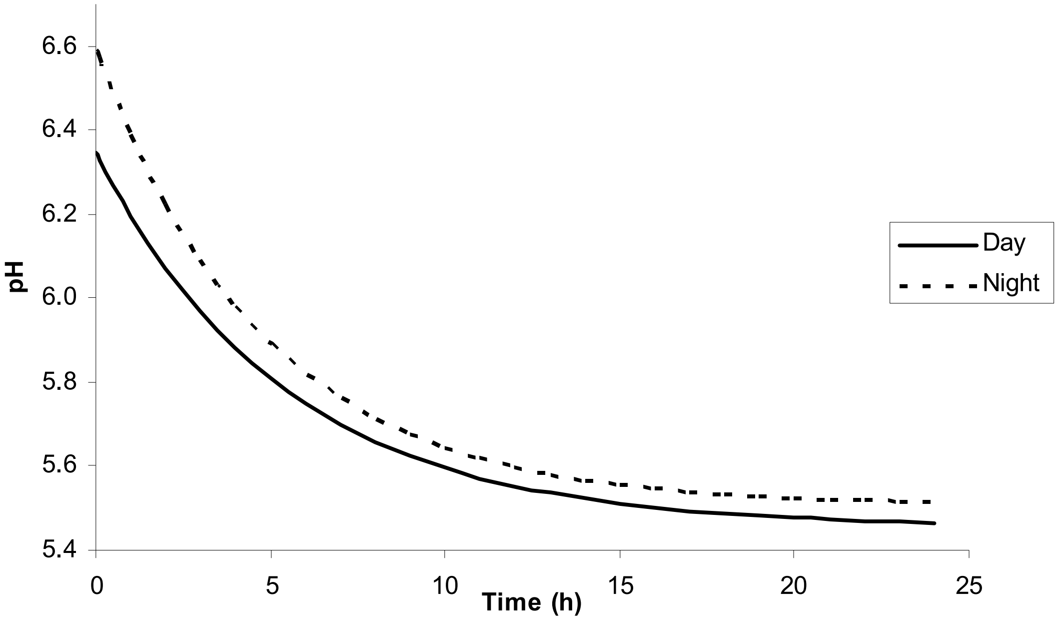

Fig. 3. Mean *M. longissimus dorsi* adjusted pH profiles for day (n=8) and night (n=10) cropped gemsbok

When gender was included as a main effect, differences ($p < 0.001$) were found between the genders for constants a and c, with females having higher values (a = 5.50 ± 0.007; c = -0.23 ± 0.011) than males (a = 5.46 ± 0.008; c = -0.16 ± 0.013). This indicates that the rate and extent of pH decline was also influenced by gender and, since more females were shot at night (n=9) than during the day (n=2), it stands to reason that this gender effect would influence the treatment effect even though the ANOVA indicated no interaction between treatment and gender. Further investigations, using a larger sample size may give a better indication of the effect of gender. The findings of this study are in contrast to those of Hoffman (2000) who found that male impala had higher a-, b- and c-values than female impala did and it was suggested that this was due to the males just having finished their rutting season so that they were in a more excitable state. Since gemsbok have no specific rutting season, it could be that gemsbok females are generally more active than the males which would explain a higher rate of pH decline. McGeehin, Sheridan and Butler, (2001) found that female lambs had faster rates of pH decline than males and concluded that it may have been the result of physiological differences between the sexes.

Water-holding capacity and tenderness

The water-holding capacity of meat (WHC) is the ability of meat to bind its own water or, under the influence of external forces, to bind added water (Swatland, 1994). It has been said to be one of the most important quality characteristics of raw products and product weight losses due to purge can average as much as 1% to 3% of fresh retail cuts (Huff-Lonergan & Lonergan, 2005; Savage, Warriss & Jolly, 1990). Accelerated pH decline and low ultimate pH values are related to the development of low WHC as is evident in the case of PSE meat, and according to Pearson and Young (1989), in the pH range of 5.0 to 6.5, any alteration of pH has a great influence on WHC. The results of this study showed no correlation between cooking loss or drip loss and the pH_u (measured at 24 hours *post*-mortem) (Table 7) or the rate of pH decline (constant c of the exponential decay model). Other authors have found contrasting results, with pH_u being strongly correlated to the WHC of the meat (Bouton, Harris & Shorthose, 1971; Dransfield, Jones & MacFie, 1981; Guignot, Vignon & Monin, 1993; Offer & Knight, 1988). These authors found that the higher the pH_u, the less water would be released from the muscle since WHC is at a minimum between pH 5.0-5.5, which corresponds to the isoelectric point of the muscle proteins (Hamm, 1986).

In the current investigation, no difference was found in drip loss or cooking loss between treatments (Table 5). Nor were any differences found between cooking loss and drip loss and any of the other main effects (age, gender and live weight). Cooking loss and drip loss values were similar to values that have been reported for other game species (Kritzinger *et al.*, 2002; Hoffman *et al.*, 2007; Mostert, 2007; Van Schalkwyk, 2004). Onyango *et al.* (1998) reported that gemsbok meat had a higher cooking loss values than beef, zebra (*Equus burchelli*) and red hartebeest (*Alcelaphus buselaphus*) and concluded that this was due to the effect of species differences on pH_u.

Table 5

Mean values of the physical meat quality parameters (LSMean ± s.e.) as measured in the *M. longissimus dorsi* of day and night-cropped gemsbok

Parameter	**Cropping technique**		
	Day	**Night**	**P < │t│**
Drip loss (%)	3.39 ± 0.382	2.37 ± 0.341	0.064
Cooking loss (%)	35.88 ± 0.958	36.76 ± 0.822	0.526
Shear force (kg/1.27cm diameter)	3.57 ± 0.154	4.19 ± 0.138	0.004

The Warner-Bratzler shear force differed ($p = 0.004$) between treatments, with night-cropped animals having the higher shear force values. Meat tenderness has been shown to be related to pH_u although this relationship is controversial, with some authors believing it to be a curvilinear relationship (Watanabe, Daly & Devine, 1996). Some studies have found that as the pH_u increases from 5.5 to 6.0, the tenderness decreases with the effect being reversed as the pH_u increases above 6.0 (Bouton *et al.*, 1971; Purchas, 1990). When animals were divided into two groups, namely those with pH_u values within this range and those with pH_u values outside this range, ANOVA revealed a difference ($P < 0.0001$) in shear force between the two groups. Those animals with pH_u between 5.5 and 6.0 produced tougher meat (4.29 ± 0.131 kg/1.27 cm diameter) than those animals with pH_u outside this range (3.43 ± 0.147 kg/1.27 cm diameter). This may explain why the night-cropped animals produced tougher meat in the current investigation, since eight of the animals shot at night (i.e. 80% within this treatment) had pH_u values between 5.5 and 6.0 while only two of the animals shot during the day (i.e. 25% within this treatment) had pH_u values within this range. pH_u was also found to be positively correlated with shear force ($P = 0.0002$; $r = 0.39$) so that shear force increased as pH_u increased, as can be seen in figure 5 (it is important to note that none of the animals had pH_u values above 6.0). This would once again explain why night-cropped animals produced tougher meat since they also had a higher mean pH_u than the day-cropped animals. A higher pH_u together with a rapid rate of pH decline can lead to the association of the actin and myosin filaments of the night-cropped animals, leading to shortening and decreased tenderness (Ouali & Talmant, 1990). Another explanation for the differences in shear force between the treatments may be the effects of temperature. A fast rate of temperature decline may be detrimental to tenderness because low carcass temperatures (usually below 15°C according to Savell *et al.*, 2005) before the onset or completion of *rigor mortis* may stimulate the massive release of calcium (Ca^{2+}) from the sarcoplasmic reticulum (SR) as well as muscle mitochondria (Lawrie, 1998; Warriss, 2000). Because there is still ATP left in the muscle, the Ca^{2+} ions activate the actomyosin ATPase, causing the muscle to contract (Savell *et al.*, 2005). Since the Ca^{2+} ions cannot be reabsorbed by the SR system, the muscle contraction is not followed by relaxation, resulting in shorter sarcomeres and tougher meat, a phenomenon generally referred to as cold shortening (Pearson & Young, 1989). Since it was shown that the carcasses of the night-cropped animals cooled at a faster rate than those of the day-cropped animals (Figure 2), the effect of temperature on the tenderness of the meat cannot be completely ignored, even though the carcasses of the former did not cool at a rate fast enough to be considered by some authors as inducing cold shortening (Pearson & Young, 1989). The findings of the current study are in contrast to those of Kritzinger *et al.* (2002), who reported lower shear force values for night-cropped animals, although the author similarly concluded that this was mainly due to the fact that these animals had higher pH_u values than those cropped during the day.

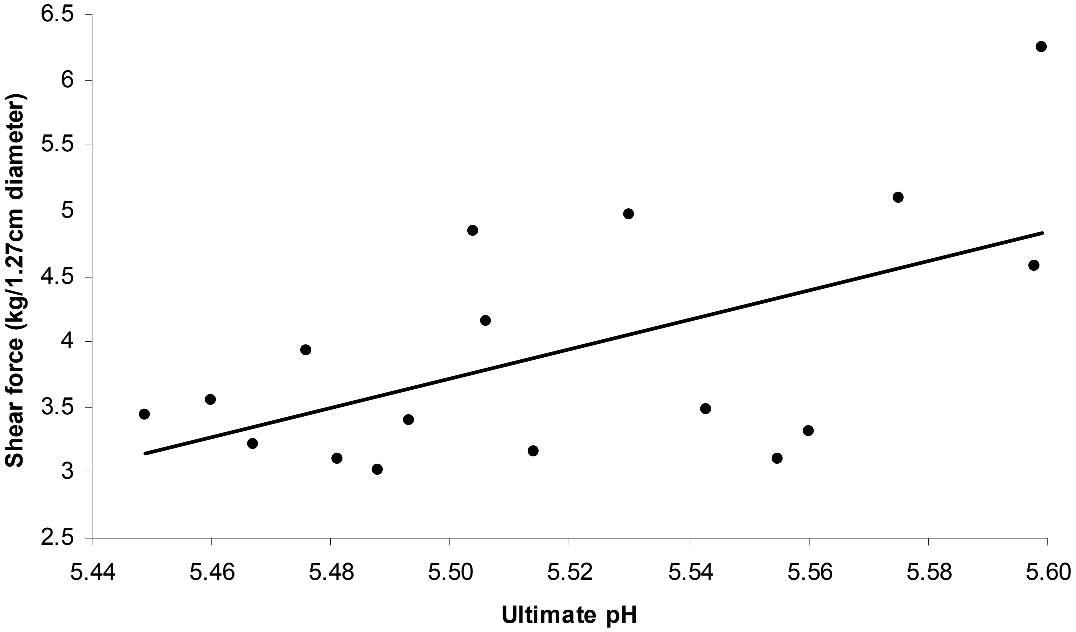

Fig. 5. Linear correlation (P = 0.0002; r = 0.39) between shear force (kg/1.27 cm diameter) and ultimate pH (pH_u) for day and night-cropped gemsbok

When other main effects were included in the model, differences in shear force were found between age- and gender groups. However, the ANOVA also revealed an interaction (P = 0.027) between live weight and age, which was most likely due to the fact that live weight increased with age such that adults had a higher (P < 0.0001) mean live weight (197.96 ± 1.905 kg) than sub-adults (129.69 ± 2.333 kg) and sub-adults had a higher (P < 0.0001) mean live weight than juveniles (80.32 ± 3.299 kg). Sub-adults weighing between 120 kg and 129 kg produced the highest mean shear force (5.88 ± 0.357 kg/1.27 cm diameter), while adults weighing between 210 kg and 129 kg produced the lowest mean shear force (3.10 ± 0.320 kg/1.27 cm diameter). Meat from females was found to be tougher (p = 0.021) than meat from males, with females having mean shear force values of 4.11 kg/1.27 cm diameter and males having mean shear force values of 3.60 kg/1.27 cm. This is in contrast to the findings of Mostert and Hoffman (2007), Hoffman, Kritzinger and Ferreira (2005) and Hoffman *et al.* (2007) who found no differences in shear force between genders in kudu, impala and springbok meat. Van Schalkwyk (2004) reported similar mean shear force values for black wildebeest (*Connochaetus gnou*) and blue wildebeest (*Connochaetus taurinus*) as was found in the current investigation. The author reported shear force values of 4.28 kg/1.27 cm for female black wildebeest and shear force values of 3.23 kg/1.27 cm for male black wildebeest. Similarly, mean shear force values of female blue wildebeest were reported as 4.60 kg/1.27 cm and for male blue wildebeest as 3.77 kg/1.27 cm. These findings are in contrast to those of studies done on conventional livestock (Diaz, Velasco, Perez, Lauzurica, Huidoro & Caneque, 2003; Jeremiah, Tong & Gibson, 1991) and it may be that gender differences in wild ungulates may be species-specific.

Colour

The colour of meat is often used by consumers as an indicator of quality and freshness, and game meat is often perceived as being a dark, unattractive colour (Issanchou, 1996; Viljoen, De Kock & Webb, 2002; Hoffman & Wiklund, 2006). According to Volpelli, Valusso, Morgante, Pittia and Piasentier (2003), the L*, a* and b* values that are characteristic of the dark-red colour of venison are L* < 40, high a* values and low b* values. It is of interest to note that all the gemsbok had relatively high L* values as compared to other game species, with 77% of the animals having L* values above 35. Smit (2004) recorded mean L* values ranging from 27.94 to 33.64 for blesbok and from 31.35 to 33.66 for red hartebeest, while Hoffman (2000) reported a mean L* value of 32.87 for impala. Hoffman *et al.* (2007) also reported mean L* values for springbok ranging from 30.71 to 33.54. The findings of this study were in agreement with the observations of Von La Chevallerie (1972), who noted that gemsbok produced the lightest meat when compared to that of blesbok, red hartebeest, impala, springbok and wildebeest. Similarly, Onyango *et al.* (1998) found that gemsbok muscles were the lightest compared to beef, zebra and red hartebeest, although the authors did not report the related mean L* values. These authors found that gemsbok meat had the lowest myoglobin pigment concentration and attributed the high L* values of the gemsbok muscles to this.

Treatment differences were found in all the colour parameters except the a* values (Table 6). Day-cropped animals produced higher L*, b*, chroma and hue angle values than night-cropped animals. The differences in L* values may partly be explained by the inverse correlation between L* and pH_u (Table 7) since the night-cropped animals had a higher mean pH_u and, as a result, produced meat with a lower mean L* than the day-cropped animals. This is in agreement with the findings of Mostert (2007) who found that pH_u was inversely correlated to L* in the *M. longissimus dorsi* of kudu and impala (P = 0.002; r = -0.368). According to Lawrie (1998), the higher the ultimate pH of meat, the further the muscle proteins will be from their isoelectric points so that more of the water in the muscle will be associated with them and the fibres will be tightly packed together, presenting a barrier to diffusion. The opposite is true for a lowered ultimate pH, which causes the protein structures of the muscle to "open" and scatter light and expose the muscle myoglobin to conditions that cause it to oxidized to bright-red oxymyoglobin. There was also an inverse correlation between hue angle and pH_u (Table 7), which is most likely due to the same reason as the correlation between L* and $pH_{u,}$ such that darker meat will have a higher mean hue value.

The mean L* value of the day-cropped animals is similar to that reported for pigs (L* = 43.7) by Fisher, Mellett and Hoffman (2000) and were higher than those reported for buffalo (35.59 ± 0.642) who had been killed with scoline and, as a result, had produced PSE meat (Hoffman, 2001). The lack of difference in WHC between treatments and the relatively high a* values of the gemsbok indicate that these animals did not produce PSE meat, which means that their higher L* values are more likely species-and pH related and that differences in pH between the treatments were not severe enough to elicit PSE.

Table 6

LSMeans (± s.e.) of L*, a*, b*, hue-angle (H_{ab}) and chroma values (C*) of gemsbok *M. longissimus dorsi* (LD) muscle for both cropping methods

Colour ordinates	**Cropping technique**		
	Day	**Night**	**P < │t│**
L*	45.40 ± 0.833	35.11 ± 0.745	< 0.0001
a*	13.50 ± 0.460	13.27 ± 0.411	0.713
b*	13.65 ± 0.405	9.70 ± 0.362	< 0.0001
C*	19.27 ± 0.521	16.51 ± 0.467	0.0002
H_{ab}	45.43 ± 1.078	36.22 ± 0.965	< 0.0001

When the other main effects were included in the statistical model, the model indicated differences ($p < 0.05$) in L*, a*, b* and chroma values between the three age groups, although the ANOVA also revealed an interaction for these ordinates between live weight and age. As previously explained, this may be due to the fact that live weight increased with age. The ANOVA indicated that sub-adults weighing between 100 kg and 109 kg produced the lightest meat (48.28 ± 2.982) and had the highest a* (18.013 ± 0.631), b* (18.35 ± 1.028) and chroma (25.71 ± 0.679) values. There was only one such animal in this study, namely a sub-adult female that weighed 103.8 kg. Even though this animal had been killed by a single shot to the head, it had been chased for up to 600 m before being killed, resulting in a stress score of 4, a cortisol level of 202 nmol/L and a pH_u of 5.56 (which is higher than the population mean pH_u of 5.51). It may thus be that this animal was severely stressed resulting in the colour discrepancies, even though the a* values are too high for the meat to be classified as PSE. Further research into the meat quality of this species is required to determine the exact effect of stress (both physical and psychological) on its meat colour. It must be taken into account that the small sample size in this investigation may explain why this one animal may have skewed the data such that an interaction was found between live weight and age. The interaction further revealed that adults weighing between 210 kg and 219 kg produced the darkest meat (L* = 32.93 ± 2.982), juveniles weighing between 80 kg and 89 kg produced the lowest a* values (9.55 ± 0.446), while sub-adults weighing between 130 kg and 139 kg produced the lowest b* (7.16 ± 1.028) and chroma (13.32 ± 0.679) values. No other interactions were found between any of the other main effect.

Differences ($p < 0.05$) were also found between the genders for L*, b*, hue and chroma, with females having lower values in all four these parameters. These results indicate that females produced darker meat with lower colour purity than males, which is in contrast to the findings of Hoffman *et al.* (2007) and Mostert (2007) who found the opposite in springbok and kudu, respectively. Lastly, L*, a* and chroma values were found to be correlated with live weight (Table 6). This is in agreement with the findings that adults produced meat with lower L* values and higher a* and chroma values than sub-adults and juveniles, and, since live weight is known to increase with age, this may explain the correlations between live weight and the colour parameters.

Table 7

Pearson linear correlation coefficients (r) between pH_u and the physical attributes of the day and night-cropped gemsbok

Characteristic	r	P < |t|
Cooking loss	0.321	0.194
Drip loss	-0.277	0.265
Shear force (kg/1.27 cm diameter)	0.388	0.0002
L*	-0.247	0.019
a*	0.049	0.645
b*	-0.143	0.177
Chroma	-0.065	0.541
Hue	-0.227	0.032

CONCLUSIONS

The results of this study indicate that both stress score and cortisol levels were higher in day-cropped gemsbok than in night-cropped gemsbok and that night-cropped animals produced a higher mean pH_u (measured at 24 hours *post-mortem*) than day-cropped animals, although the biological significance of this small difference is debatable. pH_u was also found to be correlated with shear force, L* and hue angle. The exponential decay model indicated that the rate and extent of pH fall *post-mortem* of the day-cropped animals was lower than that of the night-cropped animals, although there were no correlations between the constants of the exponential decay model and any of the meat quality parameters. Treatments did not lead to differerences in WHC, although the night-cropped animals did produce tougher meat than day-cropped animals, which is likely due to the higher pH_u of the former as well as the effects of temperature. It has been documented that gemsbok meat is generally lighter than many other species of game and it has been postulated that this is due to a lower concentration of myoglobin in the muscle of this species (Onyango *et al.*, 1998). The reason for this is unknown and differences in the CIELab values between the main effects in this study are difficult to explain, because of the lack of research on the meat quality and physiology of this species. Although the data suggest that day-cropped animals experienced more *ante-mortem* stress than night-cropped animals, there is little evidence to suggest that this adversely affected the meat quality to any great extent. Also, the data may be confounded by the fact that four animals were wounded and recovered during the day cropping, while no animals were wounded during the night cropping. Because the data set is relatively small, the increased stress experienced by certain individuals may more easily have skewed the data. The size of the data set did also not allow for a large amount of age and gender differentiation which may have confounded the statistical analysis.

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Chapter 6

A COMPARISON BETWEEN THE EFFECTS OF DAY AND NIGHT CROPPING ON KUDU (*TRAGELAPHUS STREPSICEROS*) MEAT QUALITY

ABSTRACT

Kudu has become an increasingly popular species for game meat production and the purpose of this study was to determine the effects of day and night cropping on the meat quality of this species. Eight animals were cropped during the day and eight at night. Day-cropped animals had significantly higher mean stress scores and cortisol levels (stress score = 3.0 ± 0.641; cortisol = 68 ± 1.28 nmol/L) than night-cropped animals (stress score = 1.8 ± 0.955; cortisol = 14 ± 2.15 nmol/L). Stress scores and cortisol levels were found to be significantly correlated (r = 0.823). Although the ultimate pH (pH_u) values differed significantly between the two treatments (day-cropped animals = 5.40 ± 0.030; night-cropped = 5.48 ± 0.041), it is debatable whether this slight difference is of biological significance. Significant differences were found in drip loss (day-cropped = 2.76 ± 0.261%; night-cropped = 1.36 ± 0.361%) and in shear force between treatments (day-cropped = 3.45 ± 0.171; night-cropped = 4.06 ± 0.237 kg/1.27 cm diameter). Significant correlations were found between pH_u and drip loss (r = -0.77886) and shear force (r = 0.50595). No significant differences were found between the treatments for any of the colour ordinates, except L* (day-cropped: 33.45 ± 0.435; night-cropped = 32.13 ± 0.601). The results of this study indicate that day-cropped animals experienced more *ante-mortem* stress and, as a result, produced meat with higher drip loss, a lower shear force and a lighter colour.

INTRODUCTION

The game-ranching industry in southern Africa has been growing at an annual rate of 5.6% (Eloff, 2001) with many cattle farms being converted into game farms. With this growth, there has been an increasing demand for game meat both locally and internationally, with springbok (*Antidorcus marsupialis*), gemsbok (*Oryx gazelle*), impala (*Aepyceros melampus*) and kudu being some of the most popular species utilised for this purpose (Olivier & Van Zyl, 2002; Hoffman & Wiklund, 2006). Although statistical data on the export quantities of South African game meat is lacking, it is estimated that the deboned meat from 160 000 carcasses was exported during the 2005 season alone. Of this, more than 80% was from springbok, with blesbok (*Damaliscus pygagus*) and kudu adding predominantly to the rest of the total (Hoffman & Wiklund, 2006). Kudu is an ungulate species that has been hunted in southern Africa for many years although it has in recent years grown to become a popular species for game meat production. According to Patterson and Khosa (2005), kudu was the second most utilised species for game meat production in South African between 2002 and 2004, producing as much as 64 000 tons of meat per year.

Kudu are a savanna woodland species that do not occur in desert, forest or in open grassland areas. They are gregarious and herds are usually small, seldom exceeding more than a dozen individuals (Smithers, 1983). Kudu are normally most active in the early morning and late afternoon, but can become nocturnal to escape hunting and other disturbances in developed areas. They are generally very secretive animals, spending most of their time hiding in thick bush. Their mating season is usually from May to August, although females may come into estrous outside their mating season. During the mating season, bulls become aggressive as they compete for access to female herds. They thrash vegetation and dig up soil with their horns, and fights with other males may last as long as 15 minutes (Apps, 1992). Adult males stand about 1.4 m high at the shoulder and can weigh as much as 250 kg. The live mass of a kudu bull can vary throughout the year, with breeding bulls being at their heaviest towards September, when they occur in bachelor herds (Bothma, 2002). Females are distinctly smaller with maximum masses of up to about 200 kg and shoulder heights of up to 1.25 m (Smithers, 1983). Dressing percentages range from 55.6% to 60.13% (Mostert & Hoffman, 2007). Kudu are sexually dimorphic with males having spiraled horns, although horned females have been documented. Twists in the horns increase as the animal ages with the first complete spiral developing at around two-and-a half years of age (Furstenburg, 2005).

With meat production from this species increasing, scientifically based information on the factors affecting its meat quality is required in order for it to compete with existing meat products. As noted by Skinner (1984), when producing game meat from wild ungulates the same criteria apply as those applying to meat production from domestic livestock; these include carcass yield, chemical composition and meat quality (Issanchou, 1996). As with conventional livestock, pre-slaughter handling can lead to detrimental effects on meat quality, with the most severe effects being either dark, firm and dry (DFD) meat or pale, soft and exudative (PSE) meat. Both these conditions are caused by excessive *ante-mortem* stress and can be eliminated or minimised with the use of good management practices. In the case of wild ungulates these good management practices are complicated by the inherently wild behaviour of these animals, such that slaughtering does not occur in a conventional manner (Renecker, Wiklund & Stevenson-Barry, 2001). In Southern Africa, the plains game species are usually cropped commercially during either the day or night with the use of vehicles, boma capture or helicopters (Hoffman & Wiklund, 2006). All of these methods hold advantages and disadvantages and may be better suited to some species than to others, depending on the species' behaviour. The two most popular cropping methods are shooting from vehicles during either the day or night, although there is much debate over which method induces the least amount of stress. Many authors believe night cropping to be the best method (Hoffman, 2001, 2000; Kritzinger, Hoffman & Ferreira, 2002; Lewis, Pinchin & Kestin, 1997; Veary, 1991; Von La Chevallerie & Van Zyl, 1971), although little research has been conducted on the differences between day and night cropping on different ungulate species.

The purpose of this investigation was to determine the effect of day- and night cropping by a professional cropping team (as would be the case in the commercial production of game meat) on the meat quality of kudu, with specific emphasis on *ante-mortem* stress. To our knowledge, no such study with regard to cropping methodology has been conducted on this species.

MATERIALS AND METHODS

Animals

For this study, sixteen kudu were cropped. Eight were cropped during the day and eight were cropped at night. Table 1 gives the distribution of genders as well as age groups, according to cropping methods. The animals in this study were aged based on horn development (in males), live weight and tooth wear (since tooth wear increases as an animal ages). In males, horns were used first, since live weight may vary depending on season, and then live weight was used to confirm the age. Only four males were cropped (Table 1) and all four males had horns with at least one complete spiral, and live weights ranging between 190 kg to 240 kg so that all four were classed as adults. Females were classed as juveniles if their live weight was less than 120 kg and no tooth wear was apparent. Those with live weights between 120 kg and 150 kg and relatively little tooth wear were classed as sub-adults, and those with live weights exceeding 150 kg and relatively worn-down teeth were classed as adults.

Table 1
Distribution of kudu (*Tragelaphus strepsiceros*) according to gender, age and cropping method

Age	**Day**		**Night**		**Total**
	Male	**Female**	**Male**	**Female**	
Juvenile	0	1	0	0	1
Sub-Adult	0	2	0	1	3
Adult	3	2	1	6	12
Total	3	5	1	7	16

Cropping

The same sharpshooters and cropping techniques were used as described in the materials and methods (Chapter 3) section of this thesis.

Daytime ambient temperatures ranged between 12°C and 15°C while nighttime ambient temperatures ranged between 2°C and 3°C. All the shots taken were either head- or neck shots, with the exception of three animals that were wounded either in the shoulder or neck. All wounded animals were recovered and killed within a couple of minutes after being shot.

A stress score was allocated to each animal as per Table 2.

Table 2

Stress scale for the kudu (*Tragelaphus strepsiceros*) as pertaining to perceived *ante-mortem* stress experienced

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

Stomachs and viscera were removed in the field and weighed before being discarded. Trachea, lungs and organs were left in the carcasses and removed once the carcasses were offloaded at the research laboratory. These were then tagged, covered with plastic and hung in the cooling truck at 0°C to 5°C. Once carcasses were offloaded, they were weighed again with heads and feet intact and live weight was calculated as the sum of this weight and the weight of the stomach and viscera.

Cropping occurred over a two-day period. All the night-cropped kudu were shot on the first evening and two of the day-cropped kudu shot during the first day. These animals were all shot at Neudamm Agricultural College, thirty kilometres south of Windhoek. These carcasses remained on the vehicles for two to four hours before being loaded onto the cooling truck and, as a result, cooling rates may have varied between carcasses because of differences in ambient temperatures. The remaining six kudu were shot on the second day at Vredemheim Farm in the Khomashochland, forty kilometres east of Windhoek. All the carcasses shot at Neudamm were cooled with their skins intact in a cooling truck at 0°C to 5°C and then transported after 48 hours to Farmer's Meat Market in Windhoek, where they were skinned, weighed again and red pluck removed for health inspection and weighed as well. The six kudu shot on the second farm remained on the hunting vehicle until being transported to Farmer's Meat Market that evening, where they were placed in a cooling truck at 0°C to 5°C. Again, this may have caused differences in cooling rates between the carcasses. Twenty four hours after being shot, these carcasses were skinned, the organs and trachea removed and all components weighed. At 48 hours *post-mortem*, sub-samples were taken from the *M. longissimus dorsi* between the 1st and 4th lumbar vertebrae from the left side of all of the carcasses for the various physical meat quality measurements.

Temperature and pH readings were taken at two- to three-hour intervals on the ten animals shot at Neudamm for the first twenty-four hours *post-mortem*. Ultimate pH measurements were also taken at 24 hours *post-mortem*. Due to unforeseen circumstances, only pH measurements at 48 hours *post-mortem* could be taken on the six animals shot at Vredenheim. For the purpose of this investigation, it was thus assumed that ultimate pH had already been reached by 24 hours *post-mortem* and that slight pH changes after that would be negligible.

Blood samples

Blood samples were collected during exsanguination, kept on ice for approximately three- to four hours and then centrifuged for ten minutes, after which the serum was aliquot into clean tubes and frozen. The serum samples were then used to test for cortisol, as per the procedure described in the materials and methods section (Chapter 3) of this thesis.

Physical analysis

Two sub-samples, 1.5 cm to 2.0 cm thick were taken from the *M. longissimus dorsi* of each carcass and used to determine drip loss, cooking loss, Warner-Bratzler shear force values and to record the colour measurements, using the same procedures as described (materials and methods section in Chapter 3).

Statistical analysis

The same statistical analysis was used as is the one described in the materials and methods section (Chapter 3) of this thesis. Both pH measurements at 24 (first 12 animals) and 48 hours (last 6 daytime cropped animals) *post-mortem* was taken as ultimate pH (pH_u) and compared as such. Analysis of variance (ANOVA) was used to test for differences in meat quality, stress score, cortisol levels as well as $pH_{u,}$ with treatment, age, gender and carcass weight (since kudu are sexually dimorphic) as main effects. Pearson correlation coefficients were calculated where applicable.

RESULTS AND DISCUSSION

The use of a specific cropping method may be dictated by a number of factors, such as terrain, preference, costs, time limitations as well as the behaviour of the specific species being cropped. It is of great importance that cropping always takes place in as humane a manner as possible and that animals are never intentionally exposed to severely stressful conditions. Night cropping is a method often preferred with sexually dimorphic species when specific genders are targeted since the sexes are easily distinguishable in the dark. However, in the case of kudu, many have found this method to be unsuitable since this species is predisposed to looking away from the spotlight or to close their eyes (Joubert, 1983; Mostert, 2007). This is in contrast to a species such as impala who adopt an investigative and alert posture when caught in the spotlight, making them particularly well-suited to night cropping (Lewis *et al.*, 1997). Because of their secretive nature, and because they do not occur in relatively large herds, kudu are also more difficult to find at night, so that many prefer to crop them during the day. Between veterinary authorities, the perception still exists that day-cropped animals are more stressed resulting in inferior meat quality, which may be exasperated by higher daytime temperatures.

During the entire cropping operation, all animals shot were recovered. Three animals were wounded and then shot a second or third time before being killed. Two of these animals were wounded because of the hilly and uneven terrain, which caused shots to be fired either at an up-hill or down-hill angle and making the trajectory of the bullets more difficult to control. One of the bulls (shot during the day) had a previous shoulder injury (most likely from fighting with another bull) so that it was limping severely prior to being shot. None of the bulls cropped were part of any herds, most probably because cropping occurred during the kudu mating season when territorial bulls are isolated from one other.

Stress score

The stress response is a reaction to any stressor that threatens the internal environment of an organism. It is thought that what is stressful to one species may not necessarily be stressful to another, so that an animal's response to a situation may be influenced by a number of factors, including its evolutionary past and experience (Hattingh, 1988). In general, this response consists of behavioural, autonomic and neuro-endocrine components, and measuring the stress response in terms of these components may be especially difficult in wild animals. In the current investigation, *ante-mortem* stress was quantified subjectively (Table 2) as well objectively through the measurement of *post-mortem* pH and serum cortisol as measured immediately after death.

There was a difference (P = 0.038) in stress scores between the two cropping methods with day-cropped animals having higher mean stress scores (3 ± 0.641) than night-cropped animals (1.8 ± 0.955). This indicated that the day-cropped kudu may have experienced more stress during the cropping operation because of the number of animals wounded, the amount of *ante-mortem* exercise and the time elapsed between the animal being shot and actual death, amongst other things. The stress scores were strongly correlated with the blood cortisol levels (P < 0.0001; r = 0.823), indicating that the subjective stress score was a good indication of the stress experienced by the animals (Figure 1).

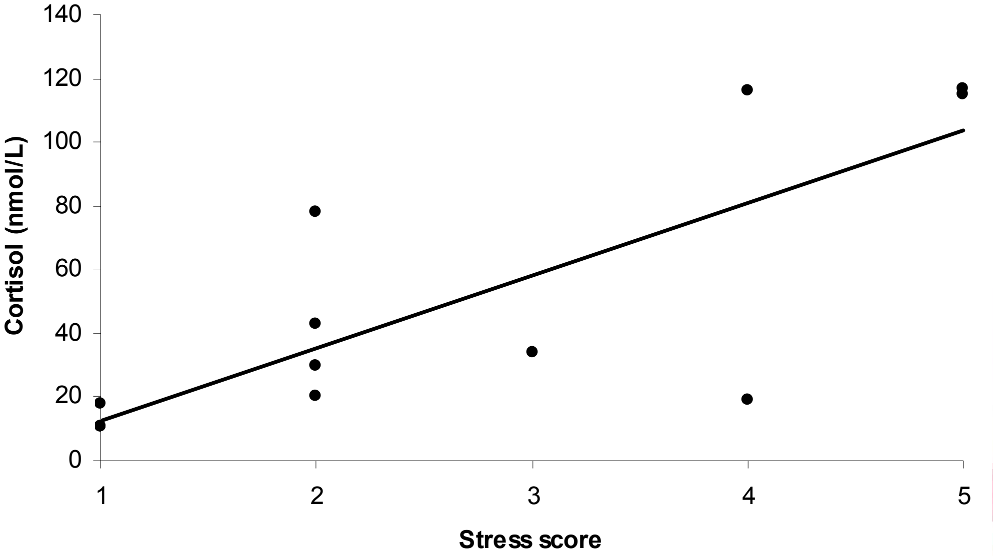

Fig. 1. Linear correlation (P < 0.0001; r = 0.823) between stress score and cortisol level (nmol/L) for day and night-cropped kudu

Cortisol

Stress activates the hypothalamic-pituitary-adrenal axis and increases the secretion of glucocorticoids from the adrenal cortex (Yoshioka, Imaeda, Ohtani & Hayashi, 2005). In most large mammals, cortisol is the main glucocorticoid found in the body and is often used as a measure of *ante-mortem* stress because of the relative ease with which it can be sampled and measured (Shaw, Trout & McPhee, 1995). Although cortisol has often been used in domestic livestock its use in wild animals is less common, although it has been used in deer to assess differences in stress between different pre-slaughter handling methods. Smith and Dobson (1990) found field-shot red deer (*Cervus elaphus*) to have lower mean serum cortisol levels (15.7 nmol/L) compared to red deer that were stunned with a captive bolt after being transported to the slaughterhouse (82.0 nmol/L).

Differences (P = 0.004) were found in serum cortisol levels between the day- and night-cropped kudu with day-cropped kudu having higher cortisol levels (68 ± 1.28 and 14 ± 2.15 nmol/L, respectively), thus indicating that the day-cropped animals experienced a greater amount of *ante-mortem* stress. It must be noted, however, that the cortisol levels of both the day and night-cropped animals are within the mean cortisol ranges that were reported for other African ungulates such as impala (19.4 – 148 nmol/L) and roan antelope (*Hyppotragus equinus*) (23.0 – 135.0) by Hattingh (1988).

pH

The major influence that pre-slaughter handling has on meat quality is its effect on muscle glycogen content which affects the rate and extent of muscle acidification *post-mortem*. This can result from both physical exhaustion and stress, which can cause a higher than normal ultimate pH (pH_u) or rate of pH decline. The relationship between elevated pH_u and physical activity or chronic stress has been observed in many ruminant domesticated species, as well as deer (McGeehin, Sheridan & Butler, 2001; Mounier, Dubroecq, Andanson & Veissier, 2006; Stevenson-Barry, Carseldine, Duncan & Littlejohn, 1999; Wiklund, Manley & Littlejohn, 2004). Knox, Hattingh and Raath (1991) found that the physical exertion and stress associated with live capture in impala caused a significant increase in the plasma and muscle lactate concentration. If these animals were to be slaughtered, there would be a limiting amount of glycogen remaining in the muscle, thereby limiting muscle acidification and resulting in an elevated pH_u. In the current investigation, a difference ($P = 0.030$) was found in the pH_u between the two treatments, so that night-cropped animals had a higher mean pH_u value than day-cropped animals (Table 3). Although a higher pH_u may be indicative of DFD, this is unlikely in the current investigation since none of the animals exhibited pH_u values within the range considered to cause DFD. According to Young and Gregory (2001), the usual pH criterion defining DFD meat is an ultimate pH above 6.0, although this value is arbitrary and the properties of DFD meat evolve as a continuum from pH 5.6 upwards. The pH_u values of the kudu ranged from 5.30 to 5.57 with a total population mean of 5.44. The differences in pH_u may thus be attributable to the differences in serum cortisol levels in that the higher serum cortisol levels of the day-cropped animals caused the mobilisation of the animals' glycogen stores shortly before death. This resulted in an increased rate and extent of lactic acid formation and muscle acidification *post-mortem* even though no correlation was found between pH_u and stress scores or serum cortisol levels. It must also be noted that although the mean pH_u differed statistically between treatments, biologically, these values may not necessarily differ significantly with regard to their effects on meat quality. It could therefore be argued that the statistical difference may have become insignificant had the sample size been larger. The findings of this study are in contrast to those of Kritzinger *et al.* (2002) and Veary (1991), who both found that pH_u was consistently higher in day-cropped impala and springbok respectively, compared to that of night-cropped animals.

Table 3

Mean pH_u values (LSMean ± s.e.) measured at 24 h or 48 h *post-mortem* for day- and night-cropped kudu

			pH ± s.e.	**P < │t│**
Treatment	Day	pH_u	5.40 ± 0.030	0.030
	Night	pH_u	5.48 ± 0.041	

No differences in pH_u were found between any of the other main effects (namely age, gender and carcass weight). The mean pH_u values were similar to those reported for impala (5.39 – 5.45) by Kritzinger *et al.* (2002) and lower than those reported for kudu (5.62 ± 0.05) by Mostert (2007), where the kudu were all shot from a hide and it could be argued that they had zero stress as they were not aware of the hunter. Hoffman (2000) and Hoffman and Ferreira (2000) also reported higher mean pH_u values for night-cropped impala (5.70 ± 0.068) and night-cropped grey duiker (*Sylvicapra grimmia*) (5.55 ± 0.080) respectively. Since the differences in pH_u between treatments was not exceptionally large, meat quality would have to be taken into consideration to make an appropriate conclusion.

Water-holding capacity and tenderness

The water-holding capacity (WHC) of meat is strongly affected by muscle pH, dropping from a high of around pH 10 to a low at the isoelectric point of the meat proteins, between pH 5.0 and pH 5.5 (Swatland, 1994). Drip loss and cooking loss are both functions of this WHC and will affect eating qualities such as juiciness and tenderness of the meat as well as product weight losses due to purging. When a high rate of pH decline occurs because of acute *ante-mortem* stress, low pH values are usually reached while muscle temperatures are high so that denaturation of the muscle proteins occurs that causes a decrease in their ability to bind water and thus decreases their WHC. On the other hand, chronic stress, particularly when experienced over a long period, can lead to a higher than normal pH_u that increases the WHC of the meat such that little or no exudate is formed.

In the current investigation, no differences were found in cooking loss between the two treatments. There were differences ($P = 0.012$) in drip loss value between the treatments such that day-cropped animals produced higher drip loss values than night-cropped animals (Table 4). This is consistent with the finding that day-cropped animals may have experienced more *ante-mortem* stress, which may have caused a more rapid pH decline whilst the carcass temperatures were still relatively high. In such a case, denaturation of the meat proteins would cause a higher loss of exudate. Although the phenomenon of PSE is most common in pigs, it has been reported in ruminant species such as beef (Young & Gregory, 2001) as well as game species such as warthog and buffalo, although the latter was reported under acute abnormal conditions (Hoffman, 2001b; Hoffman & Sales, 2007). PSE is generally determined through measuring pH at 45 minutes *post-mortem* (pH_{45}), and although pH_{45} was not measured in the current investigation, it is unlikely that the differences in pH_u and drip loss are severe enough to classify the meat from the day-cropped animals as PSE. Hoffman (2001b) reported drip loss values as high as 3.4% for warthog that had been wounded and had subsequently produced PSE meat. The results from the current study are in agreement with those of Kritzinger *et al.* (2002), who found that day-cropped impala had higher mean drip loss values (4.15 ± 2.339%) than night-cropped impala (2.93 ± 1.597%), although these values are much higher than those reported in the current investigation. The drip loss values of the night-cropped kudu are similar to the mean value of 1.40 ± 0.25% reported for kudu by Mostert and Hoffman (2007). The drip loss values of the day-cropped kudu are also similar to those reported for night-cropped impala by Hoffman (2000), which ranged from 2.45 ± 1.362 to 2.66 ± 1.097%. A negative correlation (Table 5) was found between the drip loss values and pH_u in the current investigation, indicating that a lower pH_u would result in a lower WHC and thus higher drip loss values (Figure 2). Hoffman, Kroucamp and Manley (2007) found similar results and reported that pH_u was correlated ($P < 0.01$; $r = -0.26$) to drip loss in springbok. The authors explained that although the correlation was not strong it was significant due to the large sample size and the fact that the effects of all other main effects on drip loss were also directly affected by the pH_u of the meat. This is also in agreement with Bouton, Harris and Shorthose (1971) who found that pH_u was correlated ($P < 0.001$; $r = 0.80$) with the WHC of whole muscles of mutton.

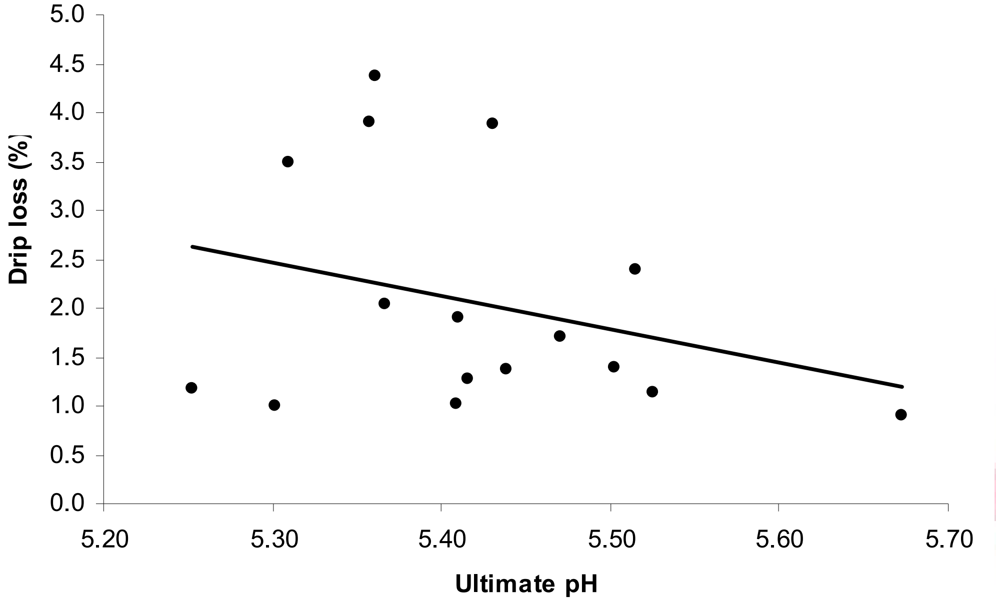

Fig. 2. Linear correlation (P = 0.0004; r = -0.779) between drip loss and ultimate pH (pH_u) for day- and night-cropped kudu

No differences in either cooking loss or drip loss were found between any of the other main effects (gender, age and carcass weight).

Table 4

Mean values of the physical meat quality parameters (LSMean ± s.e.) as measured in the *M. longissimus dorsi* of day- and night-cropped kudu

Parameter	Cropping technique		
	Day	**Night**	**P < │t│**
Drip loss (%)	2.76 ± 0.261	1.36 ± 0.361	0.012
Cooking loss (%)	34.14 ± 1.337	34.35 ± 1.849	0.880
Shear force (kg/1.27cm diameter)	3.45 ± 0.171	4.06 ± 0.237	0.003

Tenderness is often considered to be a decisive factor in determining meat quality by consumers (Koohmaraie, Veiseth, Kent, Shackleford & Wheeler, 2003) and many authors have found it to be closely related to the pH of meat (Bouton *et al.*, 1971). The relationship between pH and meat tenderness is controversial, with many authors suggesting a curvilinear relationship (Tornberg, 1996). This controversy is related to the effect of pH on the mechanisms of meat tenderisation during ageing, where proteolytic activity will be affected by the optimal pH ranges of the enzymes involved. In the current investigation, a positive correlation was found between pH_u and shear force (Table 5), although this correlation was not strong. This result is similar to previous research (Purchas, 1990), which reported that an increase in meat toughness is accompanied by an increase in pH_u from about 5.5 to 6.2, partially as a result of decreased sarcomere length at this pH region. Since the pH_u values of the kudu ranged from 5.30 to 5.57, it may explain why the correlation is not strong. Hoffman *et al.* (2007) also found similar results, with pH_u being positively correlated to shear force ($P < 0.01$; $r = 0.25$) in springbok.

Differences ($P = 0.003$) were found between treatments for shear force, with night-cropped animals producing tougher meat than day-cropped animals (Table 4). This is in contrast to the findings of Kritzinger *et al.* (2002) who found that day-cropped impala produced tougher meat than night-cropped impala. The correlation between pH_u and tenderness (Table 5; Figure 3) may partly explain the difference between treatments, since night-cropped animals had higher pH_u values than day-cropped animals. Also, the rapid attainment of a low muscle pH is widely regarded as highly beneficial to meat tenderness with this ability being ascribed to its effects on the prevention of cold shortening, the release of lysosomal enzymes and the activation of cathepsins (Marsh, Lochner, Takahashi & Kragness, 1981). This is in agreement with the findings of Hoffman (2001a), who found that buffalo killed with scoline had a pH decline rate almost three times as fast as buffalo killed with a high caliber rifle and, as a result, the former produced meat that was more tender than that of the latter. Although the rate of pH decline was not measured in the kudu, it is postulated that the day-cropped animals may have suffered more *ante-mortem* stress (as indicated by the subjective stress score and serum cortisol levels) which may have resulted in a faster drop in pH compared to that of the night-cropped animals. This would explain why the former produced meat with lower shear forces values. Furthermore, the differences in ambient temperatures between day and night (daytime ambient temperatures ranged between 12°C and 15°C, while nighttime ambient temperatures ranged between 2°C and 3°C), and the fact that 6 of the animals cropped during the day were not loaded into the cooling truck until at least 6 hours *post-mortem* may have resulted in the carcasses cooling at different rates. The rate of temperature decline was not measured. The cooler ambient temperature at nighttime may have resulted in the night-cropped carcasses cooling at a much faster rate and, since temperature is known to affect tenderness, this increased cooling rate may account for some of the differences in shear force between the treatments. A fast decrease in temperature while the pH of the muscle is still relatively high is known to decrease tenderness as the result of a phenomenon known as cold shortening (Pearson & Young, 1989).

Table 5

Pearson linear correlation coefficients (r) between pH_u and the physical attributes of the day- and night-cropped kudu

Characteristic	r	P < |t|
Cooking loss	0.156	0.563
Drip loss	-0.779	0.0004
Shear force (kg/1.27 cm diameter)	0.506	0.0003
L*	-0.236	0.379
a*	-0.073	0.788
b*	0.155	0.568
Chroma	0.208	0.440
Hue	0.029	0.914

No differences were found in shear force between any of the other main effects, although it was found that carcass weight was correlated to shear force (P = 0.046; r = 0.224). The ANOVA revealed no interaction between carcass weight and age; however, this may be due to the small sample size. The correlation between carcass weight and shear force may partly be related to the increase in toughness as an animal ages since carcass weight also increases with increasing animal age (Bouton *et al.*, 1978; Shorthose & Harris, 1990). Thus, older animals should have heavier carcasses and tougher meat than younger animals. It must also be noted that the lack of differences found in the shear force between the age groups may be explained by the small sample size as well as the fact that the animals were divided into three age groups and were not aged according to their exact age, which meant that age could not be correlated with shear force.

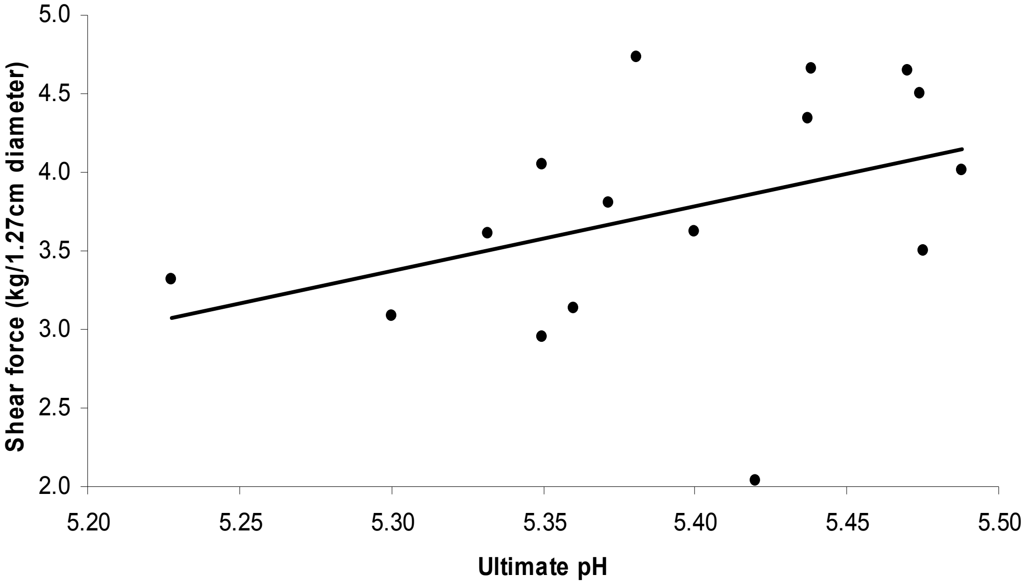

Fig. 3. Linear correlation (P = 0.0003; r = 0.506) between shear force (kg/1.27 cm diameter) and ultimate pH (pH_u) for day- and night-cropped kudu

Colour

Meat colour is an important selection criterion for consumers (Ouali *et al.*, 2006) and can often give an indication of the effect of pre-slaughter treatment on the meat quality. Although game meat is generally accepted as being a dark-red colour, exceptionally dark meat may be indicative of DFD which is caused by chronic *ante-mortem* stress. Hoffman (2000), for example, recorded values of L* = 25.44, a* = 9.13 and b* = 4.88 for a male impala that had been wounded during cropping and had, as a result, suffered severe *ante-mortem* stress for a period of ten minutes prior to being killed. Similarly, very high L* values may be indicative of PSE in which case myoglobin is exposed to conditions which causes its oxidation to metmyoglobin which has a low colour intensity (Lawrie, 1998).

The only difference for colour ordinates between treatments was for L* values (P = 0.015), with day-cropped animals producing lighter meat than night-cropped animals (Table 6). Kritzinger *et al.* (2002), on the other hand, found no differences in any of the colour ordinates between day- and night-cropped impala. The mean L* values are higher than was reported by Kritzinger *et al.* (2002) and Hoffman (2000) for impala, which is in agreement with the findings of Mostert (2007) who reported higher mean L* values for kudu as compared to impala. The latter author reported mean values ranging from 30.31 ± 0.41 to 33.21 ± 0.49, which is similar to the values found in the current investigation. Differences in L* may be attributable to the differences in pH_u, since, according to Swatland (2004), the myofilament lattice shrinks as the pH decreases, causing an increase in the myofibrillar refractive index and an increase in the light scattering of the meat. Similarly, Guignot, Touraille, Ouali and Renerre (1994) found that the lightness, redness and reflectance of veal were negatively correlated with ultimate pH, so that these measurements decreased as the ultimate pH increased. The mean L* value for the day-cropped animals is similar to that reported by Hoffman (2001b) for buffalo that produced meat with signs of PSE. The author found that buffalo killed with three or more shots (Group B) experienced a greater amount of *ante-mortem* stress than those killed with a single shot (Group A). The former group exhibited a faster pH decline and, as a result, produced meat with a mean L* value of 33.69 ± 0.786 compared to group A's mean L* value of 32.96 ± 0.786. As was the case in the current investigation, the a* and b* of the two buffalo groups did not differ significantly.

Table 6

LSMeans (± s.e.) of L*, a*, b*, hue-angle (H_{ab}) and chroma values (C*) of kudu *M. longissimus dorsi* (LD) muscle for both cropping methods

Colour ordinates	**Cropping technique**		
	Day	**Night**	**P < │t│**
L*	33.45 ± 0.435	32.13 ± 0.601	0.015
a*	15.46 ± 0.597	14.50 ± 0.826	0.109
b*	10.73 ± 0.519	10.61 ± 0.718	0.836
C*	18.90 ± 0.655	18.02 ± 0.906	0.254
H_{ab}	34.58 ± 1.439	36.32 ± 1.989	0.207

In this investigation, gender differences ($P < 0.05$) were found for L*, b* and chroma, with males producing higher L* (33.96 ± 0.516), b* (11.94 ± 0.543) and chroma (19.98 ± 0.648) values than females (L* = 32.40 ± 0.298; b* = 10.24 ± 0.313; chroma = 17.95 ± 0.374). This is in contrast to the findings of Mostert (2007) who found no gender differences in any of the colour ordinates for kudu, as well as those of Hoffman, Van Schalkwyk and Muller (2008) who also found no gender differences in any of the colour ordinates for either black wildebeest (*Connochaetes gnou*), blue wildebeest (*C. taurinus*) or mountain reedbuck (*Redunca fulvorufula*). The ANOVA revealed an interaction ($P < 0.05$) between carcass weight and age for L*, b* and chroma. It showed that juveniles weighing between 71 kg and 80 kg produced meat with the lowest L*, b* and chroma values (L* = 29.78 ± 0.513; b* = 7.87 ± 0.957; C* = 16.74 ± 1.252), while adults weighing between 141 kg and 150 kg produced meat with the highest L*, b* and chroma values (L* = 34.64 ± 0.953; b* = 13.34 ± 0.947; C* = 22.69 ± 1.252). There was only one juvenile and one adult that had carcass weights within these ranges and it can therefore be concluded that because of the small data-set size, these two animals caused the data to be skewed and thus caused the interaction between age and carcass weight. The adult had a carcass weight of 149 kg and had an old shoulder wound that resulted in a broken shoulder and the animal severely limping. This may have caused an increased amount of *ante-mortem* stress in this animal which could have resulted in it producing lighter meat. The juvenile that had a carcass weight of 75 kg was instantly killed with a head shot and theoretically it experienced very little, if any, *ante-mortem* stress. This animal also had a serum cortisol level of 43 nmol/L and a pH_u of 5.36, which is close to the population mean of 41 nmol/L and 5.39, respectively. The darker meat that this animal produced can therefore not be explained by *ante-mortem* stress and must be due to some other, unknown physiological cause.

CONCLUSIONS

Although the rate of pH decline was not measured, ultimate pH values indicated differences between the day- and night-cropped animals, with night-cropped animals having a higher mean pH_u than day-cropped animals; the biological significance of this small difference is debatable, however. Neither cropping method produced pH values high enough or low enough to be considered DFD or PSE, even though the serum cortisol levels and the subjective stress scores indicated that day-cropped animals experienced more *ante-mortem* stress than night-cropped animals. Although the meat quality values were not extreme enough for it to be considered as PSE, it is likely that the stress experienced by the day-cropped animals in the current investigation had an effect on the pH of the muscle *post-mortem* and that this, coupled with the differences in rates of temperature decline, was enough to cause differences in the meat quality between the treatments. As a result, day-cropped animals produced meat that had a higher mean drip loss percentage and lower mean shear force, as well as being lighter in colour. This suggests that night cropping caused less *ante-mortem* stress than day cropping, although the meat quality of the kudu was not adversely affected to any great extent. It must always be borne in mind that other factors, such as environment, accuracy, the efficiency of the cropping team and the behaviour of the animals, will inevitably also affect these results.

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Chapter 7

A COMPARISON BETWEEN THE EFFECTS OF CONVENTIONAL HUNTING AND NIGHT CROPPING ON IMPALA (*Aepyceros melampus*) MEAT QUALITY

ABSTRACT

In South Africa, commercial game-cropping methods usually consist of cropping at night, cropping with the aid of boma capture or cropping from a helicopter. Conventional hunting is much less efficient and usually consists of hunting on foot during the day. The purpose of this study was to compare cropping at night from a vehicle, utilising only head and neck shots, and hunting during the day on foot, utilising only flank shots. No significant differences in pH_{45} or pH_u were found between treatments. An exponential decay model ($y = a + b^{-ct}$) was fitted to the pH data. It was found that animals hunted conventionally, during the day, had significantly higher rates of pH decline (c = -0.385 ± 0.022 units per hour) than night-cropped animals (c = -0.184 ± 0.019 units per hour). Impala hunted during the day also had significantly higher constants (a = 5.424 ± 0.039; b = 1.405 ± 0.034) than the night-cropped impala (a = 5.295 ± 0.033; b = 1.556 ± 0.029). No significant differences were found for drip loss, cooking loss or shear force between the two treatments. Significant differences between the treatments were found for a* (night-cropped = 10.56 ± 0.229; day hunted = 11.41 ± 0.245) and chroma values (night-cropped = 12.81 ± 0.235; day hunted = 13.78 ± 0.252). The study therefore found that although conventional, ethical hunting affected the rate and extent of pH decline of the carcasses, the effect did not adversely affect the meat quality of the animals.

INTRODUCTION

The meat production potential of various southern African ungulate species has long been recognised (Fairall, 1982; Von La Chevallerie, 1972; Ledger, 1963; Ledger, Sachs & Smith, 1967), and with game farming becoming increasingly popular (Jooste, 1983), efficient cropping methods have also become an important aspect of such production enterprises. Due to the impala's high reproduction rates and widespread distribution across southern Africa, it has become a popular species in the game farming industry in South Africa (Kohn, Kritzinger, Hoffman & Myburgh, 2005). Impala are a gregarious species and occur in tropical and subtropical thornveld savannahs (Young & Wagner, 1968). It is numerically the most important species available for game farming in the lowveld and bushveld areas of Limpopo, Northwest, Northern Kwazulu Natal and parts of Mpumalanga. It is a medium-sized antelope with a mean mass of around 50 kg in males and 40 kg in females (Hoffman, 2000a). Dressing percentages usually range from 50% to 60% (Fairall, 1982; Van Zyl, Von La Chevallerie & Skinner, 1969; Young & Wagner, 1968), which is higher than many equivalent-sized antelope (Fairall, 1982) as well as that of domestic livestock, which range from 44% to 50%, and this obviously enhances the productivity in terms of saleable meat. The growth of impala is rapid and reaches an asymptotic mass at around five years of age (Fairall, 1982). Two main herds are usually observed: female- or breeding herds, consisting of females with dependent juveniles, and male- or bachelor herds. Breeding is strictly seasonal with the peak rutting season taking place during the months of April and June (Bothma & Van Rooyen, 2005). The wide distribution of impala, their relatively rapid reproduction rate and the fact that impala never tend to move far from their home range (Schenkel,1966) make them an ideal species to use to establish a game population on a farm in a relatively short space of time (Kohn *et al.*, 2005). Their consistently high fecundity rate under adverse conditions provides the basis for a high cropping rate (22 %), even under a large predator regime, and impala are one of the species that have been identified as having the potential to produce game meat on a sustainable basis (Fairall, 1985; Hoffman, 2000a). In order to enhance the quality of meat products from these antelope it is important to establish and quantify those *ante-mortem* factors that affect the muscle *post-mortem* and which are controllable from a management perspective. It is well known that the physical conditions imposed on the carcass *post-mortem*, as well as the physical conditions imposed on the animal, influence the meat quality (O'Halloran, Troy & Buckley, 1997). Since *ante-mortem* stress is known to have deleterious effects on meat quality cropping methods should be efficient and should also be aimed at minimising the stress experienced by the animals.

In South Africa, game meat is often perceived as being of a dark, unattractive colour and as being tough and dry. The lack of intramuscular fat in wild ungulates compared to domesticated livestock and the higher myoglobin content of game meat (Hoffman, Kritzinger & Ferreira, 2005) may be contributory factors to these conditions in the meat. These quality defects may also be due to poor cropping methodologies, resulting in what is known as dark, firm and dry meat (DFD). In fact, Hoffman (2001) noted that most game species tend towards DFD meat due to the stresses of the cropping process. This may go a long way in explaining consumer perception of game meat as dark and dry since much of the game meat consumed in South Africa originates from what is referred to as "biltong hunting", i.e. non-trophy recreational hunting (Hoffman, 2000b). In such cases, hunters may not be as experienced as would be the case with a trained marksman or cropping team so that animals may be wounded or may not die immediately after being shot. For this study, "cropping" will be defined as the killing of animals for meat-production purposes by a sharpshooter from a vehicle utilising only head and neck shots, while "hunting" will be defined as the killing of animals for meat-production purposes by a sharpshooter on foot using normal ethical hunting practices and utilising only flank shots. The latter consists of stalking the animal, shooting and then waiting for the surrounding animals to move away before approaching the fallen animal, and this, together with the placement of the shot, is a close representation of what is referred to as "biltong hunting". The former is a practice often used for many of the plains game species (springbok, blesbok, impala, black wildebeest etc.) in South Africa with great success – a single sharpshooter can remove as many as 30 to 80 animals per night with a minimum of stress to the remaining animals (Hoffman, 2001; Lewis, Pinchin & Kestin, 1997). A number of studies have been done on the effects of cropping on the meat quality of wild ungulates (Hoffman, 2000a, 2000b; Kritzinger, Hoffman & Ferreira, 2002; Veary, 1991; Von La Chevallerie, 1972) although there is still little data available that compares different methods in their effects on the stress experienced by the animals and on the meat quality.

MATERIAL AND METHODS

Animals

For this study, seventeen impala (*Aepyceros melampus*) were cropped during the month of July at Leeukop Game Ranch in Northern KwaZulu-Natal. Nine animals were shot during the day and eight animals were shot at night. Table 1 gives the distribution of the animals according to gender and treatment. The animals were all two-toothed although the ages varied between ± 8 months and ± 20 months.

Table 1

Distribution of impala (*Aepyceros melampus*) according to gender and cropping method

Treatment	**Gender**		
	Male	**Female**	**Total**
Day	4	5	9
Night	4	4	8
Total	8	9	17

Cropping

The present investigation quantified the effect of two shooting methods on the physical meat quality parameters of impala meat. As impala are normally found in denser bushveld, their cropping may be more difficult than that of other ungulate species. The first method, which will be referred to as cropping at night, consisted of shooting the animals at night using a spotlight in a method similar to that described by Lewis *et al.* (1997). These authors showed that night shooting, if conducted correctly, is suitable for cropping these antelope, since they adopt an investigative posture when startled at night and are sexually dimorphic so that males are easily distinguishable from females. In their study, they noted that a trained marksman had an overall mean time between the killing of one animal and the next (n = 305) of 28 seconds (maximum time 3 min 18 sec; minimum time 2 seconds). The method used in the current study consisted of driving with a vehicle at night and utilising a spotlight to temporarily blind animals before shooting them. All the shots were head shots and resulted in immediate death, and according to Von La Chevallerie and Van Zyl (1971), these shots result in the least amount of meat wastage from bullet damage. In the second shooting methodology, normal ethical hunting practices were utilised, i.e. hunting on foot, shooting, and waiting for the herd to move away before approaching the downed animal. This method will be referred to as hunting during the day and consisted of shooting in the daytime and utilising a flank shot, which is a shot commonly used by hunters. Normally, the shot is placed at the top of the crease at the back of the foreleg. Underlying this position are large vital organs such as the lungs and the heart, major blood vessels and important nerves (Hoffman, 2001). A bullet in this area will result in massive haemorrhaging, lung collapse and a “quick death”. This is a relatively large target area and is often more stationary than the head. Hitting a point slightly forward to the intended point of impact might miss the heart; however, it can still hit the lungs and large blood vessels. Such a shot will also most probably result in the bullet hitting and breaking the femur – an action that causes the animal to fall down immediately – this is of particular importance when a lighter calibre rifle is used (a light calibre rifle is normally used, as it causes the least meat wastage). A shot slightly behind the intended point of impact will still hit the lungs (and possibly the liver). A shot slightly low can still hit the point of the heart and both lungs, whilst a shot that is too high can hit large blood vessels or even the spinal column. In the case of this study, not all these shots resulted in immediate death. Animals that were still breathing when approached were immediately euthanised with either a second shot or by exsanguination. A single shooter fired all the shots using a .243 Winchester, fitted with a telescopic sight and silencer. The nighttime shots appeared to stress the impala herds the least, while the day shots invariably caused the herd to flee even though a silencer that helped to keep the noise level low was utilised.

Immediately after being killed, the animals were weighed to obtain a hot body weight and the jugular vein was severed to promote bleeding of the carcass. pH and temperature readings were also taken in the lumbar region of the *Longissimus dorsi* muscle at 45 minutes after death (pH_{45}) and approximately every 2 hours thereafter, up to 12 hours *post-mortem*. After 12 hours *post-mortem* the readings were taken every 4 hours up to 24 *post-mortem*. Ultimate pH (pH_u) was taken at 24 hours *post-mortem.* After the targeted number of antelope had been harvested (over a 3 hour period) the animals were transported to a commercial abattoir where they were further processed according to standard South African and Zimbabwean practices. This consisted of skinning, evisceration, cleaning of carcasses, etc. (Hoffman 2000b).

Physical analysis

Two sub-samples, 1.5 cm to 2.0 cm thick were taken from the *M. longissimus dorsi* of each carcass and used to determine drip loss, cooking loss, Warner-Bratzler shear force and to take colour measurements. The same procedures were followed as are described in the materials and methods section (Chapter 3) of this thesis.

Statistical analysis

The same statistical analysis was used as is described in the materials and methods section (Chapter 3) of this thesis. Analysis of variance (ANOVA) was used to test for differences in meat quality, as well as pH_{45} and pH_u with treatment, gender and carcass weight (since impala are sexually dimorphic) as main effects. Pearson correlation coefficients were calculated where applicable.

RESULTS AND DISCUSSION

As the consumption of game meat is growing, efficient cropping methods that minimise *ante-mortem* stress are becoming increasingly important to ensure good-quality products from wild ungulates. The deleterious effects of such stress on meat quality in domesticated animals is well documented (Bouton, Harris & Shorthose, 1971; Guignot, Touraille, Ouali & Renerre,1994; Judge, 1968; Lawrie, 1988; Okeudo & Moss, 2004; Simela, Webb & Frylinck, 2004) and, to a lesser extent, in game species and venison (Kritzinger, 2002; Hoffman 2001; Wiklund & Malmfors, 1996; Wiklund, Andersson, Malmfors, Lündstrom & Danell, 1995).

As with slaughter and stunning methods in domesticated species, shooting methods in wild ungulates need to be well suited to the particular species being utilised, in order to ensure that a minimal amount of *ante-mortem* stress is experienced by the animals. Although limited research is available on the effectiveness of different shooting methods in different species, some authors (Lewis *et al.* 1997; Hoffman, 2000b; Kritzinger *et al.*, 2002; Veary, 1991) have found that impala are well suited to night cropping and that night cropping induces the least amount of stress in these animals. Factors other than the time of cropping may also have an impact on the effectiveness of a shooting method. Such factors may include the use of vehicles versus hunting on foot, the use of different-calibre rifles as well as the placement of shots. Von La Chevallerie *et al.* (1971) found that head or neck shots resulted in animals collapsing immediately, while rib or shoulder shots often resulted in the animals being subjected to prolonged suffering. Matson, Goldizen, and Putland, (2005) found that the vigilance of impala was affected by the intensity of hunting as well as by the use of vehicles during hunting, so that the animals became more vigilant at the sight or sound of vehicles in reserves where vehicles were often used to hunt. In such cases, it might be better to hunt on foot since the animals would be less aware of the presence of the hunter. Hoffman (2000b) found that using a heavier-calibre rifle caused a higher initial muscle pH as well as a faster rate of pH decline than a smaller-calibre rifle when used in the night cropping of impala.

In this study, the two shooting methods differed in terms of the times at which they were used, and the night cropping consisted of driving with a vehicle and cropping all the animals using head shots, while the day hunting consisted of tracking the animals by foot and killing all the animals via flank shots in a scenario that depicted ethical hunting. While no animals were wounded and all animals collapsed after being shot, the latter method did result in some of the animals running a short distance before collapsing (typical of a lung or liver shot) and still breathing, so that they died only once exsanguinated.

Temperature

Muscle temperature has a marked effect on the rate of *post-mortem* glycolysis in that high *post-mortem* temperatures accelerate glycolysis, i.e. the rate of pH decline, and low temperatures retard it (Pearson & Young, 1989). An exponential decay model ($y = a + b^{-ct}$) was fitted to the temperature data in this study with R^2 values ranging from 0.949 to 0.995. Linear regression analysis revealed a difference ($P < 0.0001$) in the rate of temperature decline between treatments (Figure 1). Carcass weight was also found to have and effect on the rate of temperature decline such that there was a positive correlation between carcass weight and rates of temperature decline, namely constant c ($P = 0.019$; $r = 0.563$). When carcasses were divided into weight classes, the ANOVA showed that the heaviest carcasses, weighing between 26 kg and 30 kg ($n = 2$), cooled at less than half the rate ($c = -0.185 \pm 0.018$) of that of the lightest carcasses, weighing between 6 kg to 10 kg ($n = 2$; $c = -0.404 \pm 0.019$). This is in agreement with Okeudo and Moss (2005), who found that carcass chilling was negatively affected by back fat cover and carcass weight. This is because large carcasses have proportionally smaller surface:volume ratios and the fat cover acts as an insulatory barrier to heat loss. The latter would not be the case in impala since they have little to no subcutaneous fat (Dunham & Murray, 1982). As a result of these findings, all pH values were adjusted to a constant temperature of 4°C (Bruce, Scott & Thompson, 2001).

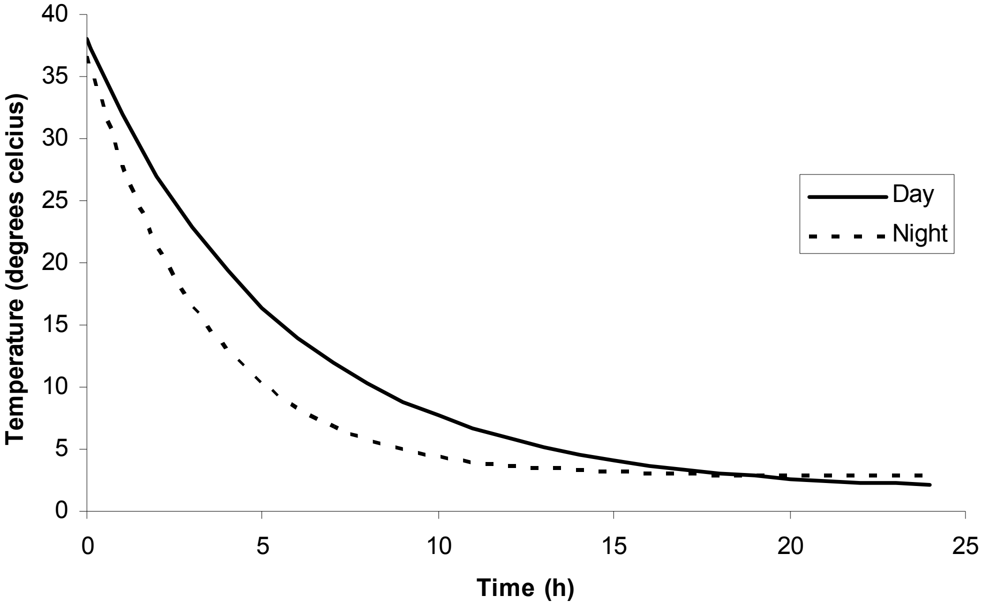

Fig. 1. Mean *M. longissimus dorsi* temperature profiles for day hunted (n=9) and night-cropped (n=8) Impala

pH

When an animal dies, anaerobic glycolysis continues in the muscle tissue, breaking down stored glycogen and producing lactic acid (Aberle *et al.*, 2001). Since this lactic acid can no longer be removed via blood circulation to the liver, it builds up in the muscle tissue, causing muscle acidification. This lowering of the muscle pH is one of the most significant *post-mortem* changes and is often indicative of those *ante-mortem* factors affecting the muscle (Aberle *et al.*, 2001). The rate and extent of *post-mortem* pH decline can most notably be affected by *ante-mortem* stress (Apple *et al*, 1995; Scanga, Belk, Tatum, Grandin & Smith, 1998; Smith & Dobson, 1990), which affects the amount of glycogen stored in the muscle prior to death and will, in turn, affect the amount of lactic acid that can be produced *post-mortem*. Pale soft and exudative meat (PSE) and dark, firm and dry meat (DFD) are the two most common examples of environmental stress affecting the quality of meat (Swatland, 1994). PSE meat is commonly defined as having a pH of less than 6 at 45 minutes *post-mortem* (pH_{45}) (Hoffman, 2001; Warriss & Brown, 1987), and although this is most commonly a problem is pigs, it has been reported in warthogs and buffalo as well (Hoffman, 2001). Hoffman (2000b) speculates that this may also be indicative of the phenomenon known as white muscle capture myopathy, which has been documented in numerous game species (Bothma & Van Rooyen, 2005). DFD, on the other hand, which is found in all species and is more common in ruminants than PSE, is generally defined as having an ultimate pH (pH_u), of higher than 5.8 as measured at 12 to 48 hours *post-mortem* (Hoffman, 2001; Warriss, 2000; Wiklund *et al*, 1995). None of the animals in the present study exhibited pH_{45} values low enough to be classified as having PSE or pH_u values high enough to be classified as DFD. Table 2 represents the mean pH_{45} and pH_u values for both cropping methods.

Table 2

Mean pH values (LSMean ± s.e.) measured at 24 h *post-mortem* for day hunted and night-cropped impala

Treatment	Measurement	Non-adjusted pH	P < │t│	Adjusted pH	P < │t│
Day	pH_{45}	6.38 ± 0.125	0.998	6.64 ± 0.128	0.709
Night	pH_{45}	6.38 ± 0.128		6.57 ± 0.131	
Day	pH_u	5.70 ± 0.056	0.883	5.74 ± 0.056	0.984
Night	pH_u	5.68 ± 0.057		5.74 ± 0.057	

There was no difference in pH values (either adjusted or non-adjusted) between the two shooting methods (Table 2). This is in contrast to the findings of Kritizinger *et al.* (2002) and Veary (1991), who both found higher pH values in day-cropped impala and springbok (*Antidorcus marsupialis*) respectively compared to night-cropped animals of the same species. It must be noted that although night cropping is perceived to be the best shooting method for antelope such as impala (Hoffman 2001, 2000a; Kritzinger *et al.*, 2002; Lewis *et al.*, 1997; Veary, 1991; Von La Chevallerie & Van Zyl, 1971), in the current study, the difference in the use of vehicles may have influenced the amount of stress experienced by the animals in that the animals were less aware of the hunters approaching on foot during the day than the hunters approaching in vehicles at night. The hunter in the present investigation was very experienced – the results also indicate that if the hunt takes place in accordance with the ethical standards propagated by the hunting fraternity, the stress experienced by the impala is minimal. According to Schenkel (1966) as well as Bothma and Van Rooyen (2005), impala often rely on their hearing rather than their sight to detect danger, lifting their head and neck with their ears in an upright position when they suspect approaching danger. This is an important aspect that is taken into account by an experienced hunter when stalking impala.

Mean pH_{45} values were similar to that reported by Kritzinger *et al.* (2002) for impala, ranging from 6.57 ± 0.131 to 6.64 ± 0.128 and much lower than were reported by Hoffman (2000b), where the pH_{45} values ranged from 7.05 ± 0.105 to 7.30 ± 0.063. Nonetheless, the pH_u values were similar to those reported for impala by other authors (Hoffman, 2000b; Kritzinger *et al.*, 2002; Mostert, 2007;).

The rate of pH decline in muscle has been found to deviate from a linear function in a more curvilinear manner (Bate-Smith & Bendall, 1956; Bendall, 1973; Bruce *et al.*, 2001; Pearson & Young., 1989; Warriss, 2000). This is because, as the muscle enters *rigor*, the rate of pH decline slows due to the decrease in myosin ATPase activity and anaerobic glycolysis as the muscle cools as well as the buffering effect of ammonia generated by the deamination of AMP (Bruce *et al.*, 2001). As a result of this slowed rate, an exponential decay model ($y = a + b^{-ct}$) was fitted to the pH data and the resulting a, b and c values determined (Table 3). The exponential decay model fitted the data well, with R^2 values for non-adjusted pH ranging from 0.870 to 0.987 and those for adjusted pH ranging from 0.916 to 0.992. The c value is indicative of the rate of pH decline, the a value is indicative of the final pH reached and the sum of the a and b values indicative of the initial pH.

Table 3

The calculated constants (LSMean ± s.e.) for the exponential equations fitted to the *M. longissimus dorsi* pH decline under normal temperature conditions and under adjusted standard temperature (4°C) for day hunted (n = 9) and night-cropped (n = 8) impala

$Y = a + be^{-ct}$	**Treatment**	**Non-adjusted pH**		**Adjusted pH**	
Constants		**Mean ± s.e.**	**P < │t│**	**Mean ± s.e.**	**P < │t│**
a	Day	5.402 ± 0.052	0.070	5.424 ± 0.039	0.013
	Night	5.527 ± 0.045		5.295 ± 0.033	
b	Day	1.105 ± 0.062	0.319	1.405 ± 0.034	0.0008
	Night	1.024 ± 0.053		1.556 ± 0.029	
c	Day	-0.514 ± 0.033	< 0.0001	-0.385 ± 0.022	< 0.0001
	Night	-0.177 ± 0.029		-0.184 ± 0.019	

The results of this study show that there is a difference ($P < 0.05$) between treatments for all the constants of the exponential decay model when the data has been adjusted to a constant temperature. Kritzinger *et al.* (2002) found similar results, with differences in a, b and c between day- and night-cropped impala. The results indicate that day-hunted impala had higher final pH values and also had rates of pH decline twice as fast as those of the night-cropped impala (Figure 3). This is a phenomenon usually associated with *ante-mortem* stress. Unlike night cropping, when it was not unusual to shoot more than one animal in a herd, the hunter was only able to shoot one animal per herd during the day, even though silencers were used, animals tended to run away as soon as an animal fell which is indicative of their awareness of the hunters. Matson *et al.* (2005) found that impala were most vigilant during the early morning and late afternoon, and since their eyesight is poor at night (Bothma & Van Rooyen, 2005) they tend to be less aware of their surroundings at night. This relative unawareness of the animals to those around them at nighttime may account for a decrease in their muscle glycolytic enzyme activity and thus decreased pH decline *post-mortem*. Another influence could be the heightened physical activity as well as foraging during the day (Matson *et al.*, 2005) so that, as a result, muscle glycogen stores were high and glycolytic enzyme activity remained high for longer periods of time resulting in a more rapid pH decline *post-mortem*. Studies have found that any feeding in the immediate *ante-mortem* period may have an effect on *post-mortem* pH (Aberle *et al.*, 2001). It must be noted that although there were differences in the rate and extent of pH fall between treatments, none of the animals exhibited values associated with severe *ante-mortem* stress. Hoffman and Ferreira (2000) found a, b and c values of 5.73, -0.367 and -0.734 respectively for a grey duiker (*Sylvicapra grimmia*) that had undergone excessive exercise stress prior to death, and Hoffman (2001) found a, b and c values of 6.084, 2.292 and -0.786 respectively for a male impala that had been wounded in the ear before being shot 4 minutes later.

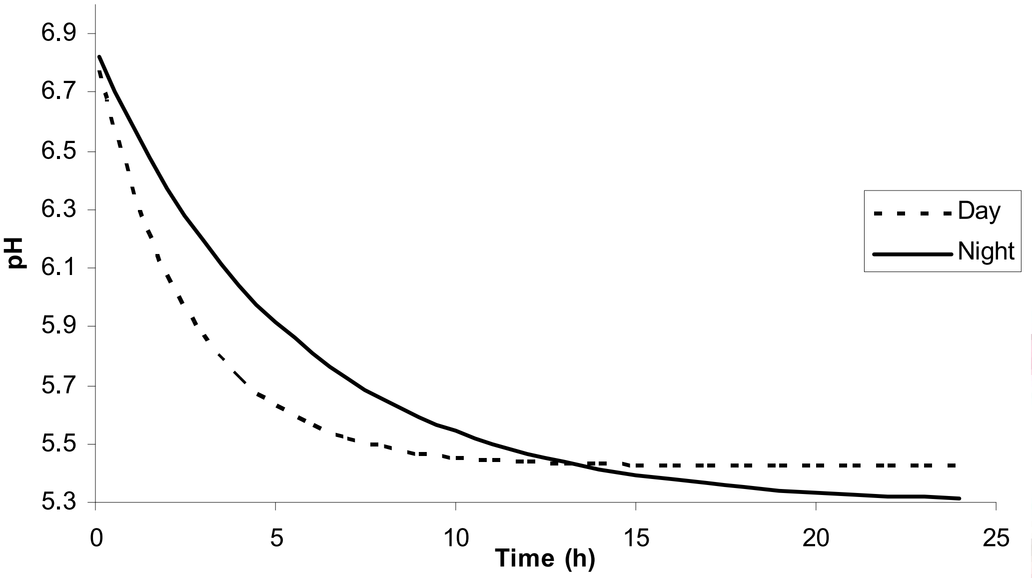

Fig. 2. Mean *M. longissimus dorsi* pH profiles for day hunted (n=9) and night (n=8) cropped impala

Gender differences ($p < 0.0001$) were also found for the constants a and b of the exponential decay model, with male impala having higher final pH values (a = 5.49 ± 0.037) than female impala (a = 5.23 ± 0.035). This may be because the males had just finished their rutting season and were in a more excitable state than the female impala. Impala rams only reach sexual maturity at around 18 months of age (Bothma & Van Rooyen, 2005) and even at this age are still said to be socially immature. Since all the impala cropped in this study were under the age of 20 months, males were still relatively young and thus still very active with regard to their interactions with other young males and females. This heightened activity may account for the lowered final pH. Bond, Can and Warner (2004) found that exercise prior to slaughter in lambs resulted in lowered muscle glycogen levels *post-mortem* as well as a greater degree of pH decline when compared to control animals.

Water-holding capacity and tenderness

The water-holding capacity (WHC) of meat is its ability to retain water, and the majority of water found in meat is held between the thick and thin filaments (Offer *et al.*, 1989). WHC is one of the most important quality characteristics of raw meat products (Huff-Lonergan & Lonergan, 2005) and is invariably linked to the pH of meat. Muscle proteins tend to denature as the pH falls, resulting in a reduction in their power to bind water (Warriss, 2000). Also, as the muscle approaches its isoelectric point, around 5.0- 5.5 (Swatland, 1994), the protein molecules have no electric charge and tend to lose the water that is bound to them. Eventually, this exudate will produce drip or be lost during the cooking of the meat (Warriss, 2000). Accelerated pH decline and low ultimate pH are related to the development of low WHC and unacceptably high purge loss (Huff-Lonergan & Lonergan, 2005).

The results of this study showed no correlation ($P > 0.05$) between drip loss or cooking loss and either pH_u or the rate of pH decline. These findings are in contrast to the those of Mostert (2007) who found that pH_u was negatively correlated to cooking loss in the *M. longissimus dorsi* of both kudu (*Tragelaphus strepsiceros*) and impala ($r = -0.277$). Hoffman, Kroucamp and Manley (2007) also found negative correlations between both cooking loss ($r = -0.42$) and drip loss ($r = -0.26$) and pH_u in springbok (*Antidorcus marsupialis*). Warriss and Brown,(1987) determined that there was a biphasic relationship between pH_{45} and drip loss since pH_{45} is often used as an indicator of PSE and PSE meat is known to produce the highest amounts of exudate. There was no correlation in this study between pH_{45} and drip loss, which may be attributable to the fact that none of the animals in this study exhibited pH_{45} values low enough to be considered detrimental to the WHC of the meat. Warriss and Brown (1987) found that exudate was highest at $pH_{45} \leq 6.1$ and decreased rapidly at pH_{45} values above 6.1. The population mean adjusted pH_{45} of the impala was 6.78.

The results of the physical quality parameters measured in the *M. longissmus dorsi* of the cropped impala are tabulated in Table 4. These results show that there was no difference ($P > 0.05$) in either drip loss or cooking loss between the two shooting methods. Kritzinger *et al.* (2002) also found no differences ($P > 0.05$) in cooking loss between day- and night-cropped impala, although the authors found that day-cropped impala had higher drip loss values than night-cropped impala, with mean drip loss values of 4.15 ± 2.339% and 2.93 ± 1.597%, respectively.

In a study conducted by Hoffman (2000b), drip loss values of 2.16 ± 1.24% and cooking loss values of 23.98 ± 1.41% were reported for night-cropped impala. Mostert (2007) reported drip loss values of 1.19 ± 0.16% and cooking loss values of 31.04 ± 0.83% for impala shot from a hide during the day. The values found in this study are higher than those reported by these authors and are similar to those reported by Kritzinger *et al.* (2002). Although no treatment differences ($P > 0.05$) were found, there was a difference ($P = 0.032$) between male and female impala with regard to cooking loss in that males exhibited a higher cooking loss (28.95 ± 0.881%) than females (26.427 ± 0.505%). Similar results were found by Hoffman *et al.* (2007) in springbok and it was concluded that these differences were attributable to differences in pH_{24} since female springbok had higher pH_{24} values than males. Although females had slightly higher pH_u values (5.46 ± 0.034) than males (5.40 ± 0.025) in this study, this difference was not significant.

Table 4

Mean values of the physical meat quality parameters (LSMean ± s.e.) as measured in the *M. longissimus dorsi* muscle of day hunted and night-cropped impala

Parameter	**Cropping technique**		
	Day	**Night**	**P < │t│**
Drip loss (%)	3.66 ± 0.540	2.78 ± 0.503	0.205
Cooking loss (%)	27.99 ± 0.548	27.41 ± 0.510	0.391
Shear force (kg/1.27 cm diameter)	4.27 ± 0.172	4.69 ± 0.204	0.116

Although meat tenderness is an important factor relating to meat quality, it remains an elusive and poorly understood attribute (Marsh, Lochner, Takahashi & Kragness, 1981). It has been found that *post-mortem* pH and temperature have a great effect on muscle properties and final meat tenderness (Bruce & Ball, 1990; Maltin, Baleerzak, Tilley & Delday, 2003; Marsh *et al.*, 1981; Silva, Patarata & Martins, 1999; Yu & Lee, 1986). In this study, no correlations (P > 0.05) were found between either pH_{45} or pH_u. Some authors have suggested a curvilinear relationship between pH and tenderness, with minimum tenderness between pH 5.8 and 6.2 (Silva *et al.*, 1999), and since none of the animals in this study exhibited pH_u values within this range, it may explain why no linear correlation was found between pH_u and tenderness. There was a difference (P = 0.001) in shear force values between the two shooting methods (Table 4). This is in contrast to the findings of Kritzinger *et al.* (2002) who found that day-cropped impala produced higher shear force values than night-cropped impala. The shear force values of the day-cropped animals in the current investigation are similar to those reported by Hoffman (2000b) and Mostert (2007) for impala (ranging from 3.65 to 4.13 kg/1.27 cm diameter) and are higher than were reported by Hoffman *et al.* (2007) for springbok (1.67 – 2.67 kg/1.27 cm diameter) and by Smit (2004) for blesbok (2.35–3.57 kg/1.27 cm diameter) and red hartebeest (2.48–3.87 kg/1.27 cm diameter). The differences in shear force between the treatments may be attributable to the differences in the rate of pH decline, as there was a negative correlation (P = 0.004; r = -0.66) between constant c of the exponential decay model and shear force in that shear force decreased as the rate of pH decline increased. This is in agreement with Marsh *et al.* (1981), who stated that the rapid attainment of a low muscle pH is beneficial for tenderness due to its prevention of cold shortening, its release of lysosomal enzymes and its activation of cathepsins. No differences (P > 0.05) in shear force values were found between genders or carcass weights.

Colour

Meat colour is considered to be one of the most important criteria used by consumers to select meat, and consumers tend to discriminate against meat that is either too pale or too dark (Issanchou, 1996; Viljoen, De Kock & Webb, 2002). The change in proteins brought about by a drop in pH increases the light scattering properties of the contractile elements of the muscle fibre (Warriss, 2000; Swatland, 1994). Also, myoglobin is the dominant pigment of meat and after slaughter it may move into the intercellular space where it may be lost in fluid dripping from the meat surface (Swatland, 2004). Thus, as the pH decreases, the amount of drip loss may increase and consequently the amount of myoglobin lost in exudate increases, so that meat may appear paler. According to Volpelli, Valusso, Morgante, Pittia and Piasentier (2003), the characteristic L*, a* and b* values of venison are L* < 40, high a* values and low b* values. The colour results of the current study are recorded in Table 5.

Table 5

LSMeans (± s.e.) of L*, a*, b*, hue-angle (H_{ab}) and chroma values (C*) of impala *M. longissimus dorsi* (LD) muscle with cropping method as main effect

Colour ordinates	**Cropping technique**		
	Day	**Night**	**P < │t│**
L*	32.76 ± 0.387	32.09 ± 0.360	0.157
a*	11.41 ± 0.245	10.56 ± 0.229	0.006
b*	7.65 ± 0.338	7.06 ± 0.315	0.159
C*	13.78 ± 0.252	12.81 ± 0.235	0.003
h_{ab}	33.86 ± 1.500	33.67 ± 1.398	0.660

All the values were typical of those for venison with the animals producing darkish, red-brown meat, characteristic of impala meat (Von La Chevallerie, 1972). L* values were slightly higher than were recorded by Hoffman (2000b) for night-shot impala (L* = 29.22 ± 0.590), Kritizinger *et al.* (2002) for day- and night-shot impala (L* = 30.53 ± 2.758 and 30.10 ± 1.296, respectively) and Mostert (2007) for impala shot from a hide (L* = 28.33 ± 0.45 to 29.87 ± 0.48). The latter author noted that shooting from a hide was an effective method that could be used to minimise *ante-mortem* stress since animals were completely unaware of the hunter's presence; this may partly explain why the animals in the current study produced slightly lighter meat. No treatment differences were found for L* and b* although treatment differences were found for a* and chroma so that, as a result, day-hunted animals produced redder meat than night-cropped animals. The increased redness in the meat of the day-hunted animals may in part be attributable to the slightly higher L* values (although not significant) of these animals. Game meat is generally perceived as being very dark in colour, mainly due to the increased amounts of myoglobin in the meat because of increased activity (Hoffman *et al.*, 2005), the relatively little intramuscular fat present, compared to domestic livestock, and the use of inefficient cropping methods to minimise stress (increased incidence of DFD). As a result, slight difference in the colour parameters may be difficult to detect (Kritzinger, 2002), whereas these differences are more easily detectable in lighter (higher L* values) meat.

Carcass weight and gender differences were found for the colour ordinates, although the ANOVA revealed an interaction between carcass weight and gender ($P < 0.05$). This is probably due to the fact that males had consistently higher ($P = 0.001$) carcass weights (22.17 ± 0.974 kg) than females (17.61 ± 0.919 kg). The ANOVA indicated that females with carcass weights between 6 kg and 10 kg produced meat with the highest L*, b* and hue angle values (L* = 38.45 ± 0.445; b* = 8.82 ± 0.461; hue angle = 42.21 ± 2.284). Females with carcass weights between 21 kg and 25 kg produced meat with the highest a* (12.47 ± 0.459) and C* (14.74 ± 0.347) values, while females weighing between 11 kg and 15 kg produced meat with the lowest a* (9.37 ± 0.459) and C* (11.29 ± 0.397) values. Males weighing between 16 kg and 20 kg produced meat with the lowest L*, b* and hue angle (L* = 21.10 ± 0.629; b* = 5.37 ± 0.652; hue angle = 25.46 ± 3.230).

CONCLUSION

Although no differences were found in pH_u or pH_{45} between treatments, the exponential decay model indicated that shooting method did have an effect on the *post-mortem* pH decline of the meat. The model indicated that day-hunted animals showed higher rates of pH decline as well as final pH values, which indicates that the day-hunting method may have caused a higher amount of *ante-mortem* stress than the night-cropping method. These differences did not adversely affect the meat quality of the animals, since no differences were found for drip loss, cooking loss or shear force values between treatments. There were a number of differences in the colour parameters of the meat, although many of them were the result of other main effects, such as carcass weight and gender. Therefore, although hunting during the day on foot may cause more *ante-mortem* stress, this is not sufficient to adversely affect the meat quality, and both shooting methods produce meat of similar quality. It must be noted, however, that the use of vehicles and the ease with which impala are cropped at night, makes this method the most practical when shooting these antelope. This is especially true when cropping impala for the commercial production of game meat since night cropping from a vehicle enables the shooter to crop numerous animals within a herd and to move around the property and follow herds at a much more efficient speed.

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Chapter 8

GENERAL CONCLUSIONS

CONCLUSIONS

1. There was no difference between the effects of day- and night cropping with the use of vehicles on either stress (as measured by the subjective stress score and serum cortisol levels), rate and extent of *post-mortem* pH decline or meat quality in red hartebeest, although day-cropped animals produced meat that was redder with greater colour intensity. Region, which denotes environment as well as the effect of hunting practices on each particular farm, had an effect on stress, *post-mortem* pH decline and meat quality in this species in that animals that occurred in an area where hunting occurs frequently, were more easily stressed by the cropping than animals that occurred in an area where hunting activity was limited to once a year.
2. Day cropping with the use of vehicles caused a greater amount of *ante-mortem* stress (as measured by the subjective stress score and serum cortisol levels) in gemsbok compared to night cropping with the use of vehicles, although night-cropped gemsbok showed a greater extent of pH decline *post-mortem*. The latter also produced meat that was tougher, although the day-cropped animals produced meat that was lighter than that of the night-cropped animals. The results therefore suggest that although day cropping caused more *ante-mortem* stress this did not adversely affect the meat quality.
3. Day cropping with the use of vehicles caused a greater amount of *ante-mortem* stress in kudu than night cropping with the use of vehicles which resulted in a higher serum cortisol level in the former. Most likely as a result of this, the day-cropped kudu had a lower mean pH_u than the night-cropped kudu. Day-cropped kudu had a higher mean drip loss percentage which was likely due to the negative correlation between drip loss and pH_u. The night-cropped animals produced tougher meat, most likely because differences in pH resulted in increased proteolytic enzyme activity in the day-cropped animals.
4. For impala, conventional, ethical hunting on foot caused a more rapid *post-mortem* pH decline compared to night cropping with the use of vehicles, indicating that the former method caused more *ante-mortem* stress. There were no differences in pH_{45} or pH_u between these two shooting methods and both methods produced meat of similar physical quality. Impala hunted on foot during the day were found to produce meat that was both redder and had a more intense colour than impala cropped at night with the use of vehicles.

SUMMARY OF CONTRIBUTIONS

1. The efficiency of a specific cropping method is dependent on species in that differences in *ante-mortem* stress may exist between cropping methods for one species but may not necessarily exist for another species. Both the red hartebeest and kudu were cropped using day- and night cropping with the use of vehicles. While the red hartebeest showed no differences in either stress score, cortisol levels or the rate and extent of pH fall *post-mortem* and both cropping methods resulted in

meat of similar quality, the day-cropped kudu had a higher mean stress score, cortisol levels and pH_u and produced meat that was lighter in colour compared to night-cropped kudu. Day cropping therefore caused more *ante-mortem* stress than night cropping in the latter species.

2. Day cropping from a vehicle caused more *ante-mortem* stress in gemsbok than night cropping from a vehicle and, as a result, day-cropped animals produced meat that was noticeably lighter, although the effect on *post-mortem* pH was minimal.
3. Day cropping from a vehicle caused more *ante-mortem* stress in kudu than night cropping from a vehicle, which affected the pH_u of the meat in that proteolytic enzyme activity was most likely increased. As a result, the meat from the day-cropped animals was more tender and had a higher drip loss percentage than that of the night-cropped animals.
4. Compared to night cropping from a vehicle, conventional hunting on foot produced meat of similar quality in impala, although it did cause a faster and more extreme pH decline in the impala muscle *post-mortem*.
5. Carcass weight, live weight and hanging position in the cooling truck affected the temperature decline in all the species where temperature decline was measured. Lighter animals and those carcasses hanging closest to the fans of the cooling truck had the highest rate of temperature decline
6. Region had an effect on the stress, *post-mortem* pH and drip loss percentage of the cropped red hartebeest. The red hartebeest cropped on the farm where hunting and cropping occurred frequently were more stressed, produced a lower mean pH_u and had a higher mean drip loss percentage compared to the red hartebeest cropped on the farm where hunting and cropping activity was limited to once a year. This may be due to the fact that the former were more aware of the vehicles and hunters because of prior experience, and because these animals occurred in much larger herds and were cropped in a much shorter period of time, so that the cropping process was much more intensified.
7. When measured, gender and age differences in *post-mortem* pH and meat quality occurred in all of the species cropped, which is to be expected since similar results have been reported for both domesticated and wild species.
8. The subjective stress score allocated to each of the animals was a relatively accurate measure of *ante-mortem* stress since it showed a strong correlation to plasma cortisol levels (nmol/L) in all species in which the latter was measured.

FUTURE RESEARCH

1. Only three different cropping methods were tested, namely day- and night cropping from a vehicle and conventional hunting on foot. It may thus be necessary to conduct future research on other commonly used commercial cropping methods, such as boma cropping and helicopter cropping.
2. Sample sizes during the collection of the current data was limited and it may thus be necessary to conduct similar research into the effect of these cropping methods using a larger number of animals, in order to substantiate the results of the current inverstigation.

3. With the ever-increasing export of game meat, the potential of various species to produce game meat will most likely be taken advantage of in times to come. The effect of the commercially-used cropping methods on a larger variety of game species will therefore become important.
4. Due to the availability of the data, the effect of region was only investigated in the red hartebeest, and it would be of interest to investigate the full effects of region on stress and meat quality as well as cropping efficiency since cropping efficiency will inevitably be affected by the terrain and environment of a region. Also, some cropping methods are best suited to certain environments and the effects of these methods on the meat quality of wild ungulates should be fully investigated in terms of their efficiency as well.
5. Seasonal differences should also be investigated since large temperature fluctuations may have detrimental effects on meat quality. In Namibia, for instance, summer temperatures can reach as high as 35°C while, in this study, nighttime winter temperatures as low as 2°C were recorded. Since carcasses may spend up to three hours on the back of a hunting vehicle (the maximum time allowed according to EU regulations) before being loaded into a cooling truck, and since the temperature decline of a carcass is known to affect meat quality, these large differences in ambient temperatures may have a more significant effect on the meat quality of an animal than the cropping method itself.