A farm to fork approach to meat science

Inaugural lecture presented

by

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Professor Voster Muchenje - short biography

Professor Voster Muchenje, who is an NRF Y2 rated scientist and has an H-Index of 12, was awarded a PhD in Animal (Meat) Science in 2008 at the University of Fort Hare (UFH). He holds an MSc (Animal Science) and BSc Agriculture (Hons) from the University of Zimbabwe and a PGDHET (UFH). Voster is also the Co-Chair of the NRF SARChI Chair in Meat Science-Genomics to Nutrinomics and Head of the Department (HOD) of Livestock and Pasture Science, UFH.

He was born and went to school in Zimbabwe. He started lecturing at the University of Zimbabwe 15 years ago. He then joined the Zimbabwe Open University (ZOU) in 1999 where he was later promoted to the senior lecturer grade in 2005. In the same year he joined the University of Fort Hare (UFH) as a visiting scientist, where he was later appointed as a senior lecturer in 2008, and HOD in 2010. He was promoted to the associate professor and full professor grades in 2011 and 2013, respectively. In 2010, he was appointed an Assistant Editor by the *South African Journal of Animal Science (SAJAS)*. In 2011, Voster was inaugurated as one of the founding members of the South African Young Academy of Science. In 2012, he was appointed to the editorial board of the journal, *Food Research International*, and was also appointed the Guest Editor of the *SAJAS* special issue on the 2012 South African Society for Animal Science (SASAS) Congress.

To date he has successfully supervised more 20 postgraduate students and has at least 67 articles in international peer-reviewed journals and one registered patent. He is an external examiner for several international and national universities, and regularly reviews manuscripts for several international journals, including *Meat Science, and Tropical Animal Health and Production*. He has been a panel member for the NRF. He was part of the SASAS 2012 Congress Organising Committee. His research group is currently supported by 5 competitive grants, including the NRF THRIP, NRF SARChI (co-chaired with Stellenbosch University) and Adam Fleming (Nguni Cattle Project). His papers in journals such as *Meat Science, Animal, Journal of Food Composition and Analysis, The Veterinary Journal,* and *Food Chemistry* enjoys extensive citations and downloads. Voster has presented more than 20 papers at conferences, in countries such as Brazil (2006), China (2007), Denmark (2009), Belgium (2011) and Germany (2013). He also has more than 20 articles in farmer journals including *The Farmer's Weekly*. Some of his research activities have been broadcast as documentaries by SABC2. He is a member of SASAS and the American Meat Science Association (AMSA). He serves (or served) on several boards which include**:** South African Qualifications Authority (SAQA) Research Committee Reference Group (2012), Academy of Science of South Africa (ASSAf) Science, Technology, Engineering and Mathematics Education Committee (STEM) Agriculture Consensus Study Group (2012); IDC-Eastern Cape Nguni Cattle Project (2011-present) and Fort Cox College of Agriculture and Forestry Board of Governors (2012 ï Present). He is also a recipient of the SASAS Presidentôs award for exceptional contribution to animal science and livestock industry (2012) and the UFH (2009) VCôs Emerging Researcher Award.

Abstract

Development processes which occur from conception up to the time an animal is slaughtered, and exposed to *post-mortem* processes affect the quality of meat. In addition to biochemical and physiological processes which affect the changing of the muscle to meat, issues such as animal welfare, consumer rights and the legal environment now play a significant role in meat science. In this lecture, recent studies that were done on meat production under low-input animal production systems and their relationships with *ante-mortem* and *post-mortem* processes on meat are reviewed. This lecture also demonstrates how a breed-based research programme, like the Nguni Cattle Project, has resulted in significant research outputs which can be applied for other species. Research has also shown that the way in which an animal is raised affects how it grows and the quality of meat produced from the same animal thereon. The quality attributes affected in such instances include; meat colour, tenderness, cooking losses, water-holding capacity, fatty acid profiles as well as sensory evaluation. Major findings on the interaction between animal welfare and meat science have also been reported. Supplementing different livestock species with feeds of plant origin, such as *Moringa oleifera* and *Acacia karroo* leaves has resulted in significant improvement of meat quality, fatty acid composition and antioxidant activities. These studies have also included perceptions of consumers, farmers and meat traders on issues ranging from animal welfare, meat quality, meat labelling and traceability. Highlights on meat consumption patterns and wellness indicators are also presented. Novel discoveries have been reported in the pain and pregnancy biomarkers research programme. In addition, excellent relationships between the meat industry, government departments/agencies, national and international research institutions, and the consumers have been developed. The research activities have also resulted in significant human resource development and strengthened collaborations. The meat science research work conducted over the last few years resulted in the recently awarded South African Research Chair Initiative (SARChI) in Meat Science: Genomics to Nutriomics which is co-hosted by the University of Fort Hare in partnership with Stellenbosch University. Despite these successes, more research need to be done in meat distribution, processing, value chains, genetic manipulation, thermodynamics, the possibility and ethics of producing genetically engineered/cultured meats, meat production and consumption ethics. Therefore the objective of this review is to present meat science research activities which have been carried at the University of Fort Hare over the last decade, how this can be used to shape the future meat science research agenda.

Keywords: animal welfare; biomarkers, consumers; genetics; meat science; meat consumption ethics; meat labelling; Nguni cattle; pre-slaughter stress; sensory evaluation

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1. Introduction

The annual average consumption *per capita* of meat in the world has been projected to increase by approximately 20% and 50% by 2050 in developed and developing countries, respectively (FAOSTAT, 2010). Locally, the livestock sector in South Africa accounts for 75% of the national agricultural output, of which cattle farming is the largest sub-sector (National Department of Agriculture, 2008). Close to 25 % of all livestock species in South Africa are found in the Eastern Cape Province. For example, records show that out of the 14.1 million cattle in South Africa, over 3.2 million heads are located in the Eastern Cape Province. Therefore to improve meat production from these livestock species, there is need to address both the genetic and environmental components that influence their development and growth processes.

The development processes which occur from conception up to the time an animal is slaughtered, and *post-mortem* processes that follow, affect the quality of meat. These processes depend on genetic and environmental factors. In addition to biochemical and physiological processes which affect all the reactions involved in changing of the muscle to meat, issues such as animal welfare, consumer rights and the legal environment now play a significant role in meat science. Of all these processes, adaptation of an animal to a particular environment is of utmost important for its survival. This is critical in arid environments where grazing and feed resources availability is limited. An adapted animal should therefore be resistant to diseases and parasites, and ultimately survive on limited available feed resources. This adaptation process is achieved through several mechanisms which include physiological, biochemical, anatomical and behavioural. Generally adaptation must be coupled with improved livestock management. Knowledge of how animals adapt to harsh conditions and how such adaptations affect their growth performance and meat yield is thus important to meet optimal results.

Despite there being a possible relationship among the environment, parasite loads, diseases, animal welfare, growth performance and meat production, research on adaptation relating to these aspects in Southern Africa have been covered separately, mostly on feedlots and cultivated pastures (Gertenbach and Henning, 1995; Collins-Luswet, 2000). Very little, if any, research has been done on combined studies in order to establish the relationship between the environment, parasite loads, diseases, growth performance, stress responsiveness and meat yield. In this there was work done at the University of Fort Hare (Muchenje, 2007) on cattle finished on natural pasture covering these issues together. Issues that are important in cattle production include internal parasite, adaptation to limited grazing and factors on how the beef cattle physiologically cope to harsh environments (Ndlovu, 2007). Due consideration should thus be given to these issues since they play a pivotal role in the profitability, growth and sustainability of the livestock industry in general. Due to the interconnections between livestock production systems in the communal areas, cattle production cannot be separated from other livestock production systems. This has resulted in research that cut across different species covering aspects from reproduction, livestock management, animal transportation, and slaughter, the quality of meat and how it is finally accepted by the consumer. All these process involve a lot of biochemical, physiological and socio-economic aspects which need to be investigated. Therefore the objective of this review is to present meat science research activities which have been carried at the University of Fort Hare over the last decade, and ultimately show how this can be used to shape the future meat science research agenda.

2. A breed-based research project and meat science

Nguni cattle possess various adaptation characteristics that make them suitable to be reared under low-input production systems in South Africa. The breed possesses phenotypic and genetic characteristics herein presented which are economically, socio-culturally and ecologically important to the rural farmers (Palmer and Ainslie, 2006). It is a low-maintenance breed therefore it can be easily managed by the rural farming people on community rangelands. Apart from this, the Nguni breed also has a special recognition in the cultural heritage of the Nguni people of Southern Africa which makes it a candidate to be conserved by the communal and small-scale farmers.

The Nguni breed is small to medium in size depending on the prevailing nutritional conditions with bulls weighing 500-700 kg and cows 320-440 kg (Colins-Lusweti, 2000; Ramsay *et al.,* 2000). Its coat is short, fine and glossy and well-pigmented with motile hides of medium thickness. The Nguni cattle are unicoloured or multicoloured; white, black, brown, grey, and red varieties can be found (Bayer *et al.,* 2004). Studies by Rege and Tawah (1999) indicated that unimproved animals are small, with withers height of about 105 cm whereas improved Nguni cattle have height at withers of 135 cm for bulls and 125 cm for cows. The adaptive characteristics make the breed suitable for *in-situ* conservation by resource-poor farmers through low maintenance cost and low medical bills.

Studies on feedlot performance indicated no significant differences in feed conversion efficiency between Nguni cattle from communal areas, non-descripts from emerging farmers (small-scale farmers), Bonsmara, Drankensburger and Tuli from commercial farmers (Chipa *et al.,* 2010). This shows the potential for commercial feedlot market from both the commercial and small-scale sectors in realising revenue for the sustenance of the conservation programme. Nguni cattle also maintain their condition in winter (Ndlovu *et al.,* 2009; Muchenje *et al*., 2008a) because of selective grazing and browsing, thus obtaining favourable nutritional value from the available natural vegetation. This makes them able to survive for a longer life span under poor rangeland conditions, a characteristic of the rural communities of South Africa (Bester *et al.,* 2003).

The Nguni cattle have long productive lives; cows calve regularly and produce 10 or more calves (Tada *et al*., 2013a). A reported by Roux (1992), showed that Nguni cows have a reproductive life span of 16 years and an average calving rate of 90%. The reconception rate i.e. the pregnancy percentage after the next mating season, of Nguni cattle was noted to be high (87.2%) (Scholtz and Theunissen, 2010;Tada *et al*., 2013a).Nguni cows registered at the Namibian Stud Breeders Association had an average inter calving period (ICP) of 402 days despite the severe drought conditions experienced during the nineties. Calves of both sexes are small at birth weighing 26kg on average or 7.5% of the mothers' weight. The dams calve easily with extremely rare calving difficulties due to conformational features such as the sloping rump and the significant maternal restriction on birth weight. Under extensive range conditions without supplementation, the Sanga type of cattle (from which the Nguni descended), has the highest average calving rate of 92%, shortest average calving interval of 372 days, and highest net income of R141 (US$18.08) when compared to the Afrikaner, Hereford, Santa Getrudis and Simmental (Moraka, 2000). A review by Schoeman (1989) indicated the high calving rate of Nguni (89.6%) compared to an average of 77.4% for Bonsmara and Drankensberger. In the same study the Nguni reached puberty much earlier (349.9 days) than Bonsmara (419 days) and Drankensberger (407.2 days). Nguni cattle seem to be the most reproductively efficient beef breed in Southern Africa therefore conservation of this breed is important in communities where off take rate has been reported to be very low

(Musemwa *et al.,* 2008). However some studies in the communal and small-scale sector of the Eastern Cape Province show a low calf to cow ratio attributed to a low plane of nutrition, low cow management levels and low bull fertility (Mapiye *et al.,* 2007; Nqeno *et al*., 2010). Thus improving the husbandry practices of the cattle on an *in-situ* conservation scheme may address this concern.

The Nguni cattle have good walking and foraging ability, low maintenance requirements and good meat quality (Muchenje *et al.,* 2008a,b; 2009a,b). In a study of growth performance and carcass characteristics conducted by Swanepoel (1990), the Nguni bulls, compared to the Afrikaner and Pedi, were found to have the heavier carcass (170.47kg), greater dressing percentage (63.27%), the more compact carcass (0.76kg/cm) and hind quarter (0.58kg/cm), and a lighter hide (9.06%) despite a lower slaughter mass of 294.5kg. Moreover, red meat from rangeland-finished cattle was found to possess essential fatty acids (e.g. conjugated linoleic acids and omega-3 fatty acids) and vitamins (b-carotene and -tocopherol) that have benefits (reduce risk of heart disease, diabetes and cancer) in human health (Mapiye e*t al.,* 2009a). The Nguni beef had the excellent sensory characteristics, such as flavour and tenderness, when raised on natural pasture (Muchenje *et al.,* 2008c; 2010). In addition, Nguni beef have favourable fatty acid profiles (Muchenje *et al.,* 2009c) and sensory attributes (Muchenje *et al.,* 2008c). This makes conservation of this indigenous breed important.

Having survived many years of exposure to climatic and other environmental extremes such as internal and external parasites, suboptimal grazing conditions and primitive management practices, the Nguni cattle have developed to suit a low-input production system. Nguni cattle are tolerant to extreme temperatures (Bester *et al.,* 2003). It is also reported to be resistant to nematodes (Ndlovu *et al.,* 2009a), ticks (Muchenje *et al.,* 2008a) and tick-borne diseases (Marufu *et al.,* 2009) making them suitable for rearing in the disease-endemic communal rangelands of South Africa. Skin hypersensitivity, avoidance behaviour, and increased grooming may also contribute to increased resistance of the Nguni breed to ticks (Mattioli *et al.,* 2000). It is envisaged that by exploiting their innate and acquired resistance against ticks and tick borne diseases, indigenous cattle can be reared with minimal tick control (Minjauw and McLeod, 2003). Tick infestation has, therefore, the potential to be a trait for selection, and *in-situ* conservation of the breed is justified.The Nguni cattle are multipurpose animals. They are used for milk and meat production, draft power, sale and various cultural purposes (Palmer and Ainslie, 2006). The comparatively docile nature of this breed allow bulls to be used in a ñspanò or team for draft and still have good quality meat (Bayer *et al.,* 2004). This docile nature of the Nguni needs to be conserved as other reports noted higher temperament values compared to Bonsmara, Afrikaner, Jersey, Friesland, Simmental and Hereford (Nekhofhe, 2002).These desirable characteristics have resulted in several Nguni cattle breeding programmes.

In 2004, the University of Fort Hare (UFH) conceptualized the Nguni Cattle Programme to enhance the Bull Scheme, empower communal and small-scale enterprises with livestock production skills, and enact community-based *in-situ* conservation of animal genetic resources in the Eastern Cape Province (Raats *et al.,* 2004). The programme involves establishing a nucleus herd in communal and small-scale enterprises composed of 10 in-calf heifers and two bulls. The enterprises are expected to give back the same number of animals after five years (Raats *et al.,* 2004). The concept was later adopted and enhanced in other provinces across the country after 2006 (IDC, 2010). This interest in the Nguni cattle breed is because of the need to have a breed that can survive under resource-limited conditions which characterise most developing countries.

In most developing countries, breed conservation such as the above-mentioned programme is secondary because of the need to initially satisfy subsistence farming thereby necessitating enabling policies (Wollny, 2003; Mavule *et al*., 2913 Tada *et al.,* 2013b). The following conclusions were drawn from a study by Tada (2012) in the Eastern Cape Province;

- The agriculture production system of the enterprises was livestock-oriented, characterized with mature and elderly farmers, pensioners and formal and/or informally trained in animal husbandry. These farmers perceived the low-input Nguni cattle *in-situ* conservation production system as profitable. The perceived monetary values of breeding animals were consistent with standard auction prices of the Nguni breed animals. Community gatherings and cattle sale pens/auctions were the common marketing options and promoting such enabling policies is seen as a way to sustainably manage the indigenous cattle genetic resources.

- After a period of three to five years, the total herd size increased by 2 - 3 times the initial herd size. Mortality rate was a major concern as breeding stock was mainly affected. Reproductive efficiency was within acceptable breed standards. Communal enterprises were not satisfied with the reproductive performance of Nguni cattle because of poor nutrition because there was not enough grazing land.

- The enterprise herd structure was depended on enterprise ownership pattern. The bulling rates were high and proportion of breeding females was acceptably low. Enterprise $N_e$were very low (below 20) while æF were high (around 6%). According to FAO/UNEP guidelines, the Nguni breed under communal low-input enterprises was classified as endangered-maintained with 74% of pure breed.

- Although enterprise ownership and demographic factors had significant effects on trait preference, generally the preferential traits for breeding bulls were in the order; aggression and mating behaviour, tick and disease resistance, body condition score, scrotal circumference, body size and conformation and coat colour. Preferential traits for breeding cows were in the order; tick and disease resistance, reproductive efficiency, body condition score, body size and conformation, coat colour and milk yield.

- Results of a CE (choice experiment) indicated that farmers opt for cheaper animals with the most favourable attributes. Farmers indicated high economic weight on reproductive efficiency of the breeding animals followed by the adaptive characteristics. The enterprise ownership pattern and socio-economic factors of farmers influenced the economic weights of the breeding trait levels to a less extent. The farmers were willing to pay competitive prices for a breeding animal with trait level of high economic weight.

- The farmers managed to deduce an ñeconomic weight-dependent culling methodò (EWCM) for each category of the breeding animal using data and information on monetary value of breeding animals, preferential traits, choice experiment and focus group discussions. A two-tier open nucleus mating strategy with bull exchange and/or culling after 2.5years, objective performance assessment using records sheets, and culling of unproductive breeding cows was the direction of cattle management postulated by the farmers. Furthermore, a two-tier open nucleus breeding programme was proposed (Figure 2.1):

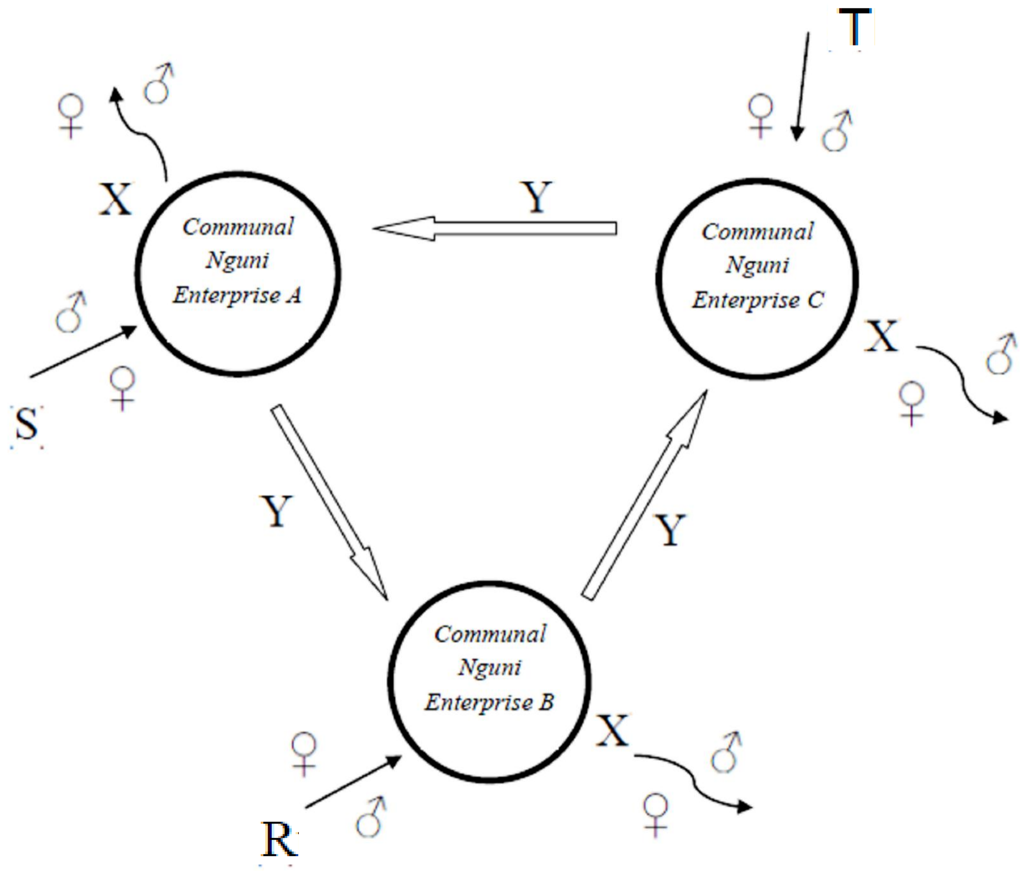


Figure 2.1: Schematic representation of the two-tier open nucleus breeding scheme for the communal Nguni cattle enterprises (Tada, 2012).

> Enterprise exits include; Productive breeding bulls (Y),Infertile heifers, cull cows and unproductive breeding bulls (X), Enterprise entries include; Productive breeding bulls and cows and heifers from genetically distant commercial stud herds (R, S, T *e.t.c*), and Proven animals from other enterprises (Y).

Such programmes are important because, in the rural areas of South Africa, the indigenous cattle breeds constitute about 50% of the total cattle population (Mapiye *et al.*, 2009). In these herds, the grazing system necessitates a common practice of random mating whereby socio-cultural interactions result in a single bull being retained for at least 10 years (Ndebele *et al.,* 2007). Random mating can compromise productivity and genetic variability, thus increasing the inbreeding rate and production of non-descript genotypes/strains (Santana *et al.,* 2010; Tada *et al*., 2013a). The low productivity results in farmers achieving low monetary returns from the cattle enterprises (Tada *et al*., 2012). This is mainly because of high mortality rates, low slaughter weights, ticks and diseases, and low reproductivity expressed through older age at first calving and longer calving intervals (Ndlovu *et al*., 2007; Nqeno *et al.,* 2010). Cattle breeding decisions in the rural areas are seldom made by the person doing day-to-day husbandry activities (Ainslie, 2005). Coupled with lack of animal performance records in these low-input low-output production systems, selection and culling of breeding stock are difficult as consultations with the cattle owner are necessary. Some farmers do not even have a breeding bull and rely on neighbours; this implies they do not have control over the genetic material of their stock (Scholtz *et al*., 2008). Currently, a few institutions are committed to promoting and conserving the low-input indigenous Nguni cattle as a strategy for alleviating protein deficiencies, generating income and sustainably managing the environment (Raats *et al.,* 2004).

Over the years, several studies have been conducted on the reproductive performance (Nqeno *et al.*, 2010; Maciel *et al*., 2012; Tada *et al*., 2013c), adaptation to parasites and low input production conditions (Muchenje *et al.*, 2008a,b; Ndlovu *et al*., 2009a,b; Marufu, 2009), breeding characteristics (Scholtz and Theussen, 2012, Tada *et al*., 2012; 2013a, b) and the quality of meat from the Nguni cattle under different conditions (Muchenje *et al*., 2008b; 2009a,b; 2010; Mapiye *et al*., 2009; Strydom, 2008; Strydom *et al*., 2000; 2001; Frylinck *et al*., 2013). From work done on Nguni cattle, several research activities in meat science have evolved. This includes the work on utilisation of plant materials such as *Acacia karroo* and *Moringa oleifera* to improve the quality of meat in different livestock species under different animal production systems (Mapiye *et al*., 2009; Marume *et al*., 2012; Moyo *et al*., 2011; 2012a,b; Xazela *et al*.,, 2012; Qwele *et al*., 2013a,b; Nkukwana, 2012; Nkukwana *et al*., 2013). However, most of the work focused on the relationship between animal welfare and meat quality. Aspects covered included consumersô and farmersô perceptions on animal welfare and meat quality; and biochemical, behavioural and physiological processes which affect animal welfare and meat quality under commercial practices.

3. Pre-slaughter animal welfare and meat quality

Animal welfare encompasses five freedoms; namely freedom from hunger and thirst; freedom from discomfort, pain, injury or disease; freedom to express normal behaviour and the freedom from fear and distress (Fitzpatrick *et al*., 2006). These freedoms are often violated because in all succeeding events prior to slaughter, animals are exposed to physical and psychological stimuli stressors through either human-animal or animal-animal interactions. These events include handling, loading, transportation, waiting in the lairage and feed deprivation, gastro-intestinal infection, crowding, noise, stocking density, poor handling facilities, agitation, bullying by others and extremes temperatures (Kadim *et al*., 2009; Miranda-de la Lama *et al*., 2010). Although animals may be adapted to the harsh environment during their lifetime at the farm, these procedures pose a major challenge on their welfare and subsequently the quality of meat available to the consumer (Kadim *et al*., 2006).

Many researchers have assessed stress through physiological measures related to changes in hormonal levels, blood chemistry as well as behavioural reactions (Kadim *et al*., 2006; Muchenje *et al*., 2009a). Although pre-slaughter stress responsiveness is influenced by the animalôs previous experience and specific features at the time of observation (Muchenje *et al*., 2009b), the welfare status of the animals also depends on breed, age of the animal, sex and health status. Improper handling of animals during and prior to slaughter results in stress and depletion of muscle glycogen, which negatively affects meat quality attributes such as juiciness, colour, flavour and tenderness (Gregory, 2008; Muchenje *et al*., 2009b).

3.1 Phases of animal handling

The activities and processes that occur from the farm until the animal is slaughtered make up the logistic chain. A logistic chain encompasses successive steps that comprise processes in a particular environment or industry (Miranda-de la Lama *et al.,* 2009; Gregory, 2010; Strappini *et al.,* 2010). According to Miranda-de la Lama *et al*. (2010), ruminant animals are reared widely under traditional extensive production where resources are limited. Therefore animal handling prior to slaughter by humans has important welfare implications on the host animal and the resulting meat product thereafter (Figure 3.1). This process is thus influenced by both interaction between the animal and the stockpersonnel, given the fact that before slaughter there should be handling of animals by farm personnel, haulier and abattoir staff.

3.2 Farm personnel

Preparation of animals for transportation to the abattoir involves events like animal collection, feeding, classification of animals and counting the stock which constitute farm activities (Gade, 2004). Animals reared extensively having lesser contact with humans; therefore they should be brought together in one place. In addition, some animals are identified for fattening, weighing and body condition scoring depending on the motive behind the activity. For example, in a food competition may result in too much activity before slaughter leading to hyper activity. In steers, higher reactivity due to humans resulted in higher serum cortisol scores at exsanguinations (Deiss *et al.,* 2009). In contrast, animals that do not fear humans usually have lower heart rates during loading and unloading. They also have fewer incidents of slipping and falling at the abattoir (Terlouw *et al.,* 2008). This implies that human contact is an important aspect in reducing fear in animals (Jago *et al.*, 1999).

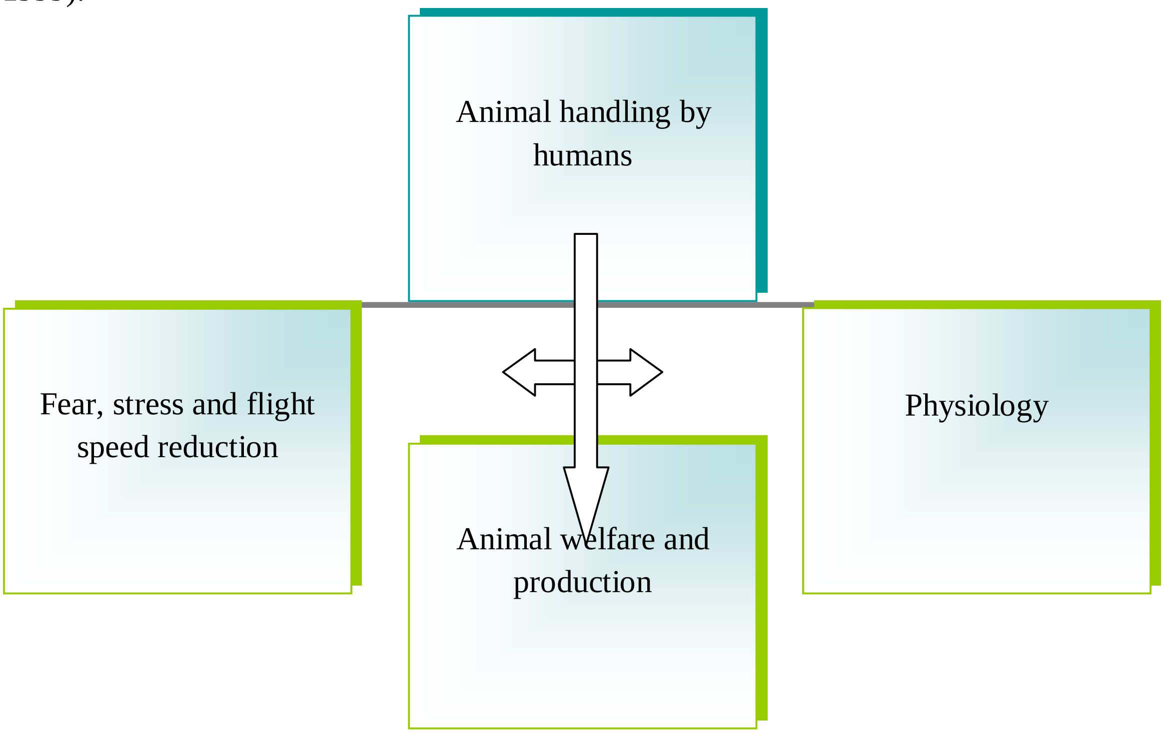


Figure 3. 1 Effect of rough handling imposed to animals (Hemsworth and Coleman, 1998; Grandin, 2006).

3.3 Haulier and abattoir staff

Haulier includes activities such as loading, transport and off-loading. Loading is a complex process that needs critical attention. Loading and transportation factors that occur at the farm up to the abattoir may differ depending on how the animals are sold. According to Strappini *et al.* (2010), other animals such as cattle are sold and transported from the farm to the slaughter plant. Loading can be stressful to the animals (Grandin, 2006). During transportation, animals can be negatively affected physiologically and physically. This consequently depletes their muscle glycogen leading to high ultimate pH (pH_u) and dark firm dry (DFD) meat. Due to its dark $pH_{u,}$ DFD meat is susceptible to bacteria (Vergara & Gallego, 2000; Genaro, Miranda de-la Lama, Monge, Villarroel, Olleta, García-Belenguer *et al.,* 2011).

Abattoir staff is responsible for moving animals to the lairage, resting them and also moving to the stunning box (Gade, 2004). During the movement of animals to the stunning box and slaughter area, rough handling and violent impact of animals against sharp-edged surfaces may occur. This causes damage to the animal tissues that can even develop into bruises (Strappini *et al.*, 2010).

3.4 Logistic chain on animal physiology

Few developed countries use semi to intensive animal production systems. In extensive production, animals seem to have dominance over the others with respect to priority to resources. This phenomenon is mostly high when there are limited resources such as feeding system, water and spacing prior to transportation. This process has been found to reduce the loading procedures. Animals that grow in the veld, harsh and arid environments usually have better quality meat than those growing indoors. This is due to the fact that they consume a lot of green grass which affect their meat quality and that their muscles are always exercising (Martinezo-Cerezo *et al.,* 2005). However, according to Kadim *et al.* (2008), temperatures higher than 32^0C reduce the reserves of glycogen and also lead to darker meat. In addition, the physiology of animal is also affected, including reduction in economic returns. Utilisation of energy is reduced due to heat stress, resulting in high water holding capacity and ultimately, dark meat (Gregory, 2010). Therefore, pre-slaughter logistics chain effects should be evaluated in order to reduce the usage of energy by animals trying to avoid the occurrence of injuries and bruises.

4. Meat Supply chain and bruises

The meat supply chain is an important aspect in the farming and meat industry; and it includes various critical stages such as transportation, (un) loading and slaughter of the animals (Ljunberg *et al.*, 2007; Tadich *et al.*, 2009). Many farmers have developed intermediate stages within this chain, thus making the process dynamic and often complicated. In South Africa, cattle are marketed through a number of channels, with selling through butcheries, auctions and abattoirs playing a leading role (Musemwa *et al.*, 2008). The use of auction markets, holding farms or feedlots often exposes the animals to stressful conditions and a breach to animal welfare standards (Jarvis *et al*., 1996; Geesink *et al*., 2001; Wright *et al*., 2002; Ferguson & Warner, 2008), often resulting in bruises (Strappini *et al*., 2010). The South African meat industry is serviced by slaughterhouses of various classes with low throughput/smallholder abattoirs playing a significant role. Information from smallholder abattoirs regarding effects of marketing channel and transportation mode on bruising and meat quality is limited.

The distribution of bruises and their frequency in certain sites is mainly indicative of transport, (un) loading and lairage practices since these are more likely to harm animals

(Grandin, 1991; Jago *et al*., 1996). Vimiso and Muchenje (2013) reported that marketing channels or transportation methods have effects on bruising, ultimate meat pH and colour in cattle. In that study cattle that passed through the market had a bruise prevalence of 63.1% while those transported directly from the farm had a bruise prevalence of 51.1% and those that walked to the abattoir had a bruise prevalence of 41.1% (Table 4.1).

Table 4. 1: Distribution of bruise age in cattle that walked to the abattoir, those transported straight to the abattoir and the ones sold through auctions.

	Walk	Straight to abattoir	Via auctions
Bruise Age	%	%	%
< 10 hours	7.69	65.55	72.34
10- 24 hours	29.32	31.71	27.66
24-38 hours	30.77	2.44	0
+ 72 hours	32.31	0	0

Source: Vimiso and Muchenje (2013).

Information on bruising is important to the meat industry because transportation of animals may vary depending on the source of the animals. In South Africa, cattle that are sold at auction markets can either be transported straight to the slaughterhouse for slaughter or they can be taken to farms or feedlots where they are held before release for slaughter (Coetzee *et al*., 2004; Musemwa *et al.*, 2008; Vimiso and Muchenje, 2013). It suffices to note that various transportation methods impacts different degrees of bruising. Findings by McNally and Warriss (1996); Weeks *et al*. (2002) showed higher bruises in cattle sourced directly from the auction markets than in cattle sourced directly from the farm. Eldridge *et al*. (1984) also reported that cattle transported directly from a farm to a slaughterhouse had significantly smaller and fewer bruises than cattle sourced through a livestock market. Contrary to these findings, Horder *et al*. (1982) reported no significant difference between the bruise scores of animals slaughtered after transport direct from farms and those from livestock markets, although bruise distribution was different.

Bruised cattle are stressed and are expected to produce meat with abnormally high pH because of glycogen depletion and the subsequent low production of lactic acid in the muscles (Kannan *et al*., 2002). High pH favours microbial growth, development of DFD beef and reduction of shelf life of meat (Chambers *et al*., 2004). Beef with pH_u above 6.0 presents with many quality problems such as dark red colour, toughness, increased water holding capacity and poor palatability (Apple *et al.,* 2005; Mounier *et al*., 2006; Muchenje *et al*., 2009b).

4.1 Impact of bruises on meat quality

A bruise is an injury that does not break the skin but results in some discolouration on the muscle. Bruises reduce the quality and quantity of meat (Von Borrel, 2001). According to Jarvis, Selkirk and Cockram (1995), bruises also lead to economic losses in the meat industry. They usually occur during loading, transportation, in the lairages, during handling and stunning (Gregory, 2008; Vimiso and Muchenje, 2013). The occurrence of injuries in extensive systems seems to be greater than in intensive systems (Goddard *et al.,* 2006). This implies that improper welfare of animal is greater in extensive systems than in intensive systems. This could be due to the fact that in intensive systems, animals are housed and are taken care. Bruises may not be easily observed in sheep, and there is a possibility of using creatine kinase levels in blood as indicators of bruising in sheep.

4.2 The potential use of creatine kinase levels as an indicator of bruising and stress in animals

Creatine kinase is an enzyme used to show the response of animals to stress caused by transportation, handling, loading and off-loading. The enzyme is a member of phosphoryl transfer enzymes usually called guanidine or phosphagen kinases (Braun *et al*., 2008) which is important in the homeostasis of Adenosine Tri-Phosphate (ATP) (Bertin *et al.,* 2007). Adenosine Tri-Phosphate is the primary source of energy in living organisms and it is also found in tissues especially in cardiac and skeletal muscles (Figure 3), brain, retina and primitive-type spermatozoa (Grzyb and Skorkowski, 2005). Poor handling and long hours of transportation result in the breaking of muscle fibres (Grzyb and Skorkowski, 2005). Creatine kinase is therefore used to indicate cellular injury, heart and liver damage (Zhang *et al*., 2010). Pre-slaughter, muscular activity and damage is severe due to transportation and handling. This increases the CK levels in the blood (Kannan *et al*., 2003). In addition, when animals are transported for more than 6 hours, CK activity increases (Kannan *et al.,* 2007). In goats, higher levels of CK in the plasma may also be caused by breed temperament, excitability and fighting against each other (Grzyb and Skorkowski, 2005).

Enzymes [Creatine kinase (CK), alanine aminotransferase (ALT) and aspartate transminase (AST)] are deposited to the bloodstream because of stress caused by bruises (Radostits *et al.,* 2000). Kannan *et al.* (2003) found that if goats were transported for more than 2 hours, deposition of CK in the blood stream is high. Therefore, CK activity and its circulation in the blood become elevated because of long hours of transportation. In addition, vigorous handling, loading, herding and unloading procedures can also damage muscles (Yu *et al.,* 2009). Adenkola and Ayo (2010) reported that in sheep, loading, herding and rough handling resulted in increased CK`s.

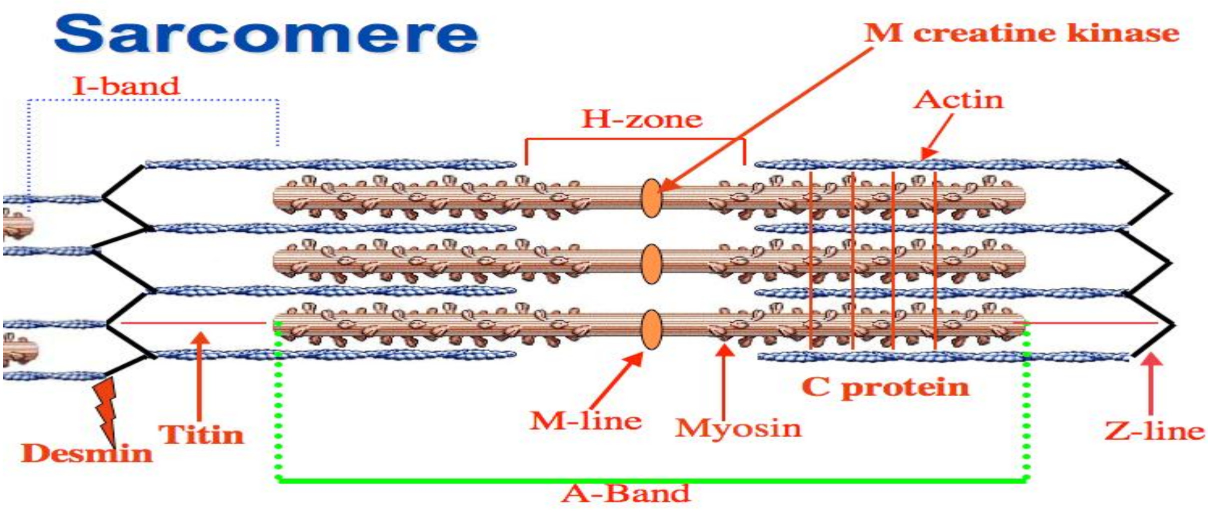


Figure 4. 1 Sarcomere lengths showing the muscle creatine kinase in the M-line of the H-zone (www.google.com/structure_of_the_sarcomere_length).

5.1 Pre-slaughter stress and ultimate pH of meat

As soon as an animal is slaughtered, its muscles are converted to meat through a number of successive metabolic and structural processes that occur at cellular level *post-mortem*. Changes that occur in the muscle *post-mortem* can be determined by measuring the level of pH and temperature of any given carcass (Deiss *et al.,* 2009). Muscle glycogen is broken down to glucose which will then is subsequently metabolised through anaerobic glycolysis (Maltin *et al*., 2003; Muchenje *et al*., 2009), generating lactate acid that will finally accumulate in the muscles thus in turn lowers muscle intracellular pH. This process occurs over a period of time during the slaughtering procedure until the muscle pH finally reaches a range of between 5.4-5.7. According to Maltin *et al.* (2003), the rate of fall of pH has an impact on the eating quality of meat, although the processes involved are complex as reported in recent studies (England *et al*., 2013; Schaefer *et al*., 2007; 2011). Another recent report of controversy surrounding this process is the concept of mitochondrial ótreasonô (Hudson, 2012).

A high ultimate pH is generally indicative of stress in animals (Dhanda *et al*., 2003; Muchenje *et al*., 2009a). It may be as a result of long periods of transportation, rough handling, inclement temperatures, or anything that causes the animal to draw on its glycogen reserves before slaughter (Warriss, 1998Minka and Ayo, 2007; Fergusson and Warner, 2008 Fergusson and Warner, 2008). Stocking density among laden animals is also an important factor in meat quality and literature shows that it has an effect on bruising, with commonly used stocking densities ranging from low, medium to high. High stocking density has more undesirable effects on meat than low or medium stocking density with more degree of bruising occurring during transportation with high densities (Gajana *et al*., 2013; Muchenje and Ndou, 2012). The high bruise scores at encountered at high stocking densities are due to the fact that when animals go down, they are trampled on the floor by others. At high stocking densities, the room to move is limited and the animals fail to adopt their preferred standing positions.

Nutritional stress that occur during cattle auctions can result in dehydration, electrolyte imbalances, negative energy balance, glycogen depletion in muscle, and catabolism of protein and fat, ultimately increasing the pHu (Dhanda *et al*., 2003). It has been established by many authors that muscle colour is highly correlated with muscle pH (Page *et al*., 2001; Muchenje *et al*., 2008). Page *et al*. (2001) reported that a*and b* values were more highly correlated with muscle pH (r = -0.58 and -0.56, respectively) than L* values (r = - 0.40), and Muchenje *et al*. (2008b) also reported weak correlations between pH_u and L* values.

Meat quality attributes such as ultimate pH (pH_u) and colour affect its acceptability/consumption by the consumers (Simela, 2005). Conditions that occur prior and post-slaughter from the farm to the abattoir are to blame for these processes. They result in an increase or decrease on meat ultimate pH depending on the level of glycogen breakdown and lactic acid accumulation in the muscle. Levels of pH affect the formation of bonds between the myosin heads and actin and which will then determine meat tenderness (Toohey and Hopkins, 2006). All in all, levels of muscle pH affect meat attributes such as colour, tenderness and cooking loss (Muchenje *et al*., 2008b; 2009a, b; Muchenje and Ndou, 2012).

5.2. Colour and beef quality

Colour is one of the most important factors considered by consumer when selecting and making decision to purchase meat and meat products. This due to the fact that colour is the first quality attribute seen by the consumer and is an indicator of freshness and wholesomeness (Muchenje *et al*., 2009b; Muchenje and Ndou; 2012; Troy and Kerry, 2010; Rani, 2012). Colour of meat depends upon several individual factors and interactions between these factors. Differences in meat colour have been associated with variations in intramuscular fat and moisture content, age dependent changes in muscle myoglobin content and the pHu of the muscle (Muchenje *et al*., 2008b). Myoglobin is the basic pigment in fresh meat and its content varies with production factors such as species, animal age, sex, feeding system, type of muscle and muscular activity. Myoglobin is purplish in colour, is fixed in the tissues and is responsible for the majority of the red colour in meat. Haemoglobin a pigment that occurs in red blood cells circulation accounts for the remaining colour of meat (Priolo *et al*., 2001). Pre-slaughter activities such as handling, transportation, loading and unloading can deplete muscle glycogen resulting in poor *post mortem* lactic acid production which results in dark red coloured (DFD) meat. It is then important for meat traders or scientists to determine the colour of meat since meat colour can be used to predict its eating quality.

6. Events at slaughter and meat quality

Most startling events that many livestock experience prior to slaughter include sudden changes in their social and physical environment (Hemsworth and Coleman, 1998). Manipulation of environments by humans will therefore be a cause of stress at slaughter (Figure 6.1; Terlouw, 2005). Naturally most animals often perceive contact with human beings as predators (Veissier *et al*., 2012). Thus negative or aversive handling experiences can lead to higher levels of fear (psychological stress), and hormonal stress reactions with adverse effects on performance and welfare of the host animal (Rushen *et al*., 1999; Dodzi and Muchenje, 2011; Njisane and Muchenje, 2013a). Aversive handling may also increase the risks of injuries to the handler and the animal if the animal reacts in an unexpected or aggressive manner, while on other hand positive handling might improve the welfare of the animal (Lensink *et al*., 2001).

Animal behavioural changes are used as indicators to prove that an animal is having challenges in coping with the external and internal environment (Broom, 2003). Behavioural measurements are usually adaptive responses to the environment and they include events such as flight, aggression, immobilisation, exploration, etc. (Terlouw, 2005). This is as a result of change of the familiar environment, disruption of the social group or presence of non-familiar individuals (Terlouw, 2005). Negative handling and fear of humans have a number of undesirable consequences for livestock, farmers and finally the consumers (Dodzi and Muchenje, 2011). The sudden, intense or prolonged elicitation of fear can seriously damage the welfare, productivity, product quality (which includes meat colour, pH, temperature, and tenderness) and profitability of farm animals. Behaviour of animals before slaughter has a huge effect on blood loss at exsanguination and ultimately the quality of meat produced (Ferguson and Warner, 2008). Behavioural variables are affected by several factors such as animal characteristics and these include sex of the animal, weight, age, and breed (Njisane and Muchenje, 2013).

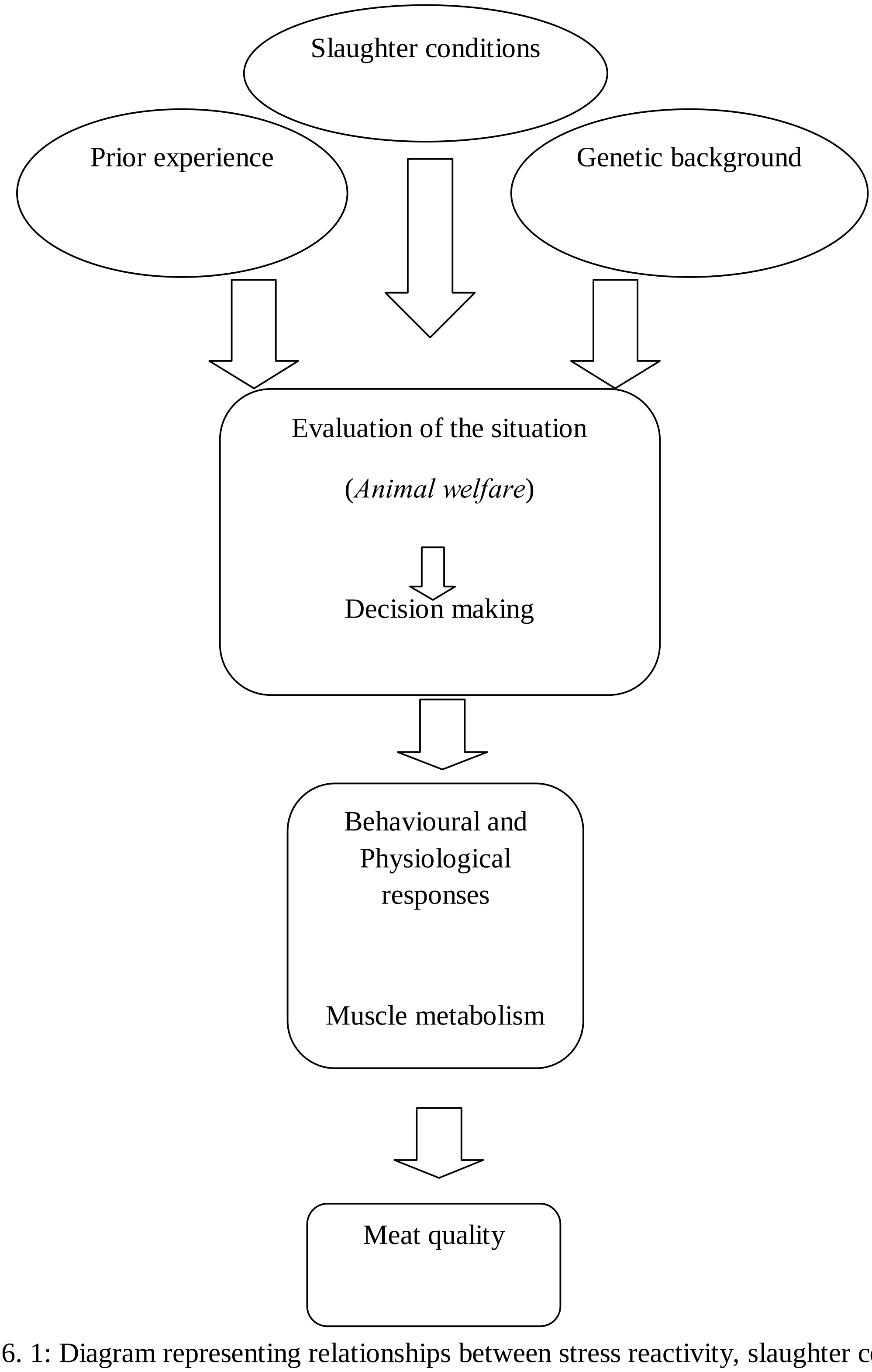


Figure 6. 1: Diagram representing relationships between stress reactivity, slaughter conditions and meat quality (Terlouw, 2005).

A rapid rate of blood loss during the slaughter process is important for a number of reasons. These reasons includes minimising the occurrence of ecchymosis (Gregory, 2008), as well as improving the quality of meat. Therefore, as much blood as possible has to be removed from the carcass *post mortem*. One of such processes is electrical stunning which increases the amount of blood lost at sticking and the muscle spasms that occur upon stunning and/or the spasmodic leg and body movements after sticking may also aid in expulsion of some blood from the muscles (Gregory, 2005). Physical activity and stress before slaughter have a detrimental effect on bleeding at exsanguination (Njisane and Muchenje, 2013). This then has an effect on the quality of the end product, which is meat itself. There are also other factors which affect the above processes and level of abattoir mechanisation is one of them (Njisane and Muchenje, 2013).

6.1 Abattoir classes

There are different types and classes of abattoirs, and the abattoir classifications depend on the type of the species slaughtered, abattoir structure and the management system practised. In spite of these differences, they function under the same standard laws and regulations to ensure a general public health safety environment. One of the laws governing abattoir operations include the Meat Safety Act (No 40 of 2000)-South Africa. There are three major red meat abattoir classes and these are the rural, the low throughput and the high throughput abattoirs (Roberts *et al.*, 2009; Tshabalala, 2011). It has been reported that commercial abattoirs have reliable and sophisticated machinery (Gregory, 2005) while most municipal abattoirs in the rural areas have poor handling facilities (Ndou *et al.*, 2011; Njisane and Muchenje, 2013).

6.2 Previous work on abattoir operations in relation to animal behaviour and meat quality

Most studies conducted in the past were mainly focusing on either behaviour or meat quality and the most considered factor was handling at slaughter. Table 6.1 shows a summary of authors and the work they have done pertaining to abattoir operations in trying to come up with solutions to improve problems that result from slaughter.

Table 6. 1: List of authors and the research they have done on abattoir operations and how they affect animal behaviour and meat production List of authors and the research they have done on abattoir operations and how they affect animal behaviour and meat production

Author	Area worked on
Jago *et al.* (1996)	Risk factors associated with bruising in red deer at a commercial slaughter plant
Chulayo et al. (2012; 2013)	Effects of pre-slaughter sheep handling and animal-related factors on Creatine Kinase levels and physico-chemical attributes of mutton.
Coleman *et al.* (2003)	The relationship between beliefs, attitudes and observed behaviours of abattoir personnel in the pig industry
Gajana et al. (2013)	Effect of pre-slaughter handling on pork quality from a smallholder abattoir
Gispert *et al.* (2000)	A survey of pre-slaughter conditions, halothane gene frequency, and carcass and meat quality in five Spanish pig commercial abattoirs
Terlouw (2005)	Stress reactions at slaughter and meat quality in pigs: genetic background and prior experience: A brief review of recent findings
Kaneene *et al.* (2006)	Abattoir surveillance: The U.S. experience
Ljungberg *et al.* (2007)	Logistics Chain of Animal Transport and Abattoir Operations
Gregory (2008)	Animal welfare at markets and during transport and slaughter
Young *et al.* (2009)	Rest before slaughter ameliorates pre-slaughter stress-induced increased drip loss but not stress-induced increase in the toughness of pork
Bourguet *et al.* (2011)	Behavioural and physiological reactions of cattle in a commercial abattoir: Relationships with organisational aspects of the abattoir and animal characteristics
Vimiso and Muchenje (2013)	Effect of marketing channel on bruising, Ultimate pH and colour of beef, and stakeholder perceptions on the quality of beef from cattle slaughtered at a smallholder abattoir
Njisane and Muchenje (2013)	Sheep behaviour at slaughter, blood loss and how they affect meat quality
Gajana *et al*. (2013)	Effect of transportation conditions on PSE and meat quality.
Chulayo (2011)	Biochemical parameters and meat quality

6.3. Animal avoidance-related behaviour at slaughter and meat quality

The commonly used avoidance behavioural measurement methods include temperament, flight speeds, and vocalizing scoring (Warriss *et al*., 1998). Gregory (2008) reported that the way in which pigs are reared can affect the ease of handling during the slaughter period and the extent to which they have to be encouraged to move. Walking backwards in the corridors is probably best interpreted as an attempt to move away from fear inducing stimuli such as moving humans or light reflections (Grandin, 1996). The process of handling the animals before slaughter evokes a sympatho-adrenal stress response, and this in turn has been shown to have deleterious consequences to the incidence of dark cutting (Ferguson and Warner, 2008). Increased activity, depending on the intensity and duration, leads to changes in muscle metabolite concentration, temperature and pH at slaughter (Warner *et al*., 2005), thus it results in a negative effect on the meat quality (Terlouw, 2005). For example, temperament of cattle and excitement has been shown to reduce meat tenderness (Ferguson and Warner, 2008).

Stressful handling of animals during transfer to the stunner had the largest effect on pHu and on muscle lactate concentration 2ï 3 h *post-mortem* (Hambrecht *et al*., 2005). A proper human-cattle relationship makes handling of cattle easier (Kosako & Imura 1999a, b) and positively influence productivity (Rushen *et al*., 1999; Hemsworth *et al*., 2000; Lensink *et al*. 2000). Exercise and psychological stress just before slaughter increases muscle metabolic activity, which may continue after death, resulting in lower early post-mortem pH (Bourguet *et al.,* 2011). Cattle which have encountered increased stress reactions are associated with a faster pH decline (Bourguet *et al*., 2011). This is because when animals are forced to make strenuous exercise, their muscles are prone to lipid peroxidation metabolites (Gregory, 2008).

6.4 Behaviour scoring at slaughter

The description of some of the behaviour observations and scores are represented in Table 6.2.

Table 6. 2 : Research on behaviour scoring at the abattoir

Author	Species	Variables
Bourguet *et al.* (2011)	Cattle	Backward movement
		Bumping in rear door
		Head lifting
		Kicks
		Head rising
Deiss *et al.* (2009)	Sheep	Locomotion
		High/low pitch bleat
		Distance to humans
		Vigilance
		Social isolation
		Social attractiveness
Probst *et al.* (2012)	Cattle	Backward movement
		Stayed calm
		Forward movement
Stockman *et al.* (2012)	Cattle	Calm, Relaxed, Comfortable, Settled, unphased, placid
		Nervous, Agitated, Scared, avoiding, distressed, panicked, flighty, restless, frustrated

7. Pain and pregnancy quantitation in slaughtered animals

The impacts of the forces aforementioned make the animal to be vulnerable to pain. Nolan (2000) found that animals especially sheep, experience hyperalgesic pain on-farm, during transportation to the lairage, at the lairage and in the process of stunning at the abattoir. During slaughter and before, pain associated with some or all of these stressors obviously violates international welfare standard codes and consequently alters the quality of mutton, lamb or ovine offal (Goddard, 2006). Under practical conditions, during electrical stunning at the abattoir the current passed through the brain causes substantial depolarisation of the neurons resulting in a brain status similar to a grand mal epileptic (Fayemi and Muchenje, 2013c; Terlouw *et al*., 2008). This is because sometimes at the slaughterhouse, electrical stunning might not result in instant death of the animal, but with avoidable tonic or clonic seizures and cardiac fibrillation (Wotton *et al*., 2000). All manners of serious physical post-stunning convulsions, epileptiform activity, groaning, vocalization, increased rate of the *post mortem* muscle glycolysis and elevated release of cathecolamines have been observed (Velarde *et al*., 2003; Gruber *et al*., 2010). Although often ignored, before electro-immobilisation is done on poorly stunned animals certain degrees of pain which compromise the essence of stunning occur and consequently affect the meat-offal quality (Rusen, 1986).

From the animal welfare view point, concerns about the pain these animals (either pregnant or non-pregnant) experience during stunning and slaughter calls for the use of biomarkers for its quantitation. Biomarkers provide a dynamic and powerful approach to understanding the spectrum of neurological conditions with applications in observational clinical trials, screening, diagnosis and prognosis (Fitzpatrick *et al*., 2006). These biomarkers have thus been defined as ña characteristic that objectively measures, evaluates or indicative of normal biologic processes, pathogenic processes or pharmacologic responses to a therapeutic interventionò (Biomarkers Definitions Working Group, 2001). Translational biomarkers have been measured in blood or urine in both experimental animals and man (Fitzpatrick *et al*., 2006; Liu *et al*., 2010; Fayemi and Muchenje, 2013a). Vaidya and Bonvente (2010) therefore gave examples of biomarkers which include proteins, lipids, genomic, metabolomic or signals and cells present on urinarylysis. Likewise, biomarkers have also been used in man to quantify the extent of traumatic brain injury (TBI).The TBI has been defined as an insult to the brain cells caused by an external force that may produce diminished or altered states of consciousness, which results in impaired cognitive abilities or physical functioning (Ghajar, 2000). The Centers for Disease Control and Prevention (CDC) further defined TBI as an injury to the head arising from blunt or penetrating trauma or from acceleration/deceleration forces.

In both cases, these forces are associated with one or more of the following: decreased level of consciousness, amnesia, objective neurologic or neuropsychological abnormality (ies), skull fracture(s), diagnosed intracranial lesion(s), or head injury leading to death (Li *et al*., 2010). Among several biomarkers coding for pain expression, ubiquitin carboxylase terminal hydroxylases (UCH-L1) is one of the most abundant which has been detected as a brain-specific protein, which is present and localised in the neurones and neuroendocrine cells in vertebrates. The brain specificity of this biomarker is responsible for its concentration in the brain to be more than other tissues (Day and Thompson, 2010). In a recent genomic study by Fayemi and Muchenje (2013c), the quantitation of ovine ubiquitin carboxylase terminal hydroxylase (ovUCH L1) in stunned sheep has been identified as a potential pain biomarker when Dohne Merino sheep were subjected to electrical stunning at the abattoir. Habitually, as applicable to Dohne Merinos are subjected to similar stunning and slaughter procedures as applicable to other other meat species. It has thus been suggested that the elicitation of post-stunning behaviours that accompany electrical stunning also requires an integrative approach for explaining the interplays of pathways or processes influencing their behaviours (Gruber *et al*., 2010). A major shift towards genomics in which specific markers are linked with specific attributes, behaviours or experiences has been reported (Papa *et al*., 2008; Fayemi and Muchenje, 2013a, b). This shift leads to further recognition of substances, which appear to be specific to the cells found in the brain that could act as biomarkers (Land, 2002; Fayemi and Muchenje, 2013b).

8. Feeding manipulation and meat quality

8.1. *Acacia karroo* supplementation and meat quality

Over the last century, the amount and proportion of animal fat in human diets have increased in many societies. Excessive fatness is one of the undesirable consequences of selection for increased growth of modern livestock. Meat contains essential fatty acids that cannot be synthesized in the human body. Recent advances in animal nutrition have shown that the essential fatty acid profile in meat can be altered through feeding. Thus through the adoption of appropriate feeding strategies, meat can become a functional food. Feeds from plants that contain tannins produce leaner carcasses and therefore leaner meat (Mokoboki *et al*., 2005; Mapiye *et al*., 2009; 2011b). In developing countries, most legumes used for animal feeding such as leucaena, cow peas acacias are high in tannins, although abundantly available; they are only used to a limited extent for livestock and poultry feeding. The emphasis has been on researching anti-nutritional effects of such feeds and the impact on animal performance. *Acacia karroo*, a condensed tannin-rich, densely populated and widespread tree used for animal feeding (Mokoboki *et al*., 2005) has potential to manipulate meat quality. It is also rich in protein (100-250 g/kg crude protein) and minerals (Mokoboki *et al*., 2005; Mapiye *et al*., 2011b) and has antihelmintic effects (Mapiye *et al*., 2009). Supplement livestock with *A. Karroo* leaves has shown that it can improve beef quality (Mapiye *et al*., 2009; 2010; 2011a) and fatty acids composition (Mapiye *et al*., 2011b). Similar results have been reported in goats (Marume *et al*., 2012; Ngambu *et al.*, 2013). More is still being done on the possible utilisation of *A. karroo* in poultry nutrition.

8.2. Moringa oleifera supplementation studies

Moringa oleifera is a member of the Moringaceae family native of the Indian subcontinent, where its various parts have been utilized throughout history as food and medicine, and is now cultivated and has become naturalizedin many tropical and sub-tropical regions of the world (Makkar and Becker, 1997; Mbikay, 2012).The tender young leaves taste like watercress and, along with the flowers, are eaten or cooked raw as vegetables (Maiga *et al*., 2005).

Moringa oleifera Lam. (Drumstick) of the family Moringaceae has been used as a herbal medicine in treating a wide variety of diseases in India (Fahey, 2005). Leaves of this plant are used as a drug. A number of variables including vitamins and amino acids (Makkar and Becker, 1997) have been identified as contributing to the observed medicinal effects of the plant. Traditionally leaves of this plant are known for or have been reported to possess various biological activities, including cardiovascular action, liver disease and hypocholesterolemic agent (Kumar and Pari, 2003). Other important medicinal properties of the leaves include antioxidant, hepatoprotective, antibacterial and antifungal activities and provides a rich and rare combination of zeatin, quercetin, kaempferom and many other phytochemicals (Kumar and Pari, 2003).

Moringa oleifera leaves also contain a profile of important minerals, and are a good source of essential amino acids, vitamins C, ß-carotene and various phenolics (Bennett *et al*., 2003); and are particularly rich in essential amino acids, including the sulphur-containing amino acids (Moyo *et al*., 2011) with patterns similar to those of soybean seeds (Ferreira *et al*., 2008).The leaves, rich in vitamin A and C, are considered useful in scurvy and respiratory ailments. Existing scientific research show that Moringa leaves to contain more vitamin A than carrots, more calcium than milk, more iron than spinach, more vitamin C than oranges,and more potassium than bananas, and that the proteinquality the rivals that of milk and eggs, while fresh leaves contain6.7% protein (Joshi and Mehta, 2010).

Scientific evidence further show that leaves of this plant, are a vital source of naturally occurring phytochemicals; which for a long time have considered as anti-nutrients, in particular for mono-gastric nutrition, because of its adverse effect of on digestion and nutrient utilisation efficiency. Although, the mechanism underlying their growth enhancing and protective action is not completely understood yet; *M. oleifera* leaves have gained research interest owing to their nutritional profile and acclaimed free radical scavenging and metal chelating activities, as well as their possible beneficial implications in both animal and human health and nutrition.

Lately, following extensive research in monogastric nutrition, plants have been identified to contain bioactive compounds which affects inthree main areas, i.e., gut micro-flora, antioxidant properties, and liver function without compromising intestinal health and/or the birdôs genetic potential (Hernandez *et al*., 2004). One such plant is *M. oleifera*, Lamarck (synonym: *Moringa pterygosperma* Gaertner), also known as horseradish tree in English; it is a small to medium-sized deciduous tree. Comprehensive beneficial effects of bioactive plant substances in animal nutrition include stimulation of appetite and feed intake, improvement of endogenous digestive enzyme secretion, activation of immune response and antibacterial, antiviral, antioxidant and antihelminthic actions (Steiner and Wegleitner, 2007). The ultimate benefit, from this plant, is derived from its positive interaction with the physiological processes of the animalôs body (Maiga *et al*., 2005); modifying the cholesterol metabolism, thus leading to a meat with healthier implications for human consumption (Wallace *et al*., 2010). A regulatory effect on glucose metabolism in rats and humans for the control of conditions such lipedeamia and hyperglycemia that render cells susceptible to oxidation has also been reported (Mbikay, 2012). Collectively, synergies between individual bioactive compounds in *M. oleifera* leaves may be an important feature of their action thereby affecting the physiological and chemical aspects of the digestive tract (Wallace *et al*., 2010; Mbikay, 2012). In many of these plants, however, bioactive compounds many be highly odorous or may taste hot or it might have a pungent smell, thereby restricting their use for animal feeding purposes (Windisch *et al*., 2008).

8.2.1 Use of Moringa oliefera as an antioxidant

Various studies have shown that a number of plant products including polyphenolic substances and various plant or herb extracts exert potent antioxidant actions (Krishnaraju *et* *al*., 2009; Moyo *et al*., 2012; Qwele *et al*., 2013). The natural antioxidants of spices and herbs are generally classified as vitamins, phenols including flavanoids and phenolic acids, and volatile compounds (Sreelatha and Padma, 2009; Joshi *et al*., 2008). Recently, there has been increasing attention in the search of natural antioxidants of plant origin because they can protect the human body from attack by free radicals, and retard the progress of many chronic diseases as well as reducing the lipid-oxidative rancidity in foods. Crude extracts of herbs and spices, and other plant materials rich in phenolics are of increasing interest in the food industry because they retard oxidative degradation of lipids and thereby improve the quality and nutritional value of food.

These natural antioxidants are considered to be safer than the synthetic antioxidants, and have greater application potential for consumerŝs acceptability, palatability, stability and shelf-life of meat products (Jung *et al*., 2010). Antioxidants are critical in maintaining optimal cellular and systemic health and well-being in animals. They are nutrients in foods which can prevent or slow the oxidative damage to animalsô bodies. These nutrients may protect cells against the effects of free radicals which have been reported to be responsible for tissue damage and loss of function in a number of tissues and organs (Kumar and Pari, 2001). Antioxidants help prevent molecular damage caused by free radicals through oxidation; this protection may help fend off many diseases including cancer, cardiovascular diseases, and muscular degeneration.

A few important antioxidant enzymes the animalŝs body naturally produces are superoxide dismutase (SOD), catalase and glutathione peroxidase. However, in order for the body to produce these substances it requires zinc, manganese, copper and selenium (Group, 2009). Likewise, all meat is prone to oxidation. Amongst all meat products, poultry meat is considered to be more prone to the development of oxidative rancidity compared to red meat (Descalzo *et al*., 2007). This is due to higher content of phospholipids in poultry meat. Phospholipids are located in the membrane structure and are rich in poly-unsaturated fatty acids. It has been demonstrated that the oxidation of meat starts by a peroxidation of the phospholipid fraction (Descalzo *et al*., 2007). Due to the high degree of poly-unsaturated lipids the phospholipids are most prone to oxidation. Unsaturation of fatty acids makes lipids susceptible to oxygen attack with negative implications on meat quality and consumer health due to lipid peroxidation (Group, 2009). However, autoxidation of lipids and the production of free radicals are natural processes occurring in biological systems leading to oxidative deterioration, drip loss (Jung *et al*., 2010), colour changes and off-flavours development. The formation of volatile lipid oxidation products strongly reduces the consumersô acceptability of the product (Group, 2009).

Lipid peroxidation is a complex process occurring in aerobic cells; itreflects the interaction between molecular oxygen and polyunsaturated fatty acids via a free radical chain mechanism, forming fatty acyl hydroperoxides, generally called peroxides or primary products of oxidation (Group, 2009). The primary auto-oxidation is followed by a number of secondary reactions which lead to degradation of lipids and the development of oxidative rancidity (Descalzo *et al*., 2007). Lipid peroxidation is one of the primary causes of quality deterioration in meat and meat products, as it largely contributes to colour and flavour deterioration, loss of nutritional value and safety, and generates compounds that may be detrimental to consumers (Krishnaraju *et al*., 2009; Moyo *et al*., 2012; Qwele *et al*., 2013). Antioxidants act as radical-scavengers, and inhibit lipid peroxidation and other free radical-mediated processes: therefore, they are able to protect consumers from several diseases attributed to the reactions of radicals (Krishnaraju *et al*., 2009). Use of synthetic antioxidants to prevent free radical damage has been reported to cause toxic side effects (Krishnaraju *et al*., 2009), making interests in the search for natural antioxidants and scavenger compounds.

On the other hand, herb extracts have an advantage of being more acceptable by consumers and have legal requirements for market access as they are also considered non or less toxic (Moyo *et al*., 2012; Qwele *et al*., 2013).

8.2.2 Studies on the use of *Moringa oliefera* in ruminants and monogastrics

There has been extensive studies on the use of Moringa leaves in goats and its subsequent effects on the growth, meat quality, fatty acid profiles and antioxidant properties. From such studies research has proven that Moringa supplemented goat had meat with the highest phenolic content. Meat samples from goats supplemented with Moringa leaves had the highest DPPH and $ABTS^+$ values which signify the ability of the plantôs bioactive properties to scavenge and neutralize the action of free radicals (Qwele *et al.,* 2013). The effect of antioxidants on DPPH is thought to be due to their hydrogen donating ability. Moringa exhibited proton-donating ability, thereby proving that it could serve as free radical inhibitor or scavenger, translating its use possibly as a primary antioxidant. The observed result obtained in reducing power showed that the meat extract possessed antioxidant activity in a concentration dependent manner. This effect may suggest the ability of Moringa to minimize oxidative damage to some vital tissues in the body (Kojic *et al*., 1998).

Moringa supplemented goats produced chevon with higher lipid oxidation inhibition than those supplemented sunflower cake and hay (Moyo *et al*., 2012; Qwele *et al*., 2013). Likewise meat samples from broilers supplemented with moringa had higher lipid oxidation inhibition properties than the unsupplemented ones. Lipid peroxidation depends upon the degree of unsaturation of the fatty acids and the levels of the antioxidant vitamin E (Ŭ-tocopherol) and prooxidants such as free iron (Descalzo *et al*., 2007). Moringa leaves have been reported to have a high content of vitamin E, which is a chain breaking antioxidants (Jyotsna Mishra *et al*., 2007) that contributes in prevention of meat quality degradation. Lipid peroxidation was shown to be inhibited by *Moringa oleifera* against antitubercular drugs induced lipid peroxidation in rats (Kumar and Pari, 2003).

9. Implications of animal product fatty acid profiles on consumer/human health

There are approximately 400 fatty acids making up most of the predominant triglycerides class (Devle *et al*., 2012). Approximately 70-75% of the total FA are saturated fatty acids (SFA), 20-25% monounsaturated fatty acids (MUFA) and up to 5% polyunsaturated fatty acids (PUFA). Saturated fatty acids are made up of C4-C18 long fatty acids, with Pamitic, myristic and stearic acids making up the largest proportion. Animal based studies indicate the link between increased plasma total low density lipoprotein (LDL) cholesterol concentrations and high intake of lauric, palmitic and myristic acids to the increased risks of CHD (chronic heart diseases) (Williams, 2000). Unsaturated fatty acids are made up of MUFA and PUFA. Oleic acid is the most dominant MUFA with single double bond and has positive implications on human health related to lowering of plasma cholesterol (Haug *et al*., 2007). However, there are two types of PUFA in meat; namely omega-6 and omega-3 FA containing two or more double bonds. The human body cannot synthesis these fatty acids and depends entirely on external source like intake from the diet. The structures of omega-6 and omega-3 FA are depicted in Figure 9.1 below. The metabolism of omega-6 and omega-3 FA and associated enzymes is also shown in Figure 9.2 below. There is need to maintain a balance between supply of LA and ALA as research has indicated that their products have an antagonistic effect on human health (Barceló-Coblijn and Murphy, 2009).

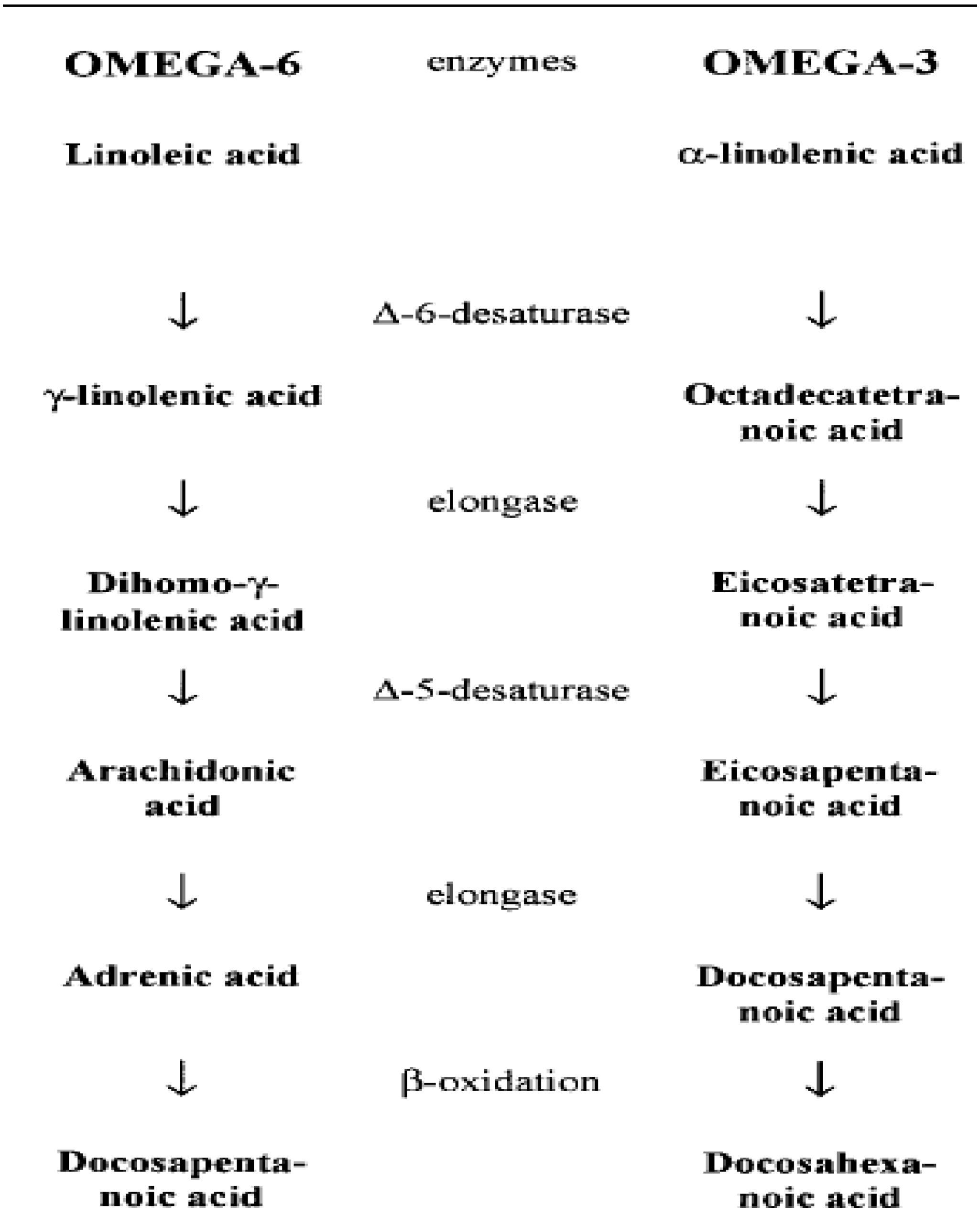
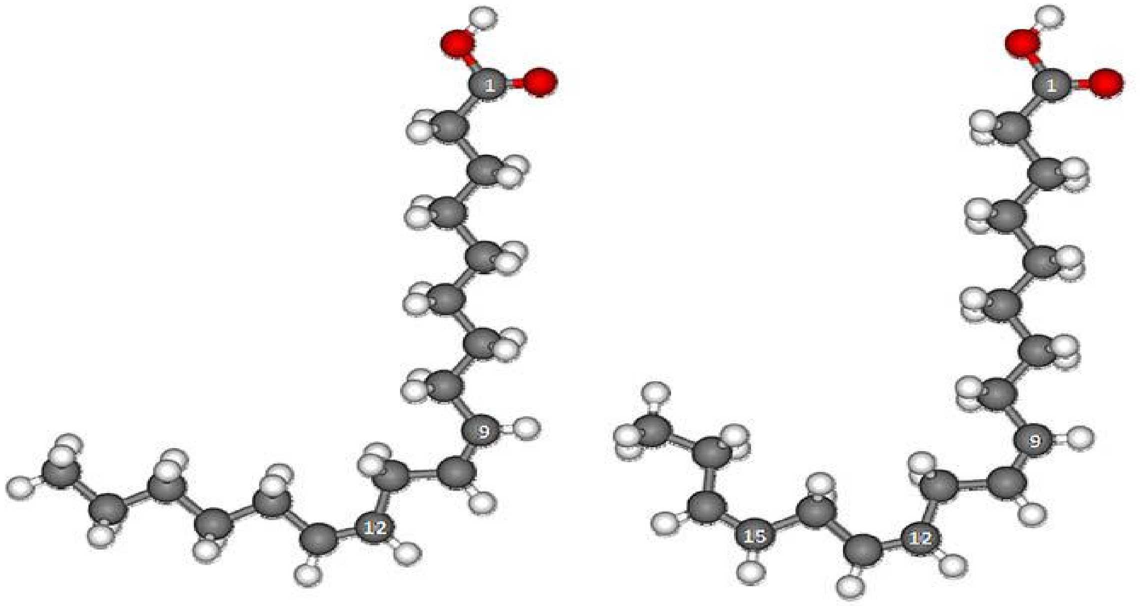


Figure 9.2 Model of the molecular structure of the cis-9, 12, 15-octadecatrienoic acid linolenic acid and the cis-9, 12-octadecadienoic acid or linolenic acid.

Source: Barceló-Coblijn and Murphy (2009)



9,12-octadecadienoic acid or linoleic acid (LNA)

9,12,15-octadecatrienoic acid or linolenic acid (ALA)

Figure 9.2: Pathways for omega-6 and omega- metabolism in ruminant

Source: Williams (2000)

Bioactive omega-6 arachidonic acid derived from LA increase chances CHD and inhibit æ^{6}desaturase enzyme which converts ALA to omega-3 eicosapentaenoic and docosahexaenoic acids (Williams, 2000). These ALA derived eicosanoids are health promoting. However, the ratio between omega-6 and omega-3 fatty acids in meat lipids, compared to milk fat, is of great concern (Garcia *et al*., 2008)..There are as many as 28 geometric and positional isomers of linoleic acid (cis-9, cis-12 octadecadienoic acid) with conjugated double bonds (Collomb *et al*., 2006) constituting <1.00% of total fat fraction of meat in most cases (Woods and Fearon, 2009). Of these, the C18:2 *cis*-9, *trans*-11 CLA (rumenic acid) is the major isomer constituting approximately 78-90% of the total CLA in meat (Muchenje *et al*., 2009b,c). The predominant CLA isomer is derived through the action of æ^{9} desaturase on intermediate vaccenic acid (C18:1 trans-11) (VA) (Figure 9.3). The intermediate is from ruminal biohydrogenation of linoleic and linolenic acid (Collomb *et al*., 2006). This implies that, C18:2*cis*-9, *trans*-11 CLA originates from two sources (Haug *et al*., 2007) and its concentration in meat is governed by VA availability and æ^{9} desaturase activity.

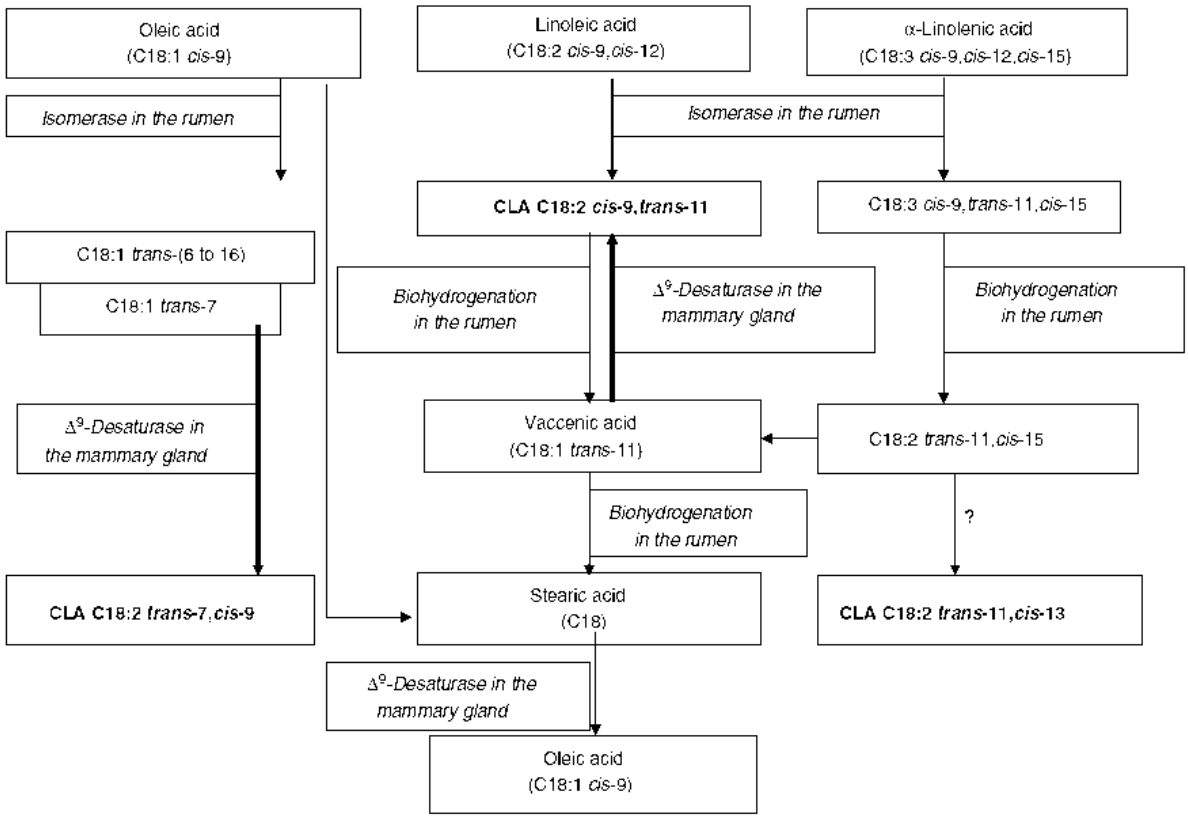


Figure 9.3. Metabolic pathways for formation of CLA isomers

Source: Collomb *et al*.(2006)

9.2 Effect of diet on meat fatty acid composition

It is now commonly accepted that the diet given to an animal has the greatest influence on its meat FA profile (Boland *et al*., 2001; Mapiye *et al*., 2011a; Marume *et al*., 2012). Many authors have indicated that CLA concentration in meatis improved when animals turn from concentrate based diets to fresh pasture (Collomb *et al*., 2006). On the hand, winter pasture and mature forages contain less PUFA especially ALA needed in the formation of CLA as compared to young summer shoots (Sun and Gibbs, 2012). Losses in PUFA during the dry season usually occur as a result of lipolysis and oxidation during wilting and maturation (Heck *et al*., 2009). Age, timing of cutting and species composition of forage sward should be considered in diet formulation as FA variations have been noted and this subsequently has an effect on meat FA profile from any animal consuming the diet at that time (Delscalzo *et al*., 2007). The increase in CLA leads to inhibition of the *de novo* synthesis of short to medium chain fatty acids (Kelly *et al*., 1998).

Another method of manipulating the meat fatty acid composition is through provision of certain marine or plant oils in the ruminant diet. Many oils have been investigated through feeding raw or processed whole seed, protected oils or free oils (Roca Fernandez and Gonzalez Rodriguez, 2012). Woods and Fear on (2009) noted that more ALA and LA was found in bovines diets from processed/protected oils and seeds as they easily release inner oils in the rumen. Increases in meat CLA was noted in animals fed diets containing marine oils. Marine oils are rich in high ALA and LA which act as substrate for CLA synthesis as noted above (Savoini *et al*., 2010).

9.3 Meat fatty acids in health and related ratios and indices

The nutritional quality and value of meat is based upon the concentrations of SFA, *trans* FA, MUFA, PUFA, CLA and cholesterol. Many nutritionists do concur that there is still a need to improve the healthiness of meat and meat products in order to reduce predisposing factors leading to severe chronic diseases. Besides, the above mentioned classes of FA, ratios such as PUFA/SFA are used in comparing and explaining the suitability of foodstuffs and benefits/harmful effects they may impart to the human consumer.

It is now well established that saturated lauric, myristic and palmitic acids and *trans* FA increase plasma low density lipoprotein (LDL). These LDL induce cholesterol synthesis which increases the risks of CHD (Williams, 2000). Contrary to other SFA, stearic acid is not involved in cholesterol build up, but helps in lowering of the concentrations of LDL. Currently, nutritionists recommend reduced intake of total fat and SFA. However, reducing concentrations of SFA at the expense of unsaturated fatty acids lower the oxidative stability of meat and meat products, leading to shorter shelf life (Boland *et al*., 2001).Similar to stearic acid, is the effect of CLA and MUFA, which has been noted for its antiatherogenic, anti-carcinogenic, anti-diabetic and immune stimulatory effects (Williams, 2000; Collomb *et al*., 2006).

There has been concerns towards the use of the *n*-6:*n*-3 in determining the risk of CHD due to its inability to distinguish between ALA and EPA/DHA (Woods and Fear on, 2009). However, researchers concur with the fact that, due to antagonistic effects of *n*-6 and *n*-3, it is important to reduce the ratio to < 4 (Simopoulus, 2002; 2006; Muchenje *et al*., 2009b). This can be achieved through increasing dietary *n*-3 fatty acids intake, while reducing *n*-6 FA

(Woods and Fear on, 2009). Higher values are detrimental and increase chances of autoimmune diseases (Roca Fernandez and Gonzalez Rodriguez, 2012).

Studies have noted a positive association between æ^{9} desaturase activity and CLA in fat (Lock and Garnsworthy, 2003). The æ^{9} desaturase enzyme is responsible for adding *cis* double bond between carbons 9 and 10 and ultimately reducing concentration of saturated fatty acids. This improves the health aspect of meat and meat products (Lock and Garnsworthy, 2003) by reducing cancer and CHD predisposing factors. Other ratios used in highlighting the health value of meat lipids include desaturase activity indices and Atherogenicity index. Desaturase activity indices measure the activity of the æ^{9} desaturase enzyme, ultimately reducing the threat of the saturated fat content. The four indices used are that of myristic acid (C14:0/C14:1), palmitic acid (C16:0/C16:1), stearic acid (C18:0/C18:1) and Rumenic acid/Vaccenic acid. However, the most common desaturase activity indicator in meat is by using C14:1 and C14:0 because all C14:0 in meat fat are produced by de novo synthesis (Tsiplakou *et al*., 2008). Research has shown that low intramuscular fat, especially in young carcasses, is positively related to high desaturase enzyme activity and CLA, which is generally higher in summer grazing animals (Serra *et al*., 2009). This has led to a common practice of intensive rearing and slaughter of young stock for health conscious consumers, since fatty acids detrimental to health are reduced in proportion. The atherogenicity index (AI) is commonly used to describe ratio between saturated and unsaturated FA or atherogenicity of fat (Sojak *et al*., 2012). Lower AI values are beneficial to health (Ulbricht and Southgate, 1991).

10 Meat and People

10.1 The farmer, trader and meat quality

Todayôs consumer and meat trader are also increasingly becoming more concerned about the rearing, handling, transportation and slaughter of meat animals (Appleby & Hughes, 1997). With more consumers and traders becoming concerned with the welfare of slaughter animals, there is scope in studying the perceptions of farmers, meat traders and consumers on welfare of slaughter cattle and how it affects meat quality. Farmer perceptions on slaughter animal welfare are important since these perceptions define producer behaviour and willingness to produce animals with acceptable meat quality (Vimiso *et al*., 2012). The interpretation of the concept of farm animal welfare tends to differ amongst farmers and is influenced by convictions, values, norms, knowledge and interests (Te Velde *et al*., 2002). The above frame work explains why farmers, meat traders and consumers tend to speak different languages when it comes to animal welfare (Vanhonacker *et al*., 2008). Farmersô norms are clearly related to factors important for optimizing production, and the need to make a living (Vanhonacker *et al*., 2008) and this might influence perceptions on animal welfare (Te Velde et al., 2002), while the farmerôs behaviour towards his animals can be modified by factors such as personality and demographic variables (e.g. age, gender, education) (Vimiso *et al*., 2012). Farmers play a crucial role at all the initial stages of the transport chain and perhaps contribute about 80% to the quality of the final product (Smith & Grandin, 1999).

Transport conditions vary according to the way animals are marketed. Cattle can be transported by vehicles directly from the farm or from live auction markets to the abattoir. In many African countries hoofing/walking cattle to smallholder abattoirs is common, especially for distances less than 20 km. Although this transportation mode still exists in the communal areas, road vehicle is slowly replacing it due to long distances and more time it takes to reach the slaughterhouse (Grandin, 2006). Furthermore, cattle in the emerging slaughterhouses are supplied by many small producers/farmers, who are located some distances away and with limited infrastructure, unlike in the established slaughterhouses which are well-equipped (Njisane and Muchenje, 2013). The main issue facing marketing of slaughter cattle through auctions is the perception that it is not conducive to the delivery of high quality beef (Ferguson and Warner, 2008), since cattle are likely to endure longer transport times, a lot of handling through (un) loading and mixing with strange potentially aggressive animals that can cause bruising (Vimiso and Muchenje, 2013).

In the meat chain, a lot of pre and post-slaughter factors influence the intrinsic quality of meat (Rani, 2012; Vimiso *et al*., 2012). At the farm, some of the following factors may influence the intrinsic quality of meat: animal feeding, disease control, the production system (intensive or extensive), and the type of breed the farmer keeps and the age of the animals (Vimiso *et al*., 2012). The type of breed a farmer keeps may influence meat quality through responses to pre-slaughter handling (King *et al*., 2006; Muchenje *et al*., 2009a). Selection for improved temperament can facilitate not only human- animal welfare benefits at handling, but also helps in the reduction in stress mediated losses in bruising and meat quality (Ferguson and Warner, 2008). A farmer has the most influence on handling and transportation strategies that affect meat quality at the end of the production chain. The farmer selects cattle to be sold or to travel and prepares them for transportation. However the most important decision the farmer makes that has a lot of bearing on beef quality is the final destination of the cattle (i.e. journey duration and distance). Smith and Grandin (1999) estimated that 80% of the aspects that contribute to poor meat quality occur before the cattle reach the abattoir.

The perception of the farmer to animal welfare is influenced by many factors, with farmers being more interested in economic and financial issues and the need to make a living. Farmersô wish to supply high quality products and to build a positive image of livestock production may also influence their perceptions on animal welfare. They also spend most of their time with their animals and have some practical knowledge on animal welfare (Vanhonacker *et al*., 2008). Te Velde *et al*. (2002) is of the opinion that farmers have the belief that animals are meant to serve humans and that meat is an important part of peopleôs diet with slaughtering animals for meat being a legitimate process. Farmersô attitudes towards animal welfare may be explained based on three factors: these are place-based, social structural factors and individualsô unique animal-related experiences. With regard to social structural factors, gender, socio-economic class, age and family status influence farmer perceptions on animal welfare. Women are regarded as having a higher concern with animal welfare as compared to men. This could be due to the task of women as primary caretakers, since they are more likely to engage in household tasks that give them more contact with animals, like caring for pets and food preparation (Burrel and Vrieze, 2003).The less educated farmers are considered as having more concern for animals and this is explained by the underdog hypothesis (Vimiso *et al*., 2012). Results that are contrary to the underdog hypothesis were found by Burrel and Vrieze (2003) where highly educated people expressed better concern for animal welfare. With regard to age, it was hypothesized that age is inversely related to the concern for animal welfare and to be related to oneôs life-cycle stage.

According to Vimiso *et al*. (2012), there were differences in meat quality due to marketing channels with cattle transported direct from farms having the highest bruise scores, pH_u and the lowest L* values. There was some general disagreement between meat traders and consumers on the use of quality attributes to predict beef quality. Consumers used the intrinsic cue of colour (for quality) and price to make a purchasing decision while traders used freshness to make a purchasing decision. Farmers perceived animal welfare as affecting meat quality; marketing channel had an effect on beef quality while consumers and meat traders perceived slaughter animal welfare as not affecting meat quality and differed on their perceptions of meat quality (Figures 10.1 and 10.2).

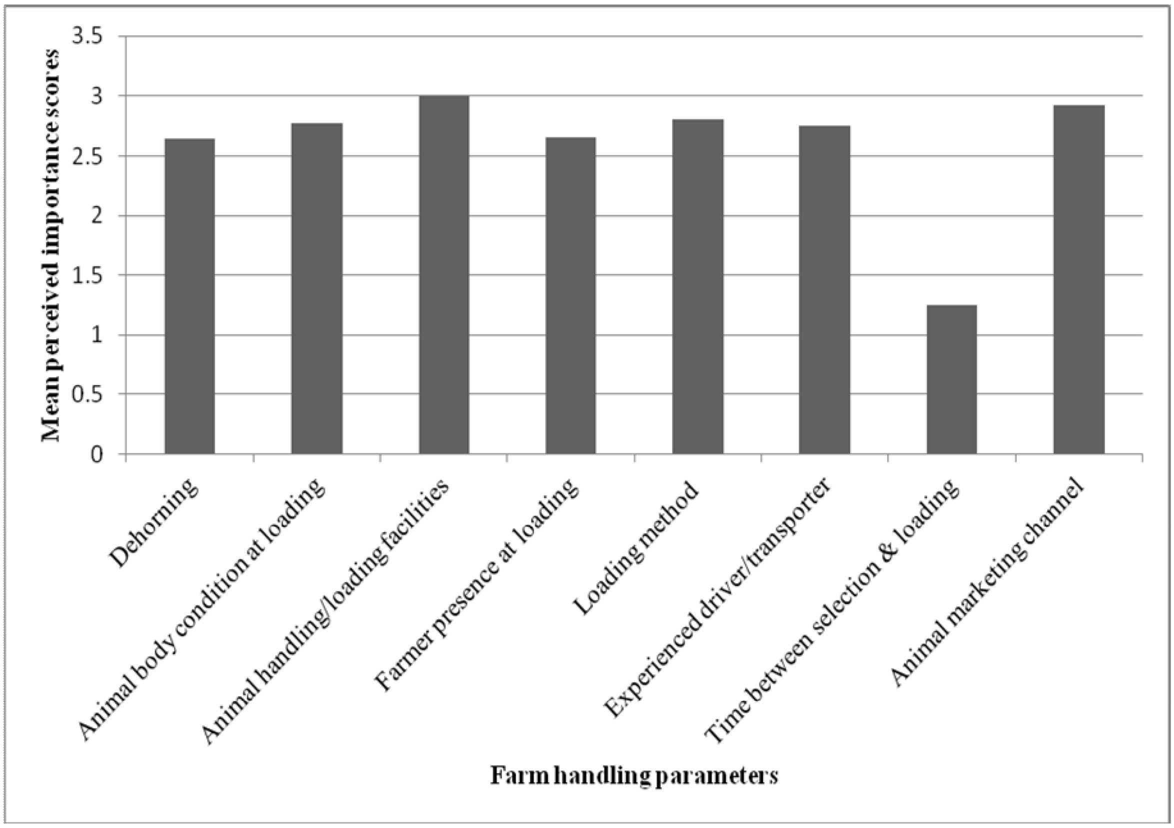


Figure 10. 1: Farmer perceptions on importance of handling of slaughter animals at the farm and their marketing.

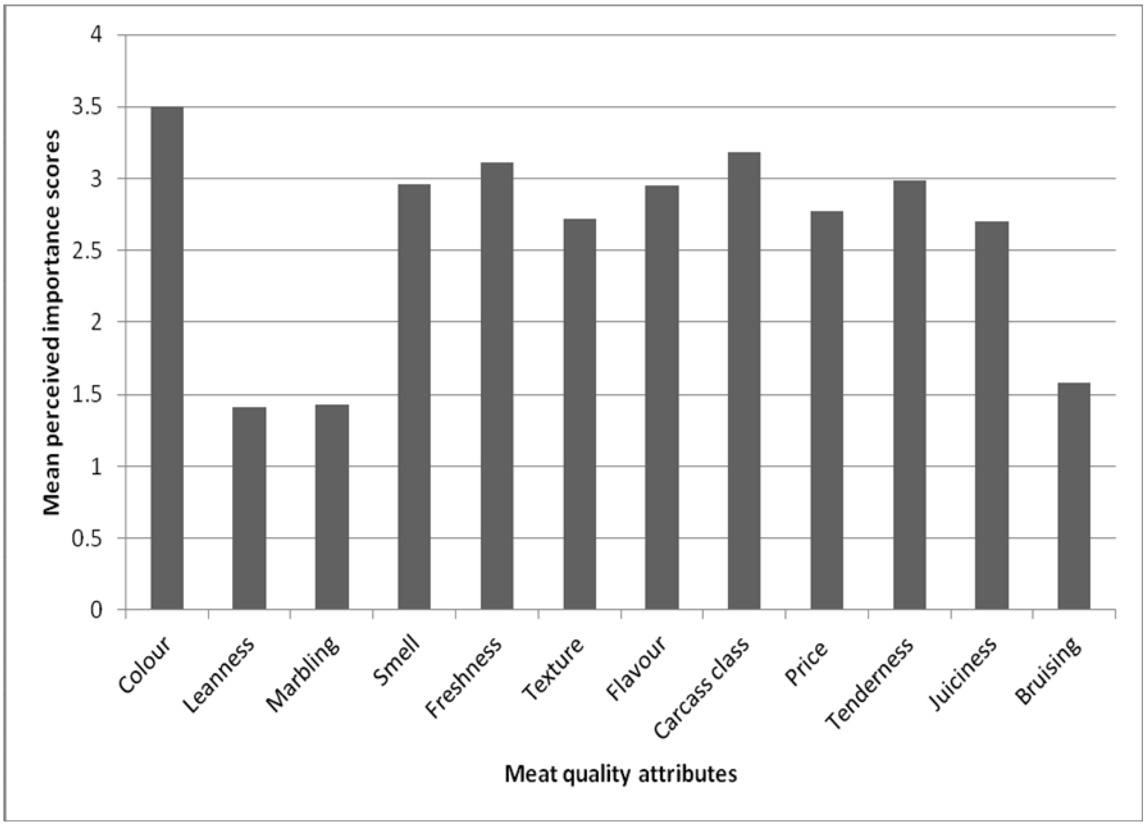


Figure 10. 2 Farmer perceptions on the importance of meat quality attributes.

10.2 Consumers' perceptions of animal welfare

Consumersô perceptions on meat and meat products are critical for the meat industry because they directly impacts on its profitability (Martelli, 2009; Troy & Kerry, 2010). Meat acceptance and purchasing behaviour by consumers is affected by quality variables, such as meat colour, tenderness and flavour, which is more often affected by pH (Muchenje *et al*., 2009b). Therefore, a negative perception of beef by consumers regarding such encounters may result in losses to the meat industry (Muchenje *et al*., 2009a; Vimiso *et al*., 2012). Meat tradersô perception of slaughter animal welfare and meat quality is important since they are responsible for selling the product to the consumer at the end of the chain. A difference in judgment of product quality among farmers, traders and consumers might result in a supply of a wrong product along the chain (Vimiso *et al*., 2012). It is important to know the intrinsic and extrinsic cues that consumers associate with product quality, as farmers and traders should focus their added value activities on those aspects that consumers value as most important (Vimiso *et al*., 2012).

10.3 Consumers' perceptions on meat

The perception of consumers on meat and meat products has a direct impact on the profitability of the meat industry. If consumers have a negative perception of any meat product, their purchasing behaviour will be affected negatively (Troy and Kerry, 2010). Perception is defined as the act of apprehending by means of the senses and/ or the mind.

Perception not only relates to basic senses such as visual, flavour and taste attributes, but also to formed learning or experiences. For consumers to willingly purchase and consume a particular beef product, their perceptions must be positive towards it. Consumersô relates to beef quality in a broad sense (Troy and Kerry, 2010). Various models have been proposed to define food quality (Grunert *et al*., 1996). These models can be related to beef and can distinguish it as a food (safety, nutrition, sensory, ethical) and as an object of trade (certification, price), or as a product before purchase (price, extrinsic quality cues, intrinsic quality cues) and as a product after purchase (beef preparation, after eating experience, sensory characteristics) (Grunert *et al*., 1996). The Total Food Quality Model with respect to meat is described by Grunert *et al*. (2004). In this model, various extrinsic and intrinsic quality cues perceived by the consumer are described. Extrinsic cues are described as those that are not physically part of the meat, (price, and place of slaughter/origin) while intrinsic cues as those that are physically part of the meat (marbling, colour). Consumers base their purchase choices on the perceived quality cues.

10.4 Quality cues

At point of purchase consumers use intrinsic cues: colour, leanness and marbling and extrinsic cues: quality assurance, place of purchase and price (Rani, 2012; Vimiso *et al*., 2012). After purchase, consumers tend to eating quality expectations: tenderness, flavour and juiciness and the correctness of the production process (Grunert *et al*., 2004; Dyubele *et al*., 2010). Consumers prefer a light pink to bright red colour and they will strongly reject dark coloured meat, believing that it is from an old or sick animal or contaminated (Muchenje *et al*., 2009a). Marbling is the visible fat present in the interfascicular spaces of a muscle (Kauffman and Marsh, 1987) and it affects affects flavour, juiciness, tenderness and visual characteristics of meat (Calkins and Hodgen, 2007). Some production factors such as animal breed, slaughter weight, feeding strategy, and growth rate affect marbling and consumer perception at point of sale.

10.5 Importance of quality cues at point of purchase

Background affects how consumers consider certain cues when purchasing meat. Jocumsen (2005) assessed Australian consumersô perceptions on the use of intrinsic and extrinsic cues in predicting the eating quality of beef. Freshness was ranked first while marbling was ranked last. For extrinsic cues, presentation was ranked first and packaging was ranked last. Females rated colour, leanness, marbling, labels and presentation as significantly more helpful in predicting the eating quality of meat as compared to males. In a similar study in Germany (Becker *et al*., 2000), country of origin and place of purchase were ranked as most helpful in assessing beef quality in the shop while smell and leanness were ranked as important eating quality attributes. Grunert (1997) found that consumers in Germany, France, Spain and the UK, perceived fat and place of purchase as crucial quality cues. Contrary to the expected norm where higher prices would mean better quality, this study showed higher prices as having a negative effect on quality expectations. Acebro´n and Dopico (2000) found that Spanish consumers considered light coloured meat, expensive meat and meat packed in trays to be more indicative of quality. Steenkamp and van Trijp (1996) surveyed Dutch consumers and found meat colour, marbling and general appearance as the major quality cues while tenderness was identified as the primary determinant of experienced quality while flavour was insignificant. In recent studies in mostly rural Eastern Cape Province South Africa, Rani (2012) and Vimiso *et al*. (20120 found that consumers considered price as the most critical cue while the farmers and the meat traders considered meat quality and the place where meat was sold as the most critical issues. At the same time an instrumental assessment of meat quality samples obtained at the point of purchase showed that there were no differences in meat obtained from different categories of butcheries/supermarkets (Rani, 2012). These point of purchase studies are also supported by further work on panel (Muchenje *et al*., 2010) and consumer sensory evaluation (Dyubele *et al*., 2010).

11. Research on cooperatives

Poultry is widely acknowledged as the livestock of the poor, and poultry production is part of most smallholder farming systems. The broiler production sector is an industry has one of the most important activities among the livestock sectors. Broiler production within a value chain has the potential to function as a primary industry in the facilitation of empowering small-scale farmers to a level of economic independence. It is an enterprise with a fast turnover; it therefore carries a lower financial risk than other enterprises; and has a strong existing market base. Broiler production dominates the agricultural sector and it is the main supplier in protein compared to all other animal protein sources. Broiler meat is not expensive, well packaged, and are short of religious restrictions against its consumers (Dyubele *et al.,* 2010). Broiler meat production is the largest segment of South African agriculture by 17.5% in 2010. Broiler farming in the Eastern Cape Province is hampered by many challenges, especially the small broiler farmers who have just started, or would like to start farming (Muchenje *et al*., 2012). Many farmers are farming in deep rural areas and they face many production constraints. Like any successful business, broiler farming requires dedication, long working hours, responsibility and high level of skill. One of the major constraints in broiler cooperatives is the incidence of diseases, lack of slaughter facilities, lack of full access to markets, high costs of feed and veterinary drugs, lack of utilities (electricity, water and telephones), and low prices offered by wholesalers and retailers. Wide price fluctuations lead to uncertainties for both producer and consumers at large. Other problems encountered by producers include delayed payments by commission agents, relatively high transport costs and lack of knowledge on actual marketing condition.

Small-scale broiler producers have difficulties in gaining access to big outlets because they cannot offer a regular supply of broiler meat (Badubi *et al.,* 2004). When farming chickens in neither very hot nor very cold areas, electricity is very important. Water is one of the keys in any kind of farming and fresh, clean water is unavailable in many rural areas. Cooperatives are therefore forced to pay excessive costs for water connections (South African Poultry Forum, 2012).

Delivery of feed for broilers in remote areas is almost impossible. As many farmers are small scale farmers, transport costs of inputsare quite prohibitive to profitability of their enterprise. Buying large quantities of feed presents its own challenge ï cash flow being number one, closely followed by storage and shelf life (Moreki, 2010). Delivery of products to consumers is another challenge faced by broiler cooperatives. Broilers will need to be taken to the market or delivered to consumers and bad roads and infrastructure can hinder deliveries and collections on small rural cooperatives. The cooperatives supply their meat mostly to individuals followed by vendors, and a combination of individuals, vendors or wholesalers. Badubi *et al.* (2004) reported that small scale farmers are forced to sell their birds live because they lack refrigeration facilities. In general, the prices offered for the live birds at the market are lower than those for dressed broilers resulting in losses. Broiler cooperatives are also faced with a problem of diseases. Without proper management and correct training, diseases become a bigger challenge. Medication and the delivery of medicines in remote areas is, however, impossible. Access to qualified veterinary offices and experts makes medication for broilers very difficult (South African Poultry Forum, 2012).

12. General summary on the 'farm to fork' meat science research conducted

Animal transportation aspects that the farmers considered as important and have an effect on meat quality are: distance between the farm and the abattoir, handling at loading, hunger and thirst during transportation, number of animals transported and the loading density. The fact that the farmers perceive these aspects as important means that they can positively contribute to the production of acceptable meat at the abattoir. Farmersô contribution to meat quality is immense considering the fact that they can influence/control most of the transportation factors that are deleterious to slaughter welfare and meat quality. Other aspects that the farmers are in direct control of are; animal body condition at loading, loading facilities at the farm, loading method, and choice of marketing channel. These aspects are all considered as important by the farmers, again an indication of their vital role in production of meat that is acceptable to the consumers. However the fact that farmers had a negative perception of human-animal relationships might be related to the nature of their farming systems, since the majority of the farmers had extensive farms. The fact that the farmers perceived colour, tenderness, flavour and carcass class as important is a positive indication to production of meat of acceptable quality

Marketing channel have significant effects on bruise score, bruise age, pH and L* values. There are positive relationships between distance, stocking density and transportation duration on bruise score and $pH_{u,}$ while a significant negative linear effect of distance, stocking density and transportation duration on L* is observed. Although the farmersô perceptions might be positive on the effects of different marketing channels and pre-slaughter handling on beef quality, this might indicate that the farmers could not do much to prevent bruising. Farmer, meat trader and consumer perceptions of slaughter animal welfare and meat quality are important in meat production. Marketing channel, mode of transportation and handling of animals influences bruising and the quality of meat produced. Meat quality attributes such as colour and freshness are important at point of purchase since they affect consumersô purchasing decisions. Quality attributes such as colour, tenderness, leanness and marbling can be controlled at the farm or during pre-slaughter handling. The consumers indicated that they would not expect differences in meat from cooperatives or established farming enterprises. The quality of meat does not necessary differ with the type of butchery/supermarket. Table 12.1 gives a summary of what we have worked on at the University of Fort Hare.

Table 12. 1: A summary of 'farm to fork' meat science research in the last 10 years at the University of Fort Hare.

Meat production aspect worked on	References
Adaptation and parasite resistance	Muchenje *et al*. (2008b), Ndlovu *et al*. (2009a,b), Marufu *et al*. (2009), Mapiliyao *et al*. (2012), Mavule *et al*. (2013)
Breeding objectives	Tada (2012), Tada *et al*. (2013a,b,c)
Pre-slaughter stress and meat quality	Muchenje *et al*. (2009a,b), Chulayo and *et al*. (2013), Gajana *et al*. (2013), Vimiso and Muchenje (2013)
At slaughter and biomarkers	Fayemi and Muchenje (2012a; 2013a,b), Njisane and Muchenje (2013),
Fatty acid profiles and oxidative stability	Muchenje *et al*. (2009a,c), Mapiye *et al*. (2011a), Marume *et al*. (2012), Moyo (2011), Moyo *et al*. (2012), Nkukwana *et al.* (2013), Qwele *et al*. (2013)
Panel and consumer sensory evaluation	Muchenje *et al*. (2008c; 2010), Dyubele *et al.* (2010)
Perceptions of consumers, farmers and meat traders	Vimiso *et al*. (2012), Rani (2012)
Broiler-producing cooperatives	Muchenje *et al.* (2011; 2012)
Informal production systems and traditional slaughter	Fayemi and Muchenje (2012b), Ndou *et al*. (2011)
Industry -commissioned review	Muchenje and Ndou (2011)
Feed manipulation and meat quality	Mapiye *et al*. (2009; 2010; 2011a,b), Marume *et al.* (2012), Moyo *et al*. (2011, 2012a,b), Ngambu *et al*. (2013), Nkukwana (2012), Nkukwana *et al*. (2013), Qwele *et al*. (2013)

13. Possible future research areas

There are several areas that need to be researched in meat science. There is need to conduct studies on the improvement of the pre-slaughter welfare of meat species and how pre-slaughter welfare affects meat quality. This is critical given the current debate on the relationship between glycolytic potential, lactic acid formation, pH levels and other meat quality attributes (England *et al*., 2013; Schefer *et al*., 2007; 2011; 13; Muchenje *et al*., 2008b; 2009a,b; Hudson, 2012). Such studies should also include how gene expression in different livestock species influences the quality of meat. The role of informal meat production chains, traditional slaughter (including cultural beliefs) in animal welfare and meat quality also deserve special attention.

More scientific studies under local conditions are required to describe the synergistic effect of climate change on meat production. The role of the constantly changing animal-producing environment (Muchenje, 2013) on meat production deserves a thorough interrogation. Production and processing models which minimise animal pain during stunning and slaughter and the occurrence of embryonic and foetal losses at the abattoir should be developed. In order to effectively plan for the ever increasing demand for quality, healthy and nutritious meat, consumption patterns and consumer wellness indicators should be part on the meat science research agenda. Meat distribution and traceability are arguably some of the most neglected research areas in the developed world. This is quite crucial in light of the recent reported adulteration of meat and products as reported in the media. Furthermore, studies on the legal framework governing animal production, slaughter and meat distribution should also be considered seriously.

Another researchable area that needs serious attention among the meat scientists is the production of cultured/engineered meats from stem cells (Post, 2012). There is a need to look into how feasible it will be to produce laboratory meat from factories, or what has been referred as meat from petri dish to the plate (Goodwin and Shoulders, 2013). It is also important to study the possible ethical, social and legal issues around cultured meats.

It can be concluded the conversion of muscle to meat depends on a lot of biochemical, physiological (and even social) processes that occur from when animal is born and its growth at the farm, its transportation to the abattoir, ante-mortem, abattoir and post mortem processes, meat distribution, storage, processing and consumption. In addition to this, the quality and wholesomeness of the consumed meat also affects the consumer. It is therefore important to holistically consider all these processes and factors in meat science.

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