Some Factors Affecting the Quality of Meat from Ruminants and Their Relevance to the Tanzanian Meat Industry - Review

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Abstract

Parameters indicative of quality of meat from ruminants are reviewed, highlighting the importance of productive, pre-slaughter and post-slaughter factors on meat quality. Further, means for obtaining quality meat under Tanzanian conditions are pointed out. Meat quality encompasses various attributes ranging from carcass composition to health and production-related issues including animal welfare. These attributes can be manipulated to man's advantage at different stages of obtaining meat. Therefore good livestock practices in production chains including development and implementation of standards and code of conducts in feeding, transportation, slaughter meat sales and processing chains should be established. Moreover, meat quality improvement should be undertaken in a holistic manner, looking at the whole product obtaining systems rather than each individual production chain. To achieve this, there is a need to design a serious follow up mechanism to ensure that regulations associated with new technologies or policies are adhered to.

Keywords: Meat quality, production factors, technological factors, critical checkpoints

Introduction

There is a rising interest of recent in the production of quality meat in Tanzania. Ranches and feedlots are being established and modern slaughterhouses as well as meat processing plants are being built. The demand for quality meat is growing due to expanding markets composed of tourism, mining industries, expatriates as well as increased income and purchasing power in segments of the wider society. This has resulted in the importation of quality meat, which could otherwise be produced in the country thus saving much needed foreign currencies. It must however be stressed that the issue of quality meat should not be limited to affluent groups of people as the ordinary people also need quality and safer meat.

In Tanzania, there is limited research on quality meat production. Majority of the key stakeholders (researchers, extension staff, policy makers, producers etc) in the meat industry have limited knowledge on issues involved in the production of quality meat. The objective of this paper is therefore to review the

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current state-of-knowledge relevant to Tanzania on what comprises meat quality highlighting the importance of productive, pre-slaughter and post-slaughter factors on the quality of meat from ruminants.

Parameters indicative of meat quality Carcass composition

Carcass composition can be expressed in terms of physically dissected tissues or chemically analysed constituents (Moran and Wood, 1986). Based on physical dissection, carcass composition reflects the relative proportion of muscle, fat and bone in a carcass. Chemical composition of dissected tissues is assessed based on the content of protein, energy, ether extract, water and ash. Variation in carcass composition is usually associated with the amount of fat, which in turn is greatly affected by nutrition and body weight at slaughter. The amount and composition of fat in a carcass may thus affect its nutritive value based on meat healthiness, flavour and juiciness (Pratiwi *et al.*, 2004). Carcasses which are perceived to be excessively fat are strongly penalised, especially in developed countries with a high incidence of cardiovascular diseases (Sanudo *et al.*, 1996; Banskalieva *et al.*, 2000). Overall, the value of a carcass is largely determined by the edible meat yield (muscle and limited amount fat), how that meat is distributed in the carcass and other quality traits of meat (Johnson *et al.*, 2005).

On the other hand, increase in carcass fatness may have positive effect on meat tenderness. Fatness in meat animals provides insulation to muscles against cold-shortening effects of rapid refrigeration (Wood *et al.*, 1999). Thus, lean carcasses may be tougher than fatty ones due to lack of fat insulation. Further, at higher intramuscular fat (marbling) content, meat will have lower resistance to shearing due to dilution of fibrous protein by soft fat. Moreover, expansion of fat cells in the perimysium will also push muscle bundles apart, hence opening the muscle structure (Wood *et al.*, 1999). Thus, to attain a good quality status, meat should have an appropriate balance of muscle, fat and bone. However, the exact cut-off point for such balance may differ between market segments and can therefore be regarded as being subjective.

Meat Tenderness

Tenderness of meat is probably the most important organoleptic characteristic of eating quality (Steen *et al.*, 1997). The level of tenderness is affected by differences in connective tissue (CT), intramuscular fat (IMF), sarcomere length (SL), and post-mortem (PM) proteolysis (Kristensen *et al.*, 2003; Kristensen *et al.*, 2004).

The amount and nature of connective tissue which do not change significantly post-mortem (Steen *et al.*, 1997), determine the so-called background toughness (Sentandreu *et al.*, 2002). Purslow (2005) reported that the connective tissue content of muscle significantly influences tenderness of cooked meat. The amount, composition and morphology of intramuscular connective tissue (IMCT) vary between muscles, species, breeds and with animal age. Within muscle, the amount, spatial distribution and composition of connective tissue vary with muscle position in the carcass and with age. Perimysium is the IMCT component that varies most in amount between functionally different muscles and it is a parameter commonly used to define the mechanical integrity of cooked meat (Purslow, 2005). Thicker perimysium is associated with reduced tenderness. The IMCT contribution to cooked meat toughness is however higher in older animals, due to its increased mechanical and thermal stability (Purslow, 2005).

Sarcomere length is the distance between two consecutive Z-discs in a muscle fibre (Fig 1). Sarcomere shortening is a causative factor of a decreased tenderness of muscles from the time of slaughter to 24 h post-mortem (Savell *et al.*, 2005). The decrease in tenderness is due to increased force needed for shearing across the areas of the sarcomere where actin fibres overlap with myosin fibres. Areas with actinomyosin crosslinks increase with increased shortening of sarcomere. Chilling pattern and suspension of carcasses shortly after slaughter and before commencement of rigor determine the extent of sarcomere shortening. Rapid cooling post-mortem leads to excessive shortening (cold shortening) of sarcomere whereas suspension of carcasses from the aitch bone (*Obturator foramen*) shortly after slaughter and before commencement of rigor reduces the shortening (Sorheim and Hildrum, 2002). Since the factors that determine the decrease of sarcomere length during rigor development are well understood, large variation in sarcomere length can therefore be controlled and prevented by appropriate handling of carcasses before rigor sets in (Kristensen *et al.*, 2003).

Although Steen *et al.* (1997) reported a negative relationship between sarcomere lengths and shear force, Buts *et al.* (1986) found no relationship between the two parameters. This discrepancy could probably be explained by the extent of shortening observed in the studies. Savell *et al.* (2005) showed that decreases up to 20 % of the initial excised muscle length do not have a significant effect on tenderness. However, toughness increases rapidly with further shortening, peaking at 40 %, after which the meat becomes progressively tenderer. Nevertheless, the importance of sarcomere length on meat tenderness decreases with ageing because of proteolysis and also because sarcomere length increases slightly during ageing (Steen *et al.*, 1997).

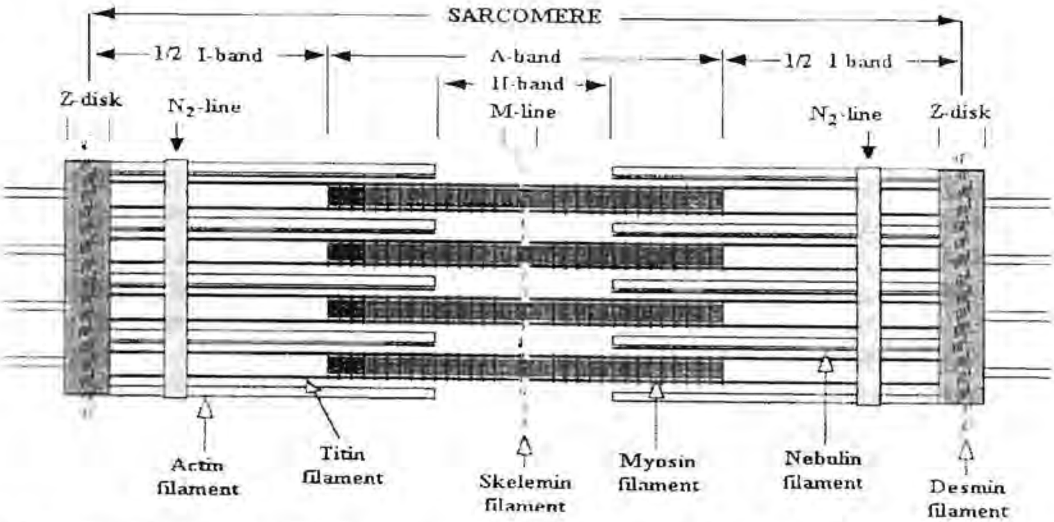

Fig 1: Diagrammatic representation of cytoskeletal network of the sarcomere; Adopted from Prates *et al.* (2002).

Muscle fibre type composition plays a part in determining tenderness (Maltin *et al.*, 2003). Muscle fibres in adult animals are usually classified into at least three groups based on their contractile and metabolic properties. The basic classification include slow-twitch oxidative (SO; type I), fast-twitch oxidative-glycolytic (FOG; type IIA) and fast-twitch glycolytic (FG; type IIB) fibre type. Fibre type proportion and sizes vary both within and between muscles, but usually glycolytic fibres attain a bigger size than oxidative fibres due to the lesser requirement for oxygen diffusion in the former than in the latter. In lamb and beef, a positive relationship is reported between proportion of SO fibres in the muscle and tenderness whereas fast-twitch glycolytic fibres are less tender (Sanudo *et al.*, 1998; Therkildsen *et al.*, 2002b). White muscles, for example *Longismus lumborum*, have lower tenderness than red muscles like *Supraspinatus* (Therkildsen *et al.*, 2002b). From this observation, it may be hypothesized that the amount and proportion of different fibres in a muscle determines its tenderness. However, the relationship between fibre types and tenderness still remains complex and it is likely that other factors interact with fibre type properties to determine eating quality.

Several muscle proteolytic enzyme systems that take part in protein turnover *in vivo* also contribute to development of tenderness development that occur post-mortem (Kristensen *et al.*, 2003). Proteolytic enzymes degrade key muscle proteins, thereby fragmenting the muscle structure, which facilitate its further breakdown in the mouth. It is hypothesized that increased proteolytic activity pre-slaughter increases the rate of meat tenderization post mortem (Kristensen *et al.*, 2002;

Therkildsen, 2005). Though several proteolytic enzymes have been implicated, most researchers agree on the major role played by calpains - calpastatin system (Pringle *et al.*, 1997; Therkildsen *et al.*, 2002c; Sazili *et al.*, 2004). The proteolytic potential, which reflects how fast a muscle may tenderize post-mortem, is measured by the ratio between the μ-calpain and the calpastatin activities in muscle at time of slaughter. This is derived from the understanding that μ-calpain is the primary proteolytic enzyme that causes tenderness development and that calpastatin is an inhibitor of μ-calpain (Kristensen *et al.*, 2002).

Meat ultimate pH

The pre-slaughter muscle glycogen reserves in animals determine ultimate pH of meat (Braggins, 1996). Shortly after slaughter, as the muscle attempts to maintain homeostasis, energy metabolism in the muscle breaks down glycogen via the anaerobic glycolytic pathway, thus phosphorylating ADP to supply ATP and producing lactic acid. A high lactic acid content lowers muscle pH up to a normal value of around 5.6 (Braggins, 1996; Maltin *et al.*, 2003). Elevated pH affects several meat characteristics, including appearance, water-holding capacity, tenderness and flavour. In its extreme, meat with high ultimate pH is called DFD because of its dark, firm, and dry appearance. As the ultimate pH increases from 5.5 to 6.0 the tenderness of cooked meat decreases, and above pH 6.0 the effect is reversed (Braggins, 1996). Moreover, at pH values above 5.8 the keeping quality of fresh chilled meat is adversely affected because of altered bacterial growth due to the lower content of lactic acid. On the other hand, a sharp drop in pH leads to poor quality meat which is characteristically pale, soft and exudative (PSE). Meat with low ultimate pH may be of poor eating quality since enzymes involved in post-mortem tenderisation are inhibited by acidification. Moreover, low ultimate pH is associated with increased drip loss resulting in meat with poor overall acceptability (Braggins, 1996; Maltin *et al.*, 2003).

Meat colour

Meat colour may influence consumer decision to purchase meat (Diaz *et al.*, 2002; O'Sullivan *et al.*, 2004). Meat from animals raised on grazing pasture is relatively darker due to higher haemic pigment content in the muscle as a result of exercise. Moreover, meat colour becomes darker and redness increases with increased slaughter and carcass weights (Sanudo *et al.*, 1996; Santos-Silva *et al.*, 2002). In red meats, consumers relate a bright-red colour to freshness, but discriminate against meat that has turned brown (O'Sullivan *et al.*, 2004). Since feeding regimen affects meat colour, diet formulation could be used as a tool for producing meat of a desired quality.

Water holding capacity (WHC)

Water holding capacity reflects the ability of fresh meat to retain its constituent water and bind extra water (Andersen *et al.*, 2005a). The higher WHC, the more suitable meat will be for different uses. The WHC is related to important meat organoleptic properties such as juiciness and tenderness (Sanudo *et al.*, 1996). Low WHC is related to low ultimate pH in meat (Rosenvold *et al.*, 2001), whereas high WHC is associated with high ultimate pH (> 6.2) (Braggins, 1996). As pH increases (within the normal pH values of meat), WHC increases and cooking losses decrease, leading to increased tenderness (Steen *et al.*, 1997).

Fatty acids content and composition

Physical and chemical properties of lipids affect eating and keeping qualities of meat. The composition of fatty acids in meat has a crucial influence on its quality, as it is related to differences in organoleptic attributes, especially flavour and to the nutritional value of fat for human consumption (Banskalieva *et al.*, 2000; Olfaz *et al.*, 2005). Saturated fatty acids increase hardness of fat and being easily solidified upon cooling, influence meat palatability. In addition, high dietary levels of long-chain saturated fatty acids (SFA) increase plasma cholesterol level compared with high levels of mono-unsaturated fatty acids (MUFA) and poly-unsaturated fatty acids (PUFA) (Banskalieva *et al.*, 2000; Caneque *et al.*, 2003). However, not all SFA have equivalent effects on plasma cholesterol. Lauric (C12:0), myristic (C14:0) and palmitic (C16:0) acids raise the plasma cholesterol level, whereas stearic acid (C18:0) does not have such an effect and is considered 'neutral' (Banskalieva *et al.*, 2000).

Although unsaturated fatty acids increase potential for oxidation thus influencing shelf life, they are relatively more beneficial for human health as they have low melting point. The correct balance of n-3 and n-6 polyunsaturated fatty acids in meat products of farm animals can improve human health. The advantages of consuming linolenic acid, one of the n-3 fatty acid families, include its capacity to diminish the thrombotic tendency of blood and the risk of suffering coronary diseases (Ponnampalam *et al.*, 2002b; Caneque *et al.*, 2003). On the other hand, higher intake of n-6 can lead to insulin resistance, higher accumulation of storage adipose tissue and in vivo platelet aggregation (Banskalieva *et al.*, 2000; Ponnampalam *et al.*, 2002b). Although there are no data available concerning all n-6 or n-3 series of PUFA in goats, Banskalieva *et al.* (2000) suggested that goat muscles contain nearly twice as much C18:2 (n-6) as lamb muscles and have more C20:4 (n-6) as well. Values recommended for n-6:n-3 and PUFA:SFA ratio for human health are less than 4 and greater than 0.45 respectively (Enser *et al.*, 1998; Wood *et al.*, 1999).

Recent studies have shown that some dietary conjugated linoleic acids (CLA) are beneficial for human health (French *et al.*, 2000; Gibb *et al.*, 2004; Schmid *et al.*, 2006). CLA, especially C18:2 cis-9 trans-11 which is the major isomer in meat, are potentially anticarcinogenic, prevent cardiovascular or diabetes diseases and have positive effects on the immune system and lipid metabolism (Banskalieva *et al.*, 2000; Aurousseau *et al.*, 2004; Nuernberg *et al.*, 2005a). Ruminant products are the richest natural source of cis-9 trans-11 CLA, which is formed during biohydrogenation in the rumen and by de novo synthesis in different tissues of cattle or sheep from trans-vaccenic acid (C18:1 t11) in the presence of the enzyme Δ^9-desaturase. The increased intake of linoleic acid by sheep elevates content of CLA in deposited fat (Gibb *et al.*, 2004).

Sensorial appraisal: texture, flavour and odour

The critical point of appraisal of meat quality occurs when the consumer eats the product.

Consumers judge and evaluate the quality of a food by the use of senses, i.e. taste, smell, sight, touch and hearing. Although sensorial assessment of meat quality might be regarded as subjective as it depends on the previous experience, expectations or attitude of a particular consumer (Martinez-Cerezo *et al.*, 2005), it provides fuller explanations of the complex set of interactions that occur when cooked meat is smelled, chewed and swallowed. As food is chewed, the odorous elements are released and are smelled by the way of retronasal passage at the back of oral cavity (Young *et al.*, 2003). Thus, sensory studies are useful when a complete evaluation of meat quality has to be made. Consumers evaluate meat samples for tenderness, bite resistance, juiciness, meat colour and aroma and flavour intensity. In sensory panel evaluation of meat quality, usually a 9-point unstructured scale between the anchors "0, no intensity" and "9, high intensity", is used for scoring meat texture, flavour and odour.

Factors affecting meat quality

Meat quality is influenced by factors ranging from intrinsic, production, pre-slaughter, slaughter and post-slaughter managerial aspects (Steen *et al.*, 1997; Sanudo *et al.*, 1998). Intrinsic factors are those directly related to the animal itself or its ancestors. Influences of man on animals during breeding, production and pre-slaughter periods are considered as extrinsic production or pre-slaughter managerial aspects. Carcass handling immediately after slaughter till meat consumption contributes to post-slaughter managerial aspects.

Species

Meat from each species has unique characteristics, for example, red meat (beef, lamb or goat) differ in various ways from white meat (young pig or chicken). The basic differences are found in appearance, flavour, tenderness, fatness and juiciness (Sanudo *et al.*, 1998; Andersen *et al.*, 2005a). Working with goat and lamb, Sen *et al.* (2004) found that shear force value was significantly higher in goat (7.42 kg/cm^2) than in sheep meat (3.74 kg/ cm^2). Meat with Warner-Bartzler shear force value exceeding 5.5 kg/cm^2 would often be considered as objectionably tough (Sen *et al.*, 2004). The species difference in tenderness can be attributed to the difference in carcass fatness and muscle fibres thickness. Goats have lower carcass fatness and higher muscle fibre thickness than sheep (Sen *et al.*, 2004). Further, goats, unlike sheep deposit more fat around the visceral organs than in the carcass. These differences in quality affect consumers' decision to purchase and/or repurchase meat from one species and not the other.

Breed

A well-known breed difference is with respect to both the amount of fat and where it is deposited. When compared at equal carcass or live weights, animals from precocious breeds, with a smaller adult format and therefore with lower daily growth, will be older and therefore will have more fat than the larger and later maturing breeds (Sanudo *et al.*, 1998; Andersen *et al.*, 2005a). The differences in precociousness in turn lead to significant differences in WHC, colour and texture between breeds. In addition, breed effects on meat quality are associated with differences in muscle distribution, muscle physical and biochemical properties in the carcass (Notter *et al.*, 1991; Santos-Silva *et al.*, 2002; Dawson *et al.*, 2002). Breed difference in eating quality between *Bos indicus* and *Bos taurus* cattle is associated with in vivo differences in muscle protein turnover, being lower in the former than in the latter (Andersen *et al.*, 2005a). Thus cattle with 1/4 or more influence of *B. indicus* are rated less tender than B. taurus cattle. With regard to differences between *B. taurus* breeds, it is very much a question of maturity, weight, fatness and management system. In lambs, breed difference in eating quality exist between lambs expressing the callipyge phenotype and normal lambs, with inferior juiciness and tenderness of meat from fast twitch muscles of callipyge lambs (Andersen *et al.*, 2005a).

Sex

Sex of an animal is considered a cause of variation in the eating quality of beef, lamb and goat. Meat from steers is usually more tender compared with meat from bulls. This difference is attributed to the rate of proteolysis post-mortem in favour of steers (Andersen *et al.*, 2005a). Less intramuscular fat (IMF) and proneness to stress in relation to transport, lairage and slaughter are other causes of the inferior quality of meat from bulls compared with meat from steers and heifers. Sanudo *et al.* (1998) attributed higher toughness of meat from bulls than steers to possible effects of testosterone on collagen accretion. In sheep, Jeremiah *et al.* (1998) recorded a higher cohesiveness (difficult to swallow) and more connective tissue of meat from rams than ewes during mastication. Further, the samples from rams were perceived to contain the least amount of fat during mastication.

The effects of sex on meat aroma are well known. Undesirable flavours may appear in rams slaughtered at older ages or heavier weights (Notter *et al.*, 1991; Arsenos *et al.*, 2002). In the study by Arsenos *et al.* (2002), panelists preferred meat from female lamb especially when heavier carcasses were being assessed. Jeremiah *et al.* (1998) reported higher order of appearance of sour aroma in female lambs, though they did not detect a significant difference in sour taste between sexes. On the contrary, Ellis *et al.* (1997) and Sanudo *et al.* (1998) reported that sex of animal did not affect an overall acceptability of lamb meat. The discrepancy in findings might be attributed to the differences in production system and age-at-slaughter.

Age of an animal

The most accurate guide to eating quality available to consumers is the animal's age at the time of slaughter and that maturity exerts a substantial influence on palatability particularly tenderness (Jeremiah *et al.*, 1998). Meat tenderness tends to decrease with animal's chronological age. Positive trends with advancing age in the fibrousnesses and density of samples (r^2 = 0.82 and 0.78, respectively), the connective tissue content of samples (r^2 = 0.75), the incidence of gristle in samples (r^2 = 0.79), and the proportion of samples with connective tissue described as being webbed fibres and hard gristle (r^2 = 0.86) were observed (Jeremiah *et al.*, 1998). Further, intensity of meat flavour increases, in some cases becoming less desirable, with increase in age of rams or bucks (Jeremiah *et al.*, 1998). With respect to ovine, collagen solubility declines with age but its concentration remains unchanged, from 4 months to 5 years (Sanudo *et al.*, 1996). Levels of collagen and relative amounts of highly cross linked collagen are negatively associated with meat quality and meat tenderness. Moreover, collagen interacts with fat deposition rates to give an explanation of the differences in meat tenderness.

Feeding

The eating quality of meat can be affected by feeding strategy and composition of a diet. Low energy grass or forage diets give rise to less tender meat compared with high energy diets fed ad libitum (Kristensen *et al.*, 2002; Therkildsen *et al.*, 2002c; Andersen *et al.*, 2005a). On the other hand, feeding strategy allowing for compensatory growth, i.e., restrictive feeding followed by ad libitum feeding may increase tenderness in meat beyond meat from ad libitum fed animals (Therkildsen *et al.*, 1998; Therkildsen *et al.*, 2002a; Andersen *et al.*, 2005a). This is because compensatory growth gives rise to higher *in vivo* protein turn over which extends to post slaughter period. Generally, besides its effect on meat tenderness, feed restriction gives rise to higher amount of lean and reductions in the amount of fat for carcasses of equal weights.

Production system affects lipid composition in meat (Ponnampalam *et al.*, 2002b; Gibb *et al.*, 2004; Nuernberg *et al.*, 2005b). The n-3: n-6 PUFA ratio is affected by the proportion of grass in a diet, as grass is rich in fatty acids of the n-3 series (Diaz *et al.*, 2002). Forage feeding of animals result into meat with more desirable balance of n-3: n-6 PUFA ratio for human health. Moreover, feeding fish oil, which is rich in the long chain n-3 fatty acids namely eicosapentaenoic (C20:5, EPA) and docosahexaenoic acid (C22:6, DHA), increases the n-3: n-6 ratio of different tissue lipids (Nuernberg *et al.*, 2005b). Linseed oil is a potential commercial alternative to fish oil as a source of n-3 fatty acids containing about 60% C18:3 n-3 (Nuernberg *et al.*, 2005b). The difference in the content of these PUFA in meat may results in variation in eating quality as n-3 PUFA affect meat flavour differently compared with n-6 PUFA series.

Pre-slaughter handling of animals

Exercises during immediate pre-slaughter period influence the rate of pH decline in meat and may affect various meat attributes including colour, flavour and tenderness (Simmons *et al.*, 1997). The rate of pH decline may also affect the rate of post-mortem proteolysis as endopeptidases are affected by low pH (Kristensen *et al.*, 2002). Simmons *et al.* (1997) observed that physical exercise treatment resulted in low post-mortem activity of μ-calpain, a principal proteolytic enzyme, and tough meat. This observation was attributed to the increase in plasma catecholamine concentrations and thus increases in intracellular Ca^{2+} levels. This in turn, stimulates peri-slaughter *in vivo* proteolysis (McCully and Faulkner, 1985). This proteolysis is calpain-induced and would deplete the ante-mortem intracellular calpain levels, thus affecting subsequent post-mortem tenderisation.

In addition, pre-slaughter animal handling practices causing stress to animals influence the quality of beef, e.g., incidence of DFD meat, which in turn is known to influence eating quality (Immonen *et al.*, 2000; Andersen *et al.*, 2005a). If muscle glycogen content is reduced by pre-slaughter stress, the intensity of abnormal or 'off' flavours is increased in beef and lamb (Young *et al.*, 1994). Moreover, the shelf life of fresh meat is adversely reduced following changes in microbial growth due to the decreased glucose and lactic acid content. Transporting animals, mixing unfamiliar animals and the extended time in the lairage before slaughter are some of the pre-slaughter stress inducing practices. A recent study has shown that 3 h transportation of bulls before slaughter gives rise to optimal tenderness and overall liking of meat compared with either 30 min or 6 h of transportation (Villarroel *et al.*, 2003). This indicates the existing delicate balance between long-term stress and short-term stress for beef quality development. Generally, meat from stressed animals is darker, has greater WHC, it is susceptible to spoilage by micro-organisms, tends to produce abnormal flavours and becomes tender or tougher depending on the ultimate pH (Braggins, 1996; Sanudo *et al.*, 1998).

Slaughter procedures

Pre-slaughter fasting and stunning, hanging and bleeding the carcasses should be well controlled to give meat of a desired quality. Stunning of animals should aim at reducing stress, consequently giving meat with desirable pH. Hanging carcasses on hooks post slaughter should allow for proper bleeding and hence improve shelf life of meat. Electrical stimulation of beef and lamb carcasses is used to accelerate bleeding and to reduce cold shortening in muscles exposed to accelerated chilling. The reduced muscle shortening has a beneficial effect on tenderness. Alternatively, suspension of carcasses from the aitch bone (*Obturator foramen*), shortly after slaughter and before commencement of rigor, can be used instead of electrical stimulation when accelerated chilling is to be used, and hereby improves tenderness in valuable cuts of beef and lamb (Wood *et al.*, 1999; Andersen *et al.*, 2005a).

Manipulation of meat quality

Ageing of meat

Meat is intermediately tender at slaughter, shortening at rigor makes meat tougher and proteolysis tenderises it progressively (Sentandreu *et al.*, 2002; Prates, 2002; Strydom *et al.*, 2005). Thus, initial tenderness contributes little to ultimate tenderness. Post-mortem storage of meat at optimum refrigerated conditions (ageing) allows for proteolytic enzymes to fragment the key myofibrilla and associated proteins that result into tender meat (Fig.2). The function of these proteins is to maintain the structural integrity of myofibrils. The proteolytic enzymes degrade proteins involved in inter- (e.g., desmin and vinculin) and intra-myofibril (e.g., titin, nebulin, and troponin-T) linkages or linking myofibrils to sarcolemma by costameres (e.g., vinculin, dystrophin), and attachment of muscle cells to the basal lamina (e.g., laminin, fibronectin) (Sentandreu *et al.*, 2002). Degradation of these proteins would therefore cause weakening of myofibrils and thus tenderization. However, with excessive ageing time, water losses may increase, changes in odour and flavour may occur as well as an increase in discoloration (Sanudo *et al.*, 1998). Changes in flavour during meat ageing are due to generation of peptides and amino acids from myofibrillar breakdown. Thus, appropriate ageing time and proper environment (for example temperature, ventilation and aeration) during meat ageing should be observed for successful post-mortem tenderisation of meat. To maximize the benefits of post-mortem storage on meat tenderness, beef should be aged for 10-14 d, goat and lamb for 7-10 d at 4 °C (Sentandreu *et al.*, 2002).

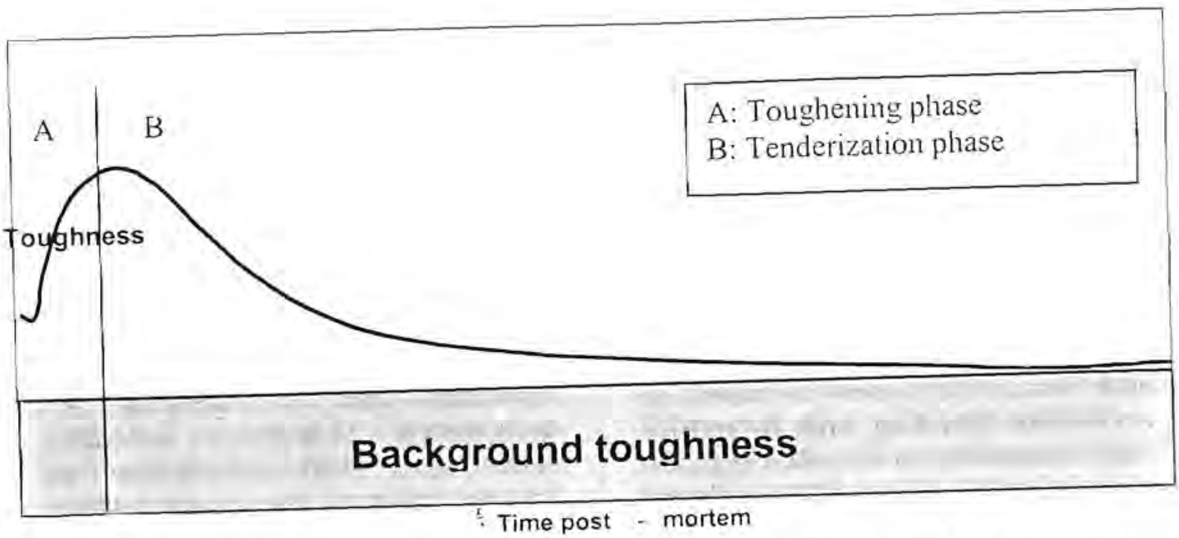

Fig. 2: Conversion of muscle to meat; Adapted from Wheeler and Koohmaraie (1994)

Chilling of carcasses

A rapid cooling causes toughening of meat (cold shortening) whereas maintaining muscles at elevated temperatures up to 50°C immediately post-slaughter results in a rapid depletion of ATP creating severe shortening (hot shortening) and early onset of rigor (Strydom *et al.*, 2005). Thus, when carcasses are cooled quickly, they tend to be affected by cold-induced shortening and/or toughening. Temperature in muscles must not drop below 10°C in the first 10 hr post-mortem or below 10°C before pH reaches 6.2 (Sanudo *et al.*, 1998; Hildrum *et al.*, 2000; Savell *et al.*, 2005). Studies show that minimal shortening occurs at about 12–15 °C resulting in optimum tenderness (Strydom *et al.*, 2005). Below this temperature, pre-rigor contracture takes place resulting in higher rigor toughness. Above 12–15 °C the rigor contracture (termed heat shortening) occurs, which has a concurrent reduction in ageing potential leading to less tender meat both at rigormortis and when fully aged. In addition, storage temperature of meat affects enzymatic degradation of myofibrillar proteins by endopetidases (Savell *et al.*, 2005). Too low a temperature inactivates calpains leading to less tender meat. Thus beef carcasses should be maintained at 12–15 °C for the first 6 hrs post-mortem and then be moved to 4°C up to 24 hrs before freezing. However, fat thickness can play a significant role in reducing the rate at which a carcass cools down during chilling processes.

Electrical stimulation of carcasses

Electrical stimulation accelerates post-mortem glycolysis such that when a muscle enters rigor it is prevented from excessive shortening. Electrical current causes muscle contraction, thereby increasing the rate of glycolysis accompanied by a rapid decline in pH (Hwang and Thompson, 2001). Electrical stimulation causes also a physical disruption of myofibrilla matrix (due to intense muscle contractions) and acceleration of proteolysis (Alvarado and Sams, 2000; Strydom *et al.*, 2005). Hwang and Thompson (2001) showed that early activation of calpains is the mechanism by which electrical stimulation improves tenderness of meat. However, timing of electrical stimulation requires special consideration: if intense stimulation is applied too early post-mortem may result into rapid pH decline that reduce the activity of calpains leading to less tender meat (Hwang and Thompson, 2001). Thus, to optimize the effectiveness of electrical stimulation on meat tenderness, excessive stimulation of carcasses immediately post-mortem should be avoided. Moreover, the contradicting reports on the relative benefits of high voltage (300 – 3000 V) or low voltage (under 100 V) on meat tenderness in the literature (Hildrum *et al.*, 1999; Sorheim and Hildrum, 2002) suggests a need for further research.

Means for obtaining quality meat in Tanzania

Tanzanian meat industry is on a move towards producing quality meat that meets requirements for both domestic and export markets. To achieve this goal, the meat industry should adapt accumulated knowledge on means for producing quality meat to Tanzanian condition. Moreover, the meat industry should observe strictly the functioning of important critical check points including creation of disease free zone, feedlot finishing of animals with poor condition scores before slaughter, less stressful and humane slaughter of animals. Other critical check points are healthy slaughterers, meat ageing, strict prevention of meat from contamination during distribution and display in butcheries as well as adding value to meat by selling as standard commercial cuts.

Parallel with creation of disease free zone, it is desirable to background slaughter animals for the time long enough to examine animals for any disease symptoms. Only animals proven to be healthy should be slaughtered. In order to improve meat marbling and tenderness, animals from the traditional production system with poor body condition, should be fattened before slaughter.

Since pre-slaughter stress tends to produce undesirable eating quality of meat, there is a need to reinforce humane stunning practices. Moreover, to take advantage of proteolytic enzymes that fragment the structure of myofibrillar proteins leading to tender meat, beef, lamb or goat carcasses should be aged by hooking the carcasses from the pelvis in a room temperature for the first 6 hours post-mortem, thereafter be moved to a cooler set at 4°C for at least a total of 48 h post-mortem before consumption.

To obtain safer meat, good hygienic practices (GHP) should be put in place and be adhered to. Such practices should address: cleaning of abattoirs and equipments; staff health in relation to food handling and staff cleanliness; cleanliness of the raw materials including live animals; ensuring all detergents, sanitizers and non-food chemicals are of a food grade standard, properly packaged, labelled and are stored correctly. All the buildings and surrounding of the abattoir, should be designed, constructed and maintained in a manner so as to minimise contamination of carcasses. Abattoir floors, doors, windows, ceiling/overhead fixtures should be constructed of materials that are durable and easy to clean and prevent contamination of meat. Ventilation system should eliminate the build-up of condensation and remove contaminated air. Hand held tools (knives, hooks and saws) should be decontaminated regularly in a hot water at a temperature of 82 °C or higher. There should be a sufficient number of conveniently located workstation hand wash basins in abattoir that should supply water at a suitable temperature and anti-bacterial soap. Moreover, no person, while known to be suffering from, or known to be a carrier of a disease likely to be transmitted through food, or carrying an infected wound, skin infection, sores or suffering from a gastroenteric illness, is permitted to work in the abattoir (Bolton *et al.*, 2004).

There is no doubt that selling meat as commercial cuts will add value to meat. The current practice of selling meat in a form of a "mix" does not allow for differential pricing of meat cuts. Education should start with butchers on how to cut carcasses into standard cuts and advantages of doing so. Consumers, especially those earning higher income, are likely to incur extra cost for the higher quality meat cuts like T-bone steak, sirloin steak, rump steak, topside, silverside club steak and fillet.

Conclusion

It is concluded from this review that the process of producing quality meat is complex and is influenced by multiple interacting factors. Tanzania meat industry should therefore put a fresh emphasis on good livestock practices in meat production chains. This should include developing and implementing standards and code of conducts in feeding, health care, transportation, slaughter meat sales and processing chains. Interventions for improving meat quality like ageing of meat and marketing based on commercial cuts should be tried under Tanzanian condition.

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