# CHAPTER 2

# 2 LITERATURE REVIEW

## 2.1 DETERMINATION OF MEAT QUALITY

The properties of meat are determined by several factors spanning from the conception of the animal to the consumption of the meat (Hofmann, 1994). These factors determine the quality of meat as described by indices such as pH, colour, tenderness, flavour, juiciness and nutritive value. In this section, some of the major processes in the evolution of meat quality are reviewed, focusing on how they affect meat quality in general and the quality of chevon specifically.

### 2.1.1 Myofibre and muscle metabolic types

Muscles are classified into metabolic types on the basis of their predominating myofibre types. There are four myofibre classes which are determined by the metabolic and contractile properties of their constituent myofibres. The three major types are the red (type I or β-red); intermediate (type IIA or α-red) and white (type IIB or α-white) (Brooke and Kaiser, 1970; Ashmore and Doerr, 1971). The fourth class, type IIC exists commonly in neonates and is a transitory link in the formation of types IIA and IIB (Young, 1984; Brandstetter, Picard and Geay, 1998a).

Type I myofibres are the smallest in diameter (Rosser, Norris and Nemeth, 1992). They are associated with more blood capillaries, a high lipid, myoglobin, mitochondria and tricarboxylic acid (TCA) cycle enzyme content to suit their high oxidative metabolism (Essén-Gustavsson, Karlström and Lundström, 1992). Strong succinate dehydrogenase (SDH) activity is thus used to identify the myofibres histologically (Brooke and Kaiser, 1970; Ashmore and Doerr, 1971; Swatland, 1981). At the other end, type IIB myofibres are the largest (Rosser et al., 1992). They hold more readily available energy compounds such as creatine phosphate, adenosine triphosphate (ATP) but less glycogen than red muscles (Monin, 1981; Rosser et al., 1992). Histologically they are distinguished by strong ATPase and lactate dehydrogenase (LDH) activity but weak SDH activity (Brooke and Kaiser, 1970; Ashmore and Doerr, 1971; Swatland, 1981). Type IIA myofibres are intermediate in size (Rosser et al., 1992). Their metabolic activity however may either be greater than or intermediate between type I or type IIB depending on the species considered (Ashmore, Tompkins and Doerr, 1972; Monin, 1981).

In line with myofibre classification, muscles are classified into red (type I), intermediate (type IIA) and white (type IIB). Red muscles have a high proportion of type I myofibres. They are

predominantly postural muscles (e.g. *M. trapezius*[*] in the shoulders; *M. semimembranosus* in the hind leg), with high oxidative capacity to meet the requirements for stamina (Totland and Kryvi, 1991; Essén-Gustavsson, 1996). Muscles involved in locomotion (e.g. *M. semitendonosus* in the hind leg) have a higher glycolytic than oxidative capacity for rapid contraction and so are dominated by the type IIB myofibres. Within individual muscles there is a topographical variation in myofibre type. For example, deeper regions of *M. semitendonosus* (ST) tend to be darker and more oxidative than outer ST regions (Dreyer, Naudé, Henning and Rossouw, 1977; Hunt and Hedrick, 1977; Totland, Kryvi and Slinde, 1988). In addition, deep type IIB myofibres are more oxidative and have smaller diameters than the superficial ones (Rosser et al., 1992).

Muscle metabolic type is also influenced by variations between animals, such as species, breed, sex, age, weight, nutrition and exercise (Essén-Gustavsson, 1996). An example of species differences is the classification of some ovine and bovine muscles (Figure 2.1). The remarkable features of this classification are that, firstly, the type IIA ovine muscles are more glycolytic than the type IIB and more oxidative than the type I. In cattle however, type IIA muscles are intermediate between type IIB and type I in glycolytic and oxidative activities. Secondly, the same muscle may classify differently in different species. For instance whereas the *M. semimembranosus* (SM) muscle is type IIA in sheep, in cattle it is type IIB (Monin, 1981).

Sex and age effects on myofibres were illustrated by Spindler, Mathias and Cramer (1980) who reported a twofold increase in the cross-sectional area *of M. biceps femoris* (BF) myofibres in steers and heifers ranging from 28 to 392 days old. As the animals grew the myofibre profile increased in type IIB and decreased in type IIA. Such changes in myofibre size and profile were also observed in later works (e.g. Seideman, Crouse and Cross, 1986; Jurie, Robelin, Picard and Geay, 1995; Brandstetter et al. 1998a). They are a result of the general differentiation pathway of type I → type IIA → type IIB (Ashmore et al., 1972) during early stages of muscle hypertrophy.

[*] The muscle nomenclature system used is that described by Kauffman, Habel, Smulders, Hartman and Bergström (1990).

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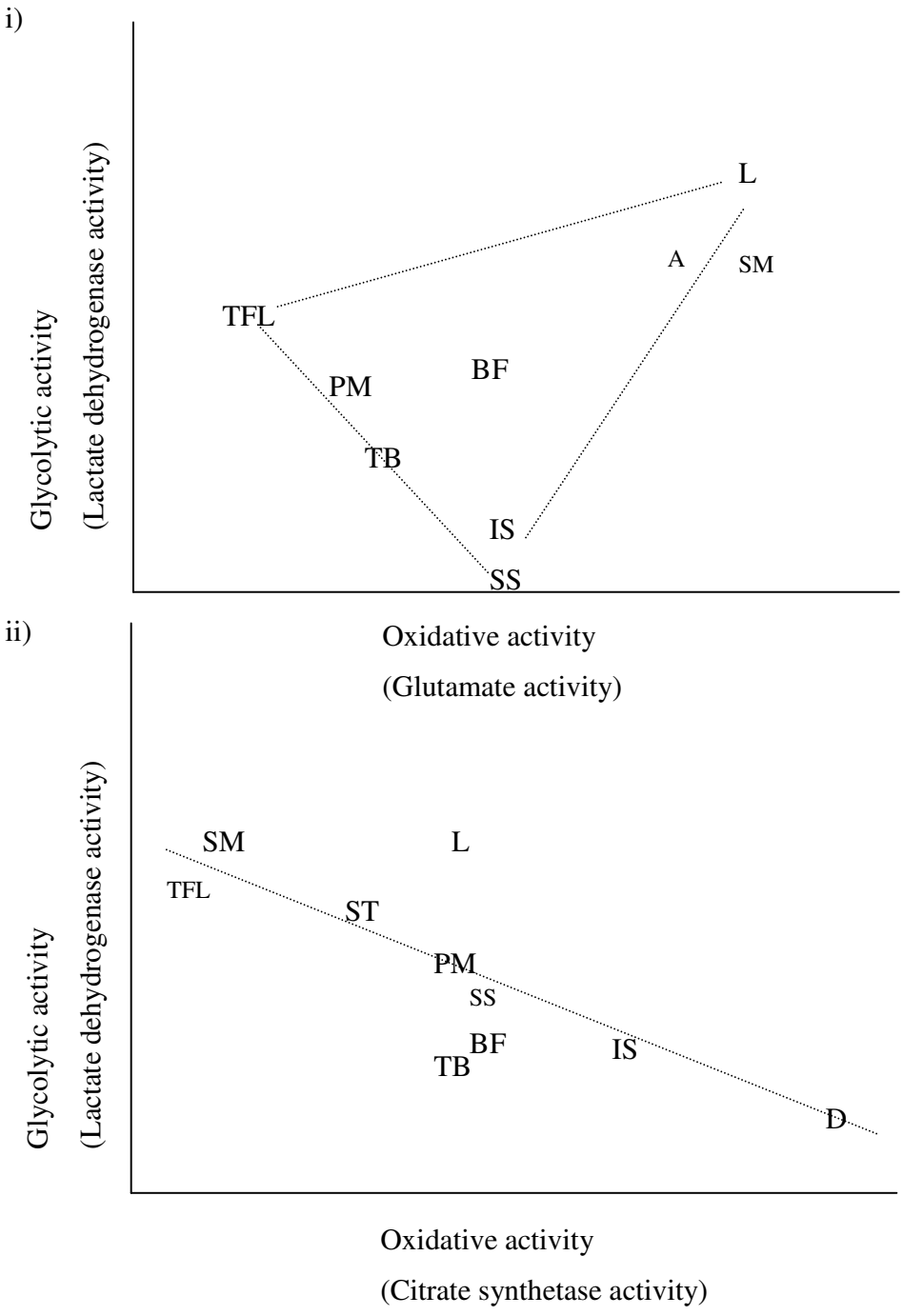


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| | | | | | |
|---|---|---|---|---|---|
| A | *M. Adductor* | L | *M. Longissimus* | SM | *M. Semimembranosus* |
| BF | M. *Biceps femoris* | PM | *M. Psoas major* | SS | *M. Supraspinatus* |
| D | *Diaphragm* | TB | *M. Triceps brachii* | ST | *M. Semitendonosus* |
| IS | *M. Infraspinatus* | TFL | *M. Tensor fasciae latae* | | |

**Figure 2.1** Diagrammatic representation of relative metabolic types of i) ovine and ii) bovine muscles (Adapted from Monin, 1981)

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Amongst the males, castration effects on muscle fibre type composition are manifested post-pubertally. Most reports, such as Dreyer et al. (1977), Young and Bass (1984), Seideman et al. (1986) and Mohan Raj, Moss, McCaughey, McLauchlan and McGaughey and Kennedy (1991) suggest that the proportion of type I myofibres is relatively unaffected by castration while type IIB increase at the expense of type IIA. Brandstetter, Picard and Geay (1998b) however reported pre-pubertal differences between bulls and steers; that bull calves start showing a tendency to a typical myofibre composition from as early as when they are four months old.

Furthermore Brandstetter et al. (1998b) observed that bulls increased in type I and decreased in type IIB myofibres while steers increase in IIB myofibres, but the proportion of IIA myofibres remained unchanged in both sexes. The argument for these changes was that androgens promote an ageing kind of differentiation in myofibres by favouring a shift to type I myofibres (Powers and Florini, 1975). On the other hand, castration delays this re-conversion, and hence the steers had a myofibre type composition that was physiologically less mature than that of bulls of similar age. Despite the differences in the reports on early myofibre type proportions in bulls and steers, most studies agree that androgens promote myofibre hypertrophy, and hence myofibres of steers, particularly types IIA and IIB, tend to be smaller than those of bulls (Dreyer et al., 1977; Young and Bass, 1984; Seideman et al., 1986; Brandstetter et al., 1998b; Dalle Zotte, Verdiglione, Rémignon, Cozzi, Andreoli, Gottardo and Andrighetto, 2000).

In a study involving the three sex classes, Young and Foote (1984) suggested that the proportion of type I myofibres is unaffected by the sex of cattle but the proportion of type IIB myofibres of females lay between that of bulls and steers. Conversely, the proportion of type IIA myofibre is higher in female cattle than in steers (Johnston, Moody, Boling and Bradley, 1981; Young and Foote, 1984).

Energy restriction leads to a reduction in myofibre size with a strong effect on type IIB atrophy (Yambayamba and Price, 1991; Ward and Stickland, 1993). Conversely, increased dietary energy results in a higher proportion of type IIB and less type IIA myofibres, while high protein diets appear to decrease the proportions of both type IIA and IIB myofibres (Johnston, Stewart, Moody, Boling and Kemp, 1975). Sex effects have been observed in myofibre response to nutrition. Brandstetter et al. (1998b) noted that energy restriction and re-alimentation did not

affect the myofibres of steers. Energy restricted bulls however increased oxidative activity but, on re-alimentation, the physiological: chronological myofibre profile was re-established. Yambayamba and Price (1991) observed a similar re-establishment of 'normal' myofibre composition and size on re-alimentation of previously restricted heifers.

Prolonged physical exertion generally causes age related changes on muscle fibre composition. It increases the proportion of oxidative myofibres, oxidative capacity, capillary density of myofibres, myoglobin content and glycogen storage capacity (Aalhus and Price, 1991). Such changes are expected to result in tough meat because red myofibres have less glycogen, are prone to cold shortening and have thicker z-line that are less susceptible to degradation post-mortem (Aalhus, Price, Shand and Hawrysh, 1991). However, Aalhus et al. (1991) reported tender SM from exercised compared to none exercised sheep. This was alluded to the increase in the myofibrillar-to-collagen protein ratio with exercise than to changes in myofibre type composition.

#### 2.1.1.1 Implications of myofibre composition on sampling for meat quality evaluation

Variations in myofibre composition within muscle in addition to the inter-muscle differences suggest that representative sampling procedures should be employed for meat quality evaluations. In the majority of meat science studies, the *M. longissimus thoracis et lumborum* (LTL) is used as the standard muscle for the evaluations. However, in goats this muscle is too small to obtain enough samples for all the standard procedures and hence other muscles such as the SM have also been used along with the LTL muscle (Babiker, El Khidir and Shafie, 1990; Schönfeldt et al., 1993a and b; Swan, Esguerra, and Farouk, 1998). There has been a suggestion that the two muscles are of similar type in cattle and sheep (Pethick, Cummins, Gardner, Jacobs, Knee, McDowell, McIntyre, Tudor, Walker and Warner, 2000) but there is no known classification of these muscles in goats. An understanding of the myofibre profile of the both the LTL and SM of goats would therefore be beneficial in making inferences on quality attributes observed on these muscles.

### 2.1.2 Conversion of Muscle to Meat

The stoppage of blood circulation at slaughter initiates a complex series of changes in muscular tissue which may be described in two phases. In the first phase, rigor mortis develops during

which muscles become inextensible and attain maximum toughness (Lawrie, 1998; Warriss, 2000). The major events accompanying rigor development are glycolysis and the denaturation of some proteins; of which the proteolytic enzymes are of particular interest. The second phase, known as conditioning, is characterised by a gradual improvement in tenderness during post-mortem storage, which is largely attributed to the activity of the calpains and other proteolytic enzymes (Lawrie, 1998; Warriss, 2000).

#### 2.1.2.1 Development of rigor mortis

The most immediate change caused by exsanguination is the cessation of oxygen supply to muscles (Lawrie, 1998). Consequently, production of ATP by oxidative respiration is arrested. Anaerobic respiration is stimulated in order to continue to maintain the integrity of cells and the relaxed state of muscles but the amount of ATP produced by this pathway is insufficient to plasticise actin and myosin for long (Tornberg, 1996). Concomitantly, the increasing acidity due to lactic acid production causes denaturation of proteins, including the glycolytic and related enzymes. The regeneration of co-enzymes, such as adenosine diphosphate (ADP) ceases (Greaser, 1986) and all these factors lead to the cessation of glycolysis. The net result is the cessation of the production of ATP and other energy-rich substrates. At extremely low concentrations of ATP (below 5 μmol/g; Warriss, 2000), the myosin filaments of the myofibrils bond with the overlapping actin filaments and the muscle becomes inextensible and rigid; rigor mortis sets in (Goll, Geesink, Taylor and Thompson, 1995).

#### 2.1.2.2 Post-mortem glycolysis

The important aspects of post-mortem glycolysis to meat quality are the rate at which it occurs as well as the extent to which it advances. Intrinsic and extrinsic factors affecting both these processes are listed in Table 2.1.

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**Table 2.1** Intrinsic and extrinsic factors affecting the rate and extent of post-mortem glycolysis

| Intrinsic factors | Extrinsic factors |
|---|---|
| **Animal species** | **Stress** |
| **Genotype** | **Pre-slaughter drug administration** |
| **Age** | *Environmental temperature* |
| Temperament | **Post-mortem temperature** |
| **Type of muscle** | *Electrical stimulation* |
| *Intramuscular location* | *Post-mortem comminution* |
| Pathology | *Post-mortem salting* |
| | *Post-mortem pressure* |
| | *Post-mortem oxygen tension* |

NB Factors that are in **bold font** affect **both** the rate and extent of glycolysis; in normal font affect the extent only; *italicised* affect the *rate only*

Adapted from Lawrie (1998)

### 2.1.2.3 Rate of post-mortem glycolysis

Of the extrinsic factors, the effect of temperature on the rate of post-mortem glycolysis is the single most influential factor on meat quality (Pearson and Young, 1989). The glycolytic rate is high at in vivo temperatures and falls as temperature declines to 5ºC (Lawrie, 1998). Within a carcass, various muscles will have different rates of post-mortem glycolysis depending on their myofibre type composition and their location within the carcass. White muscles are better adapted for efficient anaerobic metabolism and so their rate of post-mortem glycolysis can be significantly greater than that of red muscle (Fernandez and Tornberg, 1991; Przybylski, Vernin and Monin, 1994). The differences however may be partly obscured by the influence of the location of the muscle, with the deeper, and hence slow cooling muscles having higher rates than superficial ones.

The general principle in carcass chilling is that the temperature should drop as rapidly as possible to hinder microbial growth (Varnam and Sutherland, 1995). Paradoxically, a fast decline in temperature may result in cold shortening and tough meat. Cold shortening is due to the failure of the sarcoplasmic reticulum and the mitochondria to sequester calcium ions ($Ca^{++}$) quickly at low temperatures, such as when muscles are cooled to below 10ºC before the onset of rigor

mortis (Cornforth, Pearson and Merkel, 1980; Pearson and Young, 1989). The failure leads to a 30 to 40-fold increase in the concentration of $Ca^{++}$ in the sarcoplasm, which initiates a massive contraction stimulus (Pearson and Young, 1989). If such stimulation occurs while ATP concentration is still high, the resultant contractions deplete ATP; the muscles enter rigor in a contracted state and end up as tough meat (Pearson and Young, 1989).

Cold shortening is common to oxidative rather than glycolytic muscles (Totland et al., 1988; Ceña, Jaime, Beltran and Roncales, 1992). The former have more mitochondria and hence can release more calcium ions, but have a poorly developed sarcoplasmic reticulum and so cannot sequester the $Ca^{++}$ as fast as the white muscles. Cold shortening also occurs more in smaller carcasses, which are poorly insulated and are thus disposed to chilling fast. Consequently, cold shortening is more common in sheep than in cattle (Dikeman, 1996) and may be prevalent in goat carcasses.

Since cold shortening occurs when muscles attain rigor while they still have adequate energy to contract, the recommendation is that the pH of muscles should have dropped to below 6.2 when the temperatures falls to 15ºC and below (Honikel, Roncales and Hamm, 1983; Tornberg, 1996) or below pH 6.0 at 10ºC (Cornforth et al., 1980). To achieve this, a recommended protocol for chilling sheep carcasses is that they be chilled rapidly to 12 - 15ºC, held there for 18 hours and then dropped to below 5ºC (Varnam and Sutherland, 1995). Such a protocol is not acceptable in industry because it disrupts the normal flow through the abattoir and has a high risk of microbial contamination of the carcasses. Another option is to hold the carcasses in such a way that muscles in prime cuts are stretched, and hence are prevented from shortening during chilling at the normal 0ºC to 4ºC. Alternative carcass suspension methods such as tender-stretch and tender-cut have been proposed (Tarrant, 1998; Sørheim, Idland, Halvorsen, Frøystein, Lea and Hikrum, 2000). Above all these methods, electrical stimulation (ES) is widely recommended and employed to avert cold shortening in the meat industry (Savell, Smith, Dutson, Carpenter and Suter, 1977; Geesink, van Laack, Barnier and Smulders, 1994).

Electrical stimulation is the dissipation of ATP and other energy compounds in muscle by passing an electrical current through the muscle to cause intense contractions (Price and Schweigert, 1987). This promotes a rapid fall in pH (Figure 2.2), an earlier onset of rigor mortis

and tenderisation (Dransfield, 1994a). Because the carcass temperature would still be high after stimulation, the sarcoplasmic reticulum can sequester the released $Ca^{++}$ and with the contraction stimulant removed, muscles go into rigor in a relaxed state.

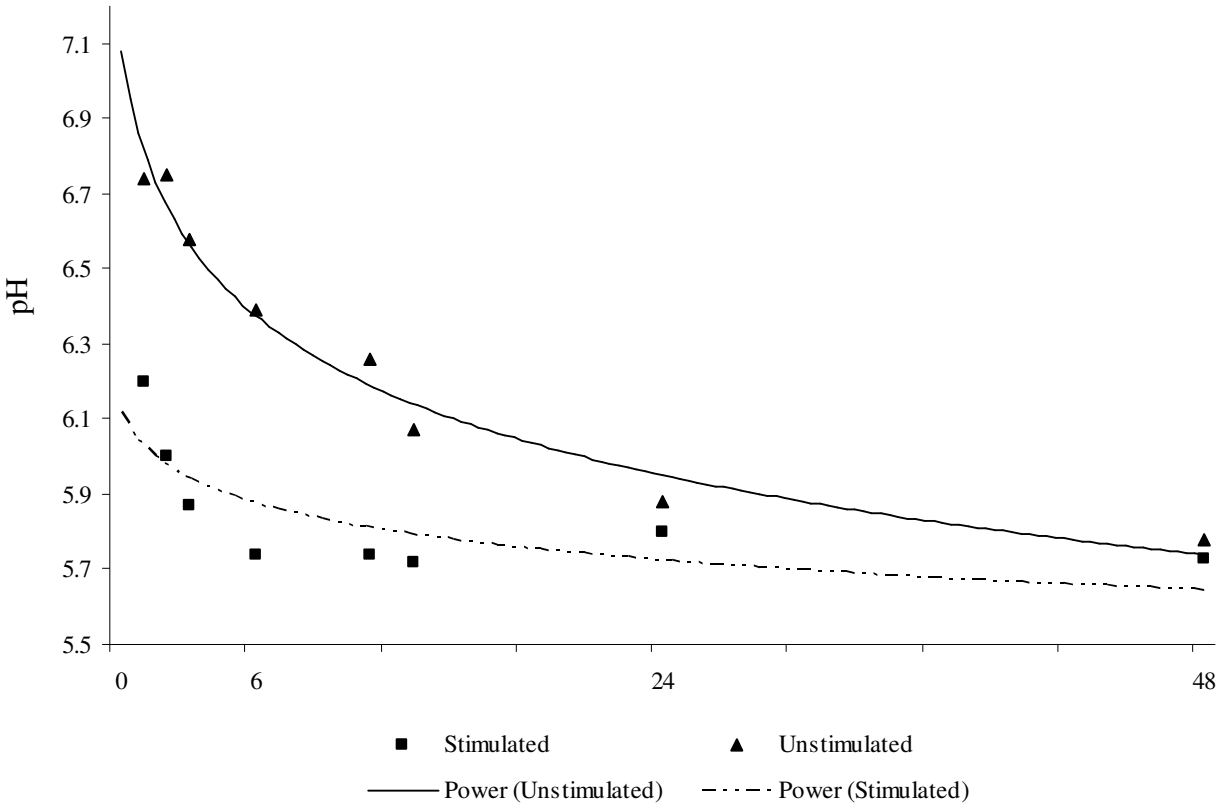


**Figure 2.2** Effect of electrical stimulation on the rate of pH decline (Adapted from Geesink, Mareko, Morton and Bickerstaffe, 2001)

### 2.1.2.4 Extent of post-mortem glycolysis

The extent of post-mortem glycolysis is reflected in the ultimate pH (pHu) attained by muscle. Ultimate pH is dependent on the amount of glycogen available to the muscle at slaughter and is attained when glycolysis ceases but not necessarily when glycogen is depleted (Warriss, Bevis and Elkins, 1989).

The normal glycogen content of skeletal muscle ranges from 30 to 100µmol/g depending on the nutritional status and activity of the animal and muscle type (Bechtel, 1986). Values between 80 and 100µmol/g have been reported for the LTL of well-fed and rested cattle (Warner, Walker,

Eldridge and Barnett, 1998). Glycolysis ceases when the muscle glycogen concentration is about 10µmol/g and lactic acid has increased from about 6-16µmol/g to 80-100µmol/g (Pearson and Young, 1989). The process takes 24 to 48 hours in cattle and some 12 to 24 hours in small ruminants (Dransfield, 1994a). Consequently small ruminant pHu is taken at 24 hours post-slaughter.

The ultimate pH is of particular importance to the chilled meat industry because it directly influences the shelf-life, colour and eating quality of meat (Fernandez and Tornberg, 1991; Przybylski, et al., 1994; Webby, Fisher, Lambert, Daly, Knight and Turner, 2000, Figure 2.3). The desirable range of pHu is 5.5 to 5.8, which is associated with light-coloured, tender meat (Gardner, Kenny, Milton and Pethick, 1999). In the range 5.9 to 6.2, meat is dark, tough, has a high water holding capacity (WHC) and is prone to bacterial spoilage (Warriss, Kestin, Brown and Wilkins, 1984; Warner et al., 1998). Above 6.2, meat has a purplish-black colour, firm texture, dry sticky surface and a reduced shelf-life (van Laack, Smulders and van Lojtestÿn, 1988). Meat with a pHu above 6.0 is associated with the dark cutting condition. The delineation of pH ranges for normal and dark cutting meat varies slightly amongst research groups (Tarrant, 1981), and hence the tendency is that each group defines the ranges they use.

Although pHu is acceptable as an indicator of the extent of glycolysis, there is considerable depletion in skeletal muscle glycogen (about 50% in some cases) before muscle pH shows any change (Warriss, 1990; Sanz, Verde, Sáez and Sañudo, 1996) because the relationship between pHu and pre-slaughter glycogen concentration is not linear (Brown, Bevis and Warriss, 1990, Gardner et al., 1999). Moreover, considerable glycolysis occurs during slaughter. For instance, in Gardner et al. (1999), lactic acid represented 6% and 10% of SM and ST muscle glycogen content of live sheep, respectively. Immediately after slaughter, the lactate concentration had increased to 27% and 43%, respectively. Therefore, for a better comprehension of the glycolytic process in the slaughtered animals, it is advantageous to determine the glycolytic potential (GP) in addition to the pHu values.

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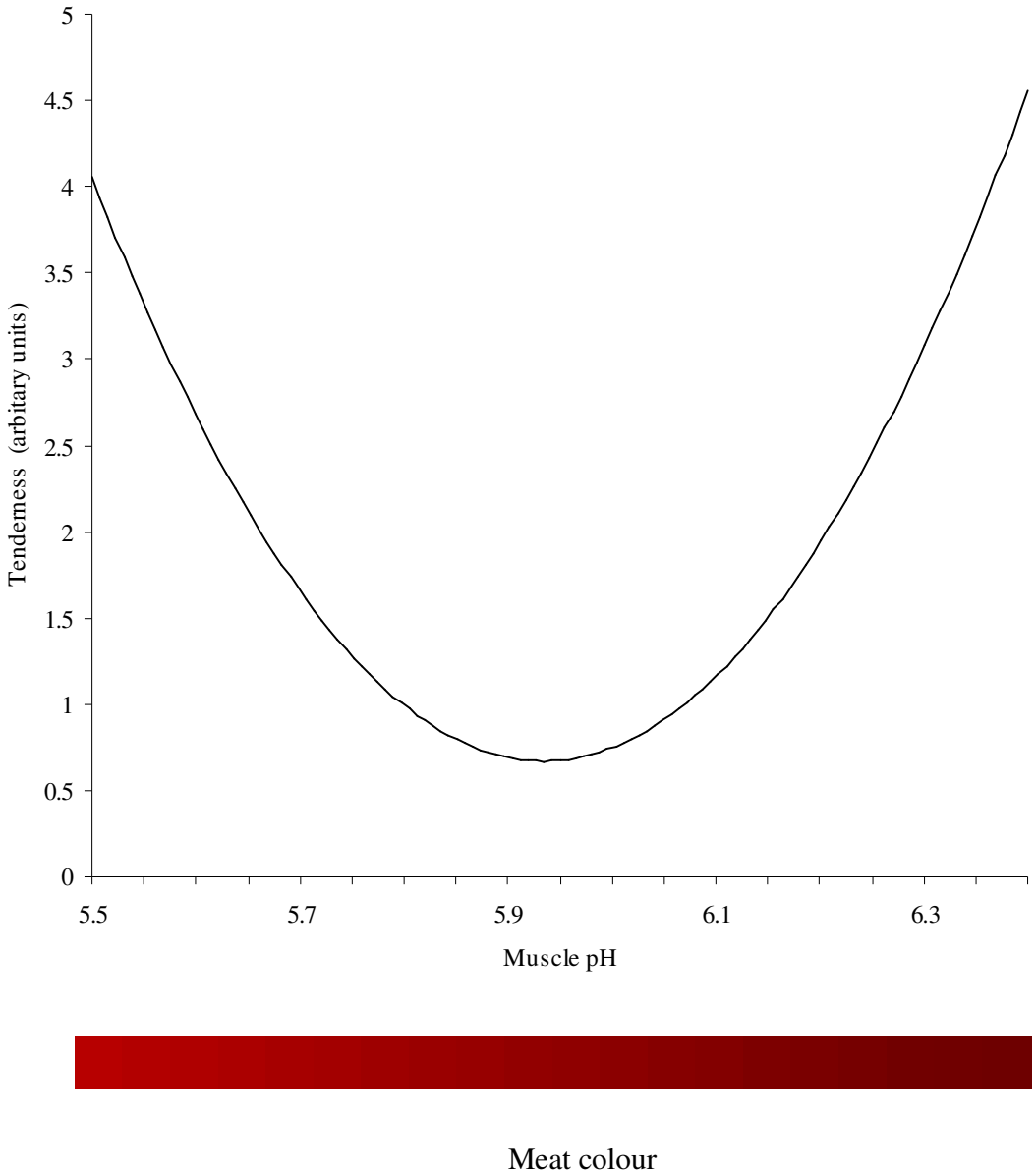


**Figure 2.3** Relationship between meat pH, tenderness and colour (Adapted from Wythes and Ramsay, 1979)

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Glycolytic potential is the sum of glycogen and its metabolites and is given by the following equation of Monin and Sellier (1985):

GP = 2([glycogen] + [glucose] + [glucose-6-phospahte]) + [lactate]

It is a measure of the total energy available to the animal pre-slaughter and the energy expenditure during and post-slaughter. It is a more sensitive indicator than pHu of whether carcasses will yield normal or dark cutting meat (Brown et al., 1990; Yambayamba, Aalhus, Price and Jones, 1998; Gardner et al., 1999).

The extent of glycolysis is influenced by the factors listed in Table 2.1 through their effect on the amount of glycogen available to the muscle at slaughter. The extrinsic peri-mortem stressors such as social and physical interactions, emotional excitement and unpropitious hormonal status and nutritional condition (McVeigh and Tarrant, 1982; McVeigh, Tarrant and Harrington, 1982) have a greater impact on pHu than the intrinsic factors. If these factors cause a depletion of glycogen reserves to critical levels, such as less than 65 µmol/g in the LTL of cattle (Shorthose and Wythes, 1988; Varnam and Sutherland, 1995), glycolysis ceases before pHu 5.5, resulting in meat which tends to the dark cutting condition at high pH (Brown et al., 1990). The critical concentration of glycogen has been set at a lower level of 50µmol/g in some instances (Monin, 1981; Purchas and Keohane, 1997).

### 2.1.2.5 Post-mortem tenderisation

The general consensus in meat science is that proteolysis of structural muscle proteins is the primary cause of post-mortem tenderisation of meat (Goll et al., 1995; Bickerstaffe, 1996; Koohmaraie, 1996). There are however, suggestions that changes in actin-myosin interactions (Goll, Thompson, Taylor and Ouali, 1998), non-enzymatic effect of calcium ions on muscle proteins (Takahashi, 1996) and/or a rise in ionic strength (Ouali, 1990) may be involved.

Three major enzyme systems have been implicated in tenderisation, namely: the calpain system (Koohmaraie, 1992; 1994), the multicatalytic protease (MCP) system (Orlowski, 1990) and the cathepsins (Penny, 1980). Current evidence points to that the calpain system plays the major role in muscle proteolysis (Uytterhaegen, Claeys and Demeyer, 1994; Koohmaraie, 1994; Dransfield,

1994b; Goll, et al., 1998; Sensky, Parr, Bardsley and Buttery, 2001). Koohmaraie (1994) built up a convincing argument to prove that the calpains are the only enzymes that fit the criteria for post-mortem proteolysis in that:

1) It has been established that increasing calcium in muscle results in increased tenderness and calpains are the only enzymes that have an absolute requirement for calcium ions (Koohmaraie, 1990a). Calcium has no effect on MCP (Koohmaraie, 1992) and may inhibit cathepsins (Barrett, 1973);
2) Calpains precisely reproduce post-mortem changes under *in vitro* conditions (Koohmaraie, 1994);
3) Calpains and MCP are localised in the cytosol, a requirement for post-mortem tenderisation enzymes (Koohmaraie, 1992) whereas cathepsins are in lysosomes that seem never to breakdown during post-mortem (Lacourt , Obled, Deval, Ouali and Valin, 1986 as cited by Koohmaraie, 1994).

#### *2.1.2.5.1 The calpains*

The calpains are responsible for the tenderisation that occurs up to 96 hours post-mortem (Dransfield, 1993). Their mode of action is thought to be through the degradation of costameric glycoproteins whose role is to maintain the structure of the sarcomeres and the filamentous structures linking adjacent myofibrils (Koohmaraie, 1994; Taylor, Geesink, Thompson, Koohmaraie and Goll, 1995; Goll et al., 1995). Degradation by the calpains significantly excludes the major myofibrillar proteins, actin and myosin, and the major Z-disk protein, α-actinin, all of which remain intact during normal tenderisation (Koohmaraie, 1994; Taylor et al., 1995). It thus appears that the role of calpains is to degrade the structural components of myofibres leaving substrates for possible degradation by other enzyme systems such as MCP (Koohmaraie, 1996) and cathepsins (O'Halloran, Troy, Buckley and Reville, 1997a). Calpains have thus been aptly labelled the rate-limiting step in the tenderisation process.

The calpain system consists of several ubiquitous and tissue specific enzymes but μ-, m- and p94 calpain are the three that are presently implicated in post-mortem tenderisation (Goll et al., 1998). Experimental evidence so far points to μ-calpain as the primary enzyme of post-mortem proteolysis. The enzyme is thought to be the first to be activated post-mortem as the pH declines to 6.02 and below, and intracellular calcium concentration rises from 0.1– 0.2 μM to over

100μM (Vidalenc, Cottin, Merdaci and Ducastaing, 1983; Jeacocke, 1993, Dransfield, 1993). Under normal muscle post-mortem conditions (pHu 5.5. to 5.8 and 5ºC) the enzyme retains 20 to 38% of at-death activity by 24 hours post-mortem (Koohmaraie, Schollmeyer and Dutson, 1986; Boehm, Kendall, Thompson and Goll, 1998, Figure 2.4). Such levels of activity are said to be sufficient to produce changes in myofibrils that are associated with stored meat (Koohmaraie et al., 1986).

The mechanisms of μ-calpain activities have not been fully elucidated. What is understood to date is that under conditions similar to post-mortem storage, the enzyme is active even under high concentration of its inhibitor, calpastatin, and this is evident from progressive autolysis and degradation of the inhibitor (Doumit and Koohmaraie, 1999) and degradation of myofibrillar proteins (Geesink and Koohmaraie, 1999a). Autolysed μ-calpain is however unstable under post-mortem conditions (Geesink and Koohmaraie, 2000) and hence the enzyme gradually loses its activity, especially under high temperatures, at which autolytic activity is greater than proteolytic activity. Consequently several studies have shown that muscles that go into rigor at temperatures above 25ºC yield tough meat (Marsh et al., 1987; Devine et al., 1996; Devine et al., 2002) owing to the reduction in calpain activity and hence ageing potential (Geesink, Bekhit and Bickerstaffe, 2000). μ-Calpain is thought to be responsible for the 50% tenderisation of muscles that occurs within the first 24 hours (Dransfield, 1994b).

m-Calpain is activated at calcium concentrations of 300 to 800 μM at pH 5.7 (Dransfield, 1993). There are doubts that such calcium levels are ever attained in normal physiological conditions. There are however suggestions that an adequate calcium concentration for m-calpain activation may be attained when the sarcoplasmic reticulum pump stops working and costameres are degraded, causing leakages in the sarcolemma, and hence an influx of $Ca^{++}$ into the sarcoplasm (Boehm, et al., 1998). Post-mortem m-calpain concentration is high throughout (Figure 2.4) and there is yet no explanation for the lack of autolysis that is expected of active calpains (Boehm et al., 1998).

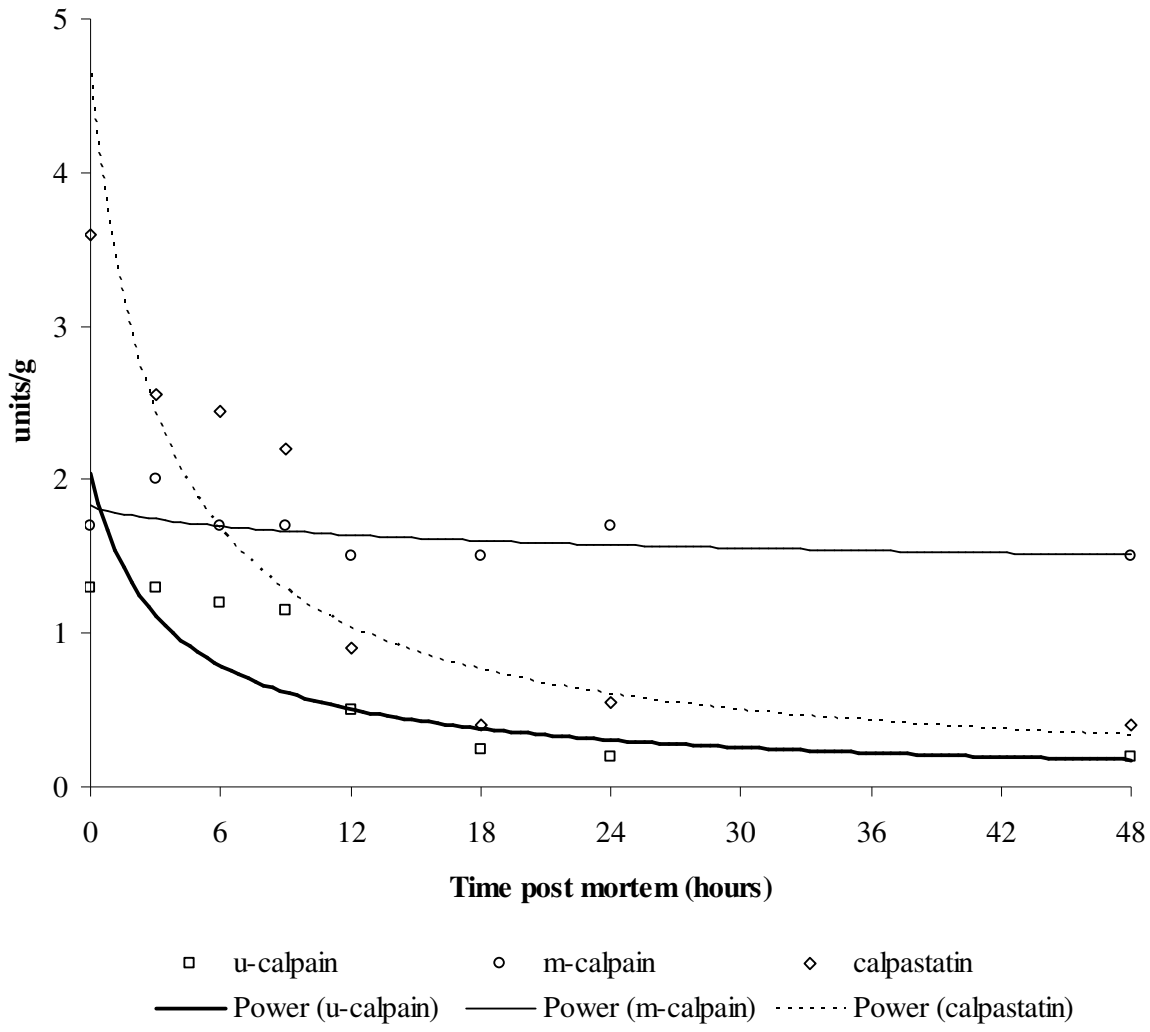


**Figure 2.4** Post mortem changes in u-calpain, m-calpain and calpastatin in the *longissimus* muscle of lamb (adapted from Bickerstaffe, 1996)

m-Calpain is said to be responsible for tenderisation that occurs beyond 24 hours post-mortem (Dransfield, 1994b) but other workers doubt its contribution because its concentration remains largely unchanged during post-mortem ageing (Vidalenc et al., 1983; Ducastaing, Valin, Schollmeyer and Cross, 1985; Geesink and Koohmaraie, 1999b) and because of its high calcium requirements (Goll et al., 1995).

Calpain p94 was discovered more recently by Sorimachi, Ishiura and Suzuki (1989). It has been observed to bind to titin at the $N_2$-line, a site at which proteolysis in the early post-mortem period

has been linked to tenderisation. (Geesink et al., 2000). There is evidence that this enzyme could be one of the major proteases of post-mortem tenderisation (Ilian, Morton, Kent, le Couteur, Hickford, Cowley and Bickerstaffe, 2001). Its role is however not yet fully understood, mainly because it is not easily extractable from muscles and it undergoes rapid autolysis at physiological levels of calcium ions (Geesink et al., 2000).

#### *2.1.2.5.2 Calpastatin*

Calpastatin in the allosteric inhibitor of the calpains. The *in vivo* activity of this enzyme is high at high pH, such as soon after death (Figure 2.4) but its levels drop as the pH declines, mainly as a result of degradation by the calpains (Dransfield, 1993). As the pH falls from 6.5 to 5.7, the enzyme is inactivated but μ-calpain activity increases from 15% to 97% of at-death activity (Dransfield, 1993), and hence the extent of tenderisation increases. Meanwhile, calpastatin activity drops to some 20% to 70% of at-death activity by 24hours post-mortem (Dransfield, 1993; Figure 2.4).

#### *2.1.2.5.3 Factors influencing concentration of calpains*

Concentration of μ- and m-calpain are less variable but the inhibitor varies significantly with species (Ouali and Talmant, 1990; Koohmaraie, Whipple, Kretchmar, Crouse and Mersmann, 1991a), genotype (Shackelford, Koohmaraie, Miller, Crouse and Reagan, 1991), β-adrenergic agonist administration (Koohmaraie, Shackelford, Muggli-Cockett and Stone, 1991b), sex (Morgan, Wheeler, Koohmaraie, Savell and Crouse, 1993a), myofibre types (Ouali and Talmant, 1990) and stress (Sensky, Parr, Bardsley and Buttery, 1996; Parr, Sensky, Arnold, Bardsley and Buttery, 2000). In all these instances animals that yielded tougher meat had elevated levels of calpastatin and little or no differences in the μ- and m-calpain levels. Therefore, since calpastatin levels vary more widely in response to different treatments than the calpain levels do, it ay be concluded that muscle calpastatin and not muscle calpain activity is related to the degree of post-mortem tenderisation (Ouali and Talmant, 1990; Koohmaraie, Killefer, Bishop, Shackelford, Wheeler, and Arbona, 1995a; Goll et al., 1998; Sensky et al.; 2001).

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## 2.2 MEAT QUALITY FACTORS

Meat quality is objectively defined as the sum of all quality factors of meat (Hofmann, 1994). The quality factors may be presented in groups that are closely related and determine a defined component of meat quality (Table 2.2).

**Table 2.2** The major components and factors of meat quality

| Component | Meat quality factors |
|---|---|
| Yield and gross composition | Ratio of fat to lean |
| | Muscle size and shape |
| Appearance and technical characteristics | Colour and water holding capacity of lean |
| | Fat texture and colour |
| | Marbling (intramuscular fat) |
| | Chemical composition of lean |
| Palatability | Texture and tenderness |
| | Juiciness |
| | Flavour |
| | Aroma |
| Wholesomeness | Nutritional quality |
| | Chemical safety |
| | Microbial safety |
| | Acceptable animal husbandry |

Adapted from Hofmann (1994)

The quality factors related to visual appeal (colour, water holding capacity and fatness) and palatability (tenderness, juiciness, flavour and aroma) are regarded as the key factors that determine consumers' initial and continued interest in the meat (Chambers IV and Bowers, 1993; Issanchou, 1996). These factors may be evaluated directly or indirectly by various physical, biochemical, histological and sensory analyses.

# CHAPTER 2

### 2.2.1 Meat Colour

Colour is one of the most important factors in consumers' selection and decision to purchase meat and meat products (Hedrick, Aberle, Forrest, Judge and Merkel, 1994). It is considered to be the single most influential criterion in this process (Kropf, 1980). For that reason an assessment of colour is included in some carcass classification systems (e.g. USDA, 1994 as cited by Page, Wulf and Schwotzer, 2001).

The characteristic colour of meat is a function of its pigment content and light scattering properties (MacDougall, 1982, Ledward, 1992). Myoglobin is the basic pigment in fresh meat and its content varies with production factors such as species, animal age, sex, feeding system, exercise, type of muscle and muscular activity (Ledward, 1992; Varnam and Sutherland, 1995). Myoglobin's physio-chemical state; i.e. purple reduced myoglobin, red oxymyoglobin and brown metmyoglobin, determines the colour of fresh meat (Varnam and Sutherland, 1995; Lawrie, 1998). Formation of the desirable oxymyoglobin is enhanced by conditions that increase oxygen solubility, such as low temperature, low pH, high oxygen tension, and low enzyme activity (MacDougall, 1982, Ledward, 1992).

Meat pH has a great effect on colour development (Abril, Campo, Önenç, Sañudo, Albertí and Negueruela, 2001; Figure 2.3) through its effect on the physical state of muscle proteins. At high pHu (>6.0), myofibres hold a lot of water which swells them up (Offer and Trinick, 1983). At such high myofibrillar volume, incident light is able to penetrate considerable depth and be absorbed by myoglobin before it is scattered (MacDougall, 1982). The meat appears translucent and dark. Furthermore, enzymes that use up oxygen are more active resulting in less oxygenation of the surface myoglobin and a dark colour (Price and Schweigert, 1987; Ledward, 1992). At normal pHu (~5.5), the myofibres hold less water, and oxygen utilising enzymes are less active. The meat appears brighter and glossier (Ledward, 1992). At the other extreme, low pH meat is pale (MacDougall, 1982; Ledward, 1992). This is due to that reduced myofibrillar volume (Offer and Trinick, 1983) as well as that denatured myosin and sarcoplasmic proteins increase the refractive properties of the meat (MacDougall, 1982; Offer and Trinick, 1983). Consequently more incident light is scattered at shallow depths of penetration and relatively little is absorbed by myoglobin.

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Besides its strong relationship with pH (Orcutt, Dutson, Cornforth and Smith, 1984; Purchas, 1990; Watanabe, Daly, and Devine, 1996), meat colour is also highly correlated with water holding capacity, evidently because the changes in myofibrillar lattice with pH also affect the ability of the muscle to retain water. Meat colour is reported to be related to tenderness (e.g. Purchas, 1990; Jeremiah, Tong and Gibson, 1991; Watanabe et al., 1996; Wulf, O'Connor, Tatum and Smith, 1997) and carcass fatness (e.g. Tatum, Smith and Carpenter, 1982; Page et al., 2001).

Meat colour is objectively defined often in terms of the Hunter colorimetric co-ordinates, L*, a* and b* (Warriss, 2000). L* is the lightness component, indicating the black-whiteness of the meat. Its values range from 0 (all light absorbed) to 100 (all light reflected); a* spans from -60 (green) to +60 (red) and b* spans from -60 (blue) to +60 (yellow) (Young, Priolo, Simmons and West, 1999). Other parameters may be calculated from these basic three, such as hue angle [$\tan^{-1}$ (b*/a*)], which describes the fundamental colour of a substance; and chroma [$\sqrt{}$ ($a^{*2}+b^{*2}$)], which describes the vividness of the colour. Hunter a* and chroma have been observed to be strongly related to visual colour scores (Eargerman, Clydesdale and Francis, 1978).

#### 2.2.1.1 The colour of chevon

Some L*, a* and b* values that have been reported for SM and *M. longissimus* of goats are shown in Table 2.3. Babiker and Bello (1986) compared the effects of different post-mortem rates of chilling and found that although exposing carcasses to high ambient temperatures post-mortem resulted in lower L* and b* values, the differences were not perceived by consumers. In another case, a taste panel did not perceive colour differences between meat from Sudanese desert lambs and kids, even though the chevon had lower L* and b* and higher a* values (Babiker, et al., 1990). The differences in the meat colour in these studies may have been in a range that was too narrow to be detected by consumers.

Dhanda Taylor, Murray and McCosker (1999) reported chevon became darker with increase in age. On the other hand Nuñez Gonzalez, Owen, and Arias Cereceres (1983) did not observe differences in the colour of chevon from goats ranging from 8kg to 24kg.

**Table 2.3** Hunter colorimetric co-ordinates of goat *M. semimembranosus*[1] and *M. longissimus thoracis*[2]

| Goat | Weight | L* | a* | b* | Source |
|---|---|---|---|---|---|
| Male Sudanese desert[1] | 28-30 kg | 31.97<br>32.43<br>33.98 | 16.47<br>16.40<br>17.48 | 8.65<br>8.77<br>9.60 | Babiker and Bello (1986) |
| Sudanese desert[1] | 35kg | 34.80 | 13.10 | 8.65 | Babiker et al. (1990) |
| Boer x Angora[2] | 32.4kg | 37.7 | 12.0 | 3.0 | Dhanda et al. (1999) |
| Boer x Saanen[2] | 36.2kg | 37.7 | 14.8 | 2.1 | |
| Feral[2] | 30.6kg | 37.1 | 14.4 | 2.0 | |
| Saanen x Angora[2] | 34.1kg | 37.0 | 14.0 | 2.5 | |
| Saanen x Feral[2] | 36.0kg | 34.6 | 12.7 | 1.7 | |
| Boer crosses[2] | Capretto | 42 | 13 | 3 | Husain, Murray and Taylor (2000) |
| Spanish does[1] | - | 42.5 | 17.8 | 8.9 | Kannan, Kouakou and Gelaye (2001) |

### 2.2.2 Water in Meat

Fresh meat contains about 75% water at slaughter (Offer and Trinick, 1983). Some of this water is lost post-slaughter in one of three ways. First are evaporative losses, which occur during carcass chilling and from the surface of cuts on display. Chilling losses are about 3% in normally processed beef carcasses but may be reduced by rapid chilling (Offer, Restall and Trinick, 1984). The latter is however not practised because it may lead to cold shortening, which could mean a greater loss in meat quality. Second is drip loss, which occurs from cut surfaces of meat. High drip loss is undesirable because it detracts from the appeal of the meat, and valuable proteins and flavour compound are lost in the exudate (Varnam and Sutherland, 1995; Lawrie, 1998). Drip loss is normally in the order of 3% in beef but may be exacerbated by very low pHu and by freezing and thawing to as much as 15% (Offer, et al., 1984). Chilling and drip losses not only affect the appeal of the meat but reduce its weight, and hence economic value. Finally, during cooking, even greater losses that may be as high as 40% occur (Offer et al., 1984). High cooking

losses not only reduce the size of the meat portion but also result in reduced succulence and tenderness and loss of flavour.

The ability of meat to retain its natural water content is termed water holding capacity (WHC, Hamm, 1986). Most of the water is held in the interfilament spaces within the myofilament lattice. The amount held depends on the volume of the interfilament spaces (Offer and Trinick, 1983) which in turn is determined by pH, sarcomere length, ionic strength, osmotic pressure and whether the muscle is in pre- or post-rigor (Offer and Trinick, 1983).

Water holding capacity is high at high muscle pH and in fact water is not readily lost from meat that is cut soon after slaughter (Offer and Trinick, 1983). This is because at high pH, the net negative charge of myofilaments results in strong repulsive electrostatic forces between the filaments, which push the filaments apart, swells the up the lattice and hence increases the space where the water is lodged. As the pH declines, the negative charge and hence the repulsive force of the filaments is gradually lost to a point when the filaments have no net charge, at the iso-electric point of actin and myosin (about pH 5.0, Hamm, 1986). The myofilaments relax, thus shrink the interfilament space and in so doing expel the water. The expelled water accumulates in the space between the muscle fibres and the endomysium and is driven to the cut surfaces by the pressure of the endomysium (Offer et al., 1984). Water holding capacity of meat is at it's lowest at pH 5.0 and any alteration of pH in the range 5.0 to 6.5 has a great influence on WHC (Hamm, 1986).

Cooking losses occur through a similar mechanism to drip loss. The denaturation of the myosin at 40 to 53ºC (Bendall and Restalll, 1983) causes a transversal shrinkage in the myofibres and a slow loss of water from the myofibres. At 60ºC, the collagen of the basement membrane shrinks, resulting in rapid fluid loss from the myofibres (Bendall and Restall, 1983). Above 64ºC collagen of the perimysium and endomysium network shrinks (Sims and Bailey, 1981; Bendall and Restall, 1983; Bailey, 1984) and thus exerts more pressure on the aqueous solution leading to a rapid loss of volume of the cooked meat.

The WHC of meat is closely correlated to meat colour in that both factors are largely determined by the effect of pH on the myofilament lattice structure (Offer and Knight, 1988). Water holding

capacity also increases with increase in intramuscular fat content, probably because the fat loosens up the myofibre microstructure and allows more water to be entrained (Lawrie, 1998). It is for this reason that good quality meat loses less water during cooking (Lawrie, 1998) besides the fact that it has less water and more fat.

In addition to its effect on the aesthetic appeal of the meat, WHC affects the technological value the meat; how well it can be processed into other products. An example is that although it is aesthetically unappealing, dark cutting meat is perfectly acceptable for a number of manufacturing purposes because of its high WHC (Hofmann, 1994).

Water holding capacity of fresh meat is best determined by gravity and suction methods that do not destroy the tissue or denature the proteins (Hofmann, 1994, Honikel, 1998). Cooking loss is recommended for heated meat (Hofmann, 1994).

#### 2.2.2.1 Water losses in chevon

Evaporative losses during chilling are probably the first water losses to have an impact on the appeal of chevon because the carcasses are relatively lean and have a high surface area to volume ratio. The losses tend to be higher for smaller than the larger carcasses. This was shown in a study conducted in Zimbabwe in which chilling losses from goats that were less than 35kg were about 3% while the losses from heavier goats were only 2.3% (Simela, Gumede, Ndlovu and Sibanda, 2000c).

While water remaining in the cooked product is the major contributor to the sensation of juiciness (Forrest, Aberle, Hedrick, Judge and Merkel, 1975), chevon cooking losses are often close to or over 35% (Babiker and Bello, 1986; Babiker et al., 1990; Swan et al., 1998; Dhanda et al., 1999). Cooking losses of the meat are possibly exacerbated by its limited fat content (Lawrie, 1998). It is partly because of these high losses that chevon has been perceived to be less juicy than lamb or mutton (Pike, Smith and Carpenter, 1973a, Schönfeldt et al., 1993b; Tshabalala et al., 2003) and beef (Pike et al., 1973a).

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### 2.2.3 Fat in Meat

Fats are present in meat as structural components of muscle membranes and as storage droplets between muscle fibres. The latter constitute what is perceived as marbling (Varnam and Sutherland, 1995). Marbling affects consumers' visual appreciation and their perception of the eating quality of the meat, and hence their decision of whether or not to buy the meat (Issanchou, 1996; Brewer, Zhu, and McKeith, 2001). Increased marbling is associated with good eating quality (Dolezal, Smith, Savell and Carpenter, 1982; Fernandez, Monin, Talmant and Mourot, 1999). Dolezal et al. (1982) demonstrated this phenomenon in that juiciness, tenderness and flavour desirability increased with increase in beef marbling score. In a similar line of research, Fernandez et al. (1999) reported an increase in ratings for pork flavour, tenderness and juiciness with increase in intramuscular fat content.

Even though it may be associated with good eating quality, excessive marbling is unacceptable to consumers. This was aptly illustrated in the work of Brewer et al. (2001) in which consumers expressed a higher degree of purchase intent for leaner than for highly marbled pork chops but found the latter more juicy, tender and flavourful than the lean ones in a 'blind' sensory test.

The extent of marbling and the colour of fat in red meat modify consumers' perception of the meat colour. Consumers appreciate white fat but yellow fat, such as that of beef from dairy cows or grass fed animals, may be less appealing (Varnam and Sutherland, 1995). Fat stained by blood from drip also reduces the visual appeal of meat.

Fats are implicated in the oxidative stability of meat and hence its shelf life (Gray, Gomaa and Buckley, 1996; Morrissey, Sheehy, Galvin, Kerry and Buckley, 1998; Enser, 2001). The oxidative stability of meat is dependent on the balance between oxidative substrates (e.g. the polyunsaturated fatty acids of the phospholipids); pro-oxidants (e.g. haeme proteins such as myoglobin, haemoglobin and cytochromes) and anti-oxidants (e.g. vitamin E,) (Morrisey et al., 1998). Once the balance is upset, oxidative deterioration occurs and results in adverse changes in colour, flavour, texture, nutritive value and possibly the production of toxic compounds (Kanner, 1994; Gray et al., 1996).

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The interest in fat in relation to consumer health lies in its content of essential fatty acids (EFAs), polyunsaturated/saturated fatty acids ratio, n-3/n-6 ratio and conjugated linoleic acid (CLA) and cholesterol. The basic EFAs are linoleic (18:2n-6) and linolenic (18:3n-3) acids. These fatty acids cannot be synthesised in human tissues but are required for the synthesis of prostaglandins, prostacyclins and thromboxenes. An intake of 1–2% of total calories as EFA is recommended (Mead, Alfin-Slater, Howton and Popják, 1986).

Linoleic acid is one of the most abundant PUFA, particularly in animals raised on grain based diets (Wood and Enser, 1997, Fisher, Enser, Richardson, Wood, Nute, Kurt, Sinclair and Wilkinson, 2000). In recent years there has been increased interest in its geometric isomer, CLA, which occurs naturally in meat particularly that of ruminants off grass diets (Shantha, Moody and Tabeidi, 1997; Enser, 2000). Conjugated linoleic acid is associated with several health enhancing properties such as anti-carcinogenesis, anti-artherogenesis, anti-diabetes, immuno-modulation and shifting the partitioning of energy towards protein instead of fat deposition (Cannella and Giusti, 2000; Stanley and Hunter, 2001).

Linoleic acid and other polyunsaturated fatty acids (PUFA) of the n-6 series have a desirable hypocholesterolaemic effect of reducing low-density lipoprotein (LDL)-cholesterol (Wiseman, 1997). N-3 PUFA (particularly eicosapentanoic acid and docosahexanoic acid) are similarly desirable because of their antithrombogenic effect and their association with low mortality from cardiovascular diseases (Wiseman, 1997). On the other hand saturated fatty acids, especially lauric (12:0) and myristic (14:0) acids increase total blood LDL- and high density lipoprotein (HDL)-cholesterol as well as the LDL:HDL ratio (Khosla and Hayes, 1994). These conditions are conducive to cardiovascular diseases. Some researchers also implicate palmitic acid (16:0) but Khosla and Hayes (1994) and Ng (1994) suggested that 16:0 only enhances hypercholesterolaemia in persons who already have high concentration of cholesterol. MUFA and stearic acid (18:0) are considered neutral in this effect (Voet and Voet, 1990). For these reasons, dieticians recommend fats that are high in PUFA, low in SFA and cholesterol.

The recommendations by the British Department of Health are that the energy supply by fats in a diet should not exceed 35% (Wood and Enser, 1997) while the USDA recommends less than 30% (Lichtenstein, Kennedy, Barrier, Danford, Ernst, Grundy, Leveille, van Horn, Williams and

Booth, 1998). Both Departments recommend that energy from SFA should be limited to less than 10% of the dietary total energy. The PUFA/SFA ratio should be between 0.4 and 1.0 (Enser, 2000). This ratio is easily attainable with non-ruminant meats such as pork, chicken and fish but ruminant meat normally has a ratio of 0.1 or less (Marmer, Maxwell and Williams, 1984; Enser, Hallett, Hewitt, Fursey, Wood and Harrington, 1998).

The fat content of meat is assessed in several ways. In industry, the traditional online methods are the visual scoring of carcass subcutaneous fat cover or measuring fat depth at specified points on the carcass, usually along the LT (Fisher and De Boer, 1994). In the laboratory, intermuscular and subcutaneous fat are traditional determined by dissections of a side or three rib sample (Miller, Cross, Bakers, Byers and Recio, 1988; Fisher and De Boer, 1994). Intramuscular fat is determined by extraction with an organic solvent such as light petroleum (Boccard et al., 1981). In addition to these methods that are several methods that have been developed for live animal and carcass evaluations, particularly for use in the industry. These include techniques such as ultrasound imaging, optical lean/fat probes, x-ray computerised tomography and magnetic resonance imaging (Cross and Belk, 1994; Monin, 1998). The detailed composition of fats, such as fatty acid and cholesterol content, is determined by chromatographic analysis (Maxwell and Marmer, 1983).

#### 2.2.3.1 Fat in chevon

Development of fat in goats occurs very late and only reaches appreciable levels when the animals are near or at their mature body weight (Owen, Norman, Philbrooks and Jones, 1978.; Owen, Arias Cereceres, Garcia Macias and Nuñez Gonzalez, 1983). The fat content is highly variable and is influenced by such factors as age, sex, body weight and growth rate (Owen et al., 1978, Kirton, 1988). Most of the fat is deposited in the visceral rather than carcass depots and hence goat carcasses are lean (Devendra and Owen, 1983; Kirton, 1988). Typically goat carcasses have about 60% dissectible lean and 5% to 14% dissectible fat (Devendra and Owen, 1983; Norman, 1991). Their subcutaneous fat cover is negligible (Pike, Smith, Carpenter and Shelton, 1973b; Dhanda et al., 1999; Simela, Ndlovu and Sibanda, 1999) and in too narrow a range to allow for the creation of meaningful classes (Pike et al., 1973b; Smith, Carpenter and Shelton, 1978; Devendra and Owen, 1983; Simela et al., 1999). For that reason, a measure of subcutaneous fat depth is not perceived as a useful quality indicator for goat carcasses (Pike et

al., 1973b; Simela et al., 1999) and hence is not employed in some goat carcass classification systems such as the South African one (SAMIC, 2004). In cases where subcutaneous fat is included in goat carcass classification, its assessment is often based on classifications developed for sheep carcasses (e.g. Government of Zimbabwe, 1995). This has resulted in the downgrading of the carcasses because of inadequate fat (Devendra and Owen, 1983; Simela, Ndlovu and Sibanda, 1998). One advantage of the low fat content of chevon is that the actual amount of the undesirable fat that is ingested by consumers per unit of chevon is much lower than for meats that have inherently higher fat content, such as beef and mutton (Teh, 1992).

### 2.2.4 Meat Juiciness

Lawrie (1998) brings out that juiciness in cooked meat has two organoleptic components. First is the impression of wetness during initial chewing, which is due to the rapid release of meat fluids. Second is the sustained juiciness resulting from the stimulatory effect of fat on salivation. The latter component explains why, for example, meat from young animals gives an initial impression of juiciness but ultimately a dry sensation due to the relative absence of fat (Lawrie, 1998). By the same token good quality meat is juicier than poor quality meat because the former has a higher intramuscular fat content.

Juiciness is related to WHC and marbling. In conjunction with tenderness, it accounts for the overall eating quality and consumers may confuse the two factors when making assessments or comparisons (Varnam and Sutherland, 1995).

In meat research, juiciness is usually determined by sensory evaluation or inferred from measures of water in meat, such as WHC and cooking losses.

#### 2.2.4.1 Juiciness of chevon

Chevon and/or chevon products have been reported to be less juicy than lamb and/or mutton products (Pike et al., 1973a; Schönfeldt et al., 1993b; Tshabalala et al., 2003), a fact that has been attributed to the low fat content of chevon. Within the species, young goats yield juicier chevon, but this depends on the age of the animals under consideration. For example, Schönfeldt et al. (1993b) found that young goats with carcasses ranging from about 10 to 25kg were juicier than the older goats with carcasses ranging from 15 to 30kg. In contrast, Pike et al. (1973b) and

Smith et al. (1978) compared kids with carcasses of 5 to 7kg to yearling goats with carcasses of 12 to 13kg and found the older goats more juicy and palatable. The findings suggests that there is an optimum age/weight at which to slaughter goats to obtain good quality chevon.

### 2.2.5 Meat Flavour and Aroma

Aroma is a result of the sensory of certain volatile substances by the olfactory organs (Lawrie, 1998). The flavour of meat is attributed to a complex mixture of compounds produced by heating the heterogeneous system containing its precursors (MacLeod and Seyyedain-Ardebili, 1981). It is composed of volatile compounds that give rise to the odour properties; non-volatile or water soluble compounds with taste tactile properties and, potentiators and synergists of flavour (MacLeod and Seyyedain-Ardebili, 1981). The water-soluble fraction of meat provides the basic meaty flavour and aroma while fat provides the species characteristic flavour and aroma, albeit in interaction with the former (Mottram and Edwards, 1983; Moody, 1983; Melton, 1990).

Phospholipids have been specifically implicated in flavour development. The phospholipids appear to provide sufficient lipids for flavour and aroma development while the triacylglycerides seem not to be essential (Mottram and Edwards, 1983) such that there may be no change in flavour with increase in carcass fatness (i.e. increase in triacylglycerides). In fact the effect of the phospholipid fraction may be diluted by the higher concentration of triacylglycerides in fat animals (Fisher et al., 2000), resulting in a weaker aroma and flavour of fatter meat. This is so because the phospholipids content in fat is fairly constant while that of triacylglycerides increases with increase in fatness. PUFA of the n-6 and n-3 series produce different flavours (Kemp, Mahyuddin, Ely, Fox and Moody, 1981; Larick and Turner, 1989; Fisher et al., 2000). Fisher et al. (2000) suggest that it is variation in the absolute concentrations as well as the relative proportions of the different fatty acids that lead to different flavour profiles.

Fats influence the flavour of meat in two ways. One is the oxidation, principally of unsaturated fatty acids (UFA), which yields carbonyl compounds that at one level of concentration produce desirable flavours and at another, undesirable flavours (Moody, 1983). Secondly fats serve as a depot for fat-soluble compounds that volatilise upon heating and strongly affect flavour. Many of the flavour compounds are produced during cooking as a result of reactions such as the Maillard reaction, Strecker degradation, lipid peroxidation and their interactions (Moody, 1983).

### 2.2.5.1 Flavour and aroma of chevon

Branched chain fatty acids (BCFA) have been specifically implicated in sheep and goat species-related flavour (Wong, Nixon and Johnson, 1975; Johnson, Wong and Birch, 1977; Ha and Lindsay, 1990). Of these fatty acids, 4-ethyloctanoic acid is associated with a powerful goaty odour and has been detected in lamb and mutton (Brennand, 1989 as cited by Madruga, Arruda, Narain and Souza, 2000; Ha and Lindsay, 1990), goat (Ha and Lindsay 1990; Brennand, Ha and Lindsay, 1989) and caprine and ovine cheese (Ha and Lindsay, 1991a). The compound has not been detected in veal, beef, pork, venison (Ha and Lindsay 1990) and bovine cheese (Ha and Lindsay, 1991a). Other BCFA implicated in goat-like flavour are 4-methyloctanoic, 4-methylnanoic (Wong et al., 1975; Brennand, 1989 as cited by Madruga et al., 2000) and 4-ethylheptanoic (Ha and Lindsay, 1990). Alkyloids, pyridines and sulphur containing compounds are other notable flavour compounds that have been identified in chevon and mutton, but were said to be unlikely to play a major role in the development of goat flavour (Ha and Lindsay, 1991b).

In most studies, sensory evaluation of the acceptability, intensity and species specificity of flavour are often reported. Schönfeldt et al. (1993a) evaluated the effect of species, age and fat class on the species specificity and acceptability of chevon and lamb/mutton flavour. They noted that the effects depended on the muscle and the method of preparation used. Where significant differences occurred, sheep flavour was rated more species specific and more acceptable than that of the goats. The flavour of meat from animals with no permanent incisors was more acceptable than that from the older groups, while the flavour of the group with between 1mm and 4mm subcutaneous fat thickness was deemed more acceptable than that of the groups with more or less subcutaneous fat. Other studies have observed similar trends with respect to comparisons of chevon to mutton; that the flavour of chevon is either as acceptable (Babiker et al., 1990; Griffin, Orcutt, Riley, Smith, Savell and Shelton, 1992) or less desirable (Pike et al., 1973a) than that of lamb/mutton.

Within the species age effects have depended on the range of ages under consideration. Amongst Schönfeldt et al.'s (1993a) goats, the younger goats (10 to 25kg carcass) had a more desirable flavour than the older ones (15 to 30kg carcass) but, where very young animals were compared

to older animals, the flavour of the latter was more acceptable (Pike et al., 1973a; Smith et al., 1978; Griffin et al., 1992).

### 2.2.6 Meat Tenderness

Meat tenderness is rated as the most important attribute of eating quality and is the factor that determines consumers continued interest in meat (Issanchou, 1996; Boleman, Boleman, Miller, Taylor, Cross, Wheeler, Koohmaraie, Shackelford, Miller, West, Johnson and Savell, 1997). Tenderness is defined as the ease of mastication, which involves the initial ease of penetration by the teeth, the ease with which the meat breaks into fragments and the amount of residue remaining after mastication (Lawrie, 1998). The two major determinants of meat tenderness are the content and state of the connective tissue and the structure and state of the myofibrils (Dutson, Hostetler and Carpenter, 1976). The two components are modified to some extent by intramuscular fat and the sarcoplasmic proteins (Lawrie, 1998).

#### 2.2.6.1 Collagen and its contribution to meat tenderness

Connective tissue toughness is often referred to as background toughness because the tissue hardly changes during the standard lengths of meat storage post-mortem (McCormick, 1994). Connective tissue accounts for less than 10% of the total variance in meat tenderness (Harper, 1999). Its contribution to toughness is believed to be a product of the state of connective tissues in the perimysium, which constitutes some 90% of the intramuscular connective tissue (Light, Champion, Voyle and Bailey, 1985). Collagen is the predominant protein of perimysial and endomysial connective tissues, constituting some 1.6 to 14.1% of the dry matter weight of muscle (Purslow, 1999). Collagen characteristics, mainly the content and solubility, are thus the basis for the determination of connective tissue contribution to meat toughness.

In addition to the biochemical methods of determining connective tissue contribution to meat tenderness, rheological methods are also used. In such instances, connective tissue toughness is perceived as the difference between initial and peak force of the Warner-Bratzler deformation curves (Bouton, Harris and Shorthose, 1975). The degree to which the meat is cooked is important in this determination (Warriss, 2000). It has been shown that between 52ºC and 70ºC, collagen shrinks during cooking, which increases the toughness of the meat (Bendall and Restall,

1983). Above 70ºC, collagen gelatinises and the extent to which this happens depends on the length of the cooking time (Bailey and Light, 1989).

#### 2.2.6.2 Myofibrillar contribution to meat tenderness

Myofibrillar contribution to meat tenderness depends on the extent of shortening during rigor development and proteolysis during conditioning (Warriss, 2000). Thus it is determined by the conditions during rigor development and post-mortem tenderisation. The two may be modified by the pre-and post-slaughter effects on the animals or carcasses.

##### *2.2.6.2.1 Pre-slaughter factors*

In general, intrinsic pre-slaughter factors (such as species, breed, sex and age) affect tenderness by determining the amount and properties of connective tissue (Lawrie, 1998). They may however, have an effect on tenderness in instances where they determine carcass conformation and fatness, and hence the degree of insulation against cold shortening. Carcass fat performs an important insulatory role in this effect. For beef, a minimum of about 5mm to 6mm subcutaneous cover is necessary to produce tender meat but above that, subcutaneous fat has little effect on changes in tenderness (Tatum et al., 1982; Dolezal et al., 1982; Jones and Tatum, 1994, Dikeman, 1996). For the smaller lamb and goat carcasses subcutaneous fat cover is more crucial because of the greater risk of cold shortening. Smith, Dutson, Hostetler and Carpenter (1976) showed that as subcutaneous fat depth increased from 3.1mm to 7.1mm in lamb carcasses chilled at 1ºC, the carcasses were increasingly able to maintain temperatures that were conducive to autolytic enzyme degradation for longer periods. They sustained less sarcomere length shortening, had lower pHu and tenderness and other meat quality attributes improved. Dikeman (1996) suggests that a minimum of 4mm subcutaneous fat is required to prevent cold shortening in lamb. Goat carcasses barely ever attain 1mm subcutaneous fat cover (Devendra and Owen, 1983; Simela et al., 1999). The impact of chilling should thus be greater on chevon than lamb/mutton carcasses.

Of the extrinsic factors, pre-slaughter stress is of greatest concern in the meat industry. Stress effects are mediated through pre-slaughter depletion of glycogen resulting in high pH meat. Meat toughness increases between pHu 5.5 and 6 and is maximum between pH 5.8 and 6.3 (Jeremiah, Tong and Gibson, 1991; Purchas and Aungsupakorn, 1993; Devine, Wahlgren and Tornberg,

1996; Figure 2.3). According to Yu and Lee (1986), meat is tender at either pHu extreme because, at low pHu, the acidic proteases are active while at the higher end, the neutral calpains are active. The range 5.8 to 6.3 is outside that of the two enzyme systems, and hence there is minimum degradation of muscle proteins.

In most studies, chevon pHu is often around or above 5.8 (Table 2.4). The high pHu is probably due to pre-slaughter stress since goats are excitable. If that is the case, it may be deducible from the GP values. A low GP at slaughter is indicative of prolonged stress prior to slaughter while a high lactate concentration and a low glycogen: lactate ratio is indicative of pre-slaughter stress.

Another possible effect of stress could be that it stimulates the release of a factor that affects calpain and calpastatin levels and/or their kinetics, resulting in reduced proteolytic activity and hence tough meat (Bickerstaffe, 1996). This view is supported by the observation that elevated plasma adrenaline levels increase calpastatin activity and expression, implying that the link between stress and meat toughness may be mediated via the calpain system (Sensky et al., 1996; Parr et al., 2000).

#### *2.2.6.2.2 Post-slaughter factors*

Sarcomere shortening is the cause of toughening early post-mortem (Smulders, Marsh, Swartz, Russell and Hoenecke, 1990; Koohmaraie, 1996). Wheeler and Koohmaraie (1994) demonstrated this phenomenon with lamb LTL whose sarcomere length (SL) decreased from 2.24µm at death to 1.69µm 24 hours post-mortem (Figure 2.5). Concomitantly, shear force values increased from 5.09kg to 8.66kg.

Koohmaraie, Doumit and Wheeler (1996) further showed that when sarcomeres were restrained from shortening, no toughening occurred. These findings concur with Marsh and Leet's (1966) observations that most tender meat has SL of 2.0 to 2.5µm, meat of intermediate tenderness 1.7 to 2.0µm and tough meat 1.5 to 1.7µm.

**Table 2.4** Some reported ultimate pH values of chevon

| Type of goat | Muscle | Mean/range of pHu | Source |
|---|---|---|---|
| Criollo males | *Longissimus* | 5.77-6.19 | Nuñez Gonzalez et al. (1983) |
| Criollo males | *Biceps femoris* | 5.80-6.10 | |
| Saanen females | Not specified | 5.88 | Hogg, Catcheside, Mercer and Duganzich (1989) |
| Saanen males | | 5.90 | |
| Feral males | | 5.55 | |
| Unspecified breed castrates | *Iliopsoas* | 6.01 | Hogg et al. (1992) |
| Unspecified breed females | | 6.00 | |
| Boer goat | *Longissimus* | 6.04 | Swan et al. (1998) |
| Cashmere | | 5.70 | |
| Boer x Cashmere | | 5.78 | |
| Bucks of various breeds | *Longissimus thoracis* | 5.6-5.8 | Dhanda et al. (1999) |
| Various breeds intact males | Composite | 6.36 | Madruga, Arruda and Nascimento (1999) |
| Various breeds castrates | Composite | 6.83 | |
| Boer cross breeds | *Longissimus* | 5.8 -6.2 | Husain et al. (2000) |
| Spanish does | *Longissimus* | 5.96 | Kannan, et al. (2001) |
| | *Semimembranosus* | 6.07 | |
| | *Triceps brachii* | 6.33 | |
| 2yr old Spanish castrates | *Longissimus* | 5.7 | Kannan, Kouakou, Terrill, Gelaye and Amoah (2003) |
| ≤1 yr Spanish castrates | *Longissimus* | 6.1 | |

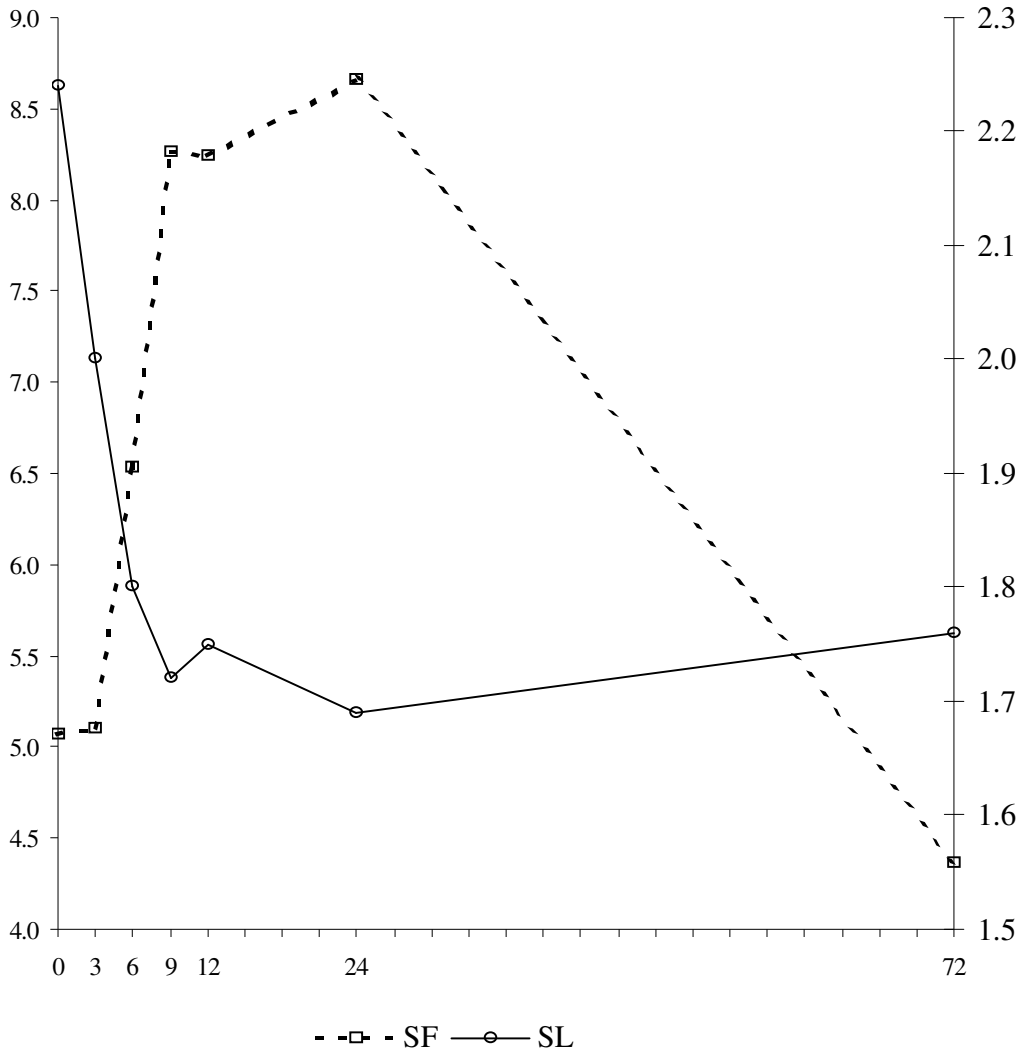


**Figure 2.5** Sarcomere length (SL, µm) and shear force (SF, kg) of lamb longissimus thoracis et lumborum at specific times post-mortem (Wheeler and Koohmaraie, 1994)

Wheeler, Shackelford and Koohmaraie (2000) further demonstrated the SL/tenderness relationship with different pork muscles, whereby all muscles with SL greater than or equal to 2.0µm (ST and *M. triceps brachii*) were rated the most tender while those with SL less than 2.0µm (LD, BF and SM) were rated less tender by taste panels. The authors thus concluded that if SL were 2.0µm or more, meat would be tender regardless of collagen content or extent of proteolysis.

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The degree of sarcomere shortening depends on the rates of chilling and post-mortem glycolysis. It is high in slow glycolysing muscles especially if they are subjected to rapid chilling, and low in fast glycolysing muscle (Marsh et al., 1987; Smulders et al., 1990; O'Halloran, Troy and Buckley, 1997b). Therefore any animal and post-slaughter environmental factors that affect the rate of post-mortem chilling and glycolysis will have an impact on the degree of sarcomere contraction.

There is however no unanimity on the relationship between SL and tenderness. Smulders et al. (1990) suggested that the relationship is dependent on the rate of glycolysis, which they measured as the pH at three hours post-mortem ($pH_3$). These workers reported no relationship between SL and tenderness for meat with $pH_3 \leq 6.3$. Above that, a strong correlation of 0.84 was realised. They thus concluded that sarcomere shortening is a major determinant of tenderness of slow glycolysing muscles. However, the effect of the glycolytic rate on the tenderness/SL relationship has not always been supported by research results (Shackelford, Koohmaraie and Savell, 1994a; O'Halloran et al., 1997b; Koohmaraie et al., 1995a). On the other hand, the impact of fast post-mortem glycolysis in enhancing tenderness is accepted by many research teams (Martin, Murray, Jeremiah and Dutson, 1983; Marsh et al., 1987; Pike, Ringkob, Beckman, Koh and Gerthoffer, 1993; Shackelford et al., 1994a; O'Halloran et al., 1997b). An exception is cases where the rate is so fast that heat shortening occurs (Marsh et al., 1987, Devine, Payne, Peachey, Lowe, Ingram and Cook, 2002). Fast glycolysis may limit tenderness even in the absence of shortening, by reducing calpain activity, and hence ageing potential (Simmons, Singh, Dobbie and Devine, 1996).

Ideally the rate of post-mortem glycolysis should be such that the pH does not drop below 6.2 before the carcass is at 15ºC (Dransfield, 1994a) or below 6.0 before 10ºC (Cornforth et al., 1980) in order to minimise sarcomere shortening and enhance proteolysis. Above these pH/temperature points, muscles have enough energy reserve to contract extensively at rigor mortis. Electrical stimulation is thus employed to expedite energy depletion from muscles and ensure that they enter rigor in a relaxed state.

A team from Texas Agricultural Experimental Station showed that ES improves tenderness not just by preventing cold shortening but by also stimulating an early onset of proteolysis and

causing stretching and tearing myofibrils (Savell et al., 1977; Savell, Smith and Carpenter, 1978a; Savell, Dutson, Smith and Carpenter, 1978b). There are suggestions that ES also causes a reduction of calpastatin activity, and hence an acceleration of proteolysis (Ferguson, Jiang, Hearnshaw, Rymill and Thompson, 2001). Other beneficial effects of ES include improvement of meat colour and flavour, and extension of shelf-life (Martin et al., 1983; Savell, et al., 1977; Savell et al., 1978a; Savell et al., 1978b). These effects have contributed to widespread commendation of ES. It is noted that a rapid decline in pH, and hence high initial muscle energy reserves are necessary for ES to be effective. If animals are stressed such that pre-slaughter glycogen reserves are very low, ES will not improve meat quality (Dutson, Savell and Smith, 1981). Thus, ES carcasses with a high initial pH of 6.7 to 7.1 tend to yield tender meat and require less conditioning time than carcasses with an initial pH of 5.8 to 6.2 (Khan and Lentz, 1973).

The effect of ES on three species is shown in Table 2.5. Notable is that beef and lamb tenderness increased without concomitant increase in SL while there was an increase in both tenderness and SL of chevon. Evidently lamb and beef were not subject to cold shortening under the experimental conditions but the increase in tenderness would have been caused by disruption of myofibrils during ES (Savell et al., 1978a) and enhancement of proteolysis. For goat carcasses, cold shortening may have been a problem and this was prevented by ES.

Toughness of meat that is caused by excessive sarcomere contraction during rigor development is resolved after a period of ageing, supposedly by proteolysis, non-enzymatic degradation of the cytoskeleton (Takahashi, 1996) and the weakening of the actin/myosin interactions (Goll et al., 1995). The state of the actin/myosin interactions post-mortem is not yet fully understood However the apparent increase in SL with ageing, such as the increase from 1.76µm at 24 hours to 1.90µm at 336 hours post-mortem, that was reported by Wheeler and Koohmaraie (1994) suggests that these interactions are slackened during conditioning.

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**Table 2.5** The effect of electrical stimulation on goat, lamb and beef loin eating quality

| | | Stimulated | Non stimulated | *P* level |
|---|---|---|---|---|
| Goat | Flavour rating | 5.4 | 5.4 | Not significant |
| | Overall tenderness | 4.5 | 3.5 | *P*<0.01 |
| | Shear force (kg) | 4.74 | 6.25 | *P*<0.01 |
| | Sarcomere length | 1.85 | 1.76 | *P*<0.05 |
| | Overall palatability | 4.6 | 3.8 | *P*<0.05 |
| Lamb | Flavour rating | 6.0 | 6.0 | Not significant |
| | Overall tenderness | 6.7 | 6.0 | *P*<0.01 |
| | Shear force (kg) | 2.87 | 3.82 | *P*<0.05 |
| | Sarcomere length | 1.83 | 1.80 | Not significant |
| | Overall palatability | 6.0 | 5.4 | *P*<0.05 |
| Beef | Flavour rating | 5.1 | 4.6 | *P*<0.01 |
| | Overall tenderness | 6.2 | 5.0 | *P*<0.01 |
| | Shear force (kg) | 6.4 | 8.5 | *P*<0.01 |
| | Sarcomere length | 1.83 | 1.84 | Not significant |

Source: Savell et al. (1978a)

As a result of the weakening of inter- and intra-myofibrillar connections during ageing, aged meat yields a high proportion of smaller fragments upon homogenisation than unaged meat (Geesink, 1993). The degree of fragmentation has been found to be highly related to the degree of tenderness and hence most laboratories use the myofibrillar fragmentation index (MFI) as a measure of tenderness. Myofibrillar fragmentation is determined as the turbidity of a homogenised meat sample at 540nm (e.g. Culler, Parrish, Smith and Cross, 1978; Koohmaraie et al., 1991b; Morgan, Wheeler, Koohmaraie, Crouse and Savell, 1993b). The index may however be confounded by sarcocyst infections that commonly occur in muscles of animals raised off the range (Levine, 1985). In such instances measuring the average length of the fragmented myofibres has been found to be a better indicator of tenderness than MFI. Some workers in the past, such as Fukazawa, Briskey, Takahasha and Yasui (1969) have used this approach, though in that case the incidence of the shorter (less than four sarcomere lengths) rather than the longer (greater than five sarcomere lengths) myofibrillar fragments was measured.

The concept of measuring products of proteolysis has been extended to measuring micro-fragments of degradation such as the 30kDa unit arising from the break down of troponin-T by the calpains (Penny, 1980; Ouali, 1990). That measurement is usually accompanied with quantification of the post-mortem changes in the concentration of the calpains.

Of all the laboratory methods of determining meat tenderness, the rheological Warner-Bratzler shear force remains the most popular (Lepetit and Culioli, 1994). By this method the peak force required to cut through a cylindrical block of meat perpendicular to the myofibres is usually determined and this has been observed to accurately reflect myofibrillar tenderness (Bouton et al, 1975). Shear force determinations are often accompanied by sensory evaluations of tenderness. The latter gives an indication of the size of shear force differences that are organoleptically perceivable.

#### 2.2.6.3 Tenderness of chevon

Most studies in the evaluation of goat meat and its palatability have compared the meat to lamb/mutton and/or other meats (e.g. Pike et al., 1973a; Babiker et al., 1990; Griffin et al., 1992; Schönfeldt et al., 1993a; Tshabalala et al., 2003). Tenderness and other palatability values for chevon are often in the acceptable range but lower than values for lamb/mutton (Table 2.6) and beef (Pike et al., 1973a). Shear force values tend to follow similar trends as tenderness ratings but the actual values vary considerably from study to study, depending on pre-slaughter treatment of the animals, post-slaughter handling of the carcasses, the muscle that was used and the method of sample preparation (Table 2.7).

**Table 2.6** Average tenderness ratings for chevon compared to lamb/mutton

| Source | Tenderness rating | | Hedonic scale |
|---|---|---|---|
| | Goat | Sheep | |
| Pike et al. (1973a) | 4.2 | 7.9 | 9 point |
| Schönfeldt et al. (1993a) | 2.8 | 4.8 | 6 point |
| Griffith et al. (1992)* | 5.5 | 4.3 | 8 point |
| Babiker et al. (1990) | 2.8 | 3.1 | 5 point |
| Sheridan, Hoffman and Ferreira (2003) | 49.6 | 83.2 | 100 point |
| Tshabalala et al. (2003) | 4.3 | 6.7 | 9 point |

* Untrained consumer panel ratings

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**Table 2.7** Some shear force values reported for chevon

| Species | Muscle | Carcass handling | Shear sample preparation | Shear force | Source |
|---|---|---|---|---|---|
| Angora goat<br>Boer goat | SM<br>SM | ES; Aged for 7d at 1 to 7°C | Defrosted from-20°C; Oven at 160°C to 75°C; 12.5mm∅ cores, Warner Bratzler shear force device | 54.05N<br>60.44N | Schönfeldt et al. (1993a) |
| Sudanese male desert goats | SM | Conditioned at 34°C then chilled at 7°C for up to 24hrs. | Water bath at 80°C for 1hr 1 x1cm cross section, Warner Bratzler shear force device | 5.7kg/cm$^2$ | Babiker and Bello (1986) |
| Boer goat<br>Cashmere goat<br>Boer x Cashmere goat | SM<br>SM<br>SM | ES; Chilled at 4°C for 20 hours | Defrosted from-20°C; Water bath at 97°C to 75°C internal temperature; 1x1cm cross section, MIRINZ tenderometer | 9.1kgF<br>5.4kgF<br>8.6kgF | Swan et al. (1998) |
| Criollo goats (24kg) | LD<br>BF | | Water bath to 70°C internal temperature; Warner Bratzler shear force device. | 58.45N<br>54.80N | Nuñez Gonzalez et al. (1983) |
| Boer, Angora, Saneen and Feral crosses | *Vastus* group | Chilled for 24 hours, temperature not given. | Water bath at 85°C to 70°C internal temperature; 1x1cm cross section; Warner Bratzler shear force device. | 4.4kg/cm$^2$ | Dhanda et al. (1999) |
| Desert goats | SM | Chilled for 24 hrs at 4°C | Defrosted from -10°C; Water bath at 80°C for 1hr; 1x1cm cross section; device not mentioned | 4.0kg/cm$^2$ | Babiker et al. (1990) |
| Saneen x Angora | *M. longissimus* | ES; chilled at 9°C for 24 and 48hrs | Water bath at 85°C to 70°C internal temperature; 1x1cm cross section; MIRINZ tenderometer | 8.6kg (24h)<br>7.6kg (48h) | Hogg et al. (1992) |
| Spanish kids<br>Spanish yearlings | SM<br>SM | Chilled at 1°C for 48 to 72hrs. | Defrosted from -23°C; Roasted at 175°C to 75°C internal temperature; 12.7mm∅ cores; Warner Bratzler shear force device | 8.8kg<br>5.3kg | Smith et al. (1978) |
| Boer goats<br>Boer goats | SM | NES; chilled for 24 hours at 4°C | Fresh samples; Water bath at 75°C for 1hour; 12.7mm∅ cores; Warner Bratzler shear force device | 11.07kg<br>14.32kg | Sheridan et al. (2003) |

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### 2.2.7 Factors of Production Quality

At each level of the production-consumption continuum there are several production factors which impact on the final quality of the meat. Some have been discussed in the preceding sections. This section focuses on those that are likely to have critical effect on the quality of chevon; that is nutritional history, physical exercise, peri-mortal treatment and post-slaughter handling.

#### 2.2.7.1 Effect of nutritional history

Nutrition is probably the single important farm-level production factor that influences meat quality. The level of nutrition influences growth rate, final live weight, dressing out percent and carcass fatness, and connective tissue composition and cross-linking (Arbele, Reeves, Judge, Hunsley and Perry, 1981; Miller et al., 1987). Perhaps most critical is the influence of nutrition on muscle glycogen concentration. If the latter is low at slaughter then tenderness, juiciness, flavour, colour and shelf-life of the meat are detrimentally affected (Warner et al., 1998).

Pethick et al. (2000) demonstrated a clear relationship between the level of glycogen in muscle and the intake of metabolisable energy (ME). Wethers and steers that came off a low plane of nutrition consistently had low levels of glycogen on-farm, at slaughter and 48 hours post-mortem than those on high energy diets. In addition, high energy diets reportedly protect slaughter stock from the potential glycogen depleting stressors (Warner et al., 1998; Immonen, Ruusunen, Hissa and Puolanne, 2000a) The protective effect is often large enough to make a difference between normal and dark cutting meat (e.g. pHu values 5.53 on high energy vs. 5.60 on low energy, Warner et al., 1998; pHu value 5.69 on high energy vs. 5.93 on low energy, Immonen et al., 2000a). McVeigh and Tarrant (1982) and Warner et al. (1998) showed that animals that have been on better nutrition prior to slaughter replete their glycogen reserves faster than those coming off poor diets. The inference from these series of works is that animals destined for slaughter should be on a high plane of nutrition so that they have adequate glycogen reserves at slaughter to alleviate the problem of dark cutting (Pethick et al., 2000).

#### 2.2.7.2 Effect of physical exercise

Long term exercise is a factor that is closely linked with extensive production systems for indigenous goats. Daily wandering around in search for food may lead to increased concentration of myoglobin in muscles as well as an increase in the activity of respiratory enzymes and glycogen stores (Lawrie, 1998). Such conditions are conducive to appropriately low pHu post-mortem (Fernandez and Tornberg, 1991; Lawrie, 1998).

Meat from chronically exercised sheep has been reported to be more tender than that from the non-exercised sheep. (Aalhus and Price, 1990; Aalhus, Price, Shand, and Hawrysh, 1991). Aalhus *et al*. (1991) suggested that the advantage of the exercised group could have been a decrease in the proportion of collagen relative to myofibrillar proteins but not exercise-induced changes in collagen metabolism. Shiba, Matsuzaki and Tsuneishi (2000) concur with Aalhus *et al*. (1991). The former observed that exercise did not to have an effect on the collagen properties of most of the goat muscles studied except the *soleus*. On the other hand, studies with rats have shown that continuous exercise impacts on collagen metabolism by retarding the increase of thermal stability (Skalicky and Viidik, 1999, 2000). In contrast to Shiba *et al*. (2000), Skalicky and Viidik (1999) found continuous exercise to be more effective than the intensity and amount of exercise. Therefore, while the effect of exercise on collagen is still not clearly understood, it seems not to have detrimental effects on meat quality.

#### 2.2.7.3 Effects Peri-mortem Treatment

Pre-slaughter stress is the single most influential production factor on glycogen concentration at slaughter, pHu and hence any quality factors that are influenced by pHu. Common pre-slaughter stressors to livestock are poor nutritional status, handling, distance, duration and conditions of travel conditions to the abattoir, inclement temperature, unpropitious hormonal status and social and physical interactions (Price and Tennessen, 1981; Lacourt and Tarrant, 1985; Kenny and Tarrant, 1988; Warriss, 1990; Sanz, et al., 1996; Lahucky, Palaska, Motjo, Zaujec and Huba, 1998). Any animals that have been subjected to these stressors invariably yield meat that has higher pHu values than unstressed groups (Table 2.8).

**Table 2.8** Effect of pre-slaughter stress on the ultimate pH taken from the *M. longissimus*

| Animal | Stress | Ultimate pH | | Source |
|---|---|---|---|---|
| | | Unstressed | Stressed | |
| Merino wethers | Transport & | 5.54 | 5.64 | Gardner et al. |
| Merino 1st cross wethers | liarage | 5.52 | 5.60 | (1999). |
| Merino 2nd cross wethers | | 5.54 | 5.58 | |
| Friesian bulls | Mixing | 5.57 | 6.45 | Warriss et al. (1984) |
| Friesian cross intact & vasectomised bulls & steers | Mixing | 5.74 | 6.04 | Mohan Raj et al. (1992) |
| Heifers of mixed breeds | Oestrous behaviour | 5.48 | 5.92 | Kenny and Tarrant (1988) |

With time, animals may recover from the travel and mixing stress. However glycogen repletion rates are generally slow in ruminants, taking between three days and two weeks (McVeigh, Tarrant and Harrington, 1982; Warriss, Kestin, Brown and Wilkins, 1984; Lacourt and Tarrant, 1985). The rate depends on the nutritional history, extent of the stress and recovery conditions. The rate of repletion is particularly slow in animals that have been on poor quality diets and/or have been fasting prior to slaughter (McVeigh et al., 1982; Warner et al., 1998). It is thus recommended that slaughter animals be allowed recovery time in liarage so that glycogen reserves may be repleted. For cattle, a 24 hour rest period before slaughter is recommended to allow the animals to recover from the travel, adapt to their new environment and replenish glycogen reserves (Wythes, Shorthose and Powell, 1988).

#### 2.2.7.4 Effects of post-slaughter handling

To produce quality meat, appropriate temperature, airflow and relative humidity must be employed in the chillers (Lawrie, 1998; Varnam and Sutherland, 1995). Chilling must be rapid enough to minimise microbial growth but avert cold shortening. The airflow must be sufficient for even cooling and not excessively dehydrate the carcasses, and humidity must be carefully controlled to reduce bacterial growth on the meat surface. A protocol recommended for sheep is to reduce the temperature rapidly to 12-15°C, hold this temperature for 18 hours followed by a

slow reduction of the temperature to 5°C (Varnam and Sutherland, 1995). Most abattoirs however use a set temperature between 0ºC and 4ºC. Paradoxically, the low temperatures used for chilling are associated with increased incidence of cold shortening, especially with small, poorly insulated carcasses. Consequently innovations to either enhance the rate of glycolysis so as to produce tender meat or mechanically restrict the interdigitation of actin and myosin filaments are recommended for use at these low temperatures. The three commonly researched on-line methods are alternatives to the traditional Achilles tendon carcass suspension, high temperature conditioning and ES.

Alternative carcass suspension works on the premise that the carcass is hung in such a way that high value muscles are stretched and not subject to shortening during chilling. Currently the popular alternatives are Tender stretch, whereby carcasses are hung by the obturator foramen (aitchbone), and Tender cut, whereby bones and connective tissue are cut in the mid loin and the round /sirloin junction of beef carcass sides to enable the weight of the carcass to stretch selected muscles before the onset of rigor mortis (Claus, Wang and Norman, 1997; Beaty, Apple, Rakes and Kreider, 1999). These techniques have been adopted in the beef industry in some countries (Tarrant, 1998; Sørheim et al., 2000).

High temperature conditioning entails holding the carcasses at high temperature for some time immediately post-slaughter before moving them into the chillers. This is so that glycolysis occurs at the high temperatures and by the time the carcasses are chilled, glycolysis would have advanced beyond the stage where cold shortening may occur. The criticism against high temperature conditioning is that it causes delays in the slaughter line and has a high risk of microbial contamination.

Electrical stimulation is widely acclaimed because it not only improves tenderness but seems to improve other quality attributes such as colour, reduced incidence of heat ring and flavour (Savell et al., 1978a and b). The effects of ES are clearly demonstrated in Table 2.5, whereby tenderness of the three meat types was considerably improved, whether through expediting of glycolysis or other effects.

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### 2.2.8 Implication of Smallholder Production Systems on Chevon Quality

In southern Africa, drastic changes in smallholder goat production systems are unlikely in the foreseeable future unless there are drastic changes in the land tenure systems (Cronjé, 1999) and marketing opportunities (Panin and Mahabile, 1998; Seleka, 2001). Until such changes occur, the goats coming off the developing agricultural sector will continue to be of the assortment that is subjected to seasonal fluctuations in rangeland nutrition (Sibanda, 1992) and walk long distances daily in search for food. The seasonality of rangeland quality has been shown to result in good quality carcasses in post rainy season and poor quality carcasses in the dry to early rain seasons (Simela, et al., 1998). The foregoing therefore suggests that in order to supply the meat markets with chevon of acceptable quality, the slaughter stock should be correctly selected from the existing flocks. In addition, carcass handling and classification should take into consideration the lean nature of goat carcasses.

## 2.3 SENSORY EVALUATION OF MEAT QUALITY

The sensory properties of a food impact on consumers' appreciation of the food and determine their perception of its acceptability and quality (Chambers IV and Bowers, 1993). Sensory properties are pivotal in this respect because consumers need to be entirely satisfied with the sensory properties before other elements become relevant (Chamber IV and Bowers, 1993; Issanchou, 1996). There have been several investigations to determine the sensory attributes that drive acceptance of food. Most have concluded that acceptability of meat can be predicted from tenderness/texture, juiciness and flavour (Horsefield and Taylor, 1976, Parrish, Boles, Rust and Olson, 1991). Studies in the United Sates of America have identified tenderness as the most important factor influencing the acceptability of beef (Morgan, Savell, Hale, Miller, Griffin, Cross and Shackelford, 1991; Boleman et al., 1997) and that juiciness and flavour have a greater effect on consumer satisfaction as toughness increases (Miller, Carr, Ramsey, Crockett and Hoover, 2001).

Laboratory techniques have been developed to quantitatively assess the palatability attributes. While laboratory methods provide technical, precise and reliable information about a product, the results do not tell whether or not the food would be acceptable to consumers. Therefore,

consumer studies are used to determine the range of quantitative values that are acceptable as well as the degree of liking or preference for a product (Muñoz and Chambers IV, 1993).

The sensory test that is carried out to determine whether or not consumers like a product is that of acceptance, which is defined as a positive attitude after the tasting experience and is directly measured on a hedonic scale (Baker, Wong Hahn, and Robins, 1994). It may be determined as an overall measure or for individual sensory attributes (Meilgaard, Civille and Carr, 1991). The test may be accompanied by a food action rating test, which requires the consumers to estimate their intended frequency of consumption of the product (Penfield and Campbell, 1990). The latter test is essential because consumers tend to be realistic when they evaluate or predict actions. As such a measure of consumption intent is considered more sensitive and action-orientated than the hedonic tests (Penfield and Campbell, 1990). A complimentary test, when several products are being evaluated, is an indication of whether or not consumers prefer one product to others. Preference determination is useful because it is possible for consumers to show a strong preference for a sample but not want to consume it frequently or to reject it for other reasons than not liking it (Penfield and Campbell, 1990).

A number of studies have been conducted on the palatability and acceptability of chevon but in most instances the studies have employed trained taste panels. In most of them, chevon and chevon products were rated as high quality (Breukink and Casey, 1989; Schönfeldt et al., 1993a and b; Tshabalala et al., 2003). Despite these outcomes, indications are that consumers perceive chevon as tough and smelly (USAID/South Africa and ARC, 1998a; Mahanjana and Cronjé, 2000). The latter findings are however based on surveys rather than on sensory evaluations. It has been shown that sometimes consumer biases against chevon may be unfounded. In a blind test carried out to determine the overall appeal rate of chevon versus beef, 42% of the consumers preferred chevon, 38% beef and 20% were indifferent between the two meats (Teh, 1992). Thus sensory evaluations help to highlight the disparities and parallelisms between consumer conceptions and tastes.

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## 2.4 SUMMARY

Substantial research has been conducted on goat production systems, productivity, carcass and meat yield. However few studies ever link animal and carcass characteristics to the quality of the meat. Details of how handling of goats, carcases and chevon throughout the production to consumption continuum are necessary in order o determine points at which measures to optimise quality may be instated.

Due to the increase in the segment of consumers that are conscientious fat content and quality in meat, it may be that the low carcass fat of chevon will be its primary selling point in the meat market. Paradoxically, the leanness of goat carcasses predisposes them to dehydration, fast chilling and slow glycolysis under normal chilling conditions in commercial abattoirs. Inappropriate handling of the lean carcasses may therefore be one of the reasons that chevon is perceived as poor quality meat. Much improvement can be made in animal handling prior to slaughter to ensure that the animals are fit to produce quality meat. However, with ever increasing concerns about food safety, it is unlikely that adjustment will be made to the chilling protocols used in abattoirs. Coupled with the view that smallholder goat production will barely change in the near future, the challenge is to select from the existing flocks, goats that will yield carcasses that process well during primary chilling in order to ensure a quality product. Achieving a technologically sound goat carcass, tied with knowledge of the nutritional value of chevon, would facilitate defining carcasses, and hence goats are acceptable to consumers.