Meat and Reformed Meat Products

Siobhan Slayven and Kim Matthews

1 Muscle Structure and Composition

1.1 Muscle Structure

Mammalian skeletal muscle is made up of approximately 90% muscle fibres and 10% connective tissues (Listrat et al., 2016). Connective tissues (primarily collagen) can be categorised as the epimysium, which surrounds each whole muscle; the perimysium, a thinner layer which surrounds bundles of muscle fibres; and the endomysium, a very thin layer which surrounds each muscle fibre.

Muscle fibres are between 10 and 100 μm in diameter and several centimetres in length. The size of fibres increases with animal age (Listrat et al., 2016) and they can extend the whole length of the muscle (Greaser & Pearson, 1999). Muscle fibre cells are multinucleated, with the nuclei located near the periphery. They include organelles called myofibrils which are the sites of force production in the cell. They are not bound by a membrane but exist as an insoluble structure in the living cell. Myofibrils line up in bundles along the length of the muscle fibre and are around 1 to 2μm in diameter. There are approximately 500–1000 myofibrils in a cross section of a mature skeletal muscle fibre, making up around 80% of the cell volume.

Myofibrils have a striated appearance with alternating light and dark bands which are caused by the actin (thin) and myosin (thick) filaments respectively. These are also referred to as the I-band and the A-band (Ertbjerg & Puolanne, 2017). Each I-band is divided into two portions by a Z-line, and the unit between each Z-line is the sarcomere, responsible for contraction (Listrat et al., 2016). The middle of the A-band is less dense, where only thick filaments are located, and is called the H-zone. In the centre of this is a dark line called the M-line which is made up of overlapping thick filaments. Across the length of the thick filaments, there are outward projections which extend toward the thin filaments and are known as cross bridges.

The pattern in which these filaments align varies with location. Thin filaments are arranged in a square pattern near the Z-lines, but in the I-band they appear randomly spaced. Where the filaments overlap in the A-band section, they form a hexagonal pattern with each thick filament surrounded by six thin filaments.

The predominant protein present in the thick filaments is myosin. Myosin molecules are divided into two sections, referred to as the head and the rod (Ertbjerg & Puolanne, 2017). The myosin molecules catalyse the breakdown of adenosine triphosphate (ATP) into adenosine

---

S. Slayven · K. Matthews (✉)
Agriculture and Horticulture Development Board, Middlemarch Business Park, Coventry, UK
e-mail: Siobhan.Slayven@ahdb.org.uk; Kim.Matthews@ahdb.org.uk

A. Rosenthal, J. Chen (eds.), *Food Texturology: Measurement and Perception of Food Textural Properties*, https://doi.org/10.1007/978-3-031-41900-3_15

diphosphate (ADP) and provide energy for muscle contraction. Thin filaments are made up of actin molecules as well as the additional proteins tropomyosin and the troponins T, I and C, which regulate muscle contraction. Sarcoplasm is the cytoplasm within muscle fibres and contains soluble proteins including enzymes for the glycolytic pathway and myoglobin which carries oxygen to the mitochondria and stains cells red. The sarcoplasm also contains glycogen, the main energy reserve for the muscle cells in addition to adipose (Listrat et al., 2016). Adipose (fat) cells, found in the perimysium and outside of the epimysium, cluster together and form a pattern referred to as 'marbling'.

1.2 Muscle Contraction

Muscle contraction is carried out by the thick and thin filaments sliding past each other. The heads of the myosin bind to actin forming a cross-bridge and pull the filaments over one another. This occurs in a cyclical pattern with the attachment and detachment of these cross-bridges causing the sarcomere to shorten in length. This change in length in the myofilaments is typically less than 0.4% but the degree to which they overlap is increased. For contraction to take place, ATP and calcium ions need to be present. Myosin heads cannot bind to actin unless calcium (released by the sarcoplasmic reticulum) make the binding sites available. This happens in response to a nerve impulse. ATP, produced when glucose proteins are used to produce energy, allows the myosin head to lock into position, bind to the actin and rotate to pull the filament. Another ATP molecule then removes the myosin head and attaches it to another binding site to keep pulling and shortening the muscle.

2 Rigor Mortis

The post-mortem changes that take place as muscle converts to meat can have a marked impact on meat eating quality (Matarneh et al., 2017). Myofibrillar toughness increases early post-mortem, during the onset of rigor mortis (Garmyn et al., 2022). Following exsanguination, the muscles continue to function and anaerobically metabolise glycogen, since there is no oxygenated blood circulating. This means that ATP is still produced, which, when hydrolysed, converts into lactate and hydrogen ions. As there is no mechanism to remove these, the pH of the muscle lowers and becomes more acidic, from around 7 to 5.5. In turn, this causes a reduction in the water-holding capacity and so calcium is released, which encourages the formation of cross-bridges between the actin and myosin filaments and results in stiffening of the muscle, referred to as rigor mortis. The onset of rigor mortis occurs in individual muscle fibres at a time rather than the whole muscle in one go (Honikel, 2014). It also does not occur at the same rate across all muscles (Ertbjerg & Puolanne, 2017) nor across different species. Complete rigor mortis can take 12–24 hours in beef, 8–12 hours in lamb, 3–6 hours in pigs and 1–4 hours in poultry (Greaser & Pearson, 1999).

Typically, in Western countries, meat is allowed to enter rigor and is further aged before consumption. However, in the East, consumers generally prefer eating meat which has not yet entered rigor mortis (known as hot-fresh or pre-rigor) as they associate this with an improved taste (Ge et al., 2021). However, Xiao et al. (2020) found that there was no significant difference in the sensory evaluation of lamb pre- and post-rigor but that there were differences in texture, with pre-rigor muscles having a lower cook loss and post-rigor meat being tougher. Li et al. (2022) further supports this, reporting that pre-rigor goat meat had a better water holding capacity and colour, as well as a richer taste when analysed by the E-nose and E-tongue.

2.1 Abnormal Rigor Mortis

Abnormal rigor patterns can occur due to a change in the acidification of the muscle, caused by pre-slaughter stress. Dark, firm and dry (DFD) meat, or ‘dark cutting’, occurs when there are not enough glycogen reserves present in the muscle before rigor mortis sets in. This means that the muscles do not metabolise enough lactic acid to lower the pH sufficiently, and the ultimate pH will stay high, at around 6 (Warriss, 2010). DFD usually occurs after a period of chronic stress where the animal has not had time to overcome the depletion of energy and rebuild its glycogen stores. The way in which DFD meat refracts light makes it appear darker in colour, and the lattice of muscle fibres gives the meat a firmer texture and inhibits moisture loss making it ‘dry’. Similarly, pale, soft and exudative (PSE) meat also follows an abnormal pH trend following slaughter. This is more typically seen in pork and can follow a period of acute stress (usually within 1 hour prior to slaughter) such as heat stress (Gonzalez-Rivas et al., 2020). The rapid fall in pH while the temperature is still high directly denatures proteins, and there may also be some effect of protein oxidation (Barbut et al., 2008). Although described as soft, this relates to the raw product and, where differences are observed, the cooked meat is generally tougher. PSE meat is lighter in colour and the arrangement of fibres means that more fluid exudes from the meat.

Other abnormal rigor patterns can occur due to intervention in post-slaughter treatments, for example thaw rigor. This is where muscles are frozen pre-rigor and, upon thawing, there is a release of calcium ions which encourage the muscle to contract (Ertbjerg & Puolanne, 2017). As the muscle freezes, ice crystals grow and penetrate the sarcoplasmic reticulum, which, once thawed, provides a rapid surge of calcium ions into the sarcoplasm, faster than the calcium pumps can remove them. Consequently, there is an increase in drip loss and toughness. The toughening of muscles following thaw rigor is much more harsh than that which occurs from cold shortening, which progresses much more slowly (Ertbjerg & Puolanne, 2017). Slower thawing can prevent this contraction taking place, but it can be eliminated by freezing meat only after it has entered full rigor.

3 Influence of Live Animal Factors

Both pre- and post-slaughter factors can affect the sensory properties of meat. When considering texture, however, pre-slaughter treatments generally have a less significant impact than those post-slaughter.

3.1 Effects of Breed and Genetics

Generally, breed has a relatively small effect on tenderness in any species; however, there is within-breed variation in meat texture as evidenced by the growing inclusion of texture traits in genetic evaluations.

In cattle, the most important effect of genotype on eating quality is the toughness observed in beef from cattle of *Bos indicus* (Zebu or Brahmin) breeding (Gazzola et al., 1999; Harper, 1999; Wheeler et al., 2010). This may be the result of greater stability of the proteinase inhibitor calpastatin (Whipple et al., 1990).

Among the *Bos taurus* breeds, results have not been consistent across studies and many show little or no effect, but taken overall, there are small tenderness advantages for Aberdeen Angus and Hereford (Sinclair et al., 2001; Tatum, 2006) which tend to be earlier maturing with more intramuscular fat. On the other hand, cattle sired by a Belgian Blue, a very lean highly muscled breed, have also produced higher tenderness scores than other breeds (Homer et al., 1997; Groth et al., 1999).

Although Dransfield et al. (1979) concluded that breed does not have any effect upon the tenderness of lamb, there is some evidence that hill breeds have more tender meat, and the selection for more heavily muscled sheep can reduce tenderness (Álvarez et al., 2022). Studies on lambs expressing the Callipyge gene have shown the loin to be significantly less tender than lambs without this gene (Koohmaraie et al., 1996). The leg is generally unaffected when roasted, but it can also be tougher when grilled as steaks (Shackelford et al., 1997) but not in every case (Goodson et al., 2001).

Studies with pig meat from the Hampshire and Duroc breeds (Hiner et al., 1965) and the Swedish Landrace and Yorkshire breeds (Malmfors & Nilsson, 1978) suggest that breed differences should be taken into account in evaluation of texture in pork, with breeds which have been less intensively bred for production traits being more tender (and having higher proportions of red muscle fibres (Maltin et al. (1997)). Furthermore, genetic selection of Duroc pigs for lean muscle growth removes the eating quality advantage, with a corresponding shift in muscle fibre type (Lonergan et al., 2001).

3.2 Effects of Fatness

Higher levels of intramuscular fat are associated with improved tenderness (Buchter, 1986; Dikeman, 1987). While this is used in major grading schemes (such as USDA beef grading), there is considerable overlap between grades and the relationship between fatness and tenderness is low according to Campion et al. (1975). Low levels of intramuscular fat are generally associated with low external fat cover, and in some cases, a strong relationship found between intramuscular fat and tenderness may be a result of the insulating effect of the external fat, preventing cold shortening. This was nicely demonstrated in lamb by Smith et al. (1976).

3.3 Influence of Sex

Two extensive reviews (Purchas, 1991; Chrystall, 1994) summarised the effects of sex upon tenderness. Researchers have reported that young bulls cannot be marketed with the same confidence as steers with the same ages. Meat from bulls is generally thought to be tougher than that from steers; however, this is not always found. Sinclair et al. (1998) and Fisher et al. (2001) observed that bulls from a suckler herd had increased tenderness when compared to randomly selected steers or weaned animals, respectively.

Sex differences for texture between castrates and intact male pigs are relatively small, but these comparisons have not been studied as extensively as in beef (Dransfield, 1994). Overall, it can be concluded that, when slaughtered before 12 months of age, ram (uncastrated male), ewe and wether (castrated male) lambs result in meat with similar tenderness. Beyond 12 months there may be a disadvantage to ram lambs (Álvarez et al., 2022).

3.4 Effect of Animal Age and the Role of Connective Tissue

There is clearly an effect of age on tenderness (see the review by Harper (1999)). Prost et al. (1975a, b) examined the tenderness of different muscles from cattle of different ages. Generally, animals of 2–5 years of age resulted in tougher meat than those of 1.5–2 years of age. The *Psoas major* (fillet) did not differ in tenderness and the *Quadriceps femoris* (thick flank) was not significantly different.

It is difficult to separate the effects of age, weight and season in lambs. Generally speaking, older/heavier lambs are tougher (Álvarez et al., 2022). In particular, spring born lambs slaughtered in the autumn/winter are likely to be tougher than those slaughtered in the summer.

The association between increasing age and decreasing tenderness does not seem to be related to an increase in the total presence of connective tissue, but rather an increase in the proportion of heat-stable collagen cross-links (Robins et al., 1973) associated with a decrease in collagen solubility (Gerrard et al., 1987). These heat-stable cross-links are resistant to cooking, thus making the meat tougher (Bailey & Light, 1989).

3.5 Influence of Growth Rate and Plane of Nutrition

Sub-optimal growth rate and nutritional stress increase toughness. Within feedlot systems, finishing cattle on high energy rations (associated with higher growth rate) is found to increase tenderness. This may be a consequence of variable enzyme activity at the time of slaughter (Aberle et al., 1981), or greater collagen solubility (Rompala & Jones, 1984). The effect is not seen across all muscles, mainly benefitting the *Longissimus dorsi* (striploin) (Archile-Contreras et al., 2010).

Others have found that there is a positive effect of growth rate on tenderness within a group of cattle (Perry et al., 2002; Perry & Thompson, 2005) but did not account for differences between groups. This suggests that reducing variation in growth rate within a group might be an important means of reducing tenderness variation, whereas manipulation of growth paths is not guaranteed to enhance tenderness. Oury et al. (2007), however, found that those commercial production systems with the highest plane of nutrition (and younger animals at slaughter) resulted in the most tender meat.

Nutritional stress followed by compensatory growth does not have any adverse effects on meat quality, including tenderness (Hogg et al., 1991).

3.6 Stress Conditions and Pre-slaughter Handling

In addition to the specific muscle quality 'defects' related to stress-induced pH changes (as discussed in Sect. 3.2), there is increasing evidence that stress prior to slaughter can result in tougher meat *per se* (Ferguson & Warner, 2008; Sierra et al., 2021). This may be the result of protein oxidation influencing the activity of enzymes post-slaughter.

There is also evidence that animals with nervous behaviours prior to slaughter result in tougher meat (Gruber et al., 2010), although selection for temperament does not result in more tender meat.

4 Effects of Stunning and Slaughter

Slaughter can be defined as the killing of animals for food, and it is usually instigated or followed by exsanguination (also known as sticking or bleeding) which refers to draining the carcase of blood. Prior to slaughter, animals may undergo a procedure to render them unconscious and ensure they do not feel any pain from slaughter; this is referred to as stunning. 'Simple' stunning causes a temporary effect of senselessness which must be followed by a procedure to kill the animal, but in some cases, stunning is irreversible and the main cause of death. Stunning can also make it safer for the operative to approach the animal to carry out the bleeding procedure. Stunning methods used include the following:

- Electrical head-only or head-to-back tongs (lamb, pigs)
- Electric water bath (poultry)
- Electric stun box with programmed electrical inputs to result in stunning, cardiac arrest (also available without) and immobilisation (cattle)
- Penetrative or non-penetrative captive bolt (cattle, lamb)
- Gas (CO_2) (irreversible) (poultry, pigs)

Depending on the electrical parameters used, electric water baths may induce cardiac arrest and result in death of the animal. Penetrative captive bolt delivers a cartridge shot to the brain which makes recovery difficult.

The process of slaughter itself, as described above, is understood to not have an impact on meat quality. There is, however, some effect of stunning method on the carcase and meat quality. Channon et al. (2003) reported that fewer meat quality defects were seen when using CO_2 rather than electrical stunning with tongs (head only and head-to-back positioning). Blood splash (the rupture of blood capillaries) is also thought to have some correlation to stunning method. Gregory (2005) explains that generalised body contractions which can arise from electrical stunning can cause severe external pressure on the venous and arterial systems which could cause them to rupture.

During religious slaughter practices such as those for the Islamic and Jewish communities, slaughter is often carried out without prior stunning. These procedures are based on rules laid down in the *Holy Quran* and the *Torah*, for Halal and shechita slaughter, respectively. In some instances, Muslim authorities may allow the use of reversible pre-slaughter stunning; however, the Jewish community do not (Fuseini et al., 2016). As animal welfare is still of paramount importance during religious slaughter, scriptures stipulate procedures which must be followed to ensure minimal distress to the animal. For example, the knife used to make the neck cut during Halal slaughter must be sharp, and slaughter must be carried out with one single movement of the knife (Fuseini et al., 2016). The effect of religious slaughter on carcase and meat quality has been widely researched and findings debated. Some findings show that the meat from cattle slaughtered without pre-stunning exhibit a higher ultimate pH (Zurek et al., 2021; Barrasso et al., 2022) which may impact the texture, colour and processing capabilities of the meat.

5 Effects of Post-slaughter Treatments

5.1 Chilling

Carcases should be kept in an environment which has a stable temperature and humidity to help reduce any microbial load from growing (Hussain et al., 2021), which not only deteriorates the meat but also poses risk of foodborne diseases (Ren et al., 2022). Cooling rates vary across different muscles within a carcase (Hannula & Puolanne, 2004) as well as across different species. Sheep, for example, cool quicker than cattle as they are smaller and have a thinner layer of subcutaneous fat (Kannan et al., 2014). The same can be seen within species, whereby animals with less fat cover cool more quickly. Key parameters need to be met for optimal chilling, particularly making sure that there is a good air flow within the chiller and adequate space around carcases to reduce their temperature efficiently.

An important consideration for chilling is the rate at which the pH lowers. It is widely accepted that a beef carcase should not reach 10 °C until the pH has lowered to around 6.1 which takes around 10 hours (Warriss, 2010). This is to avoid any adverse effects, primarily cold shortening, which has been well researched since the 1960s, initially by Locker and Hagyard (1963). This is known as the pH temperature window. Once the pH has fallen below 6.0, the tendency for cold shortening is reduced (Ertbjerg & Puolanne, 2017).

Vieira and Fernández (2014) explored three different speeds to assess the impact on the tenderness of lamb *Longissimus thoracis et lumborum*. They found that a slow chilling regime (carcases held at 12 °C for 7 hours and then 2 °C for 24 hours) gave the highest level of tenderness when compared with a conventional chill (2 °C for 24 hours) or an ‘ultra fast’ chill (−20 °C for 3.5 hours followed by 2 °C for 24 hours). Unsurprisingly, there was a noticeably shorter sarcomere length following ultra fast chilling.

5.2 Electrical Stimulation

Electrical stimulation is used to help reduce the variability in meat quality between carcases and aims to prevent cold shortening, which can decrease tenderness. The stimulation of muscles increases the rate at which the pH falls post-slaughter and accelerates the onset of rigor mortis, enabling the carcases to be moved through processing quicker. This is useful in commercial plants as carcases are often rapidly chilled and, without the use of electrical stimulation, cold shortening could occur. As well as preventing toughening through cold shortening, electrical stimulation may also increase tenderness through proteolysis, the modification of muscle structure and stretching of the sarcomere (Mikołajczak et al., 2019; Kaur et al., 2021). Further to this, a quicker chill rate following electrical stimulation also leads to a less favourable environment for microorganisms’ growth and so an improved shelf life can also be seen (Hussain et al., 2021).

Traditionally, electrical stimulation has been delivered by low and high voltages, typically to carcases as a whole. Low voltage is considered up to 100 V and applied within 5 minutes of exsanguination, whereas high voltage is over 500V and applied up to 60 minutes post-slaughter

(Warriss, 2010). Pearce et al. (2009) discussed the use of medium voltage stimulation whereby the current remains constant and only one carcase is presented at a time, allowing the voltage to vary (peaking at 300V). Maintaining a constant frequency of 15Hz saw a higher number of carcases reaching the required pH temperature window and higher levels of tenderness achieved.

5.3 Carcase Suspension Methods

In most commercial processing plants, carcases are suspended from the Achilles tendon, which extends the hind leg and puts a slight backward bend into the spine. Although this method can work well for carcase processing, the more expensive cuts of meat (in the hind quarters) have a greater opportunity to shorten and therefore a higher chance of being impacted by cold shortening should the correct pH-temperature window not be reached (Pogorzelski et al., 2022). This can be particularly important with beef carcases due to the size and economic impact of these muscles.

Suspending carcases by the hip/pelvis using the aitch-bone allows the muscles in the hind leg and along the back to be stretched during the rigor mortis period, which can help to increase the tenderness and reduce the likelihood of cold shortening occurring in these muscles (Ertbjerg & Puolanne, 2017). In this position, the tenderness of these muscles can be improved by up to 40% (Pogorzelski et al., 2022). Ahnström et al. (2012) also found that hip suspending beef carcases helped to reduce the length of ageing by 7 days with lower shear force values reported. Nian et al. (2018) saw similar results with the tenderness of beef carcases 'accelerated' when using hip suspension. If carcases are suspended for a period of time for ageing, it is also thought that hip suspension would be beneficial to increasing tenderness since the muscles are not so tightly contracted and there is less overlap of the actin and myosin filaments and, therefore, more availability for proteolytic enzymatic activity (Kamatara et al., 2014).

Despite the widely reported advantages to meat quality following hip suspension, there are limitations to its practical application. The shape of the hind quarter muscles changes and so labour and butchery changes need to be accounted for. The overall change of carcase shape may also mean that chiller and storage space is compromised. Nevertheless, it is used commercially in countries across the world, particularly for beef (Pogorzelski et al., 2022).

5.4 Ageing

Following rigor mortis, naturally occurring proteolytic enzymes break down the structure of meat resulting in an increase in tenderness (Kannan et al., 2014). This is seen to rapidly occur between 3 and 7 days in beef (Kim et al., 2018) and can continue up until 28 days post-slaughter. The early tenderisation is mostly due to calpain proteases breaking down the myofibrils and, following this, the intramuscular connective tissues weaken (Kannan et al., 2014). Research also supports the effectiveness of several other enzymes in post-mortem protein degradation (Ertbjerg & Puolanne, 2017), such as caspases. Although ageing may have some impact on lessening the extensive toughness of cold shortening, it is thought that this is limited as the actin and myosin filaments tightly overlap, reducing the availability of proteolytic susceptible sites (Kim et al., 2018). As well as tenderness, the flavour profile of aged meat can change. Proteolysis and lipolysis break down flavourless molecules into smaller fragments which increases the amount of free amino acids (Terjung et al., 2021). Free amino acids are key in the flavour development of meat which occurs during biochemical reactions upon cooking (Zhang et al., 2022).

During ageing, whole carcases or smaller specific cuts (such as ribeye) are stored in controlled refrigerated conditions; air circulation and relative humidity are key for reducing microbial growth during this time. Ageing is typically carried out in one of two ways: wet-ageing or dry-ageing. Through wet-ageing, meat is sealed in a vacuum bag and ageing is carried out anaerobically. This method does not result in too much yield loss (through evaporation or trimming) and is practical for the industry (Zhang et al., 2022). Dry-ageing is carried out aerobically with meat left open to the environment. This creates a unique flavour profile (Kim et al., 2018) which is considered a premium, with flavours being described as buttery, beefy and nutty (Zhang et al., 2022). As there are higher losses in yield, from evaporation and trimming the external discoloured edges, there is often a premium price attached to dry-aged meat. Upon review of dry- and wet-aged beef, Terjung et al. (2021) explain that the tenderness is similar. Semi-permeable dry-ageing bags have been seen to reduce the yield loss in comparison to dry-ageing and also improve the flavour profile when compared to wet-ageing (Dashdorj et al., 2016).

6 Effects of Processing

6.1 Hot-Boning

Removing muscles or sections of meat from the carcase before it has been chilled is referred to as hot-boning. This typically happens around 1 hour post-slaughter (Jose et al., 2020) and before the carcase enters complete rigor mortis. Different muscles cool and enter rigor at different rates and so there is variation in the effects of hot-boning on texture and quality across different muscles. Processing meat in this way can increase the overall yield (due to lower drip losses) as well as save on chiller space in the processing plant. However, due to the shortening of the sarcomere length, meat may increase in toughness and become darker in colour, though this is not seen across all studies and species. Ithurralde et al. (2020) found that hot boning had no impact on the colour of sheep meat. Due to the potential downgrading of quality, hot-boned meat may be used for lower value cuts or meat which is used for ground meat products (Jose et al., 2020). The use of electrical stimulation can impact the rate of glycolysis and the subsequent decline of pH within muscles and can therefore improve the tenderness of hot-boned muscles (Balan et al., 2020).

6.2 Use of Proteolytic Enzymes

Prime cuts often make up a small percentage of a carcase and the remaining cuts may not be favoured for their lack of tenderness. Given the importance of tenderness in eating quality acceptability, mechanisms for improving tenderness can be of great economic importance. Tenderness is often a result of the enzymatic breakdown of muscle fibres which happens, to an extent, naturally (see Sect. 5.4). The addition of enzymes through mechanical methods, such as dipping meat into a solution or injecting a solution directly into the meat, can also help to break down fibres in a similar way and improve tenderness (Gerelt et al., 2000). Research has also shown that the use of proteolytic enzymes can also overcome the toughening effects of cold shortening (Rhodes & Dransfield, 1973), though this was seen through injection of papain pre-slaughter. Some common exogenous proteases are retrieved from plants such as bromelain (pineapple), papain (papaya), ficin (fig), actinidin (kiwi) and zingibain (ginger). Although successful in tenderising meat, bromelain and papain may sometimes give a mushy texture and 'off' flavours (Behkit et al., 2014). The use of actinidin and zinigain have gained more interest in recent years as they have a more mild effect and less detrimental impact on the eating quality than bromelain and papain (Warner et al., 2022). Han et al. (2009) saw that actinidin could contribute 'efficiently and effectively' to meat tenderisation when looking specifically at lamb *Longissmus dorsi*. However, Ramil et al. (2021) found that bromelain from pineapple and jackfruit by-products, used at different concentration combinations, could improve beef tenderisation without impacting quality parameters such as texture and sensory attributes.

6.3 High-Pressure Treatment

In the context of meat processing, hydrostatic pressure is the pressure applied to a product when it is contained within a liquid pressurised in an enclosed container. Interest in high hydrostatic pressure (HHP) treatment of food originally developed because of its potential in preservation. Nevertheless, HHP has some important effects on meat texture, through the rupture and reformation of molecular bonds within and between protein molecules, resulting in protein denaturation, aggregation or gelation (Sun & Holley, 2010). This can lead to meat being toughened or tenderised depending on the duration of treatment and its interaction with other processing conditions (e.g. heat treatment). These effects can be used to enhance properties of conventional products or create new textured products, although the most consistent effects are seen in pre-rigor meat.

6.4 Curing

Meat curing may be defined as the addition of salt to meats for the purpose of preservation (Martin, 2012). Often this also includes the use of nitrates or nitrites to enhance preservation and provide a distinctive colour and flavour. The addition of curing salts without water (dry curing) results in changes to meat texture associated with a loss of water from the muscle (such as Parma ham) producing a unique mouthfeel depending on the curing conditions and resulting moisture content. Many of these products have a low moisture content and are designed to be eaten without cooking. The use of salts in solution generally results in an increased water content and an increase in tenderness, for example, in gammon or cooked hams.

7 Reformed Meat Products

Meat products vary in texture for several reasons: the extent to which comminution (mincing) has been carried out, their ingredients and the formation of structural matrices, usually from the proteinaceous components of meat. Fat is important for the quality of meat products because of its ability to impart specific characteristics (Goutefongea & Dumont, 1990) and, alongside water, the provision of juiciness and tenderness (Rust, 1987).

7.1 The Texture of Coarse-Ground Meat Products

In coarse-ground meat products, the microscopic structure of the muscle tissue is retained, so the inherent texture of the muscle will contribute to overall product texture, and the fat is retained in fat cells or clumps of cells. These have a texture which is described as crumbly. During product manufacture, the texture of the overall product is largely determined by the processing conditions and the ingredients used.

7.1.1 Effect of Processing Conditions on the Texture of Coarse-Ground Meat Products

Various changes to processing affect meat patty properties. More tender (softer) patties can be produced by:

- Reducing the particle size (Roth et al., 1999)
- Using hot-boned beef (Williams et al., 1994)
- Adjusting freezing conditions (Berry, 1993)

If water is added, increasing the grind size has also been shown to improve the cooking characteristics (Hoogenkamp, 1991). Increasing the temperature during comminution of British sausages results in increased cooking losses but a softer texture (Brown & Ledward, 1987).

7.1.2 Effect of Composition on the Texture of Coarse-Ground Meat Products

Reducing the fat content of meat patties and sausages and replacing with lean meat generally reduce their tenderness, juiciness and overall acceptability and increase mealiness and cohesiveness (Cross et al., 1980; Kregel et al., 1986; Troutt et al., 1992; Wong & Maga, 1995).

Added water increases the tenderness and juiciness of meat patties and coarse ground sausages (Nakai et al., 1976; Miller et al., 1993) and can generally be used to enhance the texture of low-fat versions, to the extent that an equivalent or better product can be produced (Frederick et al., 1994). Given the right ionic conditions, the meat protein acts to take up water by swelling to a gel (Hedrick et al., 1994).

A huge variety of ingredients have been tested for their effect on product eating quality and texture. Often these are used to help hold water in the product to provide a softening effect (e.g. when fat content is reduced). Many of these are effective and ingredient selection is dependent on the product, consumer expectations and non-technical factors (such as legislative requirements, price and availability). Some are included to enhance the nutritional properties, such as added fibre (Younis et al., 2022).

Changing the type of fat used as an ingredient, can have an effect on texture. Use of a softer fat has a softening effect, e.g. the use of pork instead of beef fat to soften patties whilst at the same fat content (Parizek et al., 1981).

7.2 Structure of Finely Comminuted Meat Products

Finely comminuted meat products are more properly described as batters or pastes, but are often referred to as emulsions (Ugalde-Benítez, 2012). The most well-known and researched sausage of this type is the frankfurter, a cured emulsion sausage usually prepared with beef and/or pork lean and pork fat with water, seasonings and curing agents. It can, however, be made with meat of any species. The meat content may include mechanically separated or 'reclaimed' meat. Other examples include bologna and wiener (sliceable emulsion products) and knackwurst.

Both the physical entrapment of fat within a protein gel and the emulsification of fat, by coating of droplets with protein, seem important (Barbut, 1995), as does the gelation of salt-soluble proteins on cooking (Comer, 1979). The 'liquid' phase of the emulsion consists of a fine protein matrix, usually formed by actin and myosin from the contractile muscle tissue and supplemented by collagen and added proteinaceous ingredients (such as egg or whey protein). Within this matrix, tiny pores and capillaries entrap added water and fat. The protein within the emulsion forms structural associations such as protein-protein, protein-water and protein-fat interactions. These are responsible for the swelling, gelation and emulsification of meat batters (Schmidt, 1987; Hoogenkamp, 1995).

During processing, ingredients are chopped together to produce an evenly mixed smooth paste prior to cooking. The fat disintegrates in two stages. Initially the fatty tissue disintegrates into natural fat cells. The result of the second stage depends on the hardness of the original fat. If the fat is soft then it results in the production of homogeneously divided particles, each surrounded by a protein membrane. If the fat is hard, then coalescence can occur resulting in separation of the fat ('rendering out'). This can also occur if the myosin:collagen ratio is too low; fat particles coated in collagen rupture on heating, resulting in loss of fat (Pearson & Tauber, 1984). Alleviating this problem is generally achieved by reducing the fat particle size which can be brought about by modifying the processing conditions (Ackerman et al., 1971; Lee et al., 1981).

7.2.1 Effect of Processing Conditions on the Texture of Finely Comminuted Meat Products

The processing conditions are key in determining the texture of emulsion-type meat products. Reducing the chopping time softens the product but reduces overall liking (Lee et al., 1987). Conversely, over-chopping gives rise to a firmer texture due to more protein extraction (Sutton et al., 1995). The optimum chopping time is recipe dependant, with rigid gel formation occurring at a higher chopping temperature in higher fat batters (Barbut & Mittal, 1989). The final temperature produced by chopping affects product texture and emulsion stability (Hensley et al., 1993; Sutton et al., 1993; Jiménez Colmenero et al., 1996).

The order of addition of the ingredients to the batter is also a determinant of final product texture, for example massaging the lean with the added water before adding the fat has resulted in a firmer product (Sylvia et al., 1994).

Other manipulations of the processing conditions that have been shown to modify the product texture include the following:

- Subjecting meat batters to hyperbaric pressure (1000–2000 bar) which increases firmness of meat batters (Mandava et al., 1984).
- Cooking at a high relative humidity that results in softer frankfurters (Simon et al., 1965).
- Higher final cooking temperatures resulting in a harder, more brittle frank. The minima for cohesiveness and elasticity occur at around 70–75 °C (Singh et al., 1985).
- Increasing particle size (by varying mincing plates) to increase hardness of batter products (Small et al., 1995).

7.2.2 Effect of Composition on the Texture of Finely Comminuted Meat Products

Salt concentration needs to be optimised for each recipe as it is important for the extraction of myofibrillar proteins in the formation of emulsions which has an influence on product texture. Reducing the concentration will result in reduced hardness or firmness (Matulis et al., 1995). If lower salt concentrations are required for optimum flavour, then protein extraction may become a problem. This could be resolved by adding all the salt to the lean meat, to achieve extraction before the other ingredients are added (Jantawat & Carpenter, 1989).

As with patties, reducing the fat content and replacing with lean results in a tougher, drier, less acceptable product with little or no change in flavour (Hand et al., 1987; El-Magali et al., 1995). It is not the type of fat but simply its presence that is primarily important in frankfurter texture (Mandigo & Eilert, 1993). Indeed vegetable fats can be used with little or no effect on product texture (Marquez et al., 1989; Christensen & Zeuthen, 1994). Increased levels of fat result in a more diffuse gel which is therefore weaker and so contributes to the softness and juiciness of emulsion type sausages.

The addition of water to products (at rates up to 30% of the formulation) has been found to have similar effects on texture to that of fat (Claus & Hunt, 1991; Hensley & Hand, 1995). The product becomes softer and more juicy. Water cannot, however, be exchanged for fat on a one for one basis. The effect of water seems to be more extreme than fat due to greater disruption of the protein matrix (Gregg et al., 1993; Hensley & Hand, 1995).

Non-meat proteins can be used to strengthen the protein matrix of low-fat emulsion-type sausages, to give a firmer texture (Ensor et al., 1987). Successful results have been achieved with whey protein concentrate, calcium reduced non-fat dry milk and soy protein isolate (Sofas & Allen, 1977; Decker et al., 1986; Ensor et al., 1987; Yang et al., 1995). On the other hand, low-binding meats such as heart or mechanically separated poultry meat can be used to soften the texture (Rongey & Bratzler, 1966).

The acceptability of product texture can be subjective, yet there are optimum textural attributes which must be determined for each individual product, with its target consumer in mind (Carballo et al., 1995).

8 Measurement of Texture in Meat and Meat Products

8.1 Sensory Methods

Sensory attributes can be measured using objective (instrument or trained taste panel) or subjective (consumer taste panel) methods. Trained taste panels can identify a range of characteristics based on requirements. Panels first work together to discuss definitions of traits such as 'tenderness', as this can have a different meaning to different people (Warner et al., 2021). Once decided, samples are cooked and prepared away from the panel so as not to influence their senses, and they judge each in a blind trial.

The method for sensory assessment of reformed meat products is similar to that used for whole cuts, evaluating aspects such as tenderness, juiciness and flavour. To further define differences in product attributes, sensory profiling has been used. In most cases, this involves panelling with scores being given for a wider range of attributes, pre-determined by the experimenter. In some cases, free choice profiling is used with panellists nominating the attributes needed to fully describe the product and a short list being drawn up by consensus.

Szczesniak (1963) proposed a terminology and definitions, which would allow sensory profiling and instrumental assessment to be directly comparable. This is described in Sect. 8.3 on methods to assess the textural properties of meat products.

8.2 Instrumental Assessment of Meat Cuts

An early developed method for instrumentally assessing meat texture is the Warner-Bratzler shear force test; K.F. Warner and associates established the idea of shearing a cooked sample of meat as an indication of tenderness, and L.J. Bratzler outlined the specifics of the blade and cutting speed. This is still one of the most widely used tests today due to its repeatability and correlation with consumer sensory ratings (Silva et al., 2015). One of the most important factors to consider when carrying out shear force work is the orientation of the muscle fibres within the cores to be sampled (Wheeler et al., 1997). It is key to ensure that the fibres run perpendicular to the blade so that the maximum force can be measured. Silva et al. (2015) explored the effectiveness of using cuboidal/square cores as opposed to the traditionally used round cores. The experiment showed that square cores give more accurate and sensitive results which are more like the differences seen between steaks which are judged by a taste panel. This work supported the findings of a smaller study earlier performed by Thiel et al. (1997). Holman et al. (2015) found that six cuboidal cores is the minimum number required to attain reliable results whilst still allowing trials to be repeatable; any more than this only saw negligible improvements in error.

Secondary to the fibre direction, the cooking method can have a significant impact on the results of shear force and standardised protocols can reduce variability and improve the repeatability. Methods of direct heat source, such as griddle plate, tend to cook beef samples quicker and give lower shear force values compared to oven cooking with low humidity and high temperatures (Fabre et al., 2018).

8.3 Assessment Methods Used for the Textural Properties of Meat Products

The most important factor in comparing meat products with altered formulations or processing conditions is acceptability to the consumer. However, because the textural properties of meat products are difficult to define, their assessment is quite complicated and a large number of methods have been used (Schreuders et al., 2021).

Szczesniak (1963) proposed the following terminology and definitions, which corresponds to the most common usage. Many researchers, however, use their own terms, often without defining them.

Hardness	The force required to give a certain deformation.
Cohesiveness	The strength of the internal bonds making up the body of the product.
Viscosity	The rate of flow per unit force (not relevant to cooked meat products).
Elasticity	The rate at which a deformed material goes back to its undeformed condition after the deforming force is removed.
Adhesiveness	The work necessary to overcome the attractive forces between the surface of the food and the surface of other materials with which the food comes in contact.
Brittleness	The force with which the material fractures. It is related to hardness and cohesiveness. In brittle materials, cohesiveness is low and hardness can vary from low to high.

Chewiness	The energy required to masticate a solid food product to a state ready for swallowing. It is related to the parameters of hardness, cohesiveness and elasticity (the second definition of chewiness given under the mechanical assessment of attributes below).
Gumminess	The energy required to disintegrate a semisolid food product to a state ready for swallowing. It is related to the parameters of hardness and cohesiveness.

Various mechanical measurements are used to quantify product texture. Essentially, these are either compression or punch methods. Compression equipment uses a flat plunger to push into the product to a fixed proportion (usually 75–80%) of its original height twice. The parameters are taken from a force/time curve as follows (Friedman et al., 1963; Bourne, 1978; Beilken et al., 1990; Xiong et al., 1995):

Fracturability[a] or brittleness	The force at the first significant break in the curve (may not always occur before peak force).
Fracturability[a]	The differential between the first and second peaks.
Hardness (H)	Force used to achieve the initial penetration.
Cohesiveness (C) or degree of breakdown	Ratio of work done on the first penetration to that on the second (positive area under curve). The areas can also be considered separately as first and second bite area.
Gumminess or chewiness[a]	H × C.
Elasticity (E) or springiness	Measured as the distance from the start of the curve to contact with the sample at the start of the second compression expressed as a ratio against the same measurement for an inelastic substance (e.g. clay). Alternatively, a simpler but less valid method is to measure the height the food recovers between the end of the first cycle of compression and the start of the next.
Chewiness[a]	H × C × E.
Adhesiveness	Negative force required to pull the plunger away from the sample

[a] Alternative definitions

It should be noted that measurement results vary slightly with the instrument being used due to differences in the rate of compression and the flexibility of the instrument. Brittleness and adhesiveness never occur in the same food product according to Friedman et al. (1963).

9 Summary

In writing this chapter, some areas have recent research or reviews which have been drawn upon, and in other areas, the science is well established and little new information is available. The texture of meat is influenced by many factors, ranging from animal type, through slaughter and processing, to post-slaughter treatments and processes. Reformed meat product texture is largely determined by the ingredients used and the processing conditions applied. Methods for assessing quality, and in particular texture, have been described.

References

Aberle, E. D., Reeves, E. S., Judge, M. D., Hunsley, R. E., & Perry, T. W. (1981). Palatability and muscle characteristics of cattle with controlled weight gain: time on a high energy diet. *Journal of Animal Science, 52*, 757.

Ackerman, S. A., Swift, C. E., Carroll, R. J., & Townsend, W. E. (1971). Effects of types of fat and of rates and temperatures of comminution on dispersion of lipids in frankfurters. *Journal of Food Science, 36*(2), 266–269. https://doi.org/10.1111/j.1365-2621.1971.tb04039.x

Ahnström, M. L., Hessle, A., Johansson, L., Hunt, M. C., & Lundström, K. (2012). Influence of slaughter age and carcass suspension on meat quality in Angus heifers. *Animal, 6*(9), 1554–1562. https://doi.org/10.1017/S1751731112000109

Álvarez, C., Koolman, L., Whelan, M., & Moloney, A. (2022). Effect of pre-slaughter practises and early post-mortem interventions on sheep meat tenderness and its impact on microbial status. *Food, 11*(2), 181. https://doi.org/10.3390/foods11020181

Archile-Contreras, A. C., Mandell, I. B., & Purslow, P. P. (2010). Disparity of dietary effects on collagen characteristics and toughness between two beef muscles. *Meat Science, 86*, 491–497.

Bailey, A. J., & Light, N. D. (1989). *Connective tissue in meat and meat products*. Elsevier Applied Science.

Balan, P., Farouk, M. M., Staincliffe, M., Stuart, A. D., Kemp, R., & Craigie, C. (2020). Effects of additional electrical stimulation and pre-rigor conditioning temperature on the ageing potential of hot-boned bovine muscles. *Asian-Australasian Journal of Animal Sciences, 33*(10), 1642–1655. https://doi.org/10.5713/ajas.19.0788

Barbut, S. (1995). Importance of fat emulsification and protein matrix characteristics in meat batter stability. *Journal of Muscle Foods, 6*(2), 161–177. https://doi.org/10.1111/j.1745-4573.1995.tb00564.x

Barbut, S., & Mittal, G. S. (1989). Influence of K+ and Ca++ on the rheological and gelatin properties of reduced fat pork sausages containing carrageenans. *Lebensmittel-Wissenschaft und -Technologie, 22*(3), 124–132.

Barbut, S., Sosnicki, A. A., Lonergan, S. M., Knapp, T., Ciobanu, D. C., Gatcliffe, L. J., Huff-Lonergan, E., & Wilson, E. W. (2008). Progress in reducing the pale, soft and exudative (PSE) problem in pork and poultry meat. *Meat Science, 79*(1), 46–63. https://doi.org/10.1016/J.MEATSCI.2007.07.031

Barrasso, R., Ceci, E., Tufarelli, V., Casalino, G., Luposella, F., Fustinoni, F., Dimuccio, M. M., & Bozzo, G. (2022). Religious slaughtering: Implications on pH and temperature of bovine carcasses. *Saudi Journal of Biological Sciences, 29*(4), 2396–2401. https://doi.org/10.1016/J.SJBS.2021.12.002

Behkit, A. A., Hopkins, D. L., Geesink, G., Bekhit, A. A., & Franks, P. (2014). Exogenous proteases for meat tenderization. *Food Science & Nutrition, 54*(8), 1012–1031. Available at: https://doi.org/10.1080/10408398.2011.623247

Beilken, S. L., Eadie, L. M., Jones, P. N., & Harris, P. V. (1990). Sensory and mechanical assessment of the quality of frankfurters. *Journal of Texture Studies, 21*, 395–409.

Berry, B. W. (1993). Fat level and freezing temperature affect sensory, shear, cooking and compositional properties of ground beef patties. *Journal of Food Science, 58*(1), 34–37. https://doi.org/10.1111/J.1365-2621.1993.TB03204.X

Bourne, M. C. (1978, July). Texture profile analysis. *Food Technology*.

Brown, S., & Ledward, D. A. (1987). Effect of temperature of comminution on the stability and eating quality of "English" sausages. *Meat Science, 20*(2), 97–105. https://doi.org/10.1016/0309-1740(87)90030-1

Buchter, L. (1986). *Eating quality in low-fat beef, Kreaturer-Kodkvalitet*. Danish Meat Research Institute.

Campion, D. R., Crouse, J. D., & Dikeman, M. E. (1975). Predictive value of USDA Beef quality grade factors for cooked meat palatability. *Journal of Food Science, 40*(6), 1225–1228. https://doi.org/10.1111/j.1365-2621.1975.tb01057.x

Carballo, J., Barreto, G., & Jimenez Colmenero, F. (1995) Starch and egg white influence on properties of bologna sausage as related to fat content. *Journal of Food Science, 60*(4), 673–677. https://doi.org/10.1111/j.1365-2621.1995.tb06204.x

Channon, H. A., Payne, A. M., & Warner, R. D. (2003). Effect of stun duration and current level applied during head to back and head only electrical stunning of pigs on pork quality compared with pigs stunned with CO2. *Meat Science, 65*(4), 1325–1333. https://doi.org/10.1016/S0309-1740(03)00053-6

Christensen, M., & Zeuthen, P. (1994). Substitution of animal fat with peanut oil in a meat emulsion model. In *International congress of meat science and technology*. The Hague, Netherlands.

Chrystall, B. (1994). Meat texture measurement BT. In A. M. Pearson & T. R. Dutson (Eds.), *Quality attributes and their measurement in meat, poultry and fish products* (pp. 316–336). Springer. https://doi.org/10.1007/978-1-4615-2167-9_12

Claus, J. R., & Hunt, M. C. (1991). Low-fat, high added-water bologna formulated with texture-modifying ingredients. *Journal of Food Science, 56*(3), 643–647. https://doi.org/10.1111/j.1365-2621.1991.tb05347.x

Comer, F. W. (1979). Functionality of fillers in comminuted meat products. *Canadian Institute of Food Science and Technology Journal, 12*(4), 157–165. https://doi.org/10.1016/S0315-5463(79)73127-0

Cross, H. R., Berry, B. W., & Wells, L. H. (1980). Effects of fat level and source on the chemical, sensory and cooking properties of ground beef patties. *Journal of Food Science, 45*(4), 791–794. https://doi.org/10.1111/j.1365-2621.1980.tb07450.x

Dashdorj, D., Tripathi, V. K., Cho, S., Kim, Y., & Hwang, I. (2016). Dry aging of beef; review. *Journal of Animal Science and Technology, 58*(20). Available at: https://doi.org/10.1186/s40781-016-0101-9

Decker, C. D., Conley, C. C., & Richert, S. (1986). Use of isolated soy protein in the development of frankfurters with reduced levels of fat, calories, and cholesterol. In *European meeting of meat research workers*.

Dikeman, M. E. (1987). Fat reduction in animals and the effects on palatability and consumer acceptance of meat products. In *40th Reciprocal Meat Conference*. American Meat Science Association.

Dransfield, E. (1994). Tenderness of meat, poultry and fish BT. In A. M. Pearson & T. R. Dutson (Eds.), *Quality attributes and their measurement in meat, poultry and fish products* (pp. 289–315). Springer. https://doi.org/10.1007/978-1-4615-2167-9_11

Dransfield, E., Nute, G. R., Macdougall, D. B., & Rhodes, D. N. (1979). Effect of sire breed on eating quality of cross-bred lambs. *Journal of the Science of Food and Agriculture, 30*(8). https://doi.org/10.1002/jsfa.2740300810

El-Magali, S. B., Laroia, S., & Hansen, P. M. T. (1995). Quality characteristics of low-fat ground beef patties formulated with whey protein concentrate. In *International congress of meat science and technology*. San Antonio, Texas.

Ensor, S. A., Mandigo, R. W., Calkins, C. R., & Quint, L. N. (1987). Comparative evaluation of whey protein concentrate, soy protein isolate and calcium-reduced nonfat dry milk as binders in an emulsion-type sausage. *Journal of Food Science, 52*(5), 1155–1158.

Ertbjerg, P., & Puolanne, E. (2017). Muscle structure, sarcomere length and influences on meat quality: A review. *Meat Science, 132*, 139–152. https://doi.org/10.1016/J.MEATSCI.2017.04.261

Fabre, R., Dalzotto, G., Perlo, F., Bonato, P., Teira, G., & Tisocco, O. (2018). Cooking method effect on Warner-Bratzler shear force of different beef muscles. *Meat Science, 138*, 10–14. https://doi.org/10.1016/J.MEATSCI.2017.12.005

Ferguson, D. M., & Warner, R. D. (2008). Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants? *Meat Science, 80*(1), 12–19. https://doi.org/10.1016/j.meatsci.2008.05.004

Fisher, A., Nute, G., Matthews, K., & Wood, J. (2001). Differences in tenderness between bulls and steers: Effects in different muscles. In *International congress of meat science and technology* (pp. 270–271). Krakow, Poland.

Frederick, T. L., Miller, M. F., Tinney, K. S., Bye, L. R., & Ramsey, C. B. (1994). Characteristics of 95% Lean Beef German Sausages varying in phosphate and added water. *Journal of Food Science, 59*(3), 453–455. https://doi.org/10.1111/j.1365-2621.1994.tb05537.x

Friedman, H. H., Whitney, J. E., & Szczesniak, A. S. (1963). The texturometer—A new instrument for objective texture measurement. *Journal of Food Science, 28*(4), 390–396. https://doi.org/10.1111/j.1365-2621.1963.tb00216.x

Fuseini, A., Knowles, T. G., Hadley, P. J., & Wotton, S. B. (2016). Halal stunning and slaughter: Criteria for the assessment of dead animals. *Meat Science, 119*, 132–137. https://doi.org/10.1016/J.MEATSCI.2016.04.033

Garmyn, A., Fernández-López, J., Ding, Z., Wei, Q., Liu, C., Zhang, H., & Huang, F. (2022). *The quality changes and proteomic analysis of cattle muscle postmortem during Rigor Mortis*. https://doi.org/10.3390/foods11020217

Gazzola, C., O'Neill, C. J., & Frisch, J. E. (1999). Comparative evaluation of the meat quality of beef cattle breeds of Indian, African and European origins. *Animal Science, 69*(1), 135–142.

Ge, Y., Zhang, D., Zhang, H., Li, X., Fang, F., Liang, C., & Wang, Z. (2021). Effect of postmortem phases on lamb meat quality: A physicochemical, microstructural and water mobility approach. *Food Science of Animal Resources, 41*(5), 802–815. https://doi.org/10.5851/kosfa.2021.e37

Gerelt, B., Ikeuchi, Y., & Suzuki, A. (2000). Meat tenderization by proteolytic enzymes after osmotic dehydration. *Meat Science, 56*(3), 311–318. https://doi.org/10.1016/S0309-1740(00)00060-7

Gerrard, D. E., Jones, S. J., Aberle, E. D., Lemenager, R. P., Diekman, M. A., & Judge, M. D. (1987). Collagen stability, testosterone secretion and meat tenderness in growing bulls and steers. *Journal of Animal Science, 65*, 1236.

Gonzalez-Rivas, P. A., Chauhan, S. S., Ha, M., Fegan, N., Dunshea, F. R., & Warner, R. D. (2020). Effects of heat stress on animal physiology, metabolism, and meat quality: A review. *Meat Science, 162*, 108025. https://doi.org/10.1016/J.MEATSCI.2019.108025

Goodson, K. J., Miller, R. K., & Savell, J. W. (2001). Carcass traits, muscle characteristics, and palatability attributes of lambs expressing the callipyge phenotype. *Meat Science, 58*, 381–387.

Goutefongea, R., & Dumont, J. P. (1990). Developments in low-fat meat and meat products. In J. D. Wood & A. V. Fisher (Eds.), *Reducing fat in meat animals* (pp. 398–436). Elsevier Applied Science.

Greaser, M. L., & Pearson, A. M. (1999). Flesh foods and their analogues. In *Food texture – Perceptions and measurement*. Wiley.

Gregg, L. L., Claus, J. R., Hackney, C. R., & Marriott, N. G. (1993). Low-fat, high added water bologna from massaged, minced batter. *Journal of Food Science, 58*(2), 259–264.

Gregory, N. G. (2005). Recent concerns about stunning and slaughter. *Meat Science, 70*(3), 481–491. https://doi.org/10.1016/J.MEATSCI.2004.06.026

Groth, I., Wielgosz-Groth, Z., Kijak, Z., Pogorzelska, J., & Wronski, M. (1999). Comparison of meat quality in young black and white breed bulls and their hybrids with beef breeds. *Journal of Animal and Feed Sciences, 8*, 145–156.

Gruber, S. L., Tatum, J. D., Engle, T. E., Chapman, P. L., Belk, K. E., & Smith, G. C. (2010). Relationships of behavioural and physiological symptoms of preslaughter stress to beef longissimus muscle tenderness. *Journal of Animal Science, 88*, 1148–1159.

Han, J., Morton, J. D., Bekhit, A. E. D., & Sedcole, J. R. (2009). Pre-rigor infusion with kiwifruit juice improves lamb tenderness. *Meat Science, 82*(3), 324–330. https://doi.org/10.1016/J.MEATSCI.2009.02.003

Hand, L. W., Hollingsworth, C. A., Calkins, C. R., & Mandigo, R. W. (1987). Effects of preblending, reduced fat and salt levels on Frankfurter characteristics. *Journal of Food Science, 52*(5), 1149–1151. https://doi.org/10.1111/j.1365-2621.1987.tb14030.x

Hannula, T., & Puolanne, E. (2004). The effect of cooling rate on beef tenderness: The significance of pH at 7 °C. *Meat Science, 67*(3), 403–408. https://doi.org/10.1016/J.MEATSCI.2003.11.012

Harper, G. S. (1999). Trends in skeletal muscle biology and the understanding of toughness in beef. *Australian Journal of Agricultural Research, 50*, 1105–1129.

Hedrick, H. B., Aberle, E. D., Forrest, J. C., Judge, M. D., & Merkel, R. A. (1994). *Principles of meat science*. Kendall/Hunt Publishing Company.

Hensley, J. L., & Hand, L. W. (1995). Formulation and chopping temperature effects on beef frankfurters. *Journal of Food Science, 60*(1), 55–57, 67.

Hensley, J. L., Hand, L. W., & Sutton, D. S. (1993). Chopping temperature effects on low fat, high moisture, beef frankfurters. *Journal of Animal Science, 71*(Supplement 1), 12.

Hiner, R. L., Thornton, J. W., & Alsmeyer, R. H. (1965). Palatability and quantity of pork as influenced by breed and fatness. *Journal of Food Science, 30*(3). https://doi.org/10.1111/j.1365-2621.1965.tb01800.x

Hogg, B. W., Pearson, A. M., & Dutson, T. R. (1991). Growth regulation in farm animals. *Advances in Meat Research*, 103–134.

Holman, B. W. B., Alvarenga, T. I. R. C., van de Ven, R. J., & Hopkins, D. L. (2015). A comparison of technical replicate (cuts) effect on lamb Warner–Bratzler shear force measurement precision. *Meat Science, 105*, 93–95. https://doi.org/10.1016/J.MEATSCI.2015.02.013

Homer, D. B., Cuthbertson, A., Homer, D. L. M., & McMenamin, P. (1997). Eating quality of beef from different sire breeds. *Animal Science, 64*, 403–408.

Honikel, K. O. (2014). Conversion of muscle to meat | Rigor Mortis, cold, and rigor shortening. In *Encyclopedia of meat sciences* (pp. 358–365). https://doi.org/10.1016/B978-0-12-384731-7.00096-9

Hoogenkamp, H. W. (1991). Building a better burger. *Meat Processing, 90*(9), 4–7.

Hoogenkamp, H. W. (1995). Meat emulsion variables. Influence of some compositional ingredients. *Fleischwirtschaft lnternational, 74*(1), 29–32.

Hussain, M., Nauman, K., Asghar, B., Iqbal, S., & Rashid, M. A. (2021). Effect of low voltage electrical stimulation and chilling on microbial safety and quality attributes of Beetal Bucks and Lohi Rams carcass. *Small Ruminant Research, 196*, 106315. https://doi.org/10.1016/J.SMALLRUMRES.2020.106315

Ithurralde, J., Bianchi, G., Feed, O., Nan, F., Ballesteros, F., Garibotto, G., & Bielli, A. (2020). The effects of hot boning on meat quality from six different contractile-metabolic sheep muscles: A preliminary study. *Journal of Food Processing and Preservation, 44*(10), e14778. https://doi.org/10.1111/jfpp.14778

Jantawat, P., & Carpenter, J. A. (1989). Salt preblending and incorporation of mechanically deboned chicken meat in smoked sausage. *Journal of Food Quality, 12*(5), 393–401. https://doi.org/10.1111/j.1745-4557.1989.tb00340.x

Jiménez Colmenero, F., Carrascosa, A. V., Barreto, G., Fernandez, P., & Carballo, J. (1996). Chopping temperature effects on the characteristics and chilled storage of low- and high-fat pork Bologna sausages. *Meat Science, 44*(1–2), 1–9. https://doi.org/10.1016/S0309-1740(96)00090-3

Jose, C. G., Jacob, R. H., & Gardner, G. E. (2020). Alternative cutting methods and dry aging reduce the shear force of hot boned beef striploin in Bos indicus cattle. *Meat Science, 163*, 108036. https://doi.org/10.1016/J.MEATSCI.2019.108036

Kamatara, K., Mpairwe, D., Christensen, M., Eskildsen, C. E., Mutetikka, D., Muyonga, J., Mushi, D., Omagor, S., Nantongo, Z., & Madsen, J. (2014). Influence of age and method of carcass suspension on meat quality attributes of pure bred Ankole bulls. *Livestock Science, 169*(C), 175–179. https://doi.org/10.1016/J.LIVSCI.2014.09.018

Kannan, G., Lee, J. H., & Kouakou, B. (2014). Chevon quality enhancement: Trends in pre- and post-slaughter techniques. *Small Ruminant Research, 121*(1), 80–88. https://doi.org/10.1016/J.SMALLRUMRES.2014.03.009

Kaur, L., Hui, S. X., Morton, J. D., Kaur, R., Chian, F. M., & Boland, M. (2021). Endogenous proteolytic systems and meat tenderness: Influence of post-mortem storage and processing. *Food Science of Animal Resources, 2*(41(4)), 589–607. Available at: https://doi.org/10.5851/kosfa.2021.e27

Kim, Y. H. B., Ma, D., Setyabrata, D., Farouk, M. M., Lonergan, S. M., Huff-Lonergan, E., & Hunt, M. C. (2018). Understanding postmortem biochemical processes and post-harvest aging factors to develop novel smart-aging strategies. *Meat Science, 144*, 74–90. https://doi.org/10.1016/J.MEATSCI.2018.04.031

Koohmaraie, M., Shackelford, S. D., & Wheeler, T. L. (1996). Effects of a β-Adrenergic agonist (L-644,969) and male sex condition on muscle growth and meat quality of callipyge lambs. *Journal of Animal Science, 74*(1). https://doi.org/10.2527/1996.74170x

Kregel, K. K., Prusa, K. J., & Hughes, K. V. (1986). Cholesterol content and sensory analysis of ground beef as influenced by fat level, heating, and storage. *Journal of Food Science, 51*(5), 1162–1165. https://doi.org/10.1111/j.1365-2621.1986.tb13073.x

Lee, C. M., Carroll, R. J., & Abdollahi, A. (1981). A microscopical study of the structure of meat emulsions and its relationship to thermal stability. *Journal of Food Science, 46*(6), 1789–1793. https://doi.org/10.1111/j.1365-2621.1981.tb04486.x

Lee, C. M., Whiting, R. C., & Jenkins, R. K. (1987). Texture and sensory evaluations of frankfurters made with different formulations and processes. *Journal of Food Science, 52*(4), 896–900. https://doi.org/10.1111/j.1365-2621.1987.tb14237.x

Li, S., Xiang, C., Ge, Y., Liu, H., Zhang, D., & Wang, Z. (2022). Differences in eating quality and electronic sense of meat samples as a function of goat breed and postmortem rigor state. *Food Research International, 152*, 110923. https://doi.org/10.1016/J.FOODRES.2021.110923

Listrat, A., Lebret, B., Louveau, I., Astruc, T., Bonnet, M., Lefaucheur, L., Picard, B., & Bugeon, J. (2016). *How muscle structure and composition influence meat and flesh quality*. https://doi.org/10.1155/2016/3182746

Locker, R. H., & Hagyard, C. J. (1963). A cold shortening effect in beef muscles. *Journal of the Science of Food and Agriculture Food Agriculture, 14*(11), 787–793. Available at: https://doi.org/10.1002/jsfa.2740141103

Lonergan, S. M., Huff-Lonergan, E., Rowe, L. J., Kuhlers, D. L., & Jungst, S. B. (2001). Selection for growth efficiency on Duroc pigs influences pork quality. *Journal of Animal Science, 79*, 2075–2085.

Malmfors, B., & Nilsson, R. (1978). Meat quality traits in Swedish Landrace and Yorkshire Pigs with special emphasis on genetics. *Acta Agriculturae Scandinavica, 28*(sup21). https://doi.org/10.1080/09064702.1978.11884472

Maltin, C. A., Warkup, C. C., Matthews, K. R., Grant, C. M., Porter, A. D., & Delday, M. I. (1997). Pig muscle fibre characteristics as a source of variation in eating quality. *Meat Science, 47*(3/4), 237–248.

Mandava, R., Fernandez, I., & Juillerat, M. (1984). Effect of high hydrostatic pressure on sausage batters. In *Proceedings of 40th international congress of meat science and technology* (pp. 1–6). The Hague.

Mandigo, R. W., & Eilert, S.. (1993). Processing of meat to meet consumer demand: Developments in restructured and low-fat processed products. In *International congress of meat science and technology*.

Marquez, E. J., Ahmed, E. M., West, R. L., & Johnson, D. D. (1989). Emulsion stability and sensory quality of beef frankfurters produced at different fat or peanut oil levels. *Journal of Food Science, 54*(4), 867–870. https://doi.org/10.1111/j.1365-2621.1989.tb07901.x

Martin, J. M. (2012). Meat-curing technology. In Y. H. Hui (Ed.), *Handbook of meat and meat processing* (2nd ed., pp. 523–530). CRC Press. https://doi.org/10.1201/b11479

Matarneh, S. K., England, E. M., Scheffler, T. L., & Gerrard, D. E. (2017). The conversion of muscle to meat. In *Lawrie's Meat Science* (8th ed., pp. 159–185). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100694-8.00005-4

Matulis, R. J., McKeith, F. K., Sutherland, J. W., & Brewer, M. S. (1995). Sensory characteristics of frankfurters as affected by fat, salt and pH. *Journal of Food Science, 60*, 42–47.

Mikołajczak, B., Iwańska, E., Spychaj, A., Danyluk, B., Montowska, M., Grześ, B., Banach, J. K., Żywica, R., & Pospiech, E. (2019). An analysis of the influence of various tenderising treatments on the tenderness of meat from Polish Holstein-Friesian bulls and the course of changes in collagen. *Meat Science, 158*, 107906. https://doi.org/10.1016/J.MEATSCI.2019.107906

Miller, M. F., Guerra, A. L., Ramsey, C. B., & Brittin, H. C. (1993). Determination of threshold for beef tenderness by consumers. In *46th Annual Reciprocal Meat Conference* (p. 69). University of Nebraska Lincoln: National Livestock and Meat Board.

Nakai, H., Ando, S., Ikeda, T., & Saito, F. (1976). Effect of mixing ratio of lean meat, fat and ice water on quality of pork sausage. *Bulletin of National Institute of Animal Industry, 30*, 41–51.

Nian, Y., Allen, P., Harrison, S. M., & Kerry, J. P. (2018). Effect of castration and carcass suspension method on the quality and fatty acid profile of beef from male dairy cattle*, 98*, 4339–4350. https://doi.org/10.1002/jsfa.8960

Oury, M. P., Agabriel, J., Agabriel, C., Micol, D., Picard, B., Blanquet, J., Laboure, H., Roux, M., & Dumont, R. (2007). Relationship between rearing practices and eating quality traits of the muscle rectus abdominis of Charolais heifers. *Livestock Science, 111*, 242–254.

Parizek, E. A., Ramsey, C. B., Galyean, R. D., & Tatum, J. D. (1981). Sensory properties and cooking losses of Beef/Pork Hamburger Patties. *Journal of Food Science, 46*(3), 860–863. https://doi.org/10.1111/j.1365-2621.1981.tb15366.x

Pearce, K. L., Hopkins, D. L., Williams, A., Jacob, R. H., Pethick, D. W., & Phillips, J. K. (2009). Alternating frequency to increase the response to stimulation from medium voltage electrical stimulation and the effect on objective meat quality. *Meat Science, 81*(1), 188–195. https://doi.org/10.1016/J.MEATSCI.2008.07.018

Pearson, A. M., & Tauber, F. W. (1984). Analytical methods. In A. M. Pearson & F. W. Tauber (Eds.), *Processed meats* (pp. 351–388). Springer. https://doi.org/10.1007/978-94-010-9692-8_16

Perry, D., & Thompson, J. M. (2005). The effect of growth rate during backgrounding and finishing on meat quality traits in beef cattle. *Meat Science, 69*, 691–702.

Perry, D., Thompson, J. M., Reverter, A., & Johnston, D. J. (2002). Effect of growth rate on palatability in beef cattle. In *48th International congress of meat science and technology* (pp. 276–277). Rome.

Pogorzelski, G., Pogorzelska-Nowicka, E., Pogorzelski, P., Półtorak, A., Hocquette, J. F., & Wierzbicka, A. (2022). Towards an integration of pre- and post-slaughter factors affecting the eating quality of beef. *Livestock Science, 255*, 104795. https://doi.org/10.1016/J.LIVSCI.2021.104795

Prost, E., Pelczynska, E., & Kotula, A. W. (1975a). Quality characteristics of bovine meat. I. Content of connective tissue in relation to individual muscles, age and sex of animals and carcass quality grade. *Journal of Animal Science, 41*(2), 534–540.

Prost, E., Pelczynska, E., & Kotula, A. W. (1975b). Quality characteristics of bovine meat. II. Beef tenderness in relation to individual muscles, age and sex of animals and carcass quality grade. *Journal of Animal Science, 41*(2), 541–547.

Purchas, R. W. (1991). Effect of sex and castration on growth and composition. *Advances in Meat Research, 7*, 203–254.

Ramil, A. N. M., Hamid, H. A., Zulkifli, F. H., Zamri, N., Bhuya, P., & Manas, N. H. A. (2021). Physiochemical properties and tenderness analysis of bovine meat using proteolytic enzymes extracted from pineapple (Ananas comosus) and jackfruit (Artocarpus heterophyllus) by-products. *Journal of Food Processing and Preservation, 2*, 45. Available at: https://doi-org.bris.idm.oclc.org/10.1111/jfpp.15939

Ren, Q. S., Fang, K., Yang, X. T., & Han, J. W. (2022). Ensuring the quality of meat in cold chain logistics: A comprehensive review. *Trends in Food Science & Technology, 119*, 133–151. https://doi.org/10.1016/J.TIFS.2021.12.006

Rhodes, D. N., & Dransfield, E. (1973). Effect of preslaughter injections of papain on toughness in lamb muscles induced by rapid chilling. *Journal of the Science of Food and Agriculture, 24*, 1583–1588. Available at: https://doi.org/10.1002/jsfa.2740241213

Robins, S. P., Shimokamaki, M., & Bailey, A. J. (1973). The chemistry of collagen cross-links: Age related changes in the reducible components of intact bovine collagen fibres. *Biochemistry Journal, 131*, 771.

Rompala, R. E., & Jones, S. D. M. (1984). Changes in the solubility of bovine intramuscular collagen due to nutritional regime. *Growth, 48*, 466.

Rongey, E. H., & Bratzler, L. J. (1966). The effect of various binders and meats on the palatability and processing characteristics of bologna. *Food Technology*, 134–137.

Roth, D. M., McKeith, F. K., & Brewer, M. S. (1999). Processing parameter effects on sensory and instrumental texture characteristics of reduced-fat ground beef patties. *Journal of Muscle Foods, 10*(2), 163–176. https://doi.org/10.1111/j.1745-4573.1999.tb00393.x

Rust, R. E. (1987). Sausage products. In *The science of meat and meat products* (pp. 457–486). Food and Nutrition Press.

Schmidt, G. R. (1987). Functional behavior of meat components in processing. In J. F. Price & B. S. Schweigert (Eds.), *The science of meat and meat products* (pp. 413–427). Food and Nutrition Press.

Schreuders, F. K. G., Schlangen, M., Kyriakopoulou, K., Boom, R. M., & van der Goot, A. J. (2021). Texture methods for evaluating meat and meat analogue structures: A review. *Food Control, 127*, 108103. https://doi.org/10.1016/J.FOODCONT.2021.108103

Shackelford, S. D., Wheeler, T. L., & Koohmaraie, M. (1997). Effect of the callipyge phenotype and cooking method on tenderness of several major lamb muscles. *Journal of Animal Science, 75*(8), 2100–2105.

Sierra, V., González-Blanco, L., Diñeiro, Y., Díaz, F., García-Espina, M. J., Coto-Montes, A., Gagaoua, M., & Oliván, M. (2021). New insights on the impact of cattle handling on post-mortem myofibrillar muscle proteome and meat tenderization. *Food, 10*(12), 3115. https://doi.org/10.3390/foods10123115

Silva, D. R. G., Torres Filho, R. A., Cazedey, H. P., Fontes, P. R., Ramos, A. L. S., & Ramos, E. M. (2015). Comparison of Warner–Bratzler shear force values between round and square cross-section cores from cooked beef and pork Longissimus muscle. *Meat Science, 103*, 1–6. https://doi.org/10.1016/J.MEATSCI.2014.12.009

Simon, S., Field, J. C., Kramlich, W. E., & Tauber, F. W. (1965). Factors affecting frankfurter texture and a method of measurement. *Food Technology, 19*, 410–413.

Sinclair, K. D., Cuthbertson, A., Rutter, A., & Frankiln, M. F. (1998). The effects of age at slaughter, genotype and finishing system on the organoleptic properties and texture of bull beef from suckled calves. *Animal Science, 66*(2), 329–340.

Sinclair, K. D., Lobley, G. E., Horgan, G. W., Kyle, D. J., Porter, A. D., Matthews, K. R., Warkup, C. C., & Maltin, C. A. (2001). Factors influencing beef eating quality. 1. Effects of nutritional regimen and genotype on organoleptic properties and instrumental texture. *Animal Science, 72*(2), 269–278.

Singh, Y., Blaisdell, J. L., Herum, F. L., Stevens, K., & Cahill, V. (1985). Texture profile parameters of cooked frankfurter emulsions as influenced by cooking treatment. *Journal of Texture Studies, 16*(2), 169–177. https://doi.org/10.1111/j.1745-4603.1985.tb00689.x

Small, A. D., Claus, J. R., Wang, H., & Marriott, N. G. (1995). Particle size and mixing time effects on sensory and physical properties of low-fat, high-moisture Pork Frankfurters. *Journal of Food Science, 60*(1), 40–41. https://doi.org/10.1111/j.1365-2621.1995.tb05602.x

Smith, G. C., Dutson, T. R., Hostetler, R. L., & Carpenter, Z. L. (1976). Fatness, rate of chilling and tenderness of lamb. *Journal of Food Science, 41*, 748–755.

Sofas, J. N., & Allen, C. E. (1977). Effects of lean meat source and levels of fat and soy protein on the properties of weiner-type products. *Journal of Food Science, 42*(4), 875–878.

Sun, X., & Holley, R. (2010). High hydrostatic pressure effects on the texture of meat and meat products. *Journal of Food Science, 75*, R17–R23. https://doi.org/10.1111/j.1750-3841.2009.01449.x

Sutton, D. S., Hand, L. W., & Newkirk, K. A. (1993). The effects of chopping temperatures on low fat, high moisture beef frankfurters. In *Proceedings of the 54th annual meeting of the institute of food technologists*.

Sutton, D. S., Hand, L. W., & Newkirk, K. A. (1995). Reduced fat, high moisture beef frankfurters as affected by chopping temperature. *Journal of Food Science, 60*(3), 580–582. https://doi.org/10.1111/J.1365-2621.1995.TB09831.X

Sylvia, S. F., Claus, J. R., Marriott, N. G., & Eigel, W. N. (1994). Low-fat, high-moisture frankfurters: Effects of temperature and water during extended mixing. *Journal of Food Science, 59*(5), 937–940. https://doi.org/10.1111/j.1365-2621.1994.tb08162.x

Szczesniak, A. S. (1963). Classification of textural characteristicsa. *Journal of Food Science, 28*(4), 385–389. https://doi.org/10.1111/j.1365-2621.1963.tb00215.x

Tatum, J. D. (2006). *Pre-harvest cattle management practices for enhancing beef tenderness*. National Cattlemen's Beef Association.

Terjung, N., Witte, F., & Heinz, V. (2021). The dry aged beef paradox: Why dry aging is sometimes not better than wet aging. *Meat Science, 172*, 108355. https://doi.org/10.1016/J.MEATSCI.2020.108355

Thiel, R. L., Brownlee, J. M., & Parrish Jr., F. C. (1997). Comparison of round and square cores in the determination of beef tenderness by Warner-Bratzler and Instrong. *Beef research report, paper*, p. 30. Available at: http://lib.dr.iastate.edu/beefreports_1997/30

Troutt, E. S., Hunt, M. C., Johnson, D. E., Claus, J. R., Kastner, C. L., Kropf, D. H., & Stroda, S. (1992). Chemical, physical, and sensory characterization of ground beef containing 5 to 30 percent fat. *Journal of Food Science, 57*(1), 25–29. https://doi.org/10.1111/J.1365-2621.1992.TB05416.X

Ugalde-Benítez, V. (2012). Meat emulsions. In Y. H. Hui (Ed.), *Handbook of meat and meat processing* (2nd ed., pp. 447–456). CRC Press.

Vieira, C., & Fernández, A. M. (2014). Effect of ageing time on suckling lamb meat quality resulting from different carcass chilling regimes. *Meat*

Science, 96(2), 682–687. https://doi.org/10.1016/J.MEATSCI.2013.09.017

Warner, R. D., Miller, R., Ha, M., Wheeler, T. L., Dunshea, F., Li, X., & Vaskoska, R. (2021). Meat tenderness: Underlying mechanisms, instrumental measurement, and sensory assessment. *Meat and Muscle Biology, 4*(2), 17. Available at: https://doi.org/10.22175/mmb.10489

Warner, R. D., Wheeler, T. L., Ha, M., Li, X., Bekhit, A. E. D., Morton, J., Vaskoska, R., Dunshea, F. R., Liu, R., Purslow, P., & Zhang, W. (2022). Meat tenderness: Advances in biology, biochemistry, molecular mechanisms and new technologies. *Meat Science, 185*, 108657. https://doi.org/10.1016/J.MEATSCI.2021.108657

Warriss, P. D. (2010). *Meat Science: An introductory text*. CABI (Cabi Series). Available at: https://books.google.co.uk/books?id=ExEOboVw_KUC

Wheeler, T. L., Shackelford, S. D., & Koohmaraie, M. (1997). *Standardizing collection and interpretation of Warner-Bratzler shear force and sensory tenderness data*. Available at: https://www.ars.usda.gov/ARSUserFiles/30400510/1997500068.pdf

Wheeler, T. L., Cundiff, L. V., & Shackelford, S. D. (2010). Characterization of biological types of cattle (Cycle VIII): Carcass, yield, and longissimus palatability traits. *Journal of Animal Science, 88*(9), 3070–3083.

Whipple, G., Koohmaraie, M., Dikeman, M. E., Crouse, J. D., Hunt, M. C., & Klemm, R. D. (1990). Evaluation of attributes that affect longissimus muscle tenderness in bos taurus and bos indicus cattle2. *Journal of Animal Science, 68*(9), 2716–2728. https://doi.org/10.2527/1990.6892716x

Williams, S. E., Johnson, L. P., & Reagan, J. O. (1994). Hot processed raw materials and fat level affect physical and sensory characteristics of ground beef. *Journal of Food Science, 59*(4), 707–710. https://doi.org/10.1111/j.1365-2621.1994.tb08109.x

Wong, N. H., & Maga, J. A. (1995). The effect of fat content on the quality of ground beef patties. *Developments in Food Science, 37*(C), 1345–1351. https://doi.org/10.1016/S0167-4501(06)80237-2

Xiao, X., Hou, C., Zhang, D., Li, X., Ren, C., Ijaz, M., Hussain, Z., & Liu, D. (2020). Effect of pre- and post-rigor on texture, flavor, heterocyclic aromatic amines and sensory evaluation of roasted lamb. *Meat Science, 169*, 108220. https://doi.org/10.1016/J.MEATSCI.2020.108220

Xiong, Y. L., Noel, D. C., & Moody, W. G. (1995). Textural and sensory evaluation of salted low-fat beef sausage with added water and gums. In *International congress of meat science and technology*. San Antonio, Texas.

Yang, A., Trout, G. R., & Shay, B. J. (1995). Evaluation of carrageenan, isolated soy protein and a modified starch in low-fat frankfurters. In *International congress of meat science and technology*. San Antonio, Texas.

Younis, K., Yousuf, O., Qadri, O. S., Jahan, K., Osama, K., & Islam, R. U. (2022). Incorporation of soluble dietary fiber in comminuted meat products: Special emphasis on changes in textural properties. *Bioactive Carbohydrates and Dietary Fibre, 27*, 100288. https://doi.org/10.1016/J.BCDF.2021.100288

Zhang, R., Yoo, M. J. Y., Ross, A. B., & Farouk, M. M. (2022). Mechanisms and strategies to tailor dry-aged meat flavour. *Trends in Food Science & Technology, 119*, 400–411. https://doi.org/10.1016/J.TIFS.2021.12.023

Zurek, J., Rudy, M., Kachel, M., & Rudy, S. (2021). Processes conventional versus ritual slaughter-ethical aspects and meat quality. *Processes, 9*, 1381. https://doi.org/10.3390/pr9081381