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Modern approaches to enhancing beef quality*

Declan Troy[1]

A b s t r a c t: Consumer focused research into meat eating quality has shown that tenderness, juiciness, flavour and overall palatability remain the most sought after attributes by consumers and that tenderness is deemed most important.

The most important factors known to influence eating quality of beef are established. Production, processing and cooking factors all effect meat quality. Breed, sex, feed, handling, environment, finishing weight and age at slaughter are among the main production factors that affect palatability. While from a processing point of view pH/temperature regime, hanging methods, days of maturation, and whether or not the carcass has been subjected to electrical stimulation, cooking method and 'degree of doneness' all affect beef palatability.

Providing consistently tender beef should be key priority for the beef industry. While there have been many successful efforts at improving the tenderness of beef, research has shown that an unacceptable level of variability still remains in beef tenderness. There are many controls that can be introduced into the beef processing line in order to alleviate meat tenderness inconsistencies such as hanging the carcass by its aitch bone, electrically stimulating muscles and preventing muscles from shortening.

This paper concisely reviews the main determinants of beef tenderness and how this knowledge can be utilised in the industry to produce a more consistent product of high eating quality.

Key words: *beef quality, tenderness, juiciness, flavour, palatability.*

Introduction

A thorough understanding of the most important factors which influence meat eating quality is imperative in order to produce a consistent product in line with consumers' expectations. Furthermore this understanding is necessary in order to enable the meat industry to implement appropriate interventions and controls to produce a consistent high quality product. In general however the meat industry is not highly science driven compared to other sectors like the pharmaceutical or information technology industry and does not invest heavily in research and development. Therefore there is a strong reliance by the industry on the research community to develop outputs which, based on good science, can enhance meat eating quality.

Consumer focused research into meat eating quality has shown that tenderness, juiciness, flavour and overall palatability remain the most sought after attributes by consumers and that tenderness is deemed most important (*Miller et al.,* 2002). Although consumers are willing to pay more for guaranteed tender beef a high variability (up to 20%) still exists in the market place. In research from Norway it was found that consumers were willing to pay 50 % more for very tender beef and 25 % more for tender beef compared with less tender beef (*Alfnes et al.,* 2005). Providing consistently tender beef should be key priority for the beef industry. While there have been many successful efforts at improving the tenderness of beef research has shown that an unacceptable level of variability still remains in beef tenderness (*Maher et al.,* 2004).

There are many controls that can be introduced into the beef processing line in order to alleviate meat tenderness inconsistencies such as hanging the carcass by its aitch bone, electrically stimulating muscles and preventing muscles from shortening.

This paper concisely reviews the main determinants of beef tenderness and how this knowledge can be utilised in the industry to produce a more consistent product of high eating quality.

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[1]*Teagasc Food Research Centre, Ashtown, Dublin 15, Ireland.*

Corresponding author: DeclanTroy, Declan.troy@teagasc.ie

Pre-slaughter Factors

Important factors known to influence eating quality of beef are now established and many of these have been reviewed by *Thompson* (2002). Production, processing and cooking factors all effect meat quality. Breed, sex, feed, handling, environment, finishing weight and age at slaughter are among the main production factors that affect palatability. While from a processing point of view pH/temperature regime, hanging methods, days of maturation, and whether or not the carcass has been subjected to electrical stimulation, cooking method and 'degree of doneness' all affect beef palatability.

Breed and Sex

Because of the interfering influences within and between breeds such as feed, growth rates etc., it is difficult to determine the effects of breed on meat quality. *Wulf et al.,* (1996) and *Maher et al.,* (2004) both reported that breed did not have an effect on WBSF, while in a recent study *Dikeman et al.,* (2005) found that considerable variation in WBSF of M. *longissimus* muscle steak exists between breeds, while selecting for marbling to improve tenderness would be expected to result in only subtle improvements in tenderness in most breeds. *Maher* (2003) found heifers to be more variable for tenderness than steers (mixed breed), however this maybe have been somewhat confounded by age. However, *Purchas et al.,* (2002) reported that bull beef was tougher than steer beef.

Feeding regime, finishing weight and age at slaughter

Feeding, finishing weight and the age of the animal at slaughter all have an important role to play in the determination of meat quality. Feeding regime is thought to have an indirect effect on tenderness. Leaner animals require more precise chilling control than fatter carcasses in order to reduce the risk of cold shortening (*Troy*, 1995). A number of studies have examined the effect of growth rate on tenderness by altering the feeding regime before slaughter with mixed results. *Sazili et al.,* (2003) reported that animals placed on a restricted diet for 30 days had lower shear force values than fast growing animals. However, they also reported that after 45 days on a restricted diet the shear values were similar to those for animals on the high plane of nutrition. While *Thompson et al.,* (1999) and *Purchas et al.,* (2002) reported that steers on a faster growing regime were more tender than those finished on a restricted diet.

Age at slaughter is reported to effect beef tenderness. *Wheeler et al.,* (1996) compared the tenderness scores of yearling heifers and 2 year old cows. They reported that there was a very slight difference in the tenderness scores between the two age groups, however, there was greater variation in tenderness within each group that there was between age groups. *Wulf et al.,* (1996) reported that beef from cattle slaughtered at 15 months was more tender than from those slaughtered at 18 months.

Post-slaughter Factors

Post-slaughter factors have higher influence on meat eating quality because the main determinants of meat tenderness are the extent of proteolysis on key structural proteins and the degree of shortening of the muscle fibres (a third factor is due to the connective tissue component and is often referred to as "background toughness", it is little effected by post-slaughter events and its contribution to toughness is linked to the age of an animal and/or the muscle type). Both these events take place at varying rates and extents during the post-mortem period. The most likely causative agents responsible for the breakdown of key structural proteins in post-mortem tenderisation are the calpains (*Dransfield*, 1993) even though their precise mode of action is unclear. There is strong evidence that the proteins of the cyto-skeletal network such as titin, nebulin and desmin are degraded by calpains during the tenderisation process. Furthermore it is now established that ageing beef beyond 10–12 days at 0–2C does not contribute to any greater degree of breakdown of structural myofibbrillar proteins nor detectable increase in eating quality.

It is well known that the shorter the muscle fibres the tougher the meat. This is because the contraction allows the z-discs of the myofibril to be nearer each other thereby increasing the density of filaments. This occurs during the normal onset of rigor. However when early post-mortem variables of pH, temperature and time interact in such a manner as to induce cold-shortening (sarcomere lengths < 1.7 microns) extreme toughness is experienced. Pre-rigor muscle shortens on exposure to temperatures below about 10^{o} C. The faster the temperature decline the slower the rate of glycolysis and therefore the greater the degree of shortening. Cold-shortening occurs as calcium is uncontrollably released into the sarcoplasm which in turn is due to the decrease in temperature and pH resulting in reduced ability of the sarcoplasmic reticulum and mitochondria to retain calcium.

The increase in concentration of free calcium in the presence of sufficient ATP present results in increased shortening of the sarcomeres (*Locker*, 1985). Shortening causes the thick filaments to penetrate the z-discs and may interact with actin filaments in adjacent sarcomeres. This results in the extreme cases of a continuum of myosin throughout (*Marsh and Carse*, 1974).

This dense structure is responsible for the increased toughness experienced by consumers of cold-shortened beef.

In relation to beef carcasses it follows that if pH, temperature and time post-mortem (i.e. the biochemical dynamics) of the early post-mortem period are critical in determining the tenderness/toughness of meat then meat throughout a carcass will experience a variety of biochemical profiles resulting in meat of highly variable eating quality. The rate of pH fall varies from animal to animal (*O'Halloran et al.,* 1997) and the temperature varies considerably throughout a chill, a carcass and a muscle and hence their interaction is quite variable.

Meat science has contributed to providing scientific data that has been employed effectively by the meat industry to reduce the risk of cold-shortening. From understanding of the early post-mortem period specific recommendations have been implemented by meat processors.

Chilling Rates

Although post-mortem chilling processes are primarily aimed at complying with food safety standards and to a lesser extent at extending shelf-life and reducing overall weight drip loss, chilling rates of beef carcasses can influence the rate of pH fall and thereby contribute to cold-shortening especially in lean carcasses. The well known 10/10 rule i.e. no part of the carcass should fall below 10^{o} C within 10 hours of slaughter (*Troy*, 1995) is implemented in many meat processing operations in Ireland and the UK. Various temperature and chilling regimes have been suggested (*Savell et al.,* 2005) to avoid or reduce cold-shortening. Some retailer specifications can go as high as maintaining carcass temperature above 12^{o} C for 12 hours post-slaughter. But it is not simply a matter of controlling the temperature in order to ensure high eating quality beef. Time post-mortem (especially during the first 24hours but often up to 48 hours), pH of the muscle and temperature all synergistically contribute to influencing quality. A more modern approach at factory level is to monitor what is often described as the pH/temperature window as a function of time post mortem. *Thompson* (2002) describes the biochemical basis underlying the recommendations regarding optimum values of the measured parameters. Basically cold shortening can only occur when muscles have a pH value of 6.0 or higher, contains some residual ATP to allow muscle contraction and the temperature is less than 12° C. It is thought that under such conditions calcium is uncontrollably released into the sarcoplasm and severe contraction occurs. When muscles experience pH values < 6.0, temperatures higher than 35° C (particularly during the early post-mortem period of electrically stimulated carcasses) a phenomenon known as heat shortening can occur resulting in severely contracted fibres. Heat-shortening muscle often appears in deep inside hind quarter muscles. In relation to beef carcasses it follows that if pH, temperature and time post-mortem (i.e. the biochemical dynamics) of the early post-mortem period are critical in determining the tenderness/toughness of meat then meat throughout a carcass will experience a variety of biochemical profiles resulting in meat of highly variable eating quality. The rate of pH fall varies from animal to animal (*O'Halloran et al.*, 1997) and the temperature varies considerably throughout a chill, a carcass and a muscle and hence their interaction is quite variable and complex. This partly explains why beef varies so much in eating quality.

Electrical Stimulation

Applying electrical current to a beef carcass shortly after death is widely known as electrical stimulation (ES). ES has a long history of development dating back to the 1950s (*Chrystall et al.*, 1985). The primary reasons for the use of ES in the meat industry is to ensure that the pH of the carcass is less than 6 when temperatures are less than 12° C and thereby can be chilled more rapidly. Many forms of ES applications exist ranging in magnitude of voltage, current, frequency of pulses, and waveforms (*Simmons et al.,* 2008).

Severe muscular contractions are induced throughout a carcass on applying ES. The resulting increased energy expenditure of the muscles due to contractions results in a rapid decline in pH. There is an early development of rigor thereby reducing the risk of cold-shortening should the carcass encounter temperatures below 12° C (*Troy,* 1985). Generally, meat from ES carcasses is more tender than those of non-ES treated carcasses when placed in environmental conditions that would promote cold shortening. ES can increase post-mortem temperatures in carcasses, increase the drip loss and water holding capacity of meat and increase the brightness values of the red colour of beef (*Eikelenboom and*

Smulders, 1985). Three mechanisms of tenderisation associated with ES have been reported. Firstly, the disruption of the lysosomal sac with subsequent release of proteolytic cathepsins at low pH/high temperature environment as described in *Dutson et al*., (1980). Secondly, the physical disruption of the muscle fibres brought about by severe contractions of the muscles (*Sorinmade et al*., 1982), especially in the case of high voltage stimulation (HVES see later) and, thirdly, a reduction in collagen cross--linking (*Judge et al*., 1980). These mechanisms combined would result in major and consistent benefits in meat eating quality which is not the case in reality. *Pommier et al*., (1987) reported that ES induces a toughening effect or in the absence of cold--shortening, accelerates the tenderisation process through increased initial activity of calpain brought about by inducing a higher temperature during rigor but then creating denaturing conditions which will reduce the effect (*Dransfield*, 1992; *Simmons et al.,* 2008). The application of ES is a highly variable process (voltage, frequency, etc), the type of carcass used, the subsequent chilling conditions and the location of the muscle sample within the carcass.

There are broadly two commercial systems of ES namely high voltage (HVES, 300-1000V) and low voltage (LVES, 50-120V) stimulation. Even though HVES is more expensive and requires greater safety precautions to be implemented the benefits over and above those of LVES are not immediately apparent from the literature. The rate and extent of pH decline is similar (*Eikelenboom and Smulder,* 1985; *Koh et al*., 1987) for both HVES and LVES although *Simmons et al*., (2008) has suggested that HVES produces a greater rate of pH decline and one which is more consistent and less variable than LVES treatments.

When ES is applied there is a risk of “excessive stimulation”, that is the formation of a pale, soft and exudative (PSE) like meat which can occur through a very rapid pH fall early post-mortem when the carcass temperature is high. A major decrease in meat tenderness (due to heat-shortening), increased water-holding capacity (due to protein denaturation) and detrimental colour stability (due to protein denaturation and the increase in free water resulting in increased reflectance) (*Simmons et al.,* 2008). These effects can be offset by reducing the chilling temperature (*Strydom et al.,* 2005).

ES (high or low voltage) should be seen as just one other tool to adjust a parameter (pH) of a complex system or environment under which muscle is converted to meat. While it can reduce ageing times and increase the consistency of tenderness it can also contribute to the production of poor quality meat especially where cold-shortening is not a risk. A clearer understanding of the optimum pH/temperature environment throughout the carcass would aid greater precision in its application. Great care needs to be taken in avoiding over-stimulating beef carcasses. *O'Halloran et al.,* (1996) have demonstrated that there is a great variability in the rate of pH decline in the first 24 hours post-mortem between animals and the application of ES may not be required in some cases.

Carcase Suspension Methods

Methods to reduce the degree of cold-shortening or increase the degree of stretching of sarcomeres by altering the normal hanging method of carcasses are becoming more commonly used by the industry. Various methods of hanging carcasses have been tried as an alternative to the conventional Achilles tendon method (*Troy,* 1995). Among the different hanging techniques developed to improve meat tenderness are ‘tenderstretch’, ‘tendercut’, and a forequarter hanging method (*Filho et al*., 2005).

By far the most popular of these newer techniques in use is the ‘tenderstretch’ method. For this technique the hanging position is switched from the Achilles tendon to the aitch bone thereby allowing the hind legs to hang freely. Tenderstretch induces a stretching effect on key hindquarter muscles preventing the sarcomeres from shortening and in some cases actually stretching the distances between z lines reducing the density of overlap between the filaments. *Troy* (1999) found that sarcomere lengths increases by 15%, 30%, 33% and 30% on average from tenderstretch suspended carcasses of *m. longissimus dorsi*, *semimembranous*, *biceps femoris* and the *gluteus medius* respectively. Similarly sensory analysis showed that panellists consistently rated all muscles from pelvic suspended carcasses as more tender (average 20%). In another study less cold--shortening occurred in steaks from conventionally hung compared to tenderstretch suspension carcasses in those carcasses chilled faster (*Sorheim et al.,* 2001). The *m. psoas major* or fillet has been found to be slightly toughened in pelvic suspended carcasses because of its particular position in the carcass.

In Ireland and the UK pelvic suspension forms part of numerous retailer specifications often in combination with a slow chilling regime or in combination with electrical stimulation. The industry cites some drawbacks however including the requirement for more chiller space, demands for greater labour input and the distortion in shape of some muscles.

Researchers at Virginia Polytechnic Institute and State University have examined strategic pre-rigor cutting of the backbone to improve beef tenderness (*Wang et al.,* 1994). This procedure is referred to as 'tendercut' and requires and additional input of making cuts in the skeleton of the pre-rigor carcass shortly after slaughter while maintaining the Achilles tendon suspension. The weight of the carcass below the points of cutting stretches many of the major loin and round muscles. As with 'tenderstretch' the 'tendercut' method does not benefit all muscles. *Shanks et al.,* (2002) reported that the use of the 'tendercut' technique resulted in increased tenderness in some muscles with decreased tenderness in others. A report from Australia suggests that it is not as effective in increasing tenderness as the tenderstretch method. This technique has not been widely adapted by the industry. *Filho et al.,* (2005) examined the effect of forequarter hanging on the *longissimus* and *biceps femoris* muscles. Hanging by the forequarter caused a significant improvement in tenderness of the *longissimus* muscles without any detrimental effect on *the biceps femoris*. This method has not been fully characterised up to now.

Tenderbound System

A novel method to improve the eating quality of meat by reducing the degree of contraction in hot boned beef is in the process of been developed for industry use. As discussed earlier a consistent optimum window of pH and temperature as a function of post-mortem time is very difficult to achieve given that the chilling rate, muscle location, level of fat cover, animal to animal variation in metabolism among other factors are different. The Tenderbound System or a similar type approach overcomes these difficulties.

Hot boning provides a significant advantage in that it enables individual muscles to be processed in a specific tailored fashion. The advantages and disadvantages of hot-boning have been highlighted previously (*Pisula and Tyburch,* 1996). Hot-boning requires the major commercial cuts or muscles to be excised within 90 minutes of slaughter and thereby reduces weight loss during chilling, requires less chiller space, consumes less energy, lowers labour input and increases turnover in productivity. Its major drawbacks are that it needs precise synchronisation of slaughter, boning and processing activities, very strict hygiene control and induces toughness through greater ability of muscle fibres to contract in the absence of skeletal restraint resulting in cold shortening. Hot-boning in combination with a pre-rigor restraint technique using elasticated film constitutes the Tenderbound system.

Pi-Vac Elasto-Pack system (*Maixner and Karnitzschky*, 2001) involves stretching tubes of elastic film to the inside walls of the packaging chamber, after the muscle is inserted into the chamber pressure is released and the elastic film returns to its original dimensions. The elastic film then hinders the diametrical expansion of the muscle, which restricts muscle contraction (*Troy*, 2006). *Troy* (2006) has found that hot boned meat packed in Pi-Vac can be chilled much more rapidly while the beef is tender and of consistent quality. Hot boned muscle without any restraint had higher shear force values (force required to shear through meat) after 14 days ageing compared to muscle packed in Pi-Vac (72 N and 40 N respectively). The sarcomere length, a measure of muscle extension or stretch was increased considerably by use of the Tenderbound method (1.7μm) while the sarcomere length for hot boned muscle without restraint was 1.3μm. The pre-rigor meat forms into the shape of its constraining pack and is not distorted. Using this system variability of tenderness is reduced as individual muscles can be treated optimally. Drip loss is reduced by packing early post-mortem thereby improving flavour and succulence, bacterial growth is reduced and shelf life improved because of the ability to chill at lower temperatures. Other potential benefits may include increased yield, reduced energy costs, quicker turnover of unit product in meat plant, savings in labour and transport costs, although these have yet to be verified at industry level.

Conclusions

In order to produce beef with consistently high eating quality, post-mortem parameters must be taken into account. The two main strategic approaches are: to enhance the degree of proteolytic breakdown of cyto-skeletal proteins as well as decrease the degree of shortening of sarcomeres. Ensuring a high degree of proteolysis can be approached in a number of ways but as long as the beef carcase or muscle is aged for at least 10 to 12 days almost all degradation relevant to the tenderisation process is complete. Reducing contraction can be easily carried out by aitch bone hanging or by the Tenderbound process. Pre-slaughter factors do not impinge on eating quality to a major extent within the normal production systems of Northern Europe unlike other areas where *bos indicus* type cattle are prevalent. The beef industry has the necessary knowledge to avoid producing tough beef but needs to implement more rigorous practices to do so.

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Moderni pristupi poboljšanju kvaliteta govedeg mesa

Declan Troy

R e z i m e: Istraživanja usmerena na potrošača koja se odnose na senzorski kvalitet mesa, pokazuju da mekoća, sočnost, ukus i ukupna prihvatljivost hrane i dalje su najtraženiji atributi mesa koje zahtevaju potrošači, a da se mekoća mesa smatra najvažnijom osobinom.

Utvrđeni su najvažniji faktori, za koje se zna da utiču na kvalitet govedeg mesa. Faktori koji utiču na proizvodnju, preradu i kuvanje utiču i na kvalitet mesa. Rasa, pol, hrana, rukovanje, životna sredina, uzrast i masa pre klanja su među faktorima koji utiču na ukus. Sa stanovišta prerade, pH, temperaturni režim, način kačenja, trajanje zrenja, kao i činjenica da li je trup bio podvrgnut električnoj stimulaciji, način kuvanja i „stepen završne obrade", utiču na ukus govedeg mesa.

Obezbeđivanje konzistentno mekanog govedeg mesa bi trebalo da bude ključni prioritet u industriji mesa. Iako je bilo mnogo uspešnih pokušaja da se poboljša mekoća mesa, istraživanje je pokazalo da još postoji neprihvatljivi nivo variranja ove osobine. Postoje mnoge kontrole koje se mogu uvesti u proces prerade govedeg mesa kako bi se povećala mekoća mesa odnosno ublažile nedoslednosti ove osobine, kao što su kačenje trupova, električno stimulisanje mišića i sprečavanje skraćivanja mišića.

Ovaj rad daje revijalni prikaz glavnih odrednica mekoće govedeg mesa, kao i načina na koji ovo znanje može da se iskoristi u industriji za proizvodnju konzistentnijih proizvoda koji će biti visokog kvaliteta.

Ključna reč: *kvalitet govedeg mesa, mekoća, sočnost, ukus.*

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