Factors affecting lamb meat quality

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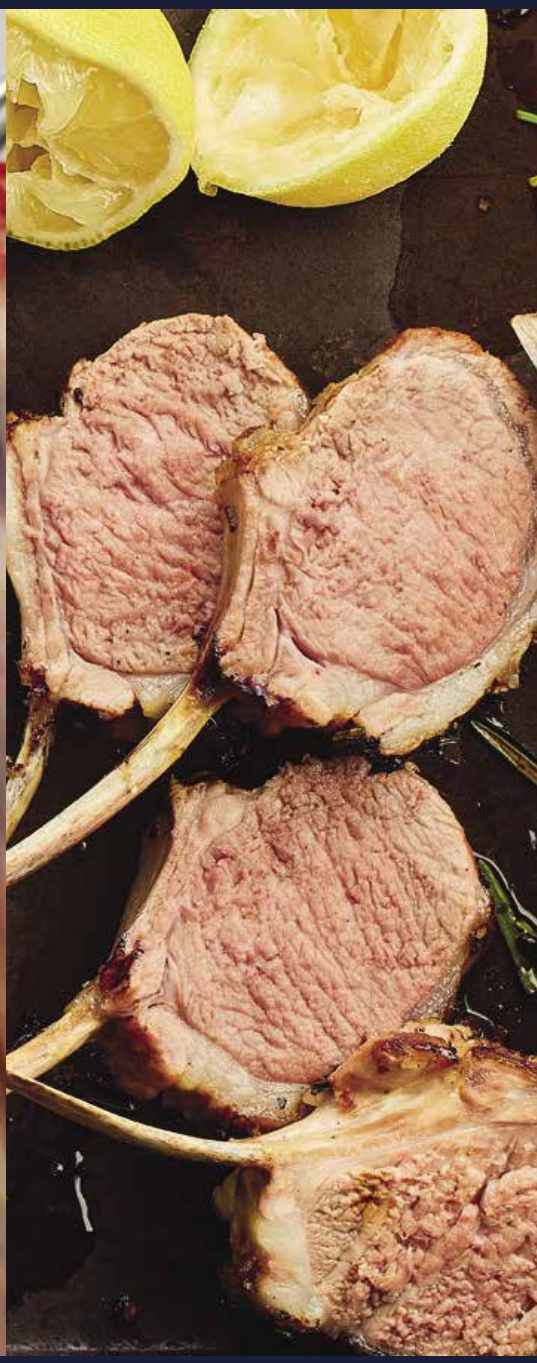
MEAT QUALITY



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The programme encompassed three strategic projects: Stoc+, an animal health planning project, Hill Ram Scheme, a genetic improvement project and the Welsh Lamb Meat Quality project, an eating quality project.

Executive summary

To maintain a sustainable lamb supply chain, it is critical to understand consumer requirements. Consumers are becoming increasingly aware of attributes of the diet linked to nutritional value and human health. Lean red meat is naturally rich in protein, vitamins and minerals and has a key part to play in a balanced diet.

Sourcing traceable meat with high credentials of sustainability and welfare is also rising in importance according to consumer surveys. Wales is especially suited to rearing cattle and sheep through non-intensive farming which relies on abundant grass and rainfall. This makes Wales one of the most sustainable places in the world to produce red meat.

Other key factors include quality and price. Quality is important for the competitiveness and economic efficiency of the meat supply chain, resulting in reduced waste and increased consumer satisfaction.

Meat quality is a combination of many related attributes, influenced by a multitude of biological and environmental factors. The understanding of factors affecting lamb meat quality is vital for a successful lamb meat industry.

Lamb meat quality is affected by genetic and non-genetic aspects of lamb production on-farm, as well as by carcase processing techniques post-slaughter. On-farm factors that affect meat quality include production system, genetic differences, lamb gender, slaughter age, diet and nutrition. Avoiding stress pre-slaughter is also known to positively enhance meat quality.

Breed-related differences in sensory meat quality traits of lamb tend to be relatively small and inconsistent, although, most meat quality attributes are under genetic control and can be influenced by selective breeding.

- Sex differences in growth rates, muscling and fat deposition can affect consumer preferences.
- Meat from ewe lambs or castrated males tends to be more tender and less susceptible to intense or off-flavours.
- Diet of the lambs can influence fatness levels and fatty acid profiles.
- Rapid growth rates will lead to a fatter carcase with increased intramuscular fat compared to slower growth rates.
- Increased age at slaughter will result in tougher, darker meat, and firmer, more yellow fat, with increased flavour and juiciness, largely due to increased fat levels.

Avoiding pre-slaughter stressors can have positive effects on meat quality attributes such as tenderness, juiciness, flavour, meat colour and microbiological shelf-life. Considering slaughter and processing techniques, benefits in meat quality can result from electrical stimulation of the carcase, suspension of carcases by the pelvis (rather than the hind leg), and by a carefully executed chilling and ageing regimes, optimising post-mortem decline in pH and temperature.

Combinations of beneficial production and processing factors should be considered to optimise lamb meat quality, in order to meet consumer requirements.

Introduction

On the journey from farm to fork, an understanding of the impact biological and environmental factors have on the ultimate eating experience is required. This will enable improvements to be made across the whole supply chain, benefiting lamb meat quality and encouraging repeat purchase. Both on-farm and processing factors can influence the eating quality experience of lamb.

What is meat quality?

The definition and understanding of meat quality is complex, and considers many attributes. Meat quality is a combination of related attributes, such as:

- Yield
- Composition
- Appearance
- Fat content and composition
- Colour
- Flavour
- Juiciness
- Tenderness or texture
- Odour
- Wholesomeness
- Ethical quality

Tenderness and juiciness are important to lamb consumers, similar to pork and beef consumers. However, flavour differences in lamb are reported to have the largest impact on overall acceptability. Lamb consumers can vary regarding their preferences across countries and regions, influenced by consumption levels, cultural effects and production practices, as well as chosen cooking methods.

Production (on-farm) factors affecting lamb meat quality

Numerous factors during the production of lamb can influence the final eating quality experienced by consumers. These include factors related to the animal (intrinsic), including breed, gender, genes, age, weight and body composition, as well as factors external to the animal (extrinsic) including nutrition/diet, management, animal health and welfare.

Genetic factors

Genetic factors, including breed, within-breed genetic variation and gender are important influences to consider in lamb meat quality.

Variation in meat quality traits is generally under complex genetic control (involving many genes, each with a small effect) and can also be influenced by a variety of environmental factors. The many gene effects make it difficult to pinpoint which specific gene/genetic marker is causing a difference in eating quality.

Several DNA segments in the genome (named quantitative trait loci, QTL) have been reported to affect meat quality characteristics, but only a few of them explain large amounts of the phenotypic variation.

Currently, meat quality traits are not commonly included in genetic selection programmes, due to the difficulty and cost of their measurement.

Breed effects:

Sheep breeds have rarely been directly genetically selected and bred for meat quality traits. Although, selection has occurred for carcase composition and growth rates and these can have an impact on meat quality traits.

Different breeds mature at different rates and reach different mature weights, consequently there are breed differences in optimum slaughter points. As a result, lambs from different breeds lay down fat at different rates and differ in the amount of fat deposited in different body depots. Breed effects on meat quality traits are often influenced by the criterion at which breeds are compared (e.g. same carcase weight, same age, or same degree of maturity). Breed differences in meat quality can be partially explained by differences in fatness at a given body weight or age, however, there is also evidence that differences in muscle fibre number and type exist between breeds. Breeds of animals with a smaller body size often have smaller muscle bundles and finer grained meat. However, breed related differences for sensory meat quality traits in lamb are considered to be relatively small and inconsistent.

What affect does breed type have on the taste of PGI Welsh Lamb?

In the first year of HCC's Welsh Lamb Meat Quality Project the treatment effect of breed type was one of the on-farm factors investigated. The study compared taste quality attributes and nutritional factors of hill, crossbred and terminal sired lambs. The 96 lambs were sourced from twenty-two farms across Wales, with a variety of different breeds included within the three breed type groups.

A total of 3,360 PGI Welsh Lamb samples were taste tested by 480 consumers at three locations across the UK. The muscles used for the consumer taste panels were loin, chump and topside.

Consumers scored the meat samples on the meat eating quality attributes of tenderness, juiciness, flavour, aroma and overall liking. Results showed that consumers had no significant preference to one particular breed type Figure 1.

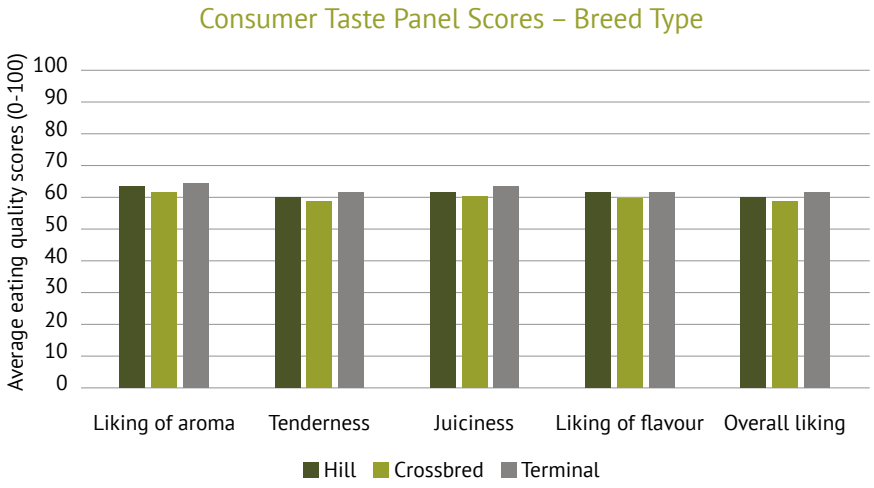


Figure 1. *Consumer taste panel scores 2020 – no significant difference in meat eating quality attributes between three breed types of hill, crossbred and terminal.*

Within-breed genetic effects:

Across meat species (beef cattle, pigs, broilers, sheep) there has been breeding and selection aimed at improving meat production efficiency, mainly through increased growth rates and carcase leanness. This has led to substantial improvements in:

- Growth rates
- Feed conversion ratio
- Lean meat yield
- Loin eye area
- Back-fat thickness (reduced)
- Overall carcase fat content (reduced)

Some meat quality traits have been negatively affected as a consequence of these selection goals, such as intramuscular fat (IMF) percentage, water-holding capacity, tenderness and sensory traits. Selection for lean meat yield in sheep has generally been less intense than in pigs and broilers, but negative impacts of such selection in sheep have also been seen. For example, in long-term studies in Australia[1], consumer taste panels found that lambs with higher breeding values for eye muscle depth have decreased tenderness, overall liking and flavour scores, across different muscles. Likewise, decreasing breeding values for subcutaneous fat depth was associated with reduced tenderness in the loin.

There are concerns that selecting purely for lean meat yield would reduce consumer eating-quality, which highlights the need for careful monitoring of selection programmes to maintain lamb eating quality. There is evidence-based concern from UK studies[2] that lambs from sires selected for leanness have reduced levels of IMF, which is known as a key determinant of meat eating quality. It is also known that selection for increased IMF will make the bloomed colour of lamb meat lighter and redder, which is critical for retail sales[3].

Heritabilities are generally low to moderate for:

- Sensory meat eating quality traits (tenderness, juiciness, flavour, liking)
- Colour
- Water-holding capacity
- pH

Footnotes:

[1] Pannier L., Gardner G.E., Pearce K.L., McDonagh M., Ball A.J., Jacob R.H. & Pethick D.W. (2014) Associations of sire estimated breeding values and objective meat quality measurements with sensory scores in Australian lamb. *Meat Science* 96, 1076-87.

Anderson F., Pannier L., Pethick D.W. & Gardner G.E. (2015) Intramuscular fat in lamb muscle and the impact of selection for improved carcass lean meat yield. *Animal* 9, 1081-90.

[2] Thomas E.M. Roden J.A., Haresign W., Richardson R.I., Lambe N.R., Clelland, Gardner G.E. & Scollan N.D. (2021) Meat eating and nutritional quality of lambs sired by high and low muscle density rams. *Animal* 15. 100136.

[3] MLA (2015) The effect of hanging method on sheepmeat eating quality. *MSAS6* 6, 2.

Ramanathan R., Mafi G.G., Yoder L., Perry M., Pfeiffer M., VanOverbeke D.L. & Maheswarappa N.B. (2020) Chapter 5 - Biochemical changes of postmortem meat during the aging process and strategies to improve the meat quality. In: *Meat Quality Analysis* (eds. by Biswas AK & Mandal PK), pp. 67-80. Academic Press.

Heritabilities are moderate to high for:

- Mechanical tenderness
- IMF

This suggests a substantial opportunity for the sheep industry to respond to consumers demands for lamb of high quality and nutritional value through genetic selection within-breed, which will result in permanent, cumulative and cost-effective improvements of heritable traits.

Few commercial breeding programmes include lamb meat quality traits. Examples include incorporation of predictors of IMF (through CT scanning of live lambs) in terminal sire breeding programmes in the UK.

Over the last decade, research on the genes determining meat quality traits has progressed and genetic factors in the genome (QTL) associated with meat quality have been identified. Examples of rare single genes (or QTL) that have been detected to have major effects on a meat quality in sheep include:

- Mutations in the myostatin gene (e.g. Myo-MAX)
- The Callipyge mutation
- LM-QTL (also known as Carwell or Loin-Max)
- Texel muscling QTL (TM-QTL)

These changes in the genome all result in favourable effects on increased muscling and reduced fatness. These QTL effects also significantly effect meat quality traits, such as reduction in IMF percentage and tenderness, and in some cases lower sensory scores by taste panels.

In the future, genomic approaches could be used to improve meat quality, advantages for this include:

- Minimal requirement for expensive measurement (phenotyping) of traits after validation
- Reduced generation interval (breeding stock can be selected using DNA sampling at a very young age)
- Increased rates of genetic gain.

Gender effects:

In lambs there are at least 3 "genders" to be considered: females, entire males and castrated males. There is a common perception that consumers experience a negative eating quality when consuming meat from entire male ram lambs, particularly in the autumn during the mating season when ram lambs would be sexually mature. Research comparing meat quality across lambs of different genders has resulted in inconsistent results, although some general conclusions can be summarised.

Entire male ram lambs grow significantly faster and have higher muscle growth, allowing a reduced age at slaughter. The male hormone, testosterone, promotes growth and favours muscle development over fat deposition. Entire male lambs have been found to be more susceptible to intense flavours and off-flavours, and this difference increases with slaughter age. Meat quality from entire males is generally within acceptable limits, although can score higher for unpleasant or off-taste intensity by taste panels. The concentration of skatole (a compound derived in the digestive tract, caused by bacterial degradation, that is mainly associated with boar taint in pork) tends to be greater in the fat of entire ram lambs than other genders. However, skatole levels measured in lamb are generally well below thresholds quoted for detection of pig-meat taint found in boars.

Castrated lambs have reduced growth rate and increased fat deposition compared to entire males, as a result of castration removing the supply of testosterone from the testes. Carcase quality from castrated male lambs is closer to that of female lambs, with both usually fatter than entire males. Consequently, IMF percentage is higher in castrated than entire males and this has been associated with higher drip loss from castrates. Comparisons of castrates and entire males in terms of fatty acid profiles are inconsistent and more research is needed. Meat from castrates generally scores higher in overall liking, flavour liking and tenderness liking than meat from entire males, although some studies report little, or no difference. In terms of meat colour, castrated animals have been reported to have paler meat.

Female lambs have less muscle deposition and more fat than entire and castrate males at the same carcase weight. Research has found that female lambs tend to have more tender meat with higher IMF and lower final pH than males. Sex differences are not often detected in taste panel assessments, but when they are, meat from females is generally preferred to meat from males (particularly from entire males).

FACT:

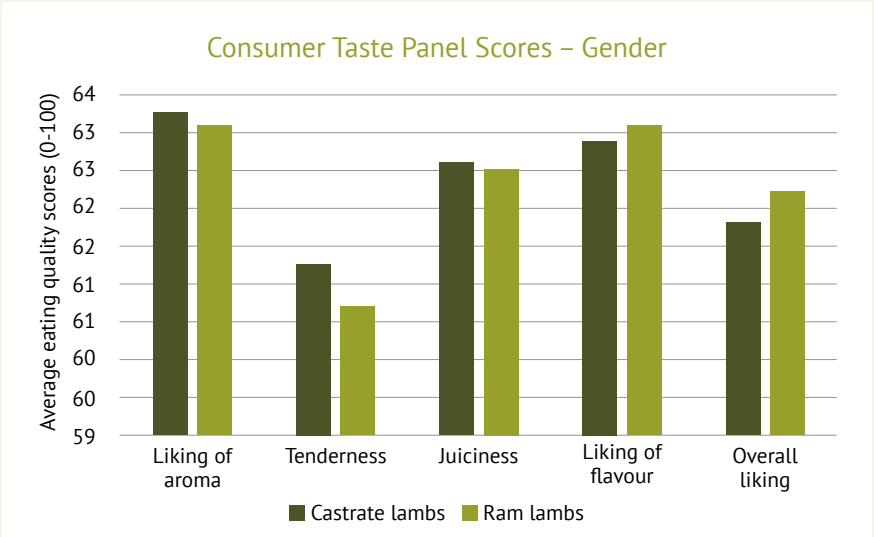
The percentage of intramuscular fat in castrated lambs and female lambs tends to be greater than entire males.

Castrate lambs, entire male lambs – is there a taste difference?

During the first trial of HCC's Welsh Lamb Meat Quality Project the on-farm factor of lamb gender was investigated. Comparisons were made between entire rams and castrate lambs sourced from 22 Welsh farms. The trial was balanced with 48 castrated lambs and 48 entire ram lambs and the same number of three breed types (hill, crossbred and terminal sired). Samples were taken during November 2019 and January 2020.

A total of 480 consumers from a variety of different demographic backgrounds took part in a consumer taste panel and rated seven lamb samples each. Consumer scores did not suggest that there was a detectable difference in the eating quality of entire ram lambs in comparison to castrate lambs. Lamb gender did not significantly affect any of the taste quality attributes (liking of aroma, tenderness, juiciness, flavour or overall liking).

Figure 2. *Consumer taste panel scores for castrates and entire ram lambs (target specification EUR, 2-3L weight 16-21kg deadweight).*



The study found that castrate lambs had significantly higher intramuscular fat than entire ram lambs. Generally, castrate lambs were found to be higher in saturated fats and monounsaturated fats in comparison to the ram lambs used in the study.

The Welsh Lamb Meat Quality Project will continue to investigate lamb gender (ewe lamb, entire rams and castrates) throughout the remainder of the study. With a focus on comparing the taste quality attributes and nutritional qualities across different seasons in the production calendar, from a variety of farming systems.

Diet and nutrition

Production systems and diets for lamb tend to vary more than other livestock species, across the UK and globally. A greater proportion of lambs in Wales are finished on forage-based diets than on concentrate diets. Well fed, fast-growing animals deposit more adipose (fat based) tissue, which tends to contain less water and a higher concentration of lipid.

Concentrate diets offer a higher plane of nutrition during finishing, will add more fat to the carcase and more IMF (marbling). An increased proportion of concentrates in the diet, especially rolled cereals, will also lead to increased proportions of unsaturated fatty acids and decreased proportions of saturated fatty acids, such as stearic acid, resulting in softer fat.

Meat quality attributes of tenderness and juiciness can be affected by feed type, however, contradictory results have been found in different studies, suggesting more research should be undertaken on this.

Comparative studies, considering consumers across different (mainly EU) countries, have found greater acceptance for tenderness, flavour and overall liking of meat from lambs fed on concentrates or mixed systems (forage and concentrates). However, differences between countries and even regions in consumer preferences for lamb eating quality characteristics have been identified, which are likely to be partially due to experience.

FACT:

Meat from grass-fed animals is darker than that of animals fed on concentrates.

Grass-fed lambs on pasture or forage diets, are reported to have a more "pastoral" flavour, more intense lamb flavour and liver flavour. Mutton flavour has been associated with pasture-fed animals, as well as lamb from older animals. Evidence has suggested that some consumers prefer pasture-fed lamb.

The meat of grass-fed animals is darker than that of animals fed on concentrates. Grazing also provides antioxidants, including vitamin E, which prevent quality deterioration during meat processing and display and can help improve the shelf life. Fat composition of lamb meat may differ seasonally due to diet.

Brassica/fodder crops effects on meat quality from feeding alternative forages, such as brassicas and lucerne, are inconclusive. These feeds can affect fatty acid profiles of the meat which may be linked to different flavours. However, some taste panel tests have detected no difference, or even positive effects on consumer acceptability from feeding lambs on these alternative crops.

In terms of other meat quality characteristics, the pH level of meat does not appear to be affected by the type of feed.

How does a lamb's finishing diet contribute to the nutritional make up?

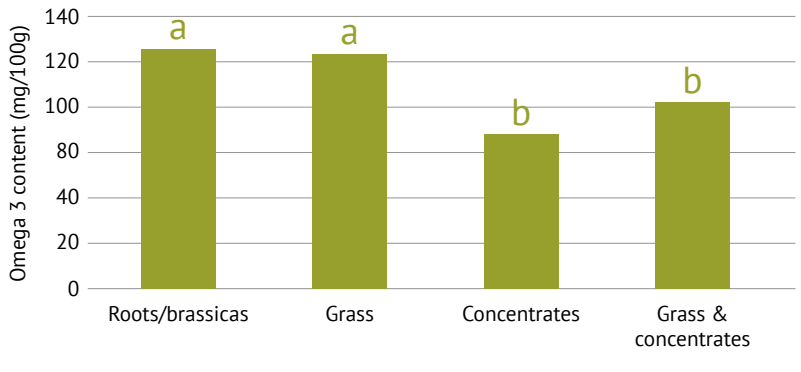
During the second trial of the Welsh Lamb Meat Quality Project the main on-farm factor investigated was the lamb finishing diet. Sixteen farms were involved in the study. There was an equal balance of lambs finished for a six-week period on one of the four diets:

- Brassica or root crop diet
- Grass only
- Grass and concentrates
- Indoor concentrates

During the six-week finishing period growth rates of 485 lambs were regularly monitored. Soil, feed and forage samples were taken and analysed, helping to understand how the production system can possibly influence or enhance the eating quality of lamb. The feed and forage results provide evidence to how the finishing diet can contribute to the nutritional benefits lamb meat can provide to the consumer.

Initial results have suggested the diet the lamb receives in the six weeks before slaughter has no significant effect on the saturated, monounsaturated or polyunsaturated fatty acid composition but does affect the essential omega-3 fatty acid content.

Figure 3. *Average omega-3 fatty acid composition from lamb finished on different diets.*



Growth rate and age at slaughter

It is important to monitor growth rate in order to optimise meat quality. A rapid growth rate, on a high plane of nutrition, will lead to a fatter carcase with increased marbling fat, whilst slower finishing rates, on a lower plane of nutrition, generally results in less fat.

High growth rates can positively affect meat quality. Low growth rates may be accentuated following a prolonged store period or severe weaning check, or may be influenced by other production factors, such as diet, genetics or health status. Early season lamb has increased tenderness, as well as less stronger flavours in comparison to later season lamb.

FACT:

High growth rates have positive effects on meat quality. Younger animals have increased meat tenderness compared to older animals.

Meat from younger animals can be less juicy, which is likely to be linked to lower levels of IMF. Flavour intensity and scores for unpleasant taste/off-flavour intensity have been found to increase with age at slaughter, which can be due to increased fatness.

Meat from older animals is darker, due to an increase in the respiratory pigment haemoglobin. Fat can be more yellow and firmer in older animals. Adipose (fat) tissue in younger animals tends to be less firm, wetter, and separates from muscle tissue more easily.

Older animals can have tougher meat, partially due to growth of muscle fibres and increased size of muscle bundles leading to coarser meat. Additionally, collagen in muscle of older animals has increased cross-linking and reduced solubility, which also increase toughness. Unlike in cattle, where tenderness decreases with age, but levels off after around 18 months, in sheep toughness of meat has been reported to increase continuously with age from lamb to mutton.

There may be limited differences in meat quality between lambs slaughtered within a typical range of a few months.

Level of finish/fat

Fat plays an important role in lamb meat eating quality. Lamb carcases that have increased quantities of fat chill more slowly, affecting propensity to cold-shortening and ultimate pH (see page 25). Fatter carcases also tend to have less or softer connective tissue and are more tender than lamb carcases with lower levels of subcutaneous or intramuscular fat (IMF).

Differences in IMF are associated with significant changes in juiciness, tenderness, and overall satisfaction ratings across different cuts of lamb. Therefore, increased fatness is generally associated with increased palatability. Highly significant correlations have been found between tenderness and IMF content, of the loin and rack cuts in particular. There is some evidence that IMF is of less importance for increasing the tenderness of leg muscles, although IMF is associated with higher juiciness in these muscles.

Minimum levels of 3% IMF in grilled cuts of red meat such as beef and lamb are recommended to ensure consumer acceptability in terms of eating quality. There may be an optimum level (suggested at above 5% in the loin), over which sensory scores start to reduce.

IMF is highly correlated with total carcase fat (so most genes which increase total fat, will also increase IMF), although they are not completely under the same genetic control, suggesting scope to select for higher IMF and lower total carcase fat in genetic selection programmes.

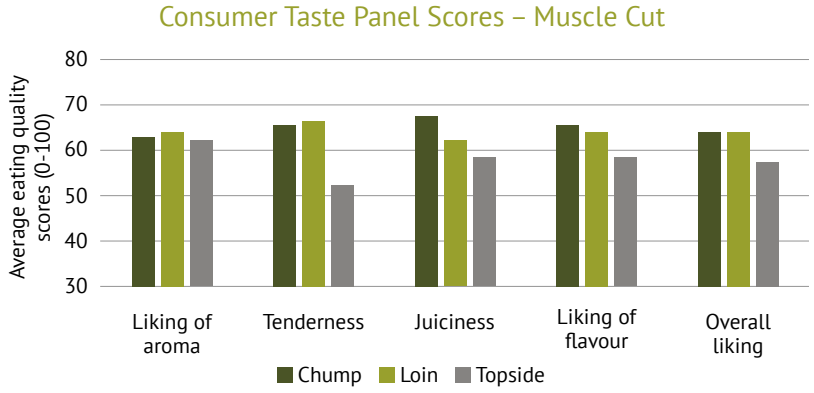
Loin, chump and topside – do they taste different?

The Welsh Lamb Meat Quality Project has investigated if different lamb cuts vary in eating quality and nutritional attributes. Trial 1 used the muscle cuts - loin, chump and topside.

Eating quality

Consumers involved in the study were able to detect a significant difference in the eating quality between muscle cuts. With the loin and chump scoring favourably for all eating quality traits amongst consumer taste panellists. The mean scores for topside were well within acceptable ranges despite scoring lower than the loin and chump.

Figure 4. *Mean attribute scores for the different muscles which were analysed in* Trial 1



Fatty Acids

Results showed muscle cut to have the greatest impact on fatty acid content in comparison to the other factors analysed – lamb gender and breed type. The topside cut had the lowest intramuscular fat content at 3%, and also lower levels of saturated and monounsaturated fat content. The muscle with the highest amount of polyunsaturated fatty acids was the chump. The variation in fat content between muscles was thought to be in relation to the biological role within the lamb. Loin was found to have higher levels of saturated fats (SFAs) and monounsaturated fats (MUFAs) but a lower concentration of polyunsaturated fats (PUFAs, including omega-3 fatty acids than the other muscles.

Processing factors affecting lamb meat quality

Post-farm gate, further factors can impact on the quality of lamb meat. These include conditions or techniques employed immediately *prior* to slaughter, such as exposure to stress, *during* slaughter, such as stunning or bleeding methods, or *after* slaughter, such as electrical stimulation, hanging method, chilling and ageing regimes.

Pre-slaughter factors

Transport and Lairage

Transport and slaughter of farm animals are the final stages of a farming system aimed to produce high-quality lamb. However, before slaughter, lambs may experience several stressors, which can ultimately affect the quality of the carcases and meat produced.

Even before being transported, stress can occur due to moving stock, physical exercise, handling, mixing of animals, or loading for travel. Stress can be minimised during this period by:

- Gentle, quiet handling
- Use of well-designed handling facilities
- Avoiding isolation of individuals
- Minimising mixing of unfamiliar animals, or ewe lambs with ram lambs.

Pre-slaughter transportation, stresses on the animals include:

- Confinement
- Movement
- Noise and vibration
- Novel and unfamiliar environment
- Mixing with unfamiliar animals
- Changes in social group structure
- Changes in climatic and weather conditions
- Food and water deprivation
- Risk of physical injuries

Transport stress has been divided into 3 categories: physical stress, physiological stress and psychological stress, with overlaps between them. Recommendations to reduce stress during transport include:

- Avoiding isolation of individuals
- Minimising mixing of unfamiliar animals, or ewe lambs with entire ram lambs
- Appropriate stocking densities
- Well-designed vehicles with appropriate ventilation and environmental conditions
- Minimal duration of transport
- Avoiding erratic driving

The period that animals are held in the lairage at the abattoir (duration and conditions) can add to the levels of stress experienced, as some stressors may remain, even if animals are allowed to rest and recover from transport. Recovery rate of animals during the lairage period may be affected by several factors, such as:

- Lairage time
- Environmental conditions
- Stocking density
- Mixing or proximity to unfamiliar animals (particularly ewe and entire ram lambs)
- Noise
- Water and food provision or withdrawal and dehydration

Appropriate rest after transportation has the potential to relieve stress and hence improve meat quality. Resting pre-slaughter avoids high body temperature which can cause imperfect bleeding and avoids depletion of glycogen reserves (which are converted to lactic acid post-mortem, resulting in a lowering of the pH of meat, as discussed below). However, long periods in the lairage can negatively affect meat quality traits, increasing the likelihood of dry, firm, dark meat, for example, if the animals are restless and fighting or mounting.

TIP:

Fasting reduces gut content and hence bacteria, reducing the risk of contamination and increases shelf life.

Feed withdrawal in animals pre-slaughter is recommended. Feed withdrawal reduces the gut content and therefore potential bacteria, reducing the risk of contamination of the carcase during dressing. Bacterial spoilage can reduce shelf-life of the meat. Overnight fasting, for around 6 to 12 hours before slaughter, is usually sufficient.

It is often a combination of stressors, particularly those occurring 12 to 48 hours prior to slaughter, that is responsible for an animal's condition pre-slaughter, rather than one single factor. Stressful conditions can reduce muscle glycogen stores, associated with elevated ultimate pH of meat and low residual levels of glucose (see explanation of post-mortem metabolism page 25). This will strongly influence post-mortem muscle biochemistry and physiology with effects on important meat quality attributes such as tenderness, water-holding capacity, flavour, meat colour and microbiological shelf-life. Meat with a high ultimate pH usually has distinct differences in meat quality and a higher susceptibility to spoilage by microorganisms.

Reducing Pre-slaughter stress

Animals

- Avoid mixing of groups
- Avoid mixing of male and female livestock
- Avoid mixing of differect ages
- Make sure animals are fit to travel

Facilities

- Handling facilities
- Light and temperature
- Loading livestock
- Transport

People

- Avoid noise
- Be aware
- Keep calm and relaxed

TIP:

Minimising stress preslaughter will positively influence tenderness, water holding capacity, flavour, meat colour and shelf life.

Not all influences on meat quality traits in lamb and other species are due to the effects of stress on ultimate pH. There is a need to focus on traits beyond pH and tenderness, such as water-holding capacity and drip loss (or purge). Water-holding capacity is the ability of meat to hold onto water, which has a positive effect on juiciness and tenderness. Reduced water-holding capacity increases: drip loss from carcases (where fluids exude from the carcase after slaughter); 'weeping' of uncooked meat; and shrinking of meat on cooking. Acute pre-slaughter stress can reduce water-holding capacity and affect the juiciness of meat.

Efforts should be made to optimise animal welfare. Factors that have a positive impact on animal welfare can also improve meat quality. These factors include good handling, plentiful supplies of feed and water and optimum stocking levels. This close link between carcase quality, meat quality and animal welfare means that improvements in animal welfare are also likely to improve carcase yield and meat quality.

Slaughter process

Stunning:

Electrical stunning is the main method used for during slaughter in sheep. In studies there is limited evidence that stunning affects water-holding capacity, shear force tenderness, or colour parameters, or can lead to detectable differences in sensory traits.

Bleeding:

It is beneficial for meat quality to remove as much blood as quickly as possible from the carcase at the point of slaughter. Blood left on the meat has an unpleasant appearance and can potentially harbour growth of micro-organisms. Bleeding soon after stunning (within five seconds) avoids "blood splash" (small dark red areas in the muscle, caused by capillaries rupturing and blood being released into the muscle).

Post-mortem metabolism and onset of rigor mortis:

It is important to understand the physiological processes that occur after slaughter, which can greatly affect the quality of the meat produced. When the animal is slaughtered its heart stops. The circulatory system can no longer supply glucose and oxygen to muscles, which begin to undergo anaerobic metabolism. Glycogen reserves are used up and lactic acid accumulates, which limits enzyme function. Post-mortem in mammalian muscles (at ~30°C) pH falls as the remaining glycogen is turned into lactate and levels of ATP (Adenosine triphosphate, which provides energy for contraction of muscles in living animals) fall, leading to the on-set of rigor mortis. An ultimate pH of around 5.5 is reached, usually 12 to 24 hours after slaughter in sheep.

Electrical stimulation

Electrical stimulation is a procedure that passes an electric current through the hot carcase immediately after slaughter. This accelerates the rigor mortis process and causes post-mortem tenderisation to start earlier. Electrical stimulation is known to improve tenderness, but muscles react differently and the effects are not always the same across all muscles in the carcase.

Different voltages can be used for electrical stimulation:

- Lower than 100 volts is known as low-voltage electrical stimulation (LVES)
- Higher than 100 volts as high-voltage electrical stimulation (HVES).

Increasing voltage has been associated with more efficient stimulation of the carcase. Stimulating the carcase earlier, longer, or with higher currents tends to increase the magnitude of pH change in the muscle.

Prevention of cold shortening:

Stimulated carcases are less prone to cold-shortening and toughening, therefore improving meat quality (see page 27). This allows swift reduction of temperature and avoidance of microbial activity. Therefore, cooling or freezing can be carried out earlier after slaughter than for carcases that have not been electrically stimulated. However, cooling or freezing the carcases too quickly after electrical stimulation can contradict the benefits and optimal timings depend on stimulation parameters. There is increasing evidence that electrical stimulation protects against rigor shortening at high temperatures in lamb (see heat shortening page 27).

FACT:

Stimulated carcasses are less prone to cold-shortening and allows accelerated tenderisation resulting in more tender lamb.

Electrical stimulation (low, medium or high voltage) has beneficial effects on meat quality of small ruminants in terms of ultimate pH, tenderness, and higher colour measurements (on scales assessing redness, yellowness and lightness of the meat). There is less evidence and more variable results for effects on juiciness, lamb flavour or abnormal flavour. In summary, electrical stimulation allows accelerated tenderisation and results in significantly more tender lamb.

Hanging method

Meat from relaxed muscles is more tender relative to that from contracted muscles. Therefore, the amount of contraction in the muscle during rigor mortis and post-mortem glycolysis of the carcase will impact on tenderness when the meat is eventually cooked and eaten.

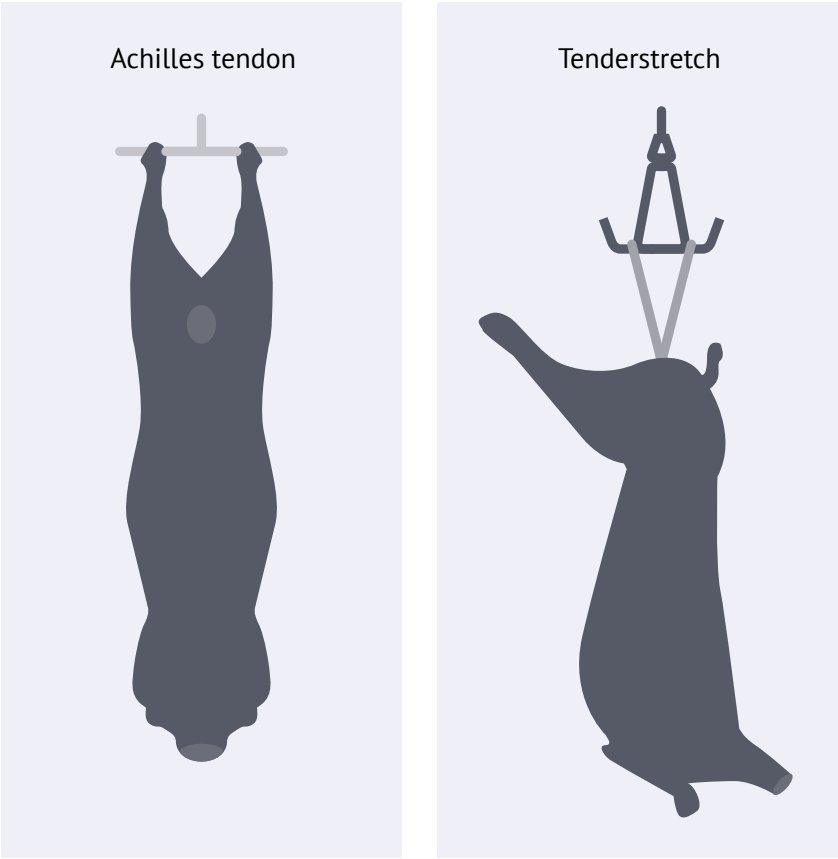
The suspension of lamb carcases by gambrels or hooks inserted behind the Achilles tendon is the established commercial practice. In this position, the spine is curved and the hindquarter muscles are not stretched.

An alternative method is pelvic or hip suspension (also known as the Tenderstretch method), which involves hanging a carcase from the aitchbone (*Obsturator foramen*), which forms part of the pelvis, soon after slaughter. This method improves the tenderness of meat, particularly from some of the high-priced muscles around the loin and the rump, comprising the eye-muscle and key hindlimb muscles (e.g. *longissimus, semimembranosus, semitendinosus* and *gluteus medius*).

A positive effect of pelvic suspension is that stretched muscles can also have reduced exudation (drip loss) at high holding temperatures. Higher water-holding capacity due to pelvic suspension has been reported in several livestock species, including lamb during long-term chilled storage.

However, the pelvic suspension hanging method is not always practical at large-scale processors as it is labour intensive, the carcases require more space and it may lead to differences in the shape of lamb cuts, requiring retraining of butchers.

Figure 5. *Tenderstretch and Achilles tendon are two hanging methods used for lambs.*



Chilling rate

Refrigeration reduces the temperature of the meat to slow (in the case of chilling) bacterial growth. A number of steps are usually carried out in a meat cold chain to progressively lower the carcase temperature, from primary chilling, to secondary chilling, to freezing.

Most larger lamb abattoirs use insulated rooms where carcases are hung on rails with evaporator coils located above and fans to circulate the air over the warm carcases. The meat is chilled, usually for a minimum of 8 hours for lamb. Cooling rate will be a function of the weight and fat cover of the carcase.

Rapid chilling of carcases pre-rigor can have severely negative effects on the texture of meat if carried out before the pH of the meat has dropped sufficiently. Several recommendations for chilling rates have been developed.

For lamb, some suggestions for improved meat quality involves:

- an accelerated ageing process,
- involving electrical stimulation;
- holding the lamb carcases above 6°C for at least 8 hours post-mortem; following which, the temperature of the deep leg should not fall below –4°C within 20 hours post-mortem;
- the temperature at pH 6 should be greater than 10°C, but less than 30°C to reduce risk of heat or cold shortening.

Another rule of thumb for chilling rate is that any part of the lamb carcase should not be chilled below 10°C until at least 10 hours after slaughter.

Drip Loss

Drip loss from meat can occur throughout the cold chain, which reduces the weight of the meat and can also have a negative impact on meat quality, resulting in economic loss to the processor. The rate of drip loss increases with storage temperature and duration. Rapid chilling reduces drip loss. Increased drip loss has been associated with reduced juiciness of meat which can cause dry meat that is associated with other negative effects, such as lack of flavour and increased toughness. However, differences in drip loss during chilling have a much smaller impact on meat quality than moisture losses during cooking.

Freezing meat can decrease water-holding capacity and so increase drip loss. However, there seems to be no conclusive evidence that the freezing method or rate of freezing has a substantial effect on meat quality characteristics or eating quality. There is some evidence that a faster rate of freezing can increase muscle colour lightness, which is due to the association between ice crystal growth and freezing rate. Small crystals formed by fast freezing can scatter more lightly than large crystals formed by slow freezing.

pH – rate of change and ultimate value

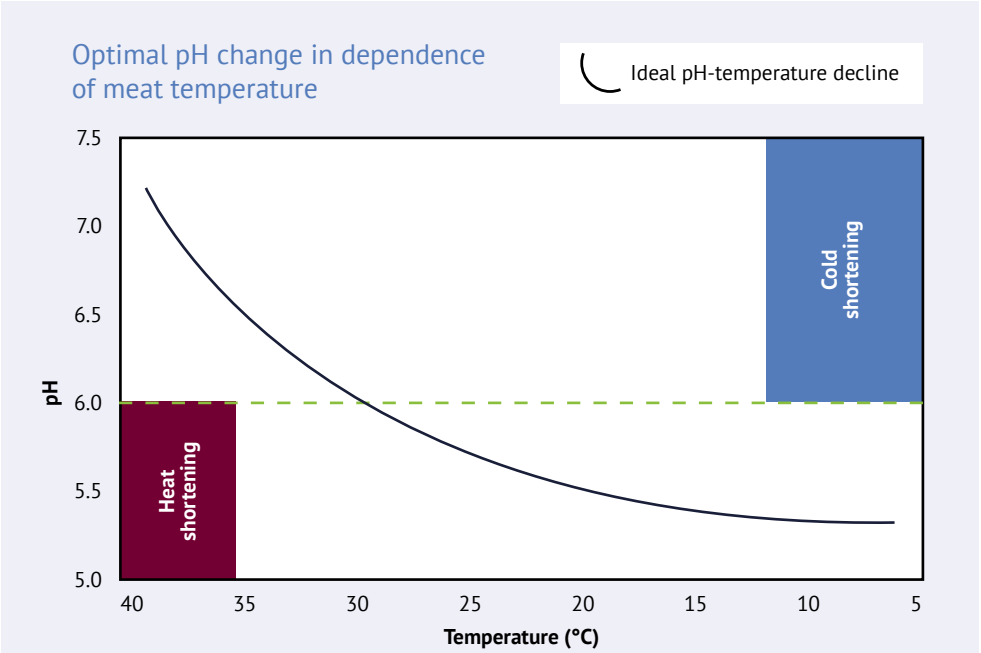
pH value

The pH value is a measure of the concentration of hydrogen, and therefore acidity. A pH of 7 represents neutral and lower values denote increasing acidity. In a normal living muscle, the pH is approximately 7.2. When muscle turns into meat, glycogen is broken down to lactic acid and the pH falls. The pH of meat can range from 5.2 to 7.0. Both, the rate in change of muscle pH, and the ultimate pH reached post-mortem, can affect meat quality. The ultimate pH is determined by the extent of the pH decline at 24 hours after slaughter, with a target value of around 5.5 in sheep.

As explained on page 20, post-mortem metabolism can be enhanced or reduced by factors occurring before, during or after slaughter. Variation in ultimate pH influences factors such as colour and the ability of the meat to retain water.

A low ultimate pH results in meat proteins having decreased water-holding capacity and a lighter colour. If pH falls too quickly, while the temperature is still high, or a low ultimate pH is reached, this can lead to pale, soft, exudative (PSE) meat, particularly in pigs. However, this condition is not usually found in lamb meat.

Figure 6. *Optimal pH changed in dependence of meat temperature.*



An expotential model (pH value = 5.255 + 0.0310* exp (0.1065* temperature)) was fitted to data provided by Pethick et al, 2005 as a graph, and re-drawn to describe the optimal pH change in dependance of meat temperature in the lamb loin muscle (12/13th nib).

FACT:

Variation in ultimate pH influences factors such as colour and the ability of the meat to retain water.

A higher ultimate pH will give a darker colour and less drip loss. If pH falls too slowly, or a high ultimate pH is reached, this can lead to dry, firm, dark (DFD) meat, also known as dark cutting meat. Although this condition is more commonly found in beef, it can occur in lamb.

FACT:

Dark firm meat (DFD) can result from long periods of stress such as fighting. This may mean there is not enough energy stored in the muscles at slaughter, resulting in dark, dry meat.

pH rate of change

Although rate of pH drop has been related to tenderness on cooking, the exact relationship between tenderness and pH differs between muscles. However, the effects of ultimate pH on tenderness seem to be less pronounced in lamb than other species.

The rate of pH and temperature decline should be monitored together to enable the best processing strategy to improve meat quality. Prior research has suggested that optimal lamb tenderness occurs when carcase pH is 6 over the carcase temperature range 18°C and 35°C, which has been referred to as the 'ideal pH decline'. A similar recommendation suggests a pH greater than 6.0 if temperature is over 35°C, and a pH below 6.0 before temperature falls below 12°C.

Ultimate pH can affect other meat quality characteristics. At a high ultimate pH, there is less reduction in meat water holding capacity, but generally less flavour intensity. Additionally, if meat with a high pH value (>6) is packaged in gas-impermeable packs, there will be increased risk of bacterial spoilage and discolouration.

Cold and heat shortening

If muscles are extended when entering rigor mortis, they are more likely to be tender on cooking, whereas if muscles are contracted, this can result in meat being tough on cooking. "Shortening" of muscles can occur if the temperature is too high or too low as they enter rigor mortis, with the optimum temperature being around 15°C to minimise shortening. However, as different muscles cool at different rates, it is difficult to standardise this across the carcase.

Cold-shortening is the term given to the muscle fibre contraction that can occur during chilling. This depends on temperature, with the minimum contraction occurring around 15°C, and the maximum contraction occurring below 10°C. If there is premature cooling of the carcase to below 10°C before rigor/pH 6, this results in an accelerated rate of post-mortem metabolism, causing toughening. Some studies have reported that the most severe effect occurs at about 3°C.

To avoid cold-shortening, the carcase should not be chilled to below 10°C before the muscles have gone into rigor mortis. The severity of cold shortening is strongly linked to pH and is greatest if the temperature of the meat is below 10ºC at pH 6.8 (rapid chilling) compared to reaching this temperature at pH 6.2 (more common commercial chilling rate).

FACT:

Cold-shortening is linked to temperature and pH at rigor and can increase toughness.

The risk of cold-shortening can be minimised to improve meat quality by employing some of the strategies discussed on page 22, using electrical stimulation, and careful chilling regimes to ensure optimum rates of decline in pH and temperature. Cold-shortening can also be avoided by wet-ageing strategies described on page 29, for example, de-boning hot carcases at a room temperature of 5 to 15°C, then keeping packed meat at this temperature for 10 hours or more after packing.

Heat-shortening: If carcases are not chilled correctly and the temperature of the meat is above 25°C at completion of rigor, then 'heat-shortening' can occur, leading to toughening of the meat. This effect is more pronounced in unstretched muscles. Heat-shortening can also increase drip loss, cooking loss and exudation of surface fluids, as well as protein denaturation. However, heat-shortening is generally considered less of a problem for meat quality in commercial lamb processing systems.

FACT:

Heat-shortening can increase drip loss, cooking loss and exudation of surface fluids.

Ageing/Conditioning

Holding unprocessed meat above freezing point is termed ageing, conditioning, or maturing. When meat is stored above freezing, it becomes progressively more tender. This is due to activity of proteolytic enzymes which breakdown protein. Immediately after slaughter, muscles are pliable and tender if cooked (for 8-10 hours following slaughter), rigor mortis then makes muscles inextensible and tough if cooked. The ageing process then leads to muscle becoming pliable again and tender when cooked. The rate of ageing depends on the temperature at which the meat is held post-rigor, with higher temperatures increasing the ageing rate, and the activity of the proteolytic enzymes falling with time at chilled temperatures of around 4°C.

As well an increasing tenderness, ageing leads to increased flavour of meat, due to enzyme and bacterial activity. However, as either time since slaughter or temperature increases, risk of microbial spoilage also increases.

Growth of micro-organisms can be decreased by:

- low temperatures,
- low moisture,
- reduced pH,
- reduced exposure to atmosphere,
- or high pressure.

Chiller environments are highly controlled to optimise the opportunity to age the meat while minimising risk of microbial spoilage. The length of time meat is kept in chilled storage also has an effect on the rate of colour change during retail display.

Fresh lamb in the UK is generally aged at chilled temperatures for around 5-7 days as standard, although some extended ageing protocols of around 10-14 days can be found. Ageing for 10 days, as compared to 5 days, has been reported to lead to increased tenderness and flavour of lamb.

With advances in carcase cleanliness, packaging technology and the use of decreased storage temperatures (e.g. –1.5°C), shelf-life can be extended. These techniques are used during export of chilled products overseas, and the extended ageing time allows the meat to fully tenderise, despite the low storage temperature.

Ageing methods

The process described above of ageing lamb by hanging carcases in a controlled refrigerated environment, at chilled temperatures, can be referred to as 'dry ageing'. This process needs to be closely monitored, as too high a temperature can lead to bacterial spoilage of the meat, whilst too low a temperature will cause the meat to freeze and stop the ageing process. During dry ageing, unpackaged products are exposed to air in a well-ventilated room with a humidity of about 85% and these low temperatures result in moisture loss, which increases with the duration of ageing.

Alternatively, the carcase may be cut into sections (sub-primals) or boned then vacuum-packaged before ageing, which can be referred to as 'wet ageing'. This method can require less time, storage space and weight loss is eliminated, as moisture is retained in the meat.

Dry ageing results in greater drip loss and shrink, although its effects on eating quality are debateable. There is potential to combine both ageing methods. For example, dry-ageing the meat for a reduced time, followed by further ageing of vacuum packaged cuts.

Combinations of processing techniques can impact on meat quality.

For example, Australian studies have found that ageing benefits tenderness more rapidly if carcases are suspended by the pelvis ('tenderstretch' method), rather than the Achilles. These studies also found that electrical stimulation followed by Achilles hanging may have a similar effect as 'tenderstretch' of unstimulated carcases, in terms of improving eating quality. Therefore, the processing factors discussed here should be considered for their cumulative effects on meat quality characteristics.

Conclusion

It is well accepted that ensuring consistent meat quality is key to returning value for the whole sheep meat supply chain. Meat quality attributes inform customers' purchasing decisions and define the final eating experience of the consumer which leads to increased consumption and repeat purchase.

Meat quality incorporates appearance traits (e.g. meat or fat colour), as well as palatability characteristics such as tenderness, juiciness and flavour. Objective systems to capture and feedback on reliable meat quality information throughout the production process could help to provide clear signals on lamb meat quality requirements which could benefit the entire supply chain and improve the quality of lamb meat.

This booklet covers a variety of factors affecting lamb meat quality, both on-farm and during processing. Some previous studies have implied that processing factors and preparation/cooking methods outweigh genetic and environmental effects during production, in terms of the magnitude of their effect on lamb meat quality. However, in reality, a combination of factors must be addressed to ensure that lamb meat quality is optimised. The most cost-effective and sustainable strategy is likely to be through wide industry communication and education of factors that can be influenced. Factors may include genetic improvement with optimised feeding and management systems, and enhanced processing protocols. Although each factor affecting meat quality has been considered separately in this review, there will be many interactions between factors that cannot be easily accounted for. Nevertheless, by understanding how each step in the chain can impact on meat quality, lamb producers and processors can make informed decisions on strategies to maximise the quality of lamb meat.

The Welsh Lamb Meat Quality project is further investigating many on-fam and processing factors described in this publication. All lambs from the project sourced from across Wales and are PGI Welsh Lamb. Over five years, the project is investigating supply chain interventions and how they may influence the meat eating quality and nutritional composition of Welsh Lamb.

PGI Welsh Lamb currently has an enviable reputation for quality, enabling it to be sold at a premium in many markets worldwide. Moving forward, the sector will have to ensure that the consumer's continued experience is consistently excellent, this should ensure that the price received for the product which is farmed to high environmental and welfare standards is optimised. World-leading research into eating quality and the production and processing factors which influence it, is therefore essential to ensure that Welsh Lamb remains competitive in the global marketplace.