



**Review of published literature and unpublished research
on factors influencing lamb quality**

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EXECUTIVE SUMMARY

A wide range of factors influence consumer acceptability of red meat. This review is focused on eating quality, with some reference to visual characteristics. The MLC (Meat and Livestock Commission) Blueprint for Lean and Tender British Lamb was launched in 1994 (MLC 1994). This current review is based on the original literature review undertaken for the Lamb Blueprint and draws on reviews undertaken since that time, updated with evidence from the last 17 years.

Research related to the entire production and marketing chain has been considered, in respect of improving the eating quality of lamb.

Meat quality traits can be influenced by production methods on farm and a wide range of factors beyond the farm gate. The review summarises the available information on these various factors for lamb.

The practical messages that have been derived from this review are:

1. Breed only has a small effect eating quality. Where differences between more traditional breeds have been suggested, separating the effect of the diet from the effect of the breed is difficult.
2. Improving genetic potential within breeds, particularly for muscle depth and reduced fatness, should be exploited where there is no detrimental effect on meat quality.
3. Attention should be directed towards genomic selection for meat quality in the next 5-10 years.
4. Whilst eating quality differences in ram lambs, wethers and ewe lambs are generally small, it has been found that older ram lambs can produce an abnormal flavour. Aim to finish ram lambs by 5-6 months of age.
5. British consumers prefer a stronger lamb flavour which develops with age, although older lambs can become tougher. Age/weight specifications may be useful to reduce flavour variations.
6. Diet has little effect on tenderness but a large influence on flavour. Lambs fed on pasture diets are preferred by British consumers. Supplementation of forage diets with concentrates does not negatively affect taste but concentrates can produce undesirable fat characteristics.
7. Forage based diets can provide a higher level of important long chain PUFAs, particularly EPA and DHA, which are nutritionally beneficial to human health.
8. Forage legumes, in particular Lucerne, can impart off flavours. Where these are used in the diet ensure lambs are grazed on grass for a period of at least 7 days prior to slaughter to restore normal flavour.

9. Vitamin E supplementation at 300 IU/kg DM, should be considered where lambs are fed concentrates in order to reduce lipid oxidation and prolong shelf life.
10. Aim for a consistent growth rate, especially in the lead up to slaughter.
11. Consumers perceive lamb as a fatty product. Whilst a level of fat has small benefits in terms of juiciness and tenderness this should be balanced against the consumer demand for lean meat. A lean, consistent, product with pleasing visual appearance should be strived for.
12. Chilling methods should be monitored in order to prevent toughness due to shortening in learner carcasses, and extremely lean carcasses should be avoided.
13. Aim for a minimum fat class of 2 and a maximum fat class of 3H
14. Whilst sheep appear to be fairly resilient to stress, good handling and creating minimal stress should always be paramount. Stocking densities, travelling times, loading, unloading and general handling are all potential stressors.
15. Careful handling is essential to avoid bruising and carcass damage.
16. Stun to stick times should be less than 15 seconds but a time of less than 10 seconds is recommended to reduce blood splash.
17. Chilling needs to be considerate to minimise the risk of either cold or hot shortening.
18. Where ES is not used avoid chilling to 10°C and below within the first 10 hours post slaughter. Where ES is used aim to achieve a pH of 6 at 18-35°C.
19. Take into account variable carcasses sizes as larger carcasses will be less prone to cold shortening. Regularly monitor pH fall and temperature.
20. Hip suspension optimises the tenderness of the hind leg and loin muscles.
21. ES can improve lamb tenderness, especially where hip suspension is not used. It can enable faster chilling against the risk of cold shortening but care should be taken to ensure hot shortening does not occur. Regularly monitor pH fall and temperature.
22. Ageing lamb, either in carcass form or in vacuum packs for a period of minimum of 7 days and optimum of 10 days improves lamb tenderness
23. Monitor pH/temperature post slaughter and adjust stimulation/chilling rates to ensure pH 6 is reached at between 18 – 35°C.

24. Monitor ultimate pH. If this falls outside the normal range review the handling procedure.
25. Avoid high oxygen packaging wherever possible.

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Review of published literature and unpublished research on factors influencing lamb quality

1) INTRODUCTION

A wide range of factors influence consumer acceptability of red meat. In 2007 a review was undertaken for Defra on factors influencing consumer perception and purchasing of red meat (MLC, 2007). This concluded that many of the things of concern to consumers are perception issues which are addressed either by changes to the production system or communication. The important quality attributes that result from changes to meat's physical or biochemical properties are appearance (colour and fat content), nutritional properties (primarily fat content and type) and eating quality (texture and flavour). This review is focused on eating quality, with some reference to visual characteristics.

The MLC (Meat and Livestock Commission) A Blueprint for Lean and Tender British Lamb was launched in 1994 (MLC, 1994). This document comprised recommendations for best practice related to eating quality. In defining these, a literature review was undertaken in order that the Blueprint was based on the available scientific literature, combined with results from MLC's own research programme. MLC scientists updated the review in 2001 as part of a project being undertaken for Quality Meat Scotland, including a literature search over the intervening years (Matthews and Warkup, 2001). Subsequently, a review on sheep meat flavour was commissioned at the University of Bristol (Wood *et al*, 2005).

The current review draws on these earlier documents as a basis, updated with evidence from the last 10 years. As with the earlier reviews, this draws on the available scientific literature, levy-funded research (both published and unpublished) and contacts within the global meat science community. Database searches have been conducted for the last 10 years' scientific publications and added to the information gathered in the earlier reviews. The literature review has been largely restricted to English language documents but knowledge of research in other countries (particularly within the EU) has also influenced the conclusions drawn. Most of the scientific literature on meat science (including eating quality) is based on work conducted on grilling and roasting cuts, particularly the loin. This review is therefore inevitably biased towards these cuts.

To make the final document as readable as possible, excessive quoting of references and detailed discussion of individual scientific papers has been mainly avoided. Sufficient references have been given to support the conclusions drawn.

Research related to the entire production and marketing chain has been considered, in respect of improving the eating quality of prime lamb (information related to mutton eating quality has not been exhaustively studied although is referenced in relation to age and quality).

A number of technologies are applicable to cuts on a batch basis (eg high pressure treatment, the hydrodyne process). These have not been included in any detail because

their small batch nature means that they are not readily applied commercially. In addition, the review has not covered substances that can be added to meat post-slaughter, such as calcium chloride, because these are regarded as food additives and the resulting meat is no longer considered fresh meat.

There is a variable volume of scientific literature covering the various factors and the evidence can be conflicting. In forming a view on the factors of importance, the evidence has been distilled and a balanced judgement made.

Contradictory data sometimes originate from overseas. This can arise as a result of both major differences in practice, and differences in the expectations of quality, particularly where consumer panelling is used.

Meat quality traits can be influenced by production methods on farm and a wide range of factors beyond the farm gate. The review summarises the available information on these various factors for lamb. Many of these production and processing factors influence meat quality through changes to the process of conversion of muscle to meat. It can be useful to have a basic understanding of this process and this is presented (largely unedited from previous versions) in section 4.

2) FACTORS AFFECTING LAMB EATING QUALITY

Consumer research has shown that the most important attribute of meat eating quality is tenderness. Flavour is usually the characteristic of next importance.

Consumers generally consider lamb to have a good eating quality, with variation in tenderness being less extreme than other species. The main criticism of lamb is in relation to the perceived fattiness. Consumer research continues to indicate that lamb can be considered fatty (55% of consumers in December 2011, source: Milward Brown). Older (MLC) consumer research indicated that lamb fat is particularly disliked because of its high melting point and hence sticky mouth feel.

Breed / Genetic effects

Various studies have compared a wide range of breeds. Whilst differences in carcase weights (Doyle *et al*, 2007) and conformation are reported, differences in meat eating quality between lamb breed and sires within breed are generally small and inconsistent. There is evidence that some minor breeds exhibit unusual quality characteristics (eg the Soay is tougher than Welsh Mountain and Suffolk, Fisher *et al*, 2000). Carcase conformation will give an indication of yield with those of E, U and R in relation to the EUROP grid tending to be the most desirable for end market products.

There are also some studies which show that certain breeds exhibit different flavour characteristics but generally diet is the most important factor in determining lamb flavour. For example, Enser *et al* (1998) found that the Herdwick (at 8 months of age) had more tender meat with higher lamb flavour than the Suffolk (at 6 months of age). Often it is difficult to separate the breed effect from the diet, with different breeds traditionally reared in different environments. The East Friesland breed has been found to have higher lamb flavour intensity than Texels or South Downs.

Breeds selected for fine wool (particularly in New Zealand and Australia) can exhibit a different flavour. In some studies this has been described as greater mutton flavour. In others it is identified as abnormal. This has been associated with high ultimate pH rather than a breed effect *per se*.

There are breed differences in the incidence of yellow fat in lambs, with Norwegian breeds seeming to exhibit a particular problem. This does not represent an eating quality issue but there is some consumer resistance to the appearance of yellow fat.

A marked genotypic effect on tenderness has been observed with the so called callipyge gene. This gene, which has peculiar inheritance (known as polar over-dominance), imparts improved conformation, particularly of the back leg. It has been found to result in tougher loin (*longissimus*). Most workers have found that leg is unaffected when roasted. When steaks from the leg are grilled the same toughness disadvantage has been found (Shackelford *et al*, 1997) but not in every case (Goodson *et al*, 2001). Because of the yield advantages workers in several countries have attempted post slaughter treatments to improve the eating quality of callipyge lambs. Most treatments

are not effective in tenderising callipyge lamb sufficiently to match controls, although calcium chloride marination has been found to be effective by some workers.

In Britain, the sheep breed societies and researchers have agreed only to import sheep carrying the callipyge gene for research purposes and are committed to keeping the gene out of commercial slaughter populations.

The Texel Muscling QTL (TM-QTL), found in purebred UK Texels, increases muscle depth although this is restricted to the loin area. Research has suggested this has little effect on meat quality provided post slaughter treatments including high voltage electrical stimulations and conditioning for a period in excess of 7 days is carried out, (Lambe *et al*, 2011). .

Selecting for high muscle depth within breeds has shown a mixed response to eating quality traits although Navaras *et al*, (2008) concluded that utilising genetics to give increased muscularity would not have a significant negative impact on eating quality. CT scanning of muscle density has been shown to provide an accurate prediction of intra-muscular fat, in turn giving an indication of eating quality (Lambe *et al* 2010).

It is often felt that the genetic variation within breeds offers sufficient potential for improving carcass and meat quality traits as can often be seen between breeds. There is therefore a need for tools to select for meat quality at the same time as production characteristics. CT muscle density offers some potential, but there is a greater potential to address this through genomic selection in the future. This will depend, however, on a breed by breed verification of genomic data (from SNP chips) against phenotypic data which are costly to collect.

Practical Messages

Breed only has a small effect eating quality. Where differences between more traditional breed have been suggested, separating the effect of the diet from the effect of the breed is difficult.

Improving genetic potential within breeds, particularly for muscle depth, should be exploited where there is no detrimental effect on meat quality.

Attention should be directed towards genomic selection for meat quality in the next 5-10 years.

Sex

Most studies on the effect of sex on meat quality in lamb have been concerned with the effects of castration. Results are conflicting but, overall, differences between ram lambs, ewe lambs and wethers are small.

Meat from rams has generally been of equivalent tenderness to that of wethers but has sometimes been found to be tougher. An MLC funded project examined spring born lambs slaughtered from June through to January and found no differences between entire male lambs and wethers for tenderness or overall acceptability. Young, *et al* (2006), found that when slaughtered at the same age, older ram lambs were found to be less tender than wethers, although sensory panels did not distinguish between sex.

Potentially of greater concern is the higher incidence of abnormal flavours which has been observed in older male lambs. Despite citing several earlier references that showed no effect of castration on flavour in male lambs, Sutherland and Ames (1996) identified the development of abnormal flavours occurs by 30 weeks of age and concluded that it is advisable to utilise ram lambs only when finishing can be achieved by 5-6 months of age. This view is supported by Mushi *et al* (2008) and is in line with industry preference, ensuring that slaughter is before ramish characteristics develop which downgrade the carcass.

Rams tend to have faster growth rates than wethers which in turn have faster growth rates than females. Also rams tend to produce leaner carcasses than wethers and females at the same liveweight, (Dransfield *et al*, 1990).

Practical Messages

Whilst eating quality differences in ram lambs, wethers and ewe lambs are generally small, it has been found that older ram lambs can produce an abnormal flavour. Aim to finish ram lambs by 5-6 months of age.

Weight and age at slaughter

It is very difficult to separate the effects of age, weight and season in lambs. Generally speaking the literature supports the view that older/heavier lambs are tougher. In particular, spring born lambs slaughtered in the autumn/winter are tougher than those slaughtered in the summer. An MLC funded project at the University of Newcastle examined the effect of diet and slaughter period on the eating quality of lamb. This clearly demonstrated an increase in toughness as lambs became older. Lambs finished as hoggets (in January following spring birth) were tougher than those finished in the summer. Those finished in the autumn were intermediate. The possibility of this being due to some factor confounded with season of slaughter cannot be excluded - lower ambient temperature increasing the incidence of cold shortening for example. As sheep become older, an increase in oxidative fibres is likely to increase toughness as well as produce darker and potentially less desirable meat. It has also been found that the overall liking for lambs fed on forage or concentrate based diets is reduced for those slaughtered in March as opposed to November (Phillips *et al*, 2008)

Conversely, as Veiseth *et al* (2004) concluded, lambs slaughtered at 10 months of age as opposed to 2 months were more tender. This was postulated to be due to the fact

older animals would have a higher level of insulation to prevent against shortening as well as a longer loin, thus longer sarcomere length.

In young lambs, increasing slaughter weight has been found to provide a more intense lamb odour and flavour (Martinez-Cerezo *et al*, 2005). However, there is also a tendency for undesirable flavours to develop in older animals, particularly rams (see above). Flavour perception is subjective. The distinction between the characteristic flavour of lamb and mutton has not been well defined (Sink and Caporaso, 1977). People apparently differ in their concept of what constitutes mutton flavour and the ability to distinguish between lamb and mutton flavour differs between individuals (Batcher *et al*, 1969). Mutton flavour may describe an entirely different flavour from lamb flavour or may merely represent a change in concentration. Mutton flavour is sometimes grouped with other undesirable flavours as 'off flavours' or 'abnormal flavour.' This is an area which may warrant further research in terms of determining what the modern consumer considers 'good' lamb flavour.

Wide variations in carcass weight can lead indirectly to meat quality issues such as mixed sizing within packaging leading to cooking time inconsistencies, as well as having a negative impact on visual appearance.

Practical Messages

British consumers prefer a stronger lamb flavour which develops with age, although older lambs can become tougher. Age/weight specifications may be useful to reduce flavour variations.

Diet and production system

Flavour

The composition of the diet influences the products of digestion and hence meat odour, flavour and fat characteristics. Whilst it is accepted growth rates and killing out percentages can be significantly higher in concentrate fed lambs, generally, stronger lamb flavour is imparted by forage finishing which is generally preferred by British consumers (Fisher *et al.*, 2000; Sanudo *et al*, 1998) Further studies have suggested that a combination of forage and cereal finishing rations have a high acceptability by British consumers in sensory analysis (Font i Furnols *et al*, 2009), although consumers would prefer to purchase grass fed lamb (Font i Furnols *et al*, 2011).

Legumes (particularly lucerne but also white clover), brassicas, oat pasture, maize silage and 'weeds' have all been found to impart off flavours to lamb. A grass grazing period of as little as 7 days can restore normal lamb flavour (Park *et al*, 1972a; Park *et al*, 1972b). MLC funded research at SAC Edinburgh (Vipond *et al*, 1995), however, found no differences between lambs fed grass (ryegrass) and clover/grass swards. It has also been observed that the branched chain fatty acids thought to be responsible for the distinctive flavour of lamb are present in higher concentrations when lambs are fed a processed grain diet (Wood and Fisher, 1990). There is some evidence that onions can

have a negative impact on flavour and tenderness of lamb. Protein source in the diet (eg soya or faba beans) can influence sensory characteristics, particularly flavour. Again this is probably a minor effect compared with the forage versus concentrate differences. The weight of evidence suggests lamb flavour from grazed animals is preferred in Britain. This may be worth testing for a specific market if a niche product is under consideration. For a thorough review of the effect of diet on lamb flavour see Field *et al* (1983) or Wood *et al*, (2005).

Whilst most lambs in Britain will be finished off grass with or without creep feeding, a number of lambs are carried over the winter period. EBLEX funded research carried out by ADAS examined finishing off grass/concentrates, ad-lib concentrates and stubble turnips. Lambs fed stubble turnips showed higher flavour and overall liking scores than the other diets, although on a par with the control group kept on permanent pasture. Growth rates may have been lower in the stubble turnips group but killing out percentages were greater. It was also found that the overall liking for both lambs fed on the forage or concentrate based diets was reduced for those killed in March as opposed to November (Phillips *et al*, 2008).

Texture

There is conflicting evidence regarding the effect of concentrate level in the diet on textural parameters with some evidence that lower concentrate/lower energy diets produce more tender and juicy meat. Lambs on lower concentrate diets have slower rates of post-mortem glycolysis (Solomon and Lynch, 1988) and this has been linked with tenderness (Marsh, 1983). On the other hand there is some research which indicates higher energy diets result in more tender meat. Overall it is likely that any effect of dietary type on tenderness is small with other associated factors such as growth rate and age, being of greater importance.

The proportion of concentrates in the diet also influences the fat composition with high concentrate diets generally resulting in softer fat. This is considered beneficial in terms of consumer perception of fat texture but can be associated with an undesirable oily odour or flavour. The effect of a concentrate diet will clearly be influenced by its composition, with lard appearing to make the lamb fat harder and whiter. **The melting point is also lower in early spring lambs than in hoggets.**

Neither the MLC or the ADAS study on diet and finishing period mentioned above showed any differences in tenderness between lambs finished on cereals, grass, silage or roots when slaughter period is taken into account.

Growth rates

Grass finishing tends to produce leaner carcasses than concentrate feeding. Taking into consideration the ideal 18-21kg carcass weight especially compared to European counterparts, the use of grass finishing may also be advantageous in producing a heavier but leaner carcass. The use of clover or high sugar grass mixes can be a useful mechanism to improve growth rates more in line with concentrate finishing, whilst talking advantage of the benefits grass has on fatty acid composition in lamb, (Dawson *et al*, 2011). Grazing chicory promotes faster growth rates and improved killing out percentages and whilst research to date has shown some mixed results on eating

quality, it is concluded that chicory will not have a detrimental effect on eating quality (Houdijk, 2010).

It is generally accepted that the diet needs to promote a good consistent growth rates and thus ensuring muscle glycogen levels are maintained so as to not produce meat with significantly high pH levels, although the incorporation of best practice during processing can potentially reduce the effects on eating quality. The withdrawal of food in the 12 hour period leading up to slaughter is often practised to prevent carcass contamination on the slaughter line.

Other dietary considerations

A grass diet also provides an increased level of nutritionally important long chain (n-3) polyunsaturated fatty acids (PUFA), in particular eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Wood *et al*, 2008). Bio-diverse grasses and more commercial rye grass pastures can all produce lambs of both high meat and eating quality. Heather and moorland fed lamb were found to contain higher levels DHA and moorland a higher level of conjugated linoleic acid (CLA), both of which have a positive effect on human health (Whittington *et al*, 2006). However, due to biohydrogenation in the rumen, the potential for levels of n-3 PUFA found in grass and forage to increase the content within muscles is reduced. The inclusion of fatty acids in the diet can improve PUFA concentrations. The incorporation of treated linseed has been shown to have a positive effect on beneficial fatty acid ratios in lamb. Pasture feeding generates higher concentrations of n-3 PUFAs but it has been suggested supplementation of concentrate diets with linseed can provide a similar level to grass finished lambs (Kitessa *et al*, 2010).

Vitamin E in the diet (at 300IU per kg dry matter) has been found to protect against lipid oxidation in lambs fed concentrate diets and hence extend shelf life. Where lambs are finished on concentrate diets or stubble turnips which are low in Vitamin E, additional supplementation in the diet may be beneficial.

In common with beef, slaughtering animals directly off their mothers has been found to result in more tender meat than those weaned first. For example, Vipond *et al* (1995) found that lambs slaughtered at 20 weeks of age directly off their mothers were more tender than those slaughtered off pasture at 28/9 weeks of age (5.8 compared with 5.0 on an eight point scale). It is unlikely that this age difference alone would have such a marked effect.

Other studies show contrasting evidence regarding the potential yield differences between artificially reared or ewe reared lamb. Research into gentling and artificial and ewe rearing showed that whilst all gentled lambs displayed a greater pH decline, no significant differences in shear force and meat quality have been observed (Napolitano *et al*, 2006).

This is an area that may warrant further research. In lamb it would be possible to use twins where one is weaned and one left at foot for a direct comparison (with slaughter at the same age/weight).

Practical Messages

Diet has little effect on tenderness but a large influence on flavour. Lambs fed on pasture diets are preferred by British consumers. Supplementation of forage diets with concentrates does not negatively affect taste but concentrates can produce undesirable fat characteristics.

Forage based diets can provide a higher level of important long chain PUFAs, particularly EPA and DHA, which are nutritionally beneficial to human health.

Forage legumes, in particular Lucerne, can impart off flavours. Where this is used in the diet ensure lambs are grazed on grass for a period of at least 7 days prior to slaughter to restore normal flavour.

Vitamin E supplementation at 300 IU/kg DM, should be considered where lambs are fed concentrates in order to reduce lipid oxidation and prolong shelf life.

Aim for a consistent growth rate, especially in the lead up to slaughter.

Animal fatness

A major MLC study on the effect of fatness on lamb eating quality was completed in 1993. Thirty lamb carcasses were selected from each of five MLC fat classes (2, 3L, 3H, 4L and 4H) between September and December 1992. Each group included 15 males and 15 females. Selections were made in eight abattoirs. Roasted leg joints and grilled loin chops were assessed by trained sensory panel. There was no significant effect of fatness on flavour, juiciness or tenderness of leg joints but there was a significant effect of fatness on tenderness and juiciness of loin chops. The 2 and 3L lambs produced loin joints with lower tenderness scores than the other three classes which were not different. The absolute effect of fatness on loin tenderness was small compared to the benefit obtained via changes in post slaughter carcass handling or ageing (discussed later).

An important study on the effect of lamb fatness on eating quality was conducted by Smith *et al* (1976) in the US. Lambs were selected from a common environment to fit into three groups: lean, fat and intermediate. Subcutaneous fat was removed from one side of the lambs in the intermediate group and all sides were chilled at 1°C. Shortening occurred in the lean group resulting in an effect of fatness on tenderness. The fat trimmed group matched the lean group in terms of toughness. These results suggest

that the major effect of fatness is the insulating effect of subcutaneous fat protecting against cold shortening during chilling.

A New Zealand report on the effects of marbling in grass fed lamb in relation to meat quality identified that whilst objective measurements on the loin showed high marbling to be more tender, sensory analysis did not show any significant difference (Young *et al*, 2009). Generally lamb fatness has been found to have a weak relationship with eating quality, in particular tenderness. Against the overall perception of lamb as a fatty meat, and the negative reaction of consumers to fatty cuts, these benefits are small. It is more important to produce lean cuts, handled according to best practice, of good visual appeal than to obtain the small benefits of fatness on eating quality. This is particularly the case in lamb where trimming of intermuscular fat from within roasting joints is particularly difficult.

Practical Messages

Consumers perceive lamb a fatty product. Whilst a level of fat has small benefits in terms of juiciness and tenderness this. A lean, consistent, product with pleasing visual appearance should be strived for.

Chilling methods should be monitored in order to prevent toughness due to shortening in leaner carcasses, although extremely lean carcasses should be avoided.

Aim for a minimum fat class of 2 and a maximum fat class of 3H

Pre-slaughter stress and handling

Sheep seem to be remarkably resistant to stress (Warriss *et al*, 1987; Knowles, 1998) and rarely exhibit the PSE or DFD conditions. Fasting or underfeeding alone does not cause dark cutting in lamb but it does lower glycogen reserves. If this occurs in conjunction with an increase in circulating adrenaline or strenuous muscular activity, glycogen breakdown can result in dark cutting. In cases of extreme fasting resulting in weight loss, the meat can be much tougher. Exercise can, on the other hand, result in more tender meat, possibly because the muscle enters rigor more quickly and cold shortening is avoided (Chrystall *et al*, 1982; Warner *et al*, 2005).

Whilst transport has a negative effect on body weight, it has very little stress effect on sheep and attempts to measure effects have given variable results. Fisher *et al* (2010) conclude that sheep can cope with road transport up to 48 hours. It is widely accepted that road type and driver style have a larger influence than journey times and it has been suggested that different physiological responses are seen in sheep of varying ages. Interestingly, recent studies have suggested an increase in lipid oxidation has been linked with transportation of young lambs (De la Fuente *et al*, 2010; Zhong *et al*, 2011). It is generally accepted that handling and loading are the most stressful periods and lambs will recover to some extent throughout the journey.

Bruising and carcass damage can occur during weighing, sorting, loading and transportation, particularly in young lambs and careful handling is essential. Whilst this does not directly have an effect on eating quality it can affect the visual appearance of meat.

Lambs should be presented for slaughter in a clean condition in line with recommendations under the Clean Livestock Policy in order to prevent carcass contamination on the slaughter line. Dagging and/or belly clipping may be necessary to achieve this and it is important that this is done considerately to reduce stress and in a manner that does not devalue the skin.

Practical Messages

Whilst sheep appear to be fairly resilient to stress, good handling and creating minimal stress should always be paramount. Stocking densities, travelling times, loading, unloading and general handling are all potential stressors.

Careful handling is essential to avoid bruising and carcass damage.

Method of killing

Stunning of sheep in the UK is generally carried out by one of two electrical methods. Head only stunning is delivered by the use of two electrodes placed on the head. Head to back stunning makes use of a third electrode in the region of the last thoracic vertebra. If sticking is not carried out sufficiently quickly after stunning then haemorrhages can result, giving rise to blood splash in the muscles, fat and other tissues. These can detract from visual appeal of the meat. There is a legal requirement for animals to be stuck without delay following stunning. A good guide to reduce blood splash is to limit this to 10 seconds.

A Stun Assurance Monitor (SAM) can be used to demonstrate effective stunning performance and provide a means to achieving high levels of animal welfare as well reassurance for consumers. A SAM can also help detect faults in the system which enables corrective action to be taken thus avoiding an impact upon carcass quality.

Practical Messages

Stun to stick times should be less than 15 seconds but a time less than 10 seconds is recommended to reduce blood splash.

Chilling

Shortening of the muscle prior to rigor mortis gives a dramatic toughening effect. It has been found that the minimum shortening for lamb occurs at chilling temperatures of 5 to 20 °C and maximum shortening occurs at 0°C (cold shortening) and 40°C (hot shortening) (Cook and Langsworth, 1966; Geesink *et al*, 2000). Lambs are particularly susceptible to cold shortening because of the small size of the carcass which enables rapid heat loss post slaughter. There is conflicting evidence as to whether meat which has been shortened responds to ageing. The safest course of action is to avoid shortening!

The key factors in determining shortening are low or high temperatures and pH over 6.2 coupled with a sufficient ATP level (3.5µ mole/g muscle) for contraction. As a general rule, chilling to avoid a temperature below 10°C in any muscle within 10 hours of slaughter will avoid cold shortening and hot shortening is rarely an issue provided carcasses are chilled following slaughter. With the use of electrical stimulation (ES), faster chilling rates can be achieved but the aim should be to reach a pH of 6 at 18-35°C, as identified by various research studies, in order to reduce the risk of shortening and is cited in Meat Standards Australia guidelines (Pearce *et al*, 2006).

The loin muscle (*Longissimus thoracis et lumborum*) is a good marker for cold shortening. It is particularly susceptible because of its shape and location in the carcass. Recent work commissioned by EBLEX, identified that in English lamb plants, a variation in the rate of pH fall is apparent, both within the same plant and between plants. Whilst the risk of severe cold shortening appeared to be minimal, there was a risk in plants not using ES. Conversely in plants using High Voltage ES there was the potential for hot shortening. Considerate chilling is essential to ensure that chilling does not lead to toughness (Matthews, 2011). .

Carcass fatness can have a more marked effect on the eating quality of lambs than the other species because of the susceptibility to cold shortening. The insulating effect of surface fat on the carcass can reduce the rate of heat loss and therefore protect to some extent against cold shortening. This was particularly well illustrated by the experiment conducted by Smith *et al* (1976) described above.

There has been some evidence that the application of an ultra rapid chilling regime (an air temperature of -20°C at a speed of 1.5m/s for example) can result in tender meat with added advantages of reduced drip loss. The results of various trials have, however, been inconsistent and there is a danger of inducing cold shortening resulting in tougher meat. Slight variations in the chilling conditions seem to yield different results and, because of the difficulty of standardising chilling in commercial practice, it appears to be a risky approach.

An alternative approach, sometimes called conditioning (not to be confused with ageing or maturation), is to delay chilling until the muscles of the carcass have already gone into rigor mortis. In practice this means holding the carcass at a temperature of 7 to 18 °C for a period of time before entry to the carcass chiller.

In many studies delayed chilling has been compared with samples chilled at 0°C which, as stated above, is known to induce cold shortening. It seems likely that all the

conditioning period achieves is the prevention of shortening. Care also has to be taken to avoid hot shortening which could occur if the holding temperature exceeds 18°C. Overall this approach adds little to the benefits obtained by control of chiller temperatures to avoid cold shortening. It can also result in poorer colour stability on retail display.

Practical Messages

Chilling needs to be considerate to minimise the risk of either cold or hot shortening.

Where ES is not used avoid chilling to 10°C and below within the first 10 hours. Where ES is used aim to achieve a pH of 6 at 18-35°C.

Take into account variable carcasses sizes as larger carcasses will be less prone to cold shortening. Regularly monitor pH fall and temperature.

Carcase suspension method

As is clear from the effect of shortening on toughness, the state of contraction of muscles is a significant factor in determining eating quality. Muscular contraction post mortem is moderated by the attachment of the muscles to the skeleton. The tension imposed on any individual muscle in the carcass depends on the position of the skeleton. Various means of suspending the carcass and manipulating the skeleton have therefore been tested for their effect on tenderness.

In lamb, Davey and Gilbert (1973) found that supporting a lamb carcass on a broomstick in a 'natural' standing position improved the loin (*longissimus dorsi*) and leg (*Biceps femoris*, *semimembranosus* and *gluteus medius*). Various studies have shown benefits on the leg and loin muscles from hip suspension of lamb carcasses. This was also found in MLC research where hip suspension yielded the biggest improvement in tenderness achieved by a single factor. The extent of the improvement achieved with hip suspension suggests that there may be benefits in addition to avoiding shortening which are not yet understood. On the other hand the loin of a conventional achilles suspended carcass will enter rigor in a shortened state in any case.

Additional tension of the loin of hip suspended carcasses can be achieved by the application of weights or by severing vertebrae or fascia/tendons overlying the loin. These have not generally been shown to benefit tenderness any further than hip suspension alone (eg Buege and Stouffer, 1974).

Abban *et al* (1975) investigated the effect of altering the posture of the carcass by use of a simple and practical pre-rigor tensioning method. This rotated the femur into a position closer to that in the live animal. This resulted in improved tenderness in 6 muscles assessed with no effect in the *psoas major* or *rectus femoris*. Recent technological introductions seen in Australia which stretch and shape carcasses were

found to have future potential in improving the eating quality as well as the product range of lamb cuts (Hopkins, 2011). .

It has also been suggested that tension of the *longissimus dorsi* will improve the consistency of tenderness along its length. The most practical method of tensioning the muscles of the carcass appears to be hip suspension (aitch bone hanging) and this has a dramatic effect on quality.

Practical Messages

Hip suspension optimises the tenderness of the hind leg and loin muscles.

Electrical stimulation (ES)

ES can be an effective means of improving tenderness of lamb. ES was developed primarily to allow rapid chilling without the risk of cold shortening. The electrical current applied stimulates the muscles to contract and hence use up ATP (and hence glycogen). This accelerates the onset of rigor mortis enabling chilling to take place earlier. It also appears that High Voltage ES (HVES) has additional benefits in tenderness, perhaps through accelerating the ageing process or direct physical damage to the muscle fibre structure (Dutson *et al*, 1975; Savell *et al*, 1977; Savell *et al*, 1978).

If low voltage stimulation is used it must be applied whilst the nervous system is still intact. In practice this means whilst the animal is being bled. Good contact (ie electrode positioning) and timing are critical for low voltage stimulation to be effective. This means that it is a less reliable approach than high voltage stimulation. There is also the risk of a toughening effect of LVES due to hot shortening. Where LVES is effective it seems to simply prevent cold shortening (eg Hildrum *et al*, 2000; Devine *et al*, 1999)

HVES does not depend on an intact nervous system. It is applied later on the slaughterline (after pelting) and therefore electrode contact is easier and the high voltage makes positioning less critical. Because it is applied later the carcass has cooled to an extent where hot shortening is less likely to be induced by stimulation.

The use of Medium Voltage ES (MVES) is common place in countries such as Australia. Pearce *et al* (2009) looked at alternating the applied frequency and the response to stimulation, especially in relation to optimising pH decline. Results showed that the treatment bringing about the highest response did not necessarily provide the most tender meat, perhaps due to the fact that there was less myofibrillar disruption. The development of new technology such as Smart Stunning offers the potential to improve carcass consistency. The system, which is currently in use in some Australian and New Zealand plants, is designed to give a series of test pulses and by measuring the carcass response to these, can adapt the amount of stimulation delivered to each carcass to ensure carcasses reaches the required pH level (Daly *et al*, 2008).

ES also has the benefit of being most effective on tougher carcasses thus reducing variation. On the other hand ES has been generally ineffective in callipyge lambs. Kerth *et al* (1999) found that ES at 550V improved the tenderness of the *longissimus* but not the *semitendinosus*, *semimembranosus*, *supraspinatus* or *triceps brachii* of callipyge lambs.

Whilst ES has been shown to improve tenderness and allow for faster chilling, it appears to have little influence on flavour, unless combined with other factors.

Practical Messages

ES can improve lamb tenderness, especially where hip suspension is not used. It can enable faster chilling against the risk of cold shortening but care should be taken to ensure hot shortening does not occur. Regularly monitor pH fall and temperature.

Ageing

The storing of lamb at low temperature for a period of time is widely used to increase tenderness. The rate of tenderisation decreases with time. That is to say that most of the benefit is achieved early on. Ageing tenderisation occurs as enzymes naturally present within the meat break down the myofibrillar structure. Dransfield (1990) calculated that 80% of the tenderisation of lamb *longissimus dorsi* has occurred at 7.7 days post slaughter at 1°C. MLC trials showed a benefit of ageing lamb loin for up to 10 days with most of the benefit occurring by 7 days.

Ageing has been found to be effective in eight muscles of the loin and hind leg but less so on three muscles of the shoulder (Bouton *et al*, 1973). It should also be noted that ageing and conditioning (at 10°C) can have a negative effect on the retail display life of meat (Moore and Young, 1991).

Ageing influences lamb flavour. In a large study looking at eating quality in lamb (SEERAD, 2004) it was concluded that ageing for a period of 10 days in comparison to 5 days improved the intensity of the lamb flavour. In addition ageing for 10 days and the use of ES saw a decline in abnormal flavour. Where ES was not used abnormal flavour increased.

Practical Messages

Ageing lamb, either in carcass form or in vacuum packs for a period of minimum of 7 days and optimum of 10 days improves lamb tenderness

Ultimate pH

Several studies across the World have examined the relationship between ultimate pH and tenderness. In some studies there is no relationship with tenderness. Where a relationship exists, the toughest meat has generally been that with an intermediate ultimate pH. For example a pH of 6.05 gave the highest panel toughness score when studied by Young *et al* (1993). New Zealand workers (Watanabe *et al*, 1996, Devine *et al*, 1993) found that an ultimate pH of 5.8-6.2 gave a higher shear force than higher or lower pH values when pH was manipulated with adrenaline injections or pre-slaughter handling. Within the normal range of pHu values expected (5.4 to 5.7) this is not a problem. It may, therefore, be worth excluding animals with an ultimate pH of 5.8 and higher.

Practical Messages

Monitor pH/temperature post slaughter and adjust stimulation/chilling rates to ensure pH 6 is reached at between 18 – 35°C.

Monitor ultimate pH. If this falls outside the normal range review the handling procedure.

Retail Packaging

Ageing (or maturation) of meat after slaughter is a widely used means of enhancing meat eating quality, particularly tenderness. It has generally been thought that ageing tenderisation occurs throughout the time under chill temperatures from slaughter to consumption. Tenderisation does not occur to any substantive degree during frozen storage or once the meat is cooked.

A significant proportion of high value meat cuts sold through the multiple retailers is packaged centrally in modified atmosphere packs (MAP, primarily 80% O₂/20% CO₂). MLC guidelines have included the period in MAP as part of the maturation period (Blueprint recommendations state a minimum of 7 days interval from slaughter to retail sale). In comparison to conventional overwrap, MAP can significantly extend shelf life, although the benefit is very much temperature dependant (Young *et al*, 2005).

MAP containing high levels of oxygen helps maintain the meat colour but this can also lead to the development of off flavours as the rate of lipid oxidation can be increased. Medel *et al* (2003) found that extended periods of storage in MAP reduced lamb flavour as well as overall acceptability. MLC research has also shown that high-oxygen packaging can result in toughening of the meat. Linares *et al* (2009) postulated that the inclusion of a small amount of carbon monoxide in MAP could help promote an improvement in colour stability and tenderness.

Vacuum packaging results in a darker, more purple, colour generally thought less desirable. It has been shown, however, that vacuum skin packaging in beef achieves better colour stability than standard vacuum packaging and equivalent colour to MAP

after 5 days (Li *et al*, 2010). This provides an opportunity to move away from MAP while providing an acceptable visual appearance. Recent work in Australia suggests that vacuum packaged primals can have a far longer potential shelf life than the 2 months often cited, however temperature control is vital (Sumner *et al*, 2011). The ideal storage temperature is thought to be around -1.5°C to -2°C.

Practical message

Avoid high oxygen packaging wherever possible.

Other treatments

High intensity ultrasound has been found to give no benefit in terms of eating quality.

A treatment called 'hydrodyne' has been used to tenderise meat cuts. In essence a meat cut is packaged and placed in a vessel containing liquid. An explosive charge is detonated within the vessel and the hydrostatic shock generated tenderises the meat. This process has been patented. Its usefulness is confined to situations where a batch process can be used. Large pressure vessels are generally costly so this may suit small throughput operations where a smaller vessel can be used.

Vascular perfusion chilling, (VPC), can provide a significantly more rapid alternative to surface chilling. VPC involves the circulation of a cold fluid around a carcasses intact vascular system. Research has shown some uptake of the perfusate into the meat. Treated carcasses showed colour differences but were significantly more tender, although this could well be due to the additional water in the meat (Brown *et al*, 2009).

Calcium chloride injection/marination of meat cuts post slaughter increases tenderness by accelerating the ageing process. This has even been effective in callipyge lambs. MLC sensory panelling identified a marked increase in off flavours with the use of calcium chloride but North American work shows that this may not be a problem with consumers, particularly if antioxidants (such as vitamin E or ascorbate) are included. Meat treated in this way would have to be treated according to meat product legislation but this treatment may offer advantages in ready meal type products.

3) BACKGROUND INFORMATION - The conversion of muscle to meat

From living muscle to rigor mortis

At the time of slaughter the muscles of the animal are predominantly metabolising aerobically (generating energy through biochemical pathways that consume oxygen). At the time of exsanguination (bleeding out) the blood supply to the muscles ceases. This means that the oxygen supply is cut off and the products of metabolism in the muscle cannot be removed via the bloodstream. These therefore accumulate in the muscle. The normal response of tissues to oxygen deprivation is to attempt to maintain cellular energy (ATP) levels. Tissues with a high oxygen requirement, such as the brain, will die very quickly, but some other tissues, particularly muscle, can have a high anaerobic capacity. This means that they are capable of producing ATP from glucose without the need for oxygen (glycolysis). One of the products of this anaerobic metabolism is lactic acid. This accumulates in the tissue and gradually reduces the pH of the muscle from about 7.2 in a normal resting live muscle to an ultimate pH (pH_u) of about 5.4 to 5.7 in normal meat. Muscle can generate energy from glucose until all the glucose is used up or until the accumulation of acid in the muscle destroys the metabolic processes.

This ability to generate energy even after slaughter means that muscle can continue to contract, for example in response to an external electrical stimulation (ES), for a considerable time after the animal's central nervous system is dead. Different muscles, or even different muscle fibre cells within a muscle, do not continue functioning for the same period after slaughter of the animal. It is an oversimplification to say that muscles consist of two fibre types, red and white, but it is a simplification that will suffice for the purposes of explanation. Some muscles or regions of muscles consist primarily of red fibres, whereas others are predominantly white. The species differences in this regard are strikingly obvious. Red fibres are more associated with sustained activity such as postural work or locomotion in animals active for long periods such as grazing animals. These fibres have higher levels of the oxygen binding pigment myoglobin. Most of their metabolic activity is oxidative and the rate at which they can derive energy in the absence of an oxygen supply is limited.

Conversely, white fibres are more associated with muscles that have short burst of high activity, and when most active cannot rely on oxygen based metabolism to provide sufficient energy. They therefore have a higher glycolytic capacity. This high glycolytic capacity means that white muscle fibres will exhaust their energy supplies after slaughter much more quickly than red muscle fibres.

The main bulk of the muscle fibres is made up of myofibrils which undertake the contractile function of muscle. The most abundant proteins in myofibrils are myosin and actin. When all of the available energy is exhausted in the post mortem muscle the myosin and actin molecules bind firmly together and the muscle loses its extensibility and flexibility. This point is termed rigor mortis.

The rate at which a muscle of a given fibre composition will go into rigor mortis can be influenced by a substantial number of factors. These include: the energy stores available within the muscle when the animal leaves the farm; the degree to which these

stores are depleted during transport and lairage; the stimulation of the metabolic processes via pre-slaughter stress; stimulation of muscular activity during the slaughtering process and the rate at which the muscle is cooled.

Shortening

Muscle will contract (shorten) naturally as it goes into rigor mortis if it is not restrained from doing so. Most muscles are under tension when the skeleton of the carcass is in its normal posture. If muscle is restrained it will develop tension as it goes into rigor but will not be able to shorten in its overall length. The extent to which muscles are able to shorten depends on the remaining energy (ATP) available at the time of shortening, the load on the muscle and the temperature of the muscle when these events occur. A shortened muscle will have shorter sarcomere lengths, ie shorter repeating units within the contractile myofibrils and a greater overlap between the contractile filaments.

Shorter sarcomere lengths are generally associated with tougher meat. In shortened muscle shear force values can increase by over 300%, but the response is not linear with the degree of shortening. Tenderness has been noted to be at its lowest with 25-40% shortening and severely shortened muscle (which had shortened 60%) was as tender as unshortened muscle (Marsh and Leet, 1966).

The temperature effect on the ability to shorten during rigor is particularly interesting, with the extent of beef muscle shortening varying with temperature at which rigor occurred according to the sequence $1 > 37 > 5 > 20$ °C (Busch *et al*, 1967). From and similar observations, the notion emerged that there were two types of shortening and that for minimum shortening muscle should be at about 15°C as it enters rigor mortis. This can never be achieved in practice for all muscle fibres because of the different rates of cooling in different locations of the carcass and the different rates of rigor development in different fibres. It is however a useful guideline.

The shortening that occurs with rigor above 20°C occurs as the energy supply is being exhausted and it is, therefore, generally quite weak. This form of rigor shortening is sometimes termed 'hot' shortening. It does have the potential to affect meat quality but its importance is still debated. 'Cold' shortening is quite different. It occurs if the muscle is exposed to low temperature (say <11°C Locker and Hagyard, 1963) prior to the development of rigor. Under these conditions the muscle spontaneously contracts and, since it does so at higher levels of ATP and pH than rigor shortening, the degree of contraction can be considerable.

It must be stressed that many of the studies of shortening have been done in muscle which has been removed from the carcass and therefore is more able to shorten than muscle which is restrained in the carcass by its attachment to the skeleton. However, the degree of restraint will depend on the carcass suspension system and even a restrained muscle can still cold shorten at least to some extent, reducing sarcomere lengths in one area and stretching or breaking sarcomeres in another (Marsh and Leet, 1966).

There seems little doubt from the literature and practical industrial experience that 'cold' shortening can occur and in some circumstances, especially in beef and lamb, can be a significant source of toughening. However, the picture is not so clear for 'hot' shortening. In one study (Locker and Daines, 1975) muscle removed from the carcass soon after slaughter and allowed to go into rigor at 37 °C had shortened 31.5% and yet had lower shear force than muscles held at 15-34 °C which had shortened less. The explanation of this is unclear but the possible higher activity of enzymes associated with post-mortem tenderisation of muscle is one possibility. It has been proposed by a number of researchers that beef tenderness is more closely related to the temperature of the muscle two hours post-mortem than later temperatures (Marsh *et al*, 1980-1; Roschen *et al*, 1950). Marsh *et al* (1987) proposed that intermediate rates of rigor development, which reduce the risk of rigor at too high a temperature but ensure rigor is achieved before 'cold' shortening temperatures are reached, are most desirable for tenderness. For beef they proposed this could be determined by a pH of ~ 6.1 at three hours post mortem.

Proteolysis

The action of enzymes that damage or destroy proteins (proteolytic enzymes) in post-mortem muscle is remarkably limited (Greaser, 1986), but what activity there is seems to be a highly significant source of variation in the tenderness of meat. Many of the major proteins of muscle are relatively undegraded, but significant proteolysis to others is associated with increasing fragmentation of myofibrils as post mortem storage time progresses. Although the fact that meat tenderises with post mortem storage time has been known for very many years, the debate as to which processes within the muscle are responsible has been a long one. There is now largely a consensus that the enzymes responsible for the tenderisation process are a family of calcium activated enzymes, called the calpains, and their inhibitor calpastatin, (Koochmarai, 1994; Taylor *et al*, 1995b). There remain significant unanswered questions as to how the calpains are regulated, the way that they interact with the development of rigor mortis and, importantly, whether other processes (perhaps non-enzymic) are also involved in the tenderisation of meat during ageing.

Generally proteolytic degradation and hence tenderisation is considered to occur more quickly in white fibres, and muscles made up predominantly of these, than in red fibres/muscle (see for example Dutson *et al*, 1974). This is reflected in differences in the rate of tenderisation (and hence optimum ageing time) between muscles within a carcass and between the species. The significance of the calcium dependency of these calpain enzymes should not be overlooked. The enzymes are more active at nearer neutral pH and at higher temperatures, therefore their greatest level of activity may be around the time of rigor when sufficiently high levels of calcium may become available. Recently, measurements of the activity of calpain enzymes in the early post-mortem period have been associated with the tenderness of pork after 8 days of ageing (Sensky *et al*, 1998). It seems possible that interactions between the processes of rigor mortis and proteolysis may be important to tenderness variation days later. This remains as active area of research but the practical consequences, based on current knowledge, are different recommended ageing periods for different meat cuts.

Abnormal conditions 1. - DFD

If the energy reserves of the muscle are depleted prior to slaughter the degree of glycolysis which can occur is diminished and the ultimate pH (pH_u) will not be as low as in normal muscle with higher energy reserves. If the pH_u is greater than 6.0 the muscle will have a dark and dry appearance with a firm texture. This condition is termed Dark Firm Dry meat (DFD) or sometimes 'dark-cutting' meat. It is most commonly seen in beef, but can also be seen in pigmeat and, rarely, lamb. A higher level of oxygen consumption by the tissue and hence a reduced depth of oxygen penetration into the meat results in less visible red oxymyoglobin pigment (bright red) and hence the dark appearance. The dryness is thought to be a consequence of the higher pH leading to a higher water holding capacity of the myofibrillar proteins. DFD meat is normally found to be more tender, perhaps due to enhanced proteolysis, but the higher pH also leads to a better environment for the growth of spoilage bacteria and consequently a poorer shelf-life (Gill and Newton, 1981).

Abnormal conditions 2. - PSE

PSE stands for Pale Soft and Exudative. This condition is of considerable economic significance in pigmeat, being first described as muscle degeneration in 1954 (Ludvigsen, 1954). A similar condition can be seen in some beef muscles held at high temperatures for prolonged periods (Locker and Daines, 1975). The basic causal mechanism is the combination of low pH and relatively high muscle temperatures that can occur if post-mortem glycolysis progresses at an accelerated rate. The two main pre-slaughter causes of the rapid pH decline are either a genetic defect in muscle calcium metabolism (the halothane gene) or a stimulation of glycolysis via pre-slaughter stress or inappropriate application of electrical stimulation. In PSE muscles the rate of pH decline is at least twice as fast as in normal muscles and rigor may occur as early as 15 minutes after slaughter.

This combination of low pH and high temperature is thought to result in denaturation of proteins and a consequent change in the lateral spacing of the contractile filaments of the muscle cell. This in turn changes the distribution of fluid within the muscle, with an increased proportion of the fluid becoming distributed in the extracellular space, from where it can more easily escape from the meat (Offer and Knight, 1988). This is of obvious economic importance with PSE carcasses having much higher fluid losses. Individual chop drip losses can be 5.8% compared with 3.0 % (Sather *et al*, 1998).

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