EFFECTS OF VARIOUS PROCESSING METHODS ON THE MEAT QUALITY OF BEEF AND PORK

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Summary

An account is given of the effect of various processing methods, such as (delayed) chilling, high temperature conditioning, electrical stimulation, carcass suspension and infusion, and their effects on the meat quality (in particular tenderness) of beef and pork. The effects of different treatments on the various meat quality aspects (such as texture, colour and WHC) may vary, and are sometimes even paradoxal as to the desired change. Since the effects are also sometimes additive, an integral approach in research is necessary. Even in the absence of commercial application of certain processing methods, study of their effects on post-mortem biological processes, offer a useful investigational tool to the meat scientist. A better knowledge of the post-mortem tenderisation process is essential for further development of methods for use under practical conditions in the meat industry.

Introduction

In practice, there is a large variation in the eating quality of meat, particularly in beef tenderness. Both production factors (such as breed, age, sex, fatness and feeding system) and post-mortem treatments affect the eating quality. Recently, Fisher *et al.* (1992) concluded from their experiments that combination of carcass processing treatments may have larger effects on meat tenderness than production factors including sex, fatness and feeding system.

To an increasing degree multiple retailers are developing process specifications for their suppliers, in order to improve meat quality and to reduce its variability. It is the task of the meat scientist to provide adequate knowledge.

This paper deals largely with some (potential) techniques in the slaughter and processing period through which meat quality, in particular meat tenderness, can be manipulated.

Ultimate pH

A major factor determining tenderness is the ultimate pH of the meat, which is influenced by the degree of pre-slaughter depletion of glycogen. Beef meat with high ultimate pH was found to be more tender than meat with normal pH (Dransfield, 1981; Yu and Lee, 1986).

In a recent experiment (Eikelenboom *et al.*, 1992), we selected pork loins on the basis of their ultimate pH (5.5 till 6.3). Good relationships ($r = 0.68$ to 0.70) were found between pH on one hand and peak force and panel judgement on the other. Particularly at pH above 5.7, there was an increase in the panel scores for tenderness and juiciness (Eikelenboom *et al.*, 1992).

There is disagreement in the literature about the linearity of the relationship between ultimate pH and tenderness. There are several reports of tenderness increasing linearly with increasing pH (see Dransfield, 1981). A curvilinear relationship was found by Purchas (1990) in bulls and steers, with a minimum of tenderness at ultimate pH-values of approximately 6.1. Jeremiah *et al.* (1991) came to similar conclusions. Exclusion of beef carcasses with ultimate pH-values

between 5.8 and 6.2 was effective in removing the majority of tough carcasses from all sex groups, regardless of breed.

It should be mentioned that only in muscle able to shorten pre-rigor on the carcass, was there evidence for a curvilinear relationship between pH and shear force values (Bouton *et al.,* 1972). Also cooking temperature may influence the nature of the relationship between ultimate pH and tenderness, with no pH-effect in raw meat (Dransfield, 1981), a curvilinear relationship at medium cooking temperatures and a linear increase at higher temperatures (Bouton *et al.,* 1971; Purchas, 1990).

A way by which an increase in ultimate pH may lead to improvements in tenderness is through the action of proteolytic enzymes. In the study on the effect of ultimate pH on the eating quality of pork (Eikelenboom *et al.,* 1992) referred to above, samples were also analysed electrophoretically at 1, 2 and 7 days post mortem for degradation of Troponin-T (TNT) and the appearance of the 30 kDa component, as indicators of post-mortem proteolysis (Barnier *et al.,* 1992). In general TNT was better related to peak force than 30 kDa. However, both TNT and 30 kDa were poorly related to panel judgement (Barnier *et al.,* 1992).

Geesink (1993) observed that the increased tenderness of DFD beef could partly be explained by a more extensive breakdown of high molecular weight proteins. He presented evidence that this is likely the effect of the action of μ-calpain. In 'normal' pH-muscles the decrease in μ-calpain activity is muscle-dependent (Ouali and Talmant, 1990). In high pH-muscles, however, the decline in μ-calpain is accelerated (indicating faster activation and subsequent autolysis) and not-muscle dependent (Geesink, 1993).

It has been suggested that intramuscular fat is an important determinant of the eating quality of pork (Bejerholm and Barton-Gade, 1986). In a recent study (Eikelenboom, data to be published), pork loins were selected for variation in intramuscular fat content (values ranging from 0.7 to 4.5 % intramuscular fat), with ultimate pH below 5.7. It appeared that the correlation of intramuscular fat with peak force and panel judgement was lower ($r = -.11$ and 0.34, respectively), than found in the study in which loins were selected for variation in ultimate pH. These results suggest that ultimate pH may be of more importance than intramuscular fat in determining eating quality of pork. In loins selected for variation in intramuscular fat content, Göransson *et al.* (1992) found that ultimate pH was more important for eating quality than intramuscular fat. Good eating quality was maintained even at low intramuscular fat values.

Chilling

Chilling of beef

The purposes of rapid chilling are, among others, to reduce weight losses and in plant residence time before further processing and transport. In excised bovine muscles that are cooled rapidly while still in a pre-rigor condition cold shortening takes place. This is associated with appreciable toughening (Locker and Hagyard, 1963), a phenomenon which has since been confirmed by many others.

Bendall (1972) calculated that a temperature fall below 11°C before the pH has fallen below 6.2 causes 'cold shortening'. Various studies (see: Jeremiah, 1978) have indeed shown that delayed chilling or high temperature conditioning (HTC) of carcasses resulted in an improved tenderness and prevention of cold shortening has been mentioned as the primary reason for the observed increase in tenderness. However, sometimes the increase in tenderness was not associated with differences in sarcomere length and other mechanisms may have been involved.

It should be mentioned that in some studies no effect, only a marginal effect or even adverse effects of delayed chilling or HTC has been observed. Crouse and Seideman (1984) found no difference in tenderness between carcasses kept for 3 hours at 1, 12 or 26°C. Marginal tenderness improvements were also found by Whipple *et al.* (1990), where carcasses (of *Bos indicus* crosses) were subjected to HTC (6hours at 22°C). At 1 day p.m. differences in tenderness were significant, but at 14 days post-mortem these differences were negligible (Whipple *et al.*, 1990). Lee and Ashmore (1985) found HTC (35°C for three hours) sides from feedlot cattle with a high degree of finish to be tougher than the control sides. This was accompanied by lower sarcomere lengths in the HTC sides. These results suggest that holding carcasses initially under relatively high temperatures might eventually produce rigor (heat) shortening and hence toughening.

Lochner *et al.* (1980) suggested that tenderness was closely related to the chilling rate in the very early post-mortem (VEP) period. According to Dransfield (1992), however, the temperature later during rigor development, when the pH is lower than 6.1, is of more importance.

It should be mentioned that during cooling a negative relationship exists between pH and temperature. A higher muscle temperature stimulates a more rapid glycolysis and, thus, shortens the VEP-period with a relatively high ultimate pH (Buts *et al.*, 1986). Smulders and van Laack (1993) suggested, therefore, that the pH of 6.1 may have been achieved in the study of Lochner *et al.* (1980) during the first two to four hours after slaughter.

In general, when cold shortening conditions are absent, the effect of delayed chilling or HTC may vary and may be the result of an earlier start and/or accelerated proteolysis (at higher temperatures). However, the tenderising effect of delayed chilling or HTC tends to disappear with increased ageing periods.

Chilling of pork

In addition to the reasons for rapid chilling mentioned before, prompt and rapid chilling of pig carcasses is recommended to reduce drip loss and to improve colour. This effect appears to be less in fast glycolysing muscles (Taylor and Dant, 1971).

It is generally accepted that because of its more rapid glycolysis pork is less susceptible to cold shortening, when exposed to low chilling temperatures. However, from observations on pre-rigor muscles, cold shortening has been found

to occur in pig muscles kept at lower temperatures (Bendall, 1975). Möller and Vestergaard (1987) studied the potential of cold induced toughening in pork loins showing different rates of pH-fall prior to chilling (pH_1>6.1 vs. pH_1<6.1). The effect of introducing a delay time before sides were transferred to the chilling tunnel (operating at -28°C to -22°C) was studied on muscles removed from the carcass at various times post-mortem. The effect of delay time on tenderness from muscle excised from the carcass at 30 hours post-mortem was much less than with early excision, but a four hour delay did significantly improve tenderness in carcasses with high initial pH. The relationship between sarcomere length and Warner-Bratzler shear force was only significant in the high pH-group (Möller and Vestergaard, 1987). These results indicate that with extremely rapid chilling conditions cold shortening can take place in pork muscle with a slow glycolysis.

Jeremiah *et al.* (1992) examined the effects of blast chilling on the palatability of pork. Carcasses blast chilled for 1 hour were more tender and were rated higher in overall palatability than carcasses blast chilled for two or three hours. According to the authors the magnitude of palatability differences limit their practical significance. The palatability of sides subjected to extremes of blast chilling (three hours, -40°C) did not differ meaningfully from that of conventionally chilled sides.

At present, blast chilling systems have been installed in many pork plants. Sometimes, partial or 'crust' freezing of the meat surface occurs, which results in an increase in drip. Another disadvantage of very rapid chilling is that a dark discoloration may occur after two to three, or more, days on the exposed internal bone surfaces. The cause of this problem is probably a disruption of the red blood cells through the formation of ice crystals, with a subsequent oxidation of the haemoglobin. Because of this problem some industries in The Netherlands have abandoned this system and moved to a system with lower (-10 to -15°C) initial temperatures in the chillers.

Electrical stimulation

Electrical stimulation of beef

There are numerous publications on the effect of electrical stimulation on muscle quality characteristics, in particular tenderness, in beef. Table 1, taken from one of our own studies (Eikelenboom *et al.*, 1985) on the effect of electrical stimulation of beef, may serve to illustrate these effects. Similar conclusions can be drawn as to the effect of electrical stimulation in (rapidly chilled) veal (Eikelenboom and Smulders, 1986). These effects can be summarized as follows (see: Tables 1 and 2):

1. An acceleration of post-mortem glycolysis, resulting in a faster pH decline to normal ultimate pH values.

2. Early post-mortem muscle temperature may be higher in stimulated muscle.

3. The percentage drip and cooking loss of stimulated muscle might be increased. The increased drip loss may be caused by some protein denaturation, since decreased protein solubility was observed in stimulated veal muscle (Eikelenboom *et al.*, 1986). The increased cooking loss is more difficult to explain. It might be argued that the negative effect on water holding capacity was due to a too rapid

glycolysis induced by the electrical stimulation., since pH at one hour post-mortem was already 6.0. (Table 1.) However, Geesink (1993) observed similar effects in stimulated beef carcasses selected for an average pH of 5.9 at three hours post-mortem.

4. A brighter muscle colour. The increase in L- (and a-) value is probably due to a change in the microstructure, which causes more light to be scattered (and reflected) in stimulated muscle. The increase in a-value might also be caused by inhibition of mitochondrial respiration, which causes a higher pO_2 at the muscle surface and consequently a better oxygenation ('blooming') of myoglobin . This effect is particularly noticeable when the *m.longissimus* is cut the day after slaughter. Particularly because of this effect (which also facilitates the setting of the marbling) and because of the prevention of 'heat ring' (a dark discolouration caused by rapid chilling), the industry is interested in electrical stimulation. However, colour stability may be negatively affected by electrical stimulation (Ledward *et al.*, 1986; Unruh *et al.*, 1986).

5. Muscle from stimulated and rapidly chilled carcasses contract less during rigor mortis, which results in lower shear force values. It should be mentioned here that, although the pH- and temperature-profiles (Table 1) suggest an absence of cold shortening conditions (Bendall, 1972), shorter sarcomeres were found in stimulated beef.

Table 1. The effect of low and high voltage electrical stimulation on post-mortem pH and temperature of *longissimus* muscle (Eikelenboom *et al.*, 1985).

Time post-mortem (hours)	*pH*			*Temperature*		
	Low voltage	*High voltage*	*Control*	*Low voltage*	*High voltage*	*Control*
1	5.96^{a}*	6.02^{a}	7.08^{b}	37.2^{a}	38.1^{b}	37.1^{a}
2	5.81^{a}	5.71^{a}	6.68^{b}	32.1	32.6	31.7
4	5.69^{a}	5.65^{a}	6.19^{b}	23.8	23.5	24.2
6	5.69^{a}	5.61^{a}	5.99^{b}	18.1	19.0	18.4
8	5.66^{ab}	5.59^{a}	5.80^{b}	14.9	15.1	14.8
24	5.66	5.61	5.68	3.4	3.0	3.1

* Figures with superscripts not containing a common letter differ significantly ($P<0.05$).

Aalhus *et al.* (1992) recently studied the effect of electrical stimulation on beef quality using conventional chilling (1°C). The consumer survey they conducted, indicated that more than 20% of steaks were rated unacceptable for tenderness when using Canadian beef production practices. Incorporation of high voltage electrical stimulation as a means of quality control would reduce the proportion of unacceptable steaks to approximately 10%.

The prevention of toughening due to rapid chilling is probably the most important contribution of electrical stimulation to the improvement of tenderness. It should be mentioned, however, that there are also reports that electrical stimulation in combination with slow chilling may have adverse effects on tenderness (Valin, 1982; Koh *et al.*, 1987; Unruh *et al.*, 1986).

Table 2. The effect of high and low voltage electrical stimulation on meat quality characteristics of *longissimus* muscle (Eikelenboom *et al.*, 1985).

Trait	*Low voltage*	*High voltage*	*Control*
Sarcomere length (m)	1.63^{a}*	1.61^{a}	1.43^{b}
Drip loss (%)	2.76^{a}	2.76^{a}	1.77^{b}
Colour, Hunter L* value	32.0^{a}	33.2^{a}	29.7^{b}
Colour, Hunter a* value	14.6^{a}	14.9^{a}	13.4^{b}
Colour, Hunter b* value	7.3^{a}	7.7^{a}	6.4^{b}
Heating loss (%)	26.1^{a}	25.8^{a}	21.4^{b}
Warner-Bratzler shear force (kg/cm2)	4.59^{a}	3.87^{a}	5.77^{b}

* Figures with different superscripts differ significantly ($P<0.05$).

Marsh *et al.* (1987) applied different forms of electrical stimulation and demonstrated that tenderness is optimal when glycolysis proceeds at an intermediate rate (pH about 6.1 at three hours post-mortem). The tenderness decreased when the pH at that time was lower or higher than 6.1. Smulders *et al.* (1990), while confirming these findings, observed in beef stimulated in various ways to obtain a range in the rate of post-mortem glycolysis, that the high correlation between tenderness and sarcomere length only exists in the slow glycolysing muscles. In fast glycolysing muscles this relationship was negligible. These results suggest that tenderness depends on shortening only in slow glycolysing muscles.

Apart from the prevention of cold contracture, electrical stimulation may cause an extra tenderising effect and several mechanism have been suggested in literature, including reduced collagen cross-linking, ultra structural damage and increased enzyme activity. The influence of electrical stimulation on changes in enzyme activity, is further discussed in the section on ageing.

The prevention of cold shortening or cold toughening by electrical stimulation must be weighed against the possibility of inducing heat (rigor) shortening (Pommier *et al.*, 1987). Rigor (heat) shortening may occur, with pH at 45 minutes <6.0 at temperatures 25°C (Honikel *et al.*, 1986). The same authors also suggest that excessive drip loss may occur with pH at three hours post-mortem <6.0 at temperatures 30°C.

Geesink (1993) conducted a risk analysis on data collected at three different beef plants, with different electrical stimulation and chilling systems. Based on the pH and temperature at 45 minutes, three hours and 20 hours post-mortem, the 'risk' (percent of carcasses) for the occurrence of the conditions described above was recorded. The results show that in commercial practice a large variation in post-mortem muscle pH- and temperature can be observed in electrically stimulated beef carcasses, not only between but also within plants. The percentage for 'cold shortening' varied between plants from 0 - 6, for 'heat shortening' from 1 - 22 and for 'excessive drip' (protein denaturation) from 14 - 43%.

Electrical stimulation of pork

There is no agreement on the usefulness of electrical stimulation of pork carcasses, which posess a relatively fast glycolysing muscle. Because electrical stimulation induces a more rapid pH-fall, there is very much a fear of decreasing the waterholding capacity and increasing the incidence of PSE as a result of this treatment.

Although in the experiments of Gigiel and James (1984) cold toughening of pork was prevented by high voltage electrical stimulation after bleeding, a substantial increase in paleness and a fourfold increase in drip in retail packs was indeed found. These disadvantages were not so much found by Taylor and Tantikov (1992), probably because they used a less severe stimulation treatment. The latter authors found a considerable tenderising effect from high voltage electrical stimulation. Drip loss tended to be slightly higher with electrical stimulation, a disadvanage which was largely overcome with rapid chilling of ES carcasses (without the danger of cold shortening). The results of Taylor and Tantikov (1992) and Taylor and Martoccia (1992) indicate that high voltage stimulation, applied either after sticking or at 20 minutes post-mortem, generally improves tenderness more than low voltage. Stimulation (HV or LV) at 20 minutes post-mortem combined with rapid chill did not induce an increase in drip loss (Taylor and Martoccia, 1992). However, when high voltage electrical stimulation (at 20 minutes post-mortem) was combined with conventional chill, drip losses were slightly higher, although no PSE was observed (Taylor *et al.*, 1992).

These interesting results need further confirmation by other researchers. The key question is if it is indeed possible to considerably improve pork tenderness by electrical stimulation, without a negative effect on waterholding capacity (and colour). If so, can this also be realised under practical conditions in a meat industry.

Hot boning

Hot boning has received much attention in research in the past decades (Cuthbertson, 1982). Unlike electrical stimulation the system has not been really adopted by the industry. The impact of the process on logistics, the investments necessary to retrofit existing facilities to a hot processing situation and possible problems in marketing of hot boned meat discourage the adoption of hot boning in most countries (van Laack, 1989). At present hot boning of muscle is predominantly used for research in order to study the behaviour of pre-rigor muscle as it reacts upon various treatments.

Pelvic suspension

Various reports in the seventies have indicated that suspension of carcasses from the aitch bone (pelvic suspension) improved the tenderness of the major muscles in beef and lamb (Bouton and Harris, 1972; Bouton *et al.* 1973; Hostetler *et al.*, 1972). Jeremiah *et al.* (1984) concluded that, in beef, the additional requirement for labour and cooler space for commercial adoption of pelvic suspension, would more than offset the relatively small improvement in tenderness which they obtained with this method.

Altered carcass suspension has also been suggested as an effective means to improve pork tenderness (Möller and Vestergaard, 1986). Smulders *et al.* (1992) found that hip-suspension (combined with limb-weighting) resulted in improved tenderness and reduced drip. In addition, the treatment resulted in 3 percent higher processing yield, when various ham muscles were processed as cooked hams.

It should be mentioned that, in spite of the various practical drawbacks, certain multiple retailers in the U.K. presently require from their suppliers that their pork supply is processed using pelvic suspension (Fisher, personal communication).

Pressurisation

Pressurisation (up to 150 MPa) of pre-rigor muscle results in tenderness improvements and various mechanisms have been suggested to explain this phenomenon (Kennick *et al.*, 1980; MacFarlane, 1985). The process can be modified such that post-mortem glycolysis can be controlled to a large extent. A procedure has also been developed for the pressure tenderisation of post-rigor muscles. It provides the only means by which toughness due to muscle contraction can be eliminated. A disadvantage of pressurisation of post rigor muscle is the necessity to heat the meat to about 60°C during pressure treatment. Apart from other drawbacks, the resulting cooked appearance limits the practical application of this method (MacFarlane, 1985).

Ageing

Although the proportion of beef which is vacuum packed and stored (as primal cuts) is still increasing, much beef is still consumed before it reaches its maximum tenderness through ageing. Thus, speeding up the ageing process through application of specific processing methods, would be of considerable benefit for the tenderness as perceived by the consumer.

Judged from the literature (Dransfield, 1992; Koohmaraie, 1992; Ouali, 1990), calpains (in particular μ-calpain) is the proteolytic system which is at present held responsible for most of the tenderisation that occurs during ageing. According to Dransfield (1992), tenderisation as a result of μ-calpain (= calpain I) activity starts when muscle reaches a pH of 6.1. Hereafter, the extent of tenderisation would be largely dependent on the amount of μ-calpain activity. The rate of tenderisation and loss of calpain activity through autolysis, would be largely temperature-dependent.

In general, the largest decrease in μ-calpain activity takes places within the first 24 hours post-mortem. As this indicates activation and subsequent loss of activity through autolysis, degradation of proteins might be expected. Yet, proteolysis at one day post-mortem is limited. Geesink (1993) suggest that proteolysis is only the first step in tenderisation. A second step might be further physical disruption of the partly degradated myofibrillar structure as a result of the ionic strength attained in post-mortem muscle (Ouali, 1992).

The involvement of cathepsins (released from the lysosomes) in meat tenderisation, is questionable. All cathepsins degrade myosin heavy chain. However, immunologically detectable degradation of myosin heavy chain occurs rapidly during ageing at 37°C, but not at refrigeration temperatures (Bandman and

Zdanis, 1988). This means that a contribution of cathepsins to tenderisation is only likely to occur in the early post-mortem period when muscle temperature is still relatively high.

Pommier *et al.* (1987) and Geesink (1993) observed that electrical stimulation resulted in a faster release of cathepsin activity and suggested that part of the tenderising effect of electrical stimulation may be due to this increased enzyme activity.

It has also be found that electrical stimulation considerably increases the rate of decline of μ-calpain, in combination with early appearance of the so-called 30 kDa component (Ducastaing *et al.,* 1985; Uytterhaegen *et al.,* 1992; Geesink, 1993). This suggests that electrical stimulation induced an early activation and subsequent inactivation through autolysis, of calpain I. However, this does not result in a simultaneous large increase in tenderness and the subsequent ageing process is very similar to that occurring in normal (unstimulated) muscle.

With respect to the ageing process, there are still many questions such as the involvement of the various proteins (myofibrillar and cytoskeletal), the relative importance of the various enzyme systems (calpains, cathepsins and possibly the multicatalytic protease), as well as non-enzymatic events that occur in post-mortem muscle (such as the increase in ionic strength). The significance of these factors to post-mortem tenderisation need to be further elucidated in future research. A better understanding of the post-mortem tenderisation process is necessary, to adequately modify post slaughter handling to improve meat quality (in particular tenderness).

Infusion of $CaCl_2$

There is evidence that calcium does play an important role in post mortem proteolysis, probably by activating the calpains (Koohmaraie, 1992). Because of this role, infusion of carcasses with calcium chloride solution (0,3 M) has recently been used as a means of successfully speeding up the tenderisation process. It appeared that in lamb carcasses ultimate tenderness values were obtained within 24 hours of post mortem storage as opposed to 7 to 14 days in non-infused ovine carcasses (Koohmaraie *et al.,* 1988). The method appeared to be also very effective in rapidly tenderising *Bos indicus* (Koohmaraie et al., 1990) and mature cow (Morgan *et al.,* 1991) carcasses. Also injection of beef round muscle has been shown to be effective in improving meat tenderness (Wheeler *et al.,* 1991). Similar results have been obtained with injection of post rigor beef *longissimus* muscle (Koohmaraie, 1992).

It has been suggested that the primary mode of action is through the activation of calpains by calcium. Although it appears that the $CaCl_2$-treatment is very effective in rapidly producing uniformly tender meat, relatively little is known of the effect of this treatment on other quality characteristics, such as water holding capacity and colour.

Geesink *et al.* (1993) recently studied the effect of injection of pre- and post-rigor beef *longissimus* muscle with solutions of $CaCl_2$ (0,3 M) or NaCl (0,6 M). Both treatments resulted in an accelerated tenderisation in pre- and post-rigor beef *longissimus* muscle. The effect on tenderness was most pronounced for NaCl injected in pre-rigor beef *longissimus*. Determination of the activity of both

calpains (u-calpain and m-calpain) as well as myofibrillar degradation products, suggest that $CaCl_2$ -treatment led to activation of calpains and subsequently in a gradual loss of activity as a result of autolysis. The effect of the NaCl-treatment could not be due to activation of calpains. Geesink (1993) suggests that the accelerated tenderisation may be due to an increase in ionic strength, which may weaken the myofibrillar structure and make it more susceptible to proteolysis (Ouali, 1992).

Pre-rigor injection with CaCl2 resulted in an increased weight loss during storage, probably as a result of the extreme contraction induced by the treatment. Colour stability, especially of CaCl2 treated muscles, was negatively affected by the treatment (Geesink, 1993). These results suggest that it is also important to investigate in future infusion and injection experiments the effects on quality characteristics other than tenderness. If the results of Geesink (1993) on WHC and colour stability are indeed confirmed this would seriously limit the potential application in practice.

Marination

The application of calcium injection or infusion methods early post-mortem to improve tenderness would require several modifications in current slaughter techniques. Therefore, it is assumed that the calcium application method will be more successful in practice, if it is used in a marinade. Alarcon-Rojo and Dransfield (1989), reported that soaking beef strips (taken at 24 hours post-mortem) in a calcium chloride solution increased tenderness by 40%. Whipple and Koohmaraie (1993) recently produced evidence that calcium marination of steaks, at a time when they are normally consumed, may be beneficial in improving tenderness. They suggest that, if adapted, tenderness could be improved with the use of substances already present in the meat and, in turn, introduce a type of calcium fortification (Whipple and Koohmaraie, 1993).

Conclusions

Multiple retailers are to an increasing degree developing process-specifications for their suppliers, in order to improve the meat quality and to reduce the variability of the supplied material. It is the task of the meat scientist to provide adequate information.

There appears a variety of slaughter and processing methods to manipulate post-mortem metabolism and ultimate meat quality. Frequently, the effects of the different treatments on the various meat quality aspects, such as texture (tenderness), water holding capacity and colour vary and are sometimes even paradoxal (desirable vs undesirable). Moreover, certain methods show additive effects (Fisher *et al.*, 1992). Therefore, a more integral approach in research is necessary, which takes this situation into account.

Even in the absence of commercial application of certain methods, study of their effects on post-mortem biological processes offer a useful investigational tool to the meat scientist. Particularly, a better understanding of the post-mortem tenderisation process is necessary for further development of methods for use under practical conditions.

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