OPTIMISATION OF TENDERISATION, AGEING AND TENDERNESS

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INTRODUCTION

riability in the quality of meat has long been the concern of the consumer and recent surveys have shown that consumers have difficulty in lecting beef because they are unsure of its quality, particularly its tenderness. Tenderness is now of primary concern to the beef ustry (Morgan *et al.*, 1991) as it changes from a production-led to a consumer-driven industry.

e practice of storing meat after death to improve its texture has been used for many generations and has been studied systematically since e beginning of this century. Ageing, for up to 3 weeks in chill, produces noticeable improvements in tenderness but doubt has been pressed commercially about the operation of such long storage times, the costs involved and the attendant risk of meat spoilage.

ficiencies in commercial ageing were demonstrated in surveys in the late 70's in Great Britain (Palmer, 1978) which showed that a riod of storage for wholesale meat was specified by more than half of the butchers. However, the duration of storage, specified by them, d much to do with the distribution and turnover of meat and could be shortened by commercial pressures. At retail, beef was kept rigerated for 1 to 4 days and most beef could be sold as early as 3 days after slaughter.

eat ageing is a very variable process, depending on a number of biological factors such as age and sex of the animal, muscle type, anabolic d repartitioning agents and on electrical stimulation, temperature and the duration of storage (Ouali, 1990).

r optimisation of ageing, knowledge of the start, the mechanism and the end of tenderisation is needed. Research over the past 20 years s established the basis for a general mechanism for meat tenderisation which shows that the factors are established during animal oduction and the process of ageing continues through to cooking. Sufficient is now known suggest ways of optimising the process.

MECHANISM

s generally accepted that tenderisation results from proteolysis by endogenous enzymes but the major problem in identifying the specific zymes has been that the enzyme activities cannot be measured in meat since they depend on local *in situ* concentrations of cofactors and hibitors. A recent approach has overcome this by modelling the relationship between the levels of enzyme and tenderness (Dransfield *et* ., 1992a,b) and their fundamental properties determined *in vitro* (Dransfield, 1992a,b). The model develops the involvement of lpains, which has been suspected for over 20 years by research findings throughout the world, by showing their activation as rigor velops by the gradual release of calcium ions from the sarcoplasmic reticulum and the mitochondria. Calpain I is activated first, at low lcium ion concentrations, and then calpain II is activated as the concentration of calcium ions rises further. There are enough free lcium ions to activate all of the calpain I but only about 30% of calpain II, which remains largely inactive in meat. Tenderisation erefore begins when calpain I starts to be activated, normally at about pH 6.3 or about 6 hours after slaughter in beef, and increases pidly as more calpain is activated. At about 16 hours in beef, calpain II becomes activated and causes a further tenderisation. When tivated, both of these enzymes are unstable and become progressively less active with storage. The combined rate of their inactivations termines the rate of tenderisation which continues until the calpains are exhausted or they are destroyed by cooking.

e projected activities and decays of calpains (Figure 1) show that, in beef *Longissimus dorsi*, most of the tenderisation is caused by lpain I. About 50% of the tenderisation occurs before 24 hours after which tenderisation continues approximately exponentially with ne.

This calpain-activity model reveals a valuable separation of texture into 3 components:

Tenderisation:

This is an increase in tenderness (decrease in toughness) at any stage of processing and is brought about by calpain tivity. The tenderisation normally begins at about pH 6.3 and continues until the enzymes are exhausted. Unfortunately, tenderisation annot be measured in the pre-rigor period because of interference from the changes in stiffness taking place due to rigor development and om the changes in pH. The extent of tenderisation is proportional to the level of calpains.

Ageing:

This is the practice of storing meat beyond the normal time taken for setting and cooling to enhance tenderness (Moran Smith, 1929). Since the time taken for setting and cooling is up to 24 hours, ageing is the latter part (50%, Figure 1) of tenderisation nd can be readily measured. The extent of ageing is related to the level of calpains at 24 hours which varies according to the initial levels nd their inactivation during rigor development. Ageing therefore is effective in enhancing tenderness but its determination appears to be f little value in understanding the fundamental mechanism of tenderisation.

Tenderness:

The level of tenderness can be assessed by sensory or instrumental methods on cooked meat. It is generally accepted at the toughness is sum of the contributions from the structural components not weakened by ageing, although interactions between the omponents have been demonstrated. At the completion of tenderisation these components include connective tissue, sarcomere length, fat nd water together with the remainder of the components not affected due to lack of calpain activity. Because the initial toughness cannot be easured, the contribution of these other structural components cannot be determined directly but only when the contribution from

FIGURE 1. Tenderisation of beef Longissimus by calpains

Relationship between the activities of calpains I and II and post-mortem tenderisation. Curves were calculated using a calpain-activity model (Dransfield, 1992b) from measured levels of calpains, rigor development, temperature and shear force determined experimentally (Whipple *et al.*, 1990; Koohmaraie *et al.*, 1991) and show the sharp rise in activity of calpain I and the much smaller contribution of calpain II to tenderisation and ageing of beef *Longissimus dorsi.*

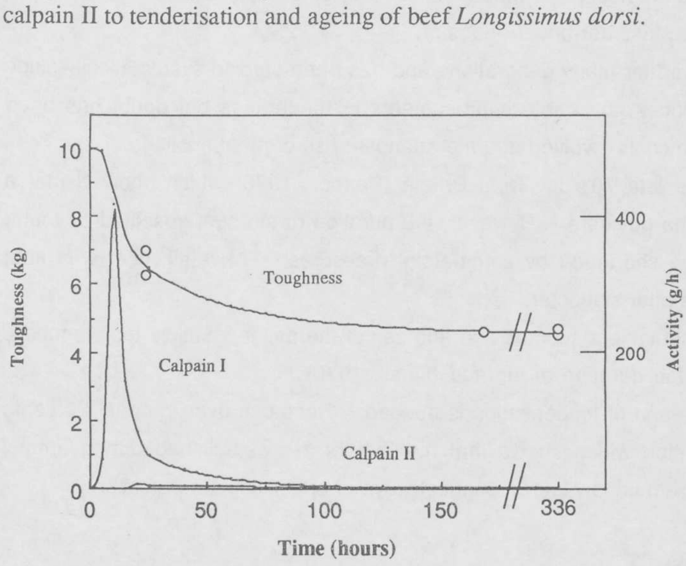
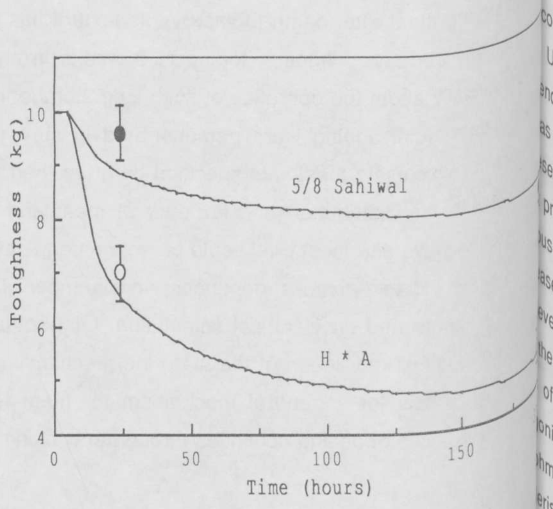


FIGURE 2. Tenderisation in Longissimus from Bos

The curves for tenderisation were calculated using a calpain-model (Dransfield, 1992b). The lower curve was used as co the upper curve derived using the same parameters except activation energy for the activity of calpains was increased The toughening predicted by the change in temperature coef compared with the shear force (±SD) determined experimental hiwal and Hereford Angus crosses (Whipple *et al.*, 1990).



calpains is also known. Unfortunately, in the vast majority of experiments which aim to relate meat composition to tenderness, calpains has not been measured.

Ideally, optimisation of tenderness would maximise tenderisation and minimise ageing. This would produce tender meat with the requirement for chill storage prior to further processing or sale. The ideal can be approached under controlled laboratory where tender beef was achieved with as little as 14% improvement during ageing (Dransfield *et al.*, 1992a).

The amount and activity of calpains vary according to animal production, rigor development and the storage conditions.

ANIMAL PRODUCTION

During animal growth the levels of calpains increase and their final level is established at the point of slaughter. Changes in components of muscle also change but many studies have shown that the rate of ageing is independent of the level of finish or steers, bulls and heifers (Martin *et al.*, 1971) and the level of collagen (Dransfield *et al.*, 1981b).

a) ACTIVITY OF CALPAINS

Animal production for meat is managed in temperate, semi-tropical and tropical regions throughout the world. A variety of crosses have been developed by breeding and selection. The suitability of livestock for production or introduction into new areas into account their degree of tolerance to heat and humidity and the duration of the conditions otherwise distress may be caused to the Their suitability is not limited to physiological reactions, they must also meet the economic and social needs of the local population. *Bos Indicus* cattle may have similar quality and yield grades to *Bos taurus* and similar score for appearance and marbling generally, as the percentage of Brahman or Sahiwal inheritance increases, carcass weights and marbling decrease. Compar usually involved British and European breeds crossed with beef or dairy cows and have shown that meat from *Bos indicus* is often than that from *Bos taurus*. The proportion of acceptable tender meat decreased from 100% in Hereford Angus crosses, 96% in 93% in Pinzgauer, 86% in Brahman to only 80% in Sahiwal (Koch *et al.*, 1982) and toughness of the meat increases as the *Bos indicus* increases (Crouse *et al.*, 1989). Several trials have been conducted to isolate the changes in composition but, research (Whipple *et al.*, 1990), the composition of meat from *Bos taurus*, with the exception of fatness, is very similar to *taurus* cattle. Adaptation to heat is an expression of the changed enzyme activity with a change in temperature coefficient of energy. One such case, in which the enzymes operate normally at high temperatures but are likely to be less effective at low was modelled and showed that such a change in activity of calpains produces tougher meat (Figure 2). Although the current ar to overestimate the early tenderisation this would be reduced by including slower rigor development which has been observed in from Brahman cattle (Wheeler *et al.*, 1990). The model gives a clear indication that a single change in temperature coefficient could nt for the toughening and is consistent with the known heat tolerance of these animals.

nisation: Should a change in the activation energy prove to be the major cause of toughening, optimisation can be sought in the control cass cooling. Computations have shown that about 50% of the toughening shown in Figure 1 could be recovered by appropriate cooling ould improve the acceptability and marketability of meat from *Bos indicus* . More accurate estimation of the optimal processing must the determination of the temperature coefficients of calpains in different muscles and breeds of *Bos indicus.*

LEVEL OF CALPAINS

tion in the amount of calpains would produce variations in the amount of tenderisation, ageing and tenderness, if all other factors were constant but, in normal production, they are also likely to vary. Variations can arise among production systems, species and muscles.

Use of growth promoters. Growth rate and feed conversion efficiency are recognised as important parameters in assessing the ency of live-stock production. More recently the control of the deposition of fat on meat animals has gained importance because excess as to be trimmed and discarded at the processing plant or left uneaten by the consumer. The introduction of ß-adrenergic agonists sent the latest use of pharmacologically active compounds which have opened up new prospect for improving efficiency and quality of products but also for the greater understanding of the metabolic control of carcass composition and meat quality.

us types of ß-agonist have been fed to cattle, sheep, pigs and poultry and all produce an increase in the toughness of meat. Cimaterol ased shear values in pigs (Jones *et al.*, 1985), sheep (Hamby *et al.*, 1986) and cattle (Tarrant, 1987). Feeding ß-agonists changes evels of calpains and their specific inhibitor, calpastatin. The changes depend on the species, type of muscle, the particular compound he time and duration of administration. All reports agree that they cause a decrease in the level of calpain I, a small reduction, to about of the control, in lamb (Kretchmar *et al.*, 1990) and a larger reduction, to 43%, in rabbit (Forsberg *et al.*, 1989). Furthermore, onists increase the level of calpain II by up to 48% (Wang & Beermann, 1988) and the level of calpastatin by up to 150% hmaraie & Shakelford, 1991). Incorporating the average changes in levels into the calpain-activity model produces less (65%) erisation, slightly slower ageing and tougher meat (Figure 3), a similar pattern to the observed changes (Ouali *et al.*, 1988).

misation: The rapid turnover of calpains in living tissues is likely to mean that the toughening effect could be reversed by withdrawal e drug, however, this is also likely to reverse some of the production advantages, might be uneconomic and would be open to abuse. The amount of calpains is affected little by ß-agonists but the reduction of calpain I, which operates under more optimal conditions, does ompensate for the increase in calpain II because it is not fully activated and it operates under poor conditions (Figure 1). Tender meat be obtained by inducing their activation by increasing the initial intracellular calcium ion concentration to above 1mM. This can be by addition of calcium chloride solution into the meat (Penny *et al.*, 1974; Alarcon & Dransfield, 1990). Modelling the addition of um ions, when the pH reached 6.3, (Figure 3) shows that very tender beef would be obtained, reversing the effect of ß-agonist, a ction similar to that obtained in lamb *Longissimus dorsi* (Koohmaraie & Shakelford, 1991).

y addition of calcium ions will increase the tenderness of all meats including Brahman beef (Koohmaraie *et al.*, 1990). To obtain the timum tenderness, the calcium level should be raised as soon as possible after slaughter raising fears that this may also induce muscle ening but appears not to be a problem when calcium salts are infused into carcasses. Studies have been limited to *Longissimus dorsi* a general effect on the majority of muscles is warranted before its commercial adoption can be considered prior to consumer testing.

Variations among muscles. Muscle type greatly influences meat quality especially tenderness (Ouali, 1990). Although studies of variation in calpains is in its infancy, a common feature of pork, lamb and beef is that the level of calpains and calpastatin are greatly enced by muscle type (Ouali, 1990). The level of calpain I in beef tends to decrease as that of calpain II increases associated with rease in muscle contraction speed (Geesink & Ouali, personal communication). This is consistent with the less ageing observed in meat h animals treated with anabolic agents (Ouali *et al.*, 1988) which causes a reduction in contraction speed (Ouali *et al.*, 1988; Ouali, 0). "Red" (slow-twitch) muscles would therefore be expected to take longer to age than "white" (fast-twitch) muscles. This is sistent with the observed low levels of calpains and little ageing (Olson *et al.*, 1976) in *M. Psoas major*. Also *biceps femoris*, which has er levels of calpains (Koohmaraie *et al.*, 1988), ages less than *longissimus* (Semlek & Riley, 1974) and chicken breast muscle ages less n the "redder" leg muscles.

e calpain-activity model shows that the rate of ageing should be unaffected by the level of calpains but may decrease slightly with higher els of calpastatin inhibitor. Workers at Texas A&M, studied 19 muscles from 125 choice beef carcasses at 1°C for up to 28 days and culations have shown that the rate constants of the exponential decay of toughness are similar but there is a 4 fold variation in the level of derness attained after complete ageing. The exponential rate constant for ageing seems to be the same in beef *Sternomandibularis*, *ngissimus*, *Psoas major* and *Semitendinosus* muscles (Dransfield *et al.*, 1981b). Few data are available among muscles of other species.

timisation: A principle emerges that meat from older animals and "redder" muscles require longer ageing and that advantages could be ned by the separation of cuts into red/white groups. The implementation of this will vary according to the processing of the carcass and ay require the development of novel cutting procedures. It is unlikely that all of the advantages could be gained since this is likely to

FIGURE 3. Tenderisation following ß-adrenergic agonist

The curves for tenderisation were calculated using a calpain-activity model (Dransfield, 1992b) for control (C) beef, that (B) following the reduction in calpain I and increase in calpain II and that (A) produced by the addition of calcium ions to B. This simulates tenderisation in beef *Longissimus dorsi*, that after the administration of ß-adrenergic agonist and after the infusion of calcium ions, respectively.

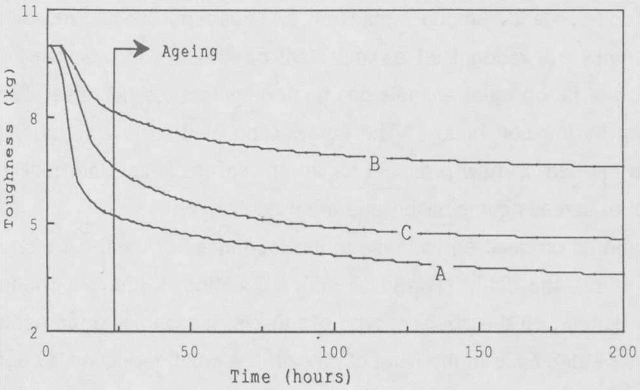
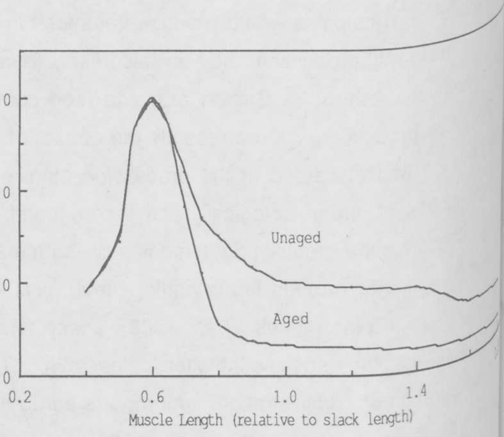


FIGURE 4. Muscle length and ageing

The relationships between the muscle length and toughness units) were determined in beef *Sternomandibularis* (neck m day (unaged) and after 3 days storage at 15 °C (aged) and ageing decreases as the muscle length decreases and, at a len (40% shortening), ageing does not occur. Curves derived *et al.*, (1967).



require a complete muscle seaming of the carcass but significant savings in storage time, energy consumption and storage spac obtained with small changes in butchery, management and stock control systems.

RIGOR DEVELOPMENT

The conditions during rigor development are the most important factors controlling tenderisation and ageing for most comme Variations in rigor can alter the muscle structure, the release of calcium ions and the activity of calpains by up to 100 fold.

(i) Muscle shortening. The rate of postmortem glycolysis is a minimum at about 17°C and increases at higher an temperatures as the muscle is stimulated to do work. At low temperatures calcium ions are released from the sarcotubular syst muscle contraction, a phenomenon known as 'cold-shortening'. The ability to cold-shorten persists whilst the pH is above 6.2 about 10 hours in some beef muscles. During this period the contraction is reversible but becomes irreversible as rigor develo near the ultimate pH, shortening occurs and more shortening occurs at higher temperatures, called 'rigor-' or 'heat-shortenin shortening then occurs in muscle cooled below 10°C whilst the pH is above 6.2 and rigor shortening whilst the temperature is a 25°C at completion of rigor. The extent of shortening also depends on the degree of restraint imposed by the attachments to th Hot deboning may remove the skeletal restraint on muscles and allow greater muscle shortening.

New Zealand workers (Davey *et al.*, 1967) first demonstrated that the extent of ageing decreased with increased muscle shorte 4) or reduction in sarcomere length. When muscles shortened to 40% (to a length of 0.6), corresponding to the maximum (Marsh & Leet, 1966), no ageing occurred. Therefore, ageing does not occur following severe cold-shortening and tough mea matter how long the muscles are stored. Unaged shortened meat is tougher than unaged stretched meat and therefore it can be as there is no early tenderisation in shortened meat. The lack of ageing is caused by structural changes which prevent the enzym from producing tenderisation and is an important feature in meat production which is not understood fully.

In practice, a wide range of degrees of shortening are likely and some ageing will take place on storage but to a greater ext shortened muscles. Variation in sarcomere length could account for some of the differences in the extent of ageing observed amo muscles. The temperature at 2 hours can be used to predict tenderness and as an index of tenderness or of ageing (Lochner *et al.*

(ii) The rate of rigor development. As the rate of rigor development increases the calpain-activity model predicts that the p tenderisation before full rigor increases and the amount of ageing decreases (Figure 5). As the rate of rigor development in

FIGURE 5. Rigor development and tenderisation

ffect of different rates of rigor development was demonstrated a calpain-activity model (Dransfield, 1992b) and a linear decline to reach 5.5 at 6, 12 or 24 hours after slaughter, with a common g rate. With rigor taking 24 hours, about 34% but taking 6 , 72% of tenderisation occurs within the first day. The total nt of tenderisation is unaffected by the rate of rigor development.

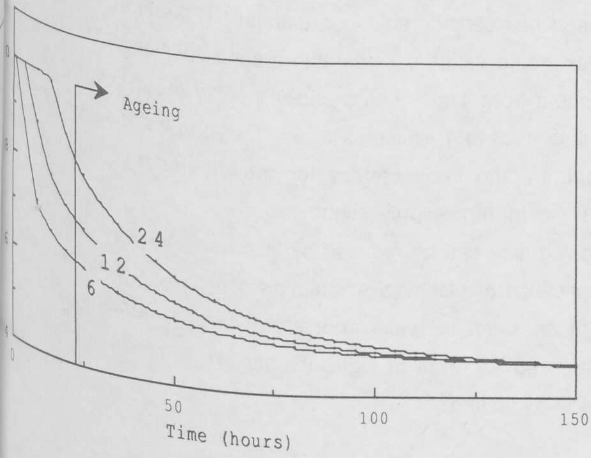


TABLE 1. Effect of ultimate pH on toughness of lamb

Lambs were injected with adrenaline to produce a range of ultimate pH values in the *Longissimus dorsi*. Toughness by shear force (lb) decreased with increasing pH but, in tensile strength (kg/cm2), unaged meat was unaffected by pH. Ageing was reduced in meat of high ultimate pH (from Bouton *et al.*, 1972).

	Shear force		Tensile strength	
Ultimate pH	Unaged	Aged	Unaged	Aged
5.7	24	12	3.4	0.75
6.0	18	10	2.3	0.80
6.5	10	7	1.3	0.85
6.8	5	5	0.7	0.90

ymes are activated earlier at the normally higher prevailing temperature. The ultimate tenderness is the same but the proportion in 24 hours is increased and the proportion during ageing is decreased. al cooling is particularly important when the temperature of the carcass is reduced from 37°C to about 4°C. During the first 24 hours r slaughter, holding at high (30°C) temperature post-rigor can produce as much as 86% of the ageing while, at chill temperatures, as e as 8% of the tenderisation occurs (Dransfield, *et al.*, 1992a). If the cooling is increased in accordance with the increase in rigor elopment, the tenderness is unaffected by the increased rate of rigor development.

ELECTRICAL STIMULATION

ctrical stimulation will hasten rigor and cause tenderisation to start earlier at the prevailing higher temperature. Early after rigor, ctrically stimulated meat will be more tender but the improvement wili decrease with storage time and the ultimate tenderness will be same as in non-stimulated meat. Most evidence, derived from carcasses or sides cooled similarly to the stimulated sides, shows a derisation following electrical stimulation (Cross, 1979; Savell *et al.*, 1981) which can be accounted for by the increased temperature ansfield *et al.*, 1992a) but others have shown no effect (Crouse *et al.*, 1985). Thus in meat from carcasses given high or low voltage mulation and slow cooling, adequate ageing in beef can be obtained in about half of the time in the *Longissimus dorsi* thus reducing the uirement and the cost of storage.

ectrical stimulation can also cause similar improvements in pigmeat and poultry meat but the rapid reduction in pH at high temperature y enhance rigor shortening and reduce the ageing. Clearly the effects of prevention of cold toughening by electrical stimulation must be ghed against the increased possibility of heat (rigor) shortening (Pommier *et al.*, 1987).

b) HIGH ULTIMATE pH

e incidence of dark, firm and dry (DFD) beef is markedly dependent on the sex of the animal. It occurs in about 1 to 5% of steers and ifers, 6 to 10% of cows and 11 to 15% of young bulls (Tarrant, 1981). DFD, or high ultimate pH meat, is produced by a reduction in ycogen prior to slaughter and, subsequently, a reduced amount of acid production in the meat. This can result in rapid rigor development ate-Smith & Bendall, 1949), early release of calcium ions and produce very active calpains which are short-lived at the prevailing high mperature. During normal cooling to an ultimate pH of 7.0, all of the tenderisation occurs before 24 hours and no ageing occurs. As the imate pH is lowered, the amount of ageing increases but the total tenderisation remains similar. Texture of DFD meat has been studied tensively in Australia. The tensile strength after ageing is unaffected by pH but shear force values of high ultimate pH meat are lowered ll further by the increased water binding (Table 1).

c) SPECIES

The rate of ageing differs significantly between species and necessitates different times for tenderisation. Beef, veal and rabbit the same rate and take about 10 days at 1°C to achieve 80% of the ageing (Table 2). Lamb ages slightly faster than beef but than pork. Chicken breast muscle ages about 10 times faster than beef. The tenderness achieved depends on the unaffected muscle components. Species with low 'background' will achieve acceptable tenderness in less time. In veal, which is than beef, acceptable tenderness can be obtained in about 5 days at 1°C compared with 10 days in beef.

The differences in ageing originate in the variation in the total amount of calpains and rigor development. The amount and calpain I varies about 10% between beef, lamb, rabbit and pig pectoralis (Etherington *et al.*, 1987) and longissimus 1991) muscles. Chicken breast muscle has slightly less total calpains and has considerably less calpain I (Etherington *et al.*, would be expected to show less ageing. However, the rate of rigor development varies considerable among species. The reached in beef from 15 to 36 hours, in lamb from 12 to 24 hours, in pigmeat from 4 to 8 hours and in poultry meat about 2 rate also varies widely within species and rigor may be completed in as little as 5 to 10 minutes in poultry and pigs meats. activity model indicates that the variations in rate of rigor development are the main causes for the difference in differences in the level of calpains and inhibitor (Koohmaraie *et al.*, 1991) contributing only slightly.

Optimisation: Ageing will be maximised by avoid muscle shortening. Ageing time can be reduced by increasing the rigor the temperature, particularly during the early stages after slaughter. Application of electrical stimulation can be recommended, will increase rigor and reduce the risk of cold-shortening, provided that it does not increase rigor shortening as demonstrated (Wakefield *et al.*, 1989) or with very slow cooling in beef (Pommier, *et al.*, 1987). Meat of high ultimate pH is more tender less ageing which would reduce the risk of spoilage and its usage should be re-evaluated.

STORAGE

Temperature is the most important factor governing ageing, since the levels of enzymes and inhibitor have been set, rigor is the temperature and time are the only variables which can be controlled to affect ageing. The variation in rate of ageing over the to 20°C was about ten times that due to muscles and 32 times that among similar commercial beef animals (Dransfield *et al.*,

a) CHILL TEMPERATURE

At constant temperature, in the range 0°C to 40°C, the rate increases about 2.5 fold for every 10°C rise in temperature 1976; Dransfield *et al.*, 1981a). This means that beef, which takes 10 days to age at 0°C, takes 4 days at 10°C and only 1.5 In chicken breast muscle, ageing takes place in 0.5 day at 0°C and only a few minutes at 20°C.

In practice variation in temperature are inevitable. Modelling shows that the effect of different temperatures is "additive" amount of ageing is then the sum of the tenderisation which takes place in each part of the time/temperature parts. Thus the stored for 1 day at 5°C followed by 5 days at 0°C is the same as that stored for 5 days at 0°C followed by 1 day at 5°C. The effect is logarithmic and therefore wider fluctuations in temperature will cause more tenderisation at the same average However, with 25% of the time spent at 10°C and 75% at 0°C, the saving for beef is less than 1 day over that stored at a more practical situation is where the chiller operates at set minimum temperature which is exceeded during movement of defrost cycles. When set at 0°C, a rise of 2.5° for 50% of the time would reduce the ageing time by less than 1 day (Figure 6). for 50% of the time by over 3 days but for only 15% of the time reduces the ageing requirement by about 1 day. Therefore savings in storage time may occur in the surface of the meat but are unlikely to occur in the deep parts of a beef side.

b) FREEZING

Freezing stops the activity of the calpains but does not destroy them and the activity remains halted throughout the period of but is regained after thawing. Thus tenderness of meat frozen at 3 days after slaughter will remain at this level no matter meat is stored. After thawing, ageing will re-commence and continue to completion. Extremely rapid freezing (in less increases the rate of ageing after thawing to 3 times that in non-frozen beef (Dransfield, 1986). Fast freezing, in 1 hour, of ageing. These increases in rate may be caused probably by cellular damage. At commercial rate of freezing, there is subsequent rate of ageing after thawing. Attempts to enhance the effect by repeated freeze-thaw cycles at commercial rates not significantly affect the subsequent rate of ageing (Locker & Daines, 1973).

This mechanism for the acceleration of ageing resolves the apparent anomaly that freezing does not affect the tenderness of increases it in unaged or partially aged beef (Hiner *et al.*, 1945). Furthermore, slower freezing at -8°C increased tenderness whereas faster freezing at -81°C increased it by 28% (Hiner *et al.*, 1945).

c) COOKING

The rate of ageing is slowed above 40°C and stops when the enzymes are completely inactivated above 60°C (Davey & Above this temperature the enzyme activity cannot be regenerated and ageing is fixed. Very slow cooking will cause the meat to w 40°C and will tend to produce an increased rate of ageing. Slow cooking will therefore tend to enhance tenderness of unaged meat but ave no effect on fully aged meat. Any improvement in tenderness will depend on the degree of ageing and the rate of heating.

nisation: If the temperature fluctuations during storage could be controlled or accounted for, the savings in ageing time could also be cted and incorporated into specifications. Practically, meat should be aged prior to freezing since a long time may be required after ng and the meat may be sold frozen and cooked from the frozen state with little or no further ageing. Chicken is exceptional in that it e aged after thawing in less than 1 day, conditions which can be achieved by thawing in a domestic refrigerator. If frozen, fast freezing w temperatures would appear to be slightly more beneficial than slow freezing.

TABLE 2. Ageing times among species

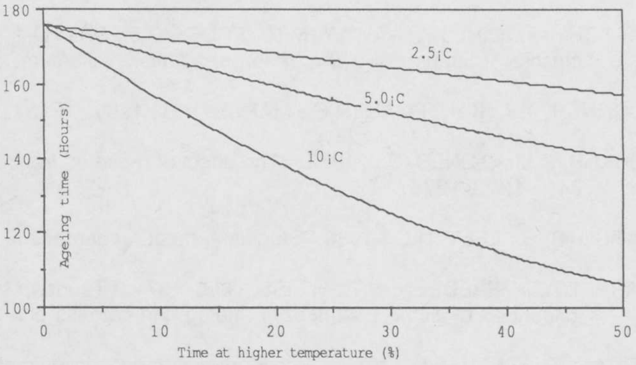
ghness was determined instrumentally on *Longissimus dorsi* except icken where *Pectoralis profundus* in was used. The change in hness with storage time at 1°C was modelled using an exponential y equation. The times are those taken for the meat to achieve 50% 80% of the ageing (from Dransfield *et al.*, 1981b).

Times taken to age meat stored at 1°C

	50%	80%
Beef	4.3	10.0
Veal	4.1	9.5
Rabbit	4.1	9.5
Lamb	3.3	7.7
Pork	1.8	4.2
Chicken	0.1	0.3

FIGURE 6. Fluctuations in chill temperature

Using the temperature coefficient for beef ageing (Davey & Gilbert, 1976; Dransfield *et al.*, 1981a), the amount of ageing was calculated at 0°C with a rise in temperature of 2.5, 5, or 10°C for up to 50% of the storage time. The curves simulate the effect of temperature fluctuations on meat ageing times.



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