MEAT TENDERNESS

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INTRODUCTION

The roles of connective tissue and myofibrillar proteins in determining meat tenderness have been considered and discussed in some detail in earlier papers. Such work will provides the fundamental knowledge needed for the meat industry to continually improve the quality and reliability of its product. Accordingly many research establishments, including here in Australia at the CSIRO Meat Research Laboratory, are still working to define and solve the problems which can affect meat quality. A large number of factors believed to affect tenderness have been investigated (and, in many cases, are still being investigated) including pre-slaughter stress, breed, level of nutrition, age, weight, species, fat cover, pre-rigor processing conditions such as chilling temperatures and rates, cooking, etc. In essence it all comes down to whether any selected factor affects (a) the contraction of the myofibrillar structure, (b) the connective tissue structure, or (c) the water-holding capacity of the muscle proteins. Even with that simplification reviewing all the work carried out on meat tenderness would be a daunting task requiring a book rather than a relatively short paper.

In this paper, therefore, I will concentrate on the approachs we have used at the MRL. I will start by outlining the work we have carried out investigating and developing the objective and subjective methods needed to assess and quantify meat tenderness. I will then discuss how we have used these methods to identify both the factors affecting tenderness and the requirements to maintain or improve tenderness.

MEASUREMENT OF TENDERNESS

It became very evident when investigating methods for measuring meat tenderness that one of the major problems in Meat Science is the multiplicity of devices used to quantify meat tenderness. Different devices can give markedly different responses to samples that have received similar treatments. An example of this is afforded by the work of groups who have independently studied the effect of cooking temperature on meat tenderness. Some have used shear devices and obtained results similar to those shown (for device A) in Fig. 1.

It can be seen that when device A is used there is a marked decrease in peak shear force values as cooking temperatures were increased from 50 to 65°C while above 65°C these values increased to a peak at about 80°C. Another group used device B (Fig. 2) and showed a 3-4 fold increase in shear values as cooking temperatures were increased from 40 to 50°C with a further doubling as cooking temperatures were increased from 60 to 75°C. It would be surprising if the groups interpreted their results in the same way.

Device A was a modified version of the original WB device with a straight instead of the triangular shear blade used in the conventional WB device and with samples of a rectangular instead of circular cross section. From the force-deformation curves obtained from device A an initial yield force (Fig.3) can be measured as well as a peak force. Initial yield force values (which can be equated with myofibrillar strength) show similar changes with cooking temperature to those obtained using device B.

These results are not totally unreconcilable since other workers at the Norwegian Food Research Institute (Martens et al. 1982) found that as beef muscle was heated from 45 to 85C its sensorily measured firmness increased with temperature but other sensory properties such as fibre cohesity, resilience, residual bolus and total chewing work decreased at temperatures above 50C. This would suggest that device B (and the initial yield force values obtained using device A) are reflecting changes in muscle firmness whereas device A (peak force values) shows there are changes in other factors such as cohesiveness between muscle fibres.

Interpretation of results is obviously complicated when such differenences can be obtained, using two rather similar devices, especially when results from both show high correlations with taste panels. There seems to be little chance of obtaining general agreement on a universal device for measuring meat texture so that individual workers and groups will do what we did and continue to use and/or develop their own methods for assessing tenderness.

In our experience a modified version of the WB shear device has shown consistent and relatively large differences in shear values between muscle samples which either have different contraction states or have been subjected to different ageing treatments. Differences in the connective tissue contribution such as inter muscle or animal age differences have less, and

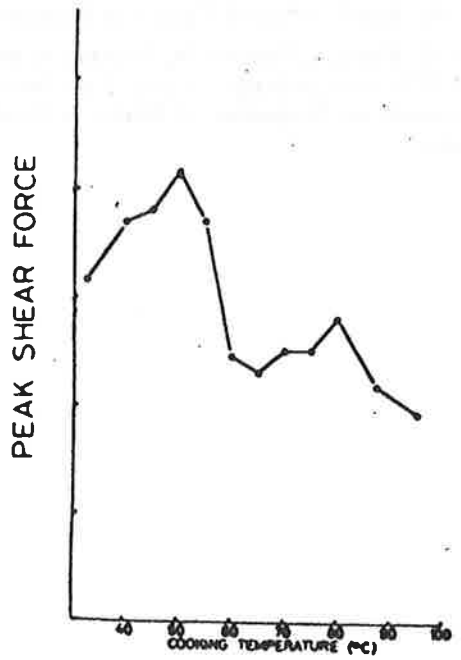

Figure 1. Peak shear force values obtained using device A, for samples cooked at temperatures from 20-95°C.

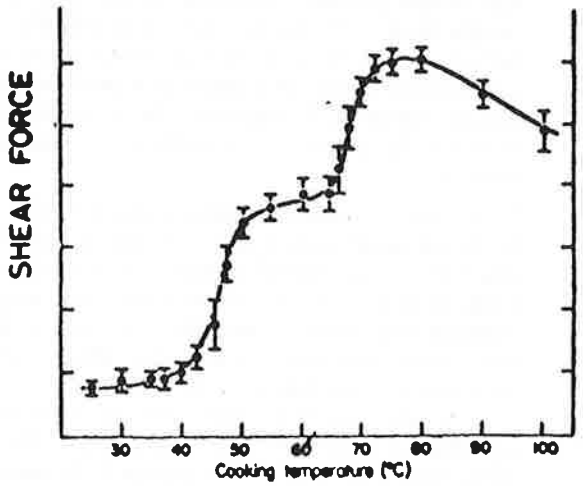

Figure 2. Shear force values, obtained using device B, for samples cooked at temperatures up to 100^{0}C.

often little, effect on shear values. It is thus our view that the WB shear device is not a good indicator of the connective tissue contribution to toughness. This assertion is backed by work which shows that taste panels detected differences in toughness between muscles of different connective tissue content although their WB shear values were not significantly different (Bouton et al. 1975a; Ratcliff et al. 1977).

We have developed a number of methods and techniques for measuring the mechanical properties of meat ranging from the modified version of the WB shear device already mentioned to a compression/penetrometer method (IC) and various types of tensile methods (Bouton et al. 1975b). We have also developed and used a high speed centrifugation method for measuring the important property of water holding capacity and shown that expressed (centrifugally) juice (EJ) relates to organoleptic juiciness (Bouton et al. 1975c). Using a combination of WB shear (reflecting myofibrillar strength) IC (reflecting connective tissue strength) and EJ (or cooking loss) results we can account for over 80% of the variation in subjective tenderness and juiciness over a wide range of myofibrillar, and connective tissue toughness and over a wide range of cooking temperatures and cooking losses (Bouton et al. 1975a).

As well as these mechanical methods for assessing tenderness we also use a pressure-heat method which we believe affects primarily the myofibrillar structure with little effect on the connective tissue (Ratcliff et al. 1977). It is well established that relatively small differences in myofibrillar contraction state can produce quite large differences in shear force values (Marsh and Leet 1966). These differences can introduce sufficient variation to obscure significant treatment effects or differences which could be unrelated to the differences in myofibrillar contraction. An illustration of this can be found in the work where the pressure-heat method was used to demonstrate significant differences between beef and buffalo (Robertson et al. 1984).

Factors affecting tenderness

It is now well documented that myofibrillar contraction state, connective tissue and water-holding capacity have major effects on the tenderness of meat. The assumption that the effect of other factors and treatments on meat tenderness would depend on how the particular factor or treatment affected one or more of these 3 major factors would appear reasonable. We have used the techniques we have developed for assessing changes in myofibrillar or connective tissue strength to determine which structural component particular factors or treatments affect.

Myofibrillar contraction. Myofibrillar contraction of muscles on the carcass is affected primarily by the temperature at which the muscles enter rigor, by skeletal restraint, by the inherent rate of glycolysis of the muscle and by pre-slaughter stress. The relationship between myofibrillar contraction state and the toughness of cooked meat was originally established by Marsh and his co-worker at MIRINZ (Marsh and Leet 1966) and there has been ample confirmation of it in many other publications by other workers since then. It should be noted, however, that when meat is cooked at 50C the relationship between shortening (sarcomere length) and toughness is reversed with samples with longer sarcomeres being tougher (Bouton et al. 1974). Avoiding the deleterious effects of myofibrillar contraction can be achieved by a variety of methods including (1) controlling chilling temperatures (conditioning), (2) physically restraining muscles from shortening (tenderstretch), (3) by the use of an effective electrical stimulation (ES) system, (4) ageing or (5) mechanical tenderizing. Of these methods the first is difficult to carry out with great efficiency since even in modern chillers it is hard to maintain or achieve uniform chilling rates and temperature in all parts of the chiller - it is also

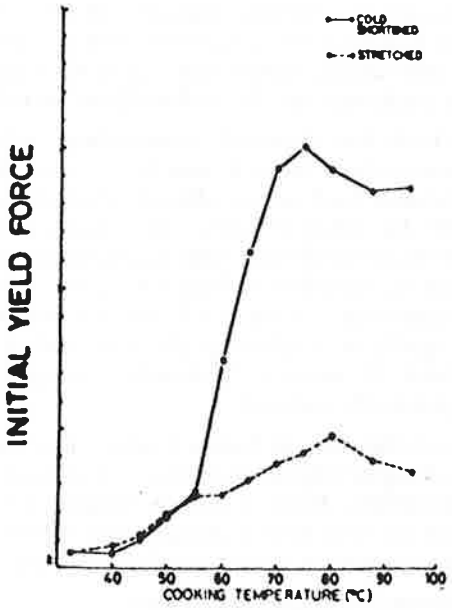

Figure 3. Initial yield force (obtained using device A).

advantageous from the aspect of weight loss to use rapid rather than slow chilling rates. The second method is simple and works very well but was not widely adopted in Australia. The third, i.e. ES, has been widely adopted in Australia and has attracted more research work and produced more publications from meat scientists than almost any other topic. ES systems generally fall into two categories i.e. ELV (extra low voltage) which in Australia means a maximum of 45V's peak - and HV (high voltage) which means 45V and, most often, 1100V peak. There have been many publications and many ES variants reported involving different voltages, stimulation times, time of stimulation after slaughter, frequency, mode of application etc. Unfortunately the selection of the optimum operation conditions has been complicated because the efficacy or otherwise of the individual ES systems reported have often been evaluated under chilling conditions too mild to produce major toughening due to myofibrillar contraction. Work at the MRL has been directed towards establishing conditions required for effective ES of beef and sheep carcasses in Australian meatworks. The main problems with the successful implementation of ES appears to be with (a) the introduction of overseas systems without checking to see if they work under Australian conditions (b) managers who have been known to place commercial expediency or convenience above efficiency and (c) the failure to adopt the proper handling methods to reduce pre-slaughter stress. This latter is of prime importance because ES does not appear to be effective where stress has produced animals with muscles of an ultimate pH greater than 5.8 (Shorthose 1988).

The best way to overcome the toughening due to myofibrillar contraction is to avoid it by using methods such as ES, conditioning or restraint. If it occurs, however, there are methods apart from comminution which can be used to reduce its effects. One of these is a pressure-heat method (Ratcliff et al. 1977) which involves pre-heating at 45C for about 45 min (or sufficient time to get the sample temperature up to 45C) then subjecting the preheated samples to 150 MNm^{-2} at 60°C for 60 min.

In Table 1 are shown the results obtained for control and pressure-heat treated samples of cold shortened and stretched beef semitendinosus (ST) muscle heated at 80°C for different times. The results showed that the effects of myofibrillar contraction could not be overcome even by extended cooking for up to 24 h at 80°C. By comparison cooking at 60°C for 24 h produced (Table 2) a significant toughening effect in cold shortened meat (Table 2) although in stretched samples values were significantly reduced.

From the data in Tables 1 and 2 it is clear that even cooking for long times at 60 or 80°C will not overcome the deleterious effects of cold shortening. It is equally clear that pressure-heat treatment (150 MNm^{-2} at 60°C for 60 min) does overcome myofibrillar toughening effects.

Connective tissue toughness

From the literature (Bouton et al. 1978) the evidence relating toughness to animal age is equivocal. However when care is taken to avoid myofibrillar toughening there appears to be a strong relationship between toughness and animal age (Shorthose and Harris 1988). The rate of toughening with animal age is markedly different between muscles such as e.g. being greatest for the semitendinosus biceps femoris and pectorals profundus muscles (with high connective tissue content) and the least for the psoas major (with low connective tissue content).

There are a number of factors which could affect the likely physical contribution of the connective tissue structure to the overall impression of toughness. The work of Rowe (1974) showed that the angle of the collagen fibres in the connective tissue network changed with myofibrillar contraction state. This suggested that the physical contribution of the collagen network to meat properties could be affected by how much the myofibrillar structure had contracted. The collagen fibres were also found to be crimped (Rowe 1974) and this would affect their stress/strain properties. Another factor was that the stress/strain properties of collagen fibres heated to above shrinkage temperature were markedly affected by restraint, i.e. prevention or limiting of shrinkage during heating to above shrinkage temperature (Snowden et al. 1977; Snowden and Weidemann 1978) as can occur during the cooking of meat. When meat is heated/cooked the myofibrillar structure loses moisture and shrinks but the collagen fibres of the intramuscular connective tissue network will be restrained by the interstitial material. The properties of collagen fibres measured in situ are, thus, likely to be different from the properties measured ex situ. Samples from stretched muscle restrained during heating at 80°C have significantly higher shear force values than similar samples allowed to shorten during heating (Table 3).

The increase in peak shear force values could be related, at least in part, to the increased fibre packing density of the restrained samples but it could also reflect an increased contribution of the connective tissue due to changes in the stress/strain characteristics of the collagen fibre network (Snowden et al. 1977).

Knowledge is not yet available to change, in a commercial situation, the connective tissue contribution to toughness by altering the crosslinking in collagen in situ or in vivo. Methods such as long term cooking at 55°C (Beilken et al. 1986) could be used to reduce the connective tissue contribution although the cooking losses are high and could make such a method uneconomic. A better approach is, perhaps, to devise methods for sorting out the cattle after slaughter and on the slaughter floor to identify those likely to provide meat with acceptable levels of connective tissue toughness. Relating a mechanical measurement on raw pre-rigor or post-rigor meat to the tenderness of the subsequently cooked meat is not easy especially for the former. However if myofibrillar toughening can be controlled, e.g. by using efficient electrical stimulation systems, there seems to be merit in looking at methods for assessing connective tissue toughness. (A number of such methods are currently being investigated).

Water holding capacity

The moisture retention properties of whole meat during heating and cooking are largely decided by the ultimate

pH although myofibrillar contraction state has a significant effect (Bouton et al. 1972). Increasing ultimate pH above 6.0 improves tenderness but the colour, texture, flavour and keeping qualities of high pH meat are likely to be unacceptable. In general, the disadvantages far outweigh the advantages of producing table meat with ultimate pH's >6.0. Considerable work has been carried out both here and overseas to eliminate or reduce those pre-slaughter stress factors which can produce ultimate pH values >5.8.

CONCLUSION

In summary it can be said that much of the work on meat tenderness reported has been concerned with restricting the loss of raw material quality rather than in significantly improving it. Methods are currently available which, if used properly on non-stressed animals, will allow deleterious myofibrillar contraction to be either reduced or avoided. Reducing connective tissue toughness is much more difficult and, in my view, is one of the big problems for meat scientists. Another problem lies in devising a measurement which can be used within a few minutes of slaughter to predict the likely connective tissue contribution in the cooked meat.

Overall much has been learned about meat and its unique properties which has led, albeit slowly, to an improvement in meat quality - at least it has in Australasia. Meat is an expensive protein product and fundamental research, both basic and applied, is necessary to improve its utilization and quality so that it can compete against the aggressive marketing of other protein products and can meet current marketing trends.

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