THE VISCOELASTIC PROPERTIES OF WHOLE BEEF (M. BICEPS FEMORIS) DURING COOKING AS RELATED TO ITS SENSORY AND STRUCTURAL CHARACTERISTICS

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SUMMARY

The elasticity of *M.biceps femoris*, measured as a function of heating temperature, increases sharply between 55 and 60°C, whereafter a decrease follows. Tenderness shows a similar behaviour with a maximum around 60-65°C. The aggregation of the sarcoplasmic proteins, and the shrinkage of the connective tissue and the meat fibres, both transversely and longitudinally, all start at around 40°C.

The results of this investigation suggest that the optimum tenderness obtained around 60-65°C originates from the fact that meat fibres are most easily cracked on chewing, when the elasticity is at its highest. This elasticity of the meat is in turn suggested to be formed by the aggregated sarcoplasmic proteins gluing the fibres and the fibre bundles together. The following decrease in elasticity and tenderness of the meat at temperatures above 65°C seems to be related to the appearance of cracks in the connective tissue, due to its shortening.

INTRODUCTION

Numerous studies have been conducted in the area of meat cookery, this being in spite of its importance. one of the least understood aspects of meat research. A good review of the literature on the meat palatability-heat-relationship is given by Seideman and Durland (1984).

The tenderness of meat on cooking can be measured by sensory evaluation, but mostly some instrumental method of texture analysis has been used. We have, in this investigation, studied the sensory attribute tenderness of the cooked meat (*M.biceps femoris*) from 45 to 85°C, samples taken every five degrees. With the aim of understanding more of the structural events, both on the colloidal and molecular level that occur during meat cooking, we have in this investigation as texture analysis used a fundamental rheological approach. such as the measurement of the viscoelastic properties of meat. This was carried out using a small-strain sinusoidal displacement device, working in shear at 1 Hz. With the availability of programmable thermal control, measurements during the heating process could be performed. Regarding the measurement of the viscoelastic properties of whole meat during cooking, no published material has so far appeared. Problems are encountered in these types of measurement, due to the sometimes substantial shrinkage/ swelling of the whole meat during cooking. We have solved this problem by constructing a pneumatically controlled device, which can follow the change in height of the meat sample continuously during the measurements.

The development of meat texture characteristics on cooking is determined by the structural changes occurring in the meat. These changes are in turn dependent on the temperature sensitivity of the proteins in question, i.e. collagen, myofibrillar and sarcoplasmic proteins. In order to elucidate some of the mechanisms behind texture formation in cooked meat, the structural change transversely and longitudinally of the meat fibres has been followed during heating in this study. Moreover, the aggregation of the sarcoplasmic proteins and the shrinkage of the connective tissue on heating have also been investigated. Good reviews of the effect of heat on muscle structure and on muscle proteins are given by Hamm (1977). Offer (1984) and by Seideman and Durland (1984).

EXPERIMENTAL METHODS

Material. Four *M.biceps femoris* (BF) muscle from young bulls (4 days post mortem) were used. The content of water, fat, protein and hydroxyproline were analysed for the muscle in accordance with earlier studies (Fjelkner-Modig and Tornberg, 1986). Muscle pH was recorded using a pH-meter (Orion 920).

Heat treatment. In all experiments the same heating rate was used. The gradient was 1.5°C/ minute up to 60°C, thereafter 0.7°C/ minute was used until the final temperature was reached.

Sensory evaluation. Sensory analyses were made 7 days post mortem (stored at +4°C) with a trained expert panel consisting of six assessors. 1.5 cm thick slices were cut from the muscle and put in plastic bags and then heated in a water bath. The temperature gradient was controlled with a thermocouple. As soon as the temperature reached 45°C samples were taken every five degrees up to 85°C.

The tenderness of the cooked meat was evaluated by the profile 1 = none, 9 = very tender. The accuracy of the tenderness determinations were ±1.4.

		Tenderness versus									
		Transverse			Longitudinally						
Sample	n	G*	G"	Phase angle	G*	G"	Phase angle	Absorb. (sarc. prot.)	Transverse shrinkage of fibre	Shrinkage of connective tissue	Shrinkage of fibre length
Muscle 2	8	0.41	0.52	0.01	0.68	0.67	-0.01	0.47	0.31	0.29	0.46
Muscle 3	8	0.80^{X}	0.80^{X}	0.49	0.91^{XX}	0.93^{XXX}	-0.04	0.48	0.40	0.55	0.60
Muscle 4	8	0.86^{XX}	0.80^{X}	-0.53	0.92^{XX}	0.91^{XX}	-0.35	0.85^{X}	0.52	0.41	-
All muscles (2-4)	24	0.66^{XXX}	0.63^{XX}	-0.09	0.81^{XXX}	0.79^{XXX}	-0.22	0.61^{XX}	0.30	0.41^{X}	0.54^{X}

Significance level: $p \leq 0.05^{X}$, $p \leq 0.01^{XX}$, $p \leq 0.001^{XXX}$

Table 1. The interrelationships between tenderness and the rheological and structural changes during cooking of meat between 45 and 85°C expressed as correlation coefficients of linear regression analyses.

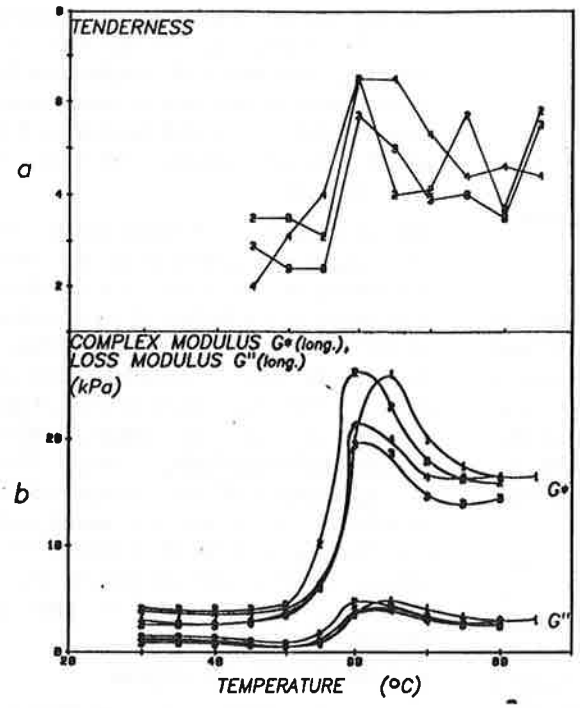

Figure 1. Tenderness (a), the complex (G*) and the loss (G") modulus (b) as a function of temperature.

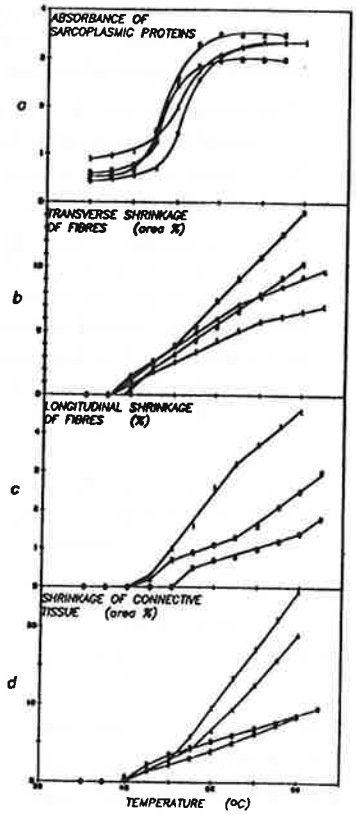

Figure 2. Effect of temperature on the absorbance of the sarcoplasmic proteins (a), the transverse (b) and longitudinal (c) shrinkage of fibres and shrinkage of connective tissue (d).

Rheological measurements. Continuous evaluation of the viscoelastic properties of the meat was followed during thermal processing by subjecting the meat sample to a sinusoidal shear at 1 Hz (Bohlin Reometer system, Bohlin Rheology AB, Lund, Sweden). The sample cell consisted of a parallel plate and the measurements were made at 2 minute intervals. The rheological behaviour was monitored as storage, loss and complex modulus (G', G" and G*) and the phase angle (δ). The shrinkage or swelling of meat during cooking was also followed continuously with a pneumatically controlled device attached to the system maintaining the same compression pressure (≈ 0.05 bar) on the sample. Measurements were performed in the linear viscoelastic region.

During the heating the meat sample was surrounded with isotonic salt solution to avoid desiccation. The lag between the temperature in the meat sample and the temperature in the surrounding isotonic solution was corrected for (≈ 5°C). The reproducibility of the method was ±1.7 kPa for G* and G' and ±0.4 kPa for G". The accuracy of the phase angle was ±1.1 degrees and for the height of the sample ±0.3 mm.

Turbidity . The sarcoplasmic fraction of the muscle proteins was isolated according to the procedure given by Olsen et al. (1976). The protein concentration of the protein solution was about 8 mg/ml. The change in optical density at 670 nm was measured, giving an accuracy of ±0.05 in absorbance.

Microscopy. The connective tissue separated by the method of Olsen et al. (1976) and the meat samples, cut along and across the fibres, were cryosectioned. The sections, 12 μm thick, were stained with aniline blue (0.2%) and aniline orange G (0.07% aniline blue, 0.13% orange G), respectively. With a heating table connected to the light microscope (Nikon Optiphot) the sections were examined. Photographs were taken continuously during heating at a magnification of 134x.

Image analysis. Photographs taken during heating in the microscope were evaluated with an image analysing system LABEYE/3PC (Innovativ vision AB, Sweden). For the micrographs of the connective tissue and the transversely cut meat samples, the shrinkage was measured as the change in area. The meat sample cut along the fibres was estimated with regard to the fibre shrinkage in length.

The shrinkage was expressed as the percentage change in area or length. The values given by the shrinkage were accurate within ±1.5% for the fibre transversely cut, ±0.5% for the fibre length and ±2.3% for the connective tissue.

RESULTS

Chemical composition. The chemical composition and the ultimate pH of the four samples of BF were similar (water 75.0% ± 0.7; fat 2.3% ± 0.5;

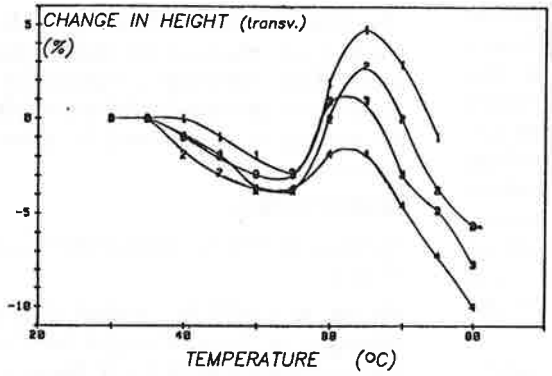

Figure 3. The change in height of the meat sample as a function of temperature measured in transverse fibre direction.

protein content 21.9% ± 0.7 and pH 5.4% ± 0.1). The connective tissue content differed somewhat between the samples, samples 1 and 4 having a content of 1.4% and 1.6%, respectively, and samples 2 and 3 2.3% and 2.4%, respectively.

Sensory properties. The course of tenderness as a function of temperature for three of the samples can be followed in figure 1a. According to the figure, there is some biological variation between the samples, in particular sample 2 behaves somewhat differently. Tenderness is relatively independent of temperature up to 55°C, whereafter it steeply rises to a maximum of about 60-65°C. The lowering of tenderness, which occurs at temperatures above this maximum is not that steep as the rise from 55 to 60°C. There are important observations to deduct from this curve. Firstly, the remarkable improvement (from 3 to almost 7 for sample 2) in tenderness by just raising the temperature from 55 to 60°C. Secondly, this subtle maximum in tenderness can be kept only over a few degrees, which really makes the cooking of meat an art.

Rheological properties . The rheological properties of the meat samples were measured both when cut transversely and longitudinally to the fibres, and they were monitored as storage (G'), loss (G") and complex (G*) modulus and the phase angle (δ). The complex and the storage modulus followed each other closely in every experiment, therefore only the complex modulus (G*) is given as a function of temperature in figure lb. We have chosen only to show the results from the longitudinally cut meat, as the results from the two ways of cutting are highly interrelated ($r = 0.91^{xxx}$ for G* and $r = 0.98^{xxx}$ for G"). The loss modulus (G"). reflecting the viscous part of the viscoelastic behaviour, can also be seen in the same figure. Like tenderness, there is a sharp increase in the two types of moduli registered between 55 and 60°C, whereafter a decrease follows at higher temperatures. The top value of G" is about 4.5 kPa, whereas the complex modulus can be as high as 25 kPa around 60°C.

Structural properties. In order to follow the structural changes in the different protein systems of the meat during cooking, we have firstly studied the aggregation of the separated, sarcoplasmic proteins by measuring the change in absorbance in a spectrometer. The results of this investigation can be seen in diagram a) of figure 2 for the four BF muscles. The increase in absorbance starts at about 40°C and terminates at 60°C, whereafter it levels off at higher temperatures.

Secondly, the shrinkage during cooking of the separated connective tissue *per se* and fibre shrinkage, both transversely and longitudinally, have been followed under the light microscope and quantified by an image analysing system. The results of these measurements are visualised in diagrams b). c) and d) of figure 2. Even with regard to shrinkage, 40°C seems to be the magic temperature where everything starts. There is a distinct variation between muscles, but the different structural changes within a muscle, especially the varying types of shrinkage, occurring on cooking of meat, are highly interrelated ($r = 0.94^{xxx}$ to $r = 0.99^{xxx}$).

DISCUSSION

In table 1, the interrelationships between tenderness and the rheological and structural properties of the meat during cooking are given. The correlations obtained for all muscles are in general lower when the muscles are treated separately. According to the table. the rheological parameters of the meat, especially the rigidity G*, correlate better with tenderness than any structural change. The correlations are especially high for muscles 3 and 4, when the elasticity G' (almost equal to G*) of the meat is measured in the longitudinal mode. The good correlation between the elasticity and the tenderness of the meat is not surprising when diagrams a) and b) of figure 1 are compared.

Intuitively, one does not expect the best tenderness when the elasticity or the rigidity of the meat is at its highest. By introducing the concept of failure mechanics as an important mechanism in governing tenderness, perhaps a better understanding of the observed phenomena can be achieved. Purslow (1984) was the first to introduce this thinking into meat texture analysis, whereas Tornberg et al. (1984) found this type of analysis fruitful when evaluating the masticatory pattern of meat and meat products. The basic principles of the current theories of failure appearance are based on the likelihood of the propagation of cracks in the sample (Jowitt, 1979). Crack propagation can be very much reduced if the stress applied to the meat sample during mastication is reduced by viscous dissipation of energy. Therefore the more elastic the viscoelastic meat is (which is the case at 60-65°C) the hither will be the probability of the applied stress being transferred within the material to the crack and there propagating it. This means that the piece of meat is then more easily fractured in the mouth and mastication and tenderness are facilitated. This type of mechanism seems to be a plausible explanation of the observed phenomena in this investigation.

Can the presented results give a hint as to the structural background of the rheological temperature dependence? The steep rise in the elasticity of the meat between 55 and 60°C suggests that a network, a gel, is formed. As the micrographs reveal no severe change in fibre structure,

except for some shrinkage, the gel probably consists of partly shortened fibres and fibre bundles connected together in some way. As Locker and Daines (1974) have shown with electron micrographs of cooked meat, that the cell membranes are grossly disrupted, sarcoplasmic proteins can be found between fibres and fibre bundles. Moreover, figure 2 reveals that the aggregation of the sarcoplasmic proteins is almost at an end at 55°C, where the meat gel starts to form. That aggregation precedes gelling is a phenomenon usually observed for globular proteins. We therefore suggest that the gluing material between fibre and fibre bundles making up the gel consists of aggregated sarcoplasmic proteins.

What is then the cause of the lowered elasticity of the meat usually observed at temperatures above 65°C? We have noticed when looking at the micrographs of the meat during cooking that, although the connective tissue in the endomysial and perimysial sheets shrinks from about 40°C, visible cracks in the tissue do not appear until about 65°C. If the endomysium and the perimysium are stretched in the muscle (as suggested by Offer et al. 1984), they will start to fracture at a certain degree of shortening, which might be the case at about 65°C. These fractures will occur between fibres and fibre bundles, thereby lowering the elasticity of the meat gel, which might be an explanation of the observed phenomenon in figure lb. This reasoning is further substantiated by the fact that the recognizable shrinkage of the whole meat sample in transverse position, as continuously registered as the height of the sample in the Reometer, does not occur until temperatures above 65°C. This is clearly visualised in figure 3, where the height of the meat sample in the Reometer is plotted as a function of cooking temperature.

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