14TH EUROPEAN MEETING OF MEAT RESEARCH WORKERS
BRNO. CZECHOSLOVAKIA AUGUST 26th – 31st 1968

Title: Effect of Heat on Meat Structure SECTION

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INTRODUCTION

The texture of cooked meat - the form in which all commercial meat is eaten either hot or cold - is influenced by a variety of factors. Chief of these appear to be 1) the pre- and post-slaughter handling of the carcase, 2) the quantity and type of the connective tissue of the muscles composing the cut of meat and 3) the cooking regime to which the meat is subjected.

It is known that the tenderness of meat is influenced by the structure and ultrastructure of the meat, this in turn is strongly influenced by the post mortem handling of the carcase (1). In particular there is an association between the sarcomere length in the myofibrils of the raw meat and the shear force (Warner Bratzler measurement) required to cut a piece of the cooked meat (2,3). Little is known, however, about the effect of heat on the ultrastructure apart from some limited studies on beef semitendinosus at 85°C (4) and chicken muscle (5).

We have been studying the changes produced in the ultrastructure of the fibres of beef fillet steak (musculus psoas major) by heating to various temperatures in the range 50°-100°C (the normal cooking range) for times varying from 15 min to 100 min. We have also studied the changes in texture (hardness and cohesiveness) of the cooked meat, to see how these parameters relate to the ultrastructural changes.

Fillet steak was chosen for this study because it has myofibrils with a well defined sarcomere structure. It has an elongated sarcomere 3.6-4.0 microns in length and has clearly defined A and I bands

Zusammenfassung

Die Beeinflussung der Struktur des Fleisches durch Erhitzen.

Die durch Erhitzen auf 50-100°C verursachten Veränderungen in den Myofibrillen und Kollagen-Fibrillen von Rindfleisch (Filetsteak) wurden elektronenmikroskopisch untersucht. Die Veränderungen in den physikalischen Eigenschaften des erhitzen Fleisches (Harte (hardness) und Kohäsionsvermögen (cohesiveness) nach Szczesniak) wurden ebenfalls untersucht, um zu sehen wie diese Merkmale mit den Veränderungen in der Feinstruktur des Fleisches in Beziehung stehen.

Zwischen 50°C und 60°C wurde die Feinstruktur der Sarkomeren zum Teil zerstört. Beim Erhitzen auf 70°C verkürzten sich die Sarkomeren auf 85% der ursprünglichen Länge nach 15 Minuten und auf 75% nach 100 Minuten; bei 100°C verkürzten sie sich auf 60% der ursprünglichen Länge. Die Myosin A-Filamente koagulierten zu einer festen denaturierten Masse, während sich die I-Filamente (Aktin) zersetzten und dadurch Lücken in der Struktur der Sarkomeren auftraten.

Erhitzen auf 70°C verursachte die Denaturierung eines Teiles der Kollagen-Fibrillen, was sich durch den Verlust ihrer charaktenstischen Feinstruktur bemerkbar machte. Nach 100 Minuten bei 80°C waren alle Kollagen-Fibrillen denaturiert.

Messungen der physikalischen Eigenschaften des Fleisches ergaben eine Zunahme der Härte mit steigender Temperatur bis zu 70°C. Uber 70°C nahm die Härte wieder ein wenig ab. Die Härte zeigte keine ausgeprägte Abnahme welche der Zersetzung der Sarkomerenstruktur zwischen 60°C und 70°C entsprechen würde. Dies lässt darauf schliessen, dass die Erweichung des Bindegewebskollagen für das Zartwerden des Fleisches während des Erhitzens wichtiger ist als die Zersetzung der Sarkomeren.

Die Möglichkeit eines Zusammenhanges zwischen den beobachteten Veränderungen der Feinstruktur und den Änderungen in den physikalischen Eigenschaften des Fleisches wird erörtert.

SUMMARY

The changes produced in the myofibrils and collagen fibrils of beef fillet steak by heating in the range 50-100°C have been studied using electron microscopy. The changes in the texture (hardness and cohesiveness) of the heated meat were also studied to see how these parameters related to the ultrastructural changes.

Between 50° and 60° some of the fine structure of the sarcomere was destroyed. At 70°C the sarcomeres shrank to 85% of their initial length after 15 min heating and to 75% after 100 min heating; and at 100°C to 60%. The myosin filaments of the A band coagulated to form a solid mass of denatured material, whereas the I filaments (actin) ruptured producing gaps in the sarcomere structure.

Heating at 70°C caused denaturation of some of the collagen fibrils, shown by a loss of their characteristic fine structure. After 100 minutes at 80°C all the collagen fibrils had denatured.

Measurement of the meat texture showed that the hardness increased with heating temperature up to 70°C. Above 70°C it showed a slight decrease. The hardness showed no marked decrease to correspond to the disruption of the sarcomere structure at 60° and 70°C. This suggested that the softening of the connective tissue collagen is more important than the disruption of the sarcomere in producing tenderness on heating.

The possible relationship between the observed ultrastructural changes and the changes in texture is discussed in the paper.

with only a small amount of interdigitation of the I (actin) and A (myosin) filaments. For this reason the interpretation of the thermal changes in the ultrastructure is easier than with other cuts of meat where the filaments are extensively interdigitated.

EXPERIMENTAL METHODS

Beef fillet steak (musculus psoas major) was obtained from animals allowed to pass into rigor in the conventional hanging posture and processed 24 hours after death.

50 g pieces were placed in small polythene bags, to which 5 ml of water was added. The bags were then suspended in a water bath at constant temperatures of 50°, 60°, 70°, 80°, 90° and 100°C. At each temperature samples were removed for electron microscopic examination

a) when the internal temperature of the sample reached the temperature of the bath, as measured by a thermocouple in the meat (about 15 min)

b) 45 min after immersion

c) 100 min after immersion.

Electron microscopy

The heated samples were allowed to cool and were then fixed with glutaraldehyde (Sabatini et al, 1963) (6) and post fixed with osmic acid (Palade, 1952) (7). After staining with 1% uranyl acetate solution for 2 hours the samples were dehydrated through a graded series of alcohols and embedded in Araldite (Glauert and Glauert, 1958) (8). Sections were cut on an LKB Ultratome 3, and stained with lead citrate solution (Reynolds, 1963) (9). They were examined in a JEM 6A electron microscope.

Texture Measurements

The hardness and cohesiveness as defined by Szczesniak (10, 11) were measured on samples of the raw and cooked meat using an Instron Materials testing machine.

RESULTS

CHANGES IN THE ULTRASTRUCTURE OF THE MYOFIBRILS OF FILLET STEAK ON HEATING

The first slight change observable in the ultrastructure was the disappearance of the triple line structure of the M line (at the centre of the sarcomere) at 50°C. At 60°C further changes became apparent. A light zone appeared at the boundary of the A and I bands. The A band assumed a coagulated appearance and the fine periodicity of the I filaments was lost. There was no change in sarcomere length.

Heating at 70°C produced a progressive shortening of the sarcomere with the period of heating. The sarcomere had shortened to 85% of its original length after 15 min and to about 75% of its original length after 100 min. The light zone at the boundary between the A and I bands became more pronounced and some of the I filaments had ruptured at both the A band and at the Z line.

Heating at 80°C caused further shrinkage of the sarcomeres to about 70% of their initial length. The A and I bands were much coagulated. The myosin filaments were no longer discernable in the A band. The I filaments had ruptured at both the A band and Z line.

When the fillet steak was heated at 100°C, the sarcomeres shrank to about 60% of their initial length. No fine structure remained in either the A or I bands. The outline of the myofibrils still remained, although the individual elements of the structure had denatured and become disorganised.

At each temperature investigated, all the ultrastructural changes appeared to have taken place within 15 min of the interior of the sample reaching the desired temperature. This suggests that the ultrastructural changes are temperature rather than time dependent.

Observations were also made of the structure of the collagen fibrils of the endomysium and perimysium (the connective tissue which surrounds the muscle fibres and fibre bundles) throughout these experiments. No changes were observed in either the characteristic (640 Å) periodicity or the fine structure of the fibrils at temperatures up to and including 60°C. At 70°C and above there was a progressive denaturation of the collagen fibrils shown by disappearance of the characteristic periodicity and the inter-period fine structure. The fibrils assumed an amorphous appearance. After 100 minutes heating at 80°C all the collagen fibrils had denatured.

CHANGES IN TEXTURE

The results of the texture measurements at different temperatures are given in Table 1.

Table 1

Hardness and cohesiveness of fillet steak samples after 15 min heating

	Hardness	Cohesiveness
Raw	1.3 ± 0.3	0.30 ± 0.03
50°	1.7 ± 0.2	0.28 ± 0.03
60°	2.6 ± 0.4	0.27 ± 0.03
70°	2.8 ± 0.3	0.35 ± 0.02
80°	2.9 ± 0.4	0.34 ± 0.02
90°	2.7 ± 0.4	0.35 ± 0.03
100°	2.0 ± 0.2	0.31 ± 0.02

It was found that the hardness increased with increase in temperature up to 70°C indicating that the meat was less tender. Heating at higher temperatures between 80°-100°C did, however, lead to a slight decrease in hardness. The cohesiveness remained almost constant throughout.

DISCUSSION

The results of these experiments have shown that a series of well defined changes take place in the ultrastructure of fillet steak on heating.

There was a marked difference in the thermal stability of the A and I bands. The M line at the centre of the sarcomere, where the myosin filament changes polarity, was the most heat labile feature of the sarcomere structure. It disappeared at 50°C indicating that the myosin filaments have begun to denature. The I filaments appeared to be more heat stable than the myosin filaments shown by the continued presence of the fine period repeat (390 Å) along the I filament even after heating at 50°C. As the denaturation proceeded the myosin filaments of the A band coagulated to form a solid mass of denatured material, whereas the I filaments ruptured, producing gaps in the sarcomere structure and blobs of denatured material. These changes became particularly obvious at 70°C and above. Similar disruption of the sarcomere structure was reported by Weidemann et al (1967) in studies of beef semitendinosus cooked at 85°C (4), and Luyet (1966) in studies of cooked chicken muscle (5).

The collagen fibril fine structure disappeared at temperatures in excess of the shrinkage temperature of bovine collagen, 63°C, and disappeared rapidly at temperatures approaching 80°C at which collagen is converted to gelatin.

The changes in sarcomere length followed a similar pattern to the changes in fibre length reported by Landmann (12). He, however, reported a 15% decrease in fibre length at 61°C, whereas we detected no change in sarcomere length at 60°C, but a 15-25% shortening of the sarcomere at 70°C depending on the heating period.

It was surprising that there was no significant decrease in the texture parameters, hardness and cohesiveness, which corresponded to the disruption of the sarcomere structure. In particular we might have expected a decrease in hardness and cohesiveness to coincide with the disruption of the I filaments at 70° and 80°C. However, no such reduction was observed. It could be that a more obvious change would be apparent in measurements of elasticity or ease of tearing of the muscle fibres since these are more likely to be affected by a weakening of the structure due to the observed disruption of the sarcomere structure. Measurements of these changes will however, be complicated by the shortening of the sarcomeres and muscle fibres which has been shown to occur at temperatures of 70° and above.

The observed increase in the hardness value at 60°C and above, over that of the raw and 50°C values is probably due to the coagulation of the proteins. This must override any possible decrease in hardness or cohesiveness due to disruption of the sarcomere structure. The slight decrease in hardness which occurred at 70°C and above, could be due to the denaturation of the collagen fibrils which was first observed at 70°C.

The optimum conditions for cooking meat to give a desirable texture are often regarded as a compromise between a) the softening of the connective tissue and b) the hardening of the muscle fibres. The results of the current series of experiments could fit in with

this hypothesis since a decrease in hardness was only observed in cases where ultrastructural observations showed a denaturation of the collagen fibrils. The temperatures at which these changes occurred correspond to the internal temperatures of medium ($70^{\circ}C$) and well done ($80^{\circ}C$) steaks.

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