

25. The Effect of Cooking on Palatability

John Thompson

Learning objectives

Objective

This lecture describes the physical and chemical changes which occur in the cooking of meat.

Learning Objectives

At the end of this chapter you should;

- understand the physical and chemical changes which occur in connective tissue and myofibres when meat is cooked.
- know what the Maillard reaction is and how it contributes to flavour and colour attributes of meat
- know what factors impact on degree of doneness of meat and its importance to the consumer
- how does low temperature cooking impact on meat quality
- what is warmed over flavour in meat and what are the factors which contribute to its incidence

25.1 Introduction

Cooking impacts on the tenderness, flavour and juiciness of meat. Changes in meat tenderness with cooking occur from alterations in both the connective tissue and myofibre proteins in the meat. The application of heat solubilises collagen which increases tenderness, whereas heat denatures the myofibre protein and this results in toughness. Therefore the resultant tenderness of meat depends upon the relative contribution of both the connective tissue and myofibre components and their interaction with time and temperature of the cooking process.

Whilst different methods of cooking use different methods of heat transfer, it is largely time and temperature which control the cooking process. The colour of the cooked meat is important whether it is the degree of doneness of a steak or the browning on the outside of a roast which contributes much of the meaty flavour to beef. As consumers move towards meal ready products there are potential problems with warmed over flavour, although there are production/processing measures by which this can be avoided.

25.2 Presentation of meat

A range of cooking techniques are used in the final presentation of meat in a meal. Cooking and presentation have a large effect on the ultimate acceptability of the meal to the consumer.

The Cooking Process

Cooking is a process in which, due to the application of heat, **physical**, **chemical** and **microbiological** changes occur in the food finally leading to a palatable product.

Cooking is a process in which due to the application of heat results in a combination of

- physical
- chemical and
- microbiological changes occurring in the meat, finally leading to a palatable product.

Figure 25.1. Some of the many ways cooked meat may be presented to the consumer.
Photograph supplied by J. Thompson.



25.3 Physical and chemical changes during cooking

The effects of heating can be summarised as a toughening of meat fibres due to heat coagulation and shrinkage of the myofibrillar proteins and connective tissue, but with prolonged heating the collagen is converted to gelatine and tenderness increases. In terms of the resultant tenderness of cooked meat, the changes which occur in both myofibrillar and connective tissue structures are important, because of their sometimes opposing actions.

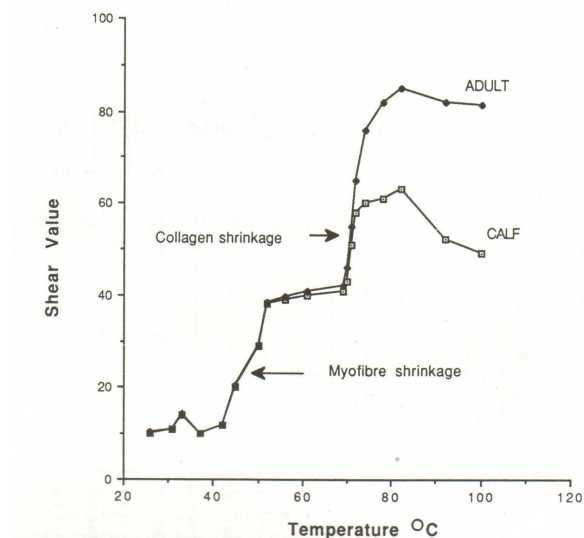
As the temperature increases the connective tissue net suddenly shortens, squeezing the meat so that water is released. As temperature is increased further the myofibres begin to denature and toughen. With further increases in temperature the connective structures begin to denature and shear force increases rapidly.

As internal temperature increases the myofibrillar toughness increases due to shrinkage and tightening of the myofibrils. If meat is only cooked for a short period of time, some connective tissue toughening occurs because of connective tissue shrinkage and tightening. However, if meat is cooked for long periods of time above the collagen shrinkage temperature ($60-65^{\circ}\text{C}$), then tenderness would increase due to the conversion of collagen to gelatine. When grilling steaks such as striploin (generally a low connective tissue content cut which is mostly cooked using dry heat methods), there was insufficient time for any connective tissue softening and so only myofibrillar toughening would occur. Consequently, when striploin steaks are cooked, it would follow that as internal temperature increased, so would toughness due to increased myofibrillar toughening. In this case the toughness would also be influenced by the quantity and quality of collagen in the steak.

As shown in the Figure 25.2 the changes in shear force show several stages in the cooking process

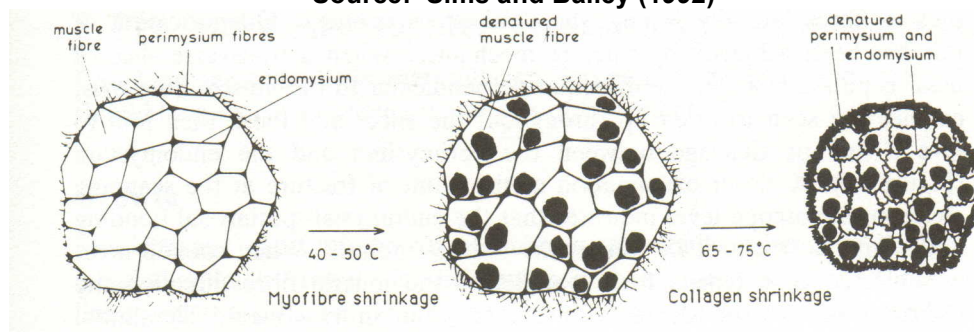
- initial toughening due to protein denaturation and myofibre shrinkage which commences when the meat is heated from 40 to 70°C .
- this is followed by a period of toughening due to connective tissue and then a period of tenderisation as gelatinisation occurs.

Figure 25.2 Changes in Shear Force with increases in temperature.
Source: Sims and Bailey, (1992)



Shrinkage of the myofibre (Figure 25.3) occurs at 40 to 50°C and this is followed by shrinkage of the connective tissue at 65-75°C, thus generating a tension which gives rise to extensive loss of fluid and an increase in toughness.

Figure 25.3 Diagrammatic representation of the shrinkage of muscles fibres during cooking.
Source: Sims and Bailey (1992)



25.4 The effect of cooking on protein denaturation

The different proteins become insoluble over a range of temperatures from 50 to 80°C

- At 50°C α-actinin, which is the most heat labile of the muscle proteins, become insoluble.
- At 55°C the light chains of myosin become insoluble,
- followed by actin at 70 - 80°C.
- Myosin and troponin, which are the most heat resistant proteins in muscle, become insoluble at 80°C.

The effect of cooking on collagen gelatinisation

To varying degrees, the toughening of contractile proteins during cooking is counteracted by changes in collagen. As temperature increased to 65 - 70°C there is an increase in shear values due to shrinkage of the perimysial collagen. At this stage of heating the perimysium collagen fibres changed from opaque inelastic fibres to translucent swollen elastic fibres. The shrinkage during denaturation generates a tension on the muscle fibres resulting in some fluid loss.

The older the animal the greater the tension generated which is consistent with tougher meat in older animals. Prolonged heating beyond 70°C will eventually result in an increase in tenderness, due to breaking the peptide bonds. In fresh meat connective tissue is of an order stronger than the myofibrillar proteins. However following cooking, muscle fibres denature and become stiffer and tougher, whilst collagen fibres denature and become weaker. Therefore the resultant toughness of cooked meat is related to the strongest component at the time of consumption.

Figure 25.4. Isometric tension experiment on 1, 2, 5 and 18 month rat tail tendons showing rapid increase in tension generated with age and the difference in residual strength of the older tendon. Source: Thompson, (2006).

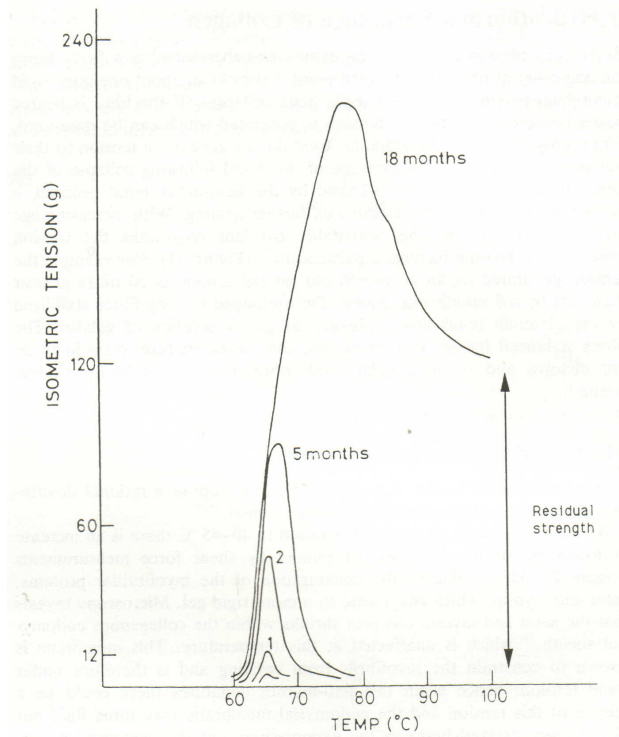


Figure 25.4 shows the effect of age on isometric tension in connective tissue from rat tail tendons. The connective tissue contribution varied with the age of the animal. In young animals the connective tissue component increased in tenderness from temperatures of 50°C, whereas in older animals the connective tissue contribution to tenderness did not commence until 60°C. Also at temperatures above 70°C the contribution of connective tissue to tenderness of cooked meat in young animals was negligible, whereas it was still substantial in older animals.

25.5 The effect of heat on muscle structure

As meat is cooked, moisture is released from the meat structure. This juice comprises

- water
- fat

plus many water and fat soluble compounds.

The expulsion of juice from the myofibrillar proteins has been attributed to the thermal shrinkage of both myofibrillar and connective tissue structures which occur with heating. The greatest amount of water expelled from meat during cooking is associated with collagen shrinkage, probably basement membrane collagen shrinkage, which is believed to be at a maximum between 57 and 63°C.

The moisture released during cooking is not only due to the tightening of the muscle structure, but also due to the proteins decrease in water holding capacity which occurs when muscle proteins become denatured. Water holding capacity has shown to decrease with increased temperatures and has been shown to be dependent on pH of raw and cooked muscle.

Water is held within the muscle as either free water (immobilised within the muscle tissue) which represents the major percentage of the total water content, or as hydrated water which is tightly bound to either myosin or actin. The influence of thermal treatment on the water holding capacity of muscle concerns mainly free water and not hydration water. However, as meat is heated, the hydrated water is released and makes its transition to free water, there is a decrease in the rate of temperature rise between 65 and 75°C which was attributed to the massive movement of water from one form to the other. Collagen shrinkage is the process presumed responsible for squeezing hydrated water from muscle fibres to its free form.

Maillard reaction

The Maillard reaction, also referred to as non-enzymatic browning, is a complex set of reactions that takes place between amines, usually from proteins and carbonyl compounds, generally sugars, especially glucose, fructose, maltose or lactose. The consequences of these reactions include the formation of many products, most of which have some impact on the flavour and appearance of the cooked food.

The Maillard reaction occurs when the proteins on the surface of the meat recombine with the sugars present. The combination creates the "meaty" flavour and changes the colour to brown. When meat is cooked, the outside reaches a higher temperature than the inside, triggering the Maillard reaction and creating the strongest flavours on the surface.

In the early twentieth century, Louis-Camille Maillard described the Maillard reaction when he was trying to understand how amino acids linked up to form proteins. He discovered that when he heated sugars and amino acids together, the mixture slowly turned brown. It was not until the 1940s that people noticed a connection between the browning reaction and flavour. World War II soldiers were complaining about their powdered eggs turning brown and developing unappealing flavours. After many studies done in laboratories, scientists figured out that the unappetizing tastes were coming from the browning reaction. Even though the eggs were stored at room temperature, the concentration of amino acids and sugars in the dehydrated mix was high enough to produce a reaction.

Most of the research done in the 1940s and 1950s centred around preventing this reaction. Eventually, however, scientists discovered the role the Maillard reaction plays in creating flavours and aromas. For example, as many as six hundred components have been identified in the aroma of browned beef. Until the Maillard reactions occur, meat continues to have relatively little flavour and the Maillard reactions generally only begin to occur above 140°C.

With braised or stewed meat, the temperature will never get above 100°C, so the Maillard reactions will never take place, and your meat will be cooked but will have relatively little flavour. This is why you are almost always instructed to brown the meat on all sides before adding it to the stew. In a pressure cooker the inside temperature is 250°C at 15psi so flavour is enhanced in all meats. Slow-cooking a roast in a low-temperature oven or cooking meats in a crockpot fails to set off the Maillard reactions, which is why some recipes encourage to brown first to develop the flavour of meat. The Maillard reactions occur only at the surface of the meat, because the moisture in the meat keeps the interior from getting above 100°C. In some instances the Maillard reaction is thought to be responsible for the development of bitter compounds.

Phospholipids may also contribute to meat flavour formation. In addition the nature of the changes in flavour suggested that the route that phospholipids promote meat flavour may involve their participation in the Maillard reaction (Farmer, 1992). Laboratory studies have shown that phospholipids conferred a more intense meaty aroma.

25.6 Doneness

Another meat component that changes during cooking is the colour of the myoglobin. Upon heating, the haem pigment turns from red to brown. This change in colour is typically used as an indication of degree of doneness, or cooking, of the meat. For beef an internal temperature of 60°C is generally considered to deliver rare beef, 70°C medium and 77-80°C well done. The susceptibility of the heme pigment to oxidation is much greater in the denatured protein than in the undenatured myoglobin.

At temperatures of greater than 90°C, caramelisation of the meat, or browning of muscle proteins begins. This is typically seen on the surface of a grilled steak. Initially the browning reaction may contribute a favourable taste, although at higher temperatures it may result in an undesirable bitter taste. The amount of brown colour is related to the level of reducing sugars in the meat.

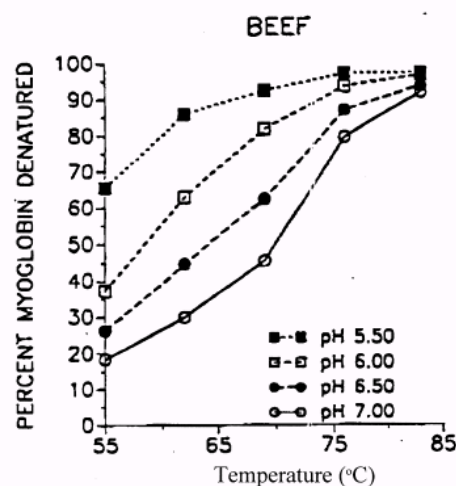
When meat is cooked, muscle fibres decrease in diameter by up to 15% and collagen is gelatinised to varying degrees. The degraded collagen around muscle fasciculi traps a multitude of molten fat droplets released from any marbling fat within the meat.

Maximum tenderness is reached when the meat reaches a certain temperature. This temperature differs between muscles and between animals, mostly in relation to the amount and strength of connective tissue.

Beef semitendinosus, for example, becomes increasingly tender up to 67°C and then becomes tougher at higher temperatures.

An early experiment by Trout (1989) used beef mince with varying amounts of lactic acid to create a wide range in ultimate pH. When these beef patties were cooked to set temperatures there was a large effect on the proportion of the myoglobin in the patties that was denatured (Fig. 25.5).

Figure 25.5. The relationship between temperature and the level of myoglobin denaturation.
Source: Trout, (1989)



The higher pH decreased the percent dematuration, particularly at the lower temperatures (ie high pH steaks appeared to be raw and undercooked compared to high pH steaks). Therefore under a set-time cooking regime, steaks with a high pH will reach a lower doneness score. Alternatively, high pH steaks need to be cooked longer to attain a similar degree of doneness to low pH steaks.

Doneness chart

A colour chart to assess doneness in cooked steaks has been developed by MSA (Fig. 25.6). This chart sets out the various degree of doneness to assist communication between chefs and their customers. It is used by a number of restaurants to either be displayed in the restaurant or on the menu.

Figure 25.6. A chart which demonstrates the range in degree of doneness is available from MSA. Source: Meat Standards Australia



A simple test to assess doneness of steaks

With practice you can tell when your meat is done with the touch of your finger or tongs. The texture of the various degrees of doneness of meat correspond closely to the feel of the fleshy part of your palm below the thumb. The more the meat is cooked, the harder the meat becomes as shown in Figure 25.7

The importance of doneness

The degree of doneness of steaks has a large effect on the consumer's perception of tenderness, taste, overall satisfaction, value for money and intent to repurchase.

Results of a large consumer study highlight the importance of doneness to the consumer (Cox et al 1997). Brief details and results from the study follow. A total of 3,554 consumers, who selected beef steak menu items at nine restaurants, were surveyed on their attitudes to beef and their assessment of beef steak meals. Consumers were asked to describe the menu item, their assessment of steak size and the degree of doneness of the steak, both as ordered and how they perceived it was delivered. Consumers rated the meal for tenderness, taste, overall satisfaction, value for money and intent to repurchase and were also asked their sex, age and attitude to beef.

Figure 25.7. Assessing doneness by the finger firmness method.

Source: www.exploratorium.edu/cooking/meat/



Rare

Touch your thumb and forefinger together and press on the fleshy part below your thumb (illustrated in the red circle in the photo) -- it should feel soft to the touch with your other forefinger and a little bouncy. This is how a rare steak feels.



Medium

Touch your thumb and middle finger together and press on the fleshy part below your thumb (see photo) -- there's some give and it's springy to the touch. A medium steak will feel the same.



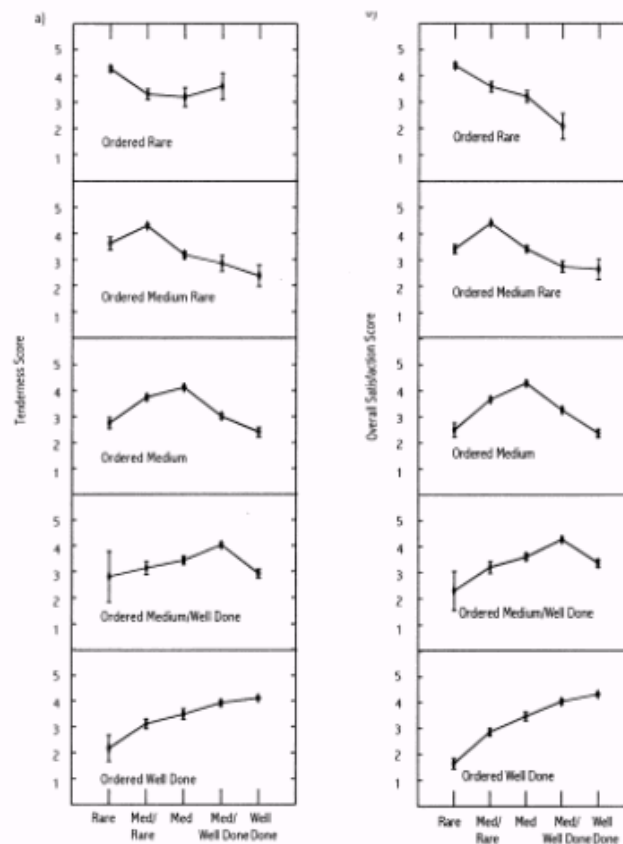
Well Done

Touch your thumb and little finger together and press on the fleshy part below your thumb (see photo) -- there's no give and it's quite firm. This is what a well-done steak feels like.

The average ordered degree of doneness for all consumers was medium. A total of 30% of consumers considered they did not receive their steaks cooked to their ordered degree of doneness. The interaction between ordered and delivered degree of doneness had a large effect on consumer scores for tenderness, taste, overall satisfaction, value for money and intent to repurchase. The maximum consumer scores were obtained when steaks were cooked to their ordered degree of doneness. If steaks were perceived not delivered as ordered, there was a decline in all consumer scores, with a greater penalty for over- than under-cooking. This study showed the dramatic penalty in consumer satisfaction for a chef failing to deliver a steak cooked to the ordered degree of doneness.

Figure 25.8 shows that, if consumers considered their steaks to be cooked and delivered to the appropriate degree of doneness, then there was no effect on sensory scores. However, if the consumer considered that the steaks were over- or under-cooked relative to their ordered doneness category, then their rating for all consumer criteria declined markedly.

Figure 25.8. Tenderness (a) and overall satisfaction (b) scores for steaks which were ordered from the five degrees of doneness categories (R=Rare, M/R=Medium/Rare, M=Medium, M/W=Medium/Well Done and D=Well Done) as a function of how the consumers perceived the actual degree of doneness of delivered steaks. Mean consumer scores were adjusted for company, restaurant within company, primal, steak size and consumer, age, sex and attitude towards meat. The bars represent standard error for each adjusted score.
Source: Cox et al, (1997). Printed with permission from Elsevier.



25.7 The effect of rate of heating and method of heat transfer on tenderness

Traditionally, the most beneficial method of cooking high quality cuts of beef (low connective tissue content such as the tenderloin and the striploin) has been to cook at high temperatures for a short period of time. The tenderisation effect of cooking meat for long periods at low temperatures has been attributed to collagen degradation or softening without extensive hardening of muscle fibres and possibly the retention of meat juices along with shrinkage of collagen.

It was reported that when cooking to an internal temperature of 60°C, a fast cooking rate resulted in a 10% decrease in steak tenderness. These steaks also had greater cooking losses than steaks cooked using medium or slow rates. The effects of cooking rate were smaller at higher internal end point temperatures (80 and 90°C). A number of authors have shown greater connective tissue contraction when samples were cooked to the same end point temperature by fast heating compared to slow heating methods. This greater contraction appeared to produce increased water loss and toughness with faster heating.

Topside (*M. semimembranosus*) samples cooked in a waterbath or roasted in an oven to a similar endpoint temperature (60°C), showed that the waterbath samples had a higher tenderness score (lower hardness, chewiness, shear cohesiveness and firmness objective measurements) than dry heat oven roasted samples. It was observed that the rate of heat penetration was slower for waterbath samples than oven roasted samples between 35-40, 50-55, and 55-60°C. The waterbath

samples were in the 50-60°C range 26% longer and the 55-60°C range 20% longer than oven roasted samples which could account for increased tenderness. It has been suggested that the slower rate of heating in the 57-60°C range may promote softening of connective tissue without hardening muscle fibres.

Meat cooked using extended cooking times showed a major decrease in shear occurred between four to six hours which was when the meat was heating between 50-60°C. A slower penetration of heat caused less juice loss and stated that, therefore, more collagenolytic activity could be retained in the meat.

The increase in tenderness associated with slow cooking may have resulted from samples being held at a temperature conducive to enzymatic tenderisation for a longer period of time. Cooking in an air forced oven effectively reduced cook times, but the dry air flow also initiated a drying effect on the cooked product which resulted in reduced moisture content and increased cooking loss.

Recent CRC studies have shown that extended cooking (up to 15 hours) resulted in a large decrease in both shear force and values. The tenderising effect occurred at an earlier cooking time in the young steers than the cows, suggesting that the application of heat took longer to affect tenderness in those samples with a more heat stable connective tissue

In addition to an improvement in mean tenderness, the variance of shear force measurements was halved suggesting a much more consistent product from extended cooking.

The effect of pre-cook temperature on tenderness

A number of studies have shown that an increase in pre-cook temperature (range 2 to 26°C) resulted in a decrease in tenderness, although the magnitude of the decline was variable. The possibility of a pre-cook temperature effect on tenderness of meat may have commercial implications which could be captured by new cooking technology.

A CRC study (Richardson et al 1997) investigated the effect of pre-cooking temperature on meat tenderness. The results from two experiments indicated that there was either no effect, or only a small difference in objective tenderness measurements when samples from stimulated carcasses were held at different pre-cook temperatures and cooked to either a set internal temperature, or for a set time. This outcome is in contrast to results from previous studies. It is difficult to suggest a mechanism which would give rise to all of the variation in results between studies. However it is possible that the differences may have been mediated by increased proteolysis or ageing in the pre-cook period, particularly in samples from unstimulated compared with stimulated carcasses.

Methods of cooking

There are basically three methods of heat transfer, convection, conduction and radiation. Usually the process of cooking meat involves more than one of these methods.

Methods of heat transfer

Convection

This is the simplest method of heat transfer. As a gas (air) or liquid (water) is heated the hot air or water expands and rises setting up circulating currents. The meat is cooked by the currents circulating around it.

Conduction

In this process the heat which consists of the vibrations of the molecules of the object being heated are passed onto the meat. Therefore meat in contact with a grilling plate is largely cooked by conduction.

Radiation

In this process radiant waves transfer heat to the meat. In conventional ovens infrared electromagnetic waves of radiant heat pass from the heat source to the pan and into the meat. Microwaves are a form of radiant energy used for cooking.

Methods of cooking meat

Grilling is usually for low connective tissue cuts whilst roasting is employed more on cuts which have a higher connective tissue content. More recently there has been research on combining several different cooking methods in a multistage procedure to produce the optimal meat quality outcomes .

Roasting

Roasting is a method by which heat is largely transmitted to the meat by convection in a closed oven. A high pre-heat temperature in the oven results in greater cooking loss and less yield, compared with a constant temperature throughout the cooking period. To ensure that end-point temperatures are achieved a meat thermometer should be inserted into the geometric centre of the roast (to get a true internal temperature of the meat the tip of the thermometer must not rest on bone, or in a seam of fat). When roasting added flavours will not penetrate more than a cm into the meat and therefore it makes little difference whether flavours and seasoning are added before or after cooking. Searing a roast does not assist in keeping in the meat juices, rather it gives the meat colour and aroma.

Grilling/broiling

Grilling and broiling are dry heat methods that largely uses radiant heat to cook the meat. As the heat usually radiates from one direction the steaks, or patties require turning. Broiling is generally used in most US Meat Science studies.

Microwave

Microwave cooking uses the heat from energised water molecules to cook the meat. A magnetron produces microwaves which are absorbed by the food causing the molecules within the food to vibrate against one another. These microwaves are a low level form of radiant energy with long wave lengths, so that their radiant energy is non-ionising. Friction is caused by the vibrating molecules causing a chain reaction from the outside where the microwaves initially hit the meat towards the centre resulting in heat penetration by conduction.

The primary advantage of microwave cooking is speed, with cooking times usually cut in half. Microwave cooking results in the greatest drip loss and generally results in the poorest palatability scores. Microwave cooking is particularly suited to heating pre-cooked and processed meats. As with other forms of cooking, 'standing time' which is used for heat equalisation after cooking is particularly important for microwave cooking where uneven heating is likely. Microwave cooking is very efficient in terms of energy usage typically using only 40 to 50% of the energy used by conventional cooking methods.

The effect of cooking from the frozen or fresh state on palatability

As discussed elsewhere freezing is a common practise in the meat industry as it allows meat to be kept for extended period with minimal deterioration in colour flavour and texture. There are some disadvantages associated with frozen storage such as freezer burn, product dehydration, rancidity, drip loss and product bleaching. Drip loss can be a particular problem if thawing— does not rapidly pass the meat through the temperature range of 10— to 2⁰C.

Several researchers have compared the impact on palatability in cooking from the fresh or frozen state. A recent experiment by Obuz and Dikeman (2003) found no differences in taste panel scores (tenderness, juiciness and flavour), or shear values between steaks cooked from the frozen or thawed states. Whereas frozen steaks required more time to cook and had a higher cooking loss, they had the advantage of thawing time being faster (and therefore less drip during thawing) and a lower risk of microbial growth. However overall the extra energy and higher cooking losses would outweigh these advantages and it would be preferable to cook steaks from the thawed state.

25.8 The effect of meat quality traits on the quality of cooked meat

Surprisingly there has been little work in this area, although it is one that is of great importance to the food services industry.

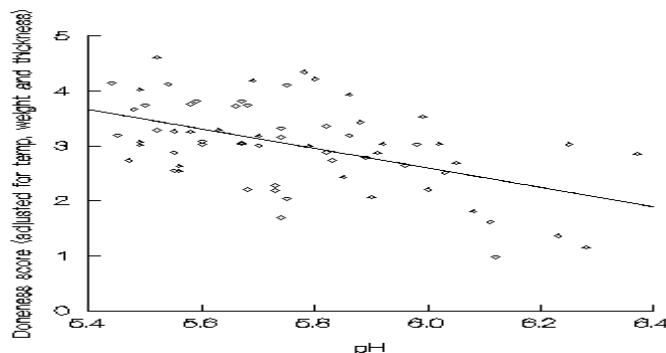
pH

A study by Cox et al (1994) examined the effect of Ph on degree of doneness in set time cooked fillet steaks. They showed that after adjustment for internal temperature, steak thickness and fresh weight there was a linear trend for a higher pH to result in a lower degree of doneness. As expected increased steak thickness resulted in a lower degree of doneness.

In the study by Cox et al (1994) the combination of internal steak temperature, pH, steak thickness and steak weight accounted for 70% of the variation in degree of doneness. However, even after adjusting for these factors, the residual $\pm$ standard error was still 0.7 doneness units, indicating that 48% and $\pm$ 16% of the steaks would still vary by at least 0.5 and 1.0 doneness scores, respectively. In a commercial operation, tight adherence to specification of these traits would make it possible to reduce variation in doneness. However in a real world situation there would still be some variation in these traits, plus variations between chefs and cooking equipment, so that it is unlikely that the tolerances in the above experiment would be easily achieved in industry.

A recent study examined the effect of pH on degree of doneness on fillet steaks cooked for a set time (Figure 25.9). It was shown that, after adjustment for internal temperature, steak thickness and fresh weight, there was a linear trend for a higher pH to result in a lower degree of doneness. .

Figure 25.9. The relationship between doneness (adjusted for cooking temperature, steak thickness and fresh weight) and fresh pH in 120 g fillet steak. Source: Cox et al (1994).



Marbling

The influence of intramuscular fat percentage on the palatability of beef is currently one of the most contentious issues in the Australian beef industry. The debate stems from the fact that Australian consumers actively discriminate against marbling in raw beef, which is in contrast to the opinions of some sectors of the food service industry who argue that marbling is desirable for eating quality. One of the perceived benefits of marbling in terms of palatability stems from the belief that marbling serves as protection against high temperature or prolonged cooking time.

In a recent study US study it was reported that the effect of marbling on palatability interacted with the internal cooking temperature end-point, ie marbling had an affect on tenderness only when steaks were taken to the higher temperature endpoint, or greater degrees of doneness. This result aligns with the food industry observation that marbling is there to act as a safeguard if steak is taken to the higher degrees of doneness.

Conversely, a recent study by the CRC (Rymill et al 1997) showed no evidence of an interaction between marbling and doneness on taste panel tenderness scores, which does not support the concept that high intramuscular fat levels are beneficial to eating quality when steaks cooked to a well done finish. There was however a slight positive effect of marbling on tenderness which showed that a 1% increase in intramuscular fat content resulted in a 1 unit increase in taste panel score (on a 100 point scale). Not surprisingly degree of doneness was considerably more important in producing tender and juicy steaks than was IMFat%.

Although the effects of marbling on palatability are still not well understood, there are effects on other attributes of the cooked product. Results from Clay Centre showed that cooking times were significantly decreased in steaks with a higher marbling score. This is because fat has a very low specific heat (ie it requires less energy to raise the temperature of fat compared to water). This is why fat or oils are used to assist the cooking process. There was also a trend for a shorter thawing time for steaks with lower marbling scores.

25.9 Warmed over flavour (WOF)

Warmed over flavour (WOF) is one of the primary causes of quality deterioration in cooked, refrigerated and pre-cooked frozen meat products. WOF is generally associated with reheated meats, which have been refrigerated for 18 hours or less. It can develop in pre-cooked frozen product in a few days, or weeks. WOF odours and flavours are commonly described by the terms stale, cardboard-like, painty or rancid. As western consumers move towards less time spent preparing a meal in the home and a greater proportion of their income on convenience food, WOF may become more of a problem.

What causes WOF

WOF is the oxidation of meat fats. Polyunsaturated fatty acids (PUFAS) are more likely to oxidise than saturated fats. PUFAS located primarily in the cell membrane as phospholipids are prone to lose additional hydrogen ions on the carbon atom adjacent to the points of unsaturation. When this occurs fat forms free radicals which are extremely reactive and tend to oxidise very quickly. Once the fat molecule takes up oxygen it tends to break apart into smaller molecules, such as pentanal, hexanal and 2,4-decadienal. These smaller molecules have the off-odours and flavours that are recognised as WOF. These substances are extremely volatile and can be detected at very low concentrations. These small molecules are fat-soluble and may partition into the fat phase where they are retained until the product is re-heated.

Because of their relative PUFA concentrations, the rate of WOF development is fish>poultry>pork>beef>lamb. A variety of things can trigger oxidation. Most either add enough energy to push the oxidation reaction into occurring (eg heat, light, oxidising enzymes), or they reduce the amount of energy necessary for the reaction to occur (eg metals, high-energy oxygen or enzymes).

Heat is the most common cause of the type of oxidation that gives rise to WOF.

Heat has a number of effects

- proteins coagulate so that they lose their functional capabilities,
- enzymes no longer assist with reactions,
- fibrous proteins no longer hold onto water so they shrink and the heme fraction can no longer hold onto the iron molecule.
- high temperature causes the release of oxygen and free iron as well promote the production of free radicals. The iron molecule, which the heme group usually protect from coming into contact with oxidisable substances, now comes into contact with the PUFAS.

Oxidation is a chain reaction. Once PUFA oxidation is initiated, it continues as PUFA free radicals catalyse additional free radical generating reactions. Therefore heating encourages oxidation to increase at a logarithmic rate. The addition of salt will also accelerate oxidation.

Metals (in addition to iron) such as copper, which can be supplied by the water, or via the addition of spices can also promote oxidation. Light especially certain wavelengths can also provide the additional energy to help the oxidation reaction get going. Blue, purple and fluorescent lights tend to be worse than other types (red-orange, tungsten halogen). As oxygen is an integral part of WOF formation, particle size is important. Grinding, churning and dicing will introduce oxygen and promote oxidation, particularly if the product is then cooked and/or stored for long periods.

Prevention of WOF

Prevention of WOF can be accomplished at several stages of the production chain. Supplementation of animals with Vitamin E will make the meat products less susceptible to oxidation. Vitamin E is a natural anti-oxidant which readily locates in the cell membrane where oxidation is likely to be a problem because of the concentration of PUFAS.

Nitrate is a powerful antioxidant. It is thought that this occurs because it may inhibit the ferrous iron release from the heme compound and stabilize the PUFA's. Herbs and spices can contribute a variety of anti-oxidants. Common spices with anti-oxidant properties include rosemary, sage, marjoram, thyme, and clove. The Maillard reaction - ie a reaction between amino acids and reducing sugars during heating to produce aroma compounds - produces anti-oxidants, which inhibit the formation of WOF.

Physical means of delaying the onset of WOF include oxygen exclusion by the use of technologies such as vacuum tumbling and vacuum stuffing prior to cooking and vacuum packaging of cooked products prior to storage. Light exclusion can also help in delaying the onset of WOF.

Readings

The following readings are available on CD:

1. Christensen, M., Purslow, P.P., Larsen, L.M., 2000. The effect of cooking temperature on mechanical properties of whole meat, single muscle fibres and perimysial connective tissue. Meat Science Vol 55 pp 301-307. Printed with permission from Elsevier.

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Summary

Summary Slides are available on CD

- As meat is cooked changes occur with both the connective tissue and myofibre components. As the temperature increases changes occur with shrinkage and denaturation of the myofibrillar proteins. This causes an expression of juice loss. The denaturation and gelatinisation of the myofibrillar protein increases the toughness as heat is applied. With the application of heat, connective tissue initially increases in tensile strength and then declines to a residual level, which is largely dependent on the level of crosslinking in the connective tissue. The component that contributes to the toughness of meat will depend upon the contributions of the contributions of the connective tissue and myofibrillar components and how much heat has been applied.

- As heat is applied to meat the myoglobin denatures and the colour of the cooked product changes from red to brown. A high pH decreases the percent of myoglobin which is denatured, and therefore under set time cooking high pH steaks appear considerably rarer than low pH steaks. Degree of doneness is an extremely important factor in determining consumer satisfaction.

- To achieve an even degree of doneness in steaks variation in pH must be controlled. Marbled steaks tend to thaw and cook more quickly than leaner steaks. The industry belief that marbling acts as an insurance against overcooking could not be substantiated. Extended cooking can result in gelatinisation of connective tissue without the myofibre hardening. The practice of pre-warming steaks prior to cooking is likely to be restricted to an increase in ageing and is unlikely to occur in stimulated product.

- Warmed over flavour (WOF) occurs in cooked product that has been chilled and then

reheated. It is caused by the oxidation of fats, which produces small amounts of extremely volatile compounds. The higher the level of unsaturation in the fat the more susceptible the product to warmed-over flavour. The oxidation of fats and the production of WOF can be triggered by reheating, addition of salt or some metals. Light can also trigger the oxidation reaction. WOF is inhibited by Vitamin E, nitrates and some herbs and spices and can be suppressed by exclusion of oxygen.

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