Heat treatment of meat: A review

Gabriela Bořilová, Iva Steinhauserová, Irena Svobodová

Department of Meat Hygiene and Technology
Faculty of Veterinary Hygiene and Ecology
University of Veterinary and Pharmaceutical Sciences Brno
Brno, Czech Republic

Abstract

Consumer acceptance of meat is strongly influenced by the sensory parameters of the final dish, and the cooking method has a great impact on these characteristics. The aim of the heat treatment of meat is the attainment of structural and chemical changes that make meat digestible and improve its sensory parameters. Conventional methods employed in the heat treatment of meat use conduction, radiation, convection or high-frequency heating. Heat treatment affects microbiological parameters and the chemical and sensory properties of meat, thereby contributing to improved digestibility, an increase in nutritional values and the assurance of the health safety of meat products.

Cooking methods, meat changes during heating, meat products, meat proteins, temperature

Introduction

Thanks to rich sources of nutritional constituents, meat is one of the basic foodstuffs in a healthy and balanced diet. Meat is an important source of high-quality proteins and an extremely good source of B vitamins, zinc, selenium, iron and phosphorous. Offal meats contain a significant amount of vitamin A and folic acid. The vast majority of meat and meat products are heat-treated before consumption. Heat treatment (cooking) is crucial for destroying foodborne pathogens, assuring microbial safety and achieving meat quality. Cooking also has an important effect on nutritional properties. Meat becomes edible and more digestible with cooking (Pathare and Roskilly 2016).

Meat proteins

Heat treatment represents the basic culinary preparation of meat before consumption. The aim of the heat treatment of meat is the attainment of structural and chemical changes that make meat tastier and more digestible (James and James 2014). Lean meat is comprised of approximately 75% water, 20% proteins and 5% fats and other substances. Proteins are denatured during heat treatment. Meat proteins can be divided into three basic groups that differ from one other in their physicochemical properties. The largest proportion is made up of myofibrillar proteins which make up around two-thirds of all meat proteins, are soluble only in salt solutions and are responsible for the toughness of meat. The most important myofibrillar proteins are actin and myosin, though around another twenty other proteins have been described. Myosin forms thick filaments, while actin forms thin filaments, and the two proteins bind around 80% of the water. The second group of proteins are sarcoplasmic proteins, which are soluble both in water and in salt solutions and make up 30 – 34% of meat proteins. There are around 50 different kinds of sarcoplasmic protein, the most of important of which are glycolytic enzymes and myoglobin. The proportion of myoglobin, oxymyoglobin and metmyoglobin influences meat colour. The last group of proteins are the proteins of connective tissue which are not soluble either in water or in salt solutions. Stromatic proteins are comprised primarily of collagen and elastin fibres surrounded by an amorphous intercellular substance composed of mucopolysaccharides. The commonest proteins in this group include collagen, which turns into gelatine at temperatures above 60 °C, and elastin and reticulin, which are both insoluble and thermoresistant. There are

Address for correspondence:

Ing. Gabriela Bořilová, Ph.D.
Department of Meat Hygiene and Technology
Faculty of Veterinary Hygiene and Ecology
University of Veterinary and Pharmaceutical Sciences Brno
Palackého tř. 1946/1, 612 42 Brno, Czech Republic

Tel: +420 541 56 2751
E-mail: gborilova@vfu.cz
www.maso-international.cz

a great many methods of heat treatment, all of which induce changes in the water content in meat and cause changes to the texture and structure of proteins and lead to their denaturation (Bejerholm et al. 2014).

The effect of temperature on meat proteins

The degree of denaturation of proteins depends on the type of protein and, in particular, on the temperature and, to a lesser extent, on its period of action (Baldwin 2012). During heat treatment, the temperature inside the meat increases from refrigeration temperatures to a minimum of 85 ºC. The temperature on the surface of the meat may, however, be extremely high – as much as 300 ºC. Observable structural changes begin at temperatures of around 40 ºC. In meat with a pH of around 5.4 (e.g. pork), such changes begin at temperatures above 30 ºC. The most significant changes occur at temperatures of between 50 and 70 ºC (Bejerholm et al. 2014).

Myofibrillar and stromatic proteins shrink with heat, while sarcoplasmic proteins lengthen. During heating, muscle fibres shrink both transversely and longitudinally, sarcoplasmic proteins coagulate and gelatinise and stromatic proteins shrink and dissolve. Shrinkage begins at temperatures of around 35 – 40 ºC; denaturation continues almost linearly up to temperatures above 80 ºC. The aggregation and gelation of sarcoplasmic proteins begins at around 40 ºC and ends at 60 ºC. Connective tissue begins to shrink at temperatures of around 60 ºC, though significant changes do not begin until around 65 ºC (Baldwin 2012). At 60 ºC, the spaces between muscle fibres close and longitudinal shrinkage of the myofibrils also begins. Longitudinal and transverse shrinkage of myofibrils causes water to be squeezed out of the meat. Shortening of the length of the sarcomeres and shrinkage of myofibrils continues with increasing temperature.

At temperatures between 40 and 60 ºC, transverse shrinkage of the muscle fibres occurs and the spaces between the actin and myosin expand. Above 60 – 65 ºC, the fibres shrink longitudinally and water is released from the meat (cooking loss). Collagen fibres are long chains of tropocollagen, which are intensively denatured at temperatures above 65 ºC with the formation of shorter water-soluble segments, and the collagen is gelatinised. Elastin fibres are not denatured by heat, but are themselves of a rubbery consistency.

The degree of heat treatment is also differentiated by the level of internal meat temperatures attained. We use the term *rare* when the meat internal cooking temperature reaches 50 ºC the term rare-medium when a temperature of 55 ºC is attained, the term medium when a temperature of 60 ºC is attained, and the term well done when a temperature above 70 ºC is attained. The colour of meat subjected to the same heat treatment is dependent on the speed at which heat is transmitted through the meat and the period of action. The faster the desired internal temperature is attained, the redder (bloodier) the meat will be; the slower this temperature is attained, the lighter in colour the meat will be (Baldwin 2012).

Changes to the tenderness of the meat also occur during heat treatment. The denaturation of actin and myosin causes toughening (hardening) of the meat that increases at temperatures above 50 ºC, falls briefly at 60 ºC and increases again as the temperature continues to rise. The denaturation of myosin is responsible for the initial toughening, the increased tenderness at around 60 ºC is induced by the denaturation of collagen, the denaturation of titin begins at around 70 ºC, and actin is denatured between 70 and 80 ºC. At temperatures above 75 ºC, the gelatinisation of collagen occurs and the meat becomes softer. Therefore, meat with a higher proportion of connective tissue must be cooked in a way that ensures that the meat internal temperature is sufficiently high in order for structural changes to the collagen fibres to occur (Fig. 1). The gelatinisation of collagen can also be attained at temperatures below 75 ºC if there is a sufficient amount of water present and if the cooking time is extended (Bejerholm et al. 2014).

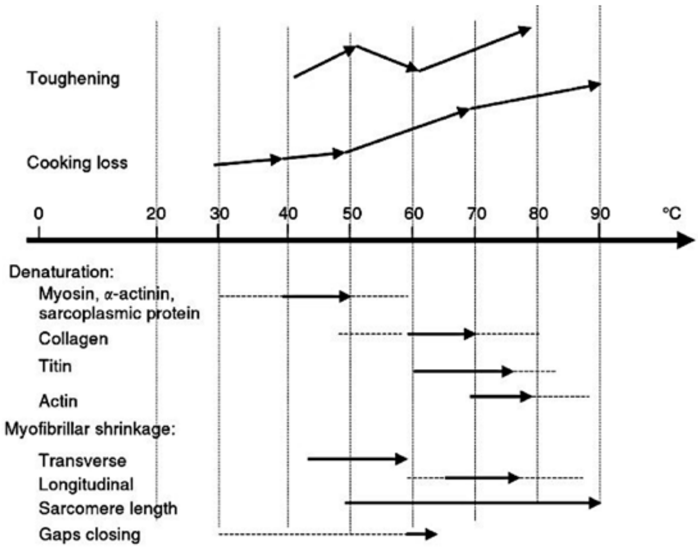

Fig. 1. Changes to meat during the course of cooking (Bejerholm et al. 2014)

Methods of heat treatment of meat

Conventional methods of heat treatment of meat use three different heating methods – conductance, radiation and convection, while untraditional methods transfer energy in other ways (e.g. microwaves) (James and James 2014). Methods of heat treatment of meat can be differentiated according to the heat source used:

- the use of dry heat (grilling, roasting and frying)
- the use of steam or water (boiling, steaming)
- the use of electromagnetic energy (microwaves)

Sometimes a combination of, e.g., dry heat and steam is used (convection ovens), while household microwave ovens sometimes have an added grill. The speed with which meat is heated through depends on its conductance and the initial surface temperature of the meat. The surface temperature is most strongly affected by the heat source, humidity and air circulation. An increase in air circulation also increases the heat conductance and evaporation from the meat surface, while a high level of humidity increases conductance and reduces weight losses resulting from the evaporation of liquids. Absorbed heat spreads in the direction from the surface to the meat core. Its speed of penetration depends on many factors including the type of meat, the amount of connective and fat tissue, size and shape (and, where applicable, weight), the ambient temperature, etc. It is, however, generally true that if temperatures are beneath 100 ºC, the meat is more evenly heated as a whole than when high temperatures are used (Fig. 2).

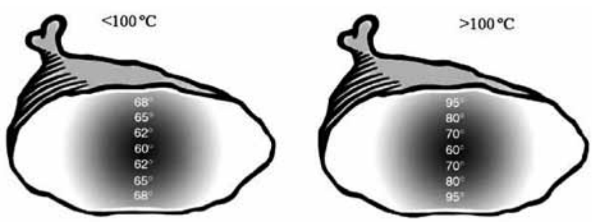

Fig. 2. Illustration of the thermal profile during cooking below 100 ºC and above 100 ºC (Bejerholm et al. 2014)

Cooking with dry heat

During roasting heat is transferred to the meat by the standard or forced circulation of air. The meat is usually placed horizontally on a shelf or grate in such a way that hot air can circulate around it. Under normal circumstances, the meat is not rotated or covered during roasting. The accelerated circulation of air shortens the period of time required for cooking (Bejerholm et al. 2014). The speed of heat treatment is monitored by means of the air temperature or measurement of the temperature of the product or according to the condensation of water vapour (James and James 2014). The temperature may be changed during roasting. Either low temperatures of 150 – 160 ºC, at which the meat is cooked more evenly, or high temperatures of as much as 250 ºC for a shorter period followed by a reduction in temperature and final roasting at around 150 ºC, are used. The use of lower temperatures (150 – 160 ºC) for the duration of roasting minimises weight losses and is particularly suitable for tender meat. The combination of hot air and steam with a higher cooking temperature is appropriate for meat with a large content of connective tissue (Bejerholm et al. 2014). Slow roasting (75 – 90 ºC) with greater humidity, with a roasting time two or three times as long, may be used to preserve juiciness when roasting large pieces of meat. Maillard reaction products are not produced during slow roasting and the taste of the meat is similar to that of boiled meat (James and James 2014). The Maillard reaction is a complex process during which the principal role is played by amino acids and reducing sugars (e.g. glucose, fructose and lactose). The aroma of cooked meat depends on the intensity of the Maillard reaction and the thermal degradation of fats. The reaction occurs at temperatures of around 130 ºC, while more intense browning and a more intense aroma are attained with the use of temperatures above 150 ºC. The intensity of the Maillard reaction increases further with higher temperatures, though it should be noted that the quantity of mutagenic substances formed also increases significantly at temperatures above 175 ºC (Baldwin 2012).

Steam cooking

Cooking in steam means heating meat in saturated air at atmospheric pressure and a temperature of 100 ºC. The pressure can be decreased or increased, which changes the temperature and cooking time. The use of steam increases the penetration of heat into the product (in comparison with the use of hot air) and thereby shortens the period of time required for cooking. If temperatures of less than 100 ºC are used, browning of the meat surface does not occur, though this is not detrimental for certain types of product (ham). Cooking in steam can be combined with the use of dry air in convection ovens (James and James 2014).

Cooking at low temperatures

Low-temperature heating over an extended period of time is at present a modern approach to cooking meat. Low temperatures generally increase the binding capacity of meat and improve its juiciness. Temperatures of less than 60 °C result in the shrinkage of transverse muscle fibres in particular, while higher temperatures cause shrinkage of also longitudinal fibres causing greater weight losses and reduced yield and resulting in greater toughness (Bejerholm et al. 2014).

The study by Becker et al. (2016) compares the effect of three different low temperatures and one method of conventional cooking. At cooking temperatures of 53 °C and 58 °C for a period of 20 hours, they demonstrated a statistically significant effect on meat tenderness in comparison with a high temperature. Meat cooked at 60 °C showed lower tenderness and better juiciness and also received a better sensory evaluation. Conventional heating to a core temperature of 80 °C at an oven temperature of 180 °C resulted in low eating quality due to high toughness and low juiciness.

Sous-vide is a special method for cooking meat. This method was developed in the 1970s and consists of the cooking of vacuum-packed meat in a water bath at temperatures between 50 and 85 °C. Sous-vide cooking requires a minimal temperature gradient and thereby limits damage to heat-sensitive proteins and supplements. Cooking losses are also reduced and juiciness preserved (Diaz et al. 2008). The long cooking time at low temperatures increases the solubility of intramuscular collagen, which significantly increases the juiciness and tenderness of the cooked meat. The advantages of the use of vacuum packaging are low weight losses, the prevention of oxidation during storage and faster softening of the meat in comparison with traditional roasting (Baldwin 2012 and Bejerholm et al. 2014).

Cooking with the use of electromagnetic energy

The cooking of meat by high-frequency heating must be divided into two types of heating – dielectric and microwave heating. During dielectric heating, the entire mass of the material is heated as deep as unabsorbed high-frequency energy penetrates. Even heating occurs only in homogenous foods and this type of cooking is not suitable for meat. Microwave cooking is an extremely popular method, particularly for defrosting and heating pre-prepared dishes. Microwaves are electromagnetic radiation at a frequency of 300 MHz to 300 GHz. The principle of microwave heating is the conversion of electromagnetic energy into thermal energy used for the preparation of meat (Bejerholm et al. 2014). The thermal effect is associated with the rotation of dipolar molecules (primarily water) in an alternating electric field at a high frequency of field polarity alternation. The internationally permitted frequencies for microwave heating are 896 (industrial use) and 2.450 MHz (household use). Microwaves are non-ionising radiation of a wavelength from 1 mm to 1 m. Devices for microwaving cooking are constructed as an oven and are used primarily in households. They are used industrially for tempering meat (to between -2 and -4 ºC) and for defrosting (James and James 2014). The time required for cooking depends on multiple factors, including the power of the oven. The basic difference over a conventional oven lies in the fact that heat is produced inside the meat and spreads towards the surface, leading to energy savings and small weight losses, for which reason the heating time is reduced to a half or a third in comparison with a traditional oven (Bejerholm et al. 2014). Actin and myosin are denatured and collagen dissolved during heat treatment. The amount of collagen dissolved is actually larger over the same period of time than in a conventional oven, though the cooking losses are higher. A larger quantity of vitamins such as retinol, thiamine and riboflavin is preserved in the meat due to the shorter preparation time. Cooking losses are also reduced by as much as 7% during the microwave heating of meat products with added polyphosphates. Meat containing bones, which reflect the radiation and lead to overheated meat in their vicinity, is not suitable for microwaving. Injecting meat with brine containing 1% salt and 0.3% polyphosphates to as much as 10% above its original weight is a relatively good guarantee of a product acceptable in terms of taste (Yarmand and Homayouni 2011). No Maillard reaction occurs during microwaving due to the low temperature on the surface of the meat and the low temperature of the surrounding air, and there is, therefore, no browning of the surface of the meat. This shortcoming may be eliminated by the addition of a grill – the meat is first heated with microwaves, after which the surface is grilled (Bejerholm et al. 2014).

High-pressure cooking

The use of a high pressure to cook meat is a relatively new method. The principle of the method lies in the action of a high pressure (50 MPa) on meat proteins and increases their solubility as a result of the depolymerisation of protein molecules which increases gelation and tenderness. A high pressure is extremely effective in attaining the required tenderisation of myofibrillar proteins, while having an extremely small effect on the intramuscular collagen in connective tissue. When meat or meat products are prepared, the devitalisation of undesirable microorganisms occurs while nutritionally important substances are preserved (Sun and Holley 2010).

Ohmic heating

Ohmic heating is an electro-heating technique. This system depends on the passage of an electric current through a food item that has electrical resistance (Stirling 1987). Electrical energy is converted into thermal energy and heat production depends on the voltage gradient and electrical conductivity (Wang and Farid 2015). Ohmic heating used for the cooking of meat products results in a rapid increase in temperature and thereby rapid cooking of the product. In addition to energy savings, ohmic heating also results in smaller weight losses and improved juiciness. A number of authors recommend the use of ohmic heating in combination with convection cooking methods, as ohmic heating on its own is not suitable for meat products containing a fat component. The heterogeneous structure of meat products causes the uneven distribution of heat in the fat and lean components of the product and results in undesirable changes in product colour and texture (Yildiz-Turp et al. 2013).

The assurance of health safety during the cooking of meat

Pasteurisation, during which vegetative forms of pathogenic microorganisms and the majority of saprophytic microflora are destroyed, and sterilisation, which also ensures the destruction of bacterial spores of both pathogenic and saprophytic microorganisms, are differentiated by the temperature during the heat treatment of meat. Sterilised products have a longer minimum storage life and, unlike pasteurised meat products, can be stored at room temperature.

In contrast, heat-treated products must be stored at refrigeration temperatures to prevent the reproduction of microorganisms that have not been destroyed by pasteurisation. Microbiological criteria for heat-treated meat products are based on the properties of *Listeria monocytogenes*, which is destroyed when a temperature of 70 ºC is maintained for a period of 2 minutes. Criteria for vacuum-packed products are based on the thermotolerance of vegetative forms of *Clostridium botulinum*, which require a temperature of 90 ºC for a period of 10 minutes for inactivation. Equivalents of the given temperature and time regimes are used in practice for various types of meat product (James and James 2014).

The rapid cooling of products following the thermal process is another important step. According to the valid legislation, products must be cooled after heat treatment to beneath 10 °C within 2 hours.

During the culinary preparation of meat, pathogenic microorganisms must be either devitalised or their quantity must be reduced to a safe limit. The most significant pathogenic microorganisms that may occur in meat include *Salmonella* spp., *Listeria monocytogenes* and *Escherichia coli.* A significant role is also played by *Clostridium perfringens*, *Clostridium botulinum*, *Bacillus cereus* and *Yersinia enterocolitica*. Treatment temperatures that must be attained throughout the whole meat product are recommended for the assurance of the safety of cooked meat. For example, the United States Department of Agriculture recommends a minimum cooking temperature of 62.8 ºC for steak, roast meat and fish, 76.7 ºC for pork and beef meat, 76.7 ºC for chicken breast, and 82 ºC for whole chicken (Pathare and Roskilly 2016).

In the European Union, microbiological requirements for meat and meat products are legislated by Commission Regulation (EC) No. 2073/2005, which gives particular consideration to *Salmonella* spp. and, in ready meals, also *Listeria monocytogenes.* For meat products cooked at high temperatures, values of temperature and time are stipulated by the national legislation for individual groups of meat products to ensure their safety.

In addition to the devitalisation of pathogenic and undesirable microorganisms, cooking also leads to the formation of a number of substances, some of which have toxic effects. Cooking leads, first and foremost, to Maillard reactions and the formation of hundreds of substances that are responsible for the typical taste, aroma and colour of meat and meat products. Some of these products (heterocyclic amino acids, acrolein, furan, acrylamide) may, however, have a negative effect on human health. Their formation depends primarily on temperature and the period of action of temperature. The substances that have a significant biological effect include advanced glycation end products and advanced lipoxidation end products. These products cause diabetes complications, kidney damage and oxidative stress, and have a pathological effect on inflammatory processes (Poulsen et al. 2013; Birlouez-Aragon et al. 2010 and Uribarri et al. 2005). The study conducted by Trevisan et al. (2016) discovered that grilling and frying hamburgers to an internal temperature below 90 °C leads to the formation of early-stage products (furosine) in particular. Fluorescent compounds (melanoidins) in particular were formed when the internal temperature was 90 – 100 °C, and similarly during meat roasting at temperatures of 180 – 240 °C. Advanced-stage products (carboxymethyl lysine) were detected at extreme temperatures of around 300 °C, though only in extremely small quantities. This is due to the small content of reducing sugar and the low lipid content, and also the fact that the core temperature of the product did not exceed 100 °C. The concentrations of acrylamide in grilled, fried and roast meat were extremely low. This is the result of the fact that acrylamides are formed by the reaction of free asparagine and reducing sugars during high-temperature cooking (above 120 °C) (Yu et al. 2014). The quantity of Maillard reaction products is negligible when meat is cooked by boiling.

Conclusions

The meat cooking method has a significant influence on the quality of meat dishes; it has a fundamental influence on the sensory parameters of meat, its digestibility and the assurance of the health safety of meat products. An understanding of heat-treatment processes, improvement to existing processes and investigation of new strategies for cooking methods are essential to the meat industry and consumers. Research should focus more on evaluation of the optimal process for the heat preparation of meat dishes to ensure an effective and rapid heat-treatment process with the lowest possible energy demands that ensures the health safety of the final product and results in a meat product attractive to the consumer in sensory terms.

Acknowledgements

This study was funded by the European Agricultural Fund for Rural Development (EAFRD) through the Rural Development Programme (RDP) of the Ministry of Agriculture of the Czech Republic (Grant No. 15/001/16220/453/000027).

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