THE MANY EFFECTS OF HEATING ON MEAT

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INTRODUCTION

Heating has many effects on meat structure, chemical composition, nutritional value, microbial flora and other properties. Cooking and/or reheating of meat or meat products is a compromise between sensory quality, microbiological quality and yield. The main variables in heating are temperature and time, but many other variables also have an effect. Very rarely does one treatment provide optimum conditions for every essential trait. Therefore, a cook or processor must always put the traits in a preference order and then choose the heat treatment according the requirements of the most important traits for him/her. This short review will discuss the complex field of meat heating in terms of technology. The phrase "heating" in this paper means temperatures over 50 °C. The effects of heating on meat proteins and tenderness has been repeatedly reviewed, and therefore this paper will only briefly touch on these areas.

THE EFFECT OF HEATING ON MEAT PROTEINS AND WATER-BINDING CAPACITY

The most important trait of meat is the water-binding capacity (WBC). The same chemical and structural factors that determine the water-binding also more or less determine most of the other important traits, especially the gelling of meat.

According to a review by Hamm (1972) heat affects the structure and WBC of myofibrillar proteins in the following manner. Between 35 - 50 °C the actomyosin molecules became unfolded. By 35 °C the aggregation of the unfolded protein chains to form new, rather labile bonds begins. Between 50 - 70 °C the unfolding of myofibrillar proteins proceeds, and new stable covalent bonds are formed causing a tight three-dimensional network of proteins. According to Hamm the distances between the filaments and protein molecules determine the amount of the bound water in the system. The formation of a tight network, consequently, means a decrease in WBC. At the same time chemical changes shift the isoelectric point up by 0.5 to 1.0 units and the pH value by 0.1 to 0.4 units. For example, if uncooked meat has a pH of about 5.7 (pH_{uc}), the actual pH will be after the heating at the isoelectric point, pH 6.1 (pH_c), which means, in addition to the effect of the tightening of the protein network, there is a minimum value for WBC (See arrow, Figure 1).

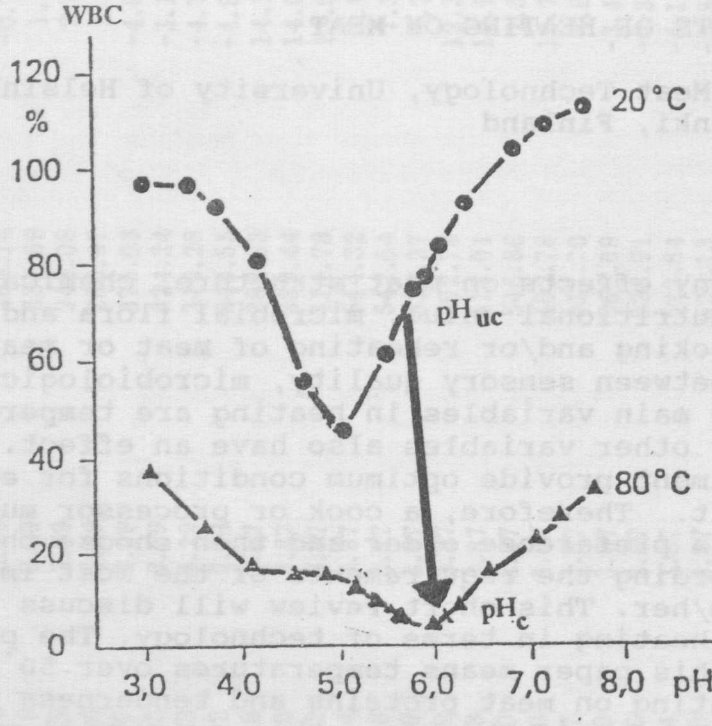

Figure 1. The effect of heating on the WBC and isoelectric point of meat (According to Hamm and Deatherage, 1960)

Bailey (review 1988) and Offer et al. (1989) showed that the volume of myofibrillar proteins in muscle fibers decreases markedly, when meat is heated to 60 °C, but endomysial connective tissue retains the water in its fibers. At higher temperatures, normally over 65 °C the connective tissue shrinks squeezing the water out of the fibers causing the cooking loss. This causes along with a weight loss a considerable toughening of the meat. Much remains to be discerned about the effects of connective tissue on the tenderness and juiciness of cooked meat.

The addition of salt changes the behaviour of the protein system remarkable, this change is even more marked if the salt is added with phosphate. Salt (NaCl) causes the swelling of myofibrils by increasing the negative net charge of the proteins (Hamm, review 1972) or by solubilizing the thick filaments so that the entropic pressure of the light meromyosin molecules generates the force for the swelling (Offer et al., 1989). The phosphates cleave the bonds between the actin and myosin heads, which makes the myosin molecules free for solubilization, if there is enough moisture to move the proteins from the myofibrils. Anyhow, these salts change the gelation properties tremendously. The proteins do not tend to aggregate as easily as they do without salts.

Many studies have shown that the optimum pH and salt concentrations for gel formation and rigidity is about 5.5 - 6.3 (5.8 - 6.1) (Trautman 1966, Ishioroshi et al. 1979, Puolanne & Matikkala 1980, Yasui et al. 1980, Acton et al. 1981) for pH and between 0.8 - 1.0 M NaCl (Hamm, review 1972, Ranken 1973, Grabowska & Hamm 1979, Ishioroshi et al. 1979, Puolanne & Ruusunen 1980) for salt concentration. In lean meat this means a salt content of about 5% (Hamm 1962), and the value for cooked sausages is 3-4 % (Niinivaara & Pohja 1954, Hermansson & Åkesson 1975), because of their higher fat content (Puolanne & Ruusunen 1980, 1983).

Phosphates increase the WBC by raising the pH-value and the ionic strength. These two changes represent about 50% of the effect produced by phosphates. The rest of the effect of phosphates is based on the specific effect of phosphates on the bivalent cations and thus on the dissociation of actomyosin. The relative value of these effects depends on salt content (Puolanne & Ruusunen 1980). The minimum salt content at which the specific effect of phosphates can be seen is about 1.0 - 1.3% NaCl, and the relative maximum of the effect is at salt contents of >1.5% NaCl. The effect of pre rigor salting is analogous to the specific effect of phosphates (Figure 2, based on the results of Puolanne & Terrell 1983). The similar effect is valid for salts other than NaCl. Thus when salts with or phosphates are added steps must be taken to prevent the eventual precipitation of the phosphate with salt ions, which jeopardizes the yield and quality of the product (Puolanne et al. 1988).

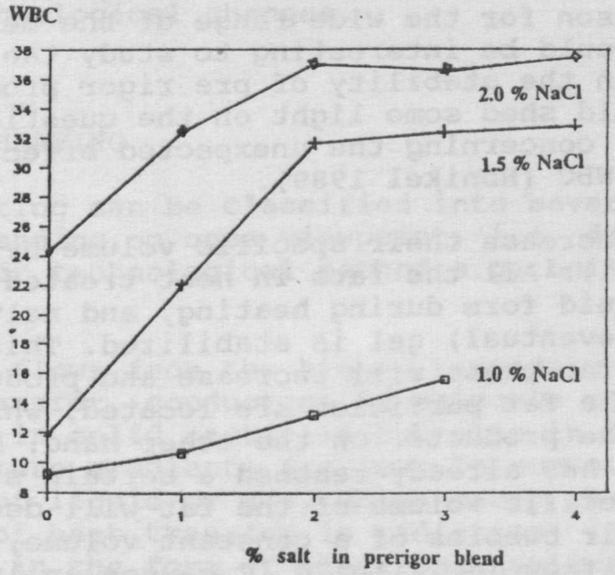

Figure 2. The effect of prerigor -curing of meat raw materials on the WBC of cooked sausage. A, B, C: salt contents of the final sausages. (According to Puolanne and Terrell, 1983)

Experience in the industry and research has shown that some time is needed for the salts to penetrate to the fibers and further on to the myofibrils. This is normally achieved by preblending (sausages) or by preinjection and tumbling, massaging etc., but in some very fast processes this may cause the problem of high cook losses. Offer et al. (1989) assume that the first stage of the changes caused on adding salt (dry salt or brine) is the diffusion of moisture from the fibers to the perimysial cavities, but later the salts penetrate into the fibers, and water also reenters the fibers. Depending on the particle size, this may need some minutes to several hours. Our preliminary observations have shown that if large meat particles are injected with excess of brine, more moisture than salt is lost with the excess brine than is expected from calculations of weight gain after the injection. This may mean that the excess brine coming out from the meat is diluted by the moisture from the fibers and extracellular fluids.

THE EFFECTS OF HEAT ON FATS

The melting temperatures of pork fat are 8-9 - 13-14 °C and 18-19 - 28-30 °C and of beef fat 3 - 14 and 18 - 30 °C (Townsend et al. 1968). The wide range of the melting temperatures are caused by the large number of different triglycerides in natural fats, each having a different melting temperature. Also polymorphism, i.e. the fact that the fats have the property of solidifying in several different "crystalline" (not real crystals) forms, due to the different cooling/heating history, is part of the reason for the wide range of the melting temperatures. It would be interesting to study the effects of the polymorphism on the stability of pre rigor processed products. This could shed some light on the questions raised by Prof. K-O. Honikel concerning the unexpected effects of pre rigor fats on the WBC (Honikel 1989).

When melted fats increase their specific volume by over 10% (Dugan, review 1971). All the fats in heat treated products all the fat are in liquid form during heating, and melting has taken place before the (eventual) gel is stabilized. This means that the volume of the fat phase will increase and produce tension in the spaces where the fat particles are located, which may affect the stability of the products. On the other hand, by the time it has cooled the gel has already reached a certain structure and volume, but the specific volume of the fat will decrease. In addition, in the air bubbles of a constant volume, the increase of the temperature from 15 °C to 70 °C causes an increase of vapour pressure and air pressure by about 0.5 atm., which also causes some tension in the batter.

THE EFFECTS OF HEAT ON MICROBES

Meat microbiology will be discussed in other session during this meeting, so I will only mention a few aspects that may be technologically important here. Most heat treated foods and products are pasteurized. This means normally that their surfaces have a rather low microbial load in the end of heat treatment, especially if the products are simultaneosly smoked. In the deeper layers and in the core of the article there are more microbes, the amount of which is a product of the sum of initial number and type of the flora, and the severity of the heat treatment. Normally, if the heat treatment has been adequate, the majority of the microbes are destroyed. The remaining relatively heat resistant ones are usually spores, mesophiles or thermophiles, but only seldom psychrotrophes. Because the elimination of all microbes (sterilization) reduces the quality of meat and is time, energy and technology intensive, pasteurization is usually preferred. This is normally enough for the distribution and market needs. Meat products normally get spoiled by surface microbes (Korkeala and Lindroth 1987), which means that the contamination comes after the heat treatment, i.e. during cooling, storage, packaging and/or contamination due packaging materials. This type of contamination cannot be controlled by cooking. An important exception might be **Listeria monocytogenes** that is relative heat resistant (survives a core temperature of 70 °C) and grows well in refrigeration temperatures. It remains to be seen whether cooking regimes must be changed because of **L. monocytogenes** and other "new" pathogens. If they have to be changed this may mean also other technological changes.

TECHNOLOGY OF HEATING

Methods of heating can be classified into several view categories depending on ones viewpoint, i.e. dry/moist, way of heat transfer or technological method e.g. boiling, roasting frying etc.

Thermal energy flows from the higher temperature to the lower. In the heat transfer, conduction is molecule mediated. It is found not only in solid particles but also in liquids and gases, if the temperature gradients are low. In convection there is always a flow of liquid or gas, which carry the energy involved. The third way of heat transfer is radiation, in which the energy is transferred in the form of electromagnetic radiation without a medium. Important factor to affect the thermal energy transfer are also the phase transformations. In the practice, usually two or three of the above mentioned effects affect the meat simultaneously.

When the effects of temperature on the cook loss is studied, the widely accepted theory is as described above in chapter "The effect of heating on meat proteins and water-binding capacity". This is the case in the procedures where the highest temperature of the system does not exceed about 80 °C. In dry heating and in deep frying the temperature of the heat source is much over the boiling point of water, and consequently the surface temperatures may be over the boiling point, which means far greater than the temperatures that are normally considered when the effects of heat are discussed.

The effects of dry heating and deep frying take place in three stages (Sköldebrand 1980). During the first stage the surface temperature (t_s) is less than the wet bulb temperature (t_w). Then moisture flows from the air to the product (dry heating). This flow is usually very small. The rate of the heat transfer is high due to the condensation of vapour on the surface. During the second stage, when $t_s=t_w$, the products starts to loose moisture. The moisture flows from the deeper areas to the surface at the same rate or faster than it evaporates from the surface. The rate of the heat transfer changes only very little. During the third stage, when $t_s>t_w$, there is not enough moisture on the surface, and the zone of evaporation moves towards deeper layers in the product. The rate of heat transfer to the product (less condensation on the surface) and in the product (steam flows towards the surface) decreases tremendously.

This kind of temperature profile has many consequences. Most of the WBC, given as expressible moisture, has been lost when the temperature reaches 60 °C, but the moisture is actually squeezed out, when the connective tissue shrinks at about 65 °C (Hamm, review 1972, Bailey, review 1988). Temperatures over the shrinkage temperature of connective tissue are first reached in the surface layers of the product, and at the same time the temperature in the deeper layers have reached the low WBC areas. The surface shrinkage presses the moisture out of the product, which causes a mass flow against the temperature gradient. This then causes a flow of cooler moisture to the surface, and also some heat energy already transferred to the product is removed from the product causing a delay in the temperature increase. Later, when the moisture has been lost as cooking loss, the core temperature raises rapidly (Puolanne, unpublished results). Therefore, the variations e.g. in the size, shape and WBC may cause differences in the temperature profiles of products, which are difficult to control and which can cause variations in the microbiological and organoleptic quality. This is particulary important when heated meats contain several muscles with different properties. Microwave heating, alone or in combination with other methods, may overcome some of these problems but, simultaneously, introduce new ones due to the differences in dielectric loss factor and structural properties of the product. - The effects of heating, although intensively studied for decades, still needs much more research.

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REFERENCES

- Acton, J.C., Hanna, M. and Satterlee, L. (1981) J. Food Biochem. 5:101.
- Bailey, A. (1988) Proc. 34th ICoMST, 152.
- Boyle, D.L., Sofos, J.N. and Schmidt, G.R. (1990) J.Food Sci. 55:325.
- Dugan, L.R., jr. (1971) By-products. The Science of Meat and Meat Products, W.H. Freeman and Co., San Francisco, 538.
- Grabowska, J. and Hamm, R. (1979) Fleischwirtschaft 59:1166.
- Hamm, R. (1962) Z.Lebensmittel-Untersuch. u. -Forsch. 116:511.
- Hamm, R. (1972) Kolloidchemie des Fleisches. Paul Parey, Berlin and Hamburg
- Hamm, R. and Deatherage, F.E. (1960) Food Research 25:587.
- Hermansson. A.-M. and Åkesson, C. (1975) J. Food Sci. 40:603.
- Honikel, K.-O. (1989) Personal communication, ICoMST 35, Copenhagen, Denmark.
- Ishioroshi, M., Samejima, K. and Yasui, T. (1979) J. Food Sci. 44:1280.
- Korkeala, H. and Lindroth, S. (1987) Int. J. Food Micr. 4:105.
- Niinivaara, F.P. and Pohja, M. (1954) Fleischwirtschaft 6:9.
- Offer, G., Knight, P., Jeacocke, R., Almond, R., Cousins, T., Elsey, J., Parsons, N., Sharp, A., Starr, R. and Purslow, P. (1989) Food Microstructure 8:151.
- Puolanne, E. and Matikkala, M. (1980) Fleischwirtschaft 60:1233.
- Puolanne, E. and Ruusunen, M. (1980) Fleischwirtschaft 60:1359.
- Puolanne, E. and Ruusunen, M. (1983) Fleischwirtschaft 63:238.
- Puolanne, E., Saarela, E. and Ruusunen, M. (1988) Proc. 34th ICoMST, 302.
- Puolanne, E. and Terrell, R.N. (1983) J. Food Sci. 48:1022.
- Ranken,M.D. (1973) Proc. 19th Eur. Meeting of Meat Res. Workers, I/5.
- Sköldebrand, C. (1980) J. Food Sci. 41:1047.
- Townsend, W.E., Ackerman, S.A., Riloff, J.A. and Swift, C.E. (1968) Food Technology 22:319.
- Trautman, J.C. (1966) J. Food Sci. 31:409.
- Yasui, T., Ishioroshi, M. and Samejima, M. (1980) J.Food Biochem. 4:61.