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COOKED MEAT PRODUCTS

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Introduction

The first mentions of meat products are from 3000 BC. Sausages, eventually fermented, were used then in the Mediterranean. It can be assumed that in homes meat has been cooked and smoked before that, and eventually kept for longer times than just for one day's use. According to Rust (1986) fermented meat products were preferred in the Mediterranean area, where warm climate required self-stable products, and in colder areas in Northern Europe cooked sausages were preferentially used. Originally, the concept of meat products was most probably first based on enhanced keepability, but later the flexibility of the formulation led to new benefits. Meat products may then have been mostly as they are largely still processor-oriented, but in our times, the needs of the consumers have became the most decisive in their production.

Meat products offer a rational way to use different parts of a carcass. In this form tenderness of the meat has no relevance, and taste and aroma can be designed within a very large range, according to consumer wishes. Keepability and consequently safety can be assured more rigidly than with fresh meat. Finally, meat products are ready to eat foods, or they can be easily prepared for a meal. Therefore, less time, effort and skill are needed.

In public discussion meat products are not often mentioned as a convenient and safe way of consuming meat. Today, they are more mentioned warningly as a source of fat, sodium, nitrite, phosphates, polycyclic aromatic compounds, process induced mutagenic compounds etc., or the low meat content or soya content are mentioned in a negative context. In most countries their reputation, especially that of sausages, is very poor, compared to meats.

In meat science, there has been less research on meat products and their technology than on fresh meat. Much research on meat products has been done by commercial companies or research establishments on contract bases, and therefore they are not being widely published. In many countries, however, the significance of meat products is increasing due to the increase of women going out to work and more single families, which means less time and eventually skills are available to cook meat. The challenge for the meat research is to find good ways to fulfill the future needs of the modern consumers and consumer segments.

There are many excellent reviews on meat structure, water-binding, gel-forming and various aspects of the usage of extenders. This review will not repeat all thit information which is already available in a concise form. This review deals mainly with structural aspects of meat products and their ingredients and discuss some technological matters that have not much been dealt with in the literature. Process technology and microbiology will be dealt with elsewhere during this meeting. The review concentrates on cured meat products, like cooked sausages and hams, and less so on other types, like hamburgers or ready to eat meat foods.

Water-binding

Most of the basic work on water-binding (or more precisely water-holding) and gel-forming has been done by Rainer Hamm (review, 1972) and Gerald Offer and coworkers (review, 1988). After these no comprehensive reviews or new fundamental findings in these areas have been published. The following summarizes the basic principles of their theories.

Hamm's hypothesis is based on the net charges of filaments. In pHs above the isoelectric point the proteins have (on average, there is no single isoelectric point in meat proteins) a negative net charge. Proteins with a negative net charge repulse each other, thus allowing water to get between the proteins. The main reasons for the changes in protein net charges are caused by pH and salts. The factor prohibiting the expansion of the protein network is crossbridges between the proteins. Hamm also points out that the repulsive forces are not dispelled by cooking. He stresses that the better the water-binding (water-holding) in raw meat or raw batter is, the better it will be in the cooked product. By this hypothesis also the phenomena seen in meat can be explained, e.g. the effects of pH, ions with different binding strength on meat proteins, pre rigor etc.

Offer's hypothesis points out that the changes in water-binding must depend on the expansion of the filament lattice. He describes the formation of a ionic "cloud" around the (negatively) charged filaments, and water is retained between the filaments by osmotic forces (osmotic pressure) causing the filament lattice to swell. After the formation of actomyosin in rigor the Z-line and actomyosin crossbridges prevent the unlimited swelling of the filament lattice (elastic pressure). The actual amount of bound water is therefore the result of an equilibrium between the osmotic pressure and the elastic pressure. Using this fact Offer is able to logically explain the phenomena experienced in meat and meat products.

Close scrutiny of these two approaches soon reveals evident that the differences between them are not particularly large. They both have the same starting point i.e. that filaments have a net charge. From this Hamm continues by stressing the repulsive forces and

Offer osmotic pressure. Both then stress the importance of crossbridges that inhibit the swelling. Offer is clearly able to demostrate that the filament lattice theory functions and that the repulsive forces are far too short-ranged to explain the observed differences in water-binding, when filaments are considered. However, although he criticizes Hamm's hypothesis for neglecting the filament lattice swelling, he concludes that the net charges and consequently the repulsive forces can be of significance between individual proteins, e.g. within a myosin filament, especially in meat products.

Therefore, it is necessary to summarize these two hypothesis from the cooked meat product point of view. In most cases, salt is added to cooked meat products, together with water and sometimes phosphates. If no water is added, the filament lattice cannot swell much, but cooking will cause exudate formation which depends inversely on the water-binding of the meat. The amount of proteins solubilized by salt will stay low because the amount of water available for solubilizing will be limited. Therefore, myofibrillar proteins will form aggregates basically where they are situated in intact sarcomeres. On the contrary, when salts and water are added, proteins tend to solubilize and partly move from their original places. When phosphates are added the actomyosin bonds will be widely cleaved and the filament lattice weakened and partly disrupted. When no mincing or chopping is utilized (e.g. ham) fibers tend to keep their original form, but the myofibrils and consequently the fibers swell. But when the process includes e.g. chopping which leads to a strong mixing and comminuting effect in the batter, the relative amount of solubilized protein will increase and move out from their original sarcomeres.

The author of this review points out that the following is not a result of his own research but merely based on combining loose facts. A rough estimate can be made about the average particle size in cooked sausage raw batter by calculating the average cutting distance in chopping. For example, if a chopper has six knives that rotate at 3000 rpm, the average length of the bowl round is π*1.15 m and the effective chopping time is 8 min., the average cutting distance is the distance of cutting/time*rpm*number of knives, i.e. 3 610 000 μm/8*3000*6 = 25 μm.

The sharp edge of a knife is about 10-100 μm, which means the width of a zone that will not bend along the knife but disrupts when the knife passes through the batter. This means that, on average, each point of the sausage batter will be covered by knife passing through, under normal industrial chopping practice. It can be assumed, though, that knives do not separate individual filaments but they mash fibers and consequently myofibrils (Hamm, review, 1972). As mentioned earlier, chopping means an intense mixing of ingredients, especially salts, phosphates and water. This also means that fat cells with a diameter from 2 to 100 μm will also be intensively disrupted. The fat particle size needed for a real emulsion (less than 1 μm) will rarely be reached, unless cavitation forces and temperature rise caused by the very fast moving knives (today they have a linear velocity of ca. 135 m/s) melt and disperse fat cells. A too long and intense chopping may have negative effects, possibly through high temperature and a too extensive dispersion of fat.

Hamm (review, 1972) discusses the effects of particle size on water-binding capacity. The smaller the particle size, the higher the water-binding capacity, but good water-binding also intensifies communition. The chopping allows the extensive comminution of the meat structure, but leaves fiber and myosin fractions. Salts, eventual phosphates and water continue a chemical disruption of the structure on the filamental and molecular level. It should be pointed out that connective tissue covering fiber bundles (perimysium) and fibers (endomysium) and also myofibrils (sarcoplasmic reticulum) are not solubilized by water and salts, and remain rather strongly bound to their sites. The less connective tissue there is and the weaker it is, the more easily the myofibrils swell thus also allowing more salt soluble protein to solubilize and then move out of the sarcomere (Puolanne *et al.,* 1983).

Solubilized myofibrillar protein will be free and able to form a gel (coagulate), different from that in swollen myofibril where it forms an aggregate. Provided that there is 70% meat in cooked sausage formulation there will be about 45% lean meat. This gives about 45g myofibrillar protein/kg. Grabowska and Hamm (1979) have found that in sausages with salt only ca. 20% of myofibrillar proteins are solubilized and ca. 35% with salt and phosphate, respectively. This means that the amount of solubilized myofibrillar protein is about 4-7g (salt only) and 15g (salt and phosphates). The amount of myosin that is the technologically most important protein is about half of the solubilized myofibrillar protein. The water of the sausage batter is still mainly within the myofibrils, and there is not much information about the actual amount of free actomyosin solution in the batter. The solubilized myofibrillar proteins form a continuous structure in raw batter and during cooking gel, as clearly shown e.g. by Katsaras (1991). The solubilized proteins cover eventual melted fat to an emulsion-like structure and also form a binding substance that binds the swollen fiber particles and myofibrils as well as fat particles into a viscous mass. This forms the solid but elastic structure of the cooked sausage. Studies have shown, however, that already 0.8% myosin in solution forms a stable gel by heating (Ishioroshi *et al.,* 1979). - The content of solubilized protein can be much less than mentioned above in a low quality sausage containing extenders, e.g. starch.

Water-binding capacity increases with increasing water addition (Hamm, review, 1972; Puolanne and Ruusunen, 1980a) This can be explained in the case of cured meat products by increasing the relative amount of solubilized myofibrillar protein, when the amount of available water increases. Although increased water addition enhance water-binding capacity, at a certain level the batter collapses during heating. This means that in any given formulation there is a minimum concentration of gel-forming factors that are able to build up a heat-stable gel. Exceeding that by dilution with water causes the collapse of the whole system, and consequently water and fat will be released.

Water-binding capacity can only be measured, when the actual amount of water exceeds the water-binding capacity, and the excess of water is released. Up to that point water-binding and water-binding capacity seem to be identical. The same can be shown in the opposite way, by plotting the meat content against the relative water-binding. When the relative increase is calculated (increase of bound water/meat added to the basic formulation), it is clearly seen that the higher the meat content, the lower the water-binding per additional weight unit of meat.

Fat-binding

Comminuted cured meat forms a viscous batter in which fat is finely distributed. According to the Hansen hypothesis (1960) the fat melts during the chopping, and then solubilized muscle protein forms a protein film on the melted fat thus stabilizing the "emulsion". Nowadays, this is not a complete explaination using the basic terms of colloid chemistry (an emulsion is a liquid-in-liquid suspension, where the smallest dimension of the particles in the dispersed phase is below 100 nm). First, meat fat is not in the liquid form in raw sausage batter, and additionally, the particle size is not only below 100nm, but most of the fat is in larger particles.

Fat binding is explained, though, by a very similar basis as water-binding. Some of the fat is indeed covered by proteins. Actomyosin is able to form a film on fat as do also other proteins, e.g. soy protein or milk protein. Shut and Brouver (1975) points out that milk proteins cover the fat particles faster than meat proteins thus "saving" meat proteins for water-binding and for forming a heat-stable gel. The more stable and firm the gel is, the better also fat will be retained in the sausage. It has been argued also that if larger proportions of solubilized meat proteins (for the amounts, see above), there can be a lack of gel-forming meat protein, and consequently the batter may collapse during cooking. This stresses the argument that the gel of a sausage is most important for a successful product.

Gel-formation

There is several excellent reviews on gel formation (e.g. Asghar *et al.* 1985) and therefore there is no need to present a comprehensive review here. Basically, in meat products the batter is a mixture of larger fibrous particles, fibers, myofibrilles, fat in various forms, solubilized protein, and eventually extenders, which all have different characteristics relative to the gel-formation in meat products.

In coarsely comminuted product the main structural components are meat particles that are fibers and fiber bundles, cut along different angles relative to the fiber axis. Here, the main aspect which is of interest, are swollen myofibrils that form aggregates of filaments during cooking. The more the filament lattice is swollen, the more it usually will be swollen also after cooking.

In finely comminuted products solubilized protein is of more importance. It forms (especially myosin) a heat-stable gel at a rather low concentration, less than 1% (Ishioroshi *et al.* 1979). In contrast to water-binding, gel strength is exponentially proportional to the concentration of the gel-forming protein (Asghar *et al.*, review, 1985). The slope of logarithmic function of gel strength varies between 1.7 to 2.0 suggesting that gel-formation is a reaction of second order. This seems reasonable, because gel strength is determined basically by crossbridges between the structural elements of the gel, and a bond is usually formed between two chains at any given point. The number of points that can form a crossbridge is proportional to square of reactive points in a given volume. In a complex system like meat product batter there is a number of additional factors influencing gel formation, e.g. pH, ionic strength, specific ions, e.g. bivalent ions, etc. thus causing variation.

The first stage of gel-forming is usually the unfolding of proteins, which means a change in their tertiary and quaternary structures. This is caused by the same factors, that influence the water-binding of meat, and heating. The second stage is the formation of new bonds by heating. (Asghar *et al.*, review, 1985).

A lot of research has been done, since Hansen (1960) introduced his hypothesis on emulsion-like structure of cooked meat raw batter, about the significance of solubilized protein in cooked sausage. Much of this research has since then based on the emulsion hypothesis. According to this hypothesis salt soluble proteins (mainly actomyosin) form a stabilizing film on the fat particles, and the rest of the actomyosin forms a gel thus stabilizing by heating the overall structure of the sausage. Today, it is thought that this is an oversimplification of the structure (see above). The key role of solubilized proteins is widely accepted, but according to the definition of an emulsion the term is not recommended to be used in connection with sausages. The phrase is still widely used in the scientific literature and in the practical life as well.

Extenders

Meat is the most expensive ingredient in meat products thus it makes them a relatively expensive food. In many countries extenders are used both to lower the price of the product and also to modify the organoleptic and technological quality. As with meat, the most important property of the extenders is their ability to retain water and form a gel on heating. Very many different kinds of extenders have been introduced to be used as meat products ingredients. They are mostly proteins or polysaccharides, from various sources.

The pH-value of cooked meat products is normally within the range 5.8 to 6.4. As water is usually added to the batter during the mixing, but when the temperature rises to over 60°C, meat and eventually other ingredients may release some of the moisture they originally contain or that they have hold during mixing. Therefore, extenders should hold added water throughout the whole process and/or be able to absorb released water during cooking. Additionally, they should be able to form a heat-stable gel on heating in the given temperature-pH-ionic environment.

As with meat, also with extenders (e.g. milk proteins, soy protein, potato starch) their contents in the product influence on the water-binding. When the content of added extender increases, the relative amount of extender-bound water (the weight of bound water per the weight of the additionally added extender) decreases hyperbolically. However, the effect of an extender on firmness, on the contrary, increases exponentially with the increasing content of the extender. For non-fat dry milk this is not clearly seen, because it is not a gel-forming ingredient, but potato starch, soy protein and connective tissue protein cause an exponential increase in firmness, when their contents in sausages are increased. When several extenders are used simultaneously, the weakest gel-forming ingredient may not actually have an effect on water-binding at all (Puolanne and Ruusunen 1983). It may, however, have on effect on firmness and/or on fat-binding, as the case with non-fat dry milk.

Aspects in the formulation

Basically sausage or ham formulation is easy. If organoleptic or nutritional quality is considered, meat content will be high, and the satisfactory water- and fat-binding will be achieved automatically. Economical aspects, however, result in products with less meat, and this in turn, leads to the need to also consider the binding capacities. By accident, the lean, fat, salt, phosphate and added water contents used today, with normal pH and cooking temperatures allow us to produce products that are widely accepted by the consumers. There is, however, increasing criticism of the salt (sodium) and fat contents of cooked meat products. This has resulted in an urgent need to reduce those ingredients. This in turn, evokes serious problems in formulation, if attemps are made to maintainthe same organoleptic quality.

The lowering of salt content or fat content, separately or simultaneously, causes a marked decrease in water-binding capacity and in the gel-forming ability of meat (Puolanne and Ruusunen, 1980b). When salt is reduced from the level of 2% or more, there is a linear decrease in water-binding. If that is done with the combined use of salt and phosphates, there is a sharp decrease in water-binding by about 1.5% NaCl. The lower the fat content, the higher will be the level of fast decrease, thus making the simultaneous lowering of salt and fat difficult. Finally, by lowering the salt close to 1% the sausage-type structure will not be achieved by any level of fat or water added, as the batter will disintegrate during cooking. The need to elevate the cooking temperature to compensate for the reduced microbial safety will increase the risk of sausages collapsing.

Linear model in formulation

The formulation of meat products can be based on various starting points. The first requirement is that the ingredients must hold all the water (e.g. sausages and other products in casings or respective closed systems) or most of the water (e.g. hams, not in casing or packaged). Then the second level of requirements is that a typical structure and consistency are achieved. The formulations are made using experience-based knowledge about the properties of the ingredients or, today more so, using alinear model to calculate the amounts in the formulation. The following discusses the bases of the linear model.

The linear model is based on the assumption that an ingredient holds the same amount water or fat (w/w) irrespective of their content in the formulation. This assumption should be treated with caution as it is only an approximation. Studies have shown (See above) that water influences the water-binding and the relative binding of ingredients is related to their contents in the formulation. The consistency is non-linearly related to the content. Finally, there are interactions between the various ingredients, and pH, ionic strength etc. influence the technological properties, which also means that one single figure cannot be given for the water-binding capacity of an ingredient, or for fat-binding capacity, respectively.

Therefore, there is some controversy over the use of linear modeling. When the water-binding is concerned, values are hyperbolically related to the level of their usage, but when firmness is concerned, they follow the exponential pattern. Nevertheless, the function is not linear. In a normal industrial formulation this does not cause much of an effect, and within the safety margins normally used, the bind values (or more precisely, firmness values) can be regarded as constants. Caution should be taken when ingredients are used at very different levels in different combinations. This is especially the case with extenders, because they can be used in such variable combinations.

Concluding remarks

Attemps to reduce fat and sodium of processed meats have resulted in the fact that the study of water- and fat-binding and gel-formation have again became more important. The problems have mostly been solved in the industry by adding non-meat ingredients (e.g. soy protein, caseinate, starch, carrageenan, or gelatin which is of meat origin. Also a method to use transglutaminase to increase the gel strength has been introduced.) that do not need salt for good binding properties, as meat does. Sometimes, low salt levels are even needed for optimal properties. Also, low-sodium salt mixtures are widely used, and very similar technological results are achieved, because the anions are more important from the technological point of view than cations. Therefore, technologically it seems possible to solve the problems associated with low salt and low fat formulations. It remains to be seen, however, whether consumers will accept the changes in organoleptic quality that are likely to follow this change.

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