Protein performance in emulsion stability

In a world of rapidly changing meat processing paradigms the processing variables have significantly changed

Both animal and vegetable origin proteins are biological products made up by amino acids designed for a wide variety of functions in living organisms. The amino acids predominantly determine the properties and performance of the specific proteins. The sequence of the amino acids – the building blocks of protein – will affect the chemical behaviour of the specific protein in terms of fat: water binding, gelation, and textural properties in processed meats.

By Henk W. Hoogenkamp

The individual amino acids that are linked together in sequence to form the protein molecules ultimately determine the properties of the protein performance. Amino acids can be hydrophobic or water-hating, or hydrophilic or water-loving. These properties determine the interaction with fat and water to form a protein film at the interface and also contribute to protein-linkage and form a firm gel during heating.

For whole muscle meats such as roast beef, the muscle structure remains largely intact. The addition of salt is also important to achieve some level of protein activation, swelling and solubilisation to increase water uptake.

The physical properties of protein like conformation, size and shape also influence the performance. Process variables such as acid or alkaline treatment as well as enzymic hydrolisation of the non-meat protein ingredients can be used to modify properties and performance. The same is true for the presence and possible interactions of added support ingredients or additives such as phosphate salt, stabilised rice bran, hydrocolloids and starches.

In processed emulsified meats, the major structural meat protein is myosin that ultimately ensures fat emulsification and water binding. Emulsion stability is influenced by a great many variables such as meat-type, pH, temperature, concentration, degree of fat cell disruption, and presence of additives and support ingredients. Also of importance are the processing conditions which influences the colloidal suspension of two immiscible liquids brought together by the stabilisation mechanism. In classical meat emulsions or meat batters, solubilised and swollen meat proteins act as emulsifying agents that surround liberated fat droplets to entrap and as such stabilise the emulsion prior to thermalisation.

Improvement protein performance

The significant impact of salt on myofibrillar proteins is due to the chloride ion that is negatively charged in solution. This feature will increase the negative charges on meat proteins which itself are already negative charged. This causes meat proteins to repel each other, increasing the space and increase water immobilisation.

There remains, however, some structural protein that cannot be manipulated by salt. To further improve protein performance of these proteins, phosphates can further assist in the release of actomyosin by virtue of widening the space between the actin and myosin filaments. Myosin in particular is valuable as a functional meat protein in meat emulsion stability because the protein molecule has highly effective water-soluble parts, thus, creating a strong interface between water and fat globules.

Extracted solubilised meat protein is crucial to the strength and stability of both raw and cooked emulsified meat products. Maximising or optimising meat proteins always should take priority before non-meat proteins are considered. Meat emulsions are complex mixtures containing solubilised and swollen meat protein, muscle fibre fragments, connective tissue, finely distributed fat/oil droplets, as well as other insoluble meat components and support functional ingredients and additives.

A high quality of the lean meat source usually generates a high (theoretical) extraction of salt-soluble myofibrillar protein. Therefore, lean bull meat and pork ham meat have above average extraction properties. It is not only the percentage of protein extraction a determining factor; also hearts have a high protein content, though a very low emulsifying capacity because the myofibrillar proteins are not soluble.

Pre-rigor meat proteins have high solubilisation because the actin and myosin has not cross-linked yet. Hot-boned meat used in pre-rigor form, however, is mostly an academic issue as its use presents many practical hurdles such as immediate use within 30 to 60 minutes after animal harvest.

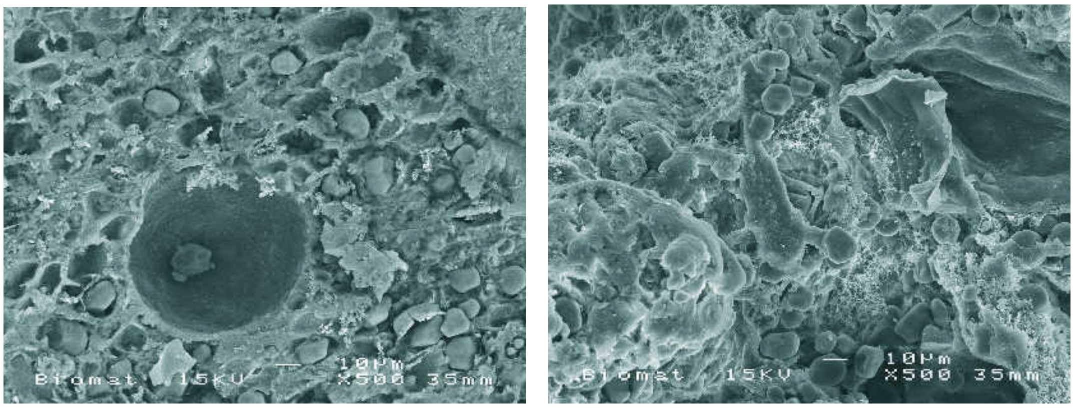
Interactions

Fat plays a major role in obtaining a stable meat emulsion. It is necessary to disrupt the fat cellular structure to liberate the fat for incorporation into the meat batter. The size of the fat/oil droplets is important as a smaller size usually increase its stability, provided sufficient solubilised protein is available to cover the fat surface area. This mechanism is referred to as interfacial adsorption. It depends on the type of protein if interfacial adsorption denatures the support protein. Much like egg albumen, upon heating solubilised myosin protein denatures. However, when sodium caseinate is used for this purpose, the interfacial adsorbed this milk protein derivative retains a pliable structure. This specific property is very important and partly explains why sodium caseinate is still the preferred choice when high degree of fat stability is needed in products such as canned or retorted frankfurter sausage.

In cases when there is insufficient solubilised protein available or protein with inadequate properties, the meat emulsion is weakened, and the fat expands during heating and subsequently breaks through the protein layer causing fat (and jelly) separation.

The influence of fat in processed meat products usually defines the quality of fat for the properties for which it is used. For example, high-quality fat is different in a frankfurter sausage as compared to softer types of fat used for liver spread. In a frankfurter-type sausage, high-quality fat should deliver and contribute to a firm texture. A variable fat texture, therefore, can be a concern for processors. It is known that genetic modification of pigs has generally resulted in leaner animals. Subsequently, this fat has a tendency to be softer because of the lower percentage of saturated fatty acids. Softer pork fat typically has a lower melting point and, subsequently, is more sensitive to processing variables such as stabilisation because softer fat liquefies more rapidly. Another potential drawback of softer fats is the tendency of oxidation and rancidity.

Considering above-mentioned criteria, it can be concluded that the selection of premium non-meat protein ingredients is



Scanning Electron Microscopic photograph of Stabilized Rice Bran (SRB) and Defatted Rice Bran (DRB) in a meat emulsion.

important to optimise fat stabilisation. For fats that need to undergo high processing temperatures such as canned frankfurter sausage or luncheon meat, sodium caseinate (a milk protein derivative) still remains the best choice.

Compared to pork- and chicken fat, beef- and mutton fat is firmer. Due to the typical nature, however, beef- and mutton fat are rather difficult to stabilise in a finely comminuted or emulsified meat product.

Rheological properties of beef fat can be influenced to a certain degree by feed and dietary regimens. For example, supplementation of animal feed regimens by Vitamin E, flax seed, rice oil and olive oil, can increase the amount of Omega-3 fatty acids and thus increase oxidative stability without affecting the processing properties of the fat.

Generally speaking, subcutaneous fat is preferred for emulsion-type of meat products. The triglycerides within the fat cells are linked to three fatty acid molecules of which the saturated fatty acids palmitic and stearic contribute to fat hardness and unsaturated fatty acids oleic and linoleic to softness and have lower melting points (30–15 °C)

In general, it can be concluded that short-chain saturated fatty acids are easier to emulsify than longer-chain fatty acids. Less saturated fatty acids are easier to emulsify than more saturated fatty acids.

These variables and observations are ultimately influencing the optimum end-point temperature of emulsified meat emulsions or meat batters. Usually these temperatures are 4–8 °C for chicken based emulsions, 14 °C for pork and >18 °C for beef and mutton fat based emulsions.

Hot water for ultra-high speed meat emulsion stabilisation

In the classical sense, the optimum temperature of water for the preparation of a finely comminuted meat emulsion (also known as meat batter or meat dough), is a no-brainer. Throughout the world, meat scientists and technologist agree that with help of salt and phosphate, ideally meat proteins need to be solubilised in a cold environment. The word 'cold' can be defined by attaining to a chopping or blending temperature range for lean meat salt and phosphate (if any) and some water or ice between –1 °C and +4 °C. To obtain these temperatures often ice is used during the first part of chopping or blending to maximise extraction of the salt soluble protein fractions of the myofibrillar proteins, prior to the addition of added non-meat protein ingredients, fat and other additives and ingredients. Until some years ago, fresh or thawed lean meat was used when added into the bowl chopper (U.S. terminology: "cutter") or mixer/blender.

However, in the modern sense, increasingly meat and especially mechanically deboned meat is used in (semi)frozen state, often in combination with ultra-high speed emulsifying equipment. For these innovative systems, such as Cozzini PrimeCut, the traditional use of water or ice can have detrimental effects on organoleptical quality as well as processing flaws.

In a world of rapidly changing meat processing paradigms, including major shifts towards the use of mechanically deboned poultry (MDM) as a main contributing component in the hot dog formula, the processing variables have significantly changed away from classical or traditional emulsification methods and time-tested know how guidelines and practical experience.

It is a known fact that the use of bowl chopper or cutters allows a greater freedom to manipulate emulsion properties and characteristics. The use of this equipment allows for staged addition and varying the chopping time and speed in order to optimise quality. In a country like Germany known for its premium quality sausage, operators of choppers and cutters generally are still the highest paid jobs in the meat plant simply because their expertise allowed fine-tuning of the specific formulae hard to achieve by automated high-speed processing equipment. The downside of manual operated choppers and cutters is an increased risks of product flaws caused by errors when less-skilled operators are in charge.

For a finely comminuted meat emulsion such as is needed for a hot dog or bologna type of sausage, choppers or cutters usually are used in tandem with a colloid mill. This set up will allow the preparation of a stable meat emulsion with the right degree of texture and chew. For many meat processors choppers and cutters as well as blenders in combination with a colloid mill are still the prefered method of processing. However, increasingly very large meat processors, including companies who need to harmonise manufacturing systems over more plants and countries, the batch-like systems will rapidly become obsolete and will be replaced by in-line continuous meat emulsion systems. The latter is also true for highly automated and computerised in-line co-extrusion systems such as Marel Townsend QX.

These high throughput continuous meat emulsion lines generally do not provide the luxury of staged addition of meat, fat and ingredients and manipulation of temperature. These drawbacks are substituted by major advantages such as increased capacity, elimination of processing errors, cost reductions and increased processing efficiency. The rapid progress of large and fully automated meat processing systems continue the "Cozzinification" of global meat processing industry.

If not addressed properly, the major stumbling block of implementing innovative ultra-high speed meat emulsion equipment are the difficulties in achieving optimum blending and emulsification temperatures when adhering to traditional processing know-how.

Because of the high throughput and microbiological requirements using high amounts of MDM, it is not an option to defrost or thaw-out frozen meat blocks. Subsequently, the (part) frozen meat blocks are coarsely ground, flaked or shaved. Auguring the meat into the large mixer/blender together with all other remaining meat follows this step and, fat sources as well as water, additives and functional ingredients. If regular tap water is used, even at prolonged pre-blending up to 30 minutes, the temperature of the coarse meat mixture will stay below

0 °C. Once a homogeneous mixture has been obtained the mixer/blender unloads its contents in-line into the ultra-high speed emulsifier, which usually increases the temperature by 6 to 8 °C. This raise in temperature often is insufficient and can create a number of issues:

- Unexplainable temperature variations in both pre-blending and final emulsification.
- Too liquid, watery or soft meat mixture appearance at pre-stage in mixer/blender.
- Premature water separation in holding bins and/or stuffer.
- Variations in controlling stuffing weights.
- Reduced surface stickiness of cooked hot dog causing extra rejects prior to post-pasteurisation packaging.
- Reduced adhesion of liquid smoke and uneven smoke appearance i.e. light spots.
- Softer texture.

Facts about pork fat

Tab.: Composition

Saturated	38–43 %	Palmitic acid	25–28 %
		Stearic acid	12–14 %
		Myristic acid	1 %
Unsaturated	56–62 %		
Monounsaturated	47–50 %	Oleic acid	44–47 %
		Palmitoleic acid	3 %

Source: Hoogenkamp — Fleischwirtschaft International 3/2011

- Secondary purge and product returns from point of sale.
- Perceived higher salt levels.

Besides the intrinsic differences from a traditional meat emulsion preparation and the ultra-high speed in-line emulsification technology, there are other variables to consider:

- Length of meat emulsion transport pipes.
- Design of emulsion flow, especially directional change of pipes and possible uneven surface within can negatively affect stability of the meat emulsion.
- Holding time prior to stuffing.
- Performance of non-meat protein ingredients such as soy protein.
- Selection criteria of other meat emulsion enhancing ingredients such as stabilised rice bran.

In general terms it can be concluded that MDM-based hot dog formulae should have the following final emulsification temperatures:

- Poultry based formulas' 8–10 °C
- Pork based formulas' 12–14 °C
- Beef based formulas' 18–20 °C (Beef fat has a dual melting point and also allows – under certain conditions – processing conditions around 0–2 °C.)

Emulsion stability variables

The type of fat and its temperature treatment prior to emulsification, as well as the specific system used for size-reduction or grinding will greatly influence emulsion stability. The fat content in this respect is a major variable; especially higher amounts of fat typically require higher amounts of protein for stabilisation. Typically U.S. hot dog formulae have an analytical fat content of just below 30%, while in Asia fat contents are approximately 10%. It is also true that in many parts of the world, including Europe, South America, Africa and Asia total lean meat content is very low which always will require heavy use of soy protein binders boosted by starch, hydrocolloids and stabilised rice bran.

The presence of pork leaf (flare) fat, beef fat, mutton fat, chicken fat and other sources of soft adipose material negatively influences stability and texture. This can result in the famous description of "fattening out" of the hot dog while still in cellulose casing. In the good old days, these problems were mainly eliminated by the use of a pre-emulsion made from the unstable fat sources and sodium caseinate (a milk protein derivative). This method is still widely in use in countries or regions such as Germany that produce high quality traditional sausage. However, for low-cost and continuous in-line processing equipment, the use of pre-made fat:water emulsions is not considered practical. Moreover, the price of sodium caseinate has increased to the point that its use is difficult to justify; perhaps with the exception of hot dogs or frankfurter sausage that is sterilised in cans. For these applications the use of sodium caseinate is still considered essential. The latter is also true when vegetable oil is used as animal fat augmentation, as is very typical for meat emulsions in the Middle East such as Turkey, Iran.

Temperature adjustment in combination with sharp cutting action will greatly benefit a high level of fat or oil liberation. The latter is of the utmost importance to allow interfacial adhesion of functional proteins. Although scientifically speaking, the use of warm or hot water for the preparation of meat emulsions is not recommended, there now are specific conditions in which the use of warm water will become a viable option. This is also the case now that MDM in combination with ultra-high emulsification equipment has become the norm for high speed and high capacity operations.

The important question that needs to be answered is: "How high water temperature can be used before it negatively causes premature denaturation of myofibrillar meat protein (SSP) causing irreversible damage to the structuring and building of a stable emulsion integrity?"

For hot dog formulae that contain low amounts of (semi) frozen lean met and high amounts (semi)frozen MDM and fat, it is possible to use warm water during the pre-blending. It generally is a matter of trial and error to determine the optimum water temperature, but many large-scale plant trials have confirmed that added water can be metered in at a temperature of 30 to 45 °C.

During the pre-blending the warmer environment will make the cellular structure of the fat cells more pliable and once the cell walls are disrupted the functional lipophyllic regions of the solubilised proteins will coat the free fat or oil droplets, and thus prevents coalescence during termalisation further down the processing line. Additionally, the warmer environment will allow added soy protein binders to build a better structuring matrix of the meat emulsion.

More variables

Although high fat levels may result in a softer texture, the use of warm water generally improves bite and overall organoleptical appearance, not to mention improved cooking yield, while significantly reducing or eliminating purge during post-pasteurisation. Although the use of warm or hot water can significantly improve meat emulsion stability and textural properties, there are some more variables to take into consideration:

- Type of emulsifier motor: 125 or 150 hp can make significant differences.
- Speed of cutting head of the ultra-high speed mill: 1800 or 2000 RPM.
- Temperature difference between meat inlet and meat outlet: For frozen meat or MDM formulated products usually a temperature rise of 8 to 16 °C is necessary.
- Size reduction of pork-skin (rinds) – if any – is a very important variable. In the final meat emulsion pork-skin should be reduced to 1.3 mm, which means that also the size of the pork-skin during pre-blending should be appropriately adjusted.
- Secondary purge in post-pasteurised hot dogs not only negatively affects shelf life and increase product returns, it also increases consumer complaints because of perceived high salt levels.

To improve texture and to avoid purge, the selection criteria of functional ingredients become even more important. For soy protein binders this generally means that high gelling types might be beneficial as its use will increase viscosity and thus increase friction. The latter contributes to the much-needed rise in temperature prior to final emulsification. However great care should be taken that the added soy protein binders have sufficient time to hydrate, swell, solubilise and unfold. Cutting corners can have detrimental effect on end-product quality and should not be allowed at this point as otherwise the soy protein will perform sub-standard and negatively affects product end-product specification. Therefore, if the mixing/blending needs to be interrupted because of line calamities it is always preferred to temporarily stop after the soy protein binders are added and well distributed throughout the meat formula components.

The use of collagen protein and plasma protein – such as the VEOS ingredients – can significantly assist in further optimising the textural quality of the hot dog. These collagen and plasma protein behave very synergistically with MDM and assist in creating a meaty appearance beyond what soy protein can offer. Furthermore, the use of 1 to 2% of stabilised rice bran – such as NutraCea RiBran – will assist to reinforce the meat emulsion structure in the sense that it will stay 'active' during the processing cycle and at point of secondary heating. To achieve a high throughput, as well as meeting end product specifications, coextrusion and processing variables including formulations, need to be carefully synchronised.

Salt and phosphate solutions

The effect of salt is greatly increased if used in conjunction with phosphate. Basic phosphates have a relatively high pH that typically raises meat pH by 0.2 to 0.5 pH units. This itself will improve protein performance because – everything else being equal – any increase in pH means that there are less H+ ions in the system. Fewer H+ ions result in a greater negative charge on meat proteins, which cause the myosin protein to swell or solubilised more and bind more water. Anything that increase meat pH will improve meat protein performance, including sodium hydroxide or sodium carbonate.

Seen from a worldwide perspective, phosphate is the most popular and appropriate method to manipulate meat pH, especially because phosphates can dissolve some of the structural proteins in the meat muscle that are not affected by salt. Additionally, now that modern dietary guidelines are aiming for sodium reduction in the daily diet, phosphates can be used to partially replace salt. Also, sodium hydroxide and sodium bicarbonate can be considered and be used in conjunction with phosphates – at levels up to 20% of the phosphate used – to increase product pH.

Phosphate also depolymerises the actin and myosin filaments meaning further swelling and release of functional protein from the filaments. These variables will gain importance when reducing sodium content in processed meat to meet dietary guidelines.

pH and solubility in water are two critical properties of phosphates. pH ranges from pH <5.0 to >pH 10.0. Solubility is measured in grams of phosphate in grams of water and can range from 10 to 100 g per 100 g of water. Phosphate also can be classified from single units (orthophosphate) to double (pyrophosphate), triple (tripolyphosphate) and multiple phosphate (polyphosphate) chains.

Salt has a specific impact on the net-electrostatic charge associated with the proteins. The net-charge on proteins is due to the amino acids that can be positively charged (+), negatively charged (–), or neutral (nonpolar). To improve upon water binding it is important to create an environment of increasing the space within the structure for more water to be immobilised. Because chloride is negative, it neutralises the positive protein sites and the result is a greater net-negative charge on the proteins that causes the protein to move farther apart and the extra space will allow the meat structure to swell and absorb water.

Phosphates are known to have antioxidative properties by chelating or tying up metal ions. The chemical formula for phosphate is PO4, which indicates one phosphorus and four oxygen molecules in each phosphate. The unique chemical structure of the phosphate molecule enables various types of phosphates to perform in meat systems.

Phosphates can be difficult to mix into solution and this is especially true for sodium polyphosphate (STPP). However, blending specific types of phosphates can improve upon solubility characteristics. For example, adding hexametaphosphate to STPP improves dissolving properties significantly.

Acid phosphates are typically excellent at improving meat protein extraction, but not really good at increasing water-holding capacity. Hexametphosphates are very good a chelating metal ions, which may improve colour stabilisation. Acid phosphates are also often used to improve the flow of the meat emulsion or meat batter, which will allow pumping the raw meat emulsion over longer distances without causing premature breakdown.

For meat emulsions, generally pyrophosphates (diphosphates) are the preferred choice as these support raw emulsions to be more rapidly processed including smoking and cooking steps. Tetrasodium pyrophosphate should preferable be used together with other types of phosphate, as it has a very high pH and can result in a soapy flavour when in contact with fat. Acid pyrophosphates should not be used as a single additive, as it has a low pH that can affect yields considerable. Usually, a blended combination of phosphates performs best.

As a side note: although tripolyphosphate will act more slowly during curing, for curing brines it actually improves water-holding capacity. For whole muscle meats, therefore, a combination of sodium tripolyphosphate and sodium hexametaphosphate is an ideal combination.

Phosphates are very effective compounds or additives of maximising or optimising meat protein performance. Pyrophosphate typically diffuses most quickly in injected muscle parts followed by tripolyphosphate (STPP). These phosphates also are very influential in actomyosin dissociation and the removal of protein structures that resist swelling and solubilisation.

At a higher pH, the myofibrillar proteins are both more soluble and functional in performance. Salt (sodium chloride or NaCl) is the most important and effective additive for protein extraction. Salt addition will not depolymerise and disintegrate to solubilised myofibrillar protein unless an ionic strength of about 0.5 or higher is achieved. The right ionic strength is of great importance as either too low or too high salt levels causes' sub-optimum extraction levels while it also can be noted that too-high salt levels can prematurely denature the myofibrillar protein rendering these useless.

Ionic strength is determined by the ion concentration in the water phase of the product. In a typical meat emulsion containing 60% total water, 2% salt equals approximately 0.5 ionic strength. Increasing salt levels will also increase myofibrillar protein extraction to a certain point. Once this point is reached the solubilisation mechanism quickly becomes detrimental to end-product quality. Too much salt addition calculated to the lean meat amount during blending or chopping will damage the protein and denatures its ability to perform. Excessive salt addition early during meat (pre) blending is an error that rather frequently occurs and cause premature denaturation of valuable meat protein.

It also can be concluded that myofibrillar protein extraction is greater when fresh unfrozen meat is used compared to previously frozen and thawed meat. This can be explained due to freezing damage of meat fibers.

Author's address

Henk W. Hoogenkamp Groteloef 36, 6581 JG, Malden, The Netherlands

Henk W. Hoogenkamp is publicist and author, and has previously been

President of DMV USA (now Friesland Campina), and Senior Director Strategic Technology, Solae LLC, (a DuPont/ Bunge Company).