

# Processing Challenges of Sodium Reduction

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## Introduction

Concerns regarding sodium reduction are not new in the meat industry. For over 20 yr researchers have been investigating means to reduce the sodium content in muscle foods. It has been well established by the medical community that high sodium diets can lead to and also exacerbate hypertension (Frost et al., 1991; Law et al., 1991a,b; MacGregor et al., 1994). This, in turn, has motivated processors to find ways to remove sodium (usually added in the form of table salt, or NaCl) from products. Unfortunately, past reactions to sodium reduction have been a little knee-jerk, and careful attention was not paid to how these reductions affected product functionality and palatability. As a result, many “low sodium” or “no sodium” products placed into the market were judged as inferior in performance and flavor by consumers when compared with their higher sodium counterparts (Nolan 1984). Many consumers, therefore, have had poor experiences with “low sodium” products, and hence it is difficult for these products to consistently maintain shelf-space at the retail market. The food industry must focus on reducing current levels of sodium as much as possible while maintaining product palatability (Nolan, 1984; Mattes, 1997; Desmond, 2006) and functionality. It is important, therefore, for the industry to constantly push the envelope downward regarding the use of sodium in products. Nachay (2008) emphasized the importance of food processors reducing salt in their formulations by indicating 75% of consumer salt intake comes from processed foods. It was also pointed out that consumers ingest twice the level of salt as recommended by both the US Department of Health and Human Services and the American Heart Association (2,300 mg/d). The industry should not be complacent with the acceptance of sodium content

in food; it should always be looking for ways to utilize the least amount possible in its formulations. Even small changes in the total sodium of a product, when considering additive effects in the diet, can be health beneficial.

## NaCl and Flavor

This brings us, of course, to the processing challenges regarding sodium. It is well accepted that NaCl is a flavor potentiator. It just plain makes foods taste better. The salty perception of NaCl is due to both its cation (70–85%) and anion (30–15%) moieties (Formaker and Hill, 1988; Mattes, 1997). When the cation or anion in NaCl replacements are larger in molecular weight, perceived saltiness decreases and bitterness increases (Guárdia et al., 2006; Chen et al., 2007). This is the case with sodium salt replacements such as KCl or MgCl<sub>2</sub>. Many investigations have been conducted regarding the affect of these sodium replacements on the sensory acceptability of meats (Terrell and Olson, 1981; Hand et al., 1982a,b, 1987). When decreasing a formulation with NaCl, the effect on flavor cannot be overlooked.

## NaCl and Protein Solubilization

Flavor is only one part of the equation when evaluating the effect of salt application in meat. There are two other important components that should be considered when formulating with salt: its effects on protein functionality and microbial growth. Protein functionality of processed meats is typically described in terms of salt solubility. There are many ways to classify meat proteins. When describing protein functionality, meat proteins (excluding collagen) are traditionally described as being either salt or water soluble. Salt solubility refers to the ability of electrostatic compounds (such as NaCl) to interact with the ionic amino acids on the protein backbone and alter the protein's native structure. This alteration in native structure increases the solubility characteristics of the protein. Proteins typically classified as salt soluble are the myofibrillar proteins. These constitute approximately 50 to 55% of the total muscle protein (Acton et al., 1983) and are responsible for motor function. The major proteins in this fraction are actin and myosin.

Salts, such as NaCl, dissociate when placed in an aqueous environment into their respective ions (e.g., Na<sup>+</sup> and

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Cl<sup>-</sup>). These ions can interact electrostatically with ionizable amino acids that are part of the protein's primary structure (Hamm, 1960). When NaCl is added to meat, it will interact with proteins, such as actin and myosin, by competing with the inter- and intra-electrostatic interactions. This has a significant effect on meat proteins because the final pH of meat (pH 5.5) is typically near the isoelectric point of actomyosin (pH 5.0; Hamm, 1960), the rigor complex that is formed from the conversion of muscle to meat. The isoelectric point (pI) of a protein describes the pH in which intramolecular interactions are favored. At the pI, the number of negatively charged ions along the protein backbone is equivalent to the number of positively charged ions. Charge repulsion is therefore minimized and the protein structure is often described as closed because the protein prefers to interact with itself rather than its aqueous environment. However, 2 things can happen when a salt is applied. First, the protein interacts with the salt ions instead of itself. It was demonstrated by Hamm (1960) that there is preferential binding of chloride ions to the myofibrillar proteins. The shielding of myofibrils by chloride ions was described by Offer and Trinick (1983). This results in an excess of negative charges along the myofibril structure and effectively shifts the pI to a lower pH value (more acid). Excess negative charges would mean additional charge repulsion at the final meat pH (~5.5). The result is depolymerization of the myofibril structure. In the case of myosin, actin or the rigor product actomyosin, this means these proteins can more freely form an intermolecular protein network that can bind and trap water.

### **Alkaline Phosphates and Protein Solubilization**

Addition of neutral salts such as NaCl is not the only means to alter protein structure and essentially affect intramolecular interactions. Basic "salts" such as sodium tetrapyrophosphate, sodium tripolyphosphate, and sodium hexametaphosphate can also be added to alter protein structure and enhance solubility. These alkaline salts influence protein structure by ionic interactions, similar to the shielding effect described for neutral salts, buffering capacity and cationic sequestering ability. The buffering capacity of pyrophosphates effectively counters the natural and fairly substantial buffering capacity of meat to raise the pH (more basic). Not only is the effective pI reduced, but the pH increase furthers the shift from the effective pI (<pH 5.0–5.4). The result is alkaline phosphates enhance the water binding ability of meats (Bendall, 1954; Offer and Trinick, 1983). Finally, a further benefit of alkaline polyphosphate addition is its ability to sequester divalent cations such as Ca<sup>2+</sup>. In terms of protein functionality, this is important with respect to dissociation of the actomyosin complex that forms once muscle is converted to meat. When calcium concentrations are low the troponin complex prevents myosin from attaching to actin. This situation would be analogous to the resting muscle of a live

animal. However, when calcium concentrations increase there is a conformational change of the troponin complex and the actin and myosin binding site is exposed. In the living animal, this situation occurs for muscle contraction and motor ability. In the non-living animal, the result of this action is rigor mortis. When muscle is converted to meat, the calcium concentration in the muscle cell is no longer regulated. Therefore, the ability of polyphosphates to complex calcium lowers the calcium concentration, allowing dissociation of the actomyosin complex, which, in turn, permits more extensive electrostatic repulsion resulting in further tenderization of the meat.

### **Effective Levels of NaCl and Alkaline Phosphate**

The question then turns to how much NaCl and alkaline polyphosphate is needed in a processed meat? This is a difficult question to answer because the effect of these additives is not one dimensional; there are several factors to consider. The primary determinant of product functionality with regard to water holding ability may rest with final pH. Hamm (1960) discussed the effect of pH on water binding in his review on the biochemistry of meat hydration. He explained that pH changes can significantly affect the water binding ability of meat, and the extent of the effect was dependent on whether the meat had high or low initial water binding capacity at the normal pH of meat (pH 5.5). He demonstrated that at pH 5.5, water binding is about 40%. At pH 5.7, the water binding increases to about 45%. However, by pH 6.0, the water binding can range between 55 and 65%. This is a substantial increase for a very small pH change. By pH 7.0, water binding is around 80%. This observation of the significance of final product pH on functional performance was also noted by Sofos (1983). He referred to results from his study on frankfurters and other supporting research (McCready and Cunningham, 1971; Poulanne and Matikkala, 1980; Poulanne and Ruusunen, 1980). There is a significant body of work on sodium reduction in and of itself and in combination with several types of phosphates (Hand et al., 1982a,b, 1987; Coon et al., 1983; Sofos, 1983; Knipe et al., 1985; Barbut, 1988; Paterson et al., 1988; Amato et al., 1989; Barbut and Mittal, 1989; Bernthal et al., 1991; Bakir et al., 1994; Detienne and Wicker, 1999; Ruusunen et al., 2002, 2003; Ruusunen and Puolanne, 2005). The general conclusions are increasing NaCl up to 2% generally improves water binding, purge, cookloss, and shear-force values. Lower amounts of NaCl can be successfully incorporated, usually the lowest amount used in a study is 0.5%, as long as alkaline phosphates are utilized in a range from 0.15 to 0.45%. The amount utilized will also be dependent on whether pre- or post-rigor meat is being utilized (Coon et al., 1983; Bernthal et al., 1991). This, of course, is tied to the distance we are shifting the pI of the meat by salt addition and the subsequent gap between the effective pI of the meat and final meat pH.

## Microbial Shelf-Life

The solution seems simple: just find a way to increase pH to improve water binding. There are several limiting factors to this approach; first, the pH increasing agent has traditionally been alkaline phosphates. The addition of phosphates is a means to reduce NaCl usage. Theoretically, phosphates could be used to replace all the NaCl added to a product. This is not possible, of course, because aside from regulatory limits (<0.5% in finished product) there is also a problem with high phosphate formulations resulting in flavor problems (Chambers et al., 1991). There is the added problem that many alkaline phosphates are themselves significant sources of sodium. In addition, neutral pHs typically promote bacterial growth rather than hinder them. In a cooked product, this may not be important. Sofos (1983) demonstrated that in a cooked product like frankfurters (final pH < 6), reducing salt did not seem to significantly affect microbial growth. However, if enhanced meat products are not further processed (i.e., cooking or smoking) this may have a significant effect on the rate of spoilage of products sold in a refrigerated retail case.

## Alternative Technologies?

There may be a solution to the conundrum of wanting to reduce salts without seriously affecting yield and texture, or reducing shelf-life. The concept of using ammonium hydroxide for enhancement of meat is relatively new. It has been used commercially in a propriety process for some years by Beef Products Inc. (BPI) in the production of their ground beef. At the 2006 Reciprocal Meat Conference in Champaign-Urbana, IL, a couple of abstracts were presented using patented technology from BPI's subsidiary, Freezing Machines, Inc. Hamling et al. (2006) evaluated subsequent tenderness in beef chuck and round muscles after enhancement with solution containing ammonium hydroxide. They demonstrated that as pH increased, tenderness increased. They found that a 30% pump produced texture in the beef perceived as too soft by sensory panelist. Evaluations of a 20% pump in triceps brachii, biceps femoris, and rectus femoris by both a consumer panel and shear force resulted in a lower shear force and increased desirability for tenderness, juiciness, flavor, and overall acceptability. Nath et al. (2006) evaluated 5 different beef muscles (longissimus lumborum, gluteus medius, triceps brachii, biceps femoris, and psoas major) also using the BPI pH enhancement with ammonium hydroxide at 0, 10, 20, and 30% pump levels. They found juiciness, tenderness, and beef flavor was highest at the 20% pump level. They concluded that pH enhancement improved consumer acceptability in all muscles except the psoas major. Everts et al. (2006a) evaluated the same pH enhancement on chunked and formed hams. They concluded that the enhancement "improved visual appearance of pale, average, and dark muscles" and resulted in better consumer sensory evaluations for

pale muscle hams. Everts et al. (2006b) also evaluated consumer preference of various meat products including grilled pork loin. Consumer ratings of "overall liking" for pork loin that was enhanced was 7.13 vs. 5.33 for non-enhanced. All of this body of work suggests that ammonium hydroxide can be used in meat products to reduce salt in much the same way that phosphate addition is used to minimize salt usage without detrimentally affecting meat functionality in terms of water holding ability, palatability, and color (fresh meats).

Where ammonium hydroxide differs from other alkaline pH treatments is its apparent ability to retard or reduce microbial growth, even at neutral pH. The literature on ammonium hydroxide use in meat as a means to control growth of microorganisms is not very well developed. Gupta et al. (1988) evaluated ammonium hydroxide (NH<sub>4</sub>OH) as a preservative in ground goat meat. They added a 25% solution of NH<sub>4</sub>OH to give final concentrations ranging from 0.134 to 0.67 M. Aerobic and gram-negative bacteria were measured in meat stored at 3 different temperatures (37, 4, and -20°C) for a period of 48 h. They noted decreases at all concentrations and storage times. In addition, at 0.4 and 0.67 M, there was no growth of aerobic bacteria at 4°C after 11 d of storage. The decreases were 2 log or less for the 0.4 M, but more than 3 log for the 0.67 M. They noted that ground meat containing NH<sub>4</sub>OH appeared "more pinkish". A study by Stopforth et al. (2004) was conducted to evaluate the effect of different chemical solutions when spray chilling beef carcasses on acid-habituated and non-acid-habituated *E. coli* O157:H7. Ammonium hydroxide was evaluated at a 0.05% concentration (pH 10.77). Carcasses were sprayed every 30 m for the first 10 h at -3°C. Ammonium hydroxide was effective in preventing further growth and actual reductions were seen over a 48 h period. It was more effective than 2% lactic acid spray chill at 36 h and just as effective at 48 h on acid habituated *E. coli*. On non-acid-habituated *E. coli* it was just as effective as lactic acid (2%) at 36 and 48 h.

Recent research conducted the past year in our lab on beef loins has demonstrated that an ammonium hydroxide-based enhancement solution can markedly affect aerobic and anaerobic microbial growth (Cerruto-Noya et al., 2007). Paired loins collected from carcasses aged for 48 h were enhanced with either an ammonium hydroxide-based solution (0.1%) or a phosphate-based solution, cut into 2.54-cm steaks, and MAP (80/20) packaged. Steaks were stored (4°C) in the dark for 4 d to mimic shipping and then retail displayed for 14 d. Ammonium hydroxide-enhanced steaks after the 14 d period had an aerobic plate count that was 1–2 logs lower than phosphate-enhanced steaks. Anaerobic plate counts were 2–3 logs lower and were virtually static from the initial counts taken at d 0 retail display. The steaks from this study, however, did not perform as well as phosphate injected steaks with respect to functional aspects such as purge, cook yield, and color. Research is currently being conducted to investigate

higher levels of ammonium hydroxide and ammonium hydroxide/alkaline phosphate combinations. Future research will look at reducing salt levels and the effect of ammonium hydroxide on *Escherichia coli* O157:H7 and *Salmonella* populations in meat.

## Conclusions

The use of ammonium hydroxide may allow processors to effectively reformulate and reduce their current usage of NaCl and alkaline phosphate without affecting product functionality, palatability, or shelf-life (especially in fresh meats). More research is needed to evaluate the use of ammonium hydroxide in a cured meat product as its effect on cure rate and color stability has not been evaluated. Sodium reduction through the use of ammonium hydroxide would be beneficial not only for consumers in terms of health, but for processors as well if ammonium hydroxide significantly affects microbial quality, safety, or both, of the meat.

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