An Overview of Functional Non-Meat Ingredients in Meat Processing: The Current Toolbox

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INTRODUCTION

My "assignment" as part of this discussion of the challenges facing meat processors trying to meet consumer demands for clean labels is to review the critical functional roles of the fundamental non-meat ingredients that are essential for processed meats. The market pressure for shorter, simpler, easier-to-understand ingredient statements is providing considerable motivation for processors to reduce or even eliminate some of the traditional, well-established non-meat ingredients. However, the practical applications of many of the traditional non-meat ingredients have been developed and refined as a result of years, decades or even centuries of use, and have clearly evolved to play very critical roles in processed meats. These ingredients comprise the "current toolbox" that provides the fundamental means to produce unique and distinctive processed meat products of various types. Raw, partially cooked, fully cooked, ready-to-eat, fermented, dried, injected, marinated and dry-cured products all derive distinctive properties from use of non-meat ingredients. Further, most of the non-meat ingredients in the current toolbox are used almost universally in processed meats despite the wide variety of products that are produced. These ingredients are analogous to the hammers, saws and tape measure in a carpenter's toolbox or the screwdrivers, pliers and wrenches in a mechanic's toolbox. Consequently, because these basic toolbox ingredients play critical roles in processed meats, it is important to remember and understand the importance of these ingredients before changes are made. Change in the use of the basic functional non-meat ingredients is virtually guaranteed to require an alternative ingredient or multiple ingredients, and/or process adjustments to achieve the same or similar finished product properties. Part of the problem of changing the use of these "toolbox" ingredients is not only the critical nature of the roles they play but also because these are all multifunctional ingredients. Because they impact several important properties of processed meats, attempting to reduce or eliminate these ingredients has implications for multiple changes in the product.

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WATER

One of the functional non-meat ingredients in the current toolbox that is often overlooked is water. While water is a major component of lean meat, it is also commonly added to many processed meat products, and, as such, becomes a non-meat ingredient. Water plays an important functional role in processed meats which is likely to be modified if other ingredients are changed.

Water is both simple and unusual compared to other chemical compounds, in ways that make water highly functional in meat products (Ruan and Chen, 1998; LeMeste et al., 2006). It is simple in its composition of two hydrogen atoms and one oxygen atom but unusual in its ability to form hydrogen bonds between water molecules, and to bond with meat proteins. The significance of the hydrogen bonding is that this allows water molecules to be "held" together within meat structures and provides binding of water molecules to polar sites in meat, most notably the myofibrillar proteins. The polar properties of water also result in its function as a "universal solvent" which, in meat, makes it a highly effective solvent, carrier and dispersing agent for salt, sugar, curing agents, phosphates and other ingredients included in processed meats. The solvent properties of water are also necessary for meat protein extraction which is critical to formation of emulsions, binding of restructured products and cooked product texture. Added water in the range of at least 10-20% provides improved protein solubility and often more is used.

Water becomes an important consideration for the brine strength in a given processed meat product because the brine strength is a major factor determining not only protein extraction, but also bacterial inhibition and product shelf life. The brine strength (salt content in the water phase or $\frac{\%\ salt}{\%\ salt + \%\ water}$) is dependent on both salt and water content so obviously any change in either component will alter the effectiveness of the combination. Finally, the available water (A_W) is the determining factor for bacterial growth especially in dry and semi-dry processed meats and reflects the water that is biologically available from the combination of water with various other ingredients in a product that may bind and restrict water availability (Jay et al., 2005).

Because water has a major functional and quality impact on processed meats, there are numerous regulations controlling the addition and/or final water content of processed meats. However, most of these regulations are focused primarily on product identity and standardization rather than issues of safety or quality (Anon., 2005).

Even though water is a highly functional ingredient, it can also introduce some problems if not monitored carefully. Hard water can be a source of contaminants that are detrimental to color and flavor of processed meats. Even softened water can change if treatment systems are changed, so periodic testing is recommended. Plumbing issues within a plant can result in water contaminated with bacteria or chemicals providing another good reason for periodic testing of the water to be used as an ingredient.

SALT (SODIUM CHLORIDE)

Salt (sodium chloride) is clearly one of the most important functional non-meat ingredients in processed meats, and probably the most common in terms of both quantity and frequency of use. The importance of salt is widely recognized due to the multifunction role of this ingredient in processed meats, some of which are indispensable. Because salt dissociates into sodium and chloride ions in the water phase of meat mixtures, its functions are largely the result of the dissociated ions. The ionic strength of the salt-water phase, for example, is necessary for the solubilization and extraction of the myofibrillar proteins which are responsible for stabilizing fat in emulsion products, binding of muscle pieces in restructured products and product textual properties that result from heat-set gelation of the proteins. An ionic strength of 0.5 or greater is needed for muscle myofibrils to swell and solubilize myofibrillar proteins (Hamm, 1986). A salt concentration of about 2% or more will achieve the necessary ionic strength under normal circumstances. Cooked product yields can be expected to decline rather sharply when salt is reduced to less than 2% (Wierbicki et al., 1976; Ruusunen and Poulanne, 2005).

While chloride ions provide much of the functionality of salt for water binding and yields, it is the sodium ion that provides the flavor expected of products with added salt. Not only does sodium provide "saltiness" but it also potentiates other flavor components to enhance the overall flavor (Ruusunen and Puolanne, 2005), and a minimum amount of salt is essential to acceptable flavor of processed meats (Corral et al., 2013; Tobin et al., 2013; Aaslyng et al., 2014). In the past 5 years, since the National Salt Reduction Initiative of 2010 www.nyc.gov/html/doh/html/diseases/salt.shtml, there have been serious efforts to reduce sodium content of foods in general including processed meats (Choi et al., 2014). It has become clear that while sodium (and consequently salt) can be reduced in processed meats to some extent, it appears to be virtually impossible to eliminate salt from processed meat formulations and still retain expected product properties.

As noted earlier, salt provides an important means of reducing available water (A_W) in processed meats to reduce microbial growth and spoilage. With all else equal, reducing the salt content of cooked processed meats will reduce the shelf life of the product and may introduce greater risk of pathogenic bacterial growth as well.

Chloride ions in a cured meat product may also play a small but potentially significant role in cured color development because chloride can accelerate the conversion of nitrite to nitric oxide during the cure development phase prior to cooking (Sebranek and Fox, 1991; Møller and Skibsted, 2002). Salt is classified as a GRAS (Generally Recognized as Safe) substance and has been considered to be self-limiting because excessive amounts greatly impact palatability. However, one of the ideas that was suggested during the recent discussions of salt reduction in food was that perhaps the GRAS status of salt should be reconsidered (Henney et al., 2010). While such a change is highly unlikely, the implications of such a change would be immense.

CURING AGENTS

Another absolutely essential tool in the processed meat toolbox is the curing agents (nitrate and nitrite). Nitrate, of course, is relatively rare in the popular, high-volume cured meats like frankfurters, hams and bacon because it must be converted to nitrite before it becomes effective as a curing agent. In fact, nitrate has been described as "useless and superfluous" in products cooked within a few hours of formulation (Honikel, 2004; 2010). On the other hand, nitrate is an important ingredient for many dry-curing processes where it is reduced to nitrite by bacteria (Leroy et al., 2006), and thus provides a reservoir of nitrite during the extended curing and or drying phases of dry-cured hams and dry sausage. More recently, the nitrate included in concentrated vegetable products such as celery and Swiss chard has been utilized as a means of providing curing agents for processed meats labeled as "natural" or "organic."

Because nitrite is the true curing agent that creates cured meat properties by reacting with a variety of meat components, it can be considered the essential curing agent whether derived from nitrate or added to meat as nitrite. The reaction products of nitrite which are delivered via nitric oxide are the reason for the unique and distinctive properties of cured meat products. Cured meat is truly unique and truly distinctive because there is no single compound that can be substituted for nitrite and achieve the same end result.

Nitrite, similar to sodium chloride, is a multifunctional ingredient but nitrite is also much more potent than sodium chloride in its effects on meat products. As little as 50-100 parts per million (0.01%) of nitrite will result in the color, flavor, antioxidant and antimicrobial inhibition expected of cured meats, though more is typically used to realize the full benefit of this ingredient. Because nitrite is an extremely reactive compound, its effectiveness as a curing agent is subject to several variables that occur in meat mixtures. These have been well-studied and include meat product pH, amino acid composition, pigment content and salt content as well as other ingredients such as ascorbate/erythorbate and phosphates (Pegg and Shahidi, 2000; Barbieri et al., 2013).

One of the most highly touted functions of nitrite has been its role as an antimicrobial agent, especially for anaerobic bacteria such as *Clostridium botulinum*. Even though current-day sanitation practices and temperature controls in processing plants makes botulism an unlikely problem, nitrite still provides an effective insurance policy for consumers after product purchase when mishandling and temperature abuse are more likely. Nitrite is not considered highly effective for Gram-negative organisms such as *Escherichia coli* though it has been reported that *E. coli* growth is slowed in the presence of nitrite (Pichner et al., 2006). It has been suggested that the effects of nitrite differ among the different bacterial species due to different inhibitory mechanisms (Tompkin, 2005). There is also some question about whether added or residual nitrite is most important for the antimicrobial function, or whether both should to be considered. The antimicrobial impact of the ingredients is one area to pay close attention when changes in product formulations and ingredients are considered.

CURE ACCELERATORS

While nitrite will react with meat components quite readily, it is often slower than desired in high-volume production environments. Consequently, curing accelerators have been added as another basic tool to the meat processing toolbox because the reduction of nitrite to nitric oxide is an absolutely essential step in the development of cured meat color and probably most of the other cured meat properties as well. These ingredients include reductants, most commonly sodium ascorbate, sodium erythorbate, ascorbic acid and erythorbic acid which react directly with nitrite to produce nitric oxide. The reductants came to fore in the 1950's when the meat industry began developing high volume, high speed production lines with the cooking step occurring within minutes after formulation instead of hours. A problem of gray product centers emerged because of inadequate "curing" time to allow for adequate nitric oxide production. The addition of the reductants significantly shortened the cure time necessary for good cured color development. These are water-soluble organic compounds with significant antioxidant potential particularly in their ability to maintain iron in myoglobin in its reduced form (Shahidi and Samaranayaka, 2004). The reductants are an optional ingredient in cured meats with one exception. For injected bacon, sodium ascorbate or erythorbate is required at 550 ppm (Anon., 1995). The purpose of this requirement is to reduce residual nitrite in bacon to very low concentrations prior to frying which reduces the risk of nitrosamine formation during the frying treatment. A 1% solution of the acid forms has a pH of around 3.0 while a solution of the salts will be pH 5.5 or higher. Because nitrite reduction is greatly favored by acid conditions, the salts may be a better choice to avoid excessively rapid generation of nitric oxide which can result in losses of nitric oxide to the atmosphere. Interestingly, evolution of regulations has resulted in the limit for the reductants in injected bacon at 550 ppm while it remains at 547 ppm (7/8 oz. per 100 lbs.) in other cured meat applications.

Acidulants are another option for accelerating the curing reaction. Sodium acid pyrophosphate (SAPP) and glucono-delta-lactone (GDL) may be used to decrease product pH slightly and accelerate curing. These ingredients are limited to 0.5% alone or in combination in comminuted cured meat products (not poultry) and will decrease product pH by 0.2 to 0.3 pH units when included. Fumaric acid is another acidulant that may be used at up to 650 ppm in cured, comminuted meat and poultry products (Anon., 1995). A pH change of 0.2 to 0.3 pH units has been shown to increase the rate of nitric oxide production from nitrite by about 2-fold.

PHOSPHATES

Another multifunctional tool to consider in the meat processor's basic toolbox is the phosphates. While the phosphates are yet another multifunctional ingredient, the phosphates are different from the other multifunctional ingredients in processed meats in that several different forms of the phosphates may be used. The different forms of phosphates differ significantly in two important properties; solubility in water and pH impact. Solubility can range from about 10 grams per 100 grams of water to over 100 grams per 100 grams of water. However, in general, the phosphates are the least soluble of the basic nonmeat ingredients consequently the solubility can be an important consideration for specific applications, particularly for preparation of brines to be used for injected products. Limited solubility can also result in phosphate precipitation in processed meats after cooking and chilling, resulting in a sandy texture or even in hard, glass-like crystals. The pH of different phosphates can range from about pH 5.0 to over pH 10.0, though most are about pH 7 or higher. The forms of phosphates available include orthophosphates, pyrophosphates, tripolyphosphates and polyphosphates. Both sodium and potassium salt of each of the phosphates may be used.

The primary function of the phosphates is to increase water retention by meat proteins to improve product yields and improve product tenderness and juiciness (Xiong, 2005). One of the related benefits is that the phosphates offer a means of reducing sodium chloride concentrations without major losses in the water binding ability of the meat matrix. Phosphates have been shown to be significant contributors to antioxidant activity and flavor protection in processed meats, particularly in uncured products where nitrite is not included (Vasavada et al., 2006). It is likely that phosphates serve a secondary role in antioxidant functions because they are effective chelators of metals and catalysts that provide initiation of the lipid oxidation sequence. The phosphates have also been reported to contribute to antimicrobial effects particularly in uncured products (Molins, 1991). Finally, phosphates have potential to reduce the viscosity of meat batters and in some cases may provide for "cleaner" stuffing of batters into casings with less fat smearing.

Because of the variations in pH and solubility among the different phosphates, phosphate suppliers have developed a variety of blends of phosphates to provide the best combination of pH and solubility for specific product applications. The suppliers can provide recommendations on the best phosphate or phosphate blend to use for a specific product depending on the properties of the phosphates they provide.

ORGANIC ACIDS - LACTATE AND DIACETATE

The final tool to consider for meat processors is the organic acids which provide a very valuable antimicrobial function. While several organic acids have been shown to be effective antimicrobials, it is the lactate-diacetate combination that has become most widely used and that has achieved status deserving of a place in the basic toolbox. Both sodium and potassium lactate may be used with sodium diacetate, which is a combination of 60% sodium acetate and 40% acetic acid. Sodium and potassium lactate may be used, singly or in combination, in all fully cooked meat and poultry products at up to 4.8% of the total formulation to inhibit the growth of several pathogenic bacteria including *Listeria monocytogenes* on ready-to-eat products. The antimicrobial effects of lactate and diacetate also impact spoilage microorganisms and have potential to improve product shelf life. The impact on spoilage bacteria is an important role for these compounds in uncooked, marinated products. Consequently, the lactates are commonly used in uncooked meats such as marinated, enhanced pork cuts to increase bacterial control and extend shelf life of those products. Sodium diacetate is typically included with lactate in cooked products, and has been shown to increase the antimicrobial effectiveness of lactate (Glass et al., 2002; Serdengecti et al., 2006). Sodium diacetate is permitted at 0.25% of the formulation as an antimicrobial. The lactates, if used at levels up to 2% are considered a flavor enhancer, and can be used for that purpose. Sodium diacetate can also be used as a flavor enhancer at concentrations up to 0.25% (9 CFR 424.21).

While the antimicrobial function of lactate-diacetate is probably the most important role that these compounds play in processed meats, lactate also provides some additional contributions to processed meat properties, and consequently can be considered yet another multifunctional ingredient in the same manner as the other basic ingredients in the meat processors toolbox. For example, use of sodium lactate has been shown to improve cooked yields of meat products, probably due to the effect of lactate on water availability. Part of the antimicrobial effect of lactate has been suggested to be due to a reduced A_w, which, due to increase water binding, could play a part in affecting cooking yields as well. Improved color stability is another contribution of lactate to processed meats, particularly for the fresh, uncooked, marinated products where metmyoglobin reducing activity is increased by the addition of lactate (Kim et al., 2006; Nair et al., 2014). Interestingly, the increased reduction of metmyoglobin by lactate has also been shown to accelerate nitrite-to-nitric oxide conversion in cured meat products and, consequently, accelerate meat curing (McClure et al., 2011). Lactate has also been reported to be a radical scavenger and this, in combination with greater metmyoglobin reduction, provides an antioxidant contribution by lactate in processed meats. Consequently, flavor stability, especially in fresh (uncured) meat products is improved with addition of lactate.

In addition to flavor protection, lactate also serves to enhance flavors to increase product flavor acceptability. Some of the effect on flavor may be due to the sodium content of the lactate salt, particularly in the marinated fresh meat products where sodium chloride use is relatively low. Regardless, lactate has been approved for use as a flavor enhancer at concentrations of up to 2%, a concentration that is not considered very effective as an antimicrobial. As noted earlier, sodium diacetate can also be used as a flavor enhancer at 0.25% or less.

These two compounds, lactate and diacetate, are playing an increasingly important role in processed meats as product formulations are modified to reduce sodium chloride and other conventional antimicrobial agents. As a result, changes in the use of lactate and diacetate should be considered carefully in light of the potential change in microbial control with related effects on shelf life and product safety.

THE BOTTOM LINE…

These basic multifunctional meat processing ingredients each provide unique product effects or contribute in their own way to the unique and expected properties of processed meat products. Because the product properties that result from these meat processing "tools" are likely to be altered if these ingredients are reduced or eliminated, processors need to consider any suggested alternatives very carefully, and proceed with caution before changing the way the basic meat processing tools are used. Further, because these are truly multifunctional ingredients that have more than one role in processed meats, changes in how they are used can introduce unexpected changes in the products, and, consequently, the use of multiple alternatives may need to be considered.

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