AMERICAN MEAT SCIENCE ASSOCIATION
WHITE PAPER SERIES
NUMBER 1 MARCH, 2007

Natural and Organic Cured Meat Products: Regulatory, Manufacturing, Marketing, Quality and Safety Issues

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Introduction

Natural and organic processed meats have been a very significant part of the explosive market growth that is occurring in natural and organic foods. Producers and processors have responded to consumer demand for foods perceived by many to be more healthy and wholesome than conventionally produced food products. To qualify as natural or organic, foods must be produced and processed in accordance with United States Department of Agriculture (USDA) regulations that define these products. In most cases, natural and organic foods very closely resemble conventional products and do not differ in the typical characteristics expected by consumers. However, in the case of processed meat products such as hams, bacon, frankfurters, bologna and others that are typically cured by addition of sodium nitrite, and sometimes sodium nitrate, the requirements for natural or organic marketing do not permit addition of nitrite or nitrate. Nitrite, whether added directly or derived from nitrate, is a unique, distinctive ingredient for which there is no substitute, consequently process and product changes are necessary to produce natural or organic processed meats that provide the properties expected of traditional cured meat products. These changes, combined with additional labeling requirements for these products, have resulted in a category of processed meats that is confusing, and perhaps even misleading, to consumers. Further, because of the key role that nitrite plays in cured meat quality and safety, quality and safety issues need to be carefully examined in light of the processing changes that are being introduced for manufacturing natural and organic processed meats.

Background

Growth in organic markets.

The annual growth in availability of natural and organic foods in the United States and around the world has been dramatic as producers and processors have responded to consumer demand for foods perceived to be "healthy" and "wholesome", even though many of the health-related claims have been difficult to substantiate scientifically. Over the past 15-plus years, since 1990, organic food sales have increased by nearly 20% each year (Winter and Davis, 2006). Meat, poultry and seafood has been the fastest growing category of organic foods, increasing by 55.4% in 2005 alone (Mitchell, 2006; Organic Trade Association, 2006). While the organic and natural foods segment is still a relatively small part of the total food industry, comprising a 2.5% share in 2005, it is expected to increase to a 5–10% share in the near future (Nutrition Business Journal, 2006). Several studies have documented that consumer preferences for organic and natural foods are based on concerns about antibiotics, pesticides, hormones, genetic modifications in plants and animals, and chemical additives that consumers associate with conventionally produced foods (Bourn and Prescott, 2002; Dreezens *et al.*, 2005; Sederer *et al.*, 2005; Saher *et al.*, 2006; Winter and Davis, 2006; Devcich *et al.*, 2007). Consumers have expressed their preferences with a strong willingness to pay significant premiums for organic and natural foods. Premiums of 10–40% for organic foods over conventional products are common (Winter and Davis, 2006), but for meat and poultry, premiums may reach 200% (Bacus, 2006) or even more. In one such example, the average retail price for four brands of organic broilers in the Midwest during April and May, 2006 was \$3.19/lb compared to \$1.29/lb for conventionally produced broilers, a 247% difference (Husak, 2007). Prices for organic processed meats have been reported to range from \$7.98/lb to \$12.99/lb (Anon., 2005).

The large premiums that consumers are willing to pay for natural and organic foods have resulted in a rapid proliferation of new products and increased marketing by retailers. While in the past, the primary retailers of natural and organic foods were small cooperatives and health food stores, the success and rapid growth of retailers like Trader Joe's Co. (over 200 stores), Whole Foods Market (181 stores), Wild Oats Market (110 stores) and Holiday Quality Food (23 stores) that feature natural and organic foods has resulted in many major supermarkets, most notably Wal-Mart, now offering these products for consumers (Petrak, 2005).

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Definitions of natural and organic processed meats

The requirements that must be met for processed meats such as hams, bacon, frankfurters and bologna to qualify as natural or organic have resulted in unique and unusual approaches to the development of these products. This is because, while "natural" and "organic" are two separate and distinct categories of meat and poultry products in terms of USDA regulations and labels, neither of these product categories can be manufactured with added sodium (or potassium) nitrite or nitrate. Because nitrate and/or nitrite create distinctive, unique properties that characterize cured meat, and because there is no known substitute for these compounds, products manufactured to simulate cured meats but without added nitrite or nitrate, and without any other modifications, will be unattractive and atypical. However, the USDA permits the manufacture of uncured versions of typical cured meats according to the Code of Federal Regulations (9 CFR 319.2) (2006) which reads:

> "Any product, such as frankfurters and corned beef, for which there is a standard in this part and to which nitrate or nitrite is permitted or required to be added, may be prepared without nitrate or nitrite and labeled with such standard name when immediately preceded with the term "Uncured" in the same size and style of lettering as the rest of such standard name: *Provided*, That the product is found by the Administrator to be similar in size, flavor, consistency and general appearance to such products as commonly prepared with nitrate and nitrite: *And providing further*, That labeling for such products complies with the provisions of 317.17 (C) of this subchapter".

Thus, there is another category of processed meats, separate from "natural" and "organic", and that category is "uncured". The definitions of natural and organic require that "Uncured" be included for products labeled with a standardized cured product name (i.e., bacon), but it is important to note that not all products labeled "Uncured" are natural or organic.

Processed meats that are labeled "natural" must comply with the definition of the term provided by the USDA Food Standards and Labeling Policy Book (USDA, 2005). This definition requires that a natural product …

> "…does not contain any artificial flavor or flavoring, coloring ingredient, or chemical preservative (as defined in 21 CFR 101.22), or any other artificial or synthetic ingredient; and the product and its ingredients are not more than minimally processed."

The term "minimally processed" includes "…traditional processes used to make food edible or to preserve it or to make it safe for human consumption, e.g., smoking, roasting, freezing, drying, and fermenting, or those physical processes which do not fundamentally alter the raw product…, e.g., grinding meat…." (USDA, 2005).

The definition of natural has not been without controversy. For example, in the 2005 edition of the USDA Food Standards and Labeling Policy Book, a note was added indicating that sugar, sodium lactate (from a corn source) and natural flavorings from oleoresins or extractives are acceptable for "all natural" claims. However, because lactate is widely recognized as an antimicrobial ingredient, such use may conflict with the "no chemical preservatives" requirement for labeling of a product as natural. This was the basis for a petition submitted to the USDA in October, 2006 after which the Agency removed lactate from the guidance statement provided for natural claims. The USDA will, however, consider use of lactate for natural foods on a case-by-case basis for applications where the ingredient may function as a flavoring rather than a preservative. Further, the Agency is currently planning to initiate new rulemaking processes in the near future for the use of the term "natural" to clarify these uses as well as the use of natural claims relative to livestock production practices (O'Connor, 2006). Currently, natural claims do not include consideration of animal production practices, and all fresh meat qualifies as natural. There is a significant amount of interest by both producers and consumers in the establishment of standards for meat animal production systems that would satisfy the perceptions consumers currently hold regarding natural foods. Consequently, it is likely that the labeling of processed meats as natural, which currently means minimally processed with no artificial ingredients or preservatives, will be more broadly defined in the near future. As of this writing, the USDA is soliciting comments on this issue until March 5, 2007 after which the rulemaking process for natural claims is expected to begin.

Products labeled as organic are much better defined and controlled than those labeled with natural claims because organic products are governed by the USDA Organic Foods Production Act (OFPA), first passed in 1990 as part of the 1990 Farm Bill (Winter and Davis, 2006). The OFPA created a National Organic Standards Board, which established a National List of Allowed and Prohibited Substances, and developed National Organic Program Standards. The standards, implemented in 2002, specify methods, practices and substances that may be used for production, processing and handling of organic foods. This means that products and ingredients used for organic foods must be certified as organic by a USDA-certified inspector. Meat, for example, must be raised using organic management and come from a certified farm. Ingredients used for processed products are clearly defined as permitted or prohibited in the OFPA National List. Organic products may be labeled in four different ways: 1) "100 % organic", which must contain only organically produced ingredients; 2) "organic", which must contain at least 95% organically produced ingredients; or 3) "made with organic ingredients", which must have at least 70% organic ingredients. Products with less than 70% organic ingredients might be considered as the 4th labeling option but are not allowed to be labeled as organic and are permitted only to list those ingredients that are organic on the information (ingredients) panel of the label. Those products that qualify for the "organic" and "100% organic" labeling are permitted to use the USDA organic seal as part of the label.

Definitions of cured and uncured processed meats

The term "cured" relative to processed meats is universally understood to mean the addition of nitrite or nitrate with salt and other ingredients to meat for improved preservation (Pegg and Shahidi, 2000). While several ingredients including sugar, spices, phosphates and other ingredients are typically included in cured meats, it is the addition of nitrate/nitrite in one form or another that results in the distinctive characteristics of cured meat (Cassens, 1990). The typical color, flavor, shelf life and safety of ham, bacon, frankfurters, bologna and other cured products are so widely recognized by consumers that these product names are considered "standardized" and "traditional" by the USDA for product labeling and therefore do not require any further clarification to communicate the expected product properties to consumers. On the other hand, products that are similar but made without nitrite or nitrate, must be clearly labeled as "Uncured" as described earlier. This is because "uncured" versions of standardized products like ham, bacon, frankfurters and bologna are significantly different from the traditional products that they emulate. At the same time, there are a number of processed meats that are traditionally manufactured without nitrite or nitrate, and that are not labeled as uncured because the standardized product name effectively communicates that the product is not cured. Fresh sausage, such as pork sausage, for example, is not labeled as "uncured" because these products are standardized, traditional and the common name is clearly understood.

The advent of natural and organic processed meat products, both of which prohibit direct addition of nitrite or nitrate, but that also resemble traditional cured meat, has made it necessary to require "uncured" as part of the traditional product name. However, because current meat processing technology has developed means by which nitrate and nitrite can be indirectly added to these products to achieve very typical cured meat properties, the labeling designations for these products as "uncured" is sometimes confusing and is technically inaccurate. Further, because the indirect addition of nitrate and nitrite to natural and organic processed meats has not been thoroughly investigated in terms of nitrite chemistry and subsequent product properties, a number of important questions concerning quality and safety remain to be answered.

Conventional Cured Meat Ingredients and Processes

Conventionally–cured meat products are characterized by the addition of nitrate and/or nitrite. While other ingredients, particularly sodium chloride, are essential parts of typical cured meat formulations, it is the nitrate/nitrite that provides the distinctive properties that are common to all cured meat products. The role of nitrate/nitrite is so commonly understood in the meat industry that the term "cure" is used as both a noun and a verb, meaning either nitrate/nitrite as chemical entities, or the addition of these ingredients to meat, respectively.

Nitrate

Numerous reviews of the history of meat curing have suggested that meat curing originally developed from the use of salt contaminated with sodium or potassium nitrate (Binkerd and Kolari, 1975: Sebranek, 1979; Pierson and Smoot, 1982; National Academy of Sciences, 1982; Cassens, 1990; Pegg and Shahidi, 2000).

While it is not clear when saltpeter (potassium nitrate) was first recognized as a curing agent, it is clear that nitrate, either as saltpeter or as a contaminant of sodium chloride, was used to cure meat for centuries before research chemists began to unravel the chemistry of meat curing. In the late 1800's, it was discovered that nitrate was converted to nitrite by nitrate-reducing bacteria, and that nitrite was the true curing agent. Further research in the early 1900's established the appropriate concentrations of nitrate and nitrite to be used in cured meat, and resulted in authorization by the USDA in 1925 of the use of sodium nitrite.

The following 45 years brought a gradual shift from nitrate to nitrite as the primary curing agent for cured meats as the advantages of faster curing time for increased production capacity became more important, and as nitrite chemistry became better understood. By the early 1970's, relatively little nitrate was being used for cured meats (Binkerd and Kolari, 1975). The late 1960's and early 1970's also brought a watershed event for the cured meat industry when it became obvious that nitrite could result in the formation of carcinogenic n-nitrosamines in cured meat. Subsequent research demonstrated that a significant factor in nitrosamine formation was residual nitrite concentration, and consequently, nitrate was eliminated from most curing processes to achieve better control over residual nitrite concentrations (Pegg and Shahidi, 2000). Today, nitrate is seldom used and then only in a few specialty products such as dry cured hams and dry sausage where long, slow curing processes necessitate a long-term reservoir of nitrite that can be slowly released over the course of the process.

Nitrite

The chemistry of nitrite in cured meat is a fascinating, sometimes frustrating mixture of interactive chemical reactions involving several different reactants and affected by several different environmental factors. Nitrite is a highly reactive compound that can function as an oxidizing, reducing or a nitrosating agent, and can be converted to a variety of related compounds in meat including nitrate, nitrous acid and nitric oxide. To further complicate the understanding of nitrite chemistry, it has become clear that the formation of nitric oxide (NO) from nitrite is a necessary prerequisite for many meat curing reactions (Møller and Skibsted, 2002). Fortunately, fundamental research on nitric oxide has become one of the most active research areas in biology because nitric oxide has been found to play crucial roles in several physiological functions in living organisms. For example, in skeletal muscle, nitric oxide appears to interact with proteins such as the ryanodine receptor-calcium release channel and regulates muscle functions including excitation-contraction coupling, blood flow, respiration and glucose homeostasis (Stamler and Meissner, 2001). Nitric oxide also plays a role in blood pressure control and immunity (CAST, 1997). The fundamental research on nitric oxide in biological systems since the early 1990's has facilitated a better understanding of nitrite and nitric oxide in cured meat (Møller and Skibsted, 2002).

The most effective way to consider nitrite chemistry in cured meat is to consider the practical effects of the addition of nitrite to meat. The first and most obvious effect is that of cured color development. Close examination of the chemical reactions likely to be involved with color development immediately make it obvious that the chemistry of nitrite in meat is a phenomenally complex event. For example, nitrite (NO_2^-) does not act directly as a nitrosylating (transfer of nitric oxide) agent in meat but first forms one or more of several intermediates that are highly reactive. For example, it is recognized that HNO_2 (nitrous acid) is formed from nitrite under acidic conditions (Fox and Thomson, 1963; Pegg and Shahidi, 2000) such as that in postmortem muscle. Further, it is believed that a principal reactive species, N_2O_3 (dinitrogen trioxide) (Fox and Thompson, 1963; Honikel, 2004) is formed from nitrous acid and will subsequently form NO (nitric oxide) or will react with other substrates in a meat mixture.

$$NO_2^- + H^+ \leftrightarrow HNO_2$$

$$2\ HNO_2 \leftrightarrow N_2O_3 + H_2O$$

$$N_2O_3 \leftrightarrow NO + NO_2$$

One of the likely substrates for N_2O_3 in meat is a reductant such as ascorbate (H-ASC) or erythorbate which then yields nitric oxide (NO) (Fox and Thomson, 1963; Møller and Skibsted, 2002), thus providing another source of nitric oxide in cured meat.

$$N_2O_3 + 2\ H\text{–}ASC \leftrightarrow 2\ \text{dehydro-}ASC + H_2O + 2\ NO$$

The NO that is formed will react with the iron of both myoglobin ($MbFe^{+2}$) and metmyoglobin ($MMbFe^{+3}$) to form cured meat pigments and cured color. These reactions demonstrate two of the most important factors governing nitrite reactions in conventionally cured meat products, namely pH and the presence or absence of various reductants. However, several other nitrite reactions are involved in cured meat chemistry and contribute to nitric oxide production. For example, when nitrite is added to comminuted meat, the meat quickly turns brown because nitrite acts as a strong heme pigment oxidant and is, in turn, reduced to nitric oxide.

$$MbFe^{+2} + NO_2^- \rightarrow MMbFe^{+3} + NO + OH^-$$

The NO reacts with metmyoglobin, and subsequent reduction reactions convert the oxidized heme to reduced nitric oxide myoglobin for the typical cured color following cooking.

$$MMbFe^{+3} + NO \rightarrow MMbFe^{+3}\text{-}NO \xrightarrow{\text{reductant}} MbFe^{+2}\text{-}NO$$

To further complicate the system, all cured meats include sodium chloride in varying concentrations, and nitrite, as nitrous acid, will react with the chloride ion to form nitrosyl chloride, which is a more reactive nitrosylating agent than N_2O_3 (Sebranek and Fox, 1985, 1991; Fox *et al.*, 1994; Møller and Skibsted, 2002).

$$HNO_2 + H^+ + Cl^- \leftrightarrow NOCl + H_2O$$

Consequently, chloride ions accelerate color development in cured meat.

Further, nitrite can also react with sulfhydryl groups on proteins to release nitric oxide in an oxidation–reduction reaction that results in a disulfide being formed (Pegg and Shahidi, 2000).

$$2\ RSH + 2HNO_2 \rightarrow RS\text{-}SR + 2NO + 2H_2O$$

In addition to the above reactions of nitrite in meat, all of which affect the rate and/or extent of cured color development, nitrite plays a key role in cured meat as a bacteriostatic and bacteriocidal agent. Nitrite is strongly inhibitory of anaerobic bacteria, most importantly *Clostridium botulinum*, and contributes to control of other microorganisms such as *Listeria monocytogenes*. The effects of nitrite and the likely inhibitory mechanisms differ in different bacterial species (Tompkin, 2005). Nitrite is not generally considered to be effective for control of Gram-negative enteric pathogens such as *Salmonella* and *Escherichia coli* (Tompkin, 2005). However, Pichner *et al.* (2006) reported that *E. coli* survived longer and reached higher counts on salami without nitrite than on salami with added nitrite. The effectiveness of nitrite as an antibotulinal agent is dependent on several environmental factors including pH, sodium chloride concentration, reductants present and iron content among others (Tompkin, 2005). While the means by which nitrite achieves microbial inhibition is not clear and many mechanisms have been proposed, all of the factors that impact nitrite inhibitory effects are also important to the known reactions that generate nitric oxide for cured color. Consequently, it is likely that the reaction sequences involving nitric oxide and color development are also important players in the antimicrobial role of nitrite in cured meat. For example, some researchers have suggested that nitrous acid (HNO_2) and/or nitric oxide (NO) may be responsible for the inhibitory effects of nitrite while others have investigated several as-yet unidentified inhibitory substances (Tompkin, 2005). Reaction of nitric oxide with iron-sulfur enzymes of anaerobic bacteria has been reported to reduce the germination of these bacteria (Payne, *et al.*, 1990). Because it appears that nitrite reactivity is key to microbial inhibition (one indicator of this is the strong dependence on pH), there has been some question whether ingoing or residual nitrite is most critical to antimicrobial effects. The USDA regulations that require specific minimum ingoing nitrite concentration of 120 ppm for cured products that are refrigerated (USDA, 1995) implies that ingoing levels of nitrite are critical. However, it may be that ingoing nitrite is important because ingoing nitrite affects the subsequent residual nitrite. Tompkin (2005) concluded that residual nitrite at the time of product temperature abuse is critical to antibotulinal effects and that depletion of residual nitrite during product storage will reach some point at which the inhibitory effects are also depleted. At the same time, it is interesting to note that residual nitrite in retail commercial cured meat products has declined by 80% from the 1970's to a range of 1 to 16 ppm in 1997 (Cassens, 1997b) without any obvious effects on product safety.

The reaction sequences of nitrite and nitric oxide probably also play a key role in the strong antioxidant function of nitrite in cured meat, because proposed mechanisms for the antioxidant effect of nitrite include reaction with heme proteins and metals, including free iron, and formation of nitroso- and nitrosyl- compounds that have antioxidant properties (Pegg and Shahidi, 2000). It is likely that these proposed mechanisms are dependent upon many of the same initial reactions of nitrite that form nitric oxide for cured color. Thus, the affinity of nitric oxide for iron appears to play a role in several of the functions of nitrite in cured meat. The nitric oxide-heme complex contributes color, nitric oxide reaction with iron-sulfur enzymes may be important to inhibition of anaerobic bacteria, and nitric oxide combination with free iron and heme iron in meat reduces the catalytic role of iron in lipid oxidation.

Nitrite is also responsible for the production of characteristic cured meat flavor, although this is probably the least well understood aspect of nitrite chemistry (Pegg and Shahidi, 2000). It is easy to distinguish cooked, cured ham from fresh roast pork on the basis of flavor but the chemical identity of distinguishing flavor components in cured meat has eluded numerous researchers. Some of the flavor difference may be due to the suppression of lipid oxidation by nitrite but other antioxidants do not produce cured meat flavor. Pegg and Shahidi (2000) listed 138 volatile compounds identified in nitrite-cured ham. Some of the volatiles listed include nitrogen- or nitrogen/oxygen-containing compounds but there have been no suggested mechanisms that directly link nitrite or nitric oxide reactions to compounds identified as flavor components. If nitrite does, in fact, form volatile flavor factors, this would represent yet another reaction product of nitrite in cured meat.

In addition to the nitrite reactions which result in cured meat color, microbial inhibition, antioxidant effects and flavor, it has been demonstrated that addition of nitrite to meat results in formation of nitrate and nitrogen gas as well as reaction with carbohydrates and lipids (Pegg and Shahidi, 2000; Honikel, 2004).

Further, there are a number of curing accelerators that are commonly used to increase the rate of nitrite-to-nitric oxide conversion. These include acidulants such as glucono delta lactone (GDL), sodium acid pyrophosphate (SAPP) citric acid, sodium citrate and fumaric acid, and reductants such as ascorbic acid/sodium ascorbate and erythorbic acid/sodium erythorbate.

The effects of the acidulants and reductants on nitrite reactions are quite dramatic because both strongly affect the initial reduction of nitrite to nitric oxide as shown earlier. A pH decrease of 0.2 pH units, for example, is sufficient to double the rate of nitric oxide formation (Fox, 1974). Both acidulants and reductants result in significantly less residual nitrite in cured meat, an important contribution relative to the potential for nitrosamine formation associated with high residual nitrite concentrations.

The point of this condensed review of nitrite chemistry and the functions of nitrite in cured meat is not to reiterate what is commonly known about nitrite but rather to emphasize the highly reactive, complex nature of nitrite-meat mixtures. Because nitrite, particularly as nitric oxide, so readily reacts with a wide variety of substrates, reaction kinetics may be an important determinant of how nitrite is proportioned among the wide array of competitive substrates and reaction products. A slow formation of nitrite (such as from nitrate) in meat might be significantly different in terms of nitrite reaction products than the direct, one-time addition of a full load of nitrite. If, for example, the fastest-reacting substrates consumed a greater share of the nitrite during slow nitrite formation than in the case where nitrite is added directly, then the end products of the more reactive substrates might achieve a greater final concentration.

Past and current safety issues associated with nitrite

Issues that have been raised concerning the safety of using nitrate and nitrite for curing meat have included chemical toxicity, formation of carcinogens in food or after ingestion, and reproductive and developmental toxicity. None of these issues represent relevant concerns for nitrate or nitrite in light of the current levels of use in processed meats. While nitrite is recognized as a potentially toxic compound, and there have been cases where nitrite was mistakenly substituted for other compounds in food or drink at concentrations great enough to induce toxicity symptoms, the normally controlled use of nitrite in processed meats does not represent a toxicity risk under normal circumstances.

However, the issue of carcinogenic nitrosamines formed from nitrite in cured meat was a very serious concern in the 1970's, and very nearly resulted in elimination of nitrite as a curing agent. Fortunately, changes in manufacturing practices and reduced levels of nitrite used in curing solved the problem of nitrosamine formation in cured meat. Yet, a low level concern about nitrite has lingered, and in the 1990's a series of epidemiological studies reported that consumption of cured meat was related to childhood leukemia and brain cancer (Preston-Martin and Lijinsky, 1994; Sarasua and Savitz, 1994; Peters *et al.*, 1994; Preston-Martin *et al.*, 1996). Further, in 1998, nitrite was proposed to be classified as a developmental and reproductive toxicant under California's Proposition 65 (Safe Drinking Water and Toxic Enforcement Act). Fortunately, both issues (nitrite as a carcinogen and as a developmental/reproductive toxicant) have been largely resolved by subsequent studies and careful scientific review of the available data (Milkowski, 2006).

The issue of ingested nitrate and nitrite first arose in the 1970's when it was recognized that carcinogenic nitrosamines could be formed in the stomach following ingestion of nitrite. Subsequent work has shown that less than 5% of the nitrite and nitrate typically ingested comes from cured meat, the rest coming from vegetables and saliva (Cassens, 1997a; Archer, 2002; Milkowski, 2006). Nevertheless, in 2006, the International Agency for Research on Cancer (IARC) concluded that "Ingested nitrate or nitrite under conditions that result in endogenous nitrosation is probably carcinogenic to humans" (Coughlin, 2006). While the IARC report is still a work in progress, the conclusions are likely to ramp up questions and concerns about nitrite as a food additive. In light of the anticipated challenges to nitrite in cured meat, it is imperative that as much information as possible is developed for all processed meat applications where nitrite and/or nitrate have a role.

Current U.S. regulations on nitrite and nitrate

Current regulations on the use of nitrite and nitrate in the United States vary depending on the method of curing used and the product that is cured. For comminuted products, the maximum ingoing concentration of sodium or potassium nitrite is 156 parts per million (ppm) or 0.25 oz per 100 lbs (7 g/45.4 kg), based on the green weight of the meat block (USDA, 1995). Maximum ingoing sodium or potassium nitrate for comminuted products is 1718 ppm. Sodium and potassium nitrite and nitrate are limited to the same quantity despite the greater molecular weight of the potassium salts. This means that the potassium salt contains less nitrite or nitrate than the equivalent weight of the sodium salt. For immersion cured, and massaged or pumped products, maximum ingoing sodium or potassium nitrite and nitrate concentrations are 200 and 700 ppm of nitrite and nitrate, respectively, again based on the green weight of the meat block. Dry cured products are limited to 625 ppm and 2187 ppm of nitrite and nitrate, respectively. If nitrite and nitrate are both used for a single product, the ingoing limits remain the same for each but the combination must not result in more than 200 ppm of analytically measured nitrite, calculated as sodium nitrite in the finished product.

Bacon is an exception to the general limits for using curing agents because of the potential for nitrosamine formation. For pumped and/or massaged bacon without the skin, 120 ppm of sodium nitrite or 148 ppm of potassium nitrite is required along with 550 ppm of sodium ascorbate or sodium erythorbate, which is also required. It is important to note that this is a specifically required amount whereas other nitrite limits are maximum quantities. To accommodate variation in pumping procedures and brine drainage from pumped products, the regulations for pumped and/or massaged bacon permit ± 20% variation from the target concentrations at the time of injecting or massaging. For example, sodium nitrite concentrations within the range of 96–144 ppm are acceptable. Nitrate is not permitted for any bacon curing method. There are two exceptions to these regulations for pumped and/or massaged bacon: first, 100 ppm of sodium nitrite (or 123 ppm of potassium nitrite) with an "appropriate partial quality control program" is permitted and, second, 40–80 ppm of sodium nitrite or 49–99 ppm of potassium nitrite is permitted if sugar and a lactic acid starter culture are included. Immersion cured bacon is limited to 120 ppm of sodium nitrite or 148 ppm of potassium nitrite while dry cured bacon is limited to 200 ppm or 246 ppm, respectively. For bellies cured with the skin on, the nitrite and reductant concentrations must be reduced by 10%, based on the assumption that skin comprises approximately 10% of the belly weight.

It is important to note that the regulations also require a minimum of 120 ppm of ingoing nitrite for all cured "Keep Refrigerated" products "unless safety is assured by some other preservation process, such as thermal processing, pH or moisture control." The establishment of minimum ingoing nitrite concentration is considered critical to subsequent product safety. This is a significant consideration for natural and organic cured meat products.

On the other hand, for cured products that are processed to ensure shelf stability (may be stored at room temperature), there is no minimum ingoing nitrite level. The USDA Processing Inspector's Calculations Handbook (USDA, 1995) suggests that, for shelf-stable products, "…40 ppm nitrite is useful in that it has some preservative effect. This amount has also been shown to be sufficient for color-fixing purposes…."

The curing accelerators permitted for use with nitrite are also restricted. Fumaric acid, for example, is limited to 650 ppm and only in cured, comminuted meat and poultry products, while GDL and SAPP are permitted at 5000 ppm only in cured comminuted meat products on a finished product basis. Ascorbic and erythorbic acids cannot exceed 469 ppm ingoing concentrations while sodium ascorbate and erythorbate are limited to 547 ppm ingoing, all based on the green weight of the meat block. Citric acid or sodium citrate may replace up to half of either form of the ascorbate/erythorbate reductants (USDA, 1995), but may not be used without the reductants.

Ingredients Used For Natural and Organic Cured Meats

Because of the negative perceptions of nitrite cured meat held by some consumers, the "uncured" natural and organic versions of typical cured meats have enjoyed wide-spread market acceptance. A survey of 56 commercial "uncured" meat products including bacon, ham, frankfurters, bologna, braunschweiger, salami, Polish sausage, Andouille sausage and snack sticks showed that most of these products demonstrated typical cured meat color and appearance (Sindelar, 2006b). A review of product ingredients statements showed that 38 products included sea salt, 33 listed evaporated cane juice, raw sugar or turbinado sugar, 19 included a lactic acid starter culture, 17 had natural spices or natural flavorings, 14 added honey and 11 included celery juice or celery juice concentrate. Interestingly enough, at the time of this survey (October–November, 2005), 16 of the products included lactate, which was recently removed from the USDA Food Standards and Labeling Policy Book guidance statement for ingredients acceptable for natural claims. Beets or other natural coloring agents are not permitted in natural products since these ingredients are viewed by the USDA as artificially coloring the meat product.

Analyses of samples of 4 selected commercial brands each of natural or organic bacon, hams and frankfurters showed that all samples except one sample of bacon contained residual nitrite at concentrations ranging from 0.9 ppm to 9.2 ppm. Residual nitrate was found in all products at concentrations of 6.8 ppm to 44.4 ppm (Sindelar, 2006a). Residual nitrite was lower in most of the natural or organic products at the time of sampling than in comparable commercial products made with the conventional addition of nitrite. Other cured meat properties including instrumental color, cured pigment concentration, lipid oxidation and sensory properties were, in general, similar for the natural or organic products relative to the conventionally cured products, but greater variation in the natural and organic products was obvious. Most notable were the low color values, low cured pigment content and low human sensory scores for those products that contained little or no residual nitrite. It is important to note that because these were commercial products selected at retail, the time of manufacture and storage history of each was unknown. Nevertheless, these results suggest that: 1) there is wide variation among the natural and organic processed meats that simulate conventionally cured products, and 2) a large majority of natural and organic processed meats demonstrate typical cured meat properties, including cured color, flavor and significant concentrations of residual nitrite and nitrate. Thus, it is clear that nitrite and nitrate are being introduced to most of these products indirectly as components of other ingredients.

Unique ingredients in natural and organic processed meats

The most common ingredient observed in review of the product labels of natural and organic processed meats was sea salt. Sea salt is derived directly from evaporation of sea water, unrefined without addition of free-flow additives and retains the natural trace minerals characteristic of the source (Kuhnlein, 1980; Heinerman and Anderson, 2001). Several varieties of sea salt are available and differ depending on the geographical origin of the water used and the mineral content (Saltworks, 2006). While sea salt has been suggested as a likely source of nitrate, limited analytical information suggested that the nitrate content of sea salt is relatively low. Herrador *et al.* (2005) reported that Mediterranean sea salt contained 1.1 ppm of nitrate and 1.2 ppm of nitrite. Cantoni *et al.* (1978) analyzed 10 samples each of 3 grades of sea salt and found nitrate and nitrite concentrations of 0.3–1.7 ppm and 0–0.45 ppm, respectively. As a GRAS substance, salt incorporated in food must comply with the Food Chemicals Codex tolerances for purity. Solar-evaporated sea salt must be at least 97.5% sodium choride with specific limits on calcium/magnesium, arsenic and heavy metals content (Food Chemicals Codex, 2003).

The second most common ingredient observed in natural and organic processed meat ingredient lists was raw sugar, most often shown as turbinado sugar. Turbinado sugar is a raw sugar obtained from evaporation of sugar cane juice followed by centrifugation to remove surface molasses. Remaining molasses gives turbinado sugar a light brown color and flavor similar to brown sugar. While it seems possible that raw sugar could include nitrate, there appears to be no evidence of significant nitrate or nitrite concentrations in raw sugar.

Natural flavorings or spices, and celery juice or celery juice concentrate were frequently listed as ingredients, and because these are plant/vegetable products, the potential contribution of nitrate from these sources is very significant. Vegetables are well-known as a source of nitrate with concentrations as high as 1500 ppm to 2800 ppm (National Academy of Sciences, 1981) in celery, lettuce and beets. Vegetable juices and vegetable powders are commercially available and may be used as ingredients in natural and organic foods. Analysis of some commercially available vegetable juices showed that carrot, celery, beet and spinach juice contained 171, 2114, 2273 and 3227 ppm of nitrate, respectively (Sebranek, 2006). After 10 days of storage at room temperature, nitrate levels in these juices declined by 14–22%. Nitrite was not detected initially but concentrations of 128–189 ppm of nitrite were found after 10 days at room temperature, probably resulting from bacterial reduction of nitrate. Analysis of commercial celery juice powder indicated a nitrate content on the order of 27,500 ppm or about 2.75%, reflecting the increased concentration following drying (Sindelar, 2006a). Clearly, vegetable products offer the greatest potential to introduce natural sources of nitrate into processed meats. Juices and powders have advantages in supplying nitrate in concentrated form. Celery juice and celery powder appear to be highly compatible with processed meat products because celery has very little vegetable pigment (as opposed to beets, for example) and a mild flavor profile similar to raw celery that does not detract greatly from finished product flavor. Further, these vegetable products may be listed as natural flavoring on meat product labels.

A critical ingredient for processed meats with natural nitrate sources is a nitrate-reducing bacterial culture, if typical cured meat properties are the final objective. The necessity of bacterial reduction of nitrate to nitrite for meat curing was discovered in the 1890's (Pegg and Shahidi, 2000) and nitrate reducing cultures have been commercially available for several years. Most applications of these cultures have been for dry sausage, where a long-term reservoir of nitrite during drying is desirable and where subtle flavor contributions from the culture are considered important (Olesen *et al.*, 2004). The lactic acid starter cultures used for fermented sausage, primarily *Lactobacillus plantarum* and *Pediococcus acidilactici*, do not reduce nitrate. However, cultures of coagulase negative cocci such as *Kocuria* (formerly *Micrococcus*) *varians*, *Staphylococcus xylosus*, *Staphylococcus carnosus* and others will reduce nitrate to nitrite. These organisms can achieve nitrate reduction at 15–20°C but are much more effective at temperatures over 30°C (Casaburi *et al.*, 2005). The typical recommended holding temperature for commercial nitrate reducing cultures is 38–42°C to minimize the time necessary for adequate nitrite formation. Recent research has documented that time is a critical parameter in the development of typical cured meat properties from natural sources of nitrate. Sindelar (2006a) reported that a holding time at 38°C was more critical than the amount of naturally–added nitrate for development of cured meat properties in small diameter cooked sausage (similar to frankfurters) and hams. Time appeared to be more critical for the small diameter cooked sausage that reached an internal temperature of 38°C quickly than for the large diameter hams where internal temperature increased to 38°C more slowly.

Sindelar *et al.* (2007a) also evaluated several quality characteristics of small diameter cooked sausages manufactured with starter culture and either 0.2 or 0.4% celery juice powder, each held at 38°C for either 30 or 120 minutes. The products were evaluated during 90 days of refrigerated, vacuum-packaged storage and compared with conventionally processed products manufactured at the same time with added sodium nitrite. Color measurements (Hunter a* values, reflectance ratios, cured pigment concentrations) indicated that treatments with short incubation time resulted in less cured color/redness than the nitrite-cured control although this difference was not always significant. Cured color/redness of the product made with the longer incubation time was, in general, comparable to the nitrite-cured control. Residual nitrite following incubation was dramatically different with 5.6 and 7.7 ppm found for the 0.2% and 0.4% celery powder levels, respectively, after 30 minutes of holding time, but 24.5 ppm and 46.0 ppm were observed after 120 minutes. No differences were noted for lipid oxidation between any of the treatments and the control. The nitrite-cured control, in general, received the highest sensory scores although differences were not significant for all sensory properties.

A similar experiment with hams (Sindelar *et al.*, 2007b) was conducted using either 0.2 or 0.35% celery powder and incubation time of 0 or 120 minutes. The treatment with no incubation time was included because the extended thermal process (3 hours, 35 minutes) used for hams relative to small diameter frankfurter-style sausage was expected to result in adequate nitrate reduction by the culture. Results showed that there were no treatment differences in objective color measurements or cured pigment concentrations for the hams, and all product treatments were similar in color properties to the nitrite-cured control. Residual nitrite, following the 120 minute incubation for the 0.2 and 0.35% celery juice powder additions, was 19.5 and 36.1 ppm, respectively. The residual nitrite was significantly less for the hams with celery juice powder (21.0–36.0 ppm at day 0; 7.2–21.3 ppm after 90 days) relative to the nitrite-cured control (63.4 ppm at day 0: 34.1 ppm after 90 days). However, residual nitrite was greater in hams with a greater amount of added celery juice (27.7–36.0 ppm from 0.35% celery powder vs. 19.3–21.0 ppm from 0.20% celery powder at day 0 compared with 11.7–21.3 ppm vs. 7.2–8.8 ppm, respectively, for each after 90 days). Sensory panel evaluations indicated that the higher amount of celery powder (0.35%) resulted in greater vegetable aroma and flavor with less ham aroma and flavor. The treatments with a lower level of celery powder (0.2%) were similar to the nitrite-cured control for all sensory properties evaluated.

The authors concluded that the celery juice powder/starter culture treatment was an effective alternative to the direct addition of sodium nitrite to small-diameter, frankfurter-style cured sausage but that incubation time at 38°C is an important factor for product quality. The celery juice powder/starter culture treatment was also effective for hams but in this case the amount of celery juice powder proved to be more critical. For large diameter products such as hams, it appears that the slow temperature increase that is part of a typical thermal process may provide enough time for the culture to achieve nitrate-to-nitrite reduction. Further, the delicate flavor profile of hams makes these products more susceptible to flavor contributed by vegetable products.

The authors also pointed out that the concentration of celery juice powder used (0.2, 0.35 and 0.4% on a total formulation weight basis) could provide, with 100% nitrate-to-nitrite conversion, maximum ingoing nitrite concentrations of 69, 120 and 139 ppm (meat block basis), respectively, based on the initial nitrate concentration of 27,462 ppm in the celery powder. Because these nitrite concentrations are, at best, significantly less than the 156–200 ppm normally included in cured comminuted products or injected products, it seems likely that product quality differences could occur in some circumstances. It is also worth noting that the USDA requires a minimum of 120 ppm ingoing nitrite for injected bacon and cured meats labeled "Keep refrigerated" to assure safety. Consequently, the actual amounts of nitrite formed from nitrate when natural nitrate sources are used could be a concern relative to microbiological safety. The shelf life of processed meats manufactured with natural nitrate sources is generally shorter than that of nitrite-cured products because less nitrite is present and other typical preservatives such as phosphates, lactate, curing accelerators and antioxidants are not included (Bacus, 2006).

Ingredients that might be considered as curing adjuncts for natural or organic processed meats include vinegar, lemon juice solids, and cherry powder. Acidulants such as vinegar have the potential to accelerate nitrite reactions because of the impact of pH. However, reducing pH in these products is also a concern for reduced moisture retention because phosphates and many of the traditional water binders cannot be used for natural or organic products. Lemon juice solids or powder are typically significant sources of citric acid which could have similar pH effects as vinegar. Cherry powder, on the other hand, is high in ascorbic acid, which functions as a strong nitrite reductant but does not have as great an impact on pH.

An evaluation of a cured, Canadian-style bacon pork product manufactured with a natural nitrate source (celery powder) and with or without 0.28% cherry powder showed that including the cherry powder reduced residual nitrite by about 50% (Baseler, 2007). Residual nitrite declined from 61 to 32 ppm during 12 weeks of storage for a nitrite-cured control, 18 to 10 ppm for the celery powder treatment and 10 to 3 ppm for the celery powder/cherry powder treatment. Addition of cherry powder did not alter the product's pH. Other product properties (color, lipid oxidation) were not consistently different although the nitrite-cured treatment showed greater redness (Hunter a* values) after about 4 weeks of storage.

Natural antioxidants such as rosemary may be used to provide flavor protection and to retard lipid oxidation in processed meats. However, these compounds do not contribute directly to nitrate/nitrite reactions in meat systems. Further, the nitrite generated from natural nitrate sources reported by Sindelar *et al.*, (2007a, 2007b) was sufficient to provide strong antioxidant effects, similar to those typically observed in nitrite-cured meats. Past research has shown that as little as 50 ppm added nitrite has a highly significant effect on lipid oxidation (Morrissey and Tichivangana, 1985). Thus, relatively small amounts of nitrite formed from nitrate probably provide an important antioxidant role in natural and organic processed meats.

Processes for Naturally Cured Meats

Most processors that use "natural curing" are following processing procedures that are generally similar to those processes that include chemical nitrites and nitrates. Naturally-cured products typically use natural sources for nitrate, but some natural ingredients may also contain nitrites. If sufficient nitrite is consistently available from a natural source, no changes in the normal process are required.

Naturally-cured meat products that use natural ingredients as a nitrate source need an ingredient that contains a relatively high natural nitrate content. When using a natural nitrate source, conversion of the nitrate to nitrite is required and this conversion is accomplished by specific microorganisms (with a nitrate reductase enzyme), as described earlier, that are also acceptable food ingredients. When using these microorganisms, the conversion process requires some time, with the specific amount of time depending upon the temperature, the environment, and the concentration of the reactants, namely the microorganisms and the naturally occurring nitrate. The conversion time can be decreased by increasing the reactant concentrations, with the amount of starter culture being the most critical variable.

In all natural curing processes, good distribution of both the nitrate source and the starter culture is essential to achieve uniform curing. The natural nitrate source, if dry, is usually either blended with the dry seasoning component for comminuted products, or added directly to curing brines. The starter culture commonly is diluted first with good quality water (i.e., distilled, or water low in chlorine or other bacteriocidal chemicals) prior to the addition to comminuted products (the USDA permits a maximum 0.5% combined water and starter culture without labeling the added water) or the starter culture may also be added directly to curing brines. Also, it is recommended that the starter culture should not be pre-blended with anything that might affect its viability (i.e., spices, salt), and hence its nitrate reducing activity. The naturally occurring nitrate is soluble, but because the starter culture is not soluble, being water dispersible, some agitation is recommended for brines to achieve optimal distribution in the meat product.

With curing brines, the pH of the brine is critical to achieving optimal natural curing as well as final product texture, because the phosphates or other buffering agents typically used with nitrite-added products cannot be included for products labeled natural or organic. Generally, low pH brines (i.e., <5.5) are not desirable, therefore the pH effect of any added natural ingredients should be considered. With comminuted meat products, the pH effect of directly-added ingredients is not as critical due to the buffering capacity of the meat.

Liquid sources of naturally occurring nitrates (vegetable juices) also are used but these ingredients pose some manufacturing issues. Typically, most of these liquids are not shelf stable, and are supplied in frozen form. Second, the added water that is a component of the juices must be considered.

Natural Cooked Sausage Products

A typical natural cooked sausage product formulation and process is shown below.

Natural Hot Dog Formulation

Pork 72's	52.60%
Beef 50's	22.70
Water	20.30
Sea salt	1.28
Natural Hot Dog Seasoning	3.10
Cane sugar, natural flavors, sea salt, celery powder, onion powder, garlic powder, oleoresin paprika	
Starter culture	0.02

Natural Hot Dog Process

1) Grind meats through a 3/16-inch (4.8 mm) plate.
2) Mix starter culture with water totaling up to 0.50% of the total batch.
3) Mix/chop lean meats, adding in order, salt, ½ of the water, fatty meats, seasoning, and remaining water.
4) Add diluted starter culture.
5) Continue mixing/chopping until the meat blend temperature reaches 50–54°F (10–12°C).
6) Emulsify to 62–64°F (17–18°C).
7) Stuff and link.
8) Place on smokehouse rack and process using the smokehouse schedule.
   a) 110°F (42°C) 60 minutes
   b) 140°F (60°C) 20 minutes
   c) 155°F (68°C) 30 minutes
   d) 175°F (79°C) 30 minutes
   e) 185°F/30% RH to 165°F (73°C) internal temperature
   f) Shower

The formulation and process are essentially the same as a typical, nitrite-added product, except that celery powder is added as a natural nitrate source to replace the typical nitrite cure, the starter culture is added, and the smokehouse process allows for an "incubation" period of 1 hour at 110°F (42°C) to achieve the nitrate conversion to nitrite prior to a typical cook cycle.

Natural Hams

For injected products, such as natural hams, a typical formulation and process is shown below.

Natural Ham Formulation

Water	79.135%
Natural Ham Seasoning	20.820
Sea salt, cane sugar, celery powder	
Starter culture	0.045

Natural Ham Process

1) Bone and trim pork, inside and outside pork rounds.
2) Dissolve and mix natural ham seasoning and starter culture into water prior to use.
3) Inject meat to 132% of green weight with the prepared pickle.
4) Macerate injected muscles on each side.
5) Tumble/massage under vacuum for a total of 5 hours. Tumble with 1/3 interval active and 2/3 intervals inactive (10 minutes on and 20 minutes off).
6) Stuff hams into pre-smoked netted casings.
7) Place hams in vacuum packager and evacuate (without packaging materials) to remove air.
8) Place hams on cook rack.
9) Smoke hams to internal temperature of 158°F (70°C) using the following smokehouse process.
10) Chill in cooler overnight (8–10 hours).
11) Remove netting before vacuum packaging.

Natural Ham Smokehouse Schedule

Dry Bulb (°F)	Wet Bulb (°F)	RH (%)	Time (minutes)
165 (74°C)	115 (46°C)	22	45
165 (74°C)	115 (46°C)	22	15
165 (74°C)	115 (46°C)	22	30
165 (74°C)	115 (46°C)	22	60
175 (79°C)	155 (68°C)	59	30
180 (82°C)	180 (82°C)	100	Core temperature 158°F (70°C). Estimated 2 hours

For injected products, since the starter culture is not soluble, the physical injection process is critical for optimum distribution. The culture does not migrate in the meat, and thus poor distribution can result in uncured spots if the culture is not present. Generally, a relatively high injection percentage of brine is preferred.

In the above process, no "incubation" is required for the nitrate conversion due to the larger diameter of the ham pieces and more gradual "come up time" for the internal temperature. With smaller diameter products and rapid heat penetration, the heating process may have to be adjusted to achieve optimal nitrate conversion.

Natural Bacon

A typical formulation and process for natural bacon is as follows.

Natural Bacon Formulation

Water	66.38%
Sea salt	22.00
Cane sugar	10.40
Celery powder	1.20
Starter culture	0.02

Natural Bacon Process

1) Trim pork bellies.
2) Prepare pickle prior to use.
3) Dissolve the following in water: sea salt, cane sugar, celery powder, and starter culture.
4) Pump pork bellies to 115% of green weight.
5) Place the pumped pork bellies on bacon hooks and smokehouse process.
6) Chill and slice.

Natural Bacon Smokehouse Schedule

Dry Bulb (°F)	Wet Bulb (°F)	RH (%)	Time (minutes)
110 (42°C)	92 (35°C)	70	75
145 (63°C)	-	-	60
145 (63°C)	-	-	15
134 (57°C)	-	-	90
140 (60°C)	120 (49°C)	55	Core temperature 128°F (53°C). Estimated 180 minutes

Generally, since injected pork bellies are relatively thin in diameter, a short "incubation" period at 110–115°F (42–46°C) is recommended prior to the common heating cycle. Some processors have found with natural bacon that their normal bacon process provides adequate incubation time during the "come up" heating phase. Because bacon is not fully cooked, relatively high bacterial counts from the added starter culture will remain in the product.

Natural Pepperoni

Natural fermented sausages do not require any adjustments in processing since an "incubation" step (fermentation phase) is already incorporated into their normal process to allow the added starter culture to reduce the sugars to lactic acid and other metabolites. Since most meat starter cultures, particularly in the United States, consist of lactic acid producing bacteria only, it is imperative to confirm that the added starter culture contains a mixed culture with one culture to ferment the added sugars and at least one other culture to reduce the naturally occurring nitrates to nitrite. Many mixed starter cultures are available to accomplish both functions, or the nitrate-reducing culture can be added "on top" of the existing acid-producing culture.

Natural Pepperoni Formulation

Pork 72	66.08%
Beef 50	12.40
Beef 65	16.20
Natural Pepperoni Seasoning	5.00
Sea Salt, Natural Cane Sugar, Spices, Natural Flavorings (including celery powder), Garlic Powder, Paprika Extractives	
Meat starter culture (lactic acid production)	0.30
Meat starter culture (nitrate conversion)	0.02

Natural Pepperoni Process

1) Temper fresh/frozen meats to 26–28°F (–3 to –2°C). Grind or chop to 15–20 mm.
2) Mix meats in paddle-type mixer OR chop in silent cutter with mixing speed, adding in sequence, seasoning and starter cultures (pre-diluted in water to 0.5% batch weight), with minimum mixing/cutting time to achieve good distribution.
3) Regrind through a 3–4 mm plate OR chop to similar particle size.
4) Stuff into regular, flat stock fibrous casings (50–53 mm for slicing) or collagen casings so as to minimize "smear" (meat temperature @ 26–28°F (–3 to –2°C)).
5) Equilibration for a minimum of 2 hours @ 71–72°F (22–23°C).
6) Fermentation:
   a) 95–104°F (35–40°C), 85% RH to pH < 5.0 (8–10 hours)
   b) 120–122°F (49–50°C), 60% RH (1 hour)
   c) 129–131°F (54–55°C), 60% RH to 128°F (53°C) internal temperature, hold 1 hour
7) Hot shower and cool to ambient temperature.
8) Dry room @ 52–55°F (11–13°C), 65–72% RH to moisture/protein ratio of 1.6/1.0 (10–14 days, 68–72% yield).

Current Issues with Natural and Organic Cured Meats

Regulatory

The current regulatory issues concerning "organic" meat products are well defined by the USDA Agricultural Marketing Service, thus processors desiring to make such products must adhere to a fixed set of regulations outlining permitted ingredients. With "natural" meat products, however, the rules for permitted ingredients have recently become more confusing. Until August, 2005, "natural" simply meant "minimally processed" and "no artificial ingredients", with any meat source considered natural. The "natural" rules were based on USDA Policy Memo 055, prepared in 1982, and focused on the process and the non-meat ingredients. With revisions outlined in the USDA Food Standards and Labeling Policy Book (USDA 2005), additional ingredients, including sodium lactate (from a corn source), cane sugar, and natural flavorings from oleoresins and extractives were permitted to be labeled as "natural". Additionally, the Policy Book referenced 7 CFR NOP Final Report, Part 205.601 through 205.606 for acceptable ingredients allowed for all natural claims.

A petition submitted to the USDA in October, 2006, suggested that the 2005 revisions to the agency's "natural" policy created inconsistencies by allowing foods carrying the "natural" label to contain synthetic ingredients and preservatives, deceiving consumers and eroding the "natural" label to a meaningless marketing policy. Much of the concern expressed by the petitioner was the allowance of sodium and potassium lactates in "natural" products, since these ingredients would be considered "chemical preservatives". Also, by allowing any ingredients on the OFPA List (for "organic" products), even some synthetic ingredients on the list were permitted in "natural" products. The petition to the USDA proposed that extensive rulemaking should be initiated for meat and poultry products labeled as "natural" in much the same way as had been done with products labeled as "organic".

Consequently, USDA reversed its position on the use of lactates, categorizing these ingredients as "chemical preservatives", and notified processors using them that they must remove lactates from their products within 30 days, unless the processor could demonstrate that such use was not as a preservative. Additionally, the USDA clarified its reference to the OFPA List, only permitting those ingredients on the List that would be considered "natural". The rule making for "natural" has begun, with a public meeting in Washington in December, 2006, and a comment period extended to March 5, 2007.

The issue of lactates as "chemical preservatives" also raised the issue of dual-function ingredients, whereby the ingredient may be considered as a natural ingredient for flavor and/or function, but can also have a dual function as a "natural" preservative. The issue of "natural preservative" vs. "chemical preservative" has not been defined, as yet. By strict interpretation, any "preservative" used in a HACCP Program, that allows a processor to classify their product in Alternative 1 or Alternative 2, in regard to *Listeria monocytogenes* control, would not be permitted to be labeled as "natural".

Many natural compounds that exist in the environment can serve to inhibit microorganisms, retard oxidation, and thus "preserve" the product and would be valuable ingredients in food products that are labeled as "natural". Until this issue of "natural" vs. "chemical" preservatives is resolved, the current regulatory environment is retarding innovative product development and may compromise food safety as well.

Manufacturing

When manufacturing "natural" and "organic" meat products using natural ingredients, the inherent variability of natural ingredients must be considered. In the natural curing process, whereby naturally-occurring nitrates are converted by starter cultures to nitrites, the concentration of the nitrate in the source will affect the degree of curing as well as the amount of nitrate-reducing activity of the starter culture. Typically, in products cured with direct addition of sodium nitrite, the ingoing nitrite is regulated at 156 ppm in most meat products and at 120 ppm for bacon. In naturally-cured meat products, the ingoing nitrate level is most often between 40–60 ppm, thus there is, at best, significantly less nitrite in these products than in the typical nitrite-cured products. Measurable residual nitrite in both types of cured products are often similar with no noticeable differences in color and stability. However, this will be very dependent upon actual nitrite formation in the product during the nitrate reduction phase of the process. While reduced shelf-life has been observed in naturally cured meats, a significant part of the change is probably due to the lack of other traditional ingredients that are not permitted in "natural" products (ie. phosphate, ascorbate, erythorbate, citric acid, and synthetic antioxidants).

Marketing

The issue of the consumer's understanding of what is meant by "natural" meat products is difficult to define. Many consumers may not comprehend that natural ingredients often contain naturally occurring chemicals virtually identical in chemical nature to those chemicals synthetically produced.

With regard to natural curing, many foods, particularly vegetables, contain naturally occurring nitrates. It is generally accepted that less than 5% of human consumption of nitrate and nitrite is due to meat products. The majority of nitrates consumed are from vegetable products (Archer, 2002). The current USDA concern with "naturally cured" meat and poultry products is that these products often contain residual nitrates and nitrites, even though correctly labeled as "no nitrates or nitrites added". According to the Code of Federal Regulations 9 CFR 319.2, the processor has no choice but to label such products (i.e., "… to which nitrite or nitrate is permitted or required to be added…") as "uncured" and no "nitrates or nitrites added", even though the processor may be using a natural curing process. The USDA attempted to remedy this issue by requiring a disclaimer (no nitrates or nitrites added … *except those naturally present in* ______) on such products that contain ingredients that may contain naturally occurring nitrates and nitrites, but this adds to consumer confusion and labeling inconsistencies. The individual USDA label reviewer must determine in each case if the added ingredients in the meat product label submittal could contain nitrates and/or nitrites, which is possible for a multitude of ingredients. Vegetables, bouillons, and fruits are ingredients that have been used in combination with meat and poultry products for centuries and have probably contributed nitrate/nitrite to these products for as long as they have been used. Also, it is possible for environmental nitrates and nitrites to contaminate the product during processing (i.e., water source, smoking).

To provide the consumer with the most accurate information, more appropriate labeling would be to use a term such as "naturally cured" because the products are truly cured with naturally occurring nitrate and/or nitrite added in the form of natural ingredients, and eliminate the "uncured" and "no nitrates or nitrites added" requirement. This would require modifying the federal regulations in 9 CFR 319.2. Residual nitrite is the real issue, not the cured meat pigments that result from the various nitrite reactions. Replacing the disclaimer with the footnote "naturally occurring nitrites may be present", would adequately inform the consumers of the potential existence of nitrite in the "naturally cured" products. Another alternative would be to allow processors to avoid the disclaimer or footnote if they can prove that they can control their process to eliminate any residual nitrites, which is the primary concern for many consumers, particularly in bacon.

Quality

The quality characteristics expected of traditional cured meats that are unique to these products include the reddish-pink color of cooked denatured nitrosylhemochrome, a flavor that is distinct from uncured products, and long-term flavor protection resulting from the strong antioxidant effect of nitrite on meat systems. The fixation of desirable color is the first and most obvious effect of nitrite when added to meat and is considered an essential function because color is a critical component affecting consumer retail purchases (Cornforth and Jayasingh, 2004). As little as 2–14 ppm of nitrite (depending on species) can induce pink coloration in cooked meats though at these levels the color is often sporadic and likely to fade with time. Extensive research in the 1970's showed that 25–50 ppm of ingoing nitrite was adequate to develop relatively stable cured color (National Academy of Sciences, 1982). While there are indications that cured color may be less intense with 40–50 ppm of nitrite instead of 150–200 ppm depending on product type, 40–50 ppm is generally considered adequate for cured color development in most products. Thus, it would appear that cured color development can be achieved relatively easily in processed meat using natural sources of nitrate and a nitrate-reducing culture. A related question, however, concerns the long term stability of the cured color formed in these products. One of the difficulties with assessing potential cured color intensity or stability with nitrate-based cures is that the absolute amount of nitrite formed from nitrate cannot be determined due to the reactive nature of nitrite in meat, and can only be estimated from the amount of nitrate that is depleted. Sindelar *et al.* (2007a), for example, reported that small diameter sausage made with celery powder and culture had 9.3–31.9 ppm of residual nitrate remaining when 69 ppm of nitrate was added as part of the celery powder, and 12.2–81.4 ppm remaining when 139 ppm was added. So, if 100% of the nitrate that was depleted was, in fact, reduced to nitrite, the ingoing nitrite concentrations ranged from 37 to 127 ppm. This is sufficient nitrite to generate desirable cured meat color characteristics in most processed meat products. Similar results were observed with hams (Sindelar, 2007b) where the residual nitrate concentrations suggested formation of nitrite in the range of 45 to 119 ppm. Thus, the quality of cured color in terms of intensity and stability is not likely to be a major issue in processed meats using natural sources of nitrate if appropriate processing procedures are followed to achieve nitrate reduction, and if adequate packaging (oxygen removal by vacuum or gas flushing and high oxygen-barrier films) is used (Møller *et al.*, 2003).

Cured flavor is an important quality attribute of cured meats that is derived from the addition of nitrite, although the chemical nature of the flavor has never been established. It is clear, however, that relatively low concentrations of nitrite result in significant cured flavor. Several researchers have reported acceptable cured meat flavor in products formulated with 40 ppm of ingoing nitrite (Pegg and Shahidi, 2000). In a series of reports, MacDonald *et al.*, (1980a, 1980b, 1980c) concluded that addition of 50 ppm of nitrite to hams was sufficient to produce significant cured meat flavor and antioxidant protection. Thus, in addition to color, it appears that 40–50 ppm or more of ingoing nitrite will result in a significant flavor contribution to cured meat.

The third quality contribution of nitrite to cured meat is the often-overlooked, but highly effective role of nitrite as an antioxidant. Whether nitrite, nitric oxide or some reaction products of these compounds are responsible for the antioxidant function is not clear despite extensive past research. It is clear, however, that nitrite is again effective at relatively low concentrations. Morrissey and Techivangana (1985), for example, using cooked, ground beef, pork, chicken and fish muscle, reported that 50 ppm of nitrite reduced TBA values by 50–64% for beef, pork and chicken, and about 35% for fish. Nitrite concentrations of 100 ppm resulted in TBA reductions of 57–72%, and 200 ppm reduced TBA values by 87–91%. There was a very clear relationship between saturated:unsaturated fat ratios and the TBA values, with more unsaturated fats resulting in greater TBA values regardless of the nitrite concentration. While nitrite is effective as an antioxidant at 50 ppm, it is more effective at greater concentrations up to 200 ppm. The nitrite concentration becomes increasingly important for meat products with greater amounts of unsaturated lipids. Further, the antioxidant function of nitrite in cured meat, while highly effective, is not as unique as the color and flavor contributions. There are a number of antioxidants including natural compounds that can protect meat lipids from oxidation and flavor deterioration.

If at least 50 ppm of nitrite is formed from nitrate during processing of meat products with natural nitrate sources, it appears that the typical quality characteristics expected of cured meat (color, flavor, flavor stability) will be achieved. A question that is more difficult to answer is the long-term stability of those quality characteristics. It is well recognized that when nitrite is fully depleted from cured meat, color fading and flavor changes typically occur. Some residual nitrite is essential to maintaining typical cured meat properties during extended product storage. It appears that the 5–15 ppm residual nitrite observed in commercial cured meats (Cassens, 1997b), is a reasonable indicator for long-term stability. It is important to keep in mind that packaging and environmental conditions, particularly temperature and exposure to light, are critical to long-term cured meat quality, and become more critical when residual nitrite is reduced.

Safety

The safety of processed meats that simulate traditional cured meats by using natural sources of nitrate is a significant issue for two reasons; first, nitrite is a very effective antimicrobial agent, particularly for preventing toxin production by *Clostridium botulinum* and second; residual nitrite concentration is a well-known risk factor in the potential formation of carcinogenic nitrosamines. In both cases, ingoing and residual nitrite concentrations must be carefully controlled to provide product safety.

The antimicrobial role of nitrite in cured meat has been well documented. Christiansen (1980), in a review of botulinal inhibition by nitrite, concluded "that any change in nitrite usage which reduces the level of residual nitrite or increases the rate of nitrite depletion could increase the above mentioned (botulinal) theoretical risk." The issue for processed meats that use natural sources of nitrate is that the true amount of nitrite formed is unknown and impossible to measure because nitrite reacts quickly with meat components. While the amount of detectable residual nitrite in these products is significant, it is often less than that found in nitrite-cured products (Sindelar *et al.*, 2007a, 2007b) depending on processing conditions. On the other hand, the nitrite reactions means that there are variable pools of nitrite-modified compounds in cured meat that remain available as reactive sources of nitric oxide (Kanner and Juven, 1980; Møller and Skibsted, 2002). Consequently, the microbial safety of processed meats manufactured with natural sources of nitrate is very difficult to assess without microbiological challenge studies. This is a very significant current research need that remains open in assessing the safety of these products.

The second potential safety issue that should be considered with these products is the implications of higher-than-usual nitrite concentrations. Elevated residual nitrite in bacon is a potential risk for nitrosamine formation and actual ingoing nitrite concentrations need to be carefully controlled to avoid this potential problem. The nature of the time-temperature relationship for reduction of nitrate to nitrite by a starter culture makes the concentration of nitrite a variable entity. Further, vegetable products are recognized as extremely variable in nitrate content as a result of different environmental conditions that occur during plant growth (National Academy of Sciences, 1981). Consequently, more information is needed on the best means by which to control nitrite formation in processed meats manufactured with natural sources of nitrate to assure that excess concentrations of nitrite do not become a safety issue.

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