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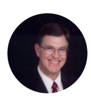
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Survey of Residual Nitrite and Nitrate in Conventional and Organic/Natural/Uncured/Indirectly Cured Meats Available at Retail in the United States

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ABSTRACT: A survey of residual nitrite (NO_2^-) and nitrate (NO_3^-) in cured meats available at retail was conducted to verify concentrations in conventional (C) products and establish a baseline for organic/natural/uncured/indirectly cured (ONC) products. In this study, 470 cured meat products representing six major categories were taken from retail outlets in five major metropolitan cities across the United States. Random samples representing both C and ONC type products were analyzed for NO_2^- and NO_3^- content (ppm) using an ENO-20 high-performance liquid chromatography system equipped with a reverse phase column. Generally, there were no differences in NO_2^- concentrations between C and ONC meat categories, but a few ONC products surveyed in certain cities were lower in NO_3^- content. Pairwise comparisons between cities indicated that NO_2^- and NO_3^- contents of all C type products were not appreciably different, and the same was true for most ONC products. Numerical NO_2^- values were less variable than NO_3^- concentrations within each meat product category. NO_2^- concentrations were similar to those previously reported by Cassens (Cassens, R. G. Residual nitrite in cured meat. *Food Technol.* **1997a**, *51*, 53−55) in 1997. Residual NO_2^- and NO_3^- values in this study were numerically lower than those reported by NAS (National Academy of Sciences. *The Health Effects of Nitrate, Nitrite, and N-Nitroso Compounds*; National Academy Press: Washington, DC, 1981) in 1981. Data from this survey provide a benchmark of NO_2^- and NO_3^- concentrations for ONC products available at retail.

KEYWORDS: *nitrate, nitrite, organic, natural, uncured/indirectly cured, cured meat products*

INTRODUCTION

Nitrite (NO_2^-) and in some cases nitrate (NO_3^-) are functional food ingredients that serve as effective antimicrobials to inhibit *Clostridium botulinum* growth, impart a distinctive cure color to meat products, provide antioxidant properties to retard lipid oxidation, and extend the shelf life of these products. Their use in meat curing can be traced to antiquity,[3,4] but it was not until the early 1900s that the chemistry of curing reactions involving NO_2^- and NO_3^- was elucidated. These ingredients remained unregulated in the United States until 1926 when government regulations established a maximum NO_2^- use concentration of 156 ppm.[5,6] The regulations have been modified only slightly since their implementation with allowances of up to 200 ppm NO_2^- for immersion or pumped products and a reduction to 120 ppm in bacon with mandatory inclusion of 547 ppm ascorbate to suppress nitrosation reactions. Current U.S. regulations allow the use of NO_2^- and NO_3^- in meat products based upon product category and method of curing.[7] Immersion cured, massaged, or pumped products such as hams or pastrami are limited to a maximum ingoing concentration of sodium or potassium NO_2^- and sodium or potassium NO_3^- of 200 and 700 ppm, respectively, based on the raw product weight.[8] Dry-cured products, however, are allowed a maximum ingoing concentration of 625 and 2187 ppm of NO_2^- and NO_3^-, respectively, since these products have longer curing times that allow for NO_2^- dissipation and NO_3^- conversion to NO_2^-. If a combination of NO_2^- and NO_3^- is used, the combination must not result in more than 200 ppm sodium NO_2^- in the finished product. Comminuted products such as frankfurters, bologna, and other cured sausages are limited to a maximum ingoing concentration of 156 ppm of sodium or potassium NO_2^- based on the raw weight of the meat block. Sodium or potassium NO_3^- may be added to these products at 1718 ppm regardless of the type of salt used. During the 1970s, the safety of cured meats related to

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human health was questioned due to their potential to form carcinogenic nitrosamines in the stomach following ingestion of NO_2^-. In 1981, a comprehensive report entitled "The Health Effects of Nitrate, Nitrite and *N*-Nitroso Compounds" was published by the National Academy Sciences[2] to assess the human health risk of these compounds. Eleven recommendations were made to reduce the risks associated with the consumption of nitrites, nitrates, and *N*-nitroso compounds in cured meats. Recommendations derived from the report and subsequent publication of additional studies on the use of NO_2^- in curing led to a change in USDA-FSIS regulations in 1978 and 1986 that reduced the allowable concentrations of NO_2^- and NO_3^- in meat products. A provision also was made for the use of reductants such as sodium ascorbate to decrease residual NO_2^- and the potential for *N*-nitroso compound formation. Reducing the concentrations of NO_2^-, restricting the use of NO_3^-, which serves as a reservoir for NO_2^-, and the inclusion of cure accelerator (sodium erythorbate) to inhibit nitrosation reactions have reduced the potential for nitrosamine formation dramatically and reduced the residual concentrations of NO_2^- and NO_3^-. However, concerns raised by epidemiological studies and weak associations of cured meat ingestion with specific types of cancer (childhood leukemia, brain cancer) have renewed concerns about the safety of this meat ingredient. These are often dietary studies, and nitrite estimates are rarely reported. If so, they have been calculated based on intake estimates and referenced values.

Dietary NO_2^- and NO_3^- when ingested are absorbed into the systemic circulation and enter into a series of reactions mediated by nitric oxide synthases (NOSs), a group of important signaling molecules that generate nitric oxide (NO). Normal functioning of the vascular tissues requires the presence of NO_2^-, which is converted to NO. Nitric oxide in turn regulates vasodilation, blood pressure, endothelial inflammatory cell recruitment, and platelet aggregation. Endogenous NO may be generated from the L-arginine-NOS pathway as well as by conversion of dietary NO_2^- and NO_3^-. Nitrate, however, must first be reduced to NO_2^- to serve as a source of NO. This may be accomplished by the action of symbiotic bacteria in the oral cavity reducing salivary NO_3^- to NO_2^- or by systemic reduction of NO_3^- to NO_2^-.[9,10] Lundberg et al.[11] reported that approximately 25% of ingested NO_3^- is secreted in saliva and 20% (or 5−8% of the total NO_3^- intake) is converted to NO_2^- by commensal bacteria on the tongue.

At issue with dietary sources of NO_2^- and NO_3^- is whether exposure to these ingredients truly poses a sufficient health risk to warrant their removal or restriction from the food supply, particularly from cured meats. As with any compound, dose dictates poison, and at high concentrations, pure NO_2^- can be toxic with an estimated lethal oral dose of 2−9 g for a 60 kg adult.[12] Other estimates of toxic NO_2^- dosages that induce methemoglobinaemia in infants have been reported to range from 1 to 8.3 mg $NaNO_2^-$/kg body weight.[13] The lowest acute oral lethal dose of NO_2^- has been reported to vary from 33 to 250 mg/kg body weight in which the lower dose range might be applied to children or the elderly.[14] Lethal doses of potassium nitrate (KNO_3^-) have been estimated to range from 4 to 30 g (70−500 mg/kg body weight), but a realistic estimate of a lethal dose in adults is 20 g NO_3^- or 330 mg NO_3^-/kg body weight.[13] The National Academy of Sciences[2] concluded that 39, 34, and 16% of the dietary intake of NO_2^- was derived from cured meat, baked goods/cereal, and vegetables, respectively. However, more recent reports have shown that less than 5% of the ingested NO_2^- and NO_3^- is derived from cured meat sources, with the remainder coming from vegetables and saliva.[1,4,15−17] As a consequence, a major source of NO_2^- and NO_3^- exposure comes from nitrate rich foods, such as vegetables. In an assessment of NO_3^-, NO_2^-, and *N*-nitroso compounds in the human diet, Gangolli et al.[13] concluded that vegetables contribute over 85% of the daily dietary intake of NO_3^- and that endogenous synthesis was an important contributor to human's overall exposure of NO_3^-. Hord et al.[10] estimated that approximately 80% of dietary NO_3^- intake was derived from vegetable consumption, while dietary NO_2^- intake included vegetables, fruit, and processed meats. Of the total dietary NO_3^- and NO_2^- consumed, it has been estimated that approximately 50% of the steady-state concentrations of NO_3^- and NO_2^- in humans comes from dietary sources.[10] Both endogenous replenishment and dietary sources contribute to the NO_3^- and NO_2^- pool to ensure a reservoir of NO for adequate cell function. Even if up to 50% of the steady-state concentrations of NO_2^- and NO_3^- were derived from dietary sources as some have estimated, the total daily NO_2^- exposure from saliva alone would be 75 μmol or 5.18 mg. On the basis of these estimates, Hord et al.[10] concluded that the normal physiologic exposure levels of NO_2^- and NO_3^- greatly exceed concentrations normally considered to produce health risks. Nitrate and NO_2^- intake is quite variable among individuals due to the variation in consumption patterns (i.e., fresh vegetables, breads, cereals, tuber crops, and water) with the greatest exposure coming from vegetables and saliva.

In a survey by Cassens,[1] the residual NO_2^- content of cured meats taken from a metropolitan supermarket was found to be 7 ppm for bacon, 6 ppm for sliced ham, and 4 ppm for hot dogs. A subsequent larger survey of over 100 retail samples of cured meats from various manufacturers taken from several U.S. cities showed the overall residual NO_2^- mean to be ∼10 ppm. This represents a considerable decrease from the 1975 report by White[18] that found an average residual NO_2^- concentration of 52.5 ppm in cured meats. A comprehensive review conducted in Canada over the period from 1972 to 1997 reported an average NO_2^- value of 28 ppm in cured meat products sampled in 1996, which is slightly higher than the concentration reported in the United States during the same time period.[19] Because several years have passed since a survey of cured meat products has taken place in the United States, we conducted a comprehensive survey to verify the actual concentrations of residual NO_2^-/NO_3^- in cured meats currently offered at retail and to establish a database for comparison to other historic surveys. Previous studies[1−4,19] have provided values for residual NO_2^-/NO_3^- in meat and food products, but no comprehensive national study has been performed to establish NO_2^-/NO_3^- concentrations in new cured meat categories (i.e., organic/natural/uncured/indirectly cured).

In recent years, there has been a significant increase in consumer demand for "natural" and "organic" foods. Organic and natural meat products are two separate and distinct categories defined in terms of U.S. Department of Agriculture regulations and label requirements. Neither category is permitted to be manufactured with added sodium (or potassium) nitrite or nitrate salts. However, the U.S. Department of Agriculture permits the manufacture of "uncured" versions of typical cured meat products according to the Code Federal Regulations. The definitions of organic and natural require that "uncured" be included on the label for products

Table 1. Total Number of Cured Meat Products Collected at Retail Outlets in Five Cities[a] Across the United States

product category	product subcategory[b]	product type: conventional cured	product type: organic/natural/uncured/indirectly cured
cured dried sausages (uncooked)	German air-dried sausage, chorizo Italian dry sausage	40	24
cured sausages (cooked)	bologna, frankfurters, polish sausage	59	30
fermented/acidified sausages (cooked)	pepperoni, summer sausage, snack sticks	52	24
whole-muscle brine-cured (uncooked)	bacon	20	18
whole-muscle brine-cured (cooked)	hams, bacon (precooked), cured poultry, pastrami, corned beef	97	44
whole-muscle dry-cured (uncooked)	dry-cured country style hams, dry-cured bacon, prosciutto	38	24
total number		306	164

[a]Chicago, IL; Dallas, TX; Los Angeles, CA; New York, NY; and Raleigh, NC. [b]Attempts were made to sample six products listed in each subcategory per city (four samples were analyzed for nitrite/nitrate content for each subcategory, and two samples were held in reserve). Some products (i.e., organic/natural/uncured/indirectly cured) were not available in some categories within some cities. A complete listing of all products sampled by subcategory within cities is given in the footnotes for Tables 3 and 4. For sausages, no products were selected as strictly poultry, beef, or pork and could have been formulated to contain one or more species within a single product, that is, poultry, beef, and pork frankfurters.

with a standardized cured product name; however, it is important to note that not all products labeled "uncured" are organic or natural. Various ingredients have been used in these categories of products that include sea salt (0−0.45 ppm NO_2^-; 0.3−1.7 ppm NO_3^-), evaporated cane juice, raw sugar or turbinado sugar, lactic acid starter culture, natural spices, natural flavorings, and juice from celery, carrots, beet, and spinach, which also serves as a source of nitrate (171−3227 ppm NO_3^-).[17]

For cured meat products, this has presented a particular challenge since traditional curing agents, NO_2^- and NO_3^-, cannot be added to natural or organic processed meats. This has created some challenges to develop products that have the distinctive color, flavor, and texture of cured meats, which will persist throughout a product's shelf life and provide the same level of safety afforded by traditional nitrite-cured meats.[17]

This survey was conducted to assess the major categories of cured meat products for residual NO_2^-/NO_3^- content by randomly sampling retail outlets in five major, geographically diverse metropolitan cities across the United States. This approach was intended to obtain a representative sampling of cured meat products and determine if changes in residual NO_2^-/NO_3^- concentrations had occurred in the past 15 years. In addition to conventional cured meats, organic/natural/uncured/indirectly cured type products were also surveyed to provide a benchmark for comparison to other databases.

■ MATERIALS AND METHODS

Sample Selection and Collection. A national survey of the major categories of cured meat products was conducted in five major U.S. cities in different geographic regions from September 2008 to March 2009. The five cities selected were based on strategic geographic regions that serve large population groups and an associated metropolitan area. The rationale was that a variety of cured meats would likely be more available to consumers in retail supermarkets in these population dense areas. Thus, by randomly selecting cured meat products in these areas, this would provide an assessment of the nitrite/nitrate content of cured products available to large numbers of consumers. Two types of cured meat products were also targeted for sampling—conventional (C) and those designated as organic/natural/uncured/indirectly cured (ONC). Random samples of each product subcategory were collected within each city with a criterion that all meat products sampled must be purchased at least 1 week before the "sell-by" date printed on the package. Cured meat products were collected regionally in retail outlets of major supermarket chains in Chicago, IL (Midwest); Dallas, TX (South); Los Angeles, CA (West); New York City, NY (Northeast); and Raleigh, NC (Mid-Atlantic). Samples selected from each broad category were determined based on production volume, consumption level, unique processing characteristics (i.e., dry cure, uncured/indirectly cured, etc.), and product regionality. The sampling scheme used is presented in Table 1 along with designations of product categories, subcategories, and types.

Random samples of 470 cured meat products were selected from retail outlets in five U.S. cities identified previously. Each city was visited once. Three cities (Dallas, Raleigh, and Chicago) were surveyed from September to November 2008, while the remaining cities (New York and Los Angeles) were surveyed during February and March 2009. Major retail outlets predominant in each city were identified in advance of sample collection.

Meat samples were collected from fresh and/or frozen retail displays, pegboard displays, and/or deli service counters. Samples collected from Dallas were left in their original packaging, placed in plastic bags, and stored in refrigerated coolers for transport to Texas A&M University, College Station, TX. Samples collected in Raleigh were transported to the Department of Food, Bioprocessing & Nutrition Sciences, North Carolina State University in Raleigh, NC, where they were placed in styrofoam shipping containers lined with frozen chill packs and labeled for shipping. Samples collected from Chicago were placed in plastic bags in their original packaging and transported in refrigerated coolers to the Department of Animal Science, University of Wisconsin in Madison, WI, where they were placed in styrofoam shipping containers lined with frozen chill packs and labeled for shipment. Samples from New York were transported to Bimmy's in Long Island City where they were placed in styrofoam shipping containers lined with frozen chill packs and labeled for shipment. Samples from Los Angeles were transported to Farmer John's Quality Assurance Department where they were placed in styrofoam shipping containers lined with frozen chill packs and labeled for shipment. Samples from all cities were shipped overnight for next day arrival at the Department of Animal Science, Texas A&M University. Upon receipt, all cured meat product samples were visually evaluated for overall condition. The temperature (≤4 °C), vacuum package integrity, and product appearance of the samples were evaluated upon arrival by one or two Ph.D. scientists with academic research and industrial experience in meat science. Graduate students and technical assistants involved in the study were also trained to assess product parameters upon receipt. All samples were labeled, placed into cardboard storage boxes in random sample order, immediately refrigerated (4 °C), and held in the dark prior to sample preparation. All samples for NO_2^-/NO_3^- analyses were prepared within 2−3 days of receipt, while all retention samples (extra backup samples) were left in their original vacuum package, placed in cardboard storage boxes, and held frozen (−15 °C) in the dark. Those

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Table 2. Comparisons between Conventional Cured and Organic/Natural/Uncured/Indirectly Cured Mean Residual Nitrite/Nitrate Concentrations of Six Cured Meat Categories Surveyed in Five U.S. Cities

city		cured dried sausages (uncooked)	cured sausages (cooked)	fermented/acidified sausages (cooked)	whole-muscle brine-cured (uncooked)	whole-muscle brine-cured (cooked)	whole-muscle dry-cured (uncooked)
Chicago	NO_2^-	N[a]	N	N	N	N	N
	NO_3^-	Y[b]	N	Y	N	N	N
Dallas	NO_2^-	N	N	N	N	N	N
	NO_3^-	N	N	Y	N	N	N
Los Angeles	NO_2^-	N	N	N	N	N	N
	NO_3^-	Y	N	Y	N	N	Y
New York	NO_2^-	N	Y	N	N	N	N
	NO_3^-	N	N	N	N	N	N
Raleigh	NO_2^-	N	N	N	N	N	N
	NO_3^-	N	N	Y	N	N	Y

[a]N, indicates that there is not a significant ($P > 0.05$) difference between the organic/natural/uncured/indirectly cured and the conventional cured mean nitrite/nitrate concentrations in the product. [b]Y, indicates that there is a significant ($P < 0.05$) difference between the organic/natural/uncured/indirectly cured and the conventional cured mean nitrite/nitrate concentrations in the product.

samples acquired from deli sources in each city were vacuum packaged on the same day of their collection prior to shipping.

Sample Preparation. Individual meat product samples (≥1 kg) were removed from their original package, and artificial casings or netting was removed if present. Samples were cut into small pieces (~0.635 cm^3) and subsampled to amass a 200 g random sample. Subsample pieces were placed in a food processor (Cuisinart Inc., model DLC-XPlus, Norwich, CT) and homogenized for 15 s. The sides of the food processor were scraped, and the sample was homogenized for an additional 15 s. This process was repeated until the sample was homogenized for a total of 60 s (four iterations). All samples were processed at cold temperature (≤4 °C) but not frozen to minimize oxidative conditions.

Extraction Procedure. For nitrite analysis, a 20 g portion of cured meat product homogenate was placed in a blender (Oster, model 6791, Sunbeam Products Inc., Boca Raton, FL) with 100 mL of phosphate buffer (pH 7.4), homogenized for 5 min, and three 40 g portions of slurry from each meat sample were individually weighed into 50 mL polycarbonate centrifuge tubes and subjected to centrifugation for 5 min at 10000*g* at 4 °C. This enabled aggregation of the lipid fraction (top layer) and allowed easier pipetting of the homogenate (bottom layer). Three 400 μL aliquots of the homogenate were pipetted into labeled, 1.5 mL centrifuge tubes (economy microtube with snap cap, nr 89000-028, VWR International, West Chester, PA). Methanol (400 μL) was added to each tube, and the samples were vortexed (Fisher Vorter Genie 2, model G-560, Fisher Scientific Inc., Bohemia, NY) and then centrifuged (Eppendorf centrifuge, model 5410, Brinkmann Instruments Inc., Westburg, NY) at 13000*g* for 8 min. After centrifugation, the sample supernatant was collected, placed in a new centrifuge tube, capped, labeled, and stored at 4 °C until shipped overnight to the Institute of Molecular Medicine at University of Texas in Houston Health Science Center (Houston, TX) for HPLC analysis. For nitrate analysis, three additional 100 μL aliquots of phosphate-buffered homogenate were collected and each diluted with 10 mL of phosphate buffer in a disposable culture tube (16 mm × 100 mm, nr 47729-572, VWR International) that was subsequently covered with Parafilm (Pechiney Plastic Packaging, Menasha, WI) and vortexed (15 s). The 1:100 dilution was required for NO_3^- to fit within the detection range and linearity of the HPLC. Three 400 μL aliquots of the homogenate were pipetted into labeled, 1.5 mL centrifuge tubes (nr). Methanol (400 μL) was added to each tube, and the samples were vortexed and then centrifuged at 13000*g* for 8 min using an Eppendorf centrifuge. After centrifugation, each sample supernatant was collected separately, placed in a new centrifuge tube, capped, labeled, and stored at 4 °C until shipped for analysis. All solutions were prepared using a sole source of distilled, deionized water. During the study, water samples were routinely analyzed for background NO_2^- and NO_3^-. Analytical reagent grade chemicals were used in this study.

Nitrite and Nitrate Determination. All sealed sample extract tubes were held refrigerated (4 °C) until packaged for shipment to the University of Texas, Houston Health Science Center (UTH-HSC) for NO_2^- and NO_3^- analyses. Freeze packs (−23 °C) were placed in the bottom of an insulated foam shipping container, tube racks containing sample extracts were wrapped in Parafilm film, and the racks were placed on top of the frozen packs. Additional frozen packs were placed on top of the tube racks, and the container was sealed and shipped via overnight carrier to UTH-HSC to arrive by 10:00 a.m. the following day. All samples were shipped to UTH-HSC within 48 h of sample extraction and preparation. Samples were analyzed in triplicate upon the day of arrival or refrigerated until analyzed the next day. Complete analytical procedures have been previously described by Bryan and Grisham.[20] An ENO-20 HPLC System (EiCom Corporation, San Diego, CA) was employed for separation of NO_2^- from NO_3^- ions using reverse phase chromatography. After separation, the NO_3^- was reduced to NO_2^- through a reaction with cadmium and reduced copper inside a reduction column. The two resolved peaks were then mixed with Griess reagent (dinitrogen trioxide, N_2O_3, generated from acidified NO_2^- that reacts with sulfanilamide) in-line to form the classical diazo compound, which can be detected spectrophotometrically at 540 nm. This system enabled rapid sample detection, minimized cross-reactivity, and was coupled with an autosampler. The system allowed for analysis of a wide range of NO_2^- and NO_3^- concentrations regardless of their respective ratios at a sensitivity level of 1 nM × 100 μL injection for each anion. No interference from protein or other colored species was noted, and NO_2^-/NO_3^- results were reported as ppm (mg/kg) of the original sample weight.

Experimental Design and Statistical Analysis. Six categories of specific cured meat products were randomly sampled in retail outlets in five metropolitan areas (described previously) to determine the NO_2^- and NO_3^- contents of each sample in each product category. For the purpose of analysis, the study was considered to be a completely randomized design with the following factors: (1) metropolitan area (MA): Chicago, Dallas, Los Angeles, New York, and Raleigh; (2) meat products (MP): cured sausages (cooked); whole-muscle brine-cured (cooked); fermented/acidified sausages (cooked); whole-muscle brine-cured (uncooked); whole-muscle dry-cured (uncooked); and cured dried sausages (uncooked); and (3) product type (PT): conventional and organic/natural/uncured/indirectly cured. From each sample, the NO_2^- and NO_3^- concentrations were determined in triplicate. These values were considered as subsamples and were used to assess the variation in the NO_2^- and NO_3^- analysis. The least-squares means, standard errors of the estimated means, and the minimum and the maximum observed concentrations of NO_2^- and NO_3^- were computed with SAS (SAS Institute, version 9.1, Cary, NC) statistical software for each combination of the factors.

Table 3. Mean Residual Nitrite Concentrations[a] (ppm) of Cured Meat Categories Classified as Conventional Cured from Each City[b]

product category	Chicago[b]	Dallas[c]	Los Angeles[d]	New York[e]	Raleigh[f]
cured dried sausages (uncooked)	1.3 ± 0.4 (0.0−7.0)	1.4 ± 0.4 (0.1−10.0)	0.2 ± 0.1 (0.0−0.7)	0.1 ± 0.0 (0.0−0.2)	0.3 ± 0.1 (0.0−1.0)
cured sausages (cooked)	10.4 ± 1.4 (0.4−29.3)	4.1 ± 0.8 (0.1−15.7)	8.6 ± 1.1 (0.3−18.6)	10.3 ± 0.9 (0.3−19.3)	4.6 ± 0.9 (0.4−21.6)
fermented/acidified sausages (cooked)	0.1 ± 0.0 (0.1−0.4)	0.3 ± 0.1 (0.0−1.4)	2.5 ± 1.3 (0.0−26.7)	0.1 ± 0.0 (0.0−0.2)	1.2 ± 0.6 (ND[g]−12.0)
whole-muscle brine-cured (uncooked)	7.4 ± 0.8 (3.7−13.0)	6.2 ± 1.4 (0.2−12.5)	7.1 ± 0.5 (4.7−9.2)	12.2 ± 4.1 (2.9−36.5)	3.4 ± 0.6 (0.5−6.4)
whole-muscle brine-cured (cooked)	7.8 ± 1.0 (0.3−22.4)	5.4 ± 0.5 (0.1−15.0)	7.8 ± 1.1 (0.1−26.7)	8.1 ± 1.1 (0.3−23.5)	8.2 ± 1.2 (0.0−27.6)
whole-muscle dry-cured (uncooked)	1.5 ± 0.4 (0.1−6.0)	4.0 ± 1.4 (0.0−16.2)	1.1 ± 0.3 (0.0−3.4)	0.3 ± 0.0 (0.0−0.8)	0.9 ± 0.2 (0.1−2.6)

[a]Mean value with standard error and minimum and maximum nitrite values in parentheses. [b]Chicago: N = 9 for cured dried sausages (uncooked), N = 12 for cured sausages (cooked), N = 12 for fermented/acidified sausages (cooked), N = 4 for whole-muscle brine-cured (uncooked), N = 19 for whole brine-cured (cooked), and N = 8 for whole-muscle dry-cured (uncooked). [c]Dallas: N = 12 for cured dried sausages (uncooked), N = 12 for cured sausages (cooked), N = 12 for fermented/acidified sausages (cooked), N = 4 for whole-muscle brine-cured (uncooked), N = 20 for whole brine-cured (cooked), and N = 7 for whole-muscle dry-cured (uncooked). [d]Los Angeles: N = 8 for cured dried sausages (uncooked), N = 11 for cured sausages (cooked), N = 12 for fermented/acidified sausages (cooked), N = 4 for whole-muscle brine-cured (uncooked), N = 19 for whole brine-cured (cooked), and N = 6 for whole-muscle dry-cured (uncooked). [e]New York: N = 6 for cured dried sausages (uncooked), N = 12 for cured sausages (cooked), N = 8 for fermented/acidified sausages (cooked), N = 4 for whole-muscle brine-cured (uncooked), N = 20 for whole brine-cured (cooked), and N = 9 for whole-muscle dry-cured (uncooked). [f]Raleigh: N = 5 for cured dried sausages (uncooked), N = 12 for cured sausages (cooked), N = 8 for fermented/acidified sausages (cooked), N = 4 for whole-muscle brine-cured (uncooked), N = 19 for whole brine-cured (cooked), and N = 8 for whole-muscle dry cured (uncooked). [g]ND, not detected.

Table 4. Mean Residual Nitrite Concentrations[a] (ppm) of Cured Meat Categories Classified as Organic/Natural/Uncured/Indirectly Cured from Each City[b]

product category	Chicago[b]	Dallas[c]	Los Angeles[d]	New York[e]	Raleigh[f]
cured dried sausage (uncooked)	0.4 ± 0.1 (0.1−0.9)	2.2 ± 1.1 (0.1−8.5)	0.4 ± 0.1 (0.0−194)	0.2 ± 0.1 (0.0−0.7)	0.1 ± 0.0 (0.0−0.3)
cured sausages (cooked)	10.0 ± 3.4 (0.8−35.4)	3.4 ± 0.7 (0.2−7.2)	4.2 ± 1.6 (0.1−23.2)	0.7 ± 0.2 (0.1−2.7)	10.2 ± 1.8 (3.2−31.1)
fermented/acidified sausages (cooked)	0.1 ± 0.0 (0.0−0.1)	0.1 ± 0.0 (0.0−0.3)	0.1 ± 0.1 (0.0−0.4)	0.1 ± 0.0 (0.0−0.1)	0.2 ± 0.1 (ND[g]−0.5)
whole-muscle brine-cured (uncooked)	11.7 ± 2.6 (1.0−27.0)	0.5 ± 0.1 (0.1−1.2)	3.1 ± 0.8 (0.1−6.3)	9.5 ± 1.9 (0.4−18.6)	16.8 ± 4.3 (5.5−36.0)
whole-muscle brine-cured (cooked)	7.1 ± 0.8 (0.5−15.3)	2.6 ± 0.5 (0.1−7.4)	6.8 ± 1.2 (0.5−22.1)	8.2 ± 1.2 (0.1−16.0)	8.2 ± 1.5 (0.2−19.8)
whole-muscle dry-cured (uncooked)	2.1 ± 0.8 (0.0−10)	0.1 ± 0.0 (0.1−0.2)	6.1 ± 2.6 (0.0−28.9)	0.1 ± 0.0 (0.0−0.1)	2.3 ± 1.2 (0.0−17.1)

[a]Mean value with standard error and minimum and maximum nitrite values in parentheses. [b]Chicago: N = 4 for cured dried sausages (uncooked), N = 5 for cured sausages (cooked), N = 4 for fermented/acidified sausages (cooked), N = 4 for whole-muscle brine-cured (uncooked), N = 9 for whole brine-cured (cooked), and N = 6 for whole-muscle dry-cured (uncooked). [c]Dallas: N = 4 for cured dried sausages (uncooked), N = 6 for cured sausages (cooked), N = 7 for fermented/acidified sausages (cooked), N = 4 for whole-muscle brine-cured (uncooked), N = 9 for whole brine-cured (cooked), and N = 4 for whole-muscle dry-cured (uncooked). [d]Los Angeles: N = 7 for cured dried sausages (uncooked), N = 7 for cured sausages (cooked), N = 3 for fermented/acidified sausages (cooked), N = 3 for whole-muscle brine-cured (uncooked), N = 10 for whole brine-cured (cooked), and N = 6 for whole-muscle dry-cured (uncooked). [e]New York: N = 5 for cured dried sausages (uncooked), N = 6 for cured sausages (cooked), N = 2 for fermented/acidified sausages (cooked), N = 4 for whole-muscle brine-cured (uncooked), N = 8 for whole brine-cured (cooked), and N = 1 for whole-muscle dry-cured (uncooked). [f]Raleigh: N = 4 for cured dried sausages (uncooked), N = 6 for cured sausages (cooked), N = 8 for fermented/acidified sausages (cooked), N = 3 for whole-muscle brine-cured (uncooked), N = 8 for whole brine-cured (cooked), and N = 7 for whole-muscle dry-cured (uncooked). [g]ND, not detected.

To determine significant main effects and interactions of the factors, a data analysis was conducted separately for NO_2^- and NO_3^- concentrations. This yielded two separate analyses: (1) analysis I: response variable, NO_2^- concentration; factors: MA, MP, and PT; and (2) analysis II: response variable, NO_3^- concentration; factors: MA, MP, and PT. For each of the analyses, an examination of the residuals from the fitted models demonstrated heterogeneous variability and either heavier than normal tails or a right skewed distribution. Therefore, a log transformation of the data was performed to satisfy the necessary conditions for conducting an analysis of variance (ANOVA). The residuals from the models using the log transformed NO_2^-/NO_3^- concentrations appeared to satisfy the conditions of homogeneous variances and a normal-like distribution. Because of the significant interactions displayed in the ANOVA, a more detailed examination of the mean NO_2^-/NO_3^- concentrations was conducted using an α = 0.05 Bonferroni multiple comparison of the least-squares means (SAS Institute, version 9.1). For each combination of MA and MP, a test of the difference in mean NO_2^-/NO_3^- concentrations for ONC versus C products was conducted. Also, an α = 0.05 Bonferroni pairwise comparison of the mean NO_2^-/NO_3^- concentrations across the five metropolitan areas was conducted separately for each combination of MP and PT. To obtain an overall assessment of NO_2^- and NO_3^- concentrations, a weighted average over the five cities and six product categories was computed. The weighting was proportional to the number of samples per city and product category.

■ RESULTS AND DISCUSSION

Comparisons of Residual Nitrite and Nitrate Concentrations between Conventional and Organic/Natural/Uncured/Indirectly Cured Meat Products. Pairwise comparisons of the NO_2^- and NO_3^- concentrations of C and ONC meat products sampled from five cities are shown in Table 2. In all cases except one, there were no differences in the

Table 5. Mean Residual Nitrate Concentrations[a] (ppm) of Cured Meat Categories Classified as Conventional Cured from Each City[b]

product category	Chicago	Dallas	Los Angeles	New York	Raleigh
cured dried sausages (uncooked)	368 ± 137 (1−2289)	24 ± 3 (0−54)	67 ± 10 (19−147)	38 ± 6 (3−71)	31 ± 7 (6−87)
cured sausages (cooked)	78 ± 23 (1−541)	17 ± 1 (2−45)	13 ± 1.3 (5−28)	40 ± 8 (15−255)	12 ± 1 (7−21)
fermented/acidified sausages (cooked)	52 ± 9 (2−251)	30 ± 3 (9−92)	51 ± 10 (13−320)	61 ± 10 (3−183)	41 ± 6 (13−78)
whole-muscle brine-cured (uncooked)	15 ± 2 (4−25)	11 ± 1 (4−14)	5 ± 2 (0−17)	26 ± 1 (18−32)	13 ± 3 (6−29)
whole-muscle brine-cured (cooked)	17 ± 3 (0−108)	14 ± 1 (3−42)	10 ± 2 (0−53)	25 ± 2 (1−47)	12 ± 2 (0−72)
whole-muscle dry-cured (uncooked)	193 ± 84 (0−1367)	28 ± 5 (0−71)	172 ± 77 (0−879)	41 ± 7 (2−107)	115 ± 37 (11−571)

[a]Mean value with standard error and minimum and maximum nitrate values in parentheses. [b]See the footnote in Table 3 for a listing of product categories sampled by city.

Table 6. Mean Residual Nitrate Concentrations[a] (ppm) of Cured Meat Categories Classified as Organic/Natural/Uncured/Indirectly Cured from Each City[b]

product category	Chicago	Dallas	Los Angeles	New York	Raleigh
cured dried sausage (uncooked)	1 ± 0 (0−2)	57 ± 17 (7−138)	6 ± 1 (0−14)	33 ± 13 (1−123)	11 ± 3 (5−35)
cured sausages (cooked)	27 ± 4 (1−45)	16 ± 4 (2−45)	4 ± 1 (1−12)	39 ± 7 (4−74)	8 ± 1 (1−22)
fermented/acidified sausages (cooked)	4 ± 1 (0−11)	4 ± 1 (ND[c]−15)	1 ± 0 (1−2)	27 ± 12 (1−57)	10 ± 4 (0−31)
whole-muscle brine-cured (uncooked)	116 ± 57 (4−462)	20 ± 4 (7−40)	7 ± 1 (3−12)	25 ± 3 (11−39)	7 ± 1 (2−12)
whole-muscle brine-cured (cooked)	26 ± 7 (ND−143)	11 ± 2 (0−42)	8 ± 1 (1−17)	17 ± 3 (1−37)	4 ± 1 (0−24)
whole-muscle dry-cured (uncooked)	12 ± 3 (0−37)	11 ± 4 (0−50)	7 ± 2 (0−19)	2 ± 0 (2−2)	2 ± 1 (0−8)

[a]Mean value with standard error and minimum and maximum nitrate values in parentheses. [b]See the footnote in Table 4 for a listing of product categories sampled by city. [c]ND, not detected.

Table 7. Pairwise Comparisons between Cities of the Mean Residual Nitrite/Nitrate Concentrations in Six Cured Meat Categories Classified as Conventional Cured or Organic/Natural/Uncured/Indirectly Cured

		pairs of cities with different means[ab]	
product category		NO_2^-	NO_3^-
cured dried sausages (uncooked)	conventional cured	none	none
	organic/natural/uncured/indirectly cured	none	CH−DA
cured sausages (cooked)	conventional cured	DA−NY; NY−RA	none
	organic/natural/uncured/indirectly cured	CH−NY; NY−RA; LA−RA[c]	LA−NY
fermented/acidified sausages (cooked)	conventional cured	none	none
	organic/natural/uncured/indirectly cured	none	none
whole-muscle brine-cured (uncooked)	conventional cured	none	none
	organic/natural/uncured/indirectly cured	CH−DA; DA−RA; DA−NY	none
whole-muscle brine-cured (cooked)	conventional cured	none	NY−RA; LA−NY
	organic/natural/uncured/indirectly cured	none	CH−RA
whole-muscle dry-cured (uncooked)	conventional cured	none	none
	organic/natural/uncured/indirectly cured	none	none

[a]Pairs of cities with significantly ($P < 0.05$) different nitrite/nitrate mean concentrations. [b]Analysis was conducted on the logarithm of the data value due to lack of normality and unequal variances. [c]CH, Chicago; DA, Dallas; LA, Los Angeles; NY, New York; and RA, Raleigh.

mean NO_2^- concentrations of C and ONC products, illustrating that even organic/natural/uncured/indirectly cured labeled product contains as much nitrite as conventionally processed meats. As shown in Table 2, significant differences in NO_2^- content were found between C and ONC types only in the cured cooked sausage category sampled in New York City. As shown in Tables 3 and 4, the NO_2^- content of this category was 10.3 ppm for C products as compared to 0.7 ppm for ONC products. The low NO_2^- concentration in ONC products may be attributed to differences in processing techniques and handling procedures. For example, inclusion of celery juice that contains nitrate may be converted less efficiently or simply provide a lower content of nitrite in the finished product than conventional processed meat formulations.

Differences in pairwise comparisons for NO_3^- content between C and ONC products were more apparent with significant differences noted for cured dried uncooked sausages sampled in Chicago and Los Angeles, fermented cooked sausages in Chicago, Dallas, Los Angeles, and Raleigh, and whole-muscle dry-cured uncooked products in Los Angeles and Raleigh (Table 2). Cured dried uncooked sausages from Chicago labeled C contained 368 ppm NO_3^- versus 1 ppm for the ONC type products. Comparable ONC values in Los Angeles were 67 and 6 ppm, respectively (Tables 5 and 6). Nitrate concentrations in fermented cooked sausages from Chicago, Dallas, Los Angeles, and Raleigh samples designated C were 52, 30, 51, and 41 ppm, while ONC products were 4, 4, 1, and 10 ppm (Tables 5 and 6). Whole-muscle, dry-cured uncooked C products from Los Angeles and Raleigh had 172 and 115 ppm of NO_3^-, while those labeled ONC contained only 7 and 2 ppm NO_3^-, respectively. Overall, for most product categories except fermented/acidified sausages, there were few differences in the NO_3^- concentration between C and ONC type products. In those cases where significant differences were

Table 8. Mean Residual Nitrite and Nitrate Concentrations (ppm) of Cured Meat Categories Classified as Conventional Cured or Organic/Natural/Uncured/Indirectly Cured from All Five Cities

		conventional cured					organic/natural/uncured/indirectly cured				
product category		*N*	mean	SE	min	max	*N*	mean	SE	min	max
cured dried sausages (uncooked)	NO_2^-	40	0.8	0.2	0.0	9.7	23	0.6	0.2	0.0	8.5
	NO_3^-	40	113	33	0	2289	24	19	4	0	138
cured sausages (cooked)	NO_2^-	59	7.6	0.5	0.1	29.3	30	5.4	0.9	0.1	35.4
	NO_3^-	59	33	5	1	541	30	18	2	1	74
fermented/acidified sausages (cooked)	NO_2^-	52	0.8	0.3	ND[a]	26.7	19	0.1	0.0	ND	0.5
	NO_3^-	52	46	4	2	320	19	7	2	ND	57
whole-muscle brine-cured (uncooked)	NO_2^-	20	6.8	1.0	0.2	36.5	18	7.9	1.2	0.1	36.0
	NO_3^-	20	14	1	4	32	19	38	14	2	462
whole-muscle brine-cured (cooked)	NO_2^-	97	7.5	0.4	0.0	27.6	44	6.5	0.5	0.1	22.1
	NO_3^-	97	16	1	1	108	44	13	2	ND	143
whole-muscle dry-cured (uncooked)	NO_2^-	38	1.5	0.3	0.0	16.2	24	2.7	0.8	0.0	28.9
	NO_3^-	39	106	23	0	1367	24	7	1	0	50
overall mean by type	NO_2^-		4.7					4.3			
	NO_3^-		48					16			
overall weighted mean	NO_2^-					4.5					
	NO_3^-					37					

[a]ND, not detected.

noted, the NO_3^- content was lower for ONC product types. The residual NO_2^-/NO_3^- concentration is not a good indicator of ingoing NO_2^-/NO_3^- levels since NO_2^- can react with or be bound to other meat tissue components and the conversion of NO_3^- to NO_2^- is contingent upon process conditions. It is possible that ONC NO_3^- levels were lower due to the ingredient source and/or conversion efficiency of the reduction reaction. In general, the survey indicates that most C and ONC cured meats across broad product categories might be expected to have similar NO_2^- and/or NO_3^- concentrations.

Comparisons of Residual Nitrite and Nitrate Concentrations between Cities. A comparison of the NO_2^- and NO_3^- concentrations between cities (Table 7) revealed no differences in NO_2^- content for C meat products, except for cured cooked sausages, which differed between two pair of cities (DA, 4.1 ppm, and NY, 10.3 ppm; NY, 10.3 ppm, and RA, 4.6 ppm) (Tables 3 and 7). The NO_2^- content of ONC cooked sausages and whole-muscle brine-cured uncooked products differed among three pairs of cities (CH, 10.0 ppm, and NY, 0.7 ppm; NY, 0.7 ppm, and RA, 10.2 ppm; LA, 4.2 ppm, and RA, 10.2 ppm, and CH, 11.7 ppm, and DA, 0.5 ppm; DA, 0.5 ppm, and RA, 16.8 ppm; DA, 0.5 ppm, and NY, 9.5 ppm), respectively (Tables 4 and 7). Paired comparisons among cities for NO_3^- content indicated no differences for C products except for the whole-muscle brine-cured cooked category, which was different between NY (25 ppm) and RA (12 ppm) and LA (10 ppm) and NY (25 ppm) (Tables 5 and 7). Only cured dried uncooked sausages, cured cooked sausages, and whole-muscle brine-cured cooked products of the ONC type differed among cities for NO_3^- content. Nitrate differences for cured dried uncooked sausages were as follows: CH, 1 ppm, and DA, 57 ppm, while cured cooked sausages differed in NO_3^- content between LA, 4 ppm, and NY, 39 ppm. Whole-muscle brine-cured cooked products differed in NO_3^- concentration between CH, 26 ppm, and RA, 4 ppm (Tables 6 and 7). Overall, the NO_2^- content of C meat products between cities was not different in most product categories sampled except for the cured cooked sausages category. For the most part, the same was true for ONC products except for two categories, cured sausages (cooked) and whole-muscle brine-cured products (uncooked). Nitrite differences between cities for ONC cooked sausages and whole-muscle brine-cured uncooked products may indicate differences in curing techniques applied to these products by processors supplying retail markets in different cities or that greater variation exists in the retention of residual NO_2^- in these products during storage or retail display as compared to C processed meats. This same conclusion is likely true of the NO_3^- content for ONC dried uncooked sausages, cured cooked sausages, and whole-muscle brine-cured cooked categories sampled in different cities. In general, within most cured meat categories and between C and ONC types, there was limited variation noted between cities for NO_2^- and NO_3^- concentrations.

Pooled Residual Nitrite and Nitrate Concentrations of Cured Meats Classified as Conventional or Organic/Natural/Uncured/Indirectly Cured. Table 8 presents the NO_2^- and NO_3^- means of individual categories of cured meat products pooled across cities and segregated into C and ONC product types. The three-way interaction among metropolitan area, cured meat product, and product type (C vs ONC) was not significant ($p > 0.05$) for NO_2^- content, nor were any of the three, two-way interactions significant ($p > 0.05$). All three of the main effects for metropolitan area, cured meat product, and product type were significant. Even though there were a few differences between cities (Table 7), the data were pooled to provide mean NO_2^- values that could be compared with the values in other databases. The NO_2^- content of C and ONC meat products ranged between 0.8 and 7.6 and 0.1 and 7.9 ppm, respectively (Table 8). It is interesting to note that the overall NO_2^- concentrations in all categories from five cities were ≤10 ppm and were similar to those reported by Cassens[1] who found residual NO_2^- values from four cities (Los Angeles, Denver, St. Louis, and Tampa) to be ∼10 ppm. The NO_3^- contents of C cured dried sausages (uncooked), cured sausages (cooked), fermented/acidified sausages (cooked), whole-muscle brine-cured (uncooked), whole-muscle brine-cured (cooked), and whole-muscle dry-cured (uncooked) were 113, 33, 46, 14, 16, and 106 ppm, while their ONC counterparts averaged 19, 18, 7, 38, 13, and 7 ppm. In only one instance (whole-muscle brine-cured) was the NO_3^- value larger

Table 9. Mean Residual Nitrite Concentrations[a] (ppm) of Cured Meat Categories Pooled Across Conventional Cured and Organic/Natural/Uncured/Indirectly Cured Classifications from Each Surveyed City[b]

product category	Chicago[b]	Dallas[c]	Los Angeles[d]	New York[e]	Raleigh[f]
cured dried sausages (uncooked)	1.0 ± 0.3 (0.0−7.0)	1.6 ± 0.4 (0.1−9.7)	0.3 ± 0.1 (0.0−1.9)	0.2 ± 0.0 (0.0−0.7)	0.2 ± 0.1 (0.0−1.0)
cured sausages (cooked)	10.3 ± 1.4 (0.4−35.4)	3.8 ± 0.6 (0.1−16)	6.9 ± 1.0 (0.1−23.2)	7.1 ± 0.9 (0.1−19.3)	6.3 ± 0.9 (0.4−31.1)
fermented/acidified sausages (cooked)	0.1 ± 0.0 (0.0−0.4)	0.2 ± 0.0 (0.0−1.4)	2.0 ± 1.1 (0.0−26.7)	0.1 ± 0.0 (0.0−0.2)	0.9 ± 0.5 (ND[g]−12.0)
whole-muscle brine-cured (uncooked)	9.6 ± 1.4 (1.0−27.0)	3.3 ± 0.9 (0.1−12.5)	3.9 ± 1.1 (0.1−16.8)	10.8 ± 2.2 (0.4−36.5)	9.2 ± 2.3 (0.5−36.0)
whole-muscle brine-cured (cooked)	7.6 ± 0.7 (0.3−22.4)	4.5 ± 0.4 (0.1−15.0)	7.5 ± 0.8 (0.1−26.7)	8.1 ± 0.9 (0.1−23.5)	8.2 ± 1.0 (0.0−27.6)
whole-muscle dry-cured (uncooked)	1.7 ± 0.4 (0.0−10.0)	2.6 ± 0.9 (0.0−16.2)	3.6 ± 1.4 (0.0−28.9)	0.3 ± 0.0 (0.0−0.8)	1.6 ± 0.6 (0.0−17.1)

[a]Mean value with standard error and minimum and maximum nitrite values in parentheses. [b]Chicago: N = 13 for cured dried sausages (uncooked), N = 17 for cured sausages (cooked), N = 16 for fermented/acidified sausages (cooked), N = 8 for whole-muscle brine-cured (uncooked), N = 28 for whole-muscle brine-cured (cooked), and N = 14 for whole-muscle dry-cured (uncooked). [c]Dallas: N = 15 for cured dried sausages (uncooked), N = 18 for cured sausages (cooked), N = 19 for fermented/acidified sausages (cooked), N = 8 for whole-muscle brine-cured (uncooked), N = 29 for whole-muscle brine cured (cooked), and N = 11 for whole-muscle dry-cured (uncooked). [d]Los Angeles: N = 15 for cured dried sausages (uncooked), N = 18 for cured sausages (cooked), N = 15 for fermented/acidified sausages (cooked), N = 7 for whole-muscle brine-cured (uncooked), N = 29 for whole-muscle cured (cooked), and N = 12 for whole-muscle dry-cured (uncooked). [e]New York: N = 11 for cured dried sausages (uncooked), N = 18 for cured sausages (cooked), N = 10 for fermented/acidified sausages (cooked), N = 8 for whole-muscle brine-cured (uncooked), N = 28 for whole-muscle brine-cured (cooked), and N = 10 for whole-muscle dry-cured (uncooked). [f]Raleigh: N = 9 for cured dried sausages (uncooked), N = 18 for cured sausages (cooked), N = 11 for fermented/acidified sausages (cooked), N = 7 for whole-muscle brine-cured (uncooked), N = 27 for whole-muscle brine-cured (cooked), and N = 15 for whole-muscle dry-cured (uncooked). [g]ND, not detected.

Table 10. Mean Residual Nitrate Concentrations[a] (ppm) of Cured Meat Categories Pooled Across Conventional Cured and Organic/Natural/Uncured/Indirectly Cured Classifications from Each Surveyed City[b]

product category	Chicago[b]	Dallas[c]	Los Angeles[d]	New York[e]	Raleigh[f]
cured dried sausages (uncooked)	255 ± 98 (0−2289)	30 ± 4 (0−138)	39 ± 7 (0−147)	36 ± 6 (1−123)	22 ± 5 (5−87)
cured sausages (cooked)	63 ± 17 (1−541)	17 ± 2 (2−45)	9 ± 1 (1−28)	40 ± 6 (4−255)	11 ± 1 (1−22)
fermented/acidified sausages (cooked)	40 ± 8 (0−251)	20 ± 3 (ND[g]−92)	41 ± 9 (1−320)	54 ± 9 (1−183)	32 ± 5 (0−78)
whole-muscle brine-cured (uncooked)	66 ± 30 (4−462)	15 ± 2 (4−40)	7 ± 1 (3−12)	25 ± 2 (11−39)	11 ± 2 (2−29)
whole-muscle brine-cured (cooked)	20 ± 3 (ND-143)	13 ± 1 (0−42)	9 ± 1 (0−53)	23 ± 2 (1−47)	9 ± 2 (0−72)
whole-muscle dry-cured (uncooked)	115 ± 50 (0−1367)	22 ± 4 (0−71)	87 ± 39 (0−879)	37 ± 6 (2−107)	61 ± 21 (0−571)

[a]Mean value with standard error and minimum and maximum nitrate values in parentheses. [b]Chicago: N = 13 for cured dried sausages (uncooked), N = 17 for cured sausages (cooked), N = 16 for fermented/acidified sausages (cooked), N = 8 for whole-muscle brine-cured (uncooked), N = 28 for whole-muscle brine-cured (cooked), and N = 14 for whole-muscle dry-cured (uncooked). [c]Dallas: N = 16 for cured dried sausages (uncooked), N = 18 for cured sausages (cooked), N = 19 for fermented/acidified sausages (cooked), N = 8 for whole-muscle brine-cured (uncooked), N = 29 for whole-muscle brine-cured (cooked), and N = 11 for whole-muscle dry-cured (uncooked). [d]Los Angeles: N = 15 for cured dried sausages (uncooked), N = 18 for cured sausages (cooked), N = 14 for fermented/acidified sausages (cooked), N = 8 for whole-muscle brine-cured (uncooked), N = 29 for whole-muscle cured (cooked), and N = 12 for whole-muscle dry-cured (uncooked). [e]New York: N = 11 for cured dried sausages (uncooked), N = 18 for cured sausages (cooked), N = 10 for fermented/acidified sausages (cooked), N = 8 for whole-muscle brine-cured (uncooked), N = 28 for whole-muscle brine-cured (cooked), and N = 11 whole-muscle dry-cured (uncooked). [f]Raleigh: N = 9 for cured dried sausages (uncooked), N = 18 for cured sausages (cooked), N = 12 for fermented/acidified sausages (cooked), N = 7 for whole-muscle brine-cured (uncooked), N = 27 for whole-muscle brine-cured (cooked), and N = 15 for whole-muscle dry-cured (uncooked). [g]ND, not detected.

Table 11. Mean Concentrations (ppm) of Residual Nitrite and Nitrate in Cured Meat Categories as Compared to Those in the NAS (1981) Study

	present study					
	conventional cured[a]		organic/natural/uncured/indirectly cured[a]		NAS (1981)[b]	
product category	NO_2^-	NO_3^-	NO_2^-	NO_3^-	NO_2^-	NO_3^-
(1) cured, dried sausages (uncooked) German air-dried sausage, chorizo, Italian dry sausage	0.8	113	0.6	19	13−17	78−89
(2) cured sausages (cooked) bologna, frankfurters, polish sausage	7.6	33	5.4	18	10−31	96−110
(3) fermented/acidified sausages (cooked) pepperoni, summer sausage, snack sticks	0.8	46	0.1	7	6−17	78−89
(4) whole-muscle brine-cured (uncooked) bacon	6.8	14	7.9	38	12−42	33−96
(5) whole-muscle brine-cured (cooked) hams, bacon (precooked), cured poultry, pastrami corned beef	7.5	16	6.5	13	16−29	140−150
(6) whole-muscle dry-cured (uncooked) dry-cured country style hams, dry-cured bacon, proscuitto	1.5	106	2.7	7	16−37	NR[c]

[a]Conventional cured and organic/natural/uncured/indirectly cured meat products means from the present study. [b]Lowest and highest means of specific (i.e., bologna, frankfurters) cured meat products in the same category; National Academy Sciences (Table 5-1). [c]NR, no data reported.

numerically than C value. Tables 9 and 10 show the NO_2^- and NO_3^- means of individual cured meat products pooled across C and ONC types from each city surveyed. When segregated by city, the NO_2^- and NO_3^- contents of cured meat products ranged between 0.1 and 10.8 ppm and 7 and 255 ppm, respectively.

Comparisons with Other Databases. Pooled mean residual NO_2^- and NO_3^- values derived from 470 cured meat samples (Table 8) and those of like or similar categories compiled in the NAS are presented in Table 11. In the present study, the lowest concentrations of NO_2^- for both C and ONC products were observed in the fermented cooked sausage (0.1−0.8 ppm), cured dried uncooked sausage (0.6−0.8 ppm), and whole-muscle dry-cured uncooked (1.5−2.7 ppm) categories. Slightly higher concentrations of NO_2^- were noted for the cured cooked sausage (5.4−7.6 ppm), whole-muscle brine-cured cooked (6.5−7.5 ppm), and whole-muscle brine-cured uncooked (6.8−7.9 ppm) categories. By comparison, these values were similar to those observed by Cassens[1] in bacon (3−5 vs 6.8−7.9 ppm), bologna (15 vs 5.4−7.6 ppm), wieners (8−9 vs 5.4−7.6 ppm), and ham (4−7 vs 6.5−7.5 ppm) derived from 154 cured products. He reported an overall mean NO_2^- value of 10.2 ppm, while the overall weighted mean in this study was 4.5 ppm (C, 4.7 ppm; ONC, 4.3 ppm) (Table 8). Thus, it appears that residual NO_2^- levels have remained low and not changed appreciably since the survey by Cassens.[1] In comparison to the studies making up the NAS[2] database, the mean NO_2^- values in this study were numerically lower by two to 17-fold within the six product categories evaluated (Table 11). Since 1981, several factors have contributed to lowering the residual NO_2^- concentration in cured meat products. These include changes in U.S. Department of Agriculture regulations (lowering the ingoing NO_2^- level in bacon, use of cure accelerants such as sodium ascorbate, restricting the use of NO_3^- in some products, etc.) improved processing techniques and better control of curing reactions especially those involving natural sources of NO_3^-.

Nitrate concentrations (Table 11) were lowest in whole-muscle brine-cured cooked (13−16 ppm), whole-muscle brine-cured uncooked (14−38 ppm), cured cooked sausage (18−33 ppm), and fermented/acidified cooked sausage (7−46 ppm) categories. Whole-muscle dry-cured uncooked (7−106 ppm) and cured dried uncooked sausage (19−113 ppm) had slightly higher NO_3^- concentrations. The overall mean residual NO_3^- concentration in this study across all cured meat categories was 37 ppm (C, 48 ppm; ONC, 16 ppm) (Table 8). In all but one category (cured, dried sausages, uncooked), NO_3^- concentrations were lower by two to 11-fold when compared to NAS[2] values compiled from multiple studies. As observed with NO_2^- values, adherence to USDA-FSIS regulations, the exclusive use of NO_2^- as a curing ingredient except for some specialized meat products and strict processing procedures continues to minimize the residual NO_3^- concentrations in cured meat products. Because low concentrations of NO_3^- were reported for cured products where NO_3^- is not allowed, it is plausible that other factors could have contributed to its presence. For example, other contributors to NO_3^- content could include residual blood remaining in muscle tissues, muscle tissues themselves (20−25 μM NO_3^- mg^{-1} protein), plant extracts in a formulation, plant-based ingredients (spices), or other ingredients that may contain residual NO_3^- (i.e., sea salt at 0.3−1.7 ppm). Another possibility is that some products within a specific category that were sampled had nitrates in their formulation, while other products within the same category had no added nitrate. This would have resulted in low NO_3^- concentrations being reported for that category.

Overall, the residual NO_2^- values observed in this survey were consistent within each product category (as noted by the relatively small individual standard errors) and not appreciably different from those reported by Cassens.[1] In comparison, the NO_2^- and NO_3^- values in this study were numerically lower than those reported in the NAS[2] study. This study confirms that residual NO_2^- concentrations in cured meat products were similar to those reported in 1997 and provides a benchmark for NO_2^-/NO_3^- concentrations in categories of organic/natural/uncured/indirectly cured products available at retail.

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