RAPID METHOD FOR DRY CURING BONELESS HAMS WITH LITTLE OR NO ADDED NITRITE

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INTRODUCTION

The dry cured ham has long been a popular food throughout the world including the Southeastern United States. These hams are produced by both the inspected packer for commercial retail sale and also by individuals for their own use. Several factors in commercial production have hampered increased production and distribution. Dry cured ham production traditionally is both time and labor intensive. Recommended aging time and time of processing can range from 3 to 12 months (Skelley, 1964; Kelly, 1974; Christian, 1977; Mussman, 1977). Furthermore, the procedures may necessitate that the hams be rubbed with cure two or three times at selected time intervals. In addition, both nitrate and nitrite are often used as part of the curing ingredients. Recent controversy has developed around the use of nitrate and nitrite in food products due to possible carcinogenic effects. It has been suggested that current levels of these ingredients be reduced or eliminated in order to eliminate their possible carcinogenic effect (Natl. Prov., 1977).

Many researchers have attempted to decrease the processing time required for dry cured hams by manipulating humidity and temperature in the traditional skin-on, bone-in form (Skelley, 1964; Cecil, 1954; Blumer,

1958). However, recent technological advances in meat processing techniques, such as tumbling and massaging, may make it possible to reduce the time and labor involvement and the amount of curing ingredients needed, as well as the ingoing amount of nitrate and nitrite. In addition, it may be possible to use mechanical agitation in conjunction with the use of nitric oxide (NO) gas in order to develop color with little or no residual nitrite present in the product.

For the reasons outlined previously, percent shrinkage, percent H_2O, percent NaCl, and residual nitrite were determined. Taste panel data were collected and analyzed as follows:

1. Triangle Test: Purpose: to determine experimental ham in contrast to traditionally processed ham.
2. Hedonic Scale: Purpose: to determine 1) tenderness, 2) flavor, 3) saltiness, and 4) overall satisfaction.

Objectives

The specific objectives of this investigation were:

1. To determine if tumbling can reduce the time required to process boneless dry-cured hams.
2. To determine if a lower level of initially added nitrite than is now recommended for ham would produce organoleptically acceptable hams.

3. To determine if nitric oxide gas may be functionally used to develop acceptable cured meat characteristics within the framework of this experiment.
4. To determine the organoleptic acceptance of such a product.

REVIEW OF LITERATURE

Dry Cured Hams

Ham curing may be defined as the application of salt, a color fixing ingredient and spices to the meat in order to obtain a desired end product. Salting and smoking of meats was a well established practice by 1000 B.C. Two intrinsic reasons for curing were, first to preserve the food at a time when other methods of preservation were not available and secondly, to impart a characteristic taste and aroma to the meat product. Curing is primarily a drying process.

Due to modern food handling practices such as refrigeration, hams are now cured primarily for aesthetic purposes. There are two methods usually used to cure hams. The conventional or pumpted ham involves the dispersion of the cure ingredient in water which is then injected either by stitch or artery pumping. The second and oldest method is the dry cure, in which the curing ingredients are rubbed on the surface of the ham in the dry form. Hams may have to be rubbed with the cure two or three times in order to ensure against spoilage.

A major disadvantage of dry cured hams is the length of time needed for the sodium chloride to diffuse throughout the muscle tissues. In dry cured hams, the sodium chloride in the outside 2.54 mm of the ham may be as much as ten times that of the center (Miller and Ziegler 1936a).

The length of time needed for salt equalization is dependent upon the weight and thickness of the ham.

In general, the methods used to dry cure hams are similar; however, spice mixtures may vary from region to region. An example of the traditional procedure for dry curing hams was given by Kelly, et al. (1974). The curing mixture consists of 3.63 kilograms of sodium chloride, .91 kilograms sugar and 56.75 grams of saltpeter (potassium nitrate). This curing mixture is to be applied to 45.36 kilograms fresh ham in three applications; one-third applied on the first day, the second on the fifth day and the last third on the tenth day of the curing program. Hams are cured for seven days per inch of thickness or three and one-half days per kilogram fresh weight at temperatures between 2.2-4.4°C. At the termination of the curing, hams are soaked for one to three hours to remove excess curing mix, scrubbed and allowed to dry. The hams are then smoked at 32.2°C to a dark color, seasoned, and then aged from five to twelve months.

Many researchers have attempted to reduce the time of processing and aging dry-cured hams. Rogers et al. (1965) injected pancreatic lipase and papain into fresh hams in an attempt to accelerate rancidity development. They reported that the control hams were preferred over enzyme treated hams as they were regarded too mushy to be acceptable. Cecil and Woodroof (1954) reported that at twelve months aging, hams stored at 20°C had optimal effect on weight loss, salt concentration,

color of fat and lean as well as the development of typical dry-cured flavor. Skelley et al. (1964) stated that very acceptable hams may be produced with less shrinkage by tempering at 18°C for 2 weeks and then aging for 12 weeks at 35°C and 60% humidity. Montgomery et al. (1976) found that skinned hams had higher salt concentrations at every period and location than did the unskinned or natural hams.

A typical commercial process was described by Stadler (1978). Salting was conducted at 4°C and a humidity of 90% for 40 days, salt equilization of hams at 10-15°C and 55-60% humidity for 20 days and aging at 27°C and 55-60% humidity for 30 days. The entire curing process was 90 days. Christian (1977) described in great length the accepted methods for curing, aging and smoking of dry-cured products.

The USDA has placed strict definitions on what may be classified Country-cured, Dry-cured and Country Style Hams (Mussman, 1977). For hams labeled Country-cured or Coultry Style, salt equilization time is 45 or more days and total time for curing, salt equilization and drying is not less than 70 days. For hams labeled "dry-cured", salt equalization is 45 or more days and total time for curing salt equalization and drying is not less than 55 days. The weight of the finished hams must be at least 18 percent less than the fresh uncured weight.

Sodium Chloride

Sodium chloride is the most important ingredient in curing mixtures for meats. The principal function of salt is to inhibit the growth of

microorganisms by increasing osmotic pressure and reducing water activity. It is particularly important that the diffusion of salt into the tissues be uniform and at an adequate level to ensure its preservative properties. The rate of diffusion is governed by temperature and concentration gradient. The salt uptake is linear with time and proportional to brine strength (Wood, 1966). The optimum temperature for salt penetration must be high enough to allow salt to diffuse rapidly and sufficiently low enough to reduce bacterial activity. A temperature of 2°C ± 1° is often recommended (Miller and Ziegler, 1936a, 1936b). Concentrations below 5.5 percent sodium chloride results in reducing the preservative effect of salt (Urbain, 1971). Bulman and Ayers (1952) reported that varying degrees of bacterial inhibition were shown in samples containing 3.5 to 4.4 percent sodium chloride, and no spoilage was detected after 28 days of incubation with salt concentrations exceeding 4.4 percent.

Spoilage in dry cured hams usually results when elevated temperatures are obtained before the salt diffuses and equalizes throughout the tissues. Haynes and Schmitt (1956) reported that a great deal of variation exists in salt concentration in hams treated similarly. The middle portion and the back of the ham had the lowest concentrations but with increased aging these areas begin to increase in salt concentrations.

Ockerman and Organisciak (1978) reported that tumbling increased the migration of sodium chloride as well as the other curing components in

hams. The increased cure movement may be due to the impact energy on the muscle tissue during the tumbling treatment. Krause et al. (1978) related that in normal curing practices cure migration is due to osmotic pressure. When hams are tumbled, the distribution of curing ingredients are affected by osmotic pressures and also by the movement of muscle tissue due to tumbling and by the disruption of the sarcolemmae. The disruption of the sarcolemma reported by Theno et al. (1976) enhances the migration of cure ingredients between muscle fibers and bundles and into fibers with fragmented sarcolemmae, resulting in a more uniform and rapid distribution of curing ingredients.

Kimoto et al. (1976) and Price and Greene (1978) found cured flavor to be obtained without sodium nitrite as long as sodium chloride was present in the formulation of the cure. Kelly (1965) found aged flavor to be highly correlated to saltiness. Blumer (1954) reported that a minimum of four percent sodium chloride was necessary for desirable aged flavor.

Sugars

Sugar is traditionally added to the curing mixtures of dry cure hams. It is added to reduce the hardening effect produced by salt (Lewis, 1937), enhances and develops flavor (Mills et al. 1960; Brady et al. 1949) and induces initial dehydration (Callow, 1947).

Brady et al. (1949) reported that for the long-cured hams, sugar had little or no effect on chemistry and flavor and that there was no

evidence of detrimental effects of sugar when added in reasonable amounts. They found that sugar was important in reducing the initial moisture content. Callow (1932) stated that sugar acts as a dehydrating agent and that unlike salt once water is removed it cannot be replaced. The liquid sugar complex may be held between muscle fibers and may explain the softer texture observed as compared to ham with no added sugar.

Mills et al. (1960) found that conventional short term sugar cured hams had no change in flavor or color in contrast to the no sugar cure. They also reported that 22.7-34.0 kilograms of sugar per 378.54 liters of water is the threshold level for detection of sweetness at 108% pump. This is usually more than the concentration used in commercial practice.

Sodium Nitrite

The origin of the intentional use of nitrite and nitrate is lost in history, but it is certain that the use of salt to preserve meat preceded the intentional use of nitrite and nitrate. Meat preservation was first practiced in the saline deserts of Asia long before the Christian era. These desert salts contained borax and nitrates as impurities. The red color indicative of cured meats was not documented until late Roman times of the 1st Century A.D. (Binkard and Kolari, 1975). Therefore, the addition of nitrite to cured meat occurred by accident as an impurity in the salts. It is common practice today to intentionally add

nitrite as a separate ingredient in order to obtain the traditional cured meat color.

Haldane (1901) reported that pure salt (sodium chloride) did not produce the traditional color of cured meats. He indicated that the color was initiated by nitrates present as contaminants in unpurified salt. Lewis (1937) and Kerr (1926) studied the use of nitrites. As a result of their findings, the USDA Bureau of Animal Industries initiated stringent regulations for the use of nitrites and the Food Safety and Quality Service of the USDA closely regulates and monitors the use of nitrites today. Limitations are placed on use of nitrite in specific meat products. Currently, processors of dry-cured meat products use fluctuating amounts of nitrate and/or nitrite. The recommended ingoing levels are 100 ppm nitrite and 300 ppm nitrate (Meat Processing, Oct. 1977).

The functions of nitrite in meat curing include: (1) development and stabilization of the "cured" color in the tissues, (2) to contribute to the characteristic flavor of cured meat, (3) to retard the development of rancidity, (4) to inhibit the growth of several food spoilage microorganisms.

The color of uncooked cured meat is red-pink, which consists primarily of nitric oxide myoglobin (NOMb). The denatured pigment nitrosomyochrome is responsible for the pink color of cooked cured meat (Rust and Olson, 1973). These "cured" colors are a result of a series of chemical reactions, the exact reaction of which are still not

understood. The addition of sodium nitrite ($NaNO_2$) to the slightly acid environment of post-rigor meat (pH 5.4) is established between the ionized salt ($Na^+ + NO_2^-$) and the unionized nitrous acid (HNO_2). The nitrous acid then decomposes to nitric oxide (NO) which then reacts with several pigment components to form the cured color (Bard and Townsend, 1971).

Nitric acid is formed from nitrite by reductants in the meat (Mac Dougall et al., 1975) and is complexed with oxidized pigments, predominantly metmyoglobin. Consequently, the nitrosylmetmyoglobin (brown) is reduced to nitric oxide myoglobin (red). The reaction of myoglobin with nitric oxide is such that the nitric oxide replaces the water attached to the iron in the heme portion of the myoglobin molecule. The oxidation state of the iron is the same (i.e. Fe^{+2}) for myoglobin, nitrosomyoglobin and nitrosomyochrome. The cooked cured pigment, nitrosomyochrome (pink), is formed upon the addition of heat which results in the denaturation of the globin portion of the molecule. Lee and Cassens (1976) have reported that heated samples contained twice as much nitric oxide than unheated samples. The globin portion was likely detached from the myoglobin by heating and two sites were made available for the binding of nitric oxide, thus lending more stability to the cooked cured pigment.

The relationship of nitrite to cured flavor was examined by Cho and Bratzler (1970) who compared pork longissimus dorsi roasts cured in

brines with and without nitrite. They reported that the nitrite-containing sample was judged to possess a more distinguishable cured flavor. Wassermann and Talley (1972) reported flavor preference for frankfurters with nitrite over those without nitrite when neither were smoked. When frankfurters were smoked no difference was detected between untreated and nitrite treated franks. Mottram and Rhodes (1973) showed that as nitrite levels increased, an almost linear increase in the intensity of bacon flavor was found up to 1500 ppm. Brown et al. (1974) showed that hams processed with 91 ppm nitrite had more cured flavor than untreated hams and that there was no increase in cured flavor in hams processed with 182 ppm nitrite. Kemp et al. (1974) also concludes that sodium nitrite is needed to produce the typical flavor associated with dry-cured hams.

However, many researchers have also found that acceptable quality hams and bellies could be produced with salt and sugar only. Mottram and Rhodes (1973) and Kimoto et al. (1976) conclude that salt is a major contributor to bacon flavor, with a less significant effect due to the addition of sodium nitrite. Eakes and Blumer (1975) found no statistical differences in flavor between nitrite-free and nitrite containing samples of dry cured hams. Kemp et al. (1974) reported that highly acceptable dry-cure hams could be produced with salt and sugar alone. Previous studies by Lillard and Ayers (1969), Hall et al, (1962) and Kemp et al, (1961) have demonstrated that the development of the dry-cured ham

flavor is accompanied by an increase in salt concentration as well as oxidation of fatty acids and proteins. Price and Greene (1978) report that a "cured" flavor may be attained without the use of sodium nitrite as long as sodium chloride (NaCl) is included in the formulation.

Nitrite also functions in the preservation of meat products by inhibiting or preventing the growth of food spoilage and poisoning microorganisms. Buchanan et al. (1972) reported that Staphylococcus aureus growth is inhibited by nitrite levels permitted in cured meats. Greenberg (1972) showed that sodium nitrite inhibits toxin formation of Clostridium botulinum in canned cured meat. Greenberg stated that it was the level of nitrite at the time of manufacture, rather than the residual nitrite concentration, that was a key factor in inhibition. Tompkin et al. (1978) suggested that nitrite in the form of nitric oxide reacts with a cation dependent material within the germinated botulinal cell and blocks a metabolic step that is essential for outgrowth. Roberts (1975) showed that in heated products the growth of surviving bacteria is controlled by the interaction of several factors which include pH, sodium chloride, storage conditions and sodium nitrite. Shank et al. (1962) demonstrated the anti-bacterial effect of nitrous acid in both vegetative bacterial cells and spores. Sauter et al. (1977) reported that the recovery of Clostridium perfringens spores in cured ground pork was significantly reduced by the use of sodium nitrite.

The safety of the use of nitrites in meats has been questioned. The safety controversy centers around the formation of certain nitrosamines which may be carcinogenic. Nitrosamines are formed when nitrites react with secondary, tertiary and quaternary ammonium compounds. This reaction takes place in cured meat products that are subjected to elevated cooking temperatures such as bacon and dry-cured ham slices. Practically all studies in the United States on the formation of nitrosamines have been conducted with bacon which has been subjected to frying for 3 min. on a side in a preheated electric frypan set at 172°C, (Kimoto et al. 1976). The Newberne report (1978) indicated an increase in incidence of tumors in experimental animals as a result of supplying them with nitrite. The carcinogenicity of nitrosamines and nitrites found in common foods and their subsequent consumption by humans have yet to be proven. There is a trend, however, to reduce even further the ingoing levels of sodium nitrite in many products especially bacon and dry cured hams (Lechowich et al. 1977).

Nitric Oxide Gas (NO)

Nitric oxide (NO) has been implicated as an effective agent in forming the red color of cured meat as early as 1901 by J. S. Haldane. Many researchers have since elucidated the many complex reactions in which it plays a role. Most of these investigations involve the reactions of nitric oxide as it is evolved from either nitrate or nitrite salts.

The use of nitric oxide gas however has not been studied as extensively. Patents for the commercial use of nitric oxide gas were assigned to Swift and Co. in 1959 and 1960 to R. A. Harper. Harper's patent involves the use of nitric oxide in the gaseous form or aqueous solution to induce cured color in comminuted meats. He reported that nitric oxide produced a cured product equal to or better than that produced under conventional methods using nitrate and nitrite salts, where color development and color stability are considerations. In conventional curing methods, the transition of curing salts to nitric oxide is incomplete and the presence of met (brown) pigments may result in a dulling of the bright red cure color that would result if the pigments were not converted completely to nitric oxide myoglobin. In this method of curing, all of the pigment should be converted to cured color. The stability of color in the nitric oxide gas treatment was reported to be affected little by light and oxygen. Harper states further that while nitric oxide gas is not harmful to the meat, a greening of the meat may result if nitric oxide comes into contact with air resulting in the formation of nitrogen dioxide. The green color of the meat does not render it inedible. Nevertheless, the greening is highly objectionable for aesthetic reasons. Therefore, curing with nitric oxide must be carried out in the absence of oxygen.

J. L. Shank (1965) also of Swift & Co., patented a process for the use of nitric oxide in imparting a cured color to sliced bacon. The

chemical pathways of nitrite and nitric oxide may not be the same. The cooked cured pigment is a result of nitric oxide myochromogen in which the globin fraction of the nitric oxide myoglobin has been heat denatured. In the nitrite curing system, the cooked cured color cannot be formed in previously denatured or cooked meat. However, when nitric oxide gas is brought into contact with denatured meat a cooked cured color results.

Mohler (1973) reported that if oxygen is completely excluded and myoglobin is brought into contact with nitric oxide, nitric oxide myoglobin is formed when excess nitric oxide is removed with nitrogen (N_2) the pigment is relatively stable to oxidation.

Ranken (1973) found that while the Swift patents dealt considerably with color formation of nitric oxide curing, little attention was given residual nitrite studies. He reported that no residual nitrite could be detected in pre-sliced bacon processed in the manner described by Shank. Ranken attempted to apply nitric oxide curing to large pieces of meat and found that the time needed to penetrate into a 10 cm cubical block of meat required 24 hours exposure to a .1% v/v nitric oxide in nitrogen in contrast to five minutes at the same concentration required for the 4mm slice of bacon. He also found that it was necessary to increase the gas volume and therefore the total quantity of nitric oxide in contact with the larger pieces of meat. Ranken suggests that it may be possible to reduce the contact time through the use of mechanical agitation in

the presence of nitric oxide, as would be possible in a specially modified tumbler.

J. L. Shank (1962) stated that nitric oxide gas has no effect on bacteria, but that the nitrous acid product of nitrite is mainly responsible for the changes that occur in the bacterial flora of cured meat.

Tumbling

The subject of tumbling has received considerable attention recently among manufacturers and researchers in the meat industry. Tumbling involves the process where whole muscle chunks are placed in a revolving drum which contains baffles thereby imparting "impact energy" to the meat (Theno, 1977). This is accomplished by letting the meat fall from the upper portion of the drum or by striking the meat chunks with the baffles. The primary function of tumbling is to extract enough protein so that the meat chunks bond when thermally processed yielding a large piece which is homogeneous in appearance. Optimal production with tumblers involves providing impact from approximately 1 meter at 16-20 rpm (Woolen, 1971). Others reported that there are three main functions of tumbling, which include the distribution of the brine solution throughout the meat, thereby improving cure uniformity; acceleration of cure time; and bring the salt soluble proteins to the surface of the meat through the addition of the salt in conjunction with the tumbling

action (Schmidt, 1977; Anon. 1971). There are many variations in tumbling methods such as vacuum tumbling, rapid tumbling, intermittent tumbling and combinations of each, in addition each variation has distinct advantages and disadvantages to the processor. However, the three main functions of tumbling outlined previously are of primary concern (Anon. 1977, 1978). Theno (1977) reported that massaging is a less rigorous process than tumbling and involves frictional energy rather than impact energy to extract the salt soluble proteins. Both processes realize similar results and advantages.

Theno et al (1978) stated that after four hours of massaging fiber disruption became evident and that this effect was more pronounced in the presence of salt. Cassidy (et al. 1977) reported that tumbling caused a significant increase in cell membrane disruption in both surface and deep muscle regions in 3 hours of continuous tumbling. Tumbling also resulted in decreased clarity of striation patterns in deep muscle.

Siegel et al (1978) reported that with the disruption of the endomysium and sarcolemma, a fat and protein exudate is released. According to Rust and Olson (1973) the protein exudate may act as a sealer, when the protein is denatured during thermal processing. The addition of salt increases the extraction and solubility of actin and myosin which have been reported essential in the binding quality of the meat (Macfarlane et al, 1977; Fukazawa, et al. 1961; Samejima et al.

1969 and Theno et al, 1978). Theno et al. (1978) examined the binding reactions of cooked ham rolls that had been massaged and reported that binding junctions from rolls with salt levels of two percent and greater exhibited good binding characteristics. Siegel et al. (1978) examined the exudate of massaged hams for specific skeletal muscle proteins. He reported that the massaging process resulted in tremendous tissue destruction at the cellular level which in turn aided in the extraction, solublilization, concentration and disruption of the major myo-fibular proteins on the surface as well as interior of the muscle which in turn aids in binding. He also reported that salt in conjunction with massaging enhances the effect of tissue destruction at the cellular level. Ockerman et al. (1978) found that tumbling for thirty minutes produced pork tissues which were soft and pliable with a tacky exudate on the surface.

Ockerman and Organisciak (1978) found that tumbling action and time of tumbling increased the migration of individual curing adjuncts as well as brine in porcine tissue. This effect became apparent at 3 to 4 hours of tumbling. Krause et al (1978) found that as a result of the disruption of the sarcolemma, myoglobin from within the muscle fiber was more readily available to nitrite and an acceptable cured color was developed more rapidly as nitrite was reduced to nitric oxide. Therefore, Krause suggested that the amount of nitrite used may be reduced in tumbled products without adversely affecting cured color development and

that the time required for color development may be reduced. Krause et al. (1978) studied the effects of fat trim on tumbled hams and found that hams trimmed to 3mm or less before tumbling had better yields, indicating more uniform distribution of curing ingredients. This is in agreement with Wood (1966) who suggested that the diffusion of salt through adipose tissue is restricted.

EXPERIMENTAL DESIGN

The study consisted of three different segments and a control. The first segment involved the use of 50 ppm ingoing levels of $NaNO_2$ used in conjunction with tumbling. The second utilized 100 ppm $NaNO_2$ ingoing in conjunction with tumbling and the third segment involved the utilization of nitric oxide gas as a curing agent together with tumbling. Controls were not tumbled but used the corresponding amount of nitrite. Objective observations were made as to residual nitrite level, moisture content and sodium chloride content. Subjective taste panel evaluations was done by difference and preference.

Presampling Treatment and Handling

Twenty-four regular (skin-on) hams weighing between 6.4 and 8.4 kg were selected at a local commercial packer. They were randomly divided into four groups, six hams per group. Hams in each group were weighed, skinned, boned and trimmed. Approximately 1-2 cm of fat was left on the outside of each ham. Most of the shank meat was removed. Hams weighed, on the average, 7.0, 7.0 and 7.5 kg for the three groups of hams, 50 ppm, 100 ppm ingoing nitrite and nitric oxide, respectively. Boned average weights were 3.7, 3.7 and 4.4 kg on a boneless yield

of approximately 4.5 kg for all three groups (Table 1). Mean boneless ham yields as expressed as a percent green weight was 54.98% for in-cure hams and 32.57% for the hams aged 14 days. The mean boneless yield as expressed as a percent of in-cure weight was 61.79% after 14 days aging.

Curing Procedures

After weighing boned hams three curing mixtures (Table 2) were made consisting of 1; 85.7% granulated table grade NaCl, 14.2% sugar and .1% sodium nitrite to give an ingoing level of 50 ppm sodium nitrite, 2; 85.6% table grade granulated NaCl, 14.2% sugar and .2% sodium nitrite to give an ingoing level of 100 ppm sodium nitrite, and 3; 3.85% table grade granulated NaCl, 15% sugar and 11% nitric oxide gas for curing without sodium nitrite. Cure was applied at 5% of the boneless in-cure weight. The total amount of the curing ingredients were placed in the tumbler with the hams.

Tumbling of Hams

The hams and total curing ingredients were placed in a stainless steel research model tumbler which contained 3 baffles and measured 50 mm in diameter and 60 mm long. The hams were tumbled continuously for 3 hours at 22 rpm at 21°C. At the end of the tumbling process, the hams were placed in 229 mm x 813 mm pre-drilled Union Carbide clear fibrous casings. The casings were previously soaked in warm tap water until

Table 1

Mean Yield of Boneless Meat & Trim from Hams

	Wt. (g)	%
Green	7174.17	---
Boneless	4537.66	63.25
Skin + Fat	1420.11	19.79
Bone	753.61	10.50
Lean Trim	325.11	4.53

Table 2

Curing Mixture

Salt	Sugar	$NaNO_2$
85.6%	14.2%	0.2%
85.7%	14.2%	0.1%
85.8%	14.2%	10% NO gas in N gas

they were supple. One-hundred and fourteen mm tin can lids were placed at each end and hams were drawn tightly in the casings in order to prevent air pockets. The hams in casings were then placed in a 4.4°C (40°F) cooler for 12 hours so that the cure ingredients could equalize.

Curing with Nitric Oxide Gas (NO)

Hams were placed in the tumbler with the curing mixture made up of 85.8% salt and 14.2% sugar added at the rate of 5% of in-cure weight. The tumbler was then sealed. The introduction of 10% nitric oxide gas in nitrogen was facilitated by 2 stainless steel stopcocks located on the lid of the tumbler.

The tumbler with hams and curing ingredients inside was subjected to (508 mm) 20 inches of vacuum. The tumbler was then back filled with NO gas to a positive pressure of (254 mm) 10 inches.

The hams were then tumbled continuously for 3 hours and then treated in the same manner as the other groups.

Smokehouse Schedule

Hams were processed in a Vortron Model TR-2 atmospherically controlled smokehouse. The original smokehouse schedule is outlined in Table 3. The hams were continuously smoked for four hours in the third and fourth stages of the cycle. The end-point of the cooking process was determined by an internal temperature of 65.5°C (150°F) as shown in Table 3.

Table 3

Smokehouse Schedule

Dry Bulb (°C-°F)	Wet Bulb (°C-°F)	Time	Relative Humidity (%)
60°C (140°F)	off	1 hour	-
60°C (140°F)	46°C - (115°F)	1 hour	40
65.5°C (150°F)	48.8°C (120°F)	2 hours	40
76.7°C (170°F)	54.4°C (130°F)	2 hours	30
82.2°C (180°F)	60.0°C (140°F)	internal temp. 65.5°C (150°F)	30

Hams were then removed from the smokehouse and placed in a 4.4°C (40°F) cooler for 12 hours in order to cool the hams. The average internal temperature at the end of the 12 hours was 13°C (55°F).

Aging Procedure

Hams were placed in an environmentally controlled cooler for a period of 14 days. The relative humidity was maintained at 60%. The cooler temperature was maintained at 15.5°C (60°F) to 21.1°C (70°F). The internal temperature of the hams was monitored at 4.4°C (40°F) at the initiation of aging to 15.5°C - 60°F in the later stages of aging. Hams were then removed, weighed, evaluated and sampled.

Sampling Treatment

Hams were cut into thirds and two 1/2 inch slices were taken from each third for sensory and chemical evaluation.

It was noted at this time that extensive microbiological activity had occurred in the internal portion of the hams where the lean surfaces came into contact. The internal areas showed a green hue and a gap between the tissues indicating gas production.

Microbiological Evaluation

Swabs were taken from the interior portion of the hams and incubated for 48 hours in Trypticase Soy Broth with the addition of 3% reagent

grade NaCl. After the incubation period, samples were studied under phase contrast microscopy. Long and short single and chain, thin rods were observed. Samples were taken from the Trypticase Soy Broth and 3% NaCl and placed in APT broth plus 3% NaCl in order to analyze for the presence of Lactobacillus (Johnson and Elliott, 1976). Samples were incubated for 24 hours and showed profuse growth and film formation. Samples were taken from the APT broth plus 3% NaCl for gram stain evaluation. The gram stain evaluation showed a mixed culture of gram positive rods in substantial numbers along with low numbers of gram negative cocci. The microbiological activity on the interior portion of the hams, indicated a microaerophile. Greening is indicative of a catalase-positive microorganism (Frazier, 1967). Salt content of the hams was 4% and in addition, the hams were subjected to elevated temperatures which indicate a salt and heat tolerant microorganism. Heterofermentative lactobacilli are gram positive rods which are salt tolerant, microaerophilic, thermoduric and catalase-positive. In addition, heterofermentative lactobacilli are gas producers. This would explain the rupture in the interior of the hams.

A .1 ml sample was taken from the APT broth plus 3% NaCl and streaked on APT agar plus 3% NaCl, incubated at 31°C for 24 hours in order to generate a fresh viable culture. At the termination of incubation on APT agar plus 3% NaCl, a loop of the culture was placed in APT broth plus 3% NaCl and incubated for 24 hours at 31°C. A thermal

death time study was prepared. Test tubes containing APT broth plus 3% NaCl that contained the incubated culture were placed in a water bath at 68.3°C (155°F) for 5, 10, 15, 20, 25, and 30 minutes. Samples were removed at each 5 minute interval for evaluation. All samples were done in triplicate. Samples from each 5 minute interval were streaked on APT agar plus 3% Nacl and incubated for 24 hours at 31°C in order to monitor growth.

All plates at 68.4°C (155°F) showed growth. The same procedure was repeated at a water bath temperature of 71.1°C (160°F). The 15 minute interval showed no growth for all three plates.

The smokehouse procedure was then altered so that the endpoint of the schedule was marked by an internal temperature of 71.1°C (160°F) for a duration of 15 minutes. Aging and sampling procedures were not changed from that outlined previously.

Analytical Procedures

Three one-half inch slices from each ham were ground three times and mixed thoroughly. Samples were then taken for each chemical determination.

The procedure outlined in the 12th edition of the AOAC for moisture determination in meat and meat products was followed. Salt and nitrite determination was done according to methods outlined in the USDA Chemistry Laboratory Guidebook.

Moisture Determination

Two grams of material were weighed and allowed to dry for 4 hours in a Precision-Scientific convection oven (Model 625) at 125°C. Samples were cooled in a desiccator and weighed. All samples were done in triplicate.

Salt Determination

Analyses for salt were done by the USDA Chemistry Laboratory Guidebook Methods (1971). A 3 g ± .05 sample from each ham was treated with .100 N $AgNO_3$ solution, then wet ashed with concentrated HNO_3. The excess $AgNO_3$ is back-titrated with .100 N NH_4CN S solution. Ferric ammonium sulfate, ($FeNH_4(SO_4)_2 \cdot 12H_2O$) was used as an indicator. Samples were done in triplicate.

Nitrite Determination

Analyses for nitrites were done according to the USDA Chemistry Laboratory Guidebook Methods (1971).

A 5.0 gram sample from each ham was placed in distilled water and heated in a water bath. Samples were filtered and a 25 ml aliquot was treated with sulfanilamide and NED. Color was allowed to develop and optical density was read @ 540 nm with a Perkin-Elmer, Coleman Model 124 double beam, grating spectrophotometer. Results were compared with a standard curve.

Nitric Oxide Determination

Nitric oxide gas (NO) concentration was determined with the use of a Fisher-Hamilton Gas Partitioner Model 28 equipped with a Fisher-Recordal Series 200 Recorder.

Analyses of nitric oxide was performed by the method described by Fisher Scientific Company bulletin, "Separation of Nitrogen Oxides".

A standard curve was developed using known amounts of nitric oxide gas. Four predetermined levels were used; 2.5%, 5.0%, 7.5% and 10% nitric oxide with the balance in nitrogen. The 10% nitric oxide was used, in conjunction with tumbling, as the "curing" agent.

A .75 ml sample of gas was injected into the gas partitioner. A two column series was used for the analyses. A column consisting of 28" x 1/4" glass tubing packed with 150/200 mesh Parapak "S" (Waters Associates, Farmingham, Mass.) was used in the first position. It was followed by a composite adsorption column consisting of a 5' section of inert packing Chromasorb P 150/200 mesh (Supelco, Bellefonte, PA), plus 7' activated molecular sieve 13 x 40/60 mesh (Linde Co.).

The gaseous samples were first passed through a trap held in dry ice and acetone in order to condense and remove water vapor and nitrogen dioxide.

The peak area (area = height x width at 1/2 height) was used to determine final concentration of the 10% nitric oxide after tumbling.

Organoleptic Evaluation

Hams that had been cured with 50 ppm ingoing sodium nitrite, 100 ppm ingoing sodium nitrite and 10% nitric oxide gas were organoleptically evaluated by a 10 member taste panel. Members of the panel were chosen on their stated preference for dry cured type hams.

Hams were rated on a 5 point hedonic scale with 1 being most desirable and 5 being least desirable. Panelists rated the hams for tenderness, flavor, saltiness and overall satisfaction.

Hams were also rated according to preference using a triangle test in which the three curing ingredients were compared to a commercially processed dry-cured ham.

The half-inch ham slices were divided into approximately one ounce pieces. The pieces were heated in an oven at 149°C (300°F) for 15 minutes prior to serving. Samples were presented under red light conditions so that color would not influence decisions. Color was judged at the time of sampling by individuals familiar with meat color.

RESULTS AND DISCUSSION

The analytical values and taste panel scores were analyzed by hierarchial analyses of variance for among and within classes. The triangle-preference test was reported as actual percentages.

Preliminary Observations

Severe shrinkage was noted at the end of the two week aging period. The hams were extremely hard and showed slight salt crystal formation on the outer portion of the casing. Cecil and Woodroof (1954), Skelley et al. (1964) and Montgomery et al. (1976) reported significant weight losses throughout the aging period, as much as 32% weight loss at 3 months, calculated on an in-cure weight basis. Hams for the three treatments averaged 38.19% shrink at 2 weeks from the in-cure weight. The control (non-tumbled) hams shrank slightly less, 36.26% from the in-cure weight.

Theno et al. (1978) reported gross physical changes in muscle that had been massaged. The 4 hour sample showed fiber disruption and destruction of endomysial-sarcolemma sheaths. The disruption and fragmentation of the myofibril results in the migration of cell contents, a major portion of which is water along with fat and myofibular proteins (Theno et al. 1977).

Cassidy et al. (1978) reported that three hour continuous tumbling caused deep tissue disruption. He also found that at the higher the cooking temperature of 72°C (160°F) more disruption was observed.

This disruption of muscle tissue may explain the differences in percent shrink between the control (non-tumbled) and the tumbled hams.

The control (non-tumbled) hams were irregular in shape, showed excessive salt leaching and were mushy in certain areas and extremely hard in other areas. In contrast, the tumbled product was more uniformly cylindrical in shape, firm and dry to the touch.

Wistreich et al. (1960) noted that the higher temperatures increased sodium chloride accumulation. The degree of opened and closed meat structure has also been recognized as an important variable in cure penetration (Callow, 1947).

Tumbling through the transmision of impact energy at ambient temperatures may raise the temperature of the ham enough to facilitate the diffusion of salt. In addition, through the disruption of muscle tissues an open structure had been created thereby enhancing diffusion of salt. This may account for the lack of diffusion of salt in the control (non-tumbled) hams in contrast to the tumbled hams.

Chemical Analysis

Moisture

Mean values for percent moisture are presented in Table 4.

Table 4. Mean values for % moisture

Treatment	$\bar{Y}$	Range	S.D.
Control	51.70	51.36 - 51.94	0.2025
0.1% $NaNO_2$	53.18	49.66 - 55.65	2.07
0.2% $NaNO_2$	52.47	46.55 - 58.83	4.19
NO gas	49.80	48.12 - 50.43	0.8374
SD within groups	2.30		
SD overall groups	2.56		
F value	2.25	Not Significant	

Since all hams were treated similarly in respect to cooking and aging, there should be no differences expected. The F test indicated that there is no significant difference among the treatments at the .05% level.

Cecil and Woodroof (1954) reported 51.4% moisture after 6 months aging at 20°C (68°F). Montgomery et al. (1976) stated that hams that have been skinned tend to lose weight more rapidly and that the skinned hams lost more weight than the skin-on hams processed similarly.

The considerable weight loss of the hams in a relatively short 14 day aging period are in agreement with the results of Montgomery.

Salt

Mean values for percent sodium chloride are shown in Table 5.

The F test indicated a significant difference among the treatments at the P = .01 level. The level of sodium chloride administered to all treatments was essentially the same. The method of applying salt to the hams as well as the treatment was different. Hams in the control (non-tumbled) groups showed the least salt uptake and concentration of the treatments. Salt, sodium nitrite, and sugar were applied in the traditional dry cure method to the control hams. The hams were then placed in the casing, held for 3 hrs at ambient temperatures, and then refrigerated at 4.4°C (40°F) for 12 hours.

Table 5. Mean values for % salt

Treatment	$\bar{Y}$	Range	S.D.
Control	3.27	3.00 - 3.74	0.2655
0.1% $NaNO_2$	5.62	5.19 - 6.15	0.3673
0.2% $NaNO_2$	4.89	4.23 - 5.19	0.3610
NO gas	4.28	4.03 - 4.53	0.2320
Overall	4.51		
SD within groups	0.312		
SD overall groups	0.927		
F value	60.91**		

Significant at 1% level

Weistreich et al. (1960) indicated that the rate of salt distribution was dependent upon temperature. Temperatures of 3, 18, 27, and 40°C resulted in sodium chloride accumulation values (mg NaCl diffused/cm^2 contact area/24 hours) of 100, 112, 128 and 145 respectively. Therefore, the control hams, without the benefit of the tumbling treatment and being refrigerated, exhibited a large amount of salt leaching and poor salt penetration. This agrees with the findings of Ockerman and Organisciak (1978) who found that the migration of salt for tumbled tissues was significantly greater than that of non-tumbled tissue at 3 hrs of tumbling.

A Duncan's multiple range test at the .05 level revealed that the salt content of the control group was less than the groups that had been tumbled.

Nitrite

Mean values for parts-per-million residual nitrite are presented in Table 6. The F test showed a significant difference among the treatments at the P = .01 level. Nitrite levels were low for treatments 1, 2, and 3. However, treatment 4, the nitric oxide treatment, was significantly higher (39.5 ppm) than the others. With the exception of the control, color of the hams was excellent, showing that sufficient nitrite had been present to allow nitrosomyoglobin and nitrosohemochrome formation. The control, because of the low concentration of curing ingredients

within the ham, was grayish and very soft in the interior portion of the ham.

This is in agreement with the findings of Lechowich et al. (1977) who reported that redness was greatly different between the fresh and cured meat even at low levels of nitrite and nitrates when measured by Hunter Color Difference. They also stated that in the absence of nitrite and nitrate in the curing mixture, the salt cured ham showed less redness than the fresh ham. The residual nitrite levels for all the tumbled hams in this experiment were far below the present accepted limits. Lechowich et al. (1977) reported residual nitrite levels of 3.91 ppm to 10.69 ppm nitrite in traditionally processed dry cured hams at 14 days of storage. The hams were treated with 8% salt and 150 ppm $NaNO_2$.

Krause et al. (1978) indicated that tumbling significantly increased the migration of salt and nitrite and resulted in increased cured color development. Ockerman et al. (1978) also found that tumbling increased sodium chloride and sodium nitrite migration and that in most instances the difference became apparent at 3 to 4 hours of tumbling.

The lower percentage of salt and residual nitrite detected in the control indicate that within the parameters of this experiment tumbling increased the migration of curing ingredients. This agrees with the findings of Krause and Ockerman.

A Duncan's multiple range test was performed to locate differences between the treatments in relation to residual nitrite levels. The

Table 6. Mean Vaues for Residual Nitrite (ppm) in Control and Tumbled Hams

Treatment	$\bar{Y}$	Range	S.D.
Control	4.79	3.98 - 5.70	0.7138
0.1% $NaNO_2$	8.59	5.1 - 13.86	3.2435
0.2% $NaNO_2$	6.53	3.12 - 9.17	2.5065
NO gas	35.93	22.82 - 41.42	7.5424
Overall	13.96		
SD within groups	4.31		
SD overall groups	13.63		
F value	60.91**		

Significant at 1% level

control, the .1% $NaNO_2$ level and the .2% level were not significantly different at the .05 level. The hams treated with nitric oxide gas were significantly different from the other three treatments at the .05 level.

Ranken (1975) suggested that an increased amount of nitric oxide gas may be necessary when treating large pieces of meat and that it may be possible to induce cured color in meat by using a suitably modified tumbler. For this reason, 10% v/v nitric oxide in nitrogen was used in this experiment. Ranken also reported that even though gas penetration may be increased through tumbling, excess nitric oxide must still be used and a residual nitrite control may therefore result.

Comparative data could not be found in the literature that related specifically to residual nitrite when nitric oxide gas is used as a "curing" agent. Harper (1960) reported that nitric oxide was effective in producing cured color with less than 1 ppm nitric oxide in an aqueous carrier. He did not report the formation of residual nitrite.

Nitric oxide gas was added to the tumbler after 20 inches of vacuum had been attained. A positive pressure of 10 inches was then attained by adding 10% v/v nitric oxide to the tumbler. In order to determine if the pressure would change the concentration of the gas, a sample was taken and analyzed in the gas partitioner. No measurable differences were found. Hams were tumbled for 3 hours and at the conclusion, a sample of gas was taken and analyzed for percent nitric oxide. Analyses

of the nitric oxide gas after tumbling of the hams showed less than 2.5% nitric oxide. This would indicate that the hams utilized at least 7.5% of the initial 10% nitric oxide concentration. Although the hams treated with nitric oxide gas showed a greater amount of residual nitrite than the other treatments, the 35.93 ppm residual nitrite is considerably below published values.

Lechowich et al. (1977) reported values for residual nitrite from 4.75 ppm to 101.64 ppm in hams cured with 8% salt, 480 ppm ingoing sodium nitrite and 1700 ppm ingoing sodium nitrate. This curing mix parallels some of those used by commercial processors. At present, there are no standards for maximum residual nitrites in dry cured hams.

Sensory Evaluation

The statistical summary of the organoleptic evaluation is presented in Table 7. The F values were insignificant in all four catagories: salt, tenderness, flavor and overall satisfaction. Each group was in the acceptable range of 3.

Even though ingoing levels of sodium nitrite were below industry norms, panelists rated the hams as being acceptable cured products. This is in agreement with the findings of Price and Greene (1978) who reported that desirable cured product flavor would still be produced provided NaCl was included in the formulation. Eakes and Blumer (1975)

Table 7. Statistical Summary for Sensory Evaluation[a] of Tumbled Ham Products

		0.1% NO_2	0.2% NO_2	NO gas
Salt[b]	$\bar{Y}$	3.0	3.0	2.9
	Range	1-5	1-5	2-4
	SD	1.41	1.15	0.74
Tenderness[b]	$\bar{Y}$	2.8	1.8	2.9
	Range	1-5	1-3	1-4
	SD	1.14	0.79	1.20
Flavor[b]	$\bar{Y}$	3.0	2.4	2.6
	Range	1-5	1-5	1-4
	SD	1.15	1.17	0.97
Overall[b]	$\bar{Y}$	3.1	2.1	2.6
	Range	1-5	1-3	1-5
	SD	1.37	0.74	1.07

[a]All scores based on 5-point hedonic scale.

[b]1 = most desirable; 5 - least desirable.

also found no statistically significant flavor differences between samples treated with sodium nitrite and samples treated with salt only.

The triangle-preference test showed that in all three treatments 90% of the panelists were able to distinguish the experimental product from the commercial product. Thirty percent of the panelists preferred the experimental product cured with 0.1% $NaNO_2$. Thirty percent of the panelists preferred the experimental product cured with 0.2% $NaNO_2$. Twenty percent of the panelists preferred the experimental product cured with nitric oxide gas.

SUMMARY AND CONCLUSIONS

The objectives of this experiment were to determine if tumbling could reduce the time required for processing boneless dry-cured hams. In addition, lower ingoing levels of sodium nitrite or nitric oxide gas were evaluated for successful use in dry curing of hams.

Twenty-four regular (skin-on) normal quality hams weighing between 6.4 and 8.4 kgs. were randomly selected at a commercial packing plant. The hams were randomly divided into 4 groups of 6 each, 1, Control (non-tumbled); 2, Tumbled with 0.1% (50 ppm) ingoing level sodium nitrite; 3, Tumbled with 0.2% (100 ppm) sodium nitrite; and 4, Tumbled with 10% v/v nitric oxide gas.

Hams in each group were weighed, skinned, boned and fat trimmed to 1-2 cm thickness. Shank meat was removed. Curing mixtures were applied at a 5% level of the in-cure weight. All of the cure was applied in one treatment. The curing mixture consisted of:

$NaNO_2$	Sugar	Salt
0.1%	14.2%	85.7%
0.2%	14.2%	85.6%
NO gas	14.2%	85.8%

Hams were tumbled for 180 minutes (3 hours) continuously with the curing mixture. Control hams were not tumbled but were treated with the same cure mixture in the traditional manner with the curing mixture being applied in one application. Hams that were exposed to the nitric oxide atmosphere were tumbled for 180 minutes (3 hours) continuously. Hams were subjected to an atmosphere of 10% v/v nitric oxide gas in nitrogen at a positive pressure of 10 inches. Upon completion of tumbling, hams were stuffed into a porous fiberous casing and held for 12 hours at 4.4°C (40°F) to allow cure to equilibrate. Hams were then cooked and smoked. Hams were aged 14 days at 60% humidity and 15.5°C (60°F) to 21.1°C (70°F). Percent shrink, percent water, percent NaCl and residual nitrite were determined. Hams were also evaluated organoleptically.

The findings of the experiment indicate that tumbling does accelerate the penetration of curing ingredients when those ingredients are applied in a dry form to the ham. The time involved for cure penetration and equalization was 15 hours in this particular experiment. In comparision to 90 days recommended by some processors, 15 hours is an extremely short time for penetration and equalization.

Aging of boneless, skinned hams had the advantage of rapid weight loss. Hams attained approximately 60% weight loss at the end of 14 days as calculated on an in-cure weight basis. In the traditional aging

process, it may take as long as 6 months in order to realize this much weight loss.

Hams that were cured with 50 ppm sodium nitrite and 100 ppm sodium nitrite showed no statistical difference in residual nitrite level. Both treatments showed sufficient color development for cured products. In addition, no statistical difference was found between the two treatments in taste panel scores. This would indicate that the ingoing level of 50 ppm sodium nitrite may be used with satisfactory results.

Hams that had been cured with 10% nitric oxide gas were statistically different (i.e. greater) in residual nitrite levels. Hams cured in this manner showed acceptable color and had an acceptable taste panel evaluation. These results indicate that it may be possible to develop a "cured" product without the direct use of sodium nitrite or sodium nitrate. The results also indicate that it may be possible to reduce the volume of nitric oxide gas in contact with the meat and thereby reduce residual nitrite levels without sacrificing acceptability.

Taste panel evaluation for all treatments were acceptable with no statistical differences noted. The controls were not evaluated due to the deteriorated condition of the hams. Therefore, it is possible that an organoleptically acceptable dry cured product may be produced with the aid of tumbling. In addition, the use of nitric oxide gas in conjunction with tumbling showed no adverse effects in sensory evaluation.

REFERENCES

Anonymous. 1978. Ham Tumbling. Meat Industry. June 1978:60.

Anonymous. 1977. The Massaging-Tumbling Revolution. Meat Industry. April 1977:36.

Anonymous. 1977. Nitrite panel recommends target levels for red meat produces. Meat Processing. October, 1977.

Anonymous. 1971. New developments in ham and meat tumbling. Food Processing Industry. Vol. 40 472:57-58.

A.O.A.C. 1975. Official method of analysis. 12th ed. Association of Official Agricultural Chemists. Washington, D.C.

Barbe, C. D., Mandigo, R. W. and Henrickson, R. L. 1966. Bacterial flora associated with rapid-processed ham. J. Food Sci. 31:988.

Bard, J. and Townsend, W. E. 1971. The Science of Meat and Meat Products. W. H. Freeman and Co. San Francisco and London. p. 452-483.

Bard, J. C. 1965. Some factors influencing extractability of salt-soluble proteins. Proceedings of the Meat Industry Research Conference. p. 96-99.

Binkard, E. F. and Kolari, O. E. 1975. The history and use of nitrite and nitrate in curing of meat. Food Cosmet. Toxicol. 13:655.

Blumer, T. N. 1954. Chemical compounds associated with aged, ham flavor. Unpublished Ph.D. Thesis, Michigan State University of East Lansing, Ann Arbor, MI.

Blumer, T. N. 1958. New ways to cure hams. Research in Farming. 17:3.

Brady, D. E., Smith, H. H., Tucker, L. M. and Blumer, L. N. 1949. Characteristics of country-style hams as related to sugar content of curing mixture. Food Res. 14:303-309.

Brown, C. L., Hedrick, H. B. and Baily, W. E. 1974. Characteristics of cured ham as influenced by levels of sodium nitrite and sodium ascorbate. J. Food Sci. 39:977.

Buchanan, R. L. and Solberg, M. 1972. Interaction of sodium nitrite, oxygen and pH on growth of staphylococcus aureus. J. Food Sci. 37:38.

Bulman, C. and Ayres, J. C. 1952. Preservation effect of various concentrations of curing salts in contaminated pork. Food Technol. 6:255-259.

Callow, E. H. 1932. Rept. Food Invest. Bd., London. 1932. p. 101.

Callow, E. H. 1947. The action of salts and other substances used in the curing of bacon and hams. Br. J. Nutr. 1:269-274.

Cassidy, R. D., Ockerman, H. W., Krol, B., Van Roon, P. S., Plimpton, R. F. Jr. and Cahill, V. R. 1978. Effect of tumbling method, phosphate level and final cook temperatures on histological characteristics of tumbled porcine muscle tissue. J. Food Sci. 43:1514.

Cassidy, R. D., Ockerman, H. W., Krol, B., Plimpton, R. F. Jr. and Cahill, V. R. 1977. The effect of tumbling method, phosphate level and final cook temperature on histological characteristics of tumbled porcine muscle tissue. Unpublished data. The Ohio Agricultural Research and Development Center, Wooster, Ohio.

Cecil, S. R. and Woodroof, J. G. 1954. Effect of storage temperature on the aging of country-style hams. Fd. Tech. 8:216-219.

Cho, I. C. and Bratzler, L. J. 1970. Effect of sodium nitrite on flavor of cured pork. J. Food Sci. 35:668.

Christian, James A. 1977. Putting the tank into country hams. Meat Industry. November, 1977:33.

Craig, H. B., Blumer, T. N., Clawson, A. J. and Smart, W. G. Jr. 1964. Chemical, physical and organoleptic evaluation of aged country-style hams with and without peanut oil. J. Anim. Sci. 23:956.

Eakes, B. D. and Blumer, T. N. 1975. Effect of nitrate and nitrite on color and flavor of country-style hams. J. Fd. Sci. 40:973-976.

Foreman, J. K. and Goodhead, K. 1975. The formation and analysis of N-nitrosamines. J. Sci. Fd. Agric. 26:1771-1783.

Fox, J. B. and Nicholas, R. A. 1974. Nitrite in meat. Effect of various compounds on loss of nitrite. J. Agr. Fd. Chem. 22:302.

Frazier, W. C. 1967. Contamination, Preservation, and Spoilage of Meats and Meat Products. In "Food Microbiology". p. 252. McGraw-Hill Book Co., New York, NY.

Fukazawa, T., Hashimoto, Y. and Yasui, T. 1961. Effect of some proteins on the binding quality of an experimental sausage. J. Fd. Sci. 26:541-549.

Goutefongea, R., Cassens, R. G. and Woolford, G. 1977. Distribution of sodium nitrite in adipose tissue during curing. J. Fd. Sci. 42:1637.

Greenberg, R. A. 1972. Nitrite in the control of Clostridium botulinum. Proc. Meat Ind. Res. Conf. p. 25.

Haldane, J. S. 1901. The red color of salted meat. J. Hyg. 1:115-122.

Hall, J. L., Harrison, D. L. and Mackintosh, D. L. 1962. Effect of free fatty acids on flavor of fat. J. Agric. Fd. Chem. 10:96-98.

Harper, R. H. 1960. Use of nitric oxide to produce cure color. U.S. patent 2,930,703:1960.

Haynes, R. D. and Schmitt, H. P. 1956. Effect of unit process on the salt and moisture content of hams processed country-style. Food Technol. 10:400-402.

Hill, L. H., Webb, N. B., Moncol, N. D. and Adams, A. S. 1973. Changes in residual nitrite in sausage and luncheon meat products during storage. J. Milk Food Technol. 36:515.

Hornsey, H. C. 1956. The colour of cooked pork. I. Estimation of the nitric oxide-haem pigments. J. Sci. Food Agri. 7:534.

Johnson, R. W. and Elliott, R. P. 1976. Meat and Poultry Products. In "Compendium of Methods for the Microbiological Examination of Foods". p. 540. American Public Health Assoc. Wash. DC.

Karmas, E. and Thompson, J. E. 1964. Preliminary studies on the significance of tissue moisture in determining the control of sodium chloride in processed meats. Food Technol. 18:571-573.

Kelly, R. F., Graham, P. P., Baldock, J. D. and Burton, J. A. 1974. Curing ham-Virginia style. Publ. 233, Va. Poly. Inst. and St. U., Blacksburg, VA.

Kelly, S. M. 1965. The changes in relative amounts of long chain fatty acids during storage of ham fat and their possible relationship to flavor. Unpublished M.S. thesis, Dept. of Food Science, North Carolina State University at Raleigh.

Kemp, J. D. and Fox, J. D. 1977. Producing boneless dry cured hams with different amounts of curing ingredients. J. Fd. Sci. 42:1487.

Kemp, J. D., Langlois, B. E., Fox, J. D. and Varney, W. Y. 1975. Effect of curing ingredients and holding times and temperatures on organoleptic and microbiological properties of dry-cured sliced ham. J. Fd. Sci. 40:634-636.

Kemp, J. D., Fox, J. D. and Moody, W. G. 1974. Cured ham properties affected by nitrate and nitrite and fresh pork quality. J. Fd. Sci. 39:972-976.

Kemp, J. D. and Langlois, B. E. Fresh ham storage as related to dry cured ham properties. J. Anim. Sci. 38:520-524.

Kemp, J. D., Moody, W. G. and Goodlett, J. L. 1961. The effects of smoking and smoking temperature on the shrinkage, rancidity development, keeping quality and palatability of dry-cured hams. Fd. Technol. 15:267-270.

Kerr, R. H., Marsh, C. T. N., Shroeder, W. F. and Boyer, E. A. 1926. The use of sodium nitrite in curing of meat. J. Agr. Res. 33:541.

Kimoto, W. I., Wasserman, A. E. and Talley, F. B. 1976. Effect of sodium nitrite and sodium chloride on the flavor of processed pork bellies. Lebensm.-Wissu.-Technol. 9:99-101.

Kimoto, W. I., Wasserman, A. E. and Talley, F. B. 1976. Sensory evaluation of flavor development in lean and adipose tissue of bacon. Lebensm.-Wissu.-Technol. 9:274-276.

Krause, R. J., Ockerman, H. W., Krol, B., Moerman, P. C. and Plimpton, R. F. Jr. 1978. Influence of tumbling, tumbling time, trim and sodium tripolyphosphate on quality and yield of cured hams. J. Fd. Sci. 43:853.

Langlois, B. E. and Kemp. J. D. 1974. Microflora of fresh and dry cured hams as affected by fresh ham storage. J. Anim. Sci. 38:525.

Lee, S. H. and Cassens, R. G. 1976. Nitrite binding sites on myoglobin. J. Fd. Sci. 41:969.

Lechowich, R. V., Graham, P. P., Pierson, M. D., Kelly, R. F. and Baldock, J. D. 1977. The effect of curing methods upon the quality and stability of country hams. Unpublished data. Dept. Food Sci. and Tech. Va. Poly. Inst. and St. U., Blacksburg, VA.

Lewis, W. L. 1937. The role of sugar in curing meat. Proc. Operating and Chem. Sections, Inst. Am. Meat Packers. pp. 60-67. Chicago, IL.

Lewis, W. L. 1937. The use of nitrite of soda in curing meat. Inst. of Am. Meat Packers, Chicago, IL.

Lillard, D. A. and Ayres, J. C. 1969. Flavor compounds in country cured hams. Fd. Technol. 23:251.

MacDougall, D. B., Mottram, D. S. and Rhodes, D. N. 1975. Contribution of nitrite and nitrate to the colour and flavor of cured meats. J. Sci. Fd. Agri. 26:1743-1754.

Macfarlane, J. J., Schmidt, G. R. and Turner, R. H. 1977. Binding of meat pieces: A comparison of myosin, actomyoscin and sacroplasmic proteins as bonding agents. J. Fd. Sci. 42:1603-1605.

Miller, R. C. and Ziegler, P. T. 1936a. How aging affects the distribution of salt in cured meats. Fd. Inds. 8:121-122.

Miller, R. C. and Ziegler, P. T. 1936b. The progress of the distribution of salt in ham during the curing process. J. Agric. Res. 52:225-232.

Mills, J., Weir, C. E. and Wilson, G. D. 1960. The effect of sugar on the flavor and color of smoked hams. Fd. Technol. 14:94-97.

Mohler, K. 1973. Formation of curing pigments by chemical, biochemical or enzymatic reactions. Proc. Int. Symp. Nitrite Meat Prod. Zeist. Sept. 10-14, 1973:13-19.

Montgomery, R. E., Kemp, J. D. and Fox, J. D. 1976. Shrinkage, palatability and chemical characteristics of dry-cure country ham as affected by skinning procedure. J. Fd. Sci. 41:1110-1115.

Mottram, D. S. and Rhodes, D. N. 1973. Nitrite and the Flavor of Cured Meat I. Proc. Int. Symp. Nitrite Meat Prod., Zeist, Sept. 10-14, 1973:161-171.

Mussman, H. C. 1977. "Country", "country-style", or "dry-cured" hams and pork shoulders. Definitions and standards of identity and composition. Fed. Register. 42(12):3298.

Newberne, P. M. 1978. Final report on contract FDA 74-2181: Dietary nitrite in the rat. Dated May 18, 1978. Department of Nutrition and Food Science, Massachusetts Institute of Technology, Cambridge, MA.

Nordin, H. R. 1969. The depletion of added sodium nitrite in ham. J. Inst. Technol. Aliment. 2:79

Ockerman, H. W. and Organisciak, C. S. 1978. Diffusion of curing brine in tumbled and non-tumbled porcine tissue. J. Fd. Prot. 41:178-181.

Ockerman, H. W., Plimpton, R. F., Cahill, V. R. and Parrett, N. A. 1978. Influence of short term tumbling, salt and phosphate on cured pork. J. Fd. Sci. 43:878-881.

Price, L. G. and Greene, B. E. 1978. Factors affecting panelists' perceptions of cured meat flavor. J. Fd. Sci. 43:319.

Ranken, M. D. 1973. A new method of curing. IFST Proceeding. British Food Manu. Ind. Res. Assoc. Leatherhead, Surrey, U.K.:157-163.

Roberts, S. A. 1975. The microbiological role of nitrite and nitrate. J. Sci. Fd. Agric. 26:1755.

Rogers, R. W., Kemp, J. D. and Varney, W. Y. 1965. Effects of enzyme addition on palatability, tenderness, and rancidity development in quick aged country-style hams. Fd. Technol. 19:1509-1513.

Rust, R. E. and Olson, D. G. 1973. Meat curing principles and modern practice. Koch Supplies, Inc. Kansas City, Kansas.

Samejima, K. and Hasimoto, Y. Yasui, T. and Fukazawa, T. 1969. Heat gelling properties of myosin, actin, actomyosin and myosin-subunits in a saline model system. J. Fd. Sci. 34:242-245.

Sauter, E. A., Kemp, J. D. and Langlois, B. E. 1977. Effect of nitrite and erythorbate on recovery of clostridium perfringens spores in cured pork. J. Fd. Sci. 42:1678.

Schmidt, G. R. 1977. Why massage or tumble? Meat Industry, November, 1977:40.

Shank, J. L., Silliker, J. H. and Harper, R. H. 1962. The effect of nitric oxide on bacteria. Appl. Micro. 10:185-189.

Siegel, D. G., Theno, D. M., Schmidt, G. R. and Norton, H. W. 1978. Meat massaging: The effects of salt, phosphate, and massaging on cooking loss, binding strength and exudate composition in sectioned and formed ham. J. Fd. Sci. 43:331.

Siegel, G. D., Theno, D. M. and Schmidt, G. R. 1978. Meat massaging: The effect of salt phosphate and massaging on the presence of specific skeletal muscle proteins in the exudate of a sectioned and formed ham. J. Fd. Sci. 43:327.

Siegel, D. G., Theno, D. M. and Schmidt, G. R. 1977. Protein extraction during ham massaging. J. Anim. Sci. (Abstr.) 42(5):1347.

Skelley, G. C., Kemp, J. D. and Varney, W. Y. 1964. Quick aging of hams. J. Anim. Sci. 23:633-637.

Shank, J. L. 1965. Use of nitric oxide in developing cured color in bacon. Canadian Patent 715,023:1965.

Stadler, C. 1978. Stadler's Country Hams. Meat Processing, Feb. 1978.

Theno, D. M., Siegel, D. G. and Schmidt, G. R. 1978. Meat massaging: Effect of salt and phosphate on the micro-structural composition of the muscle exudate. J. Fd. Sci. 43:483.

Theno, D. M., Siegel, G. H. and Schmidt, G. R. 1978. Meat massaging: effects of salt and phosphate on the ultrastructure of cured porcine muscle. J. Fd. Sci. 43:488.

Theno, D. M., Siegel, D. G. and Schmidt, G. R. 1978. Meat massaging: effect of salt and phosphate on the microstructure of binding junctions in sectioned and formed hams. J. Fd. Sci. 43:493.

Theno, D. M., Siegel, D. G. and Schmidt, G. R. 1977. Meat massaging techniques. Proceedings of the Meat Industry Research Conference March 24-25, 1977.

Tompkin, R. B., Christiansen, L. N., and Shaparis, A. B. 1978. Anti-botulinal role of isoascorbate in cured meat. J. Food Sci. 43:1368.

Tsai, S. F., Witte, V. C. and Bailey, M. E. 1974. Effect of processing on major fatty acids of separable porcine tissues. II. Influence of curing and cooking. J. Anim. Sci. 39:317-324.

Urbain, W. M. 1971. The Science of Meat and Meat Products. W. H. Freeman and Co. San Francisco, and London. p. 437.

U.S.D.A. Consumer and Marketing Service, Laboratory Services Division. 1971. Chemistry laboratory guidebook. Washington, D.C. 20250.

Viskase Limited. 1971. Growing interest in meat tumbling. Food Manufacturer, October, 1971.

Wasserman, A. E. and Talley, F. 1972. The effect of sodium nitrite on the flavor of frankfurters. J. Food Sci. 27:536.

Wierbicki, E., Lawker, J. J. and Shults, G. W. 1976. Effect of salt, phosphates and other curing ingredients on shrinkage of lean pork meat and quality of smoked processed ham. J. Fd. Sci. 41:1116.

Wildes, S. R., Reagen, J. O. and Carpenter, J. A. 1977. Processing and palatability attributes of artery and stitch pumped hams. J. Anim. Sci. 45:81.

Wistreich, H. E., Morse, R. E. and Kenyon, L. J. 1959. Curing of ham: A study of sodium chloride accumulation. I. Methods; effect of cations, muscles, temperature, and solution concentration. Fd. Technol. 13:441.

Wistreich, H. E., Morse, R. S. and Kenyon, L. 1959. Curing of Ham: A study of sodium chloride accumulation. II. Combined effects of time, solution concentration and solution volume. Fd. Technol. 14:549.

Wood, F. W. 1966. The diffusion of salt in pork muscle and fat tissue. J. Sci. Fd. Agric. 17:138.

Woolen, A. 1971. Growing interest in meat tumbling. Food Manufacture 46:(10):35.

Woolford, G., Cassens, R. G., Greaser, M. L. and Sebranek, J. G. 1976. The fate of nitrite: Reaction with protein. J. Fd. Sci. 41:585.

A P P E N D I X

Appendix Table I. Analysis of Variance for % Water, % Salt, and ppm Residual Nitrite

Variable	$\bar{Y}$	Analysis of Variance Source	df	SS	MS	F
% Water	51.79	Among groups	3	38.19	12.73	2.25
		Within groups	20	113.06	5.65	
		Total	23	151.25		
% Salt	4.5	Among groups	3	17.80	5.93	60.91*
		Within groups	20	1.95	0.097	
		Total	23	19.75		
Residual Nitrite (ppm)	13.96	Among groups	3	3903.25	1301.08	70.13*
		Within groups	20	371.00	18.55	
		Total	23	4274.25		

*Significant at the .01 level.

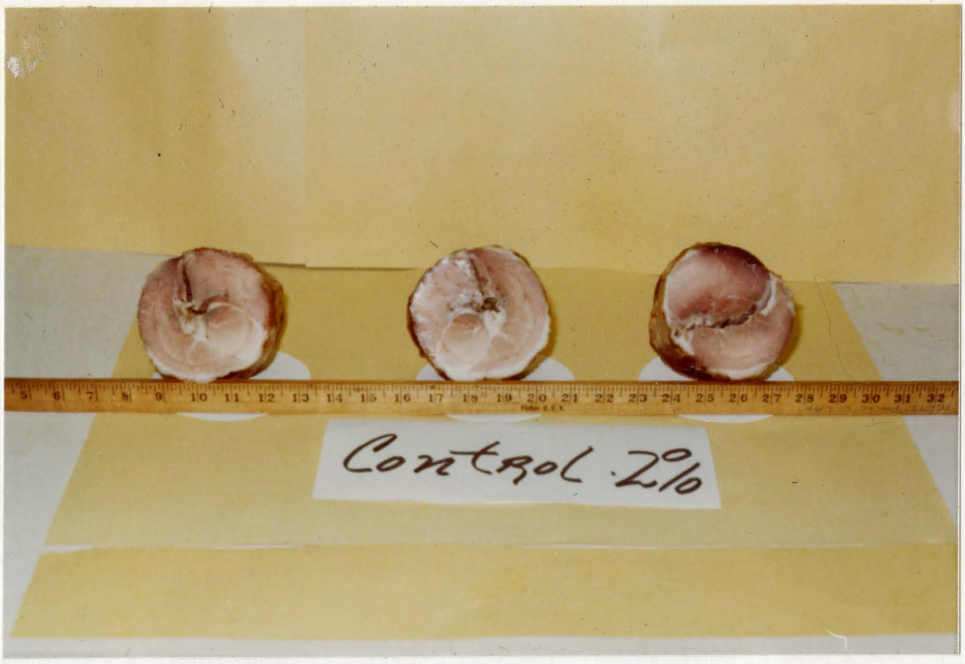
Appendix Table II. Analysis of Variance for Taste Panels Scores for Salt, Tenderness, Flavor and Overall Satisfaction

		Analysis of Variance				
Variable	$\bar{Y}$	Source	df	SS	MS	F
Salt	2.96	Among groups	2	0.066	0.022	0.0257
		Within groups	27	34.90	1.29	
Tenderness	2.50	Among groups	2	7.4	3.7	3.31
		Within groups	27	30.1	1.11	
Flavor	2.66	Among groups	2	1.86	0.93	0.7682
		Within groups	27	2.80	1.21	
Overall	2.60	Among groups	2	5.0	2.5	0.0962
		Within groups	27	32.2	1.19	

Not significant at the .05 level.

Appendix Table III. Experimental Values from Chemical Analysis

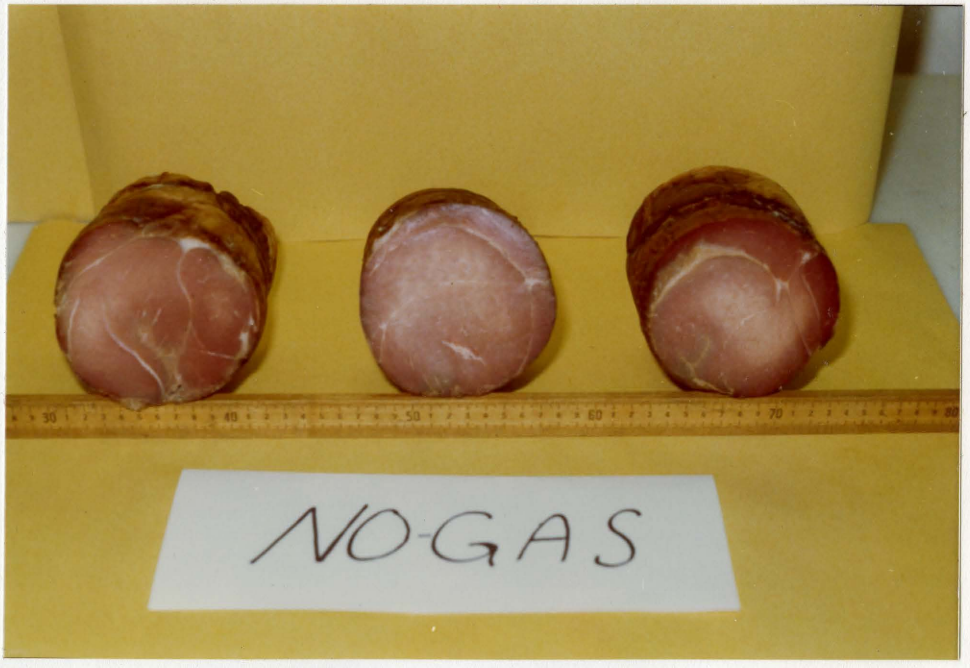
Treatment	% H_2O	% NaCl	Residual Nitrite (ppm)
Control			
1	51.84	3.00	5.31
2	51.63	3.10	5.18
3	51.94	3.12	4.57
4	51.77	3.35	4.02
5	51.65	3.30	3.98
6	51.36	3.74	5.70
0.1% $NaNO_2$			
1	49.66	5.39	5.1
2	52.86	5.19	6.5
3	54.83	5.37	13.86
4	53.17	6.15	7.92
5	52.90	5.68	10.99
6	55.65	5.92	7.15
0.2% $NaNO_2$			
1	50.85	4.23	3.12
2	51.64	5.08	5.55
3	55.37	4.72	9.17
4	46.55	5.19	9.15
5	58.83	5.06	4.58
6	51.54	5.07	7.62
NO gas			
1	50.43	4.53	39.29
2	50.10	4.50	40.76
3	50.03	4.10	22.82
4	50.14	4.03	40.51
5	49.97	4.42	41.42
6	48.12	4.07	30.75



Appendix Figure 1.

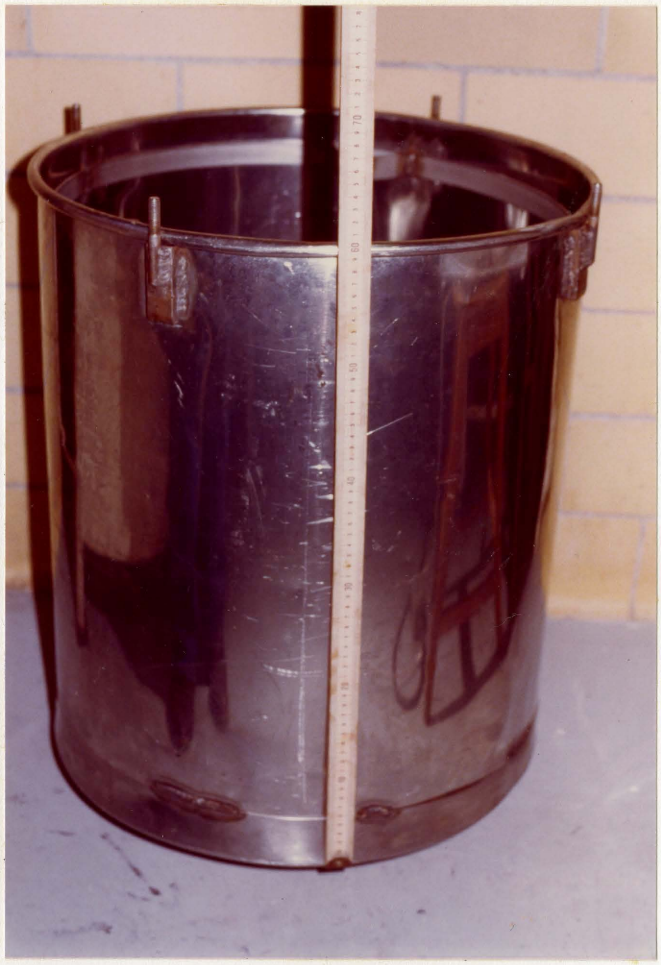
Appendix Figure 2.

Appendix Figure 3



Appendix Figure 4.

Appendix Figure 5. Experimental Tumbling Unit - Interior



Appendix Figure 6. Experimental Tumbling Unit - Exterior

Appendix Table 7. Experimental Tumbling Unit - Gas Port

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RAPID METHOD FOR DRY CURING BONELESS HAMS WITH LITTLE OR NO ADDED NITRITE

by

Jay B. Tracy

ABSTRACT

Fresh hams were skinned, boned, and fat removed to tolerance. Three curing mixtures were applied at the rate of 5% of the boneless weight. The curing mixtures consisted of (1) .1% sodium nitrite, 14.2% white sugar, and 85.7% salt, (2) .2% sodium nitrite, 14.2% white sugar and 85.6% salt, (3) 10% v/v nitric oxide gas in nitrogen, 14.2% white sugar and 85.8% salt. The entire amount of the curing mixture was applied immediately prior to the tumbling treatment. Hams were tumbled for 180 minutes (3 hours) continuously at 22 R.P.M. at 21.1°C. The hams were held 12 hours at 4.4°C for salt equalization, smoked for four hours and cooked to an internal temperature of 71.1°C for 15 minutes and then aged for 14 days at 60% humidity and 15.5 to 21.1°C.

Organoleptic evaluations were made, and slices were analyzed for salt, moisture, and residual nitrite. Panel scores were similar for all treatments, all were acceptable except for control which could not be evaluated. Percent salt and moisture were similar for the three treatments but the control (non-tumbled) had the lowest percent salt.

Variations occurred in nitrite levels, the lowest level detected was in the control (non-tumbled) hams and the highest level detected was in the hams treated with the nitric oxide. Residual nitrite levels for the hams treated with 0.1% sodium nitrite and 0.2% sodium nitrite showed no statistical differences.