AN ABSTRACT OF THE THESIS OF

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Title: Quality Characteristics of Fully-Cooked Ham, Brine-Cured Prior to Freezing

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Zoe Ann Holmes

Thirty bone-in hams from market weight hogs were used in this study, three groups of 10 each. One group was brine-cured, frozen and stored (F/S) at -20°C for 90 days prior to heat processing and smoking. A second group was similarly cured and frozen, not stored (F/NS), but thawed immediately, and heat processed. The third group was cured and heat processed without frozen storage (NF/NS). The three treatments were concurrently evaluated for weight loss, total moisture, color, shear value, and lipid oxidation. A 10-member sensory panel evaluated treatment samples for intensity of seven characteristics. F/S hams had greater overall weight loss ($p < .01$) than both F/NS and NF/NS hams, and greater loss during freezing ($p < .05$). Smokehouse losses did not differ significantly, but were rather large (> 15%) for all three treatments. Total

moisture in F/S hams was also less ($p < .01$) than in the other two treatments. F/S hams had greater ($p < .05$) L-values (lightness) than NF/NS hams, while b-values (yellowness) for F/S hams were greater ($p < .05$) than for other treatments. No differences were found in shear values or lipid oxidation by TBA analysis. Sensory panelists found F/S hams to be less firm and paler in color than other treatments ($p < .01$). For Treatment F/NS, a negative correlation ($r < -0.8$) was found to exist between sensory panel scores for color and percent weight loss.

Quality Characteristics of Fully-Cooked Ham, Brine-Cured Prior to Freezing

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INTRODUCTION

Sales of ham (uncanned) are projected to grow in volume over the next decade at an average of 1.9% annually, at least in part because this product is perceived by consumers as convenient, lean, and low in calories (Anonymous, 1989). While overall sales rise, processors nevertheless face a dilemma caused by periodic fluctuations in market demand for ham, while for other cuts of pork, demand remains fairly constant. This situation often results in processors holding hams in frozen storage until the market, and thus prices, improve (Kemp *et al.*, 1978). Most often hams are frozen green, then cured after storage and thawing, and smoked. Several studies have examined quality characteristics of hams processed in this manner (Graham and Blumer, 1972; Kemp *et al*,, 1978; Langlois *et al.*, 1979).

Currently, some processors are using an alternate approach to holding hams, namely brine-curing prior to freezing, followed by heat processing and smoking after thawing (Dickson, 1991). If found to be practical, this process could offer the potential advantage of reduced

response time to improved market conditions, since uniform cure distribution is already accomplished when the need for thawing arises. This study examined the effect on selected quality characteristics of brine-curing ham prior to freezing, thawing, and heat processing.

REVIEW OF LITERATURE

Classification of Ham

Ham, the cured and processed primal leg of pork, is classified on the basis of Federal Meat Inspection regulations according to final internal processing temperature and amount of added substances after processing (AMSA, 1982). Hams classified as "fully-cooked" are heated to a minimum internal temperature of 64.5°C (148°F), but more commonly 65-71°C (155-160°F). Such hams, often called "pasteurized," may be bone-in, semi-boneless or boneless.

Curing Methods

Categorizing hams by method of cure application is another means of classification. Rust and Olson (1973) broadly classify hams as either dry-cured or brine-cured. The former products are processed by application of cure ingredients in a dry or granular form to the exterior of the meat; the latter are processed by application of a brine in which water serves as the carrier for cure ingredients. Most often, this brine is injected into the muscle by one of several possible techniques.

Brine Application

Methods of administering a brine cure may vary, depending on a processor's personal preference, volume of

output, and economic factors. Price and Schweigert (1987) note the object of any method is uniform distribution of cure throughout the meat. Soaking meat in a cover brine is not commonly used as the sole method of curing hams, but may be used for some products such as corned beef.

Brine may also be injected into hams under pressure, a technique known as stitch pumping. With this method, brine is injected into the ham via a needle with multiple holes along its length. The needle is inserted at various sites in the muscle until the desired amount of brine is injected, as determined by desired pump weight. Stitch pumping may be accomplished with hand-held devices or, for high-volume production, through the use of continuous injection machines which operate in conjunction with a conveyor belt (Price and Schweigert, 1987).

Arterial pumping is a method of cure application in which the intact vascular system of the leg is utilized to distribute cure via a single-bore needle inserted into the femoral artery. Forrest *et al.* (1975) point out that successful use of this technique requires care to ensure pump pressure does not rupture vessels. Another requirement is careful workmanship during slaughter and fabrication, so as to leave the femoral artery intact. In addition, hams held more than a few days after slaughter may experience deterioration of the arterial system, in

which vessels become unacceptable as a means of distributing cure (Price and Schweigert, 1987). In both stitch and arterial pumping,hams are usually held under refrigeration in a cover brine for several days before heat processing to assure adequate time for equilibration of cure throughout the muscle (Rust and Olson, 1973; Price and Schweigert, 1987).

Ingredients and Functions

The brine itself consists of several ingredients, only two of which, salt and nitrite, are considered essential (Forrest *et al.*, 1975). Rust and Olson (1973) state that to function as the sole preservative, a minimum salt concentration of 17% is necessary. Historically, salt functioned in brines as a preservative; today its primary purpose is to impart flavor. Current curing practices employ salt in the form of sodium chloride at levels of 2-3% (Price and Schweigert, 1987).

The second ingredient essential to the curing process is nitrite, thought to have been present historically as an incidental contaminant in salt and to have been adopted as an essential ingredient when its role as color stabilizer and antimicrobial agent became clear (Price and Schweigert, 1987). The potency of nitrite as an additive is noteworthy: at the legal limit

of 156 ppm in the finished product it accomplishes these two functions essential to the cured product.

The chemistry of the curing reaction has been the subject of numerous studies. There is general agreement that the basic reaction (Figure 1) is one in which myoglobin (or its oxygenated form, oxymyoglobin), in the presence of nitrite, is oxidized to metmyoglobin at the same time nitrite is reduced to nitric oxide (Watts, 1957; Forrest *et al.*, 1975; Sebranek and Kipe, 1985). Natural reduction of nitrite to nitric oxide is a slow process. Typically, the slightly acid pH of post mortem muscle (5.5 - 6.0) favors formation of nitrous acid (HNO_2), often accelerated by the addition of reducing agents (sodium salts of ascorbate or its isomer, erythorbate) to brines (Forrest *et al.*, 1975).

The remainder of the curing reaction consists of the reduction of iron in the heme portion of the molecule to a ferrous state and the addition of nitric oxide to a fifth coordination position on the iron (Figure 1). This pigment is variously termed nitric oxide myoglobin, nitrosomyoglobin, or nitroslymyoglobin (Rust and Olson, 1973; Forrest *et al.*, 1975; Price and Schweigert, 1987). It is not entirely clear what intermediate compound(s) exists in the transition from metmyoglobin and nitric oxide to nitrosylmyoglobin. It has been proposed that

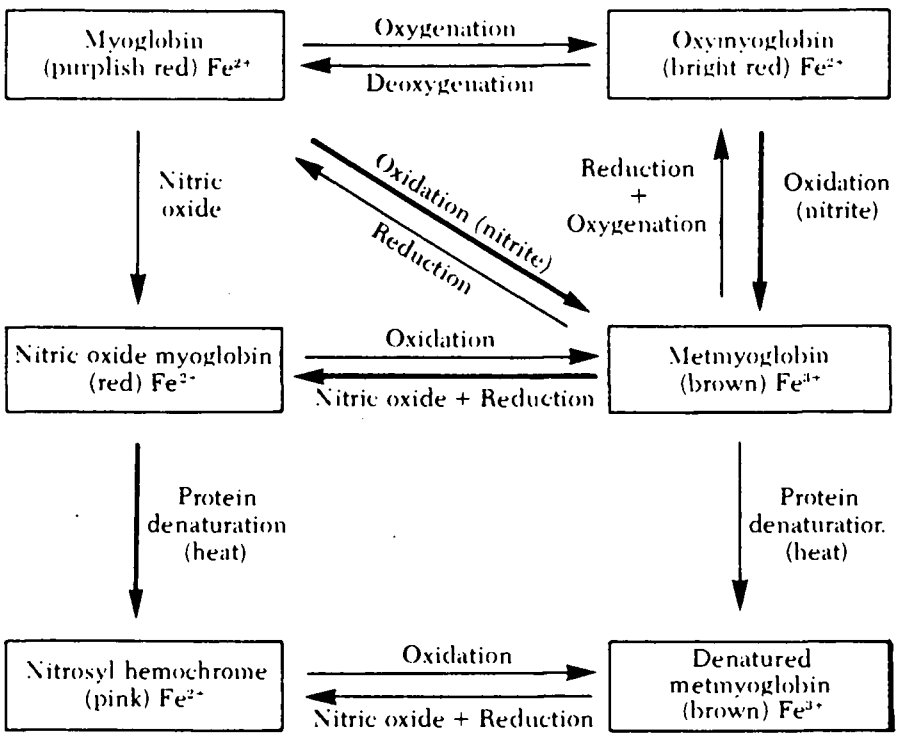

Figure 1[1]
Chemical reactions associated with changes in cured meat pigment.

[1] Forrest *et al.* (1975).

nitric oxide and metmyoglobin combine to form nitrosylmetmyoglobin prior to the reduction of ferric iron, leading to nitrosylmyoglobin (MacDougall *et al.*, 1975; Forrest *et al.*, 1975). More recently, Killday *et al.* (1988) used IR-spectroscopy and fast atom bombardment in model systems to demonstrate that at most, nitrosylmetmyoglobin is a fleeting compound, quickly reduced to an iron II radical cation, which in turn reduces to nitrosylmyoglobin (Figure 2).

Upon heating, the dark red of nitrosylmyoglobin turns to the pink commonly associated with cured meats, a result of the detachment of the protein (globin) portion of the molecule on denaturation. The final cured pigment, nitrosylhemochrome (also termed nitric oxide hemochrome or nitrosohemochrome) carries a reduced ferrous iron and was once thought to carry two nitric oxide groups at the axial coordination positions of the iron (Tarladgis, 1962; Price and Schweigert, 1987). Again, based on work with model systems, Killday *et al.* (1988) agree that the protein portion of the molecule detaches during heating, but propose that the second nitric oxide attaches to the denatured protein rather than to the heme portion of the molecule. Thus, they contend nitrosylhemochrome is a mononitrosyl, not a dinitrosyl complex (Figure 3). Further studies are needed to confirm this hypothesis.

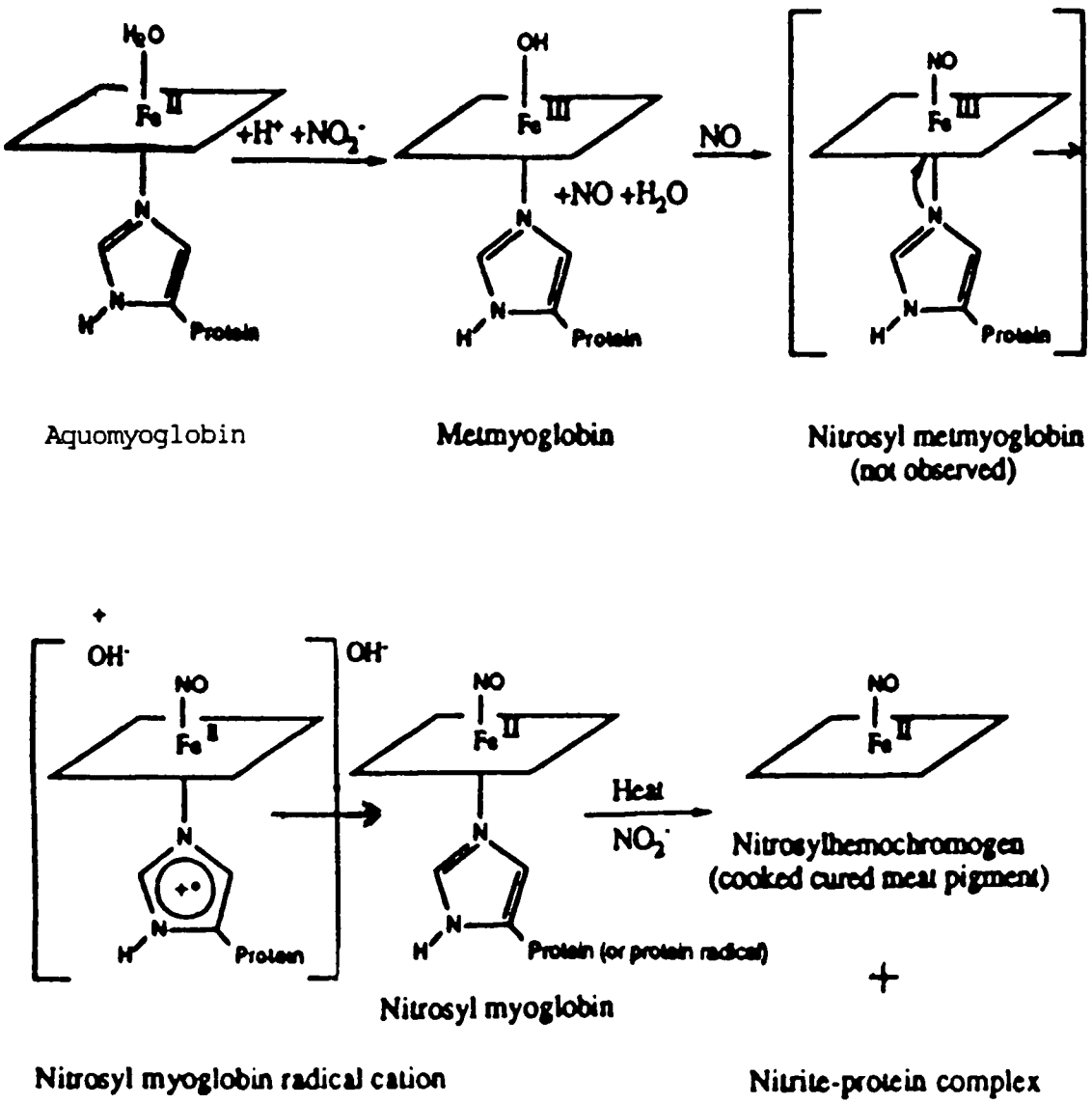

Figure 2[1]
Proposed mechanism for meat-curing reaction.

[1] Killday *et al.* (1988).

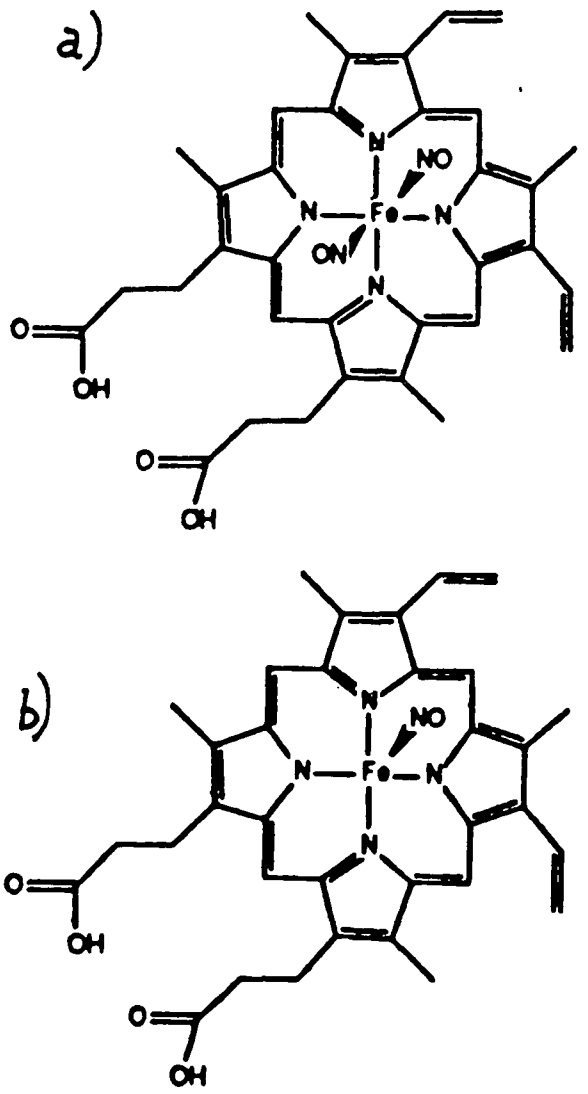

Figure 3[1]
Structure of nitrosylhemochrome, a) as previously thought to appear and b) as recently determined.

[1] Killday *et al.* (1988).

Other ingredients not integral to the curing reaction but commonly used in brines include sugar (most often sucrose), seasonings and spices, and alkaline phosphates (Forrest *et al.*,1975). The primary advantages of added alkaline phosphates are increased water binding capacity of meat and reduced "purge" during processing. By raising the pH of the system, phosphates increase the positive charges on muscle proteins, increasing the ability of those proteins to bind water (Rust and Olson, 1973). The addition of alkaline phosphates to brines can result in finished yields for hams of over 100 percent, an obvious economic advantage for processors (Price and Schweigert, 1987). Other advantages of added phosphates include retardation of lipid oxidation (most likely through chelation of proxidant metal ions) and improved texture. Nevertheless, Price and Schweigert (1987) caution that use of phosphates in brines requires skill and may present several potential problems during processing. They list six phosphates which have been approved by USDA for use in cured meats, noting that sodium tripolyphosphate and its blends with sodium hexametaphosphate are most widely used.

Heat Processing

The heating phase of the curing process is usually accomplished in conjunction with smoking. Apart from the

effect of heat on the product, smoke contributes to preservation, flavor and color through its condensible phase (Wistreich, 1977). Included among compounds termed "condensibles" are the phenolics, primarily responsible for the typical smoked flavor as well as long-term antimicrobial and antioxidative properties of smoke.

Quality Characteristics of Particular Concern in Ham

Quality characteristics of ham may be affected by a number of factors related to handling and processing. Of particular relevance are factors affecting rancid flavor and color. Light fading, or loss of the characteristic cured meat color, is a common problem encountered in ham. DuBose *et al.* (1981) determined color to be of great importance to consumer acceptance of ham. They found that even when attributes such as flavor were inferior, panelists judged meats with good cured color to be acceptable.

Color

Color change results from decomposition of nitrosylhemochrome and is accelerated by light and to some degree by heat. Watts (1957) outlined two types of nitrosylhemochrome decomposition, the first being the dissociation of nitric oxide from the heme portion of the molecule followed by oxidation of both nitric oxide and ferrous iron (Figure 4). This reaction results in grey-

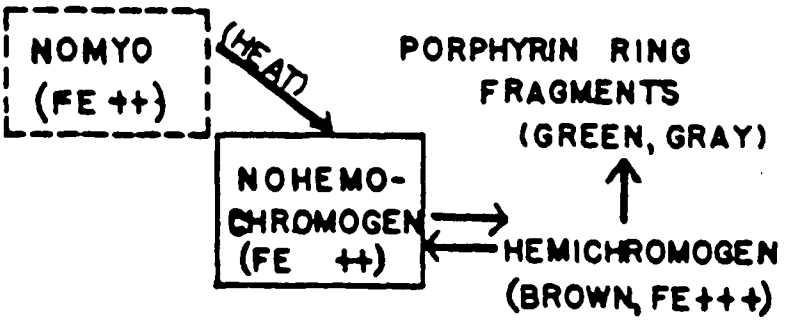

Figure 4[1]
Decomposition of cured pigment.

[1] Watts (1957).

brown hemichromogen (denatured metmyoglobin), and is reversible. Residual nitrites in the presence of added or natural reductants can ensure retention of nitrosyl-hemochrome.

The second decomposition reaction is that in which the porphyrin ring of heme is destroyed after formation of hemichromogen (Figure 4). Often termed the "greening reaction", because of the resulting green-grey color of the meat, this reaction is not reversible, even in the presence of nitrite and reducing agents. Watts (1957) states that ring destruction can occur rapidly due to peroxides of hydrogen or fat which may result from bacterial action, lipid oxidation, or ionizing radiation in the presence of oxygen. Attention to packaging, particularly vacuum packaging in wrappers impermeable to oxygen, is the best defense against color fading. Attention to packaging and storage conditions means lower levels of residual nitrite are required to maintain acceptable product quality (Sebranek and Kipe, 1985).

Rancidity and its Assessment

Lipid oxidation in meats, as in other foods, is a major cause of spoilage. Oxidative rancidity refers to the reaction between molecular oxygen and unsaturated (olefinic) centers in food lipids (Gunstone and Norris, 1983). The reaction is one involving free radicals, and

is autocatalytic, as characterized in the propagation step shown in Figure 5. The initial products of autoxidation are hydroperoxides, relatively unstable compounds which in turn react to form a wide range of secondary products including aldehydes, ketones, and primary and secondary alcohols, often resulting in characteristic flavors and odors termed "rancidity" (Nawar, 1985). Such deterioration is of great economic concern to the food industry, since oxidative rancidity can shorten a food's shelf life. Higher levels of unsaturated fatty acids in pork make it more susceptible to autoxidation than beef (Price and Schweigert, 1987).

A particular type of oxidative rancidity, termed "warmed-over flavor" (WOF) was first characterized by Tims and Watts (1958). They noted objectionable flavor changes in cooked meats, reheated after short periods of refrigeration. Igene and Pearson (1979) determined WOF to be caused primarily by oxidation products of polyunsaturated fatty acids associated with membrane phospholipids.

A close relationship exists between color loss in cured meats and lipid oxidation (Watts, 1957). Porphyrin ring destruction can occur rapidly due to hydroperoxides which result from lipid autoxidation. Zipser *et al.* (1964) found a high correlation between color loss in

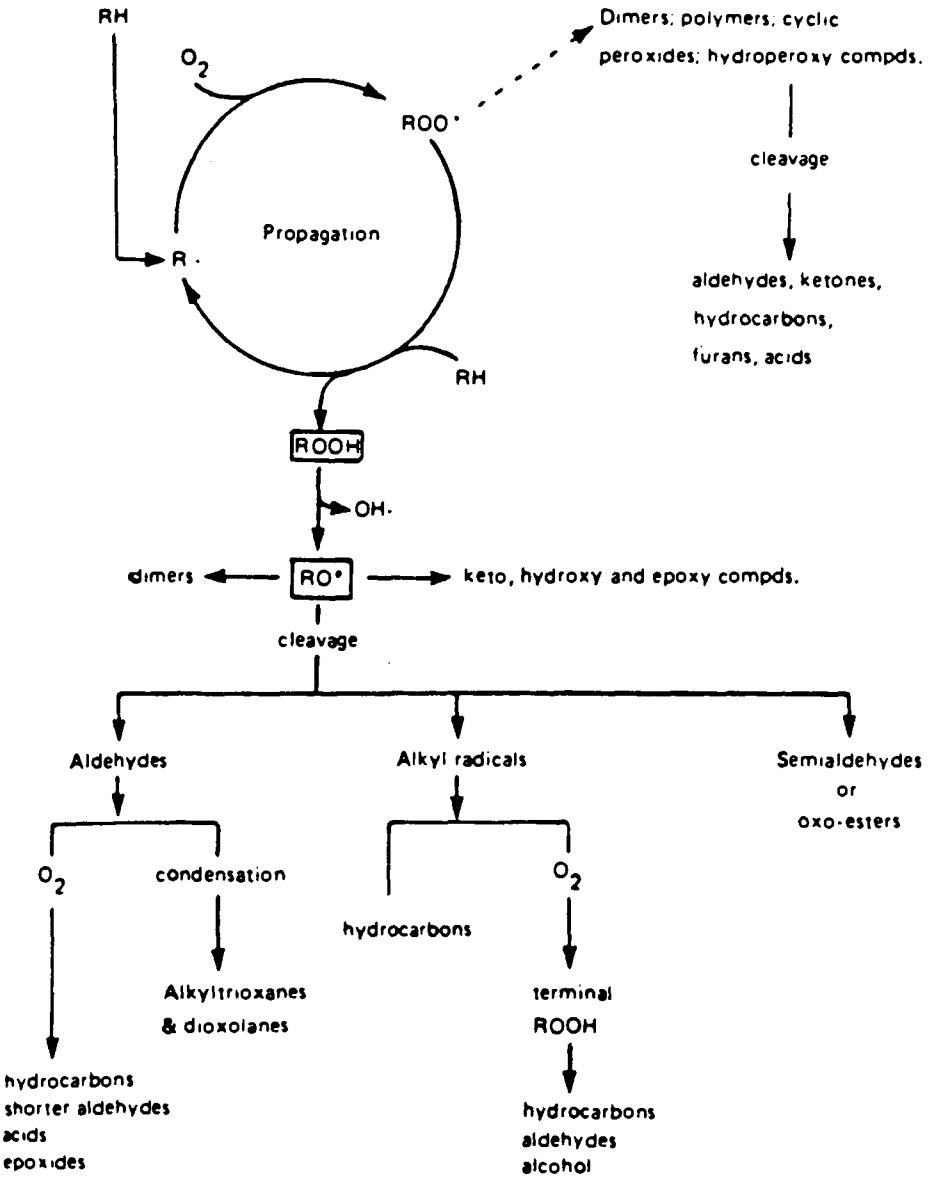

Figure 5[1]
Generalized scheme for autoxidation of lipids.

[1] Nawar (1985).

cured meat and lipid oxidation, as determined by TBA and peroxide values. They also found that any antioxidant which retarded lipid oxidation in frozen, cured pork likewise retarded color loss, and Greene and Price (1975) noted the connection between cured pigment and low TBA values.

Two commonly employed methods of measuring lipid oxidation in meats are determination of peroxide value and thiobarbituric acid (TBA) analysis (Melton, 1985). The peroxide value is reported as mEq of iodine/kg of fat and is based on the reaction of potassium iodide with oxidized fats. The peroxide test measures hydroperoxides, primary oxidation products which are readily converted to volatiles directly responsible for rancidity. Because peroxides are highly reactive, the test is an unreliable method of assessing lipid oxidation in meats during prolonged storage. During such storage it has been shown that peroxide values actually decline (Figure 6) as other chemical and sensory indicators of oxidation increase (Labuza, 1971; Melton, 1985).

The TBA test takes its name from 2-thiobarbituric acid which combines with malonaldehyde, a three-carbon product of lipid oxidation, to form a colored complex (Figure 7). Concentration of this complex is measured by spectrophotometer at 530-537 nm., with values expressed

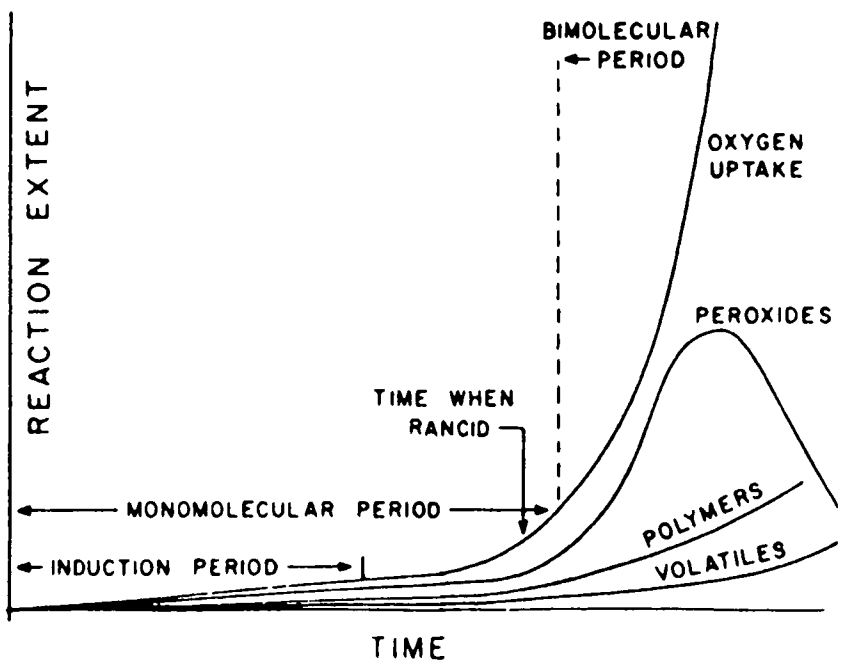

Figure 6[1]
Extent of lipid oxidation as a function of time.

[1]Labuza (1971).

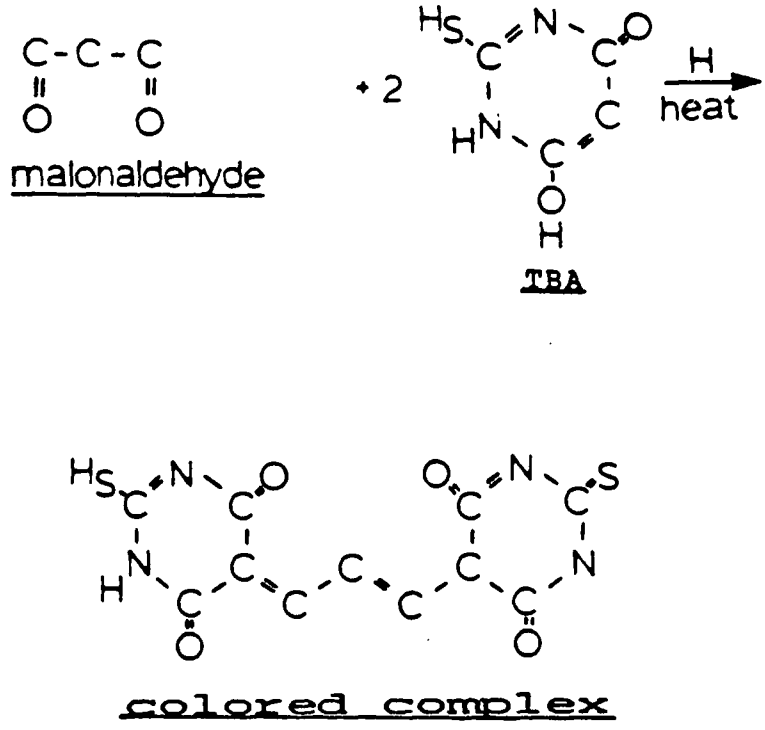

Figure 7[1]
Reaction of 2-thiobarbituric acid (TBA) with malonaldehyde to form a colored complex measured by spectrophotometer at 530-537 nm.

[1] Nawar (1985).

as mg of malonaldehyde/kg of meat (Melton,1985).

Several methods have been used for determining TBA values. Early work by Sinnhuber and Yu (1958) produced the colored complex on the whole food product, then extracted it for measurement. Probably the TBA method most documented in the literature is the distillation procedure. In this method, 10g of meat sample is homogenized with distilled water and a small amount of acid, followed by distillation to collect 50 mL of distillate. Equal amounts of distillate and TBA are mixed and heated to form the colored complex. The intensity of the colored complex is measured by spectrophotometer: the greater its concentration, the greater the extent of lipid oxidation (Tarladgis *et al.*,1960). An aqueous extraction method, which does not require distillation apparatus, was used by Witte *et al.* (1970). With this method, trichloroacetic acid is used to extract the meat, and the colored complex is formed in the extract. A modification of this procedure was reported by Salih *et al.* (1987) in which perchloric acid is used in place of trichloroacetic acid. A lipid extraction method has also been reported by Pikul *et al.* (1983) in which the complex with TBA is also formed in the extract. In later work with both extraction methods and the distillation method, Pikul *et al.* (1989) recommended the addition of butylated

hydroxytoluene (BHT) prior to homogenation in order to prevent autoxidation as an artifact of the heating step during the procedure.

Melton (1985) states that malonaldehyde is a highly reactive secondary product capable of reacting with other meat constituents such as proteins and amino acids. Witte *et al.* (1970) proposed that such reactivity accounted for decreasing TBA numbers during increasing periods of frozen storage of raw beef and pork. They used various combinations of refrigerated plus frozen storage up to a maximum of 7 days for each type of storage (14 days maximum total). Using both distillation and aqueous extraction procedures, they found significant increases in TBA numbers during refrigerated storage, but not during frozen storage. They concluded that TBA analysis was of limited value for meat samples that have been frozen.

However, in a study of raw, ground chicken which was refrigerated for six days or frozen for up to six months, Pikul *et al.* (1989) found TBA values increased during frozen storage to a level over four times as high as fresh meat. These findings were similar for all three TBA methods used.

Recognizing that TBA numbers for cured meats were often low compared to uncured, Zipser and Watts (1962)

devised a modification of Tarladgis' distillation procedure. Based on the assumption that excess nitrite in cured meats reacts with malonaldehyde, thereby making this product of lipid oxidation unavailable to form the colored complex, their modification called for the addition of sulfanilamide to bind excess nitrite prior to the homogenation step.

While this modification has been used in several studies reported in the literature (Zipser and Watts, 1962; Igene and Pearson, 1979; Miller *et al.*, 1985), its usefulness has been questioned. Shahidi *et al.* (1985) noted in comparing TBA numbers of meats cured with various nitrite levels, that at low levels of nitrite (< 50 ppm) addition of sulfanilamide actually lowered TBA values. At nitrite levels above 50 ppm, TBA values were raised, as expected when using sulfanilamide in a cured meat system. The authors speculated that sulfanilamide itself complexes with malonaldehyde, when excess nitrite is unavailable (< 50 ppm). It should be noted that Zipser and Watts (1962) were aware of the propensity for a reaction between sulfanilamide and malonaldehyde under conditions of low excess nitrite, and recommended reducing the amount of sulfanilamide to 1 mL when nitrite levels were below 100 ppm. Shahidi *et al.* (1985) used twice that amount (2mL) of the same concentration. One

wonders if different results might have been obtained had the recommended 1mL been used.

A more recent study by Kolodziejska *et al.*(1990) also questions the effectiveness of the sulfanilamide modification for TBA analysis. In model systems, they determined that sulfanilamide was effective in preventing the nitrite-malonaldehyde reaction only when added prior to nitrite. Kolodziejska *et al.* (1990) concluded that when nitrite was present with sulfanilamide it only partially prevented nitrite's reacting with malonaldehyde. They suggest that assessment by gas chromatography of hexanal, a volatile compound indicative of lipid oxidation, might be a better analytical approach. Such an approach was outlined in a study by Shahidi *et al.* (1987) in which they found hexanal levels correlated well with flavor and TBA values in cooked, ground pork. Thus, while it is clear that cured meat systems require a different approach to analysis of lipid oxidation than uncured, an ideal procedure has yet to be determined.

Several factors may enhance lipid oxidation in meats, including molecular oxygen, light, and metal ions (Nawar, 1985). Iron is naturally present as part of muscle pigment (heme iron), and may also be associated with other tissue and cell components (non-heme), thus

representing a readily available catalyst of autoxidation. A good deal of research has focused on which valence state of iron (ferrous or ferric) as well as which form of iron (heme or nonheme) is more catalytically active.

Zipser *et al.* (1964) concluded that heme iron in the ferric (3^+) state present in cooked, refrigerated, uncured meats was responsible for autoxidation in beef and mullet. In uncured, cooked pork, stored frozen, they attributed similar oxidation prior to and after freezing to ferric heme iron. Greene and Price (1975) concluded that both heme and nonheme iron are capable of catalyzing lipid oxidation in model systems and in meats. They surmised that heme pigments may be more active catalysts when iron is in the 3^+ state, while nonheme iron may be a more active catalyst in the 2^+ state. Love (1983), in reviewing the role of heme iron in lipid oxidation of red meat, stated that both valence states can influence autoxidation.

Cured meats, however are less prone to autoxidation than uncured. Tarladgis (1962) noted the antioxidative property of cured pigment in meats and suggested the structure of cured pigment might somehow make the iron unavailable to react catalytically in lipid oxidation. Zipser *et al.* (1964) observed different patterns of lipid

oxidation, as measured by TBA and peroxide analysis, between cured and uncured pork which was cooked and refrigerated. They speculated that nitrite in cured meats reduced the iron of the pigment molecule to a less catalytically active ferrous state, resulting in less autoxidation and WOF. Greene and Price (1975) likewise found that lower TBA numbers in cooked meats were associated with cured pigment, thus ferrous iron.

It has been proposed that nitrite acts as an antioxidant by chelating iron, thereby preventing its release as nonheme iron during heat processing (MacDonald *et al.*, 1980). Lower TBA values for cooked pork treated with nitrite than without nitrite were attributed by Miller *et al.* (1985) to this antioxidative effect. Similarly, Chen *et al.* (1984), observed that nitrite-treated pigment extracts exhibited less nonheme iron after heat processing than did uncured extracts. They speculated that nitrite stabilized the porphyrin ring of the heme pigment, thus preventing the release of iron in a more catalytically active (nonheme) form.

While cured meats may benefit from the antioxidative effect of nitrite, another cure ingredient, namely sodium chloride, is a proxidant. Chang and Watts (1950) demonstrated that salt accelerated oxidation in both cured and uncured meats. In addition, they found the

proxidant effect of salt to be more pronounced under conditions of reduced moisture, as would be present during frozen storage. Zipser *et al.* (1964) proposed that oxidation which occurred in cured pork during frozen storage was salt-catalyzed and was, therefore, absent in similarly stored uncured pork. Later work by Neer and Mandigo (1977) supports the role of sodium chloride as a proxidant increasing rancidity in a cured, flaked product.

Effects of Freezing on Ham

Freezing has been employed by the pork industry as a means of preservation to counteract fluctuations in supply and demand, particularly with cuts destined for curing, such as bacon and ham. Hams are most often frozen green, then shipped to a location where curing occurs, or held frozen until the need for curing arises. The effect of freezing and storing pork has been studied extensively (Berry, 1988), with attention to such quality characteristics as altered flavor and color, lipid oxidation and resulting off-flavors, as well as overall sensory acceptability.

Quality characteristics of dry-cured hams produced from frozen pork legs were studied by Graham and Blumer (1972). They found greater water loss after curing and aging in prefrozen pork compared to unfrozen.

Nevertheless, they concluded all hams in their study were of acceptable quality. Likewise, Kemp *et al.* (1978) produced acceptable hams from frozen pork. They found that applying dry cure to hams while still frozen resulted in lower weight loss, lower salt concentrations, and, for one muscle group, lower shear values than when cure was applied after thawing. A ten-member, experienced sensory panel did not find flavor, tenderness, and overall satisfaction to be significantly different for hams cured while frozen versus those cured after thawing. Similarly, the panel judged all hams to be acceptable in appearance, with no significant color differences.

Jeremiah (1980) considered the effect of frozen storage and several protective wraps on cured as well as fresh pork. Intact hams in his study were cured and cut into steaks prior to freezing at -30°C. Heat treatment occurred after thawing. Ham frozen for six time intervals up to a maximum of 196 days consistently displayed greater cooking losses than unfrozen, cured samples. A six-member sensory panel found tenderness and juiciness in frozen, cured hams decreased as the length of the frozen storage interval increased. Nevertheless, the panel judged frozen, cured samples to be acceptable throughout the 196 days. Flavor evaluations indicated a maximum of 196 days frozen storage could occur before

overall palatability deteriorated to a point approaching unaccceptable. Rancid flavors were more detectable in cured ham after 196 days storage than before. No consistent patterns were observed in frozen ham steaks with respect to peroxide values, though values generally increased after 196 days, in line with flavor deterioration after the same interval.

Miller *et al.*(1985) examined cured and uncured precooked pork loin chops, stored frozen for a maximum of 87 days. Cured samples had lower processing losses, as well as lower Warner-Bratzler shear values, lower TBA values, and greater percent moisture values. Six experienced sensory panelists, using an 8-point scale, rated cured samples significantly ($p < 0.05$) more favorably than uncured for desirability of flavor, extent of juiciness, and degree of overall acceptability.

Acceptability of a cured, flaked pork product (evaluated at three-week intervals for a 126-day period of frozen storage) declined as storage time increased (Neer and Mandigo, 1977). Nevertheless, cured samples initially judged acceptable were still judged to be so after the frozen storage period. Freezer and cooking yields decreased with frozen storage time, while shear values and color fading increased over time.

Sensory Evaluation of Ham

Studies of ham have considered the role of cure ingredients in producing "typical" cured flavor and texture (Cross and Ziegler, 1965; Cho and Bratzler, 1970; Bailey and Swain, 1973; Price and Greene, 1978). Differing conclusions concerning components responsible for cured flavor illustrate the complexity of the problem and the need to control variables inherent in sensory evaluation in general (Cross et al., 1978) and in muscle tissue specifically (Moskowitz, 1983).

Sensory assessment of food texture is multi-faceted. The problem is even more complex in the case of meats, due to variability between animals, muscle groups, and even within muscle groups. The most precise sensory assessment of meat texture often requires use of a panel trained in a descriptive profile method such as that developed by Brandt *et al.* (1963).

Studies sometimes attempt to correlate textural aspects evaluated by sensory panels with instrumental measurements, often with mixed results (Deatherage and Garnatz, 1952; Riffero and Holmes, 1983; Moskowitz, 1983). Szczesniak (1972) points out that instruments which measure texture measure only one, or at most a few, of a whole spectrum of parameters comprising that quality. In addition, Moskowitz (1983) notes that most

instrumental measurements of texture are destructive, prohibiting use of identical samples for sensory evaluation, thus increasing variability. As a means of compensating for variability, use of guidelines in selecting and training sensory panels and standardization of sample preparation and presentation are recommended (Cross *et al.*, 1978; AMSA, 1982).

METHODS AND PROCEDURES

Three treatment groups of ten hams each were compared. Treatment F/S (frozen/stored) hams were pumped, equilibrated, vacuum-packaged, stored frozen at -20°C for 90 days, thawed and smoked. Treatment F/NS (frozen/not stored) hams were treated similarly, but were thawed immediately after freezing (72 hrs.), and smoked. Treatment NF/NS (not frozen/not stored) hams were smoked following curing procedures identical to the other two treatments, without freezing and storing. Instrumental measurement of the physical properties of weight change, color, and shear value were performed. In addition, total moisture was determined and chemical assessment of lipid oxidation was done using 2-thiobarbituric acid analysis. Finished products were evaluated for intensity of seven sensory characteristics by a panel of ten screened, trained individuals.

Treatment Preparation

All thirty hams were processed at the Robert Clark Meat Science Laboratory, Oregon State University, Corvallis, Oregon. All hams were from conventionally slaughtered, market weight hogs of similar management background. Following slaughter, they were left intact in the carcass and chilled for 48 hours at 2°C prior to

fabrication, trimming, and processing.

Treatment F/S hams were pumped to 110% green weight and placed in a cover brine at 2°C for an equilibration period of two weeks. Cover brine was identical in composition to pumping brine. Following removal from the brine, they were vacuum-packaged (Cry-O-Vac), and frozen at -20°C for a period of 90 days. At the end of that period, Treatment F/S hams were thawed and tempered in a cover brine at 2°C for 14 days, before heat processing. Treatment F/NS hams were similarly treated, but were thawed immediately upon attaining a frozen state (72 hrs.). Treatment NF/NS hams had identical pumping and 14-day equilibration regimens, but were heat processed (smoked) without freezing.

Brine formulation for all hams consisted of sodium chloride, sucrose, cure (sodium nitrite), and water in the amounts shown in Table 1. Treatment F/S hams were artery-pumped, supplemented by stitch-pumping to achieve the additional 10% weight increase. Treatment F/NS and NF/NS hams were stitch-pumped only, as procedures used in obtaining primal cuts failed to maintain integrity of the femoral artery, thereby precluding artery-pumping. Differences in pumping techniques were not considered significant due to the length of time (2 wks.) pumped hams were allowed to equilibrate in a cover brine, a

Table 1. Brine formulation for hams.

Ingredient	lb.	kg.
Sodium Chloride	9.0	4.1
Granulated Sugar	7.0	3.2
Cure (6.25% Sodium Nitrite)*	3.0	1.4
Water **	90.0	41.0

* Heller Seasonings & Ingredients, Pleasanton, Ca.

** or to a 55° salometer reading

longer period than commonly used with either artery or stitch pumped hams (Rust and Olson, 1973; Price and Schweigert, 1987). All hams were maple smoked for approximately 15 hours to an internal temperature of 71°C (160°F). Smokehouse procedures included three phases. Phase 1 consisted of a one hour period during which the temperature was 71°C, dampers were open, and smoke was off. During Phase 2, the temperature remained the same, dampers were closed, and smoke was on for a period of ten hours. Phase 3 lasted four hours, during which the temperature reached 82°C, and dampers and smoke were off. After removal from the smokehouse, hams were sprayed with cool water, allowed to hang for two hours, and were then placed in a cooler at 4°C.

Hams were sliced according to American Meat Science Association Committee Guidelines (AMSA, 1982), using a 16" band saw (Butcher Boy, Lasar Mfg. Co., Inc., Los Angeles, CA.) in a cutting room environment of 7°C. Slices were immediately vacuum-packaged and transported a short distance to the Department of Nutrition and Food Management, where they were placed in a walk-in refrigerator and held at 4°C until analysis of samples began, three days later.

Objective Testing Methods

Weight Loss

Weight loss during several stages of processing was monitored, including total weight loss (green weight to final weight after smoking), heat processing loss, and loss during freezing. Losses were calculated as a percent of weight taken at the beginning of the interval considered, ie. ([weight loss/initial weight] x 100).

Total Moisture

Total moisture content was determined according to AOAC (1990) vacuum oven method (95°C, 15#). *Biceps femoris* muscles from each replication and treatment of ham were flash frozen with liquid nitrogen and ground to a powdered state in a blender (John Oster Mfg. Co., Milwaukee, WI.), according to the method of Riffero and Holmes (1983). Duplicate 5 g samples were dried in a vacuum oven (GCA Corporation, Precision Scientific Co., 3737 W. Courtland St., Chicago, Il.). Moisture was calculated as loss in percent of wet weight, with weights determined to the nearest 0.001 g on an Electronic Mettler PC 180 balance (Mettler Instrument Co., Hightstown, NJ.).

Color Measurement

Color quality of ham samples was measured with a Hunter LabScan Reflectance Spectrophotometer (HunterLab,

Reston, VA.). For each ham, the *semitendinosus* muscle was excised from a 1.27 cm thick slice, covered with plastic wrap, placed over the sensing lamp (10° standard observer; illuminant D65) and covered with a black, nonreflective cloth. Duplicate L-(lightness), a-(redness) and b-(yellowness) readings were taken on each sample just prior to its being viewed by panelists as part of sensory evaluation procedures. L,a,b data was used in the derivation of chroma and hue values (Hunter and Harold, 1987).

Shear Value

Concurrent with the period of sensory evaluation, the force necessary to break muscle fibers in ham samples, or shear force (kg/1.27 cm), was determined using a Warner Bratzler apparatus (G-R Mfg.Co., Manhattan, KS.). The *biceps femoris* muscle was excised from a 2.54 cm thick slice and 1.27 cm diameter cores running parallel with muscle fiber direction were taken. Three readings for each sample were averaged to obtain a shear value.

Thiobarbituric Acid Determination

The extent of lipid oxidation in samples was determined by reaction of 2-thiobarbituric acid (TBA) with malonaldehyde (MDA), a secondary oxidation product of unsaturated fatty acids. The distillation method as outlined by Tarladgis *et al.*(1960) was used, with

modifications by Pikul *et al.* (1983) and Zipser and Watts (1962). As suggested by Sinnhuber and Yu (1958), 1,1,3,3 -tetra- ethoxypropane (TEP) was used as the standard. This compound yields malonaldehyde with the resulting TBA value expressed as milligrams of malonaldehyde per kilogram of sample.

A standard curve was prepared with dilutions of a 4 $x10^{-4}$ M solution of 1,1,3,3-tetra-ethoxypropane (Sigma Chemical Co., St.Louis, MO.) in deionized distilled water, ranging from 0.5 x 10^{-4} to 4 x 10^{-4} moles malonaldehyde in five mL. One mL of a standard solution dilution was added to a 500 mL Kjeldahl flask containing 96.5 mL deionized distilled water. The pH was adjusted to 1.5 by the addition of 2.5 mL of a 4 N solution of hydrochloric acid (Fisher Scientific Co.,FairLawn, N.J.). Mixtures were distilled on an electric macro-Kjeldahl apparatus on high heat. Fifty mL of distillate were collected in 125 mL Erlenmyer flasks, a process taking 10-12 minutes from initiation of boiling.

A distilled water blank was similarly treated. Each distillate was mixed thoroughly, and 5 mL were pipetted into 25 mL test tubes. Five mL of a 0.02 M solution of 2-thiobarbituric acid (Sigma Chemical Co.) in 90 per cent glacial acetic acid (Ashland Chemical Co.,Columbus, Ohio) were added. Tubes were capped, mixed, and placed in a

boiling water bath for 35 minutes, followed by immersion in cold tap water for 10 minutes. The content of each test tube was transferred to a cuvette and read in a Sequoia-Turner Spectrophotometer (model 340) at 535 nm against a distilled water blank. The standard curve followed Beer's Law (Appendix).

Percent recovery of malonaldehyde was determined by reacting 2-thiobarbituric acid directly with 1,1,3,3-tetra-ethoxypropane solutions ranging in concentration from 0.5×10^{-4} to 4×10^{-4} M. Nondistilled solutions were boiled, cooled and optical density was read. The quotient of nondistilled to distilled optical density, times 100, gave percent recovery. A 4×10^{-4} M solution of standard was used to determine percent recovery on the days sample assays were run.

TBA values are expressed as milligrams of malonaldehyde per kilogram of sample. These values are obtained by multiplying the optical density of the distillate by a constant, K (Tarladgis *et al.*, 1960). The constant is derived from the adjusted regression equation from the standard curve as follows:

$$K = \frac{\text{Concentration of malonaldehyde in 5 mL of distillate}}{\text{Optical density at 535 nm}} \times \text{Molecular weight of Malonaldehyde} \times \frac{103}{\text{Sample weight}} \times \frac{100}{\text{Percent recovery}}$$

The K value obtained in this laboratory was 10.3.

Samples were prepared by excision of the *biceps femoris* muscle from previously vacuum-packaged 2.54 cm thick slices. The muscle was coarsely chopped, flash frozen with liquid nitrogen, and finely ground using an Osterizer (John Oster Mfg.Co., Milwaukee, Wis.). For each replication of the three treatments, 10 g of frozen, ground meat were weighed into a Virtis homogenizer flask (The Virtis Co.,Gardiner,N.Y.) to which 48.25 mL deionized distilled water, 1 mL of 0.5 percent sulfanilamide (Sigma Chemical Co.) in 20 percent hydrochloric acid, and 0.75 mL of 0.01 percent butylated hydroxytoluene (Fisher Scientific Co.) in ethanol were added. The mixture was homogenized for 2 minutes, and added to a 500 mL Kjeldahl flask. The Virtis flask was washed with 48 mL deionized distilled water which was also transferred to the Kjeldahl flask. Two mL of 4 N hydrochloric acid were added to adjust the pH to 1.5, and the neck of the flask was lightly sprayed with Dow-Corning Antifoam.

Several boiling stones were added, and the contents

were distilled on an electric Kjeldahl apparatus at high heat. Fifty mL of distillate were collected in 125 mL Erlenmyer flasks, a process requiring 10-12 minutes of boiling. A distilled water blank was treated in a like manner. Five mL aliquots of distillate were pipetted into 25 mL test tubes to which 5 mL of 0.02 M thiobarbituric acid was added. Test tubes were capped, thoroughly mixed, and placed in a boiling water bath for 35 minutes. They were cooled in cold tap water for 10 minutes and contents were transferred to cuvettes and read against a distilled water blank in the Sequoia-Turner Spectrophotometer at 535 nm. Optical density was multiplied by the K value derived from the standard curve to obtain a TBA value expressed as milligrams of malonaldehyde per kilogram of sample (Table 9).

Sensory Evaluation

Sensory evaluation of ham samples was conducted by a panel of ten volunteer faculty, staff, and students from the College of Home Economics, Oregon State University. There were two males and eight females, ranging in age from early 20's to early 60's. Panelists were selected on the basis of interest, availability, and demonstrated ability to perceive differences in color, texture, and flavor of ham presented during screening and training sessions. In six training sessions over a period of two

weeks, panelists were familiarized with definitions of sensory qualities to be evaluated and techniques to be used in their evaluation (Figure 8). They were encouraged during this period to offer comments and questions regarding evaluation procedures.

All sensory evaluation sessions were conducted in the Department of Nutrition and Food Management Sensory Evaluation Laboratory, Oregon State University, using established procedures (ASTM, 1977). Panelists were seated at separate tables under fluorescent lighting conditions. Written definitions of characteristics to be evaluated and techniques to be used in their evaluation were available. Ballots used are shown in Figure 9. Panelists evaluated each treatment of ham for seven characteristics, using a nine-point intensity scale (1=none, 9=extreme). Qualities evaluated included typical ham flavor, off-flavor, saltiness, sweetness, juiciness, and firmness. Similarly, a nine-point scale was used for color evaluation under controlled lighting, with 1= pale, tannish, and 9= dark,red.

Samples presented to sensory panelists were 1.27 x 1.27 cm^3, taken from the *biceps femoris* muscle, and served at 27°C. Panelists received three cubes of each of the three coded treatment samples, a total of nine cubes. For each treatment, panelists were instructed to use one

PLEASE READ ALL INSTRUCTIONS BEFORE SAMPLING.

Taste Testing First
Each treatment (coded ham variable) has three cubes.

1. Use one cube to evaluate juiciness and firmness.
2. Use a second to evaluate the intensity of the total ham flavor and off-flavor.
3. Use a third to evaluate the saltiness and sweetness.

Do this for all three treatments. You will be tasting 9 cubes of ham total.

If you wish not to consume the samples it is perfectly acceptable to expectorate (spitout) the sample after scoring is complete. There are small plastic bags you can expectorate into and just toss in the waste basket on the way out.

Please **rinse** thoroughly between tastes.

Please read the following definitions and techniques thoroughly before tasting and scoring:

DEFINITION	TECHNIQUE
Typical Ham Flavor/Intensity The degree to which sample tastes as you expect ham to taste.	Place cube between molars and chew 5 times. Note impression.
OFF-Flavor Any deviation from typical ham flavoring; any unusual or unexpected or "unhamlike" flavor.	Use the same cube and procedure as above.
Salty Self Explanatory	Place cube between molars and chew 8 times for saltiness and sweetness.
Sweetness Same as Salty.	
Juiciness The amount of moisture present in the mouth after 5 normal chews.	Place sample between molars and chew normally 5 times. Note moisture present in mouth.
Firmness The force necessary to fully compress the cube between molars.	If fiber direction is noted please chew across the fibers.

DEFINITION
Color Evaluation Please uncover one slice, score, and recover BEFORE going on to the next sample slice. DO NOT compare slices, simply evaluate each, as though you were only evaluating it and it alone.

Figure 8
Sensory panel instructions and definitions.

CODE	FLAVOR			OFF-FLAVOR	JUICINESS	FIRMNESS	COLOR
	TYPICAL HAM	SALTY	SWEET				
241							
331							
426							
COMMENTS							

FLAVOR - TYPICAL HAM	FLAVOR - SALTY	FLAVOR- SWEET	FLAVOR - OFF-FLAVOR
9 extremely intense	9 extremely salty	9 extremely sweet	9 extremely off-flevor
8	8	8	8
7 very intense	7 very salty	7 very sweet	7 very off-flevor
6	6	6	6
5 moderately intense	5 moderetely salty	5 moderately sweet	5 moderetely off-flevor
4	4	4	4
3 slightly intense	3 slightly salty	3 slightly sweet	3 slightly off-flevor
2	2	2	2
1 no flevor	1 no salty flavor	1 no sweet flevor	1 no off-flevor

JUICINESS	FIRMNESS	COLOR
9 extremely juicy	9 extremely firm	9 extremely reddish/brown
8	8	8
7 very juicy	7 very firm	7 very reddish/brown
6	6	6
5 moderately juicy	5 moderetely firm	5 reddish/brown
4	4	4
3 slightly juicy	3 slightly firm	3 pink
2	2	2
1 none	1 none	1 greyish/pale

COMMENTS REGARDING ANY OF THE ATTRIBUTES PLEASE

Figure 9
Ballots used for sensory evaluation of hams.

ham cube to evaluate typical ham and off-flavors, one for saltiness and sweetness, and one for juiciness and firmness. Panelists were instructed to rinse between treatments with room temperature water, and expectoration was encouraged. Soda crackers were available to assist in clearing the palate between treatments.

Each treatment was assigned a random, three-digit code number for each of the five evaluation sessions. Panelists were instructed to evaluate one treatment for all characteristics before evaluating the next randomly selected treatment. Two replications were completed during each of the five sessions, for a total of ten replications for each treatment.

Samples used for sensory panel color evaluation were covered in clear plastic wrap and viewed under a MacBeth light simulating a sunny day at high noon. Panelists viewed, scored, and covered a treatment before evaluating the next treatment. Samples viewed by the panel were identical to those used earlier for instrumental analysis (Hunter LabScan).

Statistical Design and Analysis

Statistical analysis of sensory data employed ANOVA for a 1 (panelist) X 3 (treatment) X 10 (replication) factorial arrangement for each of the seven characteristics evaluated (SAS, 1985). Other data was

analyzed using Student's t-test and ANOVA for a 3 (treatment) X 10 (replication) arrangement. Correlation analysis was performed on appropriate variables. Significance was determined at the $p < .05$ level.

RESULTS AND DISCUSSION

Percent Weight Loss

Water-holding capacity (WHC) in meat can be measured indirectly by weight loss. Hams in this study were weighed before and after pumping, prior to and just after freezing (F/S and F/NS hams), and before and after smoking and cooling. Treatment F/S hams showed significantly ($p < 0.01$) more weight loss from both green and pumped weights to ending weight, compared to the other two treatments (Table 2). There were no significant differences between treatments for other percent weight loss intervals calculated, with the exception of freezer loss. Analysis of percent weight loss for both frozen treatments was done using a students t-test, and demonstrated a statistically significant difference between F/S and F/NS hams ($p < 0.05$), with treatment F/S losing more weight. In actual magnitude, however, the difference was not great (0.48% vs 0.35%).

It has been shown that water holding capacity in meat decreases as a result of frozen storage (Hamm, 1986). Studies show that drip loss and/or cooking loss from thawed meats tend to increase as frozen storage time increases (Penny, 1975; Jeremiah, 1980; Hamm, 1986). By far, the greatest percent weight loss for all three

Table 2. ANOVA[1] means,(standard deviations), p-values[2], and least significant differences for physical measurements of quality characteristics.

	Treatment[3]	Mean	(sd)	p-value	LSD
Color					
L-value	F/S	53.58[a]	(2.82)		
	F/NS	51.50[ab]	(1.94)	0.04	2.10
	NF/NS	51.03[b]	(1.99)		
a-value	F/S	11.173	(0.80)		
	F/NS	11.595	(0.76)	0.26	
	NF/NS	11.632	(0.41)		
b-value	F/S	8.896[a]	(0.94)		
	F/NS	7.787[b]	(0.83)	0.03	0.85
	NF/NS	7.990[b]	(1.01)		
Total Moisture (percent)	F/S	69.501[a]	(0.97)		
	F/NS	72.296[b]	(0.66)	0.00	0.69
	NF/NS	72.425[b]	(0.64)		
Shear Value (kg/ 1.27 cm)	F/S	1.996	(0.36)		
	F/NS	2.236	(0.50)	0.28	
	NF/NS	2.340	(0.56)		
Wt.Loss (percent)					
Green-to-end	F/S	6.599[a]	(2.15)		
	F/NS	2.455[b]	(1.73)	0.00	2.50
	NF/NS	0.017[b]	(3.82)		
Pumped-to-end	F/S	15.095[a]	(2.02)		
	F/NS	11.730[b]	(1.75)	0.00	2.07
	NF/NS	9.939[b]	(2.84)		
Freezer	F/S	0.475[a]	(0.137)		
	F/NS	0.348[b]	(0.113)	0.02	
Smokehouse	F/S	16.823	(1.45)		
	F/NS	15.925	(1.67)	0.21	
	NF/NS	17.037	(1.23)		

[a,b]: different superscripts = significant differences

[1] 3 treatments x 10 replications; 30 observations.

[2] alpha = 0.05; student's t-test critical value = 2.3.

[3] treatment F/S: frozen/stored 90 days; treatment F/NS: frozen/not stored; treatment NF/NS: neither frozen nor stored.

treatments occurred during smoking and heat processing (Table 2). Smokehouse facilities used did not allow strict control of relative humidity, and it is possible that excessive water loss during heat processing obscured any significant differences that might have existed between treatments due to freezing and/or frozen storage.

Total Moisture

Loss of water in meats may occur during frozen storage, thawing, or subsequent cooking (Berry, 1988). The nature and degree of moisture loss can be dependent on a variety of factors, including rate of freezing and thawing, freezer temperature, length of storage, type of protective covering applied during frozen storage, and, in the case of hams, smokehouse conditions, including temperature and humidity (Forrest et al., 1975; Jeremiah, 1980; Miller et al., 1985).

In this study, significant ($p < 0.05$) differences in total moisture content were found to exist, with Treatment F/S hams having the lowest percent total moisture (69.5%) compared to both Treatments F/NS and NF/NS (72.3% and 72.4%, respectively). Considering the three treatment regimens, it is possible that the period of frozen storage undergone by F/S hams may have been a critical factor in determining moisture loss, since F/NS hams, though frozen, were not stored, and NF/NS hams

shared neither process. Treatment differences in total moisture were similar to differences in percent weight loss, as might be expected.

Color

As noted, color was measured instrumentally, using a Hunter reflective spectrophotometer (Hunter L,a,b system). Though a-values were not significantly different between treatments ($p > 0.05$), Treatment F/S had the lowest a-value and was, therefore, the least red. This result corresponds with differences in color perceived by sensory panelists (Table 3).

A significant difference did exist ($p < 0.05$) between b-values for Treatment F/S, versus Treatments F/NS and NF/NS. As can be seen in Figure 10, Treatment F/S values were more in the yellow direction along the yellow-blue color dimension, followed by NF/NS and F/NS respectively.

Additionally, significant differences between Treatments F/S and NF/NS were found to exist for Hunter L-values ($p < 0.05$). As Figure 10 indicates, F/S hams were furthest toward white (lighest) along the black-to-white dimension. This finding was also supported by sensory panelists who perceived Treatment F/S as most pale, less red. Janicki et al. (1967) in a study of porcine muscle noted a negative relationship between

Table 3. Treatment means, (standard deviations), p-values[1], and least significant differences from ANOVA[2] for sensory panel data.

	Treatment[3]	Mean[4]	(sd)	P-value	LSD
Typical Ham	F/S	4.74[a]	(1.49)		
	F/NS	4.62[a]	(1.34)	0.03**	0.171
	NF/NS	4.33[b]	(1.28)		
Off-Flavor	F/S	2.37	(1.56)		
	F/NS	2.26	(1.60)	0.71	
	NF/NS	2.23	(1.46)		
Saltiness	F/S	4.85[a]	(1.29)		
	F/NS	4.45[a]	(1.46)	0.00**	0.164
	NF/NS	4.19b	(1.37)		
Sweetness	F/S	2.94	(0.39)		
	F/NS	3.15	(0.42)	0.37	
	NF/NS	3.10	(0.34)		
Juiciness	F/S	4.49	(1.32)		
	F/NS	4.72	(1.33)	0.23	
	NF/NS	4.51	(1.36)		
Firmness	F/S	5.09[a]	(1.05)		
	F/NS	5.19[a]	(1.25)	0.00	0.155
	NF/NS	5.48[b]	(1.18)		
Color	F/S	4.27[a]	(1.26)		
	F/NS	4.61[b]	(1.11)	0.00	0.107
	NF/NS	4.59[b]	(1.10)		

[a,b]: different superscripts = significant differences.
[1] alpha= 0.05
[2] 3 treatment groups x 10 panelists; 10 replications.
[3] treatment F/S: frozen/stored 90 days; treatment F/NS: frozen/not stored; treatment NF/NS: neither frozen nor stored.
[4] 1= no intensity; 9= extreme intensity.
** significant panelist x treatment effects.

water-holding capacity (WHC) and L-values. In the present study, Treatment F/S exhibited the greatest water loss (lowest WHC) and the highest L-values.

Perhaps a more meaningful application of Hunter L,a,b values is the representation of color perception by the attributes of lightness (L), chroma, and hue (Hunter and Harold, 1987), derived as functions of L,a,b values (Table 4). Hue signifies what is commonly called color; chroma refers to the purity, depth, or intensity of the particular hue. Lightness is that range from black (dark) to white (light), with grey as midpoint. Hunter represents these attributes as a three-dimensional color solid, with hue being the angle from the horizontal on the color circle, and chroma, (or saturation) the distance away from grey (the center or origin) of the color circle (Figure 11).

All treatment averages of chroma were similar, 14.0 (+/-) 0.2, with Treatment F/S having the greatest depth or purity of color (furthest from grey). Since Treatment F/S was the lightest (largest L-value) and least red (lowest a-value), its chroma, highest of the three, can be attributed to its higher b-value (Table 4).

Hue is the angle from the horizontal on the color circle (Hunter and Harold, 1987). An angle of 0° falls on a line joining grey, pink, and red, while an angle of 90°

Table 4. Color attributes (Hunter L,a,b)

Hunter L,a,b Values					
Treatment[a]	L[b]	a[c]	b[d]	Chroma[e]	Hue[f]
F/S	53.580	11.173	8.896	14.28	38.53
F/NS	51.501	11.595	7.787	13.97	33.88
NF/NS	51.031	11.632	7.990	14.11	34.49

[a] Treatment F/S: frozen/stored for 90 days; F/NS: frozen/not stored; NF/NS: neither frozen nor stored.

[b] L-Lightness (0=black; 100=white).

[c] a-Red (+100) to Green (-80).

[d] b-Yellow (+70) to Blue (-80).

[e] Chroma= $(a^2+b^2)^{1/2}$ (Hunter and Harold, 1987).

[f] Hue=arctan (a/b) (Hunter and Harold, 1987).

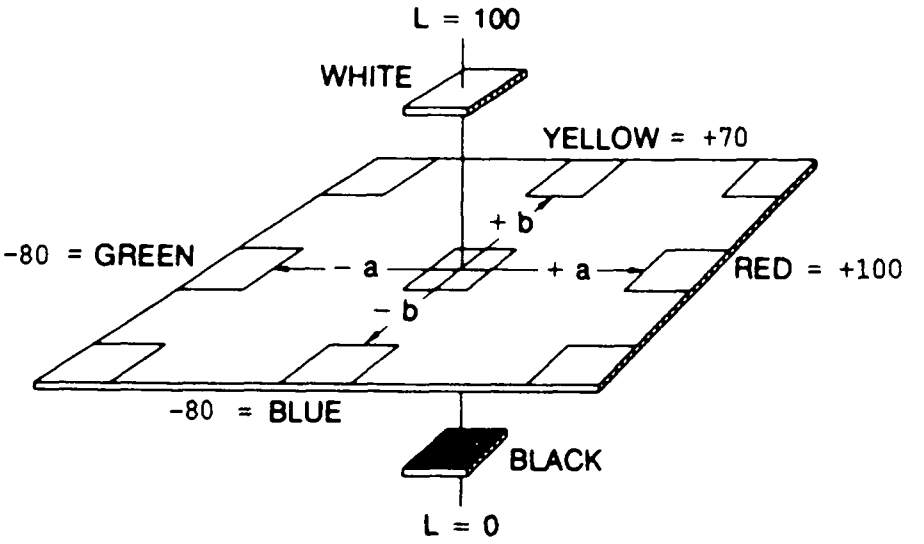

Figure 10[1]
Spatial arrangement of Hunter L,a,b opponent-color coordinate system.

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[1]Hunter and Harold, (1987).

a-value= Red (+100) to Green (-80).

b-value= Yellow (+70) to Blue (-80).

L-value= Lightness (0=Black; 100=white).

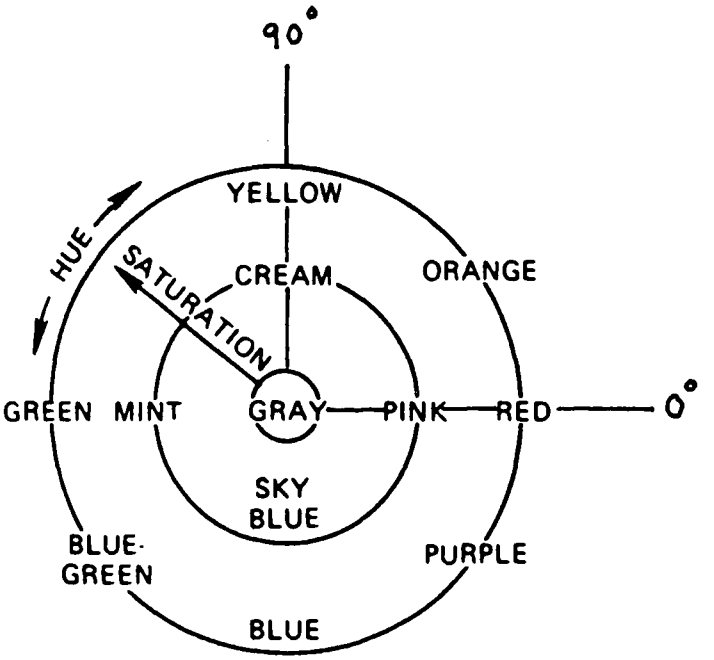

Figure 11[1]
Arrangement of a color circle showing hue[2] and chroma[3] (saturation).

[1] Hunter and Harold,(1987).

[2] Hue= the angle from the horizontal (0°).

[3] Chroma= the distance away from grey (center of circle).

falls on the line joining grey, cream, and yellow (Figure 11). Thus, the average angle (hue) of each treatment is between pink-red and cream yellow. Treatment F/S, with the largest angle (Table 4), is furthest from pink-red, followed by Treatments NF/NS and F/NS respectively. This order corresponds with Hunter a-values which place Treatment F/S furthest from red on the red-green color line, and with sensory perceptions of F/S as least red, paler (pink) than the other treatments. Practically speaking, however, all three treatment averages are within 0.3° and are closer to the pink-red line than the cream-yellow line (that is, closer to 0° than 90°). It is likely all treatments would be considered within a typical color range for ham.

Shear Value

Warner-Bratzler shear values were not significantly different ($p > 0.05$). As can be seen in Table 2, averages and standard deviations for all three treatments were quite similar. Neer and Mandigo (1977) found shear values increased with frozen storage time in a flaked, cured pork product, but differences in tissue integrity may make invalid a comparison of their study with the present one.

TBA Analysis

Some studies have shown that unacceptable flavors in meats increase in direct proportion to TBA values (Zipser *et al.*, 1964; Salih *et al.*, 1987). Statistical analysis of TBA values (Table 5) from this study revealed no significant ($p > 0.05$) differences between treatment TBA values. While it may be that the mean degree of lipid oxidation was, in fact, similar in every treatment, other possibilities should be considered. While comparing extraction and distillation methods of TBA analysis, Witte *et al.* (1970), concluded that the test in either form was of limited value when performed on frozen samples. They suggested that malonaldehyde formed might react during frozen storage with compounds such as alpha amino acids and be rendered unavailable for reaction with TBA.

Recognizing a tendency for malonaldehyde to react with nitrite in cured meats, Zipser and Watts (1962) recommended addition of sulfanilamide prior to distillation during TBA analysis. Ideally, sulfanilamide reacts with residual nitrite, to prevent the reaction of nitrite with malonaldehyde, yielding higher TBA values, and thus a more accurate assessment of lipid oxidation. In light of this recommendation, sulfanilamide was added to samples in the present study prior to distillation.

Table 5. Mean TBA numbers and sensory scores for off-flavor and typical ham flavor.

Treatment[a]		Mean[b] TBA Number	Mean[c] Sensory Scores Off-Flavor	Typical Ham Flavor
(1)	F/S	0.373	2.4	4.7
(2)	F/NS	0.388	2.2	4.6
(3)	NF/NS	0.434	2.2	4.3

[a] Treatment F/S: frozen/stored for 90 days; F/NS: frozen/not stored; treatment NF/NS: neither frozen nor stored.

[b] Average of two determinations for ten hams in each treatment.

[c] Average of ten panelists' scores for ten hams in each treatment.

However, a more recent study by Shahidi *et al.* (1985) determined that the desired effect of sulfanilamide on TBA numbers occurred only when residual nitrite was 100-200 ppm. When nitrite levels were lower (in their study 0-50 ppm), TBA values were lower with addition of sulfanilamide, a result they attributed to a reaction between sulfanilamide and malonaldehyde. Kolodziejska *et al.* (1990) also suggest this reaction is possible. It should be noted, however, that the amount of sulfanilamide used by Shahidi *et al.* (1985) was 2mL, twice the amount recommended by Zipser and Watts (1962) for nitrite levels < 100 ppm. Concentrations of sulfanilamide used the two studies were identical (0.5% in 20% HCl, v/v). The brine in this study was formulated to produce nitrite levels within the USDA maximum, 156 ppm. It was not determined what residual nitrite levels were at the time TBA analysis was done.

In defense of the argument that TBA scores were representative of actual low levels of lipid oxidation, it should be noted that sensory scores for off-flavor averaged 2.4, 2.2, and 2.2 for treatments F/S, F/NS, and NF/NS, respectively. All averages were between the "slight" and "no off-flavor" categories.

The difficulty of accurately determining the extent of lipid oxidation in cured meats by TBA analysis is

pointed out by Kolodziejska *et al.* (1990), particularly in light of an increased reaction rate between nitrite and malonaldehyde under acidic conditions typical of the procedure. While it is possible that TBA values from this study reflect equally low levels of lipid oxidation in all three treatments, it is not possible to be certain. It may be that a method of assessing lipid oxidation by the presence of hexanal, as proposed by Shahidi *et al.*, (1987), would be more useful in subsequent studies.

Sensory Panel

For the characteristic of firmness, Treatment NF/NS was judged most firm, significantly more so ($p < 0.01$) than both Treatment F/S, and Treatment F/NS. The amount of water present in ham may affect the sensory characteristic of firmness. Hams containing phosphates as part of their cure, for example, have increased water-holding capacity and a firmer mechanical textural quality (Rust and Olson, 1973; Price and Schweigert, 1987). As noted earlier, studies have shown the water-holding capacity of pork is reduced due to freezing (Miller, 1985). Treatment NF/NS was distinguished from Treatments F/S and F/NS by its not having been frozen. It has been stated that Treatment NF/NS did have the highest total moisture content. It is possible that the other two treatments lost more water due to the freezing/thawing

process and, thus, were perceived as less firm by sensory panelists. Nevertheless, all three treatments averaged between 5.0 and 5.5, in the "moderately firm" range (Table 3).

With regard to color, panelists judged Treatment F/S to be significantly more pale and less red than either of the other two treatments ($p < 0.01$). Treatment F/S underwent the longest period of time between curing and evaluation. Color stability and uniformity are often maintained by the addition to curing brines of reducing agents such as ascorbate or its isomer, erythorbate (Brown *et al.*, 1974; Forrest *et al.*, 1975; Price and Schweigert, 1987). In light of the fact that no reducing agents were added to the brine in this study, Treatment F/S would be the one most likely to suffer color fading. It is noteworthy, however, that all three treatment averages were within the range of 4.3 - 4.6, more red than pink (Table 3).

Analysis of sensory data revealed significant differences ($p < 0.05$) between treatment groups for four of the seven sensory characteristics evaluated, including firmness, color, saltiness, and typical ham flavor (Table 3). The latter two of these categories, however, exhibited highly significant panelist x treatment effects as well ($p < 0.01$). These effects indicate differences

between panelists in the way they scored one treatment relative to another, and detract from the validity of significant treatment effects (Meilgaard *et al.*, 1987). Panelist interactions in these two areas may indicate a need for more extensive panelist training or better definition of these two sensory characteristics. For this reason, only the first two characteristics (firmness and color) can be considered to have demonstrated significant treatment differences. Other sensory characteristics including sweetness, off-flavor, and juiciness, showed no significant differences between treatments.

Correlation analysis was done for sensory characteristics relative to one another, and for sensory versus physical and chemical parameters deemed appropriate. An r-value of ≥ 0.80 was considered significant, in light of the fact that the number of values used was relatively small (10). Only one correlation exhibited significant r-values (Table 6), relating total weight loss to sensory color perception. For Treatment F/NS total percent weight loss correlated negatively with perceived color. Thus, as the percent weight loss increased, color was perceived as less red, more pale. With respect to overall percent weight loss, the r-value was - 0.82. Both "pale, soft exudative" (PSE) pork and so-called "dark cutting" beef demonstrate the

Table 6. Correlation coefficients used for selected parameters of quality characteristics in ham.

Correlated Parameters	Coeffecient of Correlation	Significance ($r \geq 0.80$)
Sensory Color & L-value		
F/S	-0.27	N.S.
F/NS	-0.31	N.S.
NF/NS	-0.65	N.S.
Sensory Color & a-value		
F/S	+0.43	N.S.
F/NS	+0.29	N.S.
NF/NS	+0.67	N.S.
Sensory Color & b-value		
F/S	-0.31	N.S.
F/NS	-0.11	N.S.
NF/NS	-0.23	N.S.
Firmness & Shear Value		
F/S	+0.45	N.S.
F/NS	+0.38	N.S.
NF/NS	+0.08	N.S.
Juiciness & Total % Wt. Loss		
F/S	-0.30	N.S.
F/NS	+0.15	N.S.
NF/NS	-0.18	N.S.
Off-flavor & TBA		
F/S	+0.02	N.S.
F/NS	+0.69	N.S.
NF/NS	+0.32	N.S.

Table 6 (Continued)

Correlation	Coefficient	Significance
Typical Ham & Total % Wt. Loss		
F/S	-0.38	N.S.
F/NS	-0.41	N.S.
NF/NS	-0.15	N.S.
Off-flavor & Total % Wt. Loss		
F/S	-0.03	N.S.
F/NS	-0.15	N.S.
NF/NS	-0.26	N.S.
Salty-flavor & Total % Wt. Loss		
F/S	+0.03	N.S.
F/NS	-0.42	N.S.
NF/NS	-0.42	N.S.
Sweetness & Total % Wt. Loss		
F/S	+0.15	N.S.
F/NS	-0.47	N.S.
NF/NS	-0.04	N.S.
Juiciness & Total % Wt. Loss		
F/S	-0.15	N.S.
F/NS	-0.51	N.S.
NF/NS	+0.12	N.S.
Firmness & Total % Wt. Loss		
F/S	-0.65	N.S.
F/NS	+0.63	N.S.
NF/NS	-0.23	N.S.
Sensory Color & Total % Wt. Loss		
F/S	+0.62	N.S.
F/NS	-0.82	Sig.
NF/NS	-0.34	N.S.

Treatment F/S: frozen/stored 90 days; F/NS: frozen/not stored; NF/NS: neither frozen nor stored.

effect water content of meat may have on appearance (Price and Schweigert, 1987). It is not clear, however, why only F/NS hams would demonstrate such a relationship between moisture loss (as measured through weight loss) and perceived color.

Ideally, future studies would more closely duplicate actual industry conditions with respect to pumping, equilibration practices, and smokehouse technology. In addition, consumer sensory (acceptance) testing would be useful to better gauge whether differences detected by trained panels are great enough to affect overall acceptance or rejection of ham processed in this manner.

SUMMARY

Freezing brine-cured hams prior to storing, thawing, and heat processing resulted in some differences in quality characteristics compared to hams similarly processed without storage, and hams processed without freezing. Statistically significant differences ($p < .05$) were found in percent weight loss, with Treatment F/S losing significantly more weight overall, and through the freezing process, though freezer losses were small in magnitude. This difference was likewise reflected in total moisture which was significantly less in Treatment F/S. The frozen, stored treatment exhibited significantly higher Hunter LabScan b-values (yellowness) than the other two groups and significantly higher L-values (lightness) than NF/NS hams. Interestingly, a-values (redness) were not significantly different. No significant differences were found in lipid oxidation as assessed by TBA analysis, or in shear values. Sensory panelists found Treatment F/S to be significantly paler than the other treatments, and judged both frozen treatments to be significantly less firm. It should be noted, however, that average sensory scores for color and firmness were all in the median range of the 9-point scale. Panelists did not find treatment differences in

sweetness, or juiciness.

Results do not rule out use of the alternate method of processing hams examined in this study, though some differences in quality characteristics were observed. Further study is needed, however, in order to draw sound conclusions regarding the practicality of freezing hams after cure application.

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APPENDIX

Table 7. Mean weights (standard deviations) of hams (green) by treatment group[1].

Treatment	Mean (lbs)	(Standard Deviation)
F/S	15.46	(1.02)
F/NS	17.78	(0.90)
NF/NS	17.85	(0.90)

[1] ten hams in each group

Table 8. Optical density of distilled dilutions of 1,1,3,3,-tetra-ethoxypropane (TEP) used in derivation of the standard curve.

Concentration of TEP (x 10^{-4})		Optical Density
Run no.1	4	0.389
	2	0.215
	1	0.123
	.5	0.080
Run no. 2	4	0.444
	2	0.229
	1	0.121
	.5	0.084
Run no. 3	4	0.434
	2	0.215
	1	0.142
	.5	0.074
Mean	4	0.422
	2	0.220
	1	0.129
	.5	0.079

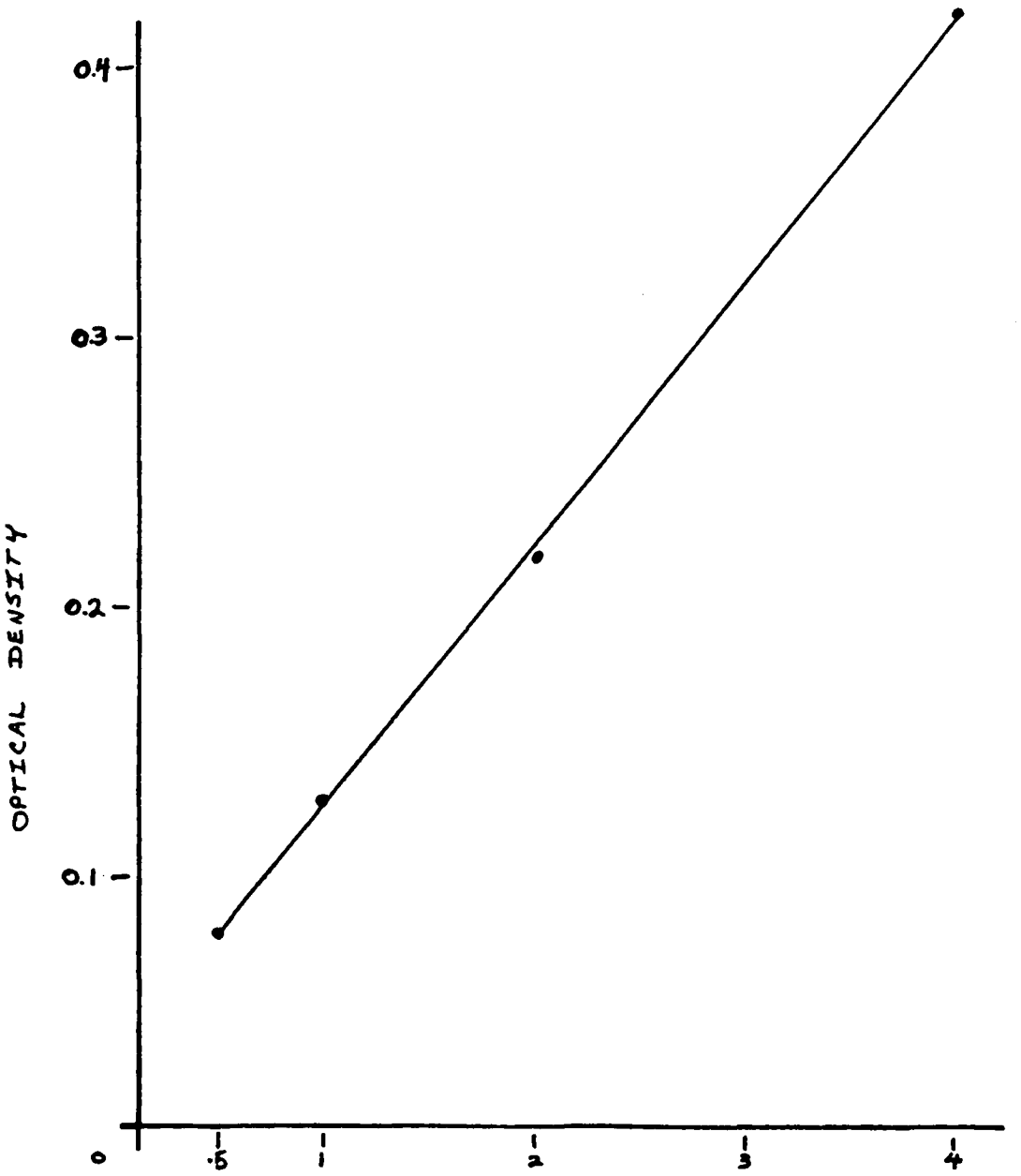

Figure 12.
Optical density of distilled dilutions of a 4 x 10^{-4} solution of 1,1,3,3,-tetra-ethoxypropane.

Table 9. TBA numbers for three ham treatments.

TREATMENT	REPLICATION	TBA	MEAN
F/S	1	0.350	
	2	0.366	
	3	0.567	
	4	0.324	
	5	0.324	
	6	0.304	
	7	0.397	
	8	0.309	
	9	0.391	
	10	0.397	
			0.373
F/NS	1	0.716	
	2	0.299	
	3	0.268	
	4	0.613	
	5	0.258	
	6	0.433	
	7	0.340	
	8	0.381	
	9	0.294	
	10	0.273	
			0.388
NF/NS	1	0.448	
	2	0.438	
	3	0.438	
	4	0.464	
	5	0.541	
	6	0.489	
	7	0.386	
	8	0.397	
	9	0.443	
	10	0.294	
			0.434