DETERMINATION OF FREEZING AND TEMPERING PARAMETERS FOR COOKED-CURED HAM

By

DANIEL SCOTT WEBB

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1996

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1999

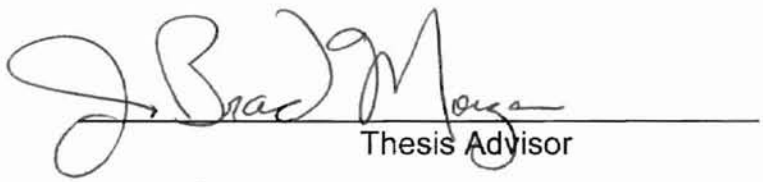
OKLAHOMA STATE UNIVERSITY

DETERMINATION OF FREEZING AND TEMPERING

PARAMETERS FOR

COOKED-CURED HAM

Thesis Approved:



Thesis Advisor

Dean of the Graduate College

ACKNOWLEDGEMENTS

I wish to express my gratitude to everyone who has helped make this an enjoyable and rewarding past two years. First, I want to thank my advisor Dr. Brad Morgan for allowing me the opportunity to continue my education with all of his guidance and expertise. I also want to extend my appreciation for the rest of my committee Dr. Dolezal and Dr. Nanke for all of their experience and help along the way. Dr. Ray, you were a great help and I appreciate all of your advice you had to offer when I was in need.

Linda Guenther, Kris Novotny, and Betty Rothermel we all know how little could be accomplished without your help.

I want to express my gratitude to Dr. Robert Henrickson for all of his help and coordinating the work with the Refrigeration Research and Education Foundation (TRREF). This project would not have been possible without the help of several organizations including TRREF and The National Pork Producers Council (NPPC) for their funding of this project. Angela Steves from TRREF for all of her help and cooperation throughout the study. I also would like to thank Tom Evans of Smithfield Foods for their donation of all of the hams used in the study.

I will never forget all of the wonderful friends I have made throughout my career at Oklahoma State University. The first of which would be my office

mates Dave and Amy I'll never forget all of our very "interesting" discussions had. Dave always remember to cheer for the pokes in College Station or wherever you may be. I also need to thank all of the graduate students who showed me the way in the beginning Brett, Jake and of course Bilynn. Kirby (The Glove), Clint (Wally) and rest of the graduate students thank you for all of your help and I wish all of you the best of luck in your future.

To my parents Gary and Kenna I want to thank you for all of your help and support through the years. I also want to thank my father and mother in law Bob and Dee for their encouragement for Kary as well as myself.

I owe all of this to my loving wife Kary, without you none of this would have been possible without your love, encouragement and support.

GO POKES!!!!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Format of Thesis

This Thesis is presented in the Journal of Muscle Foods style format, as outlined by the Oklahoma State University graduate college style manual. The use of this format allows for independent chapters to be prepared suitable for submission to scientific journals.

CHAPTER I

INTRODUCTION

Traditionally fresh or chilled meat has been proposed as being the most suitable raw material for the manufacture of cooked ham (Martin, 1992). However, the use of frozen meat offers advantages in long-term storage life and allows for fluctuations in production and consumption trends. Refrigerated facilities storing cured-cooked ham are in desperate need for accurate information concerning the proper storage conditions as well as appropriate freezing and thawing parameters which increase product quality an ensure food safety. This is a growing concern due to greater processor emphasis on food safety and product quality.

In 1997, 17.2 billion pounds of pork was harvested producing approximately 3.8 billion pounds of ham in the United States. A very large amount of the bone-in ham products are stored frozen. In 1997 frozen bone-in ham storage ranged from approximately 25 million pounds during December to an astonishing 65 million pounds in July and August leading up to the holiday season. Total hams in frozen storage exceeded 113 million pounds during June and July of 1997.

Extending shelf-life has become increasingly important, as more pork producers are becoming case-ready as well as the increased demands for the pork export market. An additional problem for processors is the greater emphasis being placed on food safety and product quality. Ham is prepared by the processor in four types: 1) Country Cured Ham, 2) Ham with Natural Juices, 3) Ham, Water Added and 4) Ham-Water Product. In order to satisfy the consumer demand for a leaner more tender product, it is estimated that 92% of the total yearly production of ham contains added water. These classification differences have brought about changes permitting the processor to increase the levels of added water and still maintain consumer appeal. Commercial ham producers that are able to manufacture low fat products are doing so by adding increased amounts of water. Increasing the water content by 10 to 45%, causes detrimental quality changes such as increased purge, unstable lean color, increased microbial growth, as well as changes in aroma, texture and flavor (Brewer, 1991; Jeremiah 1990). Producing water-added ham has caused a change in the storage and tempering parameters.

Freezing and frozen storage can produce damaging effects on the structural and chemical properties of muscle foods, which influence the quality attributes of meat products (Miller *et. al.,* 1980). Luyet (1959) demonstrated the damaging effects of ice crystal growth on muscle fiber morphology and reported the structural changes that occur in muscle. Ashby and James (1973) research indicated that faster freezing rates of pork bellies and hams resulted in less product "shrinkage". Moisture loss during initial freezing and subsequent

reabsorbtion of moisture due to condensation during storage and tempering where shown to be the most influential factors in the total shrinkage of the hams during refrigerated storage (Ashby, 1973). Therefore, the objective of this study was to evaluate the effects of various freezing and tempering procedures on partially cooked cured ham quality so recommendations for optimal freezing and tempering criteria can be made to refrigeration storage organizations.

CHAPTER II

REVIEW OF LITERATURE

PORK QUALITY

Meat usage has increased over the past two decades, primarily due to increased poultry and fish consumption; however, during this time pork consumption has remained relatively steady (American Meat Institute, 1992). Health conscious consumers have forced the pork industry to respond by developing new leaner products. This move to a leaner product has not progressed without some perceived and/or realized quality problems. More than 30 years ago, the University of Wisconsin developed pork quality standards to characterize the quality deviations (University of Wisconsin, 1963). Kauffman (1969) described meat quality to include wholesomeness, nutrient content, palatability traits, attractiveness and the capacity of muscle to retain water. The combination of consumer acceptance as well as technological aspects was used to define pork quality (van de Wal *et al.*, 1997).

Fresh meat is characterized as being muscle, which has been chilled, post-slaughter and stored at refrigerated temperatures prior to use. Trends in production and consumption annually create inventory problems, which typically

lead to concerns with the storage of fresh meat. For long term storage, freezing is normally applied (Downet and Beauchene, 1997). However, consumer's perceive frozen meat as being inferior to fresh meat and thus is reduced in price (Jeremiah, 1981). Therefore, frozen meat must be thawed before marketing for retail consumption.

The 1994 National Pork Quality Audit addressed factors influencing pork quality (Cannon *et al.* 1995). Long-term storage, chilling, packaging along with carcass composition, genetics, nutrition, growth promotants, preslaughter handling, immobilization and postmortem handling were noted as factors influencing pork quality. Meisinger and Miller (1997) reported that most of the quality problems the pork industry faces daily are lean color, drip loss, intramuscular fat and palatability (defined as juiciness, tenderness and flavor inconsistencies). Lean color, drip loss (i.e., purge) and palatability can be affected by storage (i.e., freezing). Quality defects result in lost earnings for all sectors of the pork industry. Consequently, the industry must devise the best system for processing, warehouse storage, and distribution of ham and other pork products to achieve the maximum economic return.

When cooked by the consumer, the quality of meat, which has been frozen and thawed, is a result of the entire processing chain from the producer through processing, freezing, storage and thawing to consumer preparation. Freezing and thawing are very important steps in the inventory storage process for high quality pork products.

In the Pork Chain Quality Audit (Cannon *et al.,* 1995), packers reported a 10% incidence of pale, soft, and exudative (PSE) pork and a 4% incidence of dark, firm, and dry (DFD) pork. Processors reported poor water-holding capacity in 20% of their pork products. Retailers ranked variation in color followed by excess purge as their major quality defects. Color as well as purge may be influenced by initial quality (i.e., PSE or DFD) in addition to storage conditions.

Freezing effects were determined for initial pork quality, of comparing PSE and DFD to normal pork (Greer and Murray 1991). Thaw drip loss for PSE pork did not differ from that of normal pork, 109g/kg and 128g/kg, respectively, although DFD was significantly lower 40g/kg than normal or RFN (Red firm and non-exudative) muscle (Greer and Murray, 1991). This research is in contrast to numerous other studies that indicated high drip loss along with a pale unstable color for PSE pork (Wismer-Pederson, 1959; Sayre and Brisket, 1963 Jeremiah and Wilson, 1987). Nonetheless, freezing caused significant increases in drip loss for all quality groups. Research by Warner et al. (1997) showed a decrease in thaw loss of 10.9% for PSE compared to 3.1% for DFD pork and a cook loss of 29.8% to 16.1%, accordingly.

THE FREEZING PROCESS

Freezing has long been recognized as an excellent method for preserving meat. Freezing implies the removal of heat, accompanied by the changing of water to ice. This results in fewer undesirable changes in taste, texture, and nutritive properties than any other method of long term preservation (Judge *et al.*,

1989). Due to variations in freezing and thawing conditions, loss of nutritive value occurs in the drip loss of muscle (Judge *et al.*, 1989). Meat is easily frozen and stored until needed for processing. Although few changes are created in chemical or sensory traits, frozen meat is not as widely accepted by consumers as some other food products. However, the hotel and restaurant sector welcomes the convenience of frozen inventory and the ability to purchase hams when wholesale prices are low (Devine *et al.*, 1996). Other frozen foods are widely accepted by consumers, so why is meat not as well accepted? Devine *et al.* (1996) stated that this lack of acceptance is due to the difficulty to store frozen meat. On the other hand, cooking of frozen meat can be beneficial for reducing microbial populations. Consumers like the idea of purchasing meat that is "fresh"; however, meat is not considered actually "fresh" after being frozen. This may contribute to lack of consumer acceptance of frozen meat. However, consumers often purchase meat and place it in their own freezer for later use.

Problems associated with freezing muscle have significantly decreased since the design and the implication of vacuum packaging. The benefit of vacuum packaging can be seen in that shrinkage for vacuum packaged versus unwrapped bellies decreased from 3.10% to 1.61%, respectively (Cooper, 1970; TRRF, 1966). The primary objective of freezing meat is to maintain as much of the original characteristics of the product as possible for an extended period of time (George, 1997). Recent developments in freezing systems are providing better methods for accomplishing this objective.

THE INFLUENCE FREEZING RATE HAS ON MEAT QUALITY

In recent years a great deal of attention has been focused on freezing foods as rapidly as possible. Rapid freezing promotes the growth of a large number of small ice crystals (George, 1997). However, there is a dilemma between the speed of freezing and the economics of the freezing operation. Production of frozen foods requires an enormous capital investment in all segments of the industry. Processing plants and warehouse storage facilities require special refrigeration for the ability to freeze and store large quantities of product. These requirements are much greater than normal refrigeration temperatures (3°C). When marketing frozen foods at the retail level or selling to food service outlets, these establishments require expensive refrigerated facilities with the capability of reaching frozen temperatures (Jones, 1997).

The official definition of freezing rate as published by the International Institute of Refrigeration in 1971 is: "The ratio between the minimum distance from the surface to the thermal center and the time elapsed between the surface reaching 0°C and the thermal center reaching 5°C colder than the temperature of initial ice formation at the thermal center; where the depth is measured in cm and time is in hr, the freezing rate will be expressed as cm/hr."

Freezing rate and final storage temperature determine the size and location of ice crystals formed during freezing which affect quality parameters such as, exudate, texture and color of the final product (Martino et al., 1998).

There are several parameters, which have a direct influence on the rate and magnitude of freezing time. These parameters include product size, freezing medium temperature, and initial product temperature (Heldman, 1983).

Low temperatures maintain a longer storage life of meat by delaying microbial growth and other enzymatic and chemical reactions that cause spoilage (Urbain and Campbell, 1987). Water in muscle tissue begins to freeze at -1°C; however at -5°C, approximately 80% of the freezable water is frozen. At -30°C approximately 90% of the free water is present in the frozen state (Riedel, 1961; Love, 1966). During freezing two major events occur, the formation of ice crystals (or nucleation) and their subsequent increase in size (crystal growth). The rate of crystal growth following nucleation is determined by three factors: rate of reaction, diffusion rate of water, and the rate of heat removal (George, 1997).

Ashby et al. (1973) found that shrinkage of ham was primarily dependent upon dehydration during initial freezing, reabsorption of available moisture during storage and duration of storage. Ramsbottom (1947) and Peters (1970) showed that storage temperature was the primary factor affecting shrinkage. The lower the storage temperature, the less shrinkage that occur. During frozen storage, the amount of ice will generally remain constant, the number of ice crystals will reduce thus the average size will increase (Blanshard and Franks, 1987; Reid, 1994).

Slow freezing usually decreases the overall food quality as a result of extensive physical damage (Martino et al., 1998). Slow freezing begins in the

extracellular space, thus increasing the concentration of solids in the extracellular fluid. Water is drawn osmotically from the unfrozen cell, which adds to the ice crystals grow (Hamm, 1986). Consequently, slow freezing results in fewer nuclei and larger ice-crystal formation. Conversely, rapid freezing rates result in the increased rate of nucleation and a decrease in the size of the ice-crystals. Grujic et al. (1993) found that slow freezing generated ice crystals formed intercellularly with large diameters. The faster the shift of temperature from 0 to -5°C, the less translocation of water that will occur during freezing (Powrie, 1973). The fastest freezing rates are associated with the least damage (Gruji *et al.*, 1993). A Greater water binding capacity was reported for quick frozen muscle than for the slow frozen muscle (Deatherage and Hamm, 1960; Crivelli, 1972). Damage caused by freezing is due to massive destruction to cell membranes. These effects cause problems during thawing as the ice crystals formed during freezing produce drip (Devine *et al.*, 1996). For this reason early studies by meat researchers focused on the relationship between drip loss and freezing conditions of muscle tissue (Cook *et al.*, 1926; Moran, 1932; Ramsbottom and Koonz, 1939 and 1940). Fast freezing results in small ice crystal growth in both intracellular and extracellular sections of the tissue and very limited translocation of water (Devine *et al.*, 1996). This leads to a reduced amount of drip loss during thawing; therefore, the surface reflects more light making for a more desirable appearing product to the consumer.

The salt concentration is lower in the intercellular space than inside the cells; therefore, the liquid between the muscle fibers has a higher freezing point

than liquid inside the fibers. Slow freezing rates result in crystallization in the intercellular space, which increases the concentration of dissolved solids in the remaining water (Grujic et al., 1993). Frozen/thawed hams had lower salt levels than refrigerated hams from, although both groups had the normal salt levels for cooked meat products (Cambero et al., 1994; Redin et al., 1994; Pena et al., 1998). DeFreitas and co-workers (1997) state that the addition of salt increases water-holding capacity as well as enhancing the flavor. Pena et al., (1998) also reported a significant increase in total protein from 71.9% for refrigerated to 80.7% for hams which had been frozen/thawed, thus a decrease in fat from 16.3 % to 7.5 % accordingly.

FREEZING METHODS

The type of freezing method used is dependent upon the characteristics of the product. Many of the most popular freezing systems can be categorized as, (1) still air, (2) plate freezing, (3) cold air blast, (4) liquid immersion and liquid sprays, and (5) cryogenic freezing (George, 1997).

Still air freezing is the slowest of the systems, because air is the heat transfer medium (Judge *et al.*, 1989). This is the principle that home freezer units operate on. Long freezing times are required to reduce the temperature of the thermal center of the product to the desired frozen storage temperature, which commonly ranges from –13°C to -10°C.

The most common method used in commercial freezing of meat products is air blast freezing in rooms or tunnels equipped with fans to circulate air. As in

still air freezing, air is the medium used for heat transfer in blast freezing. In contrast, the rate of freezing is accelerated because of its rapid airflow (Judge *et al.*, 1989). Temperatures range from -10°C to -40°C in blast freezers. Proper spacing of the product on pallets or stacked shelves is needed to ensure good air circulation. Samples which are blast frozen have lower drip loss percentage when compared to plate frozen samples (Anon and Calvero, 1980; Ziauddin et al., 1993).

Another relatively slow method of freezing meat is plate freezing. This method uses a metal plate cooled by a mechanical refrigeration system. The plate is used as the heat transfer medium and is placed in direct contact with the food (Judge *et al.*, 1989). Plate freezing is more suited to thin pieces such as steaks, chops and patties.

An alternate form of contact freezing is liquid immersion, where products are transferred through an immersion tank. Liquids used to fill the immersion tank must be nontoxic, relatively inexpensive, and have a low viscosity (Judge *et al.*, 1989). Sodium chloride, glycerol and salt-sugar-alcohol solutions are widely used. Modern systems are able to enclose the product in a flexible membrane, to prevent direct contact of the product with the liquid (George, 1997).

The fastest form of freezing is by the use of liquefied (cryogenic) gases such as nitrogen or carbon dioxide as the refrigerant. Rapid freezing of the product surface minimizes dehydration losses that are associated with air blast freezing (George, 1997). However, the major disadvantage is the cost of the system and the high cost of the gases. Cryogenic freezing which may produce a

more superior quality product than slower freezing methods may cause problems associated with physical cracking of the product (Kalichevsky et al., 1995). Hams are not recommended for this method of freezing because of cracking or shattering that occurs with products that have large surface areas. Therefore, relatively small sized products such as patties, meatballs, or sliced meats are recommended for cryogenic freezing.

Ashby and James (1974) research showed the effects of freezing methods on shrinkage of hams of 1.22, 1.09 and .79 percent for still air, forced air and blast freezing, respectively.

INFLUENCE OF FROZEN STORAGE ON PORK QUALITY

It was reported as early as 1908 that frozen storage of meat was an acceptable method of preservation (Richardson and Scherubal, 1908). Holding hams in frozen storage is a common practice in the United States today. Frozen storage aids in the balances of pork supplies during periods of low and high production and consumption. Fresh pork ham muscles are particularly suited for frozen storage because they become more porous upon thawing and are more receptive to curing solutions (American Meat Institute Foundation, 1960).

Once a product enters frozen storage chemical and physical changes do not cease, but continue at a greatly reduced rate than at ambient temperatures (Reid, 1990). In many cases, there is an acceleration in the rate of chemical change at temperatures near but below the freezing point (Fennema, 1975). There have been numerous studies on the relationship of freezing and thawing

pork quality. Freezing and thawing has only marginal effects on pork color (Nilsson, 1969; Nocito et al., 1973; Jeremiah, 1980) and palatability traits (Berry et al., 1971; Kemp et al., 1976; Jeremiah 1980) except during extend periods of frozen storage, which may cause rancidity problems (Enser, 1974). If frozen rapidly, the process of freezing has little effect on meat quality after cooking (Urbain, 1987). However, frozen storage may result in odor and flavor acceptability problems such as off flavors. The method of freezing in addition to packaging and storage temperature determines length of acceptable storage (Jeremiah, 1980).

In 1997, during the peak month of August, there were over 64 million pounds of bone-in ham and 49 million pounds of boneless ham commercially frozen in the United States (USDA, 1997). With these large quantities of frozen product, even small amounts of shrinkage due to dehydration during freezing and storage will result in large economic losses.

Judge et al. (1989) provided a maximum recommendation for the length of storage of an individual meat item at various temperatures, for the preservation of optimum quality. The recommended lengths for fresh pork are 2, 4, 6, and 8 months at temperatures of -12°C, -18°C, -24°C, and –30°C, respectively. These storage lengths were decreased to 1.5, 2.5, 4, and 6 months corresponding to the same temperatures (Judge et al., 1989). In comparison, beef and lamb have recommended storage lengths of 4, 6, 12 and 12 months at the above mentioned temperatures. The variation of time in which meat from the different species can maintain an acceptable quality during frozen storage is dependent on the

concentration of saturated fatty acids. Because pork, fish and poultry have a higher concentration of unsaturated fatty acids than beef and lamb, they are more susceptible to oxidative changes (Judge et al., 1989). The reduction flavor and odor acceptability is primarily due to oxidation of these lipids. The explanation for the decreased storage time from fresh to cured pork is due to the addition of salts, which is a prooxidant accelerates the development of rancidity in meats (Judge et al., 1989).

EFFECT OF THE THAWING PROCESS ON PORK QUALITY

Thawing meat is probably a more detrimental source of damage to meat quality than freezing. Several factors are responsible for the damaging effects that occur during thawing. As temperature rises near the thawing point, considerable opportunity for chemical reactions and recrystallization are present (Fennema, 1973).

Thawing is not simply the reverse of freezing. In fact, thawing is the difference in heat capacity, thermal conductivity, and thermal diffusion of water compared to ice (Reid, 1997). Judge *et al.* (1989) stated that when temperature conditions are the same, thawing would occur more slowly than freezing.

This is effectively demonstrated by an experiment conducted in which cans were filled with starch gel and were immersed in mediums having temperatures of -80°C and +80°C (Fennema, 1973). Following equilibration, the cans were interchanged between the two mediums and the rate of the temperature change was measured. It was concluded that cans which were

initially -80°C to reach +80°C than for the cans submerged in the +80°C to reach -80°C. However, during the thawing process, the gel reached a temperature of -6°C and remained there for a long period of time during the thawing procedure. As previously discussed, this temperature is in the range where problems occur in ham product quality, therefore, thawing protocols must be designed to minimize the time spent by the product in this intermediate temperature range because of the significant detriment to quality.

EFFECT OF THAWING RATE ON PORK MUSCLE QULAITY TRAITS

When meat is thawed, quality changes are expressed that were initiated during freezing. The thawing process should be designed to minimize drip loss, microbial growth and further deterioration of the product. As stated earlier, thawing is a much slower process than freezing of meat. There are two major reasons for these differences. First, the thermal conductivity of thawed meat is about one third that of frozen meat. Therefore, the heat passing through the thawed outer portion of the meat to the frozen center portion is conveyed more slowly than from the opposite process which is freezing. Second, it is not practical to use a very rapid force for thawing, as this will induce significant cellular structural changes (Devine *et al.*, 1996).

Large amounts of frozen meat are utilized in the meat industry and substantial time is required for thawing. There is often a large decrease in product quality following thawing. Few acceptable rapid methods are available for thawing meat. Most meat is thawed in a cooler, which allows extended time

for microbial and sensory attributes to be negatively affected (Zhao et al., 1998). Therefore, techniques need to be developed for thawing pork to minimize drip loss, microbial growth and further deterioration.

The higher the thawing temperature, the faster the meat will pass through temperatures between -2°C and 10°C and remain at high temperatures where maximum deterioration of meat proteins occurs (Devine *et al.*, 1996). In addition specific locations of the product may reach temperatures at which microbial spoilage will occur more rapidly than other locations.

Contrary to freezing techniques, thawing rapidly produces significant changes to tissue structure (Devine et al., 1996). The same liquid immersion procedures used for freezing are sometimes used in commercial meat thawing process. There are several other thawing technologies possible such as vacuum, dielectric, electrical resistance, microwave, infrared thawing, and hydrostatic pressure, (Devine et al., 1996).

One of the quality obstacles the industry has to overcome is the amount of exudate, which occurs during thawing of fresh pork muscle and cured ham products. The definition of drip loss, as defined by Hamm (1986), is "The formation of exudate from meat or meat systems without the application of external forces." Drip loss, also known as purge, is also defined as simply the amount of fluid that collects in packages. The exudate contains a loss of nutrients such as proteins, amino acids, lactic acid, purines, B complex vitamins, and various salts. As discussed earlier, freezing and thawing protocols can have a significant effect on drip loss. In addition, processing plays an important role in

the amount of drip that occurs in meat products during processing, storage and cooking. Therefore, larger pieces of meat are more suited for freezing than smaller pieces (e.g., hams compared to chops). One very consistent observation in past studies is the dramatic increase in drip loss associated with various freeze thaw relationships (Penny, 1974; Jalong'O et al., 1987). Drip loss of frozen pork increased as frozen storage increased from 13 and 39 weeks from 2.6 to 7.4 percent, respectively (Brewer and Harbers, 1991).

Cooking loss is defined by Hamm (1986) as the "release of fluid after heating of meat or meat systems either with or without application of external forces (e.g., centrifugation or pressing)." This is often used as a measure of water holding capacity. Cooking loss was significantly ($P< 0.05$) higher for ham steaks that were frozen compared to fresh ham steaks throughout all storage times (Jeremiah, 1980). Cooking losses from beef were also shown to increase with extended times of frozen storage (Smith et al., 1969; Tuma, 1971). In contrast, other studies such as Campbell and Mandigo (1978) have detected no significant differences in cooking loss among frozen storage times ranging from 0 to 6 weeks. These undetectable differences may be attributed to the fact that this study utilized on pork patties rather than whole muscle products.

Consumers have always considered lean color a very important characteristic in the assessment of pork quality. The color and the stability of color are important to retailers as well as consumers (Hoving-Bolink et al., 1998). Problems with color stability have been reported in frozen meats (Bernholdt, 1971). The amount and chemical state of the pigment myoglobin affect meat

color, which after oxidation results in an unattractive color (Faustman and Cassens, 1991).

In a study by Jeremiah (1981), it was reported that color scores were significantly darker for ham steaks stored for 196 days than for their counterparts stored for 84 d. These results agree with previous reports (Skenderovic and Rankov, 1976; Smith and Capenter, 1977) that pork and other meats discolor during frozen storage, causing a decrease in redness hence a more undesirable lean color (Dhillon and Maurer, 1975).

In a study by Hoving-Bolink (1998), freezing/thawing procedures had a negative effect on lean color stability even with the use of supplemental vitamin E to the growing animal diets. Vitamin E supplemented pork longissimus lumborum muscle had decreased L* and a* values. Taylor (1974) reported that protection against moisture loss during frozen storage could help maintain the red color of the meat.

EFFECTS OF FREEZE/THAW MICROBIAL CHARACTERISTICS AND PROXIMATE ANALYSIS

The microbiology of meat is often investigated in order to determine safety and ability to maintain quality. Temperature is the one of most controllable environmental and important factors influencing the growth of microorganisms. The lower the temperature, the lower the rate of microbial activity that will occur. Freezing has advantages over chilling of fresh meat in that it allows for longer storage periods by halting microbial growth and reducing microbial numbers.

However, a few microbial enzymes remain active causing spoilage (Rosset, 1982). Ingram (1974) explains that the storage life of frozen pork is limited to rancidity caused by microbial lipolysis.

The thawing process is more detrimental to microorganisms than freezing. Due to the slower thawing process, microbes are exposed for a longer period of time to damaging temperatures. Although, according to Ingram and Mackey (1976), thawing rate has little effect on microbes except when comparing ultra-rapid thawing to slow thawing. Jay (1997) states that faster thaw rates support a larger number of bacteria that will survive.

Past research has reported reduced bacterial populations due to various freeze/thaw treatments (Nassos et al., 1988). Freezing of muscle extends the lag phase before the start of bacterial growth (Rey et al., 1972; Lowry and Gill, 1985), as well as, reducing growth rate of microorganisms (Sulzbacher, 1952).

Poor freezing/thawing conditions result in increased drip loss and a decrease in water holding capacity (Offer, 1989). This water loss causes an increased loss of nutrients, such as vitamins and proteins, thus a decrease in the economic value of the product (Hamm, 1986).

CHAPTER III

DETERMINATION OF FREEZING AND THAWING PARAMETERS FOR COOKED-CURED HAM

ABSTRACT

The objectives of this research was to evaluate the effect of refrigerated and frozen storage conditions on the quality of cured, cooked, bone-in hams and to determine the optimal freezing and thawing conditions for this product. Water added hams (n=242) were assigned to one of seven freeze/thaw treatment combinations. Treatments included a control (-2°C) as well as two initial freezing groups (Fast: -34°C, Slow: -18°C) in combination with three thaw procedures. Hams in the two freezing groups were then stratified among three thaw treatments; single stage (3°C), dual stage (-8°C for 2 wks; -2°C until internal temperature reached -2°C) or a triple stage thaw (-12°C for 2 wks; -6°C for 2 wks; -2°C until internal temperature reached -2°C). In summary, hams which were fast frozen and thawed using either a two or three-stage procedure had the least ($P< 0.05$) purge loss compared to either slow frozen hams or samples that were thawed in a single stage thaw. Moisture loss during cooking was the highest ($P< 0.05$) for the hams which were slow frozen and thawed using a

single stage thaw (40.50% loss), compared to hams that were slow frozen using a three stage thaw (32.00%). Freezing or thawing had no effect (P> 0.05) on proximate analysis or salt concentration. No PSE pork lean characteristics were observed visually in any hams. The single stage thaw procedure resulted in ham cut lean surfaces with higher (P<0.05) b* values indicating a more yellow or more pale lean color than hams subjected to the dual or triple stage thaw procedures. Microbial plate counts were similar for all of the freeze/thaw procedures. Therefore, in order to maintain acceptable quality hams rapid freezing in combination with dual or triple stage thaw procedures was the most successful in reducing purge, cook and total water loss.

Key Words: Freezing, Thawing, Purge, Pork

INTRODUCTION

Recent record increases in pork production in combination with relatively stable pork consumption have lead to an enormous decline in pork prices. From October 1997 to October 1998 U.S. farm hog prices have declined 47.8% and wholesale prices dropped 20.8% compared to a minor 2% drop in retail price across the country (Wisconsin Farm Bureau, 1998). Consequently there is an abundance of pork supply throughout the industry. Therefore, there is a tremendous need for an acceptable method of long term preservation of pork products.

Traditionally, meat is kept chilled or fresh (2 to 4°C); however, the use of fresh meat imposes serious limitations to the industry and consumers due to its limited storage life. Freezing has long been recognized as an acceptable method for long term preservation of meat and allows for improved control in production levels. The merchandising of pork cuts previously frozen and thawed could provide flexibility in pork production to meet the high and low levels of consumption. However, quality problems associated with freezing/thawing must be determined in order to optimize retail acceptability, palatability, and overall consumer acceptance (Jeremiah, 1981).

Pork production in 1998 (.76 billion kg) was up 14% compared to 1997 production. This figure was 3% above the pork producers record high previously set in 1994 (USDA, 1998). In November 1998 the USDA reported over 75 million pounds of bone-in ham in cold storage.

Freezing procedures, frozen storage conditions and thawing have the potential for significantly influencing the quality of meat depending on the methods used (Miller et al., 1980). Weight loss which occurs during freezing and thawing is a major concern to product owners (Strange, 1987). With these large quantities of pork in frozen storage even small amounts of shrinkage from dehydration during freezing and frozen storage results in larger significant economic losses. Ashby and James (1974) found that ham shrinkage was dependent on dehydration during initial freezing and reabsorption of available moisture during storage and thawing.

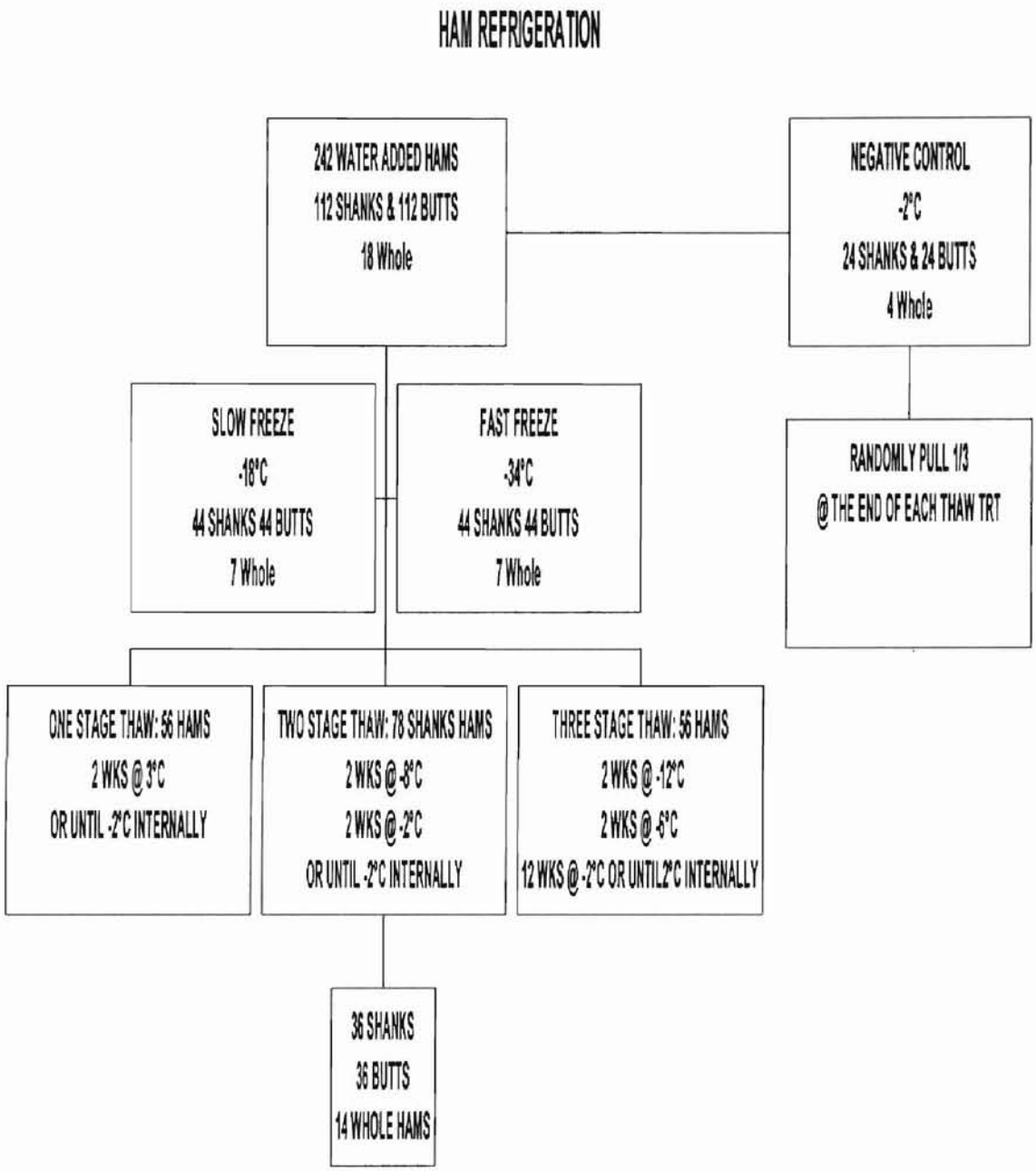
There are several problems with the current freezing thawing methods such as improper storage temperatures, long warehouse storage periods, and improper thawing systems (Jeremiah, 1990). The industry objective of this investigation is to determine the best system for freezing/thawing pork cured products stored in warehouse freezing systems.

MATERIALS AND METHODS

SAMPLE COLLECTION

Data used for these analyses were obtained from 242 cured and smoked hams (18 whole hams, 112 shank and 112 butt portions), were supplied by Gwaltney of Smithfield located in Smithfield, Virginia. Hams were placed in a 3°C cooler and allowed to equilibrate for 48 h. Baseline (BL) data were collected and the samples were divided into two freeze treatments fast (-34°C) or slow (-18°C). Freeze and thaw procedures and design are described in Figure 1. Hams were then allocated into one of eight groups, baseline (BL), negative control (C), fast freeze, one stage thaw (F1), slow freeze, one stage thaw (S1), fast freeze, two stage thaw (F2), slow freeze, two stage thaw (S2), fast freeze, three stage thaw (F3), and slow freeze, three stage thaw (S3) for analysis of the data. In the single stage thaw procedure hams were thawed in a 3°C cooler until the internal temperature reached -2°C. The dual stage thaw procedure

Figure 1. General Project Design



consisted of placing 78 hams at -8°C for two wks and then moved to a -2°C cooler until the internal core temperature reached -2°C. 56 hams were assigned to the triple stage thaw procedure were placed in a -12°C freezer for two wks, then moved to a -8°C freezer for two wks and were ultimately moved to a -2°C cooler until internal temperature reached -2°C. Hams, which were never frozen, were stored in a -2°C cooler to serve as negative controls. One third of the control hams were removed for analysis of purge loss, cook loss, proximate analysis, color measurements, total plate counts and salt concentration at the end of each thaw period.

Purge Loss. After thawing, purge loss was determined by weighing each individual ham (sample + purge), and initial weight (g) was recorded. The sample was then removed from the bag, and the bag was allowed to air dry and then weighed. The sample and the bag were weighed again (final weight, g). Purge was then calculated as a percentage of total weight by the following formula:

$$\frac{(\text{wt of sample + bag + purge} - \text{wt of bag})}{\text{wt of sample + bag} - \text{wt of bag}} \times 100$$

Total Microbial Plate Count. After quantification of purge accumulation, total plate counts (TPC) were determined by aseptically removing a purge sample from each ham. Duplicate samples were serially diluted with sterile 0.1% peptone water and spread plated on a Petrifilm® plate. Inoculated plates were

incubated for 24 h at 37°C. Colonies were then counted and recorded as colony forming units (CFU/ml).

Color Analysis. Baseline and post-storage ham semimembranosus muscle color was determined by using a Minolta® Colormetric device (model CR-200b, Ramsey, NJ). The method used was the determination of L (lightness), a* (redness), and b* (yellowness).

Cook-Loss Determination. Water cook loss was determined by placing a 5g sample of ham semimembranosus muscle into a centrifuge tube and then placed into a boiling water bath for 20 min. Following boiling, the samples were allowed to cool to 21°C, centrifuged and all liquid was discarded. The remaining sample portion was blotted dry between two sheets of filter paper, centrifuged tube was also dried, and then the sample was placed back into the original centrifuge tube and reweighed. Water loss was reported as the percentage of expressible moisture loss resulting from cooking and was calculated as (%purge loss + %cook loss)/ sample weight.

Salt Determination. A sub-sample portion of ham semimembranosus muscle was frozen liquid nitrogen and pulverized. After pulverizing, a 5g sample was processed and salt concentration was determined using an electrode attached to a microprocessor ionizer. Salt was determined according to the Carpentier Volhard method (AOAC, 1990).

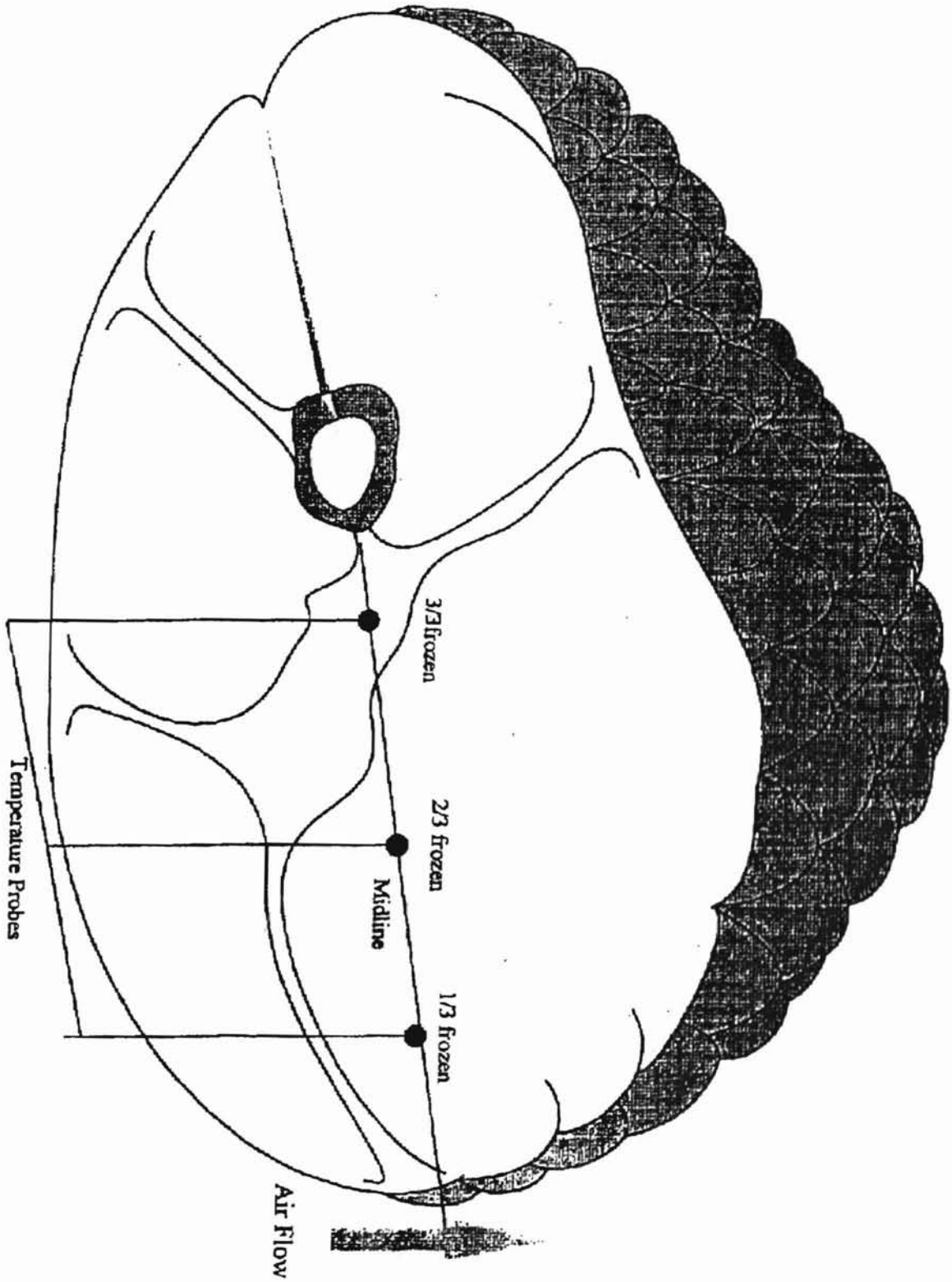
Proximate Analysis. Similar to salt concentration, proximate analysis of hams was determined to aid in characterizing the sample population. Proximate analyses for moisture; lipid and protein were performed in duplicate according to procedures outlined by AOAC (1990). Each sample was frozen individually in liquid nitrogen and powdered in a Waring® Commercial Blender. Three grams of the powdered sample were placed in glass thimbles, dried at 100°C for 24 h, dried for 1 h and reweighed for moisture determination. Following moisture determination, samples were placed in a soxhlet for 24 h for ether extraction of lipids followed by drying for no more than 24 h. Each sample was then dried and re-weighed to determine the lipid content. Protein content was determined and recorded from a separate .5 g pulverized sample using a LECO Nitrogen Determinator Model FP-428, (St. Joseph, MI.).

Temperature Recordings. The internal temperatures (freezing decline and thawing incline) were monitored and recorded using copper constantan thermocouples and a OMGEA (OM-5000) recording chart thermometer. The thermocouples were placed in three locations along the midline of the ham (See Figure 2). Probe depth was placed in the center of the ham relative to probe location. Temperatures were recorded every 30 min to collect accurate freezing and thawing rates. A shank as well as a butt portion of the ham was monitored in each group.

Pale, Soft, Exudative Pork (PSE). Three-trained panelist evaluated each product for color, texture and exudation using the NPPC Pork Quality Standards (1994). This was conducted during processing after each freeze/thaw procedure was completed. Evaluation for the incidence of PSE was conducted to note any interactive effect of pork muscle quality and freezing.

Air Flow. Airflow over the cartoned product as well as the air cell volume were measured. A Velometer Jr. D117 (OMEGA, Stamford, CT) was used to measure the air flow velocity directly over the product and throughout the pallet. A baffling system was created to distribute the air to all boxes within the pallet. The fast air cell volume was measured at the point at which the air exits the fan-cooling unit. Airflow rates met the recommended rates of between 400 and 700 ft^3/min. The average air flow rate was 497 ft^3/min.

Figure 2 Cross section example of probe placement for thermal conductivity test in cured hams



Air Temperature. Air temperature was monitored during the freezing and thawing process to ensure proper conditions were maintained. Temperatures were monitored using data logging devices (OMEGA Dataloggers (RD-temp), Stamford, CT) that were attached to individual cartons of the palletized products. This allowed for detection of any problems that could have occurred during frozen storage.

Statistical Analysis. All data was analyzed using models that contained the fixed effects of freeze and thaw treatments. The general linear model procedure of SAS (1990) was used in the analysis of all data. These means were compared using least squares means analysis. The Plot procedure of SAS (1990) was used for the analysis of all temperature recordings to determine rate of change in temperature.

RESULTS AND DISCUSSION

Temperature. Each freeze treatment group, fast (-34°C) and slow (-18°C), reached the freezing point (-2°C) in the geometric center of the ham within five h of being placed in the freezer. Slow frozen hams reached their final internal temperature of -2°C by 60 h compared to fast frozen hams which reached their final temperature of –15.5°C after 78 h and remained relatively constant for the remaining time in frozen storage (Figure 5). Temperature decline for each probe

location followed the order from higher for the outside, to the center (Figures 6 and 7.).

Initial temperature increased during thawing were more rapid for the fast frozen hams (Figures 8-10). Fast and slow frozen hams were similar in their thawing patterns after each had reached approximately -10°C (Figures 8-10). Figures 11 and 12 show each step for fast and slow frozen hams. As expected single stage frozen hams were thawed much faster than the dual and triple stage treatments. As depicted in Figures 11 and 12, the second stage of thawing began at 140 h and the third step in the triple stage thaw began at 280 h.

Purge Loss. One of the obstacles the industry has to overcome is the amount of exudate, which occurs during the freezing/thawing process. The results of the present study have shown that purge was significantly higher ($P < 0.05$) for slow (-18°C) frozen hams (Tables 1). The use of a two or three stage thawing procedure lowered purge loss ($P<0.05$) when compared to one stage thawing (Table 2). Control hams had lower percent purge than slow frozen/thawed hams. This supports past observations that show an increase in drip loss associated with freezing and thawing (Penny, 1974; Jalong'O et al., 1987). Comparing all freeze/thaw combinations the use of a fast freeze (-34°C) along with a two stage thaw had a lower ($P < 0.05$) percent purge loss than a one stage thaw or a two stage thaw with a slow freeze (-18°C). However, there was no difference ($P < 0.05$) in a two vs. three stage thaw. Slow freezing usually decreases the overall food quality as a result of extensive physical damage

(Martino et al., 1998). This is largely due to the larger crystal size of slow freezing and rapid freezing promotes the growth of a large number of small ice crystals (George, 1997).

Cook Loss. Least squares means and standard deviations for all freeze and thaw treatments as well as each combination are reported in Tables 4 to 6. Control hams if stored for the single stage thaw period had a lower ($P < 0.05$) cook loss percentage. This agrees with studies that indicate cooking loss increases with extended frozen storage (Smith et al., 1969; Tuma, 1971). One stage thawing procedure had the highest ($P < 0.05$) cook loss regardless of freeze treatment (Table 6). Fast freezing was beneficial along with two stage thawing at reducing ($P < 0.05$) cook loss (Table 6). Cook loss is often used as a measure of water holding capacity.

Total Water Loss. Means for total water loss for freeze and thaw treatments are shown in Figures 3 and 4. As expected, cook loss and water total loss was lower for controls than for fast freeze or slow freeze treatments. One stage thaw was higher ($P < 0.05$) than either the two or three stage thaw.

Color Measurements. Least squares means and standard errors for L, a*, and b* values are listed on Tables 19 to 21. Freeze treatment showed no differences ($P < 0.05$) in color. There was a significant ($P < 0.05$) reduction in b* values of 7.04, 5.94, and 4.65 for each thaw treatment one, two, and three stage

respectively. Three stage thaw for each freeze treatment exhibited a darker color or lower b* value ($P < 0.05$). This may be due to the longer time in frozen storage due to increased time to thaw. These results agree with past studies that report that pork and other meats discolor during frozen storage, causing a darker lean and more undesirable color (Skenderovic and Rankov, 1976; Smith and Carpenter, 1977; Dhillon and Maurer, 1975).

Proximate Analysis. Significant differences were noted in Tables 10-18 among freeze/thaw treatments for all proximate analysis least squares means with the chemical composition of the ham samples. Mean salt levels ranged from 2.78% for control hams to 3.34% for hams that were slow frozen and thawed using a single stage thaw. There were no difference ($P<.05$) in salt levels among freeze treatments (Tables 7 to 9). However, 1 stage thaw showed significantly ($P < 0.05$) higher salt levels than either a 2 or 3 stage thaw. There was no explanation of the random levels between groups.

Least squares mean protein levels for all groups of hams were 16.15%. Moisture percentage levels as determined by analysis were (73.37% ±6.3) with no differences between treatment groups. The lipid percentages were not significantly different between freeze or thaw treatments. Fresh hams had numerically higher means for lipid percent, although there were no significant differences.

IMPLICATIONS

To produce high-quality frozen pork products that will receive widespread consumer acceptance cooked-cured hams should be frozen in a fast (-34°C) manner in combination with a 2 or 3 stage tempering procedure. Fast freezing has shown to be the most effective at reducing purge, cook loss and overall water loss. Single stage thaw resulted in increased purge, cook loss and higher b* values. Limited differences were noticed between double and triple stage thawing treatments. The combination of these treatments allows producers the flexibility needed to control a quality inventory throughout the year.

Table 1. Least squares means and standard errors for purge loss of cured hams stratified by freeze treatment[1]

Freeze Rate	Mean	SE
Slow (-18°C)	3.12	0.09
Blast (-34°C)	2.76	0.09
Control	2.47	0.13

[1] Purge loss is expressed as percentage of total weight

Table 2. Least squares means and standard errors for purge loss of cured hams stratified by each thaw treatment[1]

Procedure	Mean	SE
1 Stage	3.41	0.15
2 Stage	2.55	0.07
3 Stage	2.39	0.09

[1] Purge loss is expressed as percentage of total weight

Table 3. Least squares means and standard errors for purge loss of cured hams stratified by freeze/thaw protocols[1]

Protocol	Mean	SE
Slow freeze/ 1 stage thaw	4.21[a]	0.20
Blast freeze/ 1 stage thaw	3.70[a]	0.20
Slow freeze/ 2 stage thaw	2.71[c]	0.10
Blast freeze/ 2 stage thaw	2.38[b]	0.11
Slow freeze/ 3 stage thaw	2.42[bc]	0.15
Blast freeze/ 3 stage thaw	2.21[b]	0.15
Control	2.47[bc]	0.13

[1] Purge loss is expressed as percentage of total weight
[a, b, c] Within a column, means lacking a common superscript differ ($P<0.05$)

Table 4. Least squares means and standard errors for cook loss of cured hams stratified by freeze treatment[1]

Freeze Rate	Mean	SE
Slow (-18°C)	36.19	0.80
Blast (-34°C)	36.05	0.82
Control	34.76	1.20

[1] Cook loss is expressed as percentage of total weight

Table 5. Least squares means and standard errors for cook loss of cured hams stratified by thaw treatment[1]

Procedure	Mean	SE
1 Stage	36.92	1.35
2 Stage	35.05	0.60
3 Stage	35.03	0.76

[1] Cook loss is expressed as percentage of total weight

Table 6. Least squares means and standard errors for cook loss of cured hams stratified by freeze/thaw protocol[1]

Protocol	Mean	SE
Slow freeze/ 1 stage Thaw	40.50[a]	1.81
Blast freeze/ 1 stage Thaw	38.50[a b]	1.81
Slow freeze/ 2 stage Thaw	36.06[b]	0.89
Blast freeze/ 2 stage Thaw	33.32[c]	0.95
Slow freeze/ 3 stage Thaw	32.00[d]	1.31
Blast freeze/ 3 stage Thaw	36.33[ab]	1.37
Control	34.76 [bc]	1.20

[1] Cook loss is expressed as percentage of total weight

[a, b, c, d] Means within the same column followed by a common superscript do not differ ($P<0.05$)

Figure 3. Effect of thaw treatment on total water loss (%purge + %cook loss)/ sample

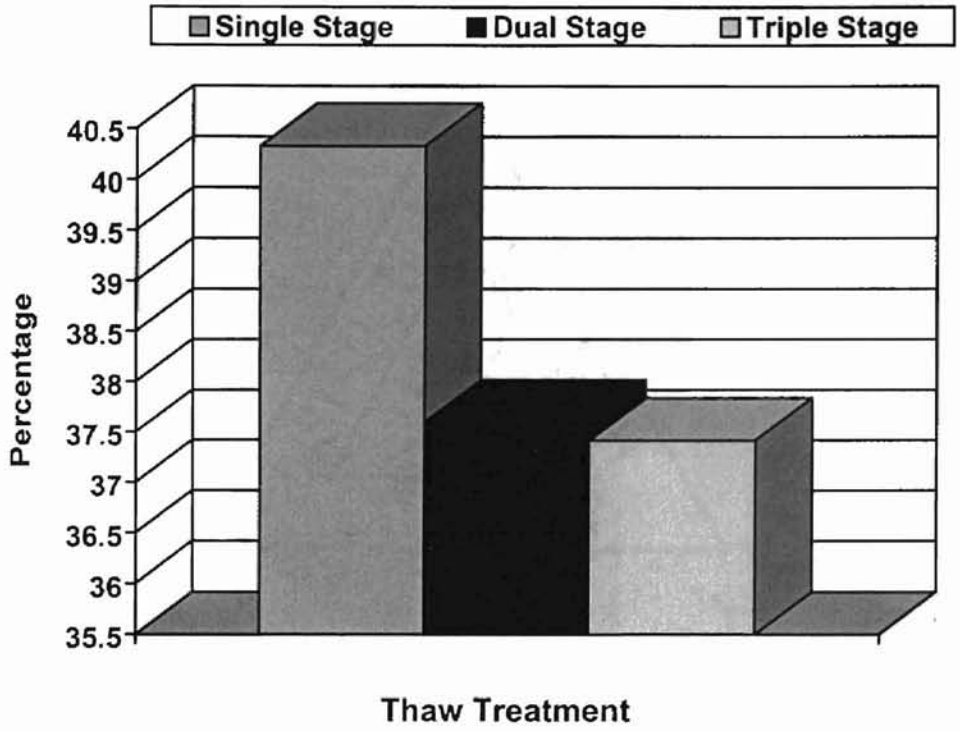


Figure 4. Effect of freeze treatment on total water loss (%purge + %cook loss)/ sample wt, %

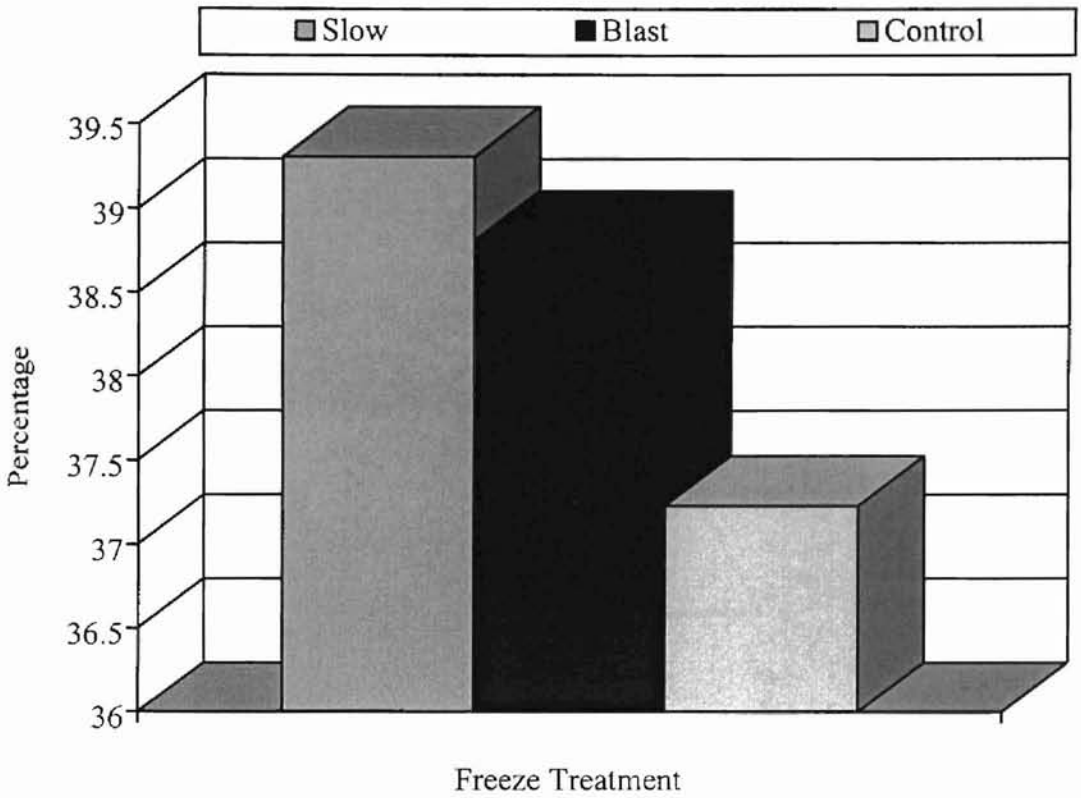


Table 7. Least squares means and standard errors for salt levels of cured hams stratified by freeze treatment[1]

Freeze Rate	Mean	SE
Slow (-18°C)	2.91	0.05
Blast (-34°C)	2.81	0.05
Control	2.78	0.07

[1] Salt levels are expressed as percentage of total weight

Table 8. Least squares means and standard errors for salt levels of cured hams stratified by thaw treatment[1]

Procedure	Mean	SE
1 Stage	3.30	0.08
2 Stage	2.59	0.04
3 Stage	2.61	0.05

[1] Salt levels are expressed as percentage of total weight

Table 9. Least squares means and standard errors for salt levels of cured hams stratified by freeze/thaw protocol[1]

Protocol	Mean	SE
Slow freeze/ 1 stage Thaw	3.34[a]	0.11
Blast freeze/ 1 stage Thaw	3.31[a]	0.11
Slow freeze/ 2 stage Thaw	2.58[c]	0.05
Blast freeze/ 2 stage Thaw	2.59[c]	0.06
Slow freeze/ 3 stage Thaw	2.80[b]	0.08
Blast freeze/ 3 stage Thaw	2.55[c]	0.08
Control	2.78[b]	0.07

[1] Salt levels are expressed as percentage of total weight

[a, b, c] Means within the same column followed by a common superscript do not differ ($P<0.05$)

Table 10. Least squares means and standard errors for protein levels of cured hams stratified by freeze treatment[1]

Freeze Rate	Mean	SE
Slow (-18°C)	16.16	0.18
Blast (-34°C)	16.67	0.27
Control	16.50	0.18

[1] Protein levels are expressed as percentage of total weight

Table 11. Least squares means and standard errors for protein levels of cured hams stratified by thaw treatment[1]

Procedure	Mean	SE
1 Stage	16.39	0.30
2 Stage	16.38	0.13
3 Stage	16.57	0.17

[1] Protein levels are expressed as percentage of total weight

Table 12. Least squares means and standard errors for protein levels of cured hams stratified by freeze/thaw protocol[1]

Protocol	Mean	SE
Slow freeze/ 1 stage Thaw	16.00[b]	0.41
Blast freeze/ 1 stage Thaw	16.67[a]	0.41
Slow freeze/ 2 stage Thaw	16.14[b]	0..20
Blast freeze/ 2 stage Thaw	16.70[a]	0.21
Slow freeze/ 3 stage Thaw	16.35[b]	0.29
Blast freeze/ 3 stage Thaw	16.14[b]	0.31
Control	16.50[a]	0.18

[1] Protein levels are expressed as percentage of total weight

[a, b] Means within the same column followed by a common superscript do not differ ($P<0.05$)

Table 13. Least squares means and standard errors for fat levels of cured hams stratified by freeze treatment[1]

Freeze Rate	Mean	SE
Slow (-18°C)	2.85	0.15
Blast (-34°C)	2.93	0.16
Control	3.24	0.23

[1] Fat levels are expressed as percentage of total weight

Table 14. Least squares means and standard errors for fat levels of cured hams stratified by thaw treatment[1]

Procedure	Mean	SE
1 Stage	2.89	0.26
2 Stage	2.80	0.11
3 Stage	3.33	0.15

[1] Fat levels are expressed as percentage of total weight

Table 15. Least squares means and standard errors for fat levels of cured hams stratified by freeze/thaw protocols[1]

Protocol	Mean	SE
Slow freeze/ 1 stage Thaw	2.58 [a b]	0.35
Blast freeze/ 1 stage Thaw	2.83[a]	0.35
Slow freeze/ 2 stage Thaw	2.80[b]	0.17
Blast freeze/ 2 stage Thaw	2.73[a]	0.18
Slow freeze/ 3 stage Thaw	3.17[b]	0.25
Blast freeze/ 3 stage Thaw	3.24[b]	0.26
Control	3.33[b]	0.25

[1] Fat levels are expressed as percentage of total weight

[a, b] Means within the same column followed by a common superscript do not differ ($P<0.05$)

Table 16. Least squares means and standard errors for moisture of cured hams stratified by freeze treatment[1]

Freeze Rate	Mean	SE
Slow (-18°C)	75.52	0.20
Blast (-34°C)	73.27	0.30
Control	73.09	0.21

[1] Moisture is expressed as percentage of total weight

Table 17. Least squares means and standard errors for moisture of cured hams stratified by thaw treatment[1]

Procedure	Mean	SE
1 Stage	73.33	0.34
2 Stage	73.55	0.15
3 Stage	72.99	0.19

[1] Moisture is are expressed as percentage of total weight

Table 18. Least squares means and standard errors for moisture of cured hams stratified by freeze/thaw protocol[1]

Protocol	Mean	SE
Slow freeze/ 1 stage Thaw	73.83[a]	0.45
Blast freeze/ 1 stage Thaw	73.17[a]	0.45
Slow freeze/ 2 stage Thaw	73.50[a]	0.22
Blast freeze/ 2 stage Thaw	73.23[a]	0.24
Slow freeze/ 3 stage Thaw	73.22[a]	0.33
Blast freeze/ 3 stage Thaw	73.43[a]	0.34
Control	73.09[a]	0.21

[1] Moisture is expressed as percentage of total weight
[a] Means within the same column followed by a common superscript do not differ (P<.05)

Table 19. Least squares means and standard errors for L, a*, and b* values of cured hams stratified by freeze treatment

Rate	L	SE	a*	SE	b*	SE
Slow	54.65[a]	1.63	10.84[a]	0.17	5.84[a]	0.20
Fast	56.86[a]	1.67	11.06[a]	0.17	5.82[a]	0.20
Control	55.85[a]	2.43	11.24[a]	0.25	5.97[a]	0.29

[a] Means within the same column followed by a common superscript do not differ ($P<0.05$)

Table 20. Least squares means and standard errors for L, a*, and b* values of cured hams stratified by thaw treatment

Treatment	L	SE	a*	SE	b*	SE
1 Stage	54.73[a]	2.73	10.80[a]	0.29	7.04[a]	0.33
2 Stage	54.97[a]	1.20	11.09[a]	0.13	5.94[b]	0.14
3 Stage	57.66[a]	1.57	11.25[a]	0.16	4.65[c]	0.19

[a, b, c] Means within the same column followed by a common superscript do not differ ($P<0.05$)

Table 21. Least squares means and standard errors for L, a*, and b* values of cured hams stratified by thaw treatment

Treatment	L	SE	a*	SE	b*	SE
Slow/ 1stage	53.59[a]	3.66	10.76[a]	0.38	6.57[a b c]	0.44
Fast/ 1 stage	53.97[a]	3.66	10.62[a]	0.38	6.89[a b]	0.44
Slow/ 2 stage	55.66[a]	1.79	10.88[a]	0.19	5.98[b c]	0.21
Fast/ 2 stage	53.65[a]	1.91	11.00[a]	0.20	6.07[b c]	0.23
Slow/ 3 stage	54.68[a]	2.70	10.88[a]	0.19	4.96[d e]	0.32
Fast/ 3 stage	62.96[b]	2.84	11.57[a]	0.30	4.51[e]	0.34
Control	55.85[a]	2.43	11.24[a]	0.25	5.97[bc]	0.29

[a, b, c, d, e] Means within the same column followed by a common superscript do not differ ($P<0.05$)

Table 22. Means for total water loss, % for all freeze/thaw combinations[1]

Protocol	Mean
Slow freeze/ 1 stage Thaw	44.71[a]
Fast freeze/ 1 stage Thaw	42.20[a]
Slow freeze/ 2 stage Thaw	38.77[ab]
Fast freeze/ 2 stage Thaw	35.70[b]
Slow freeze/ 3 stage Thaw	34.42[bc]
Fast freeze/ 3 stage Thaw	38.54[ab]
Control	37.22[b]

[1]Total Water Loss was calculated by (%purge loss + %cook loss)/ sample wt
[a, b, c, d, e] Means within the same column followed by a common superscript do *not differ* ($P<0.05$)

Figure 5. Temperature decline for fast vs. slow frozen hams (center probe)

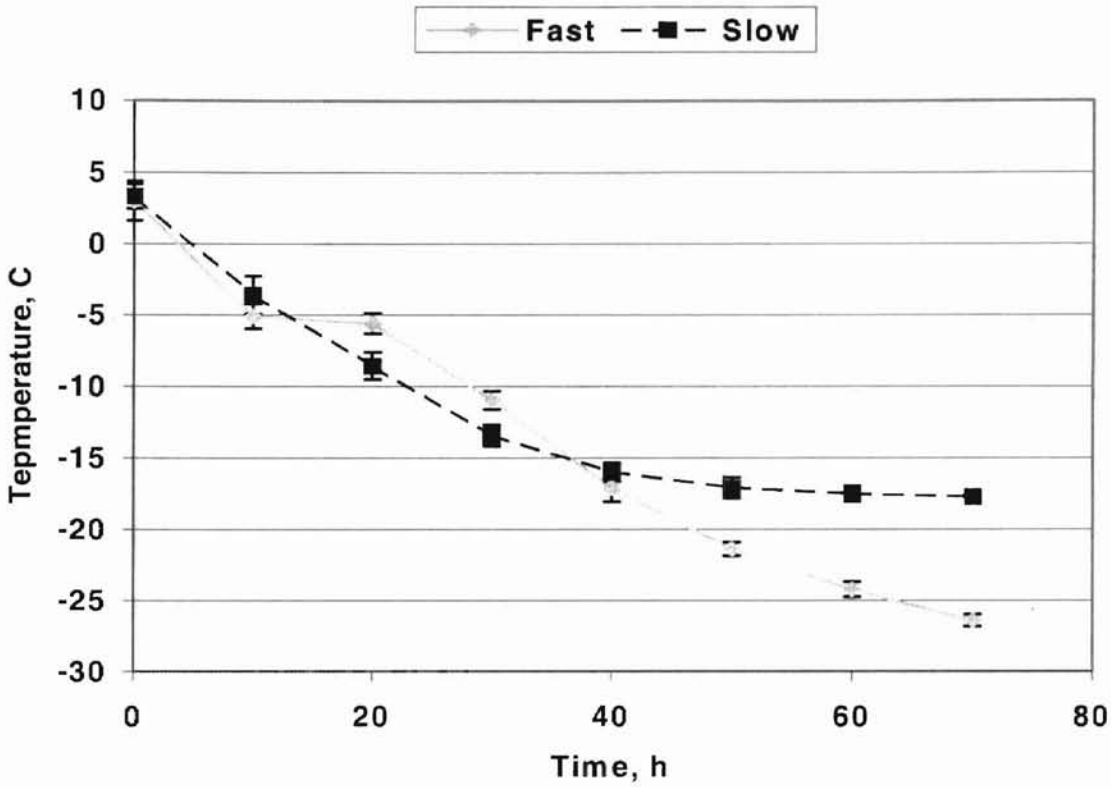


Figure 6. Temperature decline for fast frozen hams stratisfied by probe location

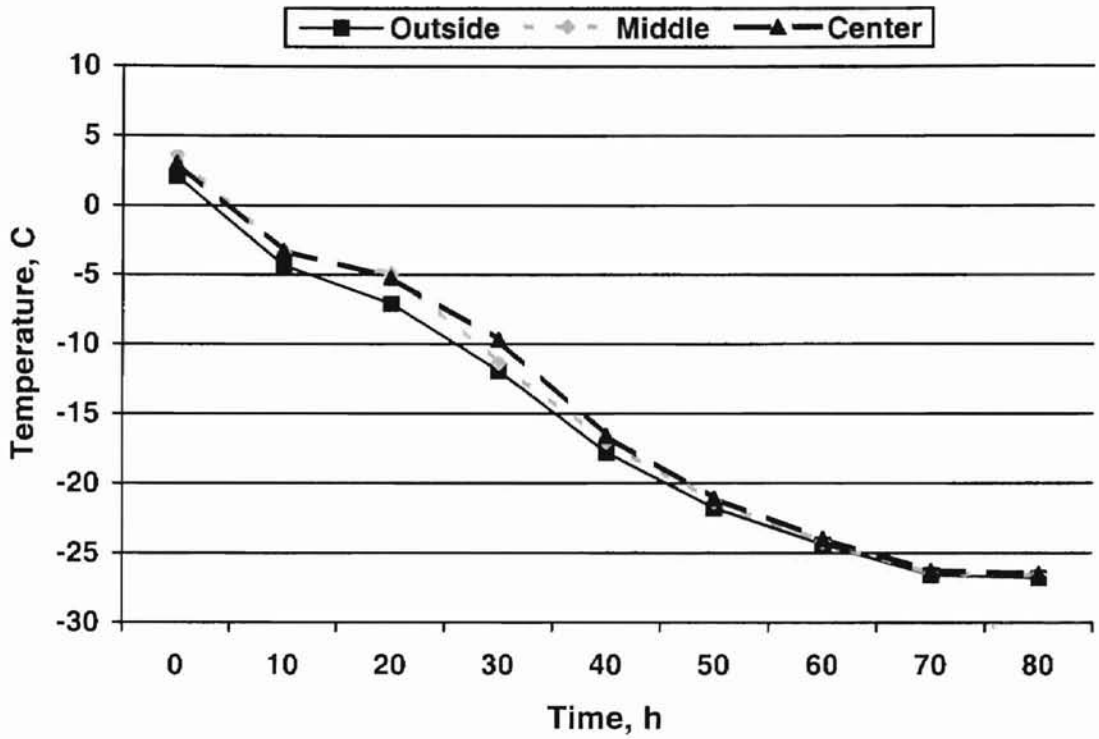


Figure 7. Temperature decline for slow frozen hams stratisfied by probe location

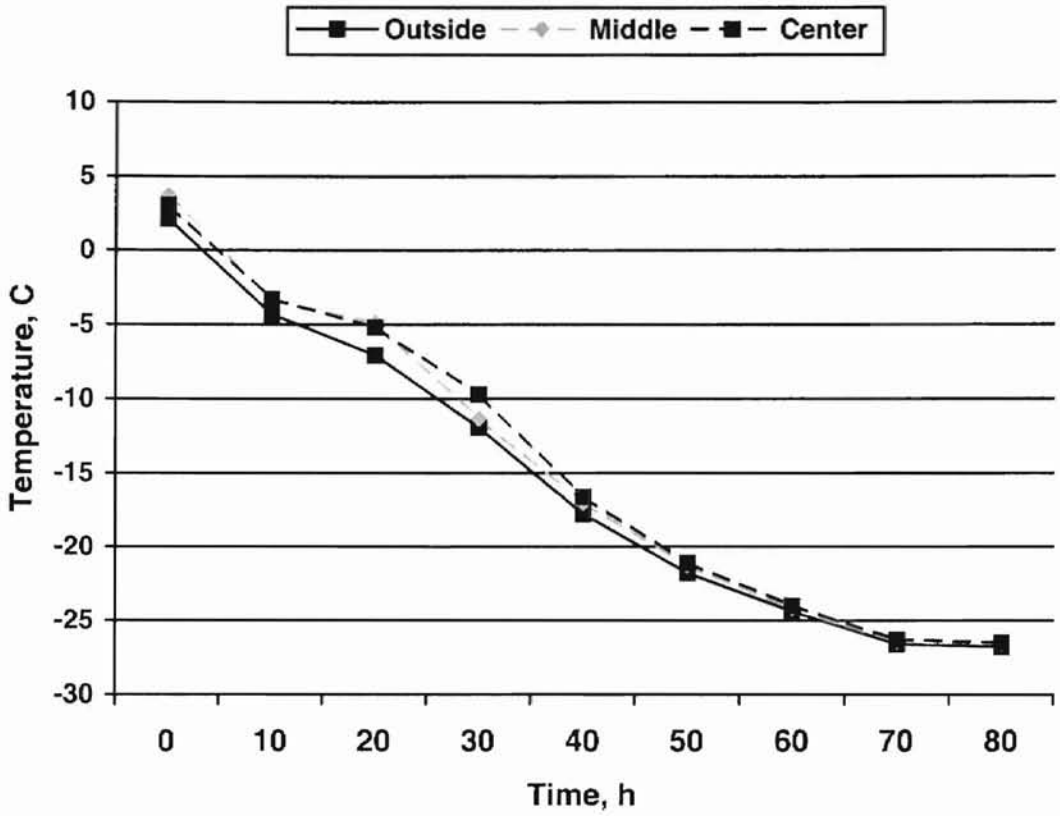


Figure 8. Temperature increases over the single stage thawing period for fast and slow frozen hams (center probe)

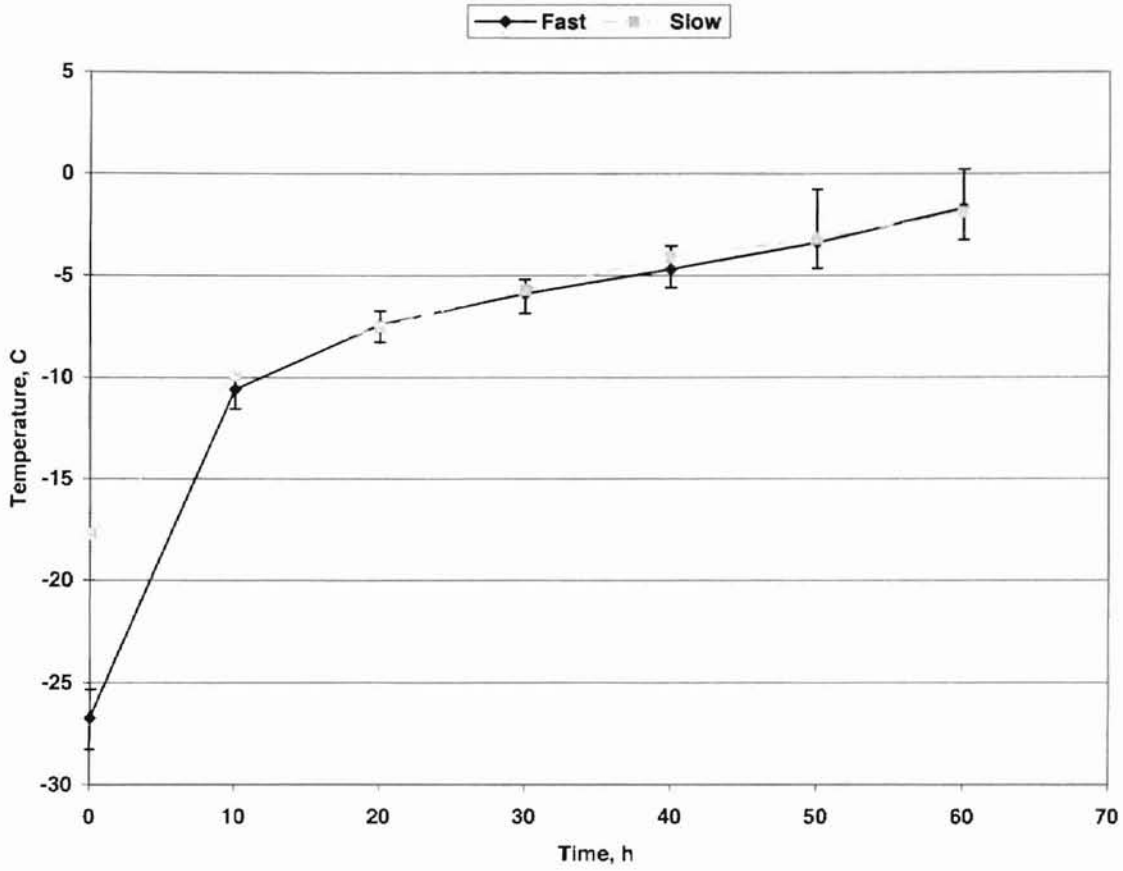


Figure 9. Temperature increases over the dual stage thawing period for fast and slow frozen hams (center probe)

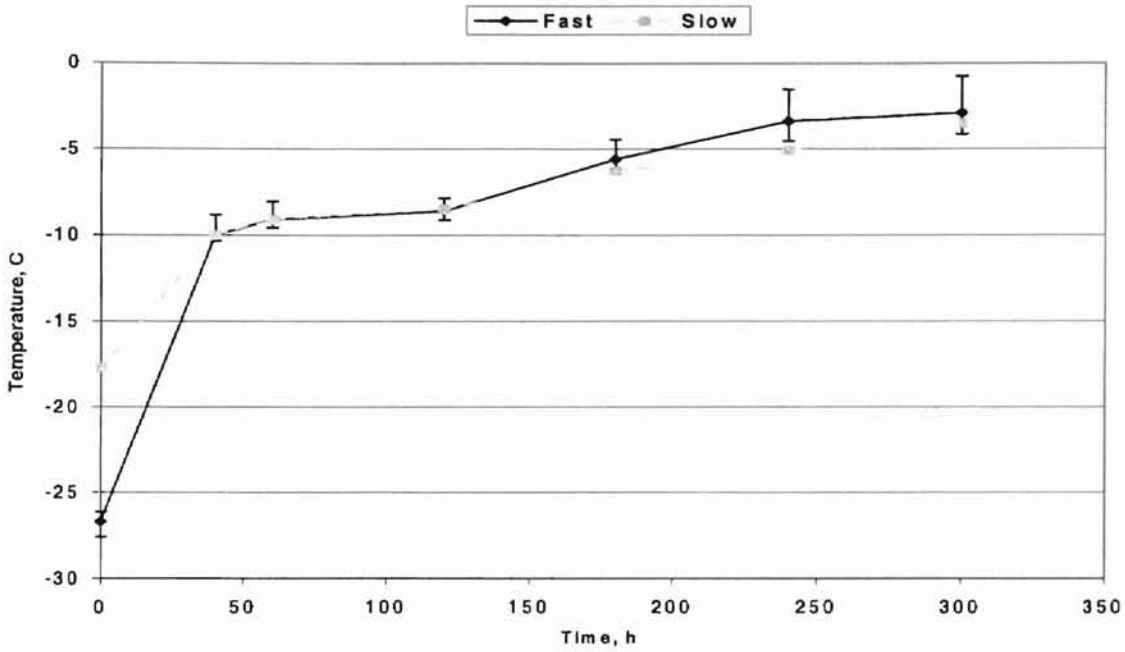


Figure 10. Temperature increases over the triple stage thawing period for fast and slow frozen hams (center probe)

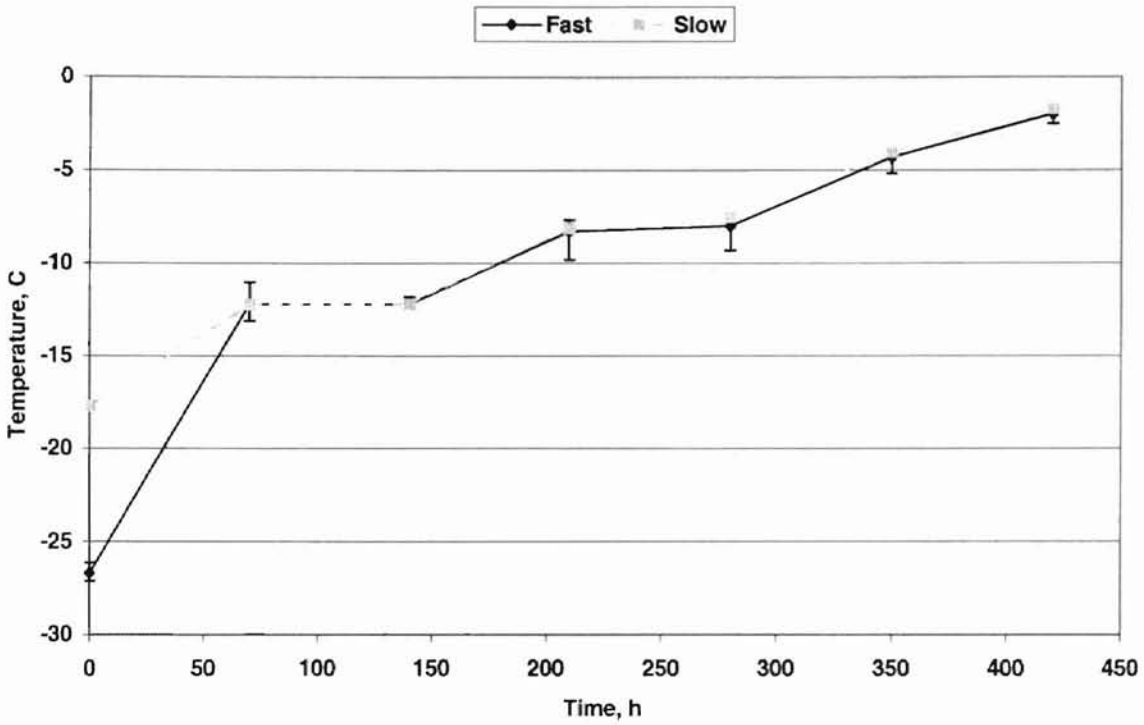


Figure 11. Temperature increases for fast frozen hams for each thaw procedure (center probe)

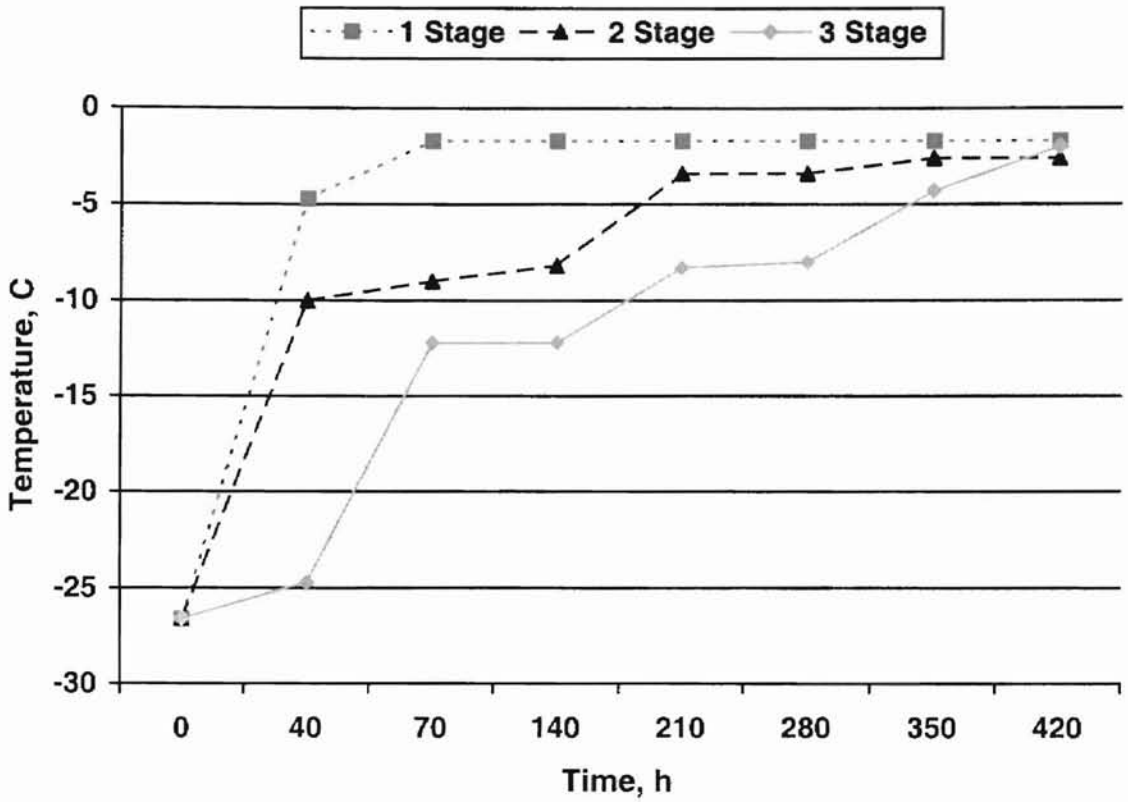
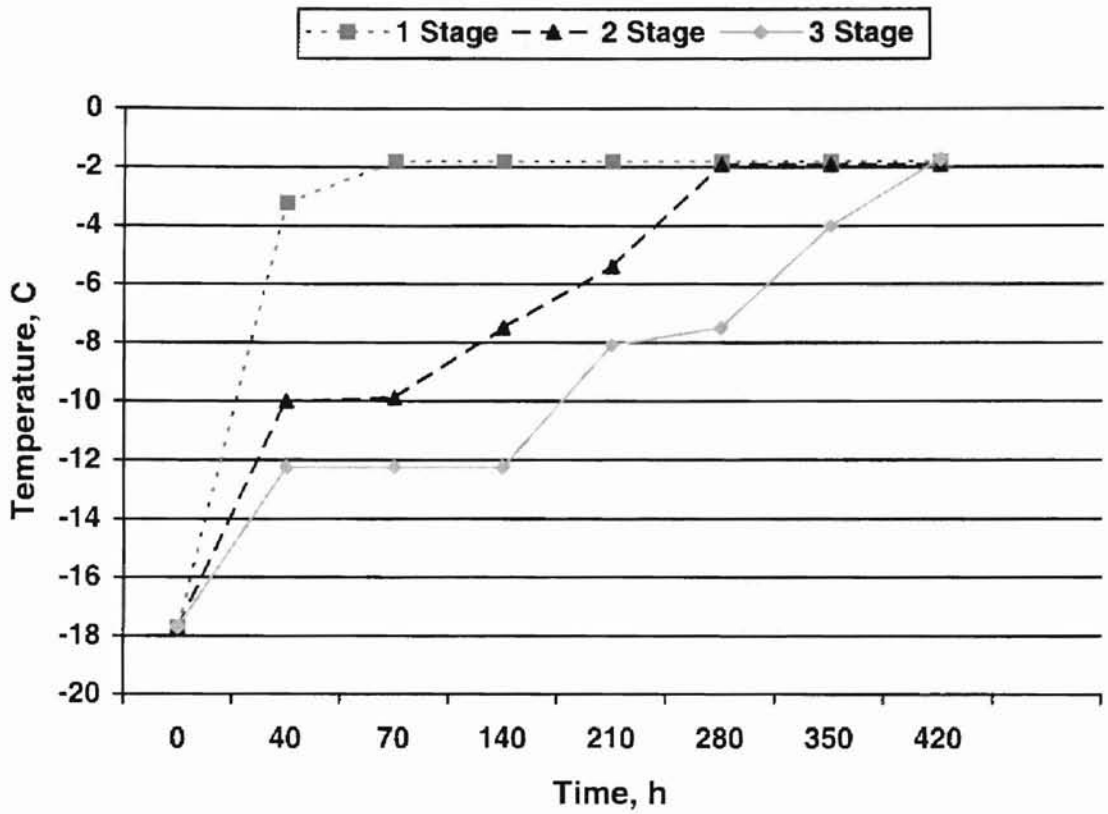


Figure 12. Temperature increases for slow frozen hams for each thaw procedure (center probe)



CHAPTER IV

LITERATURE CITED

American Meat Institute Foundation. 1960. "The Science of Meat and Meat Products." W. H. Freeman & Co., San Francisco, CA.

American Meat Institute. 1992. Meat Facts. American Meat Inst. Washington DC.

American Meat Institute. 1998. Meat Facts. American Meat Inst. Washington DC.

Anon, M. C. and A. Calvelo 1980. Freezing rate effects on the drip loss of frozen beef. Meat Sci. 4(1): 1-14.

AOAC. 1990. *Official Methods of Analysis*, 15th ed. Association of Official Analytical Chemists. Washington, D.C.

Ashby, B. H. and G. M. James 1973. Effects of freezing and packaging methods on shrinkage of hams in frozen storage. J. Food Sci. 38: 254-257.

Ashby, B. H. and G. M. James 1974. Effects of freezing and packaging methods on shrinkage and freezer burn of pork bellies in frozen storage. J. Food Sci. 39: 1136-1139.

Bernholdt, H. F. 1974. Merchandising frozen meat and consumer attitudes in purchasing and preservation. Meat Res. Inst. Symposium 3: 4.1-4.7.

Berry, B. W., G. C. Smith, J. V. Spencer and G. H. Kroening 1971. Effects of freezing method, length of frozen storage and cookery from the thawed or frozen state on palatability characteristics of pork. J. Anim. Sci. 32:636.

Blanshard, J. M. V. and F. Franks 1987. Ice crystallization and its control in frozen-food systems. In *Food Structure and* Behavior. (Blanshard, J. M. V. and Lillford, P., eds.) pp. 51-65, Academic Press, London.

Breidenstein, B. C. and J. C. Williams 1987. Contribution of red meat to the U.S. diet. pp. 24. National Livestock and Meat Board, Chicago, IL.

Brewer, M. S. and C. A. Z. Harbers 1991. Effect of packaging on physical and sensory characteristics of ground pork in long-term frozen storage. J. Food Sci. 56 (3): 627-631.

Calvelo, A. 1981. Recent studies on meat freezing. Ch. 5. In *Developments in Meat Science-2* R. Lawrie, ed. Applied Science Publishers, Engelwood, NJ.

Cambero, M. I., J. A. Ordonez, C. I. Pereira, A. Cobbs, and L. de la Hoz, 1994. Perspectives en la fabrication de productos carnicos hiposodicos. Alimentacion Equipos y Tecnologia 1: 11-116.

Campbell, J. F. and R. W. Mandigo 1978. Properties of restructured pork patties as affected by cooking method, frozen storage and reheating method. J. Food Sci. 43: 1648-1651.

Cannon, J. E., J. B. Morgan, J. Heavner, F. K., McKeith, G. C. Smith and D.L. Meeker 1995. Pork Quality Audit: A review of the factors influencing pork quality. J. Muscle Food. 6: 369-402.

Cannon, J. E., J. B. Morgan, G. R. Schmidt, J. D. Tatum, J. N. Sofas, G. C. Smith, R. J. Delmore, and S. N. Williams 1996. Growth and fresh meat quality characteristics of pigs supplemented with vitamin E. J. Anim. Sci. 74: 98-105.

Cheah, K. S., A. M. Cheah, and D. L Krausgill 1995. Effect of dietary supplementation of vitamin E on pig meat quality. Meat Sci. 39: 255-264.

Cook, G. A., E. F. J. Love, J. R. Vickery, and W. J. Young 1926. Studies on the refrigeration of meat. 1. Investigations Into the Refrigeration of Beef. Australia J. Exptl. Biol. Med. Sci: 3: 15.

Cooper, T. J. R. 1970. Control of weight losses during chilling, freezing storage, and transport of pig meat. Weight Losses in Foodstuffs. International Institute of Refrigeration, Paris France, Annexe 3: 175.

Crivelli, G., D'Aubert, S. and Aguzzi, U. 1972. Influence of aging, freezing time and storage on the physical and microbiological evaluation of frozen poultry meat. Bull. Inst. Int. Froid. Annexe, 2: 171.

Cross, H. R., Kotula, A. W., and Nolan, T. W. 1978. Stability of frozen ground beef containing mechanically deboned beef. J. Food Sci. 43 (2), 281-284.

Deatherage, F. E. and R. Hamm 1960. Influence of freezing and thawing on hydration and charges of the muscle protein. Food Res. 25: 623-629.

Devine, C. E., R. G. Bell, S. Lovatt, and B. Chrystall, 1996. Red meats. Ch. 2. In *Freezing Effects on Food Quality* L.E. Jeremiah, ed. Markel Dekker, Inc., New York.

Dhillion, A. S. and A. J. Maurer 1975. Stability study of comminuted poultry meats in frozen storage. Poultry Sci. 54: 1407.

Dirinck, P., A. de. Winne, M. Casteels, and M. Frigg 1996. Studies on vitamin E and meat quality. 1. Effect of feeding high vitamin E levels on time-related pork quality. J. Ag. Food Chem. 44: 65-68.

Downey, G. and D. Beauchene 1997. Discrimination between fresh and frozen-then-thawed beef *m. longissimus dorsi* by combined visible-near infrared reflectance spectroscopy: A feasibility study. Meat Sci. 45(3): 353-363.

Dransfield, E. 1974. Influence of freezing on the eating quality of meat. Meat Res. Inst. Symposium No. 3, Bristol, England, 9: 9.1-9.5.

Empey, W. A. 1933. Studies on the refrigeration of meat: Conditions determining the amount of drip from frozen and thawed muscle, J. Soc. Chem. Ind. 52: 230T.

Enser, M. B. 1974. Factors affecting the development of oxidative rancidity in frozen meat. Meat Res. Inst. Symposium No. 3: p. 111.

Faustmann, C. and, R. G. Cassens 1990. The biochemical basis for discoloration in fresh meat: a review. J. of Muscle Foods 1: 217-243.

Fennema, O. 1975. Reaction kinetics in partially frozen aqueous systems. In "Water Relations of Foods," ed R. B. Duckworth, p. 539. Academic Press, New York.

Fennema, O. R. (1973). *In "Low Temperature Preservation of Foods and Living Matters"* O. R. Fennema, W. D. Powrie, and E. H. Marth, eds., pp. 101 and 504. Dekker, New York.

George, R. M. 1997. Freezing Systems. Ch. 1. In *Quality in Frozen Food* Erickson, M.C., and Y.C. Hung ed. International Thompson Publishing, Florence, KY.

Greer, G. G. and A. C. Murray 1991. Freezing effects on quality, bacteriology and retail-case life of pork. J. Food Sci. 56(4): 891-894.

Gruji, R., L. Petrovi, B. Pikula, and L. Amilzic 1993. Definition of the optimum freezing rate-1. Investigation of Structure an Ultrastructure of Beef m. longissimus dorsi frozen at different freezing rates. Meat Sci. 33:301.

Grujic, R., L. Petrovic, B. Pikula, and L. Amidzic 1993. Definition of the optimum freezing rate-1. Investigation of structure and ultrastructure and ultrastructure of beef *M. longissimus dorsi* frozen at different freezing rates. Meat Sci. 33: 301-318.

Hamm, R. 1986. Functional Properties of the Myofibrillar System and Their Measurements. Ch. 4. In *Muscle as Food* P. J. Bechtel, ed. Academic Press, Inc., Orlando, Fl.

Hamm, R. 1986. *Muscle as Food Science and Technology*, P. J. Bechtel, ed., Academic Press, London. Vol. 164.

Heldman, D. R. 1983. Factors influencing food freezing rates, Food Technol. 4: 103-109.

Ingram, M. and B. M. Mackey 1976. Inactivation by cold. In *Inhibition and Inactivation of Vegetative Microbes.* eds. F. A. Skinner, and W. B.Hugo Society for Applied Bacteriology, Symposium Series No. 5, Academic Press, London: pp. 111-151.

Ingram, M. 1974. Freezing, an integrated procedure. In *Meat Chilling. Why and How?* Meat Research Institute, Langford, Bristol: 1.1-1.4.

International Institute of Refrigeration. 1971. "Recommendations for the processing and handling of frozen foods." Second Ed. Internat. Inst. of Refrig. Paris.

Jalong'O, J. W., G. L. Saul, and R. A. Lawrie 1987. Observation on muscle press juice from bovine, ovine and porcine muscles. Meat Sci: 21: 73.

Jay, J. M. 1997. Processed Meats and Poultry. In *Modern Food Microbiology*, Fifth Ed. Chapman and Hall New York.

Jensen, C., J. Guidera, I. M. Skovaard, H. Staun, L. H. Skibsted, S. K. Jensen, A. J. Moller, J. Buckley, and G. Bertelsen, 1997. Effects of dietary alpha-tocopherol acetate supplementation on alpha-tocopherol deposition in porcine *m. psoas* and *m. longissimus dorsi* and on drip loss, colour stability and oxidative stability of pork meat. Meat Sci. 45: 491-500.

Jermiah, L. E. 1980. Effect of frozen storage and protective wrap upon the cooking losses, palatability, and rancidity of fresh and cured pork cuts. J. Food Sci. 45: 187-196.

Jermiah, L. E. 1981. The effects of frozen storage and thawing on the retail acceptability of ham steaks and bacon slices. J. Food Qual. 5: 43-58.

Jermiah, L. E. 1982. The effects of frozen storage and protective storage wrap on the retail case-life of pork loin chops. J. Food Qual. 5: 311-326.

Jermiah, L. E. and R. Wilson 1987. The effects of PSE/DFD conditions and frozen storage upon the processing yields of pork cuts. Can. Inst. Food Sci. Technol. J. 20:25.

Jermiah, L. E., A. C. Murray, and L. L. Gibson 1990. The effects of differences in inherent muscle quality and frozen storage on the flavor and texture profiles of pork loin roasts. Meat Sci. 27: 305-327.

Jones, E. 1997. Overview of physical/chemical aspects of freezing. Ch. 2. In *Quality in Frozen Food* M.C. Erickson, Y.C. Hung, ed. International Thompson Publishing, Florence, KY.

Judge, M. D., E. D. Aberle, J. C. Forrest, H. B. Hedrick, and R. A. Merkel 1989. Storage and preservation of meat. Ch. 9. In *Principles of Meat Science*, Kendall/Hunt Publishing Company., Dubuque, Iowa.

Kalichevsky, M. T., D. Knorr, and P. J. Lillford 1995. Potential food applications of high-pressure effects on ice-water transitions. *Trends in Food Science and Technology* 6(8): 253-258.

Kauffman, R. G., B. C. Breidenstein, D. Garrigan, and Q. E. Kolb 1969. Meat Quality circular 1007. Coop. Ext. Sv., Coll. Agr., University of Illinois, Urbana, USA.

Kauffman, R. G., G. Eikelenboom, P.G. Wal, G.van der Merkus, B. Engel, and M. Zarr 1986. The use of filter paper to estimate drip loss of porcine musculature. Meat Sci. 18 (3):191-200.

Kemp, J. D., R. E. Montgomery, and J. D. Fox, 1976. Chemical, palatability and cooking characteristics of normal and low quality pork loins as affected by freezer storage. J. Food Sci. 41:1.

Locker, R. H. and G. J. Daines 1973. The effect of repeated freeze-thaw cycles on tenderness and cooking loss in beef, J. Sci. Food Agric. 24:1273.

Love, R. M. 1966. In *"Crybiology"*. ed. H.T. Meryman. pp. 313. Academic Press, New York.

Luyet, B. 1959. The freezing of tissues as seen at the molecular level. Proc. Meat Ind. Res. Conf. pp 39.

Lynch, N. M., C. L. Kastner, and D. H. Kropf 1986. Consumer acceptance of vacuum packaged ground beef as product color and educational materials. J. Food Sci. 51: 253.

Martain, S. 1992. *Manual Practico de la Carne*. Martain y Macias, Madrid.

Martino, M. N., L. Otero, P. D. Sanz, and N. E. Zaritzky 1998. Size and location of ice crystals in pork frozen by high-pressure-assisted freezing as compared to classical methods. Meat Sci. 50(3): 303-313.

Miller, A. J., S. A. Ackerman, and S. A. Palumbo 1980. Effects of frozen storage on functionality of meat for processing. J. Food Sci. 45: 1466-1471.

Monahan, F. J., D. J. Buckley, P. A. Morrissey, P. B. Lynch, and J. I. Gray 1992. Influence of dietary fat and alpha-tocopherol supplementation on lipid oxidation in pork. Meat Sci. 31: 229-241.

Moran, R. and H. P. Hale 1932. Rapid freezing. temperature of storage. J. Soc. Chem. Ind. London 51: 20T.

Nassos, P. S., A.D. Jr. King, and A. E. Stafford 1988. Lactic acid concentrations as an indicator of acceptability in refrigerated or freeze-thawed ground beef. Appl. Environ. Microbiol. 54:822.

Nilsson, R. 1969. The influence of freezing and thawing on the quality of pork, *Proc. Eur. Meat Res. Work Conf.* 15:492.

Nocito, J. S., B. H. Bayne, M. P. Penfield, and B. H. Meyer 1973. Myoglobin content and color of raw pork loin roasts as affected by freezing at two rates. J. Anim. Sci. 37: 1339.

NPPC Pork Quality Standards 1994. National Pork Producers Council in Cooperation with the National Pork Board.

Offer, G. and P. Knight 1989. In Developments in Meat Science-4. ed. R. Lawrie, Ch. 3 and ch. 4: pp. 63. Applied Science, London.

Paz de Pena, M., C. Cid, and J. Bello 1998. A method for identification of frozen meat used for production of cooked ham. Meat Sci. 48(3/4): 257-264.

Penny, I. F. 1974. The effect of freezing on the amount of drip from meat. Meat Res. Inst. Symposium No. 3: pp. 8.1.

Peters, J. A. 1970. Relation of humidity to economic loss during storage of fishery products. ASHRAE Journal 12: 73.

Powrie, W. D. 1973. In "*Low Temperature Preservation of Foods and Living Matters*" O. R. Fennema, W. D. Powrie, and E. H. Marth, eds., pp282. Dekker, New York.

Precise Color Communication 1994. Minolta Corporation. Ramsey, New Jersey.

Ramsbottom, J. M. 1947. Freezer storage effect on fresh meat quality. Refrig. Engin. 53:18.

Ramsbottom, J. M. and C. H. Koonz 1939. Freezing temperatures as related to drip of frozen-defrosted beef. Food Res. 4:425.

Ramsbottom, J. M. and C. H. Koonz 1940. Relationship between time of freezing beef after slaughter and amount of drip. Food Res. 5:423.

Redin, R., I. Astiasaran, and J. Bello 1994. Composicion y valor nutritivo de pastas finas carnicas comerciales. Alimentaria 251: 37-40.

Reid, D. S. 1990. Optimizing the quality of frozen foods, Food Technol. 44(7): 78-82.

Reid, D. S. 1994. Basic physical phenomena in the freezing and thawing of plant and animal tissue. In *Frozen Food Technology*. C. P. Mallet, ed. pp. 1-19, Blackie Academic & Professional, Glasgow.

Reid, D. S. 1997. Overview of physical/chemical aspects of freezing. Ch. 2. In *Quality in Frozen Food* M.C. Erickson, Y.C. Hung, ed. International Thompson Publishing, Florence, KY.

Renerre, M. 1990. Review: Factors involved in the discoloration of beef. International Journal of Food Sci. and Technol. 25: 613-630.

Richardson, W. D. and E. Scherubal 1908. The deterioration and commercial preservation of flesh foods. First paper. General introduction and experiments on frozen beef. J. Am. Chem. Soc. 30: 1515-1564.

Riedel, L. 1961. Kaeltetechnik 13, 122.

Rosset, R. 1982. Chilling freezing and thawing. In *Meat Microbiology* M. H. Brown, ed. Applied Science Publishers LTD., New York.

SAS. 1990. SAS Procedures Guide, (Version 6, 3rd Ed.). SAS Inst., Inc., Cary, NC.

Skenderovic, B. and Rankov, M. 1976. Changes in the technological properties of frozen pork during storage. Proc. 22nd Meet. European Meat Res. Workers 22, D7.1.

Smith, G. C. and Z. L. Carpenter 1977. Systems for centralized pre-packaging pork loin chops. J. Food Sci. 42, 1513.

Smith, G. C., Z. L. Carpenter, and G.T. King 1969. Considerations for beef tenderness evaluation. J. Food Sci. 34: 621.

Smith, G. C., J. B. Morgan, and J. D. Tatum 1993. Marketing vitamin E for meat-quality enhancement in the U.S.A. Proc. Roche Vitamin E Workshop. pp 1. (Luzden, Switzerland) Roche Vitamins and Fine Chemicals, Nutely, NJ.

Stewart, D. J., R. A. Field, and G. Brown 1974. Palatability and collagen gelatinization in beef. J. Anim. Sci. (Abstr.), 38: 1328.

Strange, E. D. 1987. Quantitation and characterization of drip from frozen-thawed and refrigerated pork liver, J. of Food Sci. 52 (4), 910-915.

Stuby, M. A., J. W. Lamkey, and H. G. Dolezal 1993. The effect of freezing on aging of beef. Res. Report Oklahoma State Univ. p. 55-59.

Sulzbacher, W. L. 1952. Effect of freezing and thawing on the growth rate of bacteria in ground meat. Food Technol. 6: 341.

Taylor, A. A. 1974. Packaging of frozen meat. Meat Res. Inst. Symposium. 3: 19.1-19.3.

The Institute of Refrigeration 1972. Recommendations for the processing and handling of frozen foods (2^{nd} edn), Institut International du Froid, Paris.

TRRF. 1966. Shrinkage on Pork Products. The Refrigeration Research Foundation, Washington, D.C., Alert No. 66-1.

Tuma, H. J. 1971. Processing technology for freezing retail meat cuts, Proc. Meat Ind. Res. Conf., Chicago, Ill, pp. 53.

United States Department of Agriculture. 1999. National Agriculture Statistics Service. Available http://www.usda.gov. /nass/ Accessed February 15,1999.

University of Wisconsin 1963. Pork Quality Standards. Wisc. Agric. Expt. Sta. special Bull. No. 9, Madison, Wisc.

Urban, W. M. and J. F. Campbell 1987. Meat Preservation. Ch. 10. In *The Science of Meat and Meat Products Third Edition* Price, J.F. and Schweigert, B. S., ed. Food and Nutrition Press, Inc., Westport, CT.

van der Wal, P.G., B. Engel, B. Hulsegge 1997. Causes for variation in pork quality. Meat Sci. 46(4): 319-327.

Warner, R. D. and R. G. Kauffman, and M. L. Greaser 1997. Muscle protein changes *post mortem* in relation to pork quality traits. Meat Sci. (45)3: 339-352.

Wisconsin Farm Bureau, 1999. Available http://www.wfbf.com/news/pork%prices.htm Accessed January, 10, 1999.

Zhao, Y., R. A. Flores, and D. G. Olson 1998. High hydrostatic pressure effects on rapid thawing of frozen beef. J. Food Sci. 63(2): 272-275.

Ziauddin, K. S., N. S. Mahendrakar, D. N. Rao, and B. L. Amla 1993. Effect of freezing, thawing and frozen storage on physico-chemical and sensory characteristics of buffalo meat, Meat Sci. 35: 331-340.

APPENDIX

United States Pork in Cold Storage, Monthly, 1997

Month	Total Hams[a]	Total Frozen Pork[a]
January	47,285	342,168
February	52,658	383,878
March	55,795	404,715
April	85,783	440,248
May	101,114	413,352
June	106,755	406,202
July	113,201	388,667
August	113,485	371,750
September	101,277	346,637
October	88,789	354,235
November	61,331	334,100
December	46,320	346,390

[a]1,000 pounds

Source: NASS, 1998

United States Pork in Cold Storage, Annually, December, 31

Year	Total Hams[a]	Total Frozen Pork[a]
1993	32,898	299,213
1994	33,993	357,453
1995	38,307	334,780
1996	33,506	313,823
1997	46,320	346,390
1998	65,517	504,480

[a]1,000 pounds

Source NASS, 1998

Mean and range of room temperature for coolers and freezers over the entire study as recorded by temperature dataloggers

Room	Mean	Minimum	Maximum
Slow Freeze (-18°C)	-17.72	-13.97	-18.86
Fast Freeze (-34°C)	-27.58	-22.51	-28.56
1 Stage Thaw (3ºC)	2.87	1.36	4.1
2 Stage Thaw			
1st step (-8ºC)	-8.77	-9.71	3.72
2nd step (-2ºC)	-2.36	-2.97	-1.69
3 Stage Thaw			
1st step (-12º)	-12.56	-13.22	-12.06
2nd step (-6ºC)	-6.23	-7.12	-6.11
3rd step (-2ºC)	-2.45	-3.12	-1.87
Control (-2°C)	-2.72	-3.19	.56

VITA

Daniel Scott Webb

Candidate for the Degree of

Master of Science

Thesis: DETERMINATION OF FREEZING AND TEMPERING PARAMETERS FOR COOKED-CURED HAM

Major Field: Food Science

Biographical:

Personal Data: Born in Duncan, Oklahoma, On April 16, 1974, the son of Gary and Kenna Webb.

Education: Graduated from Bray-Doyle High School, Bray, Oklahoma in May 1992; received Associate of Science degree in Agriculture from Connors State College, Warner, Oklahoma in May 1994; received a Bachelor of Science degree in Animal Science with a minor in Agriculture Economics from Oklahoma State University, Stillwater, Oklahoma in December, 1996; completed requirements for the Master of Science degree with a major in food Science at Oklahoma State University in May 1999.

Professional Experience: Undergraduate Research Assistant; Oklahoma State University Vet Med Anaplasmosis Research, Stillwater, Oklahoma, May 1995-May 1996; Internship Advance Food Company, Enid, Oklahoma, May 1996 – August 1996; Internship Thorn Apple Valley, Ponca City, Oklahoma, August 1996 - September 1996; Graduate Research Assistant, Oklahoma State University Department of Animal Science, Stillwater, Oklahoma, January 1997 to present.

Professional Memberships: Animal Science Graduate Student Association, American Meat Science Association