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A COMPARISON OF PROCESSING CHARACTERISTICS OF PRE-RIGOR AND POST-RIGOR COW BEEF

A Thesis

Presented for the

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ABSTRACT

Two Holstein cows were slaughtered and divided into pre-rigor and post-rigor processed sides. Salt (NaCl) was added at levels of 0%, 4%, and 8% to test preblending possibilities. Four chilling treatments were conducted upon coarse ground vacuum packaged samples of each salt level for the pre-rigor processed blends. The four chilling treatments included CO_2 snow chill, agitated brine chill, 0°C chill, and -29°C chill. A fifth chilling treatment was the 0°C conventional chill of the side not processed pre-rigor. This treatment served as a post-rigor control for processing characteristic comparisons.

All salt level and chilling treatment (pre- and post-rigor) combinations were analyzed for fat, moisture, pH, water holding capacity, emulsifying capacity, odor, aerobic psychrophile, mesophile, and lactic acid bacteria counts. Patties from the 0% salt level blends for each chilling treatment were analyzed for cook loss and shear force to test for retail application.

Moisture content, fat content, pH, water holding capacity, and redness increased ($P<.05$) as salt level increased. Emulsifying capacity was highest at the 4% salt level and lowest at the 0% salt level.

Chilling treatments processed pre-rigor had higher pH and emulsifying capacities than the post-rigor processed control ($P<.05$). There was no difference ($P<.05$) in water holding capacity between

pre- and post-rigor processed treatments. There were no differences in color, cookloss, or shear force between pre- and post-rigor chilling treatments ($P<.05$). There was a trend for aerobic, mesophilic, psychrophilic, and lactic acid bacteria counts to be lower for the post-rigor chilling treatment than for the four pre-rigor chilling treatments.

Results indicate that pre-rigor cow beef is equal to or superior than post-rigor cow beef for use in preblends containing approximately 4% salt or for use in retail or food service ground beef patties.

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CHAPTER I

INTRODUCTION

The destination of most fed livestock produced in this country today is the packing house. Farmers spend millions of dollars every year feeding and fattening animals for the market. Packers and processors spend additional millions chilling carcasses, cutting them up, packaging them as hundreds of types of products, and shipping them nationwide.

The conventional methods of processing an animal into a marketable meat product involves facilities unique to no other industry. Carcasses are bulky, heavy and irregular in shape and require complicated systems of overhead rails and labor to move them around. Large doorways are needed for moving carcasses and thus cause cold air losses and decreases in cooler efficiency. Bones and other inedible materials present on carcasses are chilled as the carcasses are chilled and yet require reheating in the rendering process. There is even a 2-4% shrink loss that occurs as carcasses are chilled. These problems in conjunction with increasing energy costs are driving the product costs for meat upwards (Williams, 1978).

The emergence of hot processing during the past couple of decades offers many advantages to packers, processors and consumers. Processing rates are faster, cooler space need is reduced, and shrink loss is practically eliminated. There are also processing characteristics of hot-processed muscle that enable it to be used more functionally

than conventionally processed muscle. Resulting products can be lower in cost to produce, which may be reflected in retail prices. All of these factors help to enhance the packer-livestock feeder relationship.

However, another problem exists for the small farmer who may not feed livestock to specified degrees of finish. Dairy farmers often practically give their older, out-produced stock to the packer just so they can get some return for an animal that no longer is of economic benefit to have around the farm. These animals may have little if any intramuscular fat and consequently produce poor quality primal cuts. These animals also have a high bone and inedible material to muscle tissue ratio once again labeling them as poor quality. However, these animals have one trait in common with fed livestock. Each are composed of muscle that has relatively the same functionality. Therefore, the functional characteristics that are enhanced by hot processing lower value carcasses can give these carcasses more usefulness in the meat processing industry.

The objectives of this study were two-fold. The initial objective was to determine the usefulness of pre-rigor cow beef as a coarse ground salt-added pre-blend to be used in further processed meat products. Since method of chilling has been known to affect muscle protein functionality (Williams, 1978), treatments for this project involved chilling methods as well as salt level.

A second objective of this study was to determine the usefulness of finely ground pre-rigor cow beef as a source for a retail or food

service ground beef. The hamburger or ground beef pattie has emerged as a traditional and integral component of the American diet. In 1970, about 20% of the beef consumed in this country was consumed in the ground form. Today, the beef consumed in the ground form represents nearly 60% of this country's beef consumption (Nusbaum, 1979).

Through hot processing and either pre-blending or formulation into a retail product, the cow otherwise not highly useful to the farmer or meat processor may find a place in today's consuming economy.

CHAPTER II

REVIEW OF LITERATURE

1. ECONOMICAL ASPECTS OF HOT PROCESSING

The meat packing and processing industries utilize heavily resources and labor and have often been characterized as the most energy intensive of all the food industries (Smith, 1980; Hendrickson, 1981). Among all standard Industrial Classification groups, Unger (1975) estimated that food products ranked sixth in energy use and first in labor use. Within the food and food product group, meat packing and processing was the fifth highest user of energy (USDC, 1977). Major sources of energy for the meat packing and processing industries include natural gas, 46%; electrical power, 27%; petroleum fuel, 14.5% and coal, 12%. With escalating energy costs, energy saving process innovations seem to be a requirement for improving process efficiency and will ultimately determine the industry process direction (Hendrickson, 1981). Escalating energy costs have focused meat packer and processor attention on alternative systems that reduce energy consumption.

One alternative system is that of hot boning or hot processing. Since 65% to 70% of all conventionally chilled beef carcasses are processed into boxed beef at the slaughter or processing plant, it seems to make sense that packers and processors are needlessly chilling excess fat and bone which are removed prior to boxing (Smith,

1980). In fact, recent studies on product quality indicated that hot boning or hot processing could be applied to produce vacuum packaged, boxed beef (Kastner, 1977; Anonymous, 1978; Cuthbertson, 1979).

Hendrickson (1981) found that conventionally chilling a 600 pound choice carcass for 20 hours and then holding that carcass for 48 hours resulted in a temperature drop from 100°F to 32°F. He found that the heat to be removed from this 600 pound carcass at 100°F (as calculated by the formula mass x specific heat x temperature differential) was roughly equal to approximately 31,824 BTU's of energy. The lean portion of the carcass (62%) had about 21,500 BTU's of energy whereas the fat and bone portions contained about 5,630 and 4,400 BTU's of energy, respectively. He found that a removal of unwanted bone and fat of 18% and 10%, respectively, resulted in only about 24,300 BTU's of product to be chilled or roughly a 24% energy reduction. Smith (1980) found that carcasses processed hot and boxed immediately require about 64 BTU per pound of finished product less energy than conventionally processed carcasses--a 42% reduction in refrigeration energy.

Hendrickson (1981) also found that a 600 pound choice carcass required about 80 in. x 36 in. x 30 in. or 86,400 cubic inches as well as an above-below carcass space requirement of 34,000 cubic inches resulting in a total space requirement of 120,400 cubic inches per carcass. Even in a bone-in boxed primal operation he found that each 600 pound carcass required about 90,000 cubic inches.

However, the edible portion of the carcass may be cooled in about 25,000 cubic inches. Therefore, on the basis of space requirements for cooling, hot boned cuts required 80% less space as compared to whole carcass chilling (Hendrickson, 1981; Cordray and Huffman, 1983).

Hendrickson (1981) also found that since hot boned beef was small in size relative to post rigor beef, the likelihood was possible for developing a steady meat flow through a cooling system. He estimated that through conveyorized freezing of hot boned beef, a 63% energy reduction could be realized through a 20% reduction in mass and a 40% energy reduction through improved chilling system design. To put those energy reductions into more meaningful dollar values, Smith (1980) showed that through space reduction and reduced energy consumption there could be a $.27 to $.34 savings per carcass. He has also shown a 2.65 cent per carcass savings gained from not using and maintaining shrouds and a $.65 savings per carcass gained through the disposal of the neck pins (i.e., no neck pin needed for hot boned carcasses). The result of these two factors alone shows a 3.30 cent savings per carcass. It was also found by Smith (1980) and Hendrickson (1981) that workers accustomed to boning hot carcasses could bone a hot side of beef in 18-20 minutes whereas 25-26 minutes were required for a conventionally chilled side of beef. This reflected a 25% reduction in labor, time, and a consequent increase in daily production. Smith (1980) did, however, find that more time was involved in wrapping and packaging hot meat. Although more time consuming in this respect, labor efficiency increased as workers'

hands remained more comfortable handling warm muscle than chilled muscle.

Other savings may be realized as sidelines of meat packing and processing industries utilize hot by-products for rendering and cooked meat products. Higher initial temperatures of these starting products create a lower energy demand from rendering (Kastner, 1982).

Another area of the economic importance of hot processing is yield. Schmidt and Keeman (1974) found that hot processing resulted in higher cutting yields when compared to conventional processing. Other research (Cuthbertson, 1980; Gilbert, 1978) showed a slight advantage or no advantage at all concerning yield of hot processing. Those researchers concluded that their observation of lower yield could be a direct result of difficulties in trimming hot carcasses and a lack in thoroughness of bone cleaning. Cuthbertson (1980) determined that these difficulties of trimming and boning may be overcome by using leaner cattle and improved trimming methods.

As can be seen from this presentation of economic aspects of hot processing, there are no clear-cut lines that can be established since each packing and processing plant must work under its own unique conditions, both physical and monetary. Opportunities for economic advantages exist, but only if packers and processors are willing to take risks and implement new ideas (Hendrickson, 1981).

2. PHYSIOLOGICAL ASPECTS OF PRE-RIGOR MUSCLE

The biochemical reactions which occur in intact muscle tissue of meat animals post-mortem have been studied in many investigations;

however, few authors have looked at the post-mortem changes in ground muscle. Postmortem changes in muscle, minced while in the pre-rigor state, are of increasing interest since processing of meat immediately after slaughter is of economic advantage (Hamm, 1977). Processing of beef before the onset of rigor mortis provides an excellent quality in sausages made from such meat (Hamm, 1972, 1982). Ground muscle in the pre-rigor state has a high water holding capacity (WHC) (Hamm, 1982), a high pH (Bate-Smith, 1938), a high oxygen consumption rate (Bendall, 1972), and a highly desirable ability to emulsify fat (Swift and Sulzbacher, 1963; Trautman, 1964; VanEerd, 1972). Those highly acceptable post mortem physiological processing properties of prerigor muscle are directly related to its high level of ATP which results in a more relaxed state and greater myofibrillar hydration and solubility (Hamm, 1972).

The regulatory enzymes which control ATP metabolism and glycolysis in the living tissue are still active in the muscle post-mortem, but those enzymatic mechanisms are not able to maintain the ante-mortem levels of ATP and glycogen because the oxygen supply of the cell is stopped as soon as blood circulation is interrupted by death of the animal. The lack of aerobic ATP synthesis from ADP in the muscle mitochondria results in a depletion of glycogen and consequently in a disappearance of ATP within a few hours postmortem. In this respect, there is no major difference between intact and ground tissue but only a difference in the rate of these postmortem changes (Hamm, 1977).

Since the rate of ATP (adenosine triphosphate) breakdown determines the rate of postmortem glycolysis, the grinding of prerigor muscle causes an accelerated hydrolysis of ATP as well as ADP (adenosine diphosphate) (Dalrymple and Hamm, 1975; Hamm, 1977). Hamm (1977) found that this rapid hydrolysis causes a faster increase in IMP (inosine monophosphate) concentration and hence an accelerated glycolysis. He also speculated that the increase in ATP turnover by grinding prerigor meat might be due to a faster release of Ca^{+2} ions from the grind-damaged sarcoplasmic reticulum and the exchange of Ca^{+2} with sodium. This speculation was produced into fact by Honikel and Hamm (1978) in a study measuring the influences of temperature and salt content on ATP depletion.

One influence for an enhanced ATP breakdown rate is the addition of salt usually in the form of sodium chloride (NaCl) (Dalrymple and Hamm, 1975; Hamm, 1977; Honikel and Hamm, 1978; Marsh, 1981). Although effects of salt addition will be described in a later section, it is necessary to mention the effect of NaCl on ATP breakdown rate. Honikel and Hamm (1978) found that if NaCl is not added, the rate of ATP breakdown decreases with falling temperature to about 6°C but then increases with further cooling. A maximum rate is reached at -1°C at which temperature the meat remains for a relatively long period during freezing. They also found that if salted, the rate of ATP hydrolysis decreases with falling temperature until the meat is frozen. Above 3°C, Honikel and Hamm (1978) found concentration of ATP to be lower in salted than unsalted meat in the first hours

postmortem, but below this temperature the position is reversed. They also found that the influence of temperature on the rate of glycolysis with or without salt follows similar patterns. Therefore, according to these researchers, it is more desirable to salt prior to freezing rather than during preparation to ensure that ATP depletion during freezing is kept to a minimum.

The cessation of glycolysis basically results from the inactivation of the glycolytic control enzymes phosphorylase (E.C. 2.7.1.1) and phosphofructokinase (PFK-E.C. 2.7.1.11) and can also be influenced by a low pH and low or limiting levels of adenine nucleotodes (Dalrymple and Hamm, 1975). They noted however that it should be emphasized that the glycolytic control enzymes and the rate of glycolysis are actually governed by the adenosine triphosphate turnover rate (ATP-ase activity) through their response to the changing adenine nucleotide levels. Hamm (1977) noticed that after several hours postmortem an inhibition of glycolysis occurs in salted tissue and attributes this inhibition to a denaturation of the glycolytic enzymes by a low pH (around 6) and high ionic strength.

Corresponding with an increase in ATP depletion and lactic acid build-up in postmortem muscle tissue is a drop in pH (Bate-Smith, 1948; Hamm, 1960; Newbold and Harris, 1972; Marsh, 1981). Hydrogen ion concentrations has a marked effect on both physical and biological properties of meat. At the upper (basic) end of the pH scale, meat color is darker, meat is slimy and yielding to the touch, meat juices are not easily expressed, meat has a high electrical resistance and

salt does not easily penetrate meat to form a cure or pickle. Bacterial growth is also more favorable in high pH meat (Bate-Smith, 1948). Tenderness is another problem area in postmortem muscle. Newbold and Harris (1972) found that the rate and extent of postmortem pH fall are related to the tenderness of the resulting meat. They showed that beef is toughest at pH 6.0 and increases in tenderness as the ultimate pH increases above or decreases below this value. Numerous other studies have shown that meat cooked soon after slaughter was more tender than meat cooked soon after the development of rigor mortis (Moran and Smith, 1929; Ramsbottom and Strandine, 1949; Paul et al., 1952; deFremery and Pool, 1963; Marsh, 1964; Weidemann, Kaess, and Carruthers, 1967). Hence, prerigor pH values (about 6.5) are favorable for tenderness if the muscle is able to maintain this high pH. But, since the primary intention of aging meat for a period after slaughter is to lower pH while increasing tenderness (Bate-Smith, 1948), low pH meat has commonly been associated with tenderness. Also regarding pH and prerigor tissue, Marsh (1981) suggests that of the early post-mortem events and conditions that influence meat properties, many are independent of time at which the muscle is excised. Thus a muscle will reach the same ultimate pH, through glycolytic acid production regardless of the time of boning, 0, 10, or 100 hours postmortem. He advocates that pH may be safely ignored in specific relations to hot boning in order to concentrate on other pre-rigor features whose effects are strongly influenced by the length of time between slaughter and excision. Honikel et al. (1981) however found that a rapid drop

in pH followed by a leveling-off stage causes an increase in cold shortening prior to rigor mortis onset. In fact, they found that at a temperature of 16°C, rigor shortening increases with rising temperature thus reinforcing the idea that the rate of pH fall in muscle depends upon incubation temperature. Cold shortening (Hamm, 1982) can be explained by changes at low temperatures in the lipoprotein system of the membrane. These changes inactivate the ATP-driven calcium pump of the sarcoplasmic reticulum and increase the permeability of the membranes of the sarcoplasmic reticulum or mitochondria to calcium. The consequentally enhanced concentration of calcium in the myofibrillar space, together with still appreciable levels of ATP, initiates muscular contraction before the onset of rigor mortis. It is of practical importance to know the time of post-mortem storage after which rigor occurs at a given temperature. The length of this period depends on the temperature of the muscle because the time necessary for reaching pH 5.9 (rigor onset) increases linearly with falling temperature (Newbold and Harris, 1972; Honikel et al., 1981; Hamm, 1982).

Another pH related occurrence is known as thaw shortening (Newbold and Harris, 1972). This happens when frozen pre-rigor muscles are thawed. Thaw shortening can be prevented by keeping the muscle at a temperature just below freezing point for several days before allowing it to thaw. At this temperature, chemical changes for rigor development can occur while there is enough ice in the muscle to prevent shortening. Hydrogen ion concentration (pH) plays many other roles

in prerigor muscle utilization. However, these roles will be discussed as separate characteristics of pre-rigor meat.

High water holding capacity (WHC) in lean meat is a decisive factor for producing a high quality sausage (Hamm, 1982). Water holding capacity or hydration of meat is closely related to taste, tenderness, and color of the final product. Treatment such as transporting, storage, ageing, grinding, salting, curing, beating, freezing, thawing and drying are all affected by water holding capacity. Therefore, an investigation of meat hydration is not only of scientific but also of economic interest.

An easily understood definition of water holding capacity is the ability of meat to hold fast to its own or added water during application of any force such as pressing, beating or grinding (Hamm, 1960). pH greatly affects water holding capacity (Hamm, 1960, 1977, 1980, 1982; Honikel and Hamm, 1978; Honikel et al., 1981). Immediately after slaughter, meat has a very high water holding capacity due to a high pH. However, a rapid reduction in water holding capacity occurs until a minimum is reached in 24 to 48 hours postmortem. This initial fall in water holding capacity is due in part to the decrease in pH to 5.9 caused by glycolytic formation of lactic acid. This fall in pH is also independent of temperature (Honikel et al., 1981). A majority of the reasons for the loss of water holding capacity is due to the cleavage of ATP in postmortem tissues. Since ATP imparts the state of high hydration, this hydration is lost as ATP is destroyed.

Following a period of minimum water holding capacity, water holding capacity increases with increased storage time, thus enhancing muscle tenderness through ageing and protein degradation (Hamm, 1960).

The major reason for the high water holding capacity of pre-rigor muscle tissue is the high pH relative to post rigor tissue. At a high pH, protein is more associated with water, hence pre-rigor muscle tissue is also darker in color due to the hydration of proteins. Tissues high in fat and collagen also generally have a higher water holding capacity.

Among other factors that affect water holding capacity, the presence of salt is perhaps second most important only to pH. Above pH 5.9, the addition of salt causes a strong increase in water holding capacity of muscle homogenate (Hamm, 1960, 1977, 1982; Honikel, 1981). Since the addition of salt accelerates ATP breakdown, it is best to allow salt to penetrate tissue before the ATP concentration has fallen to a level at which the onset of rigor mortis occurs. However, Hamm (1977) found that the high water holding capacity of prerigor salted ground beef did not decrease post mortem in spite of the high rate of ATP breakdown. He attributed this property to the inhibition of rigor mortis in the muscle fiber fragments caused by a combined effect of ATP, high pH and salt ions. Honikel et al. (1981), on the other hand, found that rigor mortis did not influence the water holding capacity of unsalted muscle homogenates but caused a strong decrease in water holding capacity of salted muscle homogenates. However, he found that if muscle tissue was salted and ground pre-rigor, water holding capacity would be enhanced.

There are several methods for detecting water holding capacity of muscle tissue. These methods of detection can only be based on differences in the immobilization of free water. Most methods are based on measurement of loose water liberated by applying pressure on the muscle tissue. Hamm (1960) found several methods of detecting loose water. These included normal acceleration using forces of gravity or sedimentation, acceleration of gravity by centifugal methods, filtration, or pressing between two plates to express moisture. Of these methods, the pressing methods are generally more favored due to ease and practicality (Hamm, 1960; Bowling et al., 1978; Honikel et al., 1981). Pressing methods were normally and originally used for cooked meats, but with the advent and use of filter papers, pressing methodology became a quantitative technique (Hamm, 1960). The more loosely water is bound, the better it is absorbed by filter paper when pressure is applied to the water-holding muscle tissue. The area of the moisture ring is proportional to the amount of loose water. According to Hamm (1960), advantages to pressing methods included: (1) the technique was applicable for ground and unground tissues with or without added water, (2) only a small amount of tissue was needed, (3) the technique required very little time, and (4) the resulting moisture ring was fixed and could be evaluated any time after the test. However, Hamm (1960) also found that the pressing technique was not applicable for samples that contained large amounts of fat or samples that contained more than 100% added water. Using a Carver laboratory press, Grau and Hamm (1953) and Bowing et al. (1978)

found that a pressure of 282 kilograms per square centimeter for 5 minutes produced the best results as long as the sample being tested weighed 300 milligrams. Wierbicki and Deatherage (1958) and Ockerman (1981) however found that pressing a 400 to 600 milligram sample under 500 pounds per square inch for 1 minute gave reproducible results within a 2% to 5% range. Also using a Carver press, Miller and Harrison (1965) found that 300 milligrams pressed under 10,000 pounds per square inch for 5 minutes produced the best results for water holding capacity.

Another popular method of detecting water holding capacity is through measuring cooking loss (Honikel et al., 1981). Using this method, they placed 5 grams of muscle homogenate into a preweighed corex centifugal tube and covered the tube with a glass marble. They next placed the tube in a boiling water bath for 20 minutes. The contents were then allowed to cool after which the juice was drained. The cooked meat was then blotted with filter paper, replaced into the boilding tube, and reweighed to determine percent moisture loss during cooking.

Since pH greatly affects water holding capacity--the minimum being found at the isoelectric point of actomyosin or a pH of 5.0--there must be ways in which to maintain moisture retention. Hamm (1982) stated:

> It must be regretted that the excellent processing properties of pre-rigor meat are not widely used and that methods for preserving these properties of hot meat by pre-salting and freezing are not generally applied.

Hamm found that the high water holding capacity of unsalted prerigor ground beef could be preserved by freezing the ground beef in 1 cm. layers at -40°C and holding the frozen tissue below -18°C to prevent further ATP breakdown. He found that if prerigor frozen meat was thawed, shortening and contraction of muscle fibers occurred resulting in a loss of water holding capacity. To prevent this loss, Hamm found that frozen beef should be chopped with added salt and water without thawing. Under these conditions, sausages of excellent quality could be produced even after several months of storage. He also found that the high water holding capacity of prerigor salted meat could be preserved for years through lyophilisation. Honikel and Hamm (1978) conducted similar research and found that the high water holding capacity of pre-rigor beef could be preserved for months by rapid freezing of minced salted or unsalted muscle tissue prior to the onset of rigormortis and concurrent breakdown of ATP. Maintaining a high level of ATP results in a more relaxed state and a greater level of myofibrillar hydration and solubility. Hamm (1960) found that a minimum water holding capacity coincided with a maximum of muscle rigidity. Therefore he concluded that rigor mortis and ATP depletion were related to the decrease of meat hydration post mortem.

A final physiological aspect of prerigor muscle tissue that needs to be considered is the rate of oxygen consumption. Bendall (1972) found that the oxygen consumption rate falls to a steady level after 1 hour post mortem. However, he also found that greater tissue damage insured a greater oxygen consumption rate and a greater ATP

turnover rate. As temperature of the muscle tissue decreased, the oxygen consumption rate also decreased due to the rate limiting reduction of mitochondrial respiration as temperatures dropped. Bendall (1972) also found that in post rigor muscle, the oxygen consumption rate and ATP turnover rate were scarcely affected by the degree of comminution damage since the semipermeability of the fiber membrane had been lost during rigor onset and acidification.

3. PROCESSING CHARACTERISTICS OF PRE-RIGOR MUSCLE TISSUE

Economic desirability and physiological superiority lay the groundwork for a variety of other favorable characteristics of pre-rigor muscle tissue. Among these are numerous processing characteristics that take advantage of the physical and chemical states of prerigor muscle.

Salt has long been a valuable tool used in processing muscle. Basically, salt serves to retard microbial growth, solubilize myosin proteins, and contribute to taste (Kramlich, Pearson, and Tauber, 1980). Although other salts are applicable, sodium chloride (NaCl) is most often referred to for the previously mentioned properties. The ionic properties of sodium chloride enable this salt to affect processing characteristics of prerigor muscle tissues in a variety of ways.

Drerup, Judge, and Aberle (1981) conducted a study that involved the characteristics of salt and prerigor muscle tissue. This study compared characteristics of prerigor ground and salted

tissue, prerigor ground-post rigor salted, and post rigor ground and salted pork sausage ranging from 19% to 24% fat and 59% to 61% moisture. They found that prerigor ground and salted (w/w 2%) maintained a higher pH. However, they also concluded that while pH decline was accelerated by prerigor grinding, the extent of this decline may have been limited due to prolonged aerobic metabolism supported by the oxygen incorporated rather than solely due to the effect of salt. It has also been found by Hamm (1977) and Honikel and Hamm (1978) that the addition of salt to ground muscle before rigor development inhibits glycolysis and production of lactic acid and hence reduces the chances for oxidation and subsequent spoilage. Drerup et al. (1981) also found that prerigor ground and salted muscle tissue had a lower cooking loss. This characteristic, they concluded, was due to the improved moisture retention characteristic of high pH (pre-rigor) tissue.

Taste panels conducted by Drerup et al. (1981) indicated that pork sausage that was pre-rigor ground and salted had high juiciness scores and was less easily fragmented when cooked in patty form. Ockerman and Organisciak (1979), Siegel, Theno, Schmidt, and Norton (1978), and Viskase (1971) found that added salt in the amount of at least 0.6% helped extract salt-soluble proteins to the meat surface and thus improved the binding characteristics of the pre-rigor muscle tissue. Siegel et al. (1978) found that the addition of salt at a 2% level was optimal for protein extraction and subsequent bond of pre-rigor tissue.

Siegel and Schmidt (1979) found myosin to be the most capable of the muscle proteins for developing adequate binding properties

not only in sectioned and formed meats but emulsified and comminuted sausage products as well. They found that the extraction of myosin from the muscle required salt and phosphate levels of at least 2% and 0.3%, respectively. Salt and phosphate linearly increased the ability of myosin to bind meat pieces by solubilizing the protein. They also found that increasing protein levels in conjunction with increasing temperature increased binding ability when the temperature was in the 45-80°C range and protein was in the 2-8% range.

Ford et al. (1978) found that when crude myosin or a mixture of crude myosin and sarcoplasmic proteins with little or no added salt were added as binding agents in restructured meat products, adequate binding properties were produced. Macfarlane, Schmidt, and Turner (1977) found that the binding strength of myosin was greatest in the presence of salt up to 1.0M. At concentrations greater than 1.0M, the binding strength of myosin was not significantly higher than that of actomyosin. Therefore it was shown that the addition of myosin as the binding agent offered a method for improved binding quality without using unwanted high levels of salt and phosphate.

Findings from Pepper and Schmidt (1975) showed that hot-boned (pre-rigor) beef rolls gave higher cook yields and lower binding strengths than cold boned beef rolls in both salt added and salt-phosphate added treatments. They also found that bind strength generally increased with increased mixing time due to greater protein extraction. In a similar study, Soloman and Schmidt (1980) looked at the effect of vacuum and mixing time on the extractability and functionality

of pre- and postrigor beef. They found that pre-rigor vacuum mixed meat had higher crude myosin levels and that these levels were therefore more extractable by mixing. Since there was more extractable protein in pre-rigor muscle, they concluded that overmixed pre-rigor muscle was less susceptible to mechanical damage and subsequent loss of functional characteristics than overmixed post-rigor muscle. Saffle and Galbreath (1964) also found that 50% more salt soluble protein could be extracted from mixing pre-rigor beef than from mixing beef 48 hours post mortem. Concerning post-rigor beef, Booren et al. (1979) found that sarcoplasmic proteins decreased with increased mixing time while myofibrillar proteins extracted were highest after 8 minutes of mixing. Overall, they found that a 16 minute mixing time combined with 0.5% salt resulted in the best adhesion without toughness in post rigor beef.

Phosphates have also been used in post-rigor beef. Huffman et al. (1981) found that as phosphates were added, water binding ability of post-rigor tissue was enhanced. They also found that the addition of salt and phosphate to post-rigor ground beef increased cooking yield, tenderness, color and taste panel acceptability.

However, in prerigor ground tissue, Hamm (1977) found that the addition of phosphate in the presence or absence of salt resulted in an acceleration of ATP and glycogen breakdown and a subsequent decrease in pre-rigor processing characteristics.

One of the most widely used processing characteristics of prerigor muscle tissue is the capacity to form a stable protein, fat

and water emulsion. Pre-rigor muscle has a higher emulsifying capacity than does post-rigor muscle (Swift, Lackett, and Fryar, 1961; Swift and Sulzbacher, 1963; Hegarty, Bratzler, and Pearson, 1963; Trautman, 1964; Pearson et al., 1965; Inklaar and Fortuin, 1969; Froning and Neelakantan, 1970; Webb et al., 1970; VanEerd, 1972; Smith et al, 1973; Crenwelge et al., 1974; Marshall et al., 1975). According to Trautman (1964):

> Salt soluble protein and fat emulsions were the most stable of any of the protein fractions; however, the time post mortem had a very great influence on the fat-emulsifying capacity. The post-rigor salt soluble protein and fat emulsion separated at 45 minutes after blending. The pre-rigor salt-soluble protein and fat emulsion was extremely stable and did not separate until 10 hours after blending. The difference in separation time between the pre-rigor and post-rigor salt soluble protein and fat emulsions indicates that the pre-rigor proteins are several times as effective in fat emulsification as the postrigor proteins.

Various methods have been used to measure emulsification capacity of a specific protein system. A common method has been to observe the sudden drop in viscosity indicating emulsion endpoint (Swift et al., 1961; Pearson et al., 1965; Hegarty et al., 1963; Inklaar and Fortuin, 1969). Another method often used involves the measurement of change in amperage required to drive the blender motor used in forming the emulsion (Swift et al., 1961; Smith et al., 1973; Crenwelge et al., 1974). A third method has also been used in which electrical resistance between two electrodes in the emulsion is measured (Webb et al., 1970). Marshall et al. (1975) used yet another method for determining emulsion endpoint. They used colored oil droplets in determining the visual endpoint. The use of colored oil was associated

with significant reductions in the volume of oil required to produce emulsion endpoint and collapse. This difference was the result of the increased visibility of the coalesced droplets of colored oil. Since emulsion inversion point was more easily detected, there was also a reduction in error inherent to visual emulsion endpoint determinations. In fact, in all instances, they found that the colored oil technique did not decrease the precision of emulsion endpoint determination.

4. CARCASS CONDITIONING AND CHILLING OF PRE-RIGOR MUSCLE

Despite the highly desirable processing characteristics and ideal chemical makeup of prerigor tissue, a factor still exists that can eliminate the benefits of prerigor processing from a tenderness and palatability standpoint. The factor in reference is the manner in which the pre-rigor tissue is chilled. The muscle tissue can either be chilled prior to processing (carcass conditioning) or after being fabricated into wholesale or retail cuts while hot.

Identification of the optimum pre-rigor conditioning treatment should be based on considerations of energy requirements, labor expenditures, shrinkage, processing losses, and appearance and organoleptic characteristics of the retail product (Bowling et al., 1978). Most conditioning treatments involve a semi-rapid decline in carcass temperature thus accelerating the rate of pH decline and glycolysis.

Regarding individual cuts of meat from pre-rigor and post-rigor conditioned carcasses, Kastner and Russell (1975) found no flavor

difference and, in fact, found that hot boned cuts were consistently lower in percent loss than cold boned cuts. West (1983) found that temperature control during processing and storage was critical for insuring acceptable shelf life of ground products. High microbial counts on boneless meat associated with increased human and equipment contact, exposure to elevated processing room temperatures and heat from friction during grinding and mixing necessitated that direct temperature control be used. West (1983) proposed various types of temperature control. For prepackaging control, he suggested the addition of cryogenic materials such as carbon dioxide or liquid nitrogen to create the individually quick frozen effect for meats. For post-packaging temperature control, West (1983) suggested cryogenic tunnels, forced air systems and liquid contact chillers. Temperature control has been a costly problem in the production of ground products from chilled meat. However, West (1983) found that with pre-rigor (hot) meat, the problems were magnified since the temperature of raw materials was 25 to 30°C rather than 3 to 6°C as for chilled meat. Despite these problems, Taylor, Shaw, and MacDougal (1981) found that much of the weight lost by evaporation during conventional cooling of a beef side could be saved if the meat was removed from the carcass whole in the pre-rigor state and vacuum packaged as primals before chilling began. In most studies, the quality of the final product from hot processed meat depended upon the chilling method and storage procedure used in processing.

5. SENSORY ASPECTS OF PRE-RIGOR MUSCLE

Accompanying optimal characteristics for processing and production of meat products, acceptable sensory characteristics play an important role on the usage of pre-rigor muscle tissue. Sensory values most often utilized when describing pre-rigor muscle tissue include both mechanical terms and perceptual terms. Mechanical sensory terms include tenderness, texture and contortion whereas perceptual terms include flavor, juiciness and color.

Nusbaum (1979) found no sensory (other than taste and tenderness values) differences between pre-rigor and post-rigor ground beef patties. He therefore concluded that pre-rigor meat, when processed under proper conditions, could be utilized successfully in the production of frozen ground beef patties.

In a similar study involving hot deboning of beef with and without electrical stimulation, Taylor et al. (1981) found no differences between conventional boning and hot boning in juiciness, texture, or flavor. However they concluded that these characteristics depended strictly upon any type of pre-rigor conditioning. Their conclusions regarding effects of electrical stimulation will be presented later in this section when tenderness attributes of pre-rigor tissue are discussed.

Another project conducted by Dransfield, Brown, and Rhodes (1976) showed that when individual muscles of beef were excised soon after slaughter and were held at 10°C for 24 hours prior to chilling, the eating quality was equal to that from meat cut 24 hours post

differences in tenderness between hot boning and conventionally chilled carcasses. Accordingly, Cross et al. (1978b) concluded that instrumental analysis results do not correlate highly with sensory tenderness. In fact, most researchers have used sensory tenderness results as a basis for reporting.

It has often been shown that prerigor meat cooked soon after slaughter was more tender than meat cooked after the development of rigor mortis (Moran and Smith, 1929; Ramsbottom and Strandine, 1949; Paul et al., 1952; deFremery and Pool, 1963; Marsh, 1964; Weidemann et al., 1967).

But Falk, Hendrickson, and Morrison (1975) found while studying the effects of boning beef carcasses prior to chilling that there were no significant differences in tenderness between beef boned 3 hours post mortem and that boned at 48 hours post mortem. Pepper and Schmidt (1975) also concluded that hot boned beef rolls were quite acceptable from a tenderness and textural standpoint. However, Taylor et al. (1981) found that toughness was slightly greater for hot processed meat than for meat processed post-rigor.

Toughness in pre-rigor processed meat can be explained in several ways. Perhaps the majority of responsibility for the tenderness or toughness of pre-rigor processed meat can be accepted by the role of pH in muscle biochemical reactions. Newbold and Harris (1972) found that the rate and extent of post mortem pH fall were related to the tenderness of the resulting meat. They found that beef, for example, was toughest at pH 6.0 and increased in tenderness as the ultimate pH increased above or decreased below that value.

It has also been found by many researchers that a phenomenon called cold shortening caused toughness in pre-rigor muscle tissue (Locker and Hagyard, 1963; Davey and Gilbert, 1974; Dransfield et al., 1976; Taylor et al., 1981; Hamm, 1982). As explained by Hamm (1982), "cold shortening is muscular contraction before rigor mortis." He explained that cold shortening was caused by low temperature induced changes in the lipoprotein system of the membranes. The combination of the low temperature and lipoprotein changes caused the inactivation of the ATP-driven calcium pump of the sarcoplasmic reticulum and increased membrane permeability of the sarcoplasmic reticulum to calcium. The increased calcium levels in the myofibril in combination with existing ATP caused muscular contraction before rigor mortis. Davey and Gilbert (1974) explained the increase of the concentration of ionic calcium in the myofibrillar region as a "thirty to forty fold increase." They found further evidence that cold shortening and rigor mortis were separate and unassociated events, and they explained that contractions of 60% of the initial muscle fiber length had occurred before rigor mortis. One controlling factor that they determined to reduce cold shortening was the degree to which the sarcoplasmic reticulum had been developed. Cold shortening was less likely to occur in fast acting muscle rich in calcium absorbing reticulum than in slow acting muscles where the calcium absorbing reticulum was not so abundant.

A study conducted by Locker and Hagyard (1963) showed that maximum cold shortening occurred rapidly at 0°C. Minimum cold

shortening was encountered between 14°C and 19°C followed by a slow and steady increase in percent shortening above 19°C. The delayed shortening found at higher temperature was accompanied by a rapid decline in muscle extensibility. Therefore, they concluded that percent shortening increased as the onset of rigor mortis approached. They also found that the delayed shortening found with higher temperatures was reversible as evidenced by removing muscle pieces from the cold temperatures at various times and allowing them to return to normal length in a short matter of time.

Temperature was the major factor involved in causing cold shortening as found by Dransfield et al. (1976). This study showed that cold shortening would occur if pre-rigor meat temperature fell below 10°C to 14°C. Therefore, any cooling system that was efficient would cause cold shortening if applied immediately after dressing.

Cia and Marsh (1976) found both desirable and undesirable aspects of cold shortening in a study that investigated cooked properties of pre-rigor beef. They found that when the sternomandibularis muscle was cooked rapidly, a 60% length change and severe toughening occurred due to a shortening effect. However, if the carcass was held for 3 hours post slaughter prior to cooking, extreme shortening occurred. This shortening was so severe so as to shatter the myofibril structure and consequently this treatment produced a more tender cut of meat when cooked. Although more tender, these cuts with severe shortening reflected a very high fluid loss when exposed to a complete freeze and thaw cycle. This condition has been referred to by

Behnke and Fennema (1973) as thaw rigor. They found that if beef muscle was frozen pre-rigor and stored at a low subfreezing temperature, rapid thawing resulted in the highly undesirable phenomenon called thaw rigor. They characterized thaw rigor as a condition of ATP depletion, glycogenic breakdown, lactic acid accumulation, decreased pH, extreme contraction and excessive fluid loss. Newbold and Harris (1972) determined that greater shortening than that produced by cold shortening occurred in frozen pre-rigor muscles when rapidly thawed. In fact they also found that when thaw rigor exceeded 50%, large fluid loss from the meat occurred. To prevent thaw rigor, both Behnke and Fennema (1973) and Newbold and Harris (1972) found that if the muscle were maintained at a temperature just below its freezing point for several days before being allowed to thaw, chemical changes for rigor mortis development could occur while there was enough ice present in the muscle to prevent shortening.

Another change that Cia and Marsh (1976) found associated with cold shortening was contortion or shape change of the pre-rigor muscle. They found that pre-rigor muscle length decreased much more than volume therefore causing appreciable thickening. Conversely post-rigor muscle declined more in volume than in length and therefore a decrease in cross sectional area occurred. Concerning ground product, Cross et al. (1978a, 1979) found that beef patties from hot processed carcasses had less configurational changes than patties fabricated from chilled carcasses.

The opportunity for toughness and muscle contortion as caused by cold shortening can be prevented according to Taylor et al. (1981).

They found that cold shortening could be reduced or completely avoided by delaying chilling. However, they showed that maximum savings in time could be achieved when hot boning was combined with electrical stimulation. It has also been found that there were no adverse effects of electrical stimulation on physical, sensory or cooking properties of ground beef patties (Berry and Stiffler, 1981; Countreras et al., 1981; Cross and Tennet, 1981).

The tenderness and toughness phenomena continue to be subjects for current research as they are very important sensory traits of any meat product. However, the appearance of the meat as described in color terms is very important. In fact, Booren and Mandigo (1981), Kropf (1980), and Walker (1980) found that when selecting fresh meat, a bright cherry red color was the most important factor considered by the consumer at the point of purchase.

The two major red pigments in meat are myoglobin and hemoglobin. Booren and Mandigo (1981) found that myoglobin contributed to 90% of the red color in meat and functioned to store oxygen whereas hemoglobin contributed to 10% of the red color in meat and functioned to carry oxygen. Huffman (1980) explained that myoglobin, a sarcoplasmic protein, was comprised of a protein moiety, a globin (approximately 150 amino acid groups), and a heme prosthetic group. The heme prosthetic group, responsible for the color of myoglobin, consisted of four pyrrole rings connected by methine bridges with an iron atom in the center. There are three forms of myoglobin in fresh meat. Reduced myoglobin, oxymyoglobin and metmyoglobin are

represented by purple color, cherry-red color and brown color, respectively. The proportions of each of these forms of myoglobin in the muscle tissue have been found to determine the color of the meat (Cutaia and Ordal, 1964; Huffman, 1980; Booren and Mandigo, 1981). However, Jeremiah, Carpenter, and Smith (1972) found that the concentrations of these pigments did not serve as a reliable guide for monitoring visual color of beef.

The major reason for color change in muscle tissue has been found to be a result of a chemical change in the state of the myoglobin (Cutia and Ordal, 1964; Lanier, Carpenter, and Toledo, 1977; Huffman, 1980; Walker, 1980; Booren and Mandigo, 1981). Walker (1980) found that surfaces of freshly cut meat, upon exposure to air, changed quickly from a purplish-red due to myoglobin to a bright red due to oxymyoglobin. This color, however, did not last long due to oxidation of oxymyoglobin to metmyoglobin, the brown colored surface pigment. Booren and Mandigo (1981) found that there were five factors affecting the change from myoglobin to metmyoglobin. These factors were microbial contamination, light, oxygen tension, oxidizing agents and temperature. In addition to these factors, Lanier et al. (1977) found that the presence of artificial atmospheres and the drying of the meat surface could affect the color appearance of meat. Cutaia and Ordal (1964) found that initial pH and fat content affected the rate of metmyoglobin formation and that initial microbial load had little or no effect upon the conversion of oxymyoglobin to metmyoglobin.

Conversion of oxymyoglobin to metmyoglobin, although an important factor in acceptability of meat color, has not been the major issue

concerning the color of pre-rigor muscle tissue. The dark purple color of cuts from pre-rigor processed beef is one reason pre-rigor processing has not been well accepted by retail marketers. Although explanations vary, the phenomenon of dark purple color in pre-rigor processed muscle was explained by Huffman (1980) as the result of a higher degree of oxygen utilization in muscular enzymatic systems therefore maintaining myoglobin in a reduced state. Another explanation as found by Cornforth and Egbert (1985) showed that oxygen reserves in pre-rigor muscle tissue were used for mitochondrial respiration and this action maintained myoglobin in the reduced state. However, Huffman (1980) found that if oxygen were incorporated into pre-rigor meat products by flaking, reduced myoglobin became oxidized and resulted in the desirable cherry-red meat color. But where any unflaked pre-rigor chunks of muscle were imbedded in restructured steaks made with and without pre-rigor muscle, the purple reduced myoglobin state existed. This produced a visually unacceptable product due to the contrast in the pigment. He concluded that until there was better consumer acceptance of the reduced myoglobin color, pre-rigor muscle cuts would have difficulty selling at the retail level.

The measurement of meat color can involve two methods, human visual appraisal and instrumental analysis (Hunt, 1980). Each method, Hunt found, involved myoglobin chemistry of a meat surface phenomenon. These methods were found to generally fit into one of the following categories: (1) evaluation of a sample's color for selection purposes, (2) grading, (3) to obtain consumer response, (4) to meet marketing

specifications, and (5) to detect deteriorative color changes due to processing and storage.

Strange et al. (1974) found that the preferred method for measurement of consumer acceptability was color evaluation by a panel of trained observers. This method had several serious disadvantages for continuous evaluation of meat color changes. Panel measurements were time consuming, prone to subjective errors and limited in the number of evaluations which could be made at one time. Hunt (1980) determined that if a panel were to be used, the panel members needed to be screened for discrimination using a variety of color tests. He added that descriptive visual color scales needed to be used for trained panels whereas hedonic scales needed to be used for consumer panels.

Eagerman, Clydesdale, and Francis (1977) found that visual impressions of fresh meat color were formed from all three parameters of color, hue, value, and chroma. Other factors included gloss, relative pigment content and the presence of surface and moisture. They also determined that there was a mental "ideal value" for each parameter and factor and that deviations from that ideal in any direction caused meat to be rated lower visually. Since deviations could occur among any of the parameters, they concluded that instrumental methods were inaccurate in predicting visual color quality of fresh meats. Conversely, Clydesdale (1976) found that due to psychophysical relationships, it was possible to predict human sensory response by way of instrumentation in the color area more

easily than in other sensory areas. He stressed the need for instrumentation to establish optical classifications, meat-light interactions and quality concepts for meat color. Hiner (1954) pioneered instrumental meat color analytical techniques by concluding that the color of meat had both a psychological and a real effect on the consumer. He showed that the psychological effect occurred because the color caused an almost immediate positive or negative response, and the real effect was an indication of quality, amount of time held, temperature of holding, and how the product was handled.

Strange et al. (1974) suggested that reflectance measurement of color should be the instrumental methods of choice since it measured surface color as observed by the consumer and was nondestructive. They preferred colorimeters and spectrophotometers with reflectance attachments. The colorimeter required less than 30 seconds per measurement and could be used for large numbers of samples. Its major disadvantage was that a standard curve had to be established for each color difference meter used. The spectrophotometric methods were slower and did not give consistent agreement with sensory panel color evaluation. They found spectrophotometers advantageous since results from different instruments were comparable provided that the same reflectance attachment was used.

Hunt (1980) determined that instrumental methods were helpful in determining meat color due to meat's reflectance of incident light. He divided instrumental methods into methods that provided a physical

description and methods that reflected myoglobin properties. He suggested for descriptive color methods the Hunter, CIE-Tristimulus, and Munsell instruments. These instruments, he concluded, did not explain reasons for color changes but rather gave information regarding how a color was perceived. On the other hand, he found that reflectance and transmission spectrophotometry provided useful information relative to how a treatment affected pigment stability and that this data was able to be manipulated mathematically. He concluded that accurate instrumental analysis depended upon uniformity of physical factors such as glossiness and surface fiber orientation and that instruments could not make decisions on color acceptability.

Another factor that has been found to play a role in color acceptability of meat is packaging type. Mackinney, Little and Briner (1966) found that color, as seen through a packaging film, depended upon the physical characteristics of the film including opaqueness, translucence, glossiness, matteness and the degree of wrinkling that occurred when the film was used. Kropf (1980) determined that not only package type but also display lighting conditions affected the color of retail fresh meat. He found that display light effects could result from temperature evaluation at the meat surface, photochemical effects and differences in light rendition due to different spectral energy distribution patterns. He concluded that flourescent lamps, which radiated one-fifth as much heat as incandescent, when used at low intensity levels would optimize display life of red meat products.

6. MICROBIOLOGICAL CHARACTERISTICS OF PRE-RIGOR MUSCLE

The microbiology of meat is extremely important since it is the goal of industry to provide the consumer with meat and meat products of the highest quality (Kotula et al., 1980). As the use of pre-rigor muscle tissue increases throughout the industry for processing and economic reasons, packers must be aware of the potential for microbiological problems.

McMillin, Sebranek, and Kraft (1981) found that many conditions during hot processing of meat favored the growth of microorganisms. These included the high temperature of the meat during processing, the high oxidation-reduction potential of pre-rigor muscle tissue and the high pH of pre-rigor muscle tissue. However, it has been determined by Gill and Penny (1979) that intact, healthy, functioning muscle tissue was essentially free of microorganisms because of the scavenging action of the reticulo-endothelial system and the natural barrier membranes of the animal. After slaughter, the surface of the carcass and meat became innoculated with bacteria from contact with air or other surfaces which contained bacteria. In fact, as meat was ground, contamination from equipment and handling resulted and growth was further encouraged (McMillin et al., 1981). Duitschaever, Arrott, and Bullock (1973) found that bacteria that were normally present on the meat surface were distributed throughout the entire product by grinding. Hence, an ideal condition for their multiplication was created. They showed that since ground beef was not heated or otherwise processed to ensure the absence of pathogenic and

spoilage organisms, microbiological quality depended upon the meat used for grinding, sanitary conditions, practices during preparation, and time and temperature of storage. Stringer, Bilskie, and Naumann (1969) found that bacterial numbers on meat cuts increased as time in the distribution system progressed. However, Ockerman and Organisciak (1979) found that although aerobic plate count increased with refrigerated storage time, anaerobic plate counts in refrigerated product increased only up to six days and then decreased. Both aerobic and anerobic plate counts remained unchanged if the product was stored frozen.

The microbial quality of hot processed beef has often been of concern to researchers. In fact, it has been shown that the bacteriological quality of stored ground beef from hot boned beef carcasses was equal to or superior to ground beef prepared from chilled beef carcasses (Anonymous, 1978). Schmidt and Gilbert (1970) also found that pre-rigor excision (1 to 2 hours postmortem) with subsequent aging in vacuum packages at 59°F for 24 hours produced microbiologically acceptable beef. Cross et al (1978a) found that ground beef prepared from hot-boned carcasses had bacterial quality and shelf-life capabilities that were equal to or better than those of ground beef from chilled carcasses.

In a detailed study that investigated the bacteriological quality of ground beef prepared from hot and chilled beef carcasses, Emswiler and Kotula (1979) found aerobic plate counts in hot boned beef to be significantly lower than those from cold boned beef. They

also found no significant differences in MPN's of coliforms including E. coli. between hot boned and cold boned ground beef stored at 0°C. McMillin et al. (1981) agreed with the results found by Emswiler and Kotula (1979) provided that the ground beef patties were cryogenically frozen. They also found that patties held up to eight hours before chilling were equal to or better than conventionally processed product in microbial growth.

Acknowledging that meat came from a supposedly sterile source, Mercure (1967) found that contamination with microorganisms of the surface of meat was unavoidable. In a study that supported Mercure's findings, Lin et al. (1979) found that pre-rigor sausage samples stored at 2-5°C had higher total aerobic mesophile and lipolytic bacterial counts. They attributed these higher numbers of bacteria first to a higher pH resulting from the addition of salt and the concomitant reduction in glycolytic rate and secondly to the higher temperature of the meat during processing. Fung et al. (1980) also found that temperature control of hot-boned meat during the first several hours of chilling was critical from a microbial standpoint. Their temperature decline data indicated that hot-boned cuts had longer (several hours) periods of rapid bacterial growth (above 21°C) than conventionally treated cuts. They also found that even in a vacuum package (14 days at 2.2°C), hot-boned cuts had higher mesophilic and psychrotrophic counts than conventionally treated cuts.

7. GROUND BEEF FROM PRE-RIGOR MUSCLE TISSUE

If the many favorable characteristics of pre-rigor beef muscle could be utilized in a single product, ground beef would take advantage of most of them. Hot processed ground beef patties have been found to be superior to the conventionally processed product in sensory attributes such as tenderness, juiciness and overall acceptability (Cross et al., 1979; Jacobs and Sebranek, 1980; McMillin et al., 1981). Objective evaluation has shown that hot-processed ground beef shrunk less, had a higher pH and had less resistance to shear (Randall and Larmond, 1977; Nusbaum, 1979; McMillin et al., 1981).

In a study that evaluated the effects of freezing ground beef prior to rigor mortis and then cooking from the frozen state to eliminate thaw rigor, Jacobs and Sebranek (1980) found that ground beef patties from pre-rigor processed beef sides had greater consumer acceptability. Wells, Berry, and Douglass (1980) found that the higher moisture level in pre-rigor processed ground beef patties may have been a factor in the higher palatability scores they obtained for the same product.

Ground beef from hot processed carcasses has also been found to require unique storage conditions. Apple (1981) found that in combination with microbial cleanliness and low temperatures; a film with an oxygen transmission of 60-70 cubic centimeters per square meter per 24 hours at 73°F would provide vacuum packaged storage of

pre-rigor ground beef for up to 28 days at 36°F. These conditions were adequate to maintain product bloom throughout the entire storage period.

CHAPTER III

MATERIALS AND METHODS

Two Holstein cows that averaged 1,100 pounds in weight were slaughtered in the University of Tennessee Meat Science abattoir in the conventional manner. Carcasses were split prior to the onset of rigor mortis. One side was immediately boned while still hanging on the rail and the other side was wrapped in a moistened carcass shroud and held in a 32°F cooler for a 24 hour chill period to allow the onset of rigor mortis. Each cow represented one replication of the experiment.

The experiment was divided into five chilling treatments, the first four of which were conducted on the pre-rigor sides with the fifth conducted on the post-rigor sides. Meat from each treatment was also formulated with 0, 4 and 8% added salt in the form of crystalline sodium chloride (Table 1).

TABLE 1. Experimental Treatments

	Treatment				
	1	2	3	4	5
Processing condition	Pre-rigor	Pre-rigor	Pre-rigor	Pre-rigor	Post-rigor (Conventional)
Chill method	CO_2	Brine	0°C	-29°C	0°C
Salt content (%)	0, 4, 8	0, 4, 8	0, 4, 8	0, 4, 8	0, 4, 8

The 0% sodium chloride group for each pre-rigor chilling treatment was the first group to be processed. After the hot beef sides were completely boned, they were ground through a three-fourths inch plate and then mixed for 5 minutes in a Leland mixer. The hot mixed 0% salt meat was removed to a stainless steel tub and used for each of the four pre-rigor chilling treatments.

The first pre-rigor chilling treatment was conducted using CO_2 snow. CO_2 snow was added to 15 pounds of the pre-rigor ground muscle while the meat was mixed. The snow was applied at the same 1:10 ratio of CO_2 to beef as described by Cross et al. (1979); Emswiler and Kotula (1979) and Wells et al. (1980) until the meat reached a temperature of 0°C. The meat was then vacuum packaged into three, five-pound chubs using Cryovac barrier heat shrink bags and Cryovac double chamber vacuum packaging machine. After packaging, this treatment was held in the dark at 0°C for seven days.

The second pre-rigor chilling treatment was conducted using an agitated brine chill. The brine was formulated at a saturation point to achieve the coldest solution possible. This solution was held at -29°C for 24 hours prior to use. The solution was constantly agitated using compressed air bubbling out of holes in an anchored 1 inch diameter rubber hose. Three, five-pound vacuum packages of the 0% salt meat were chilled in this manner until an internal temperature of 0°C was reached. Temperature was monitored using a fourth vacuum package and a probe type thermometer. Meat from this chilling treatment was then held in the dark at 0°C for seven days.

The third chilling treatment used a 0°C cooler. Three, five-pound vacuum packages of the pre-rigor muscle tissue were stored in dark refrigeration at 0°C for seven days.

The fourth chilling treatment was a blast freeze process. Three, five-pound vacuum packages were placed in a -29°C blast freezer for 24 hours after which they were held in dark refrigeration at 0°C for six days.

The pre-rigor samples with 4 and 8% salt added were chilled in the same manner as the 0% salt added samples. The salt was added on a weight to weight basis during a five minute mixing period to insure uniform incorporation. Ten pound aliquots of each salt level were taken for use in the four pre-rigor chilling treatments. Samples were packaged in five-pound vacuum packages as in the 0% salt treatments. All treatment parameters were identical to the parameters for the 0% salt treatments mentioned previously.

The fifth chilling treatment was the control from the post-rigor half of the carcasses. Those sides of beef in each replication were chilled 24 hours at 0°C while shrouded. After the 24 hour chill, the sides were boned, ground and mixed in the same manner as the pre-rigor sides of the previous day. Also, as in the pre-rigor chilling treatments, the post-rigor meat was divided into three salt-added classifications, 0%, 4%, and 8%. Three five-pound vacuum packages of each salt level group were stored seven days under dark refrigeration at 0°C.

Evaluation of the chilling treatments in combination with the three salt levels began after the seven day dark refrigerated holding period for each treatment. Analyses of the four pre-rigor chilling treatments occurred one day prior to analysis for the fifth (post-rigor) treatment. For each chilling treatment (pre-rigor and post-rigor) and salt level combination, one five-pound chub was used for measurement of processing characteristics that included water holding capacity, emulsification capacity, pH level, color, fat content, and moisture content. A second five-pound chub from each treatment and salt level combination was used for microbial analyses, and a third chub from each of the 0% salt level groups in each chilling treatment was used to evaluate cooking loss and shear value. Shear and cooking loss were only tested on the 0% salt level groups since these were the only samples that could have retail application. The major interests in the 4% and 8% salt groups were functional characteristics such as water holding capacity, emulsification capacity, pH, and microbiological stability. These characteristics could play a major role in the use of these salt-added blends as pre-blends for further processing into processed meat products.

As found in the literature, the processing characteristics evaluated in this experiment were most commonly associated with product quality from processing and palatability standpoints.

The method used to obtain an indication of water holding capacity was adopted from similar methods used by Wierbicki and Deatherage (1958) and Ockerman (1981). Triplicate 0.3 gram samples from each

treatment and salt level combination (triple-ground, 1/8 inch plate) were placed on Wattman No. 1 filter paper and compressed between plexiglass plates using a Carver Laboratory Press at 10,000 psi for 5 minutes. A compensating polar planimeter was used to obtain the areas of pressed meat and expressed liquid. Water holding capacity was reflected as an expressible-liquid index and was calculated by dividing the meat ring area by the difference between the expressed juice and meat ring areas. Relative water holding capacity, although not reported, could be determined by subtracting the expressible-liquid index from one. These were the same method specifications and calculations as used by Miller and Harrison (1965).

Two methods were used to determine the emulsification capacity of the chilling treatment and salt combinations. The main method used was the visual method as described by Ockerman (1981). However, this method was backed up by measuring electrical resistance change using a Micronta Model 22193 Ohm meter as described by Webb et al. (1970) and Ockerman (1981). Emulsification capacity measurements were conducted on triple-ground (1/8 inch plate) samples in triplicate and reported as milliliters of oil emulsified per gram of sample.

The pH of the chilling treatment and salt combinations was measured using a Fisher Accumet Model 600 pH meter. The method used was the same as described by Ockerman (1981) and Koniecko (1979). All samples were measured in triplicate, and the samples were prepared by triple grinding each through a one-eighth inch plate.

Color values for each of the chilling treatment and salt level combinations were measured using the Hunterlab Color/Difference Meter Model D25-2 and a modification of the method described by Hunter (1958). Samples were single ground through a one-eighth inch plate and measured in triplicate. All samples were covered after grinding and allowed five minutes of light exposure before being measured. The samples were prepared by forming a pattie on an optically pure clear glass plate and hand-pressed so as to remove any air spaces between the glass and the sample. The Hunter colorimeter was standardized with a pure white color standard (L:91.03, a:-1.3, b:1.6). Measurements taken included the "L" range denoting lightness, the "a" range denoting redness, and the "b" value denoting blueness. Optically pure clear plates were cleaned and dried after each usage.

Moisture contents of each treatment and salt level combination were determined in triplicate by the vacuum oven drying procedure as described by A.O.A.C. (1975) and Ockerman (1981). Samples were prepared by triple grinding through a one-eighth inch plate followed by freezing in liquid nitrogen and powdering in a Waring blender. Two gram samples were enclosed in sample "envelopes" made from Whattman No. 1 filter paper and dried according to method specifications.

The same samples used to analyze for moisture were used for fat analysis. Fat content was determined by the Soxhlet method as described by A.O.A.C. (1975) and Ockerman (1981). Dried triplicate samples were extracted for 16 hours, air dried, oven dried for 4 hours, and weighed. Fat was determined by loss in weight from the dried moisture determination sample.

A second five-pound vacuum pack from each chilling treatment and salt level combination was used for microbial analysis. Aerobic plate counts for mesophiles, psychrophiles, and lactic acid bacteria in each treatment and salt level combination were made after sampling at 0, 2, 4, and 6 days of dark refrigerated (0°C) storage beyond the initial 7 days of dark refrigerated (0°C) storage. All samples were maintained in Cryovac heat shrink barrier bags and re-vacuumed after each day of sampling. Twenty-five gram cores were taken using a sterilized, sharpened coring device. Mesophiles were incubated on standard methods agar (BBL Microbiology Systems) for 48 hours at 32°C (89.6°F) before being counted. Psychrophiles were also incubated on standard methods agar (BBL MIcrobiology Systems) but were incubated 10 days at 4°C (39.2°F) before being counted. Lactic acid bacteria were incubated on A.P.T. agar (Difco Laboratories) and incubated 48 hours at 32°C (89.6°F) before being counted (Draughon, F.A., 1984; Kotula et al., 1980). Counts were recorded as Log_{10} colony forming units (American Public Health Association, 1980; Fung et al., 1980; Kotula et al., 1980).

All samples were diluted with sterile peptone (Difco Laboratories) water prepared as described by Draughon (1984). Dilution technique and Stomacher Model 400 (Cook Laboratory Products, Div. Dynatech Labs, Inc., Alexandria, VA) methodology were the same as described by Kotula et al. (1980) and Ockerman (1980). Microbiological evaluation of the various treatment and salt level combinations was conducted only on the first replication of the experiment.

A third five-pound vacuum package from the five chilling treatments and 0% salt level combinations was used to evaluate cooking loss and shear. As mentioned previously, the cooking and toughness qualities were only measured from the 0% salt level groups since these results could have reflected a possible use of one of the treatments for a retail product.

In order to create a more realistic retail product, each five-pound vacuum packaged chub that was to be used to measure cook loss and shear was formulated to 20-22% fat by using frozen fine-ground partially defatted beef fatty tissue supplied by Travis Meat and Seafood Company, Knoxville, Tennessee. This fat range was found to be the most common used in the literature (Cross et al., 1978a; Cross et al., 1979; Emswiler and Kotula, 1979). Final fat level was verified by modified Babcock method as described by A.O.A.C. (1975) and Ockerman (1981). The fat and lean components were mixed before a single grind through a three-sixteenths inch plate. After the grind, patties were formed using a Koppens Model VM400 Foodforming Machine. The four most uniform patties in each treatment were selected for cooking. Patties formed weighed 113 grams (4 ounces) and were stored at -29°C for 24 hours prior to cooking. After being weighed, the frozen patties were cooked on electric Farberware Broilers (Model 450-A) according to the method described by Cross et al. (1979). Cooking loss was calculated as percent total loss or weight loss divided by frozen weight and this quantity multiplied by 100. After cooking, the patties were allowed to cool to room temperature in preparation for

shear testing. The Instron Universal Testing machine (Model 1132) was used to evaluate shear. In order to fit into the shear compression cell, each patty was cut to a smaller diameter core using a sharpened biscuit cutter 2.5 inches in diameter. Each core was weighed in grams so as to claculate shear force in kilograms per gram of sample. A L.E.E. Kramer shear attachment was used to shear each sample according to the method described by Behnke, Fennema, and Haller (1973). However this experiment employed the use of a 500 kg load cell and a crosshead chart speed of 10 centimeters per minute. Total force across the chart was set at 100 kg.

All data were analyzed by analysis of variance with replicate, chilling treatment, and salt levels as independent variables (Snedecor and Cochran, 1967). A treatment by salt percent by replication error term was specified in all analysis of variance tests to eliminate possible interaction effects. The Tukey's Studentized range test was used to test the range of all means as well as differences between any pair of means (Sokal and Rohlf, 1981).

CHAPTER IV

RESULTS AND DISCUSSIONS

Prior to discussion of any of the results, differences in the replicate must be noted. Table 2 shows differences between replicates in fat and moisture content. The significant differences represented by the individuality of the carcasses were manifested any time a variable was compared between replications. However, the application of the analysis of variance procedure in combination with the Tukey's Studentized Range test (Sokal and Rohlf, 1981) eliminated the influence of replicate differences when variables were compared by treatment or salt level. For example, Table 3 shows this effect when evaluating fat and moisture content according to salt level.

The major processing properties evaluated are shown in Table 4. Significant differences in pH among the chilling treatments suggest an effect of rate of chill on ultimate pH. The post-rigor treatment 5 pH value was within an expected range of 5.3-5.7 although at the upper end of that range. The higher pH found in the CO_2 chill (treatment 1) was expected as noted in the literature since this method was the most rapid in terms of achieving the endpoint temperature of 0°C. All pre-rigor processed treatment values were significantly higher than the post-rigor processed treatment pH value.

Emulsification capacity results, also found in Table 4 showed that each of the four pre-rigor processed chilling treatments emulsified significantly more oil per gram of sample than the post-rigor

TABLE 2. Mean Fat and Moisture Content of Cow Beef[1] by Replicate

Variable	Replicate 1	Replicate 2
Fat Content (%)	7.115[x]	19.708[y]
standard deviation	±1.070	±1.793
Moisture Content (%)	69.490[y]	59,720[x]
standard deviation	±1.804	±2.090

[1]1/8 inch triple ground sample.

[xy]Means in the same row with different superscripts are significantly different at P<.05.

TABLE 3. Mean Fat and Moisture Content of Cow Beef by Salt Level[1]

Variable	Salt Level (%) 0	4	8
Fat Content (%)	14.091[z]	13.570[y]	12.573[x]
standard deviation	±6.486	±6.897	±6.401
Moisture Content (%)	66.684[z]	64.523[y]	62.608[x]
standard deviation	±5.093	±5.050	±5.175

[1]1/8 inch triple ground sample.

[xyz]Means in the same row with different superscripts are significantly different at P<.05.

TABLE 4. Mean pH, Emulsifying Capacity, and Expressible Liquid Index for Cow Beef[1] by Treatment

Variable	Treatment[2] 1	2	3	4	5
pH	6.029^{z}	5.950^{xy}	5.967^{y}	5.933^{x}	5.679^{w}
standard deviation	±0.252	±0.305	±0.295	±0.306	±0.084
Emulsifying capacity (ml oil/gram sample)	98.667^{y}	95.507^{x}	102.067^{z}	99.733^{y}	88.200^{zw}
standard deviation	±5.854	±10.014	±12.116	±10.274	±6.122
Expressible liquid index[3]	6.181^{w}	3.491^{w}	3.998^{w}	4.251^{w}	2.257^{w}
standard deviation	±5.315	±2.470	±3.762	±3.818	±1.630

[1]1/8 inch triple ground sample.

[2]Treatments: 1 = pre-rigor CO_2 chill; 2 = pre-rigor brine chill; 3 = pre-rigor 0°C chill; 4 = pre-rigor -29°C chill; 5 = post-rigor conventional chill.

[3]Expressible liquid index = meat area/juice area - meat area (Miller and Harrison, 1965).

[wxyz]Means in the same row with different superscripts are significantly different at $P<.05$.

processed chilling treatment. This finding agreed with the literature; however, it was interesting to note that the 0°C chill (treatment 3) was significantly higher in emulsifying capacity than the other pre-rigor processed chilling treatments. Emulsification capacity was very difficult to measure using the electrical resistance method described by Webb et al. (1970) and Ockerman (1981). A constant decrease in resistance continued until actual collapse occurred. Endpoint determination was much more consistently determined by watching the emulsion break and listening for the change in motor sound at the breakpoint.

Converse to what was found in the literature, water holding capacity expressed in terms of expressible liquid index for pre-rigor processed treatments was not significantly different from post-rigor processed treatments at the 5% level (Table 4). However, the index values for the pre-rigor treatments were all higher than those for the post-rigor treatments. It should be noted that a larger ratio indicates an increase in the meat area thus showing more bound water. Since water holding capacity has been shown to be directly related to pH, it is interesting to note that this relationship did not hold true in this case.

Table 5 shows the effects of salt level on processing characteristics. The significant differences found for all three of these variables were consistent with the literature. However, the lower emulsifying capacity for the 8% salt level than for the 4% salt level was unexpected and may reflect a maximum salt level

TABLE 5. Mean pH, Emulsifying Capacity, and Expressible Liquid Index for Cow Beef[1] by Salt Level

Variable	Salt Level (%) 0	4	8
pH	5.623[x]	6.043[y]	6.070[z]
standard deviation	±0.098	±0.224	±0.230
Emulsifying capacity (ml oil/gram sample)	91.648[x]	102.868[z]	95.988[y]
standard deviation	±6.830	±11.957	±7.847
Expressible liquid index	1.157[x]	4.852[y]	6.097[z]
standard deviation	±0.589	±3.369	±4.267

[1]1/8 inch triple ground sample.

[2]Expressible liquid index = meat area/juice area - meat area (Miller and Harrison, 1965).

[xyz]Means in the same row with different superscripts are significantly different at P<.05.

for optimum emulsification ability. Also reflecting significant difference was the effect of replicate on pH, emulsifying capacity, and expressible liquid index (Table 6). Differences in fat and moisture contents between replicates (Table 2) account for this significance. However, it should be noted that despite differences between replicates, the mean pH, emulsifying capacity, and expressible liquid index values expressed in the by-replicate analyses were consistently higher than means for the same variables for the fifth (post-rigor) treatment in the by-treatment analyses (Table 4).

Results from color analyses by treatment can be found in Table 7. Contrary to some literature reports, there were not significant differences in Hunter L, Hunter a, or Hunter b values between any treatments. Perhaps the effect of oxygen incorporation during grinding is responsible for this non-significance as Huffman (1980) found. Other reasons could include the effect of the vacuum-holding of the product, and since all five treatments were held in the same atmospheres, the reduced chemical state of myoglobin may have been prevalent throughout.

Salt content, however, did show significant effects upon Hunter a and Hunter b values (Table 8). Hunter L values, denoting lightness or darkness showed no differences between salt levels. A reason for differences between Hunter a and Hunter b values between salt levels could be related to the effect of salt level upon the water holding capacity expressed as expressible liquid index found in Table 5. Since water content has been shown to affect meat color (Eagerman

TABLE 6. Mean pH, Emulsifying Capacity, and Expressible Liquid Index for Cow Beef[1] by Replicate

Variable	Replicate 1	Replicate 2
pH	5.978[y]	5.845[x]
standard deviation	±0.334	±0.199
Emulsifying capacity (ml oil/gram sample)	91.296[x]	102.373[y]
standard deviation	±5.550	±10.699
Expressible liquid index[2]	3.415[x]	4.656[y]
standard deviation	±3.372	±4.069

[1]1/8 inch triple ground sample.

[2]Expressible liquid index = meat area/juice area - meat area (Miller and Harrison, 1965).

[xy]Means in the same row with different superscripts are significantly different at $P<0.05$.

TABLE 7. Mean Hunter Colorimeter Values for Cow Beef[1] by Treatment

Variable	Treatment[2] 1	2	3	4	5
Hunter L[3]	34.317[x]	34.600[x]	34.908[x]	34.425[x]	33.850[x]
standard deviation	±2.507	±2.494	±2.666	±2.634	±2.055
Hunter a[4]	22.567[x]	20.808[x]	20.150[x]	19.408[x]	22.692[x]
standard deviation	±3.746	±4.195	±4.483	±3.562	±2.155
Hunter b[5]	12.108[x]	11.742[x]	11.658[x]	11.233[x]	12.183[x]
standard deviation	±1.097	±1.684	±1.741	±1.694	±0.689

[1]1/8 inch triple ground sample.

[2]Treatments: 1 = pre-rigor CO_2 chill; 2 = pre-rigor brine chill; 3 = pre-rigor 0°C chill; 4 = pre-rigor -29°C chill; 5 = post-rigor conventional chill.

[3]Hunter "L" denotes lightness or darkness; 100 is perfect white, 0 is black (Pomeranz and Melona, 1982).

[4]Hunter "a" denotes redness/greenness; higher numbers indicate greater redness (Pomeranz and Melona, 1982).

[5]Hunter "b" denotes yellowness/blueness; higher numbers indicate greater yellowness (Pomeranz and Melona, 1982).

[x]Means in the same row with different superscripts are significantly different at $P<.05$.

TABLE 8. Mean Hunter Colorimeter Values for Cow Beef[1] by Salt Level

Variable	Salt Level (%) 0	4	8
Hunter L[2]	34.635[x]	34.600[x]	34.025[x]
standard deviation	±2.186	±2.564	±2.569
Hunter a[3]	18.385[x]	21.570[y]	23.420[z]
standard deviation	±2.843	±4.015	±2.741
Hunter b[4]	11.170[x]	11.780[y]	12.405[z]
standard deviation	±1.337	±1.661	±1.025

[1]1/8 inch single ground sample.

[2]Hunter "L" denotes lightness or darkness; 100 is perfect white, 0 is black (Pomeranz and Meloan, 1982).

[3]Hunter "a" denotes redness/greenness; higher numbers indicate greater redness (Pomeranz and Meloan, 1982).

[4]Hunter "b" denotes yellowness/blueness; higher numbers indicate greater yellowness (Pomeranz and Meloan, 1982).

[xyz]Means in the same row with different superscripts are significantly different at $P<.05$.

et al., 1977), it seems logical to relate the effect of salt on available moisture to final product color.

The differences indicated between replicate as found in Table 9 were to be expected. Factors besides fat and moisture levels that could have affected final product color could have included animal age, muscle activity, or muscle oxygen consumption rate at the time of slaughter.

Table 10 shows cooking loss and shear force values compared among the five chilling treatments. There was no significant difference in cooking loss or in shear force between any of the treatments. If shear force is considered as a measurement of toughness, then these findings contradict those of Taylor et al. (1981) who found pre-rigor processed meat to be tougher than post-rigor processed meat. Since all treatments were mixed and packaged in the same manner, similarities in protein extraction due to mechanical action were likely. Therefore shear force and cooking loss represented in this experiment may have been affected by consistencies in protein extraction, pH, and expressible liquid index among pre-rigor chilling treatments (see Table 4, page 53).

Significant differences, however, were found when shear force and cook loss were analyzed by replicate (Table 11). Once again, individual carcass composition was mostly responsible for these differences.

Microbiological growth patterns compared with salt level and treatment are found in Figures 1 through 9. It is important at

TABLE 9. Mean Hunter Colorimeter Values for Cow Beef[1] by Replicate

Variable	Replicate 1	Replicate 2
Hunter L[2]	32.367[x]	36.473[y]
standard deviation	±1.073	±1.432
Hunter a[3]	19.897[x]	22.353[y]
standard deviation	±4.294	±2.858
Hunter b[4]	10.723[x]	12.847[y]
standard deviation	±1.137	±0.753

[1]1/8 inch single ground sample.

[2]Hunter "L" denotes lightness or darkness; 100 is perfect white, 0 is black (Pomeranz and Meloan, 1982).

[3]Hunter "a" denotes redness/greenness; higher numbers indicate greater redness (Pomeranz and Meloan, 1982).

[4]Hunter "b" denotes yellowness/blueness; higher numbers indicate greater yellowness (Pomeranz and Meloan, 1982).

[xy]Means in the same row with different superscripts are significantly different at $P<0.05$.

TABLE 10. Mean Shear Force and Cooking Loss for 0% Salt Ground Cow Beef Patties[1] by Treatment

Variable	Treatment[2] 1	2	3	4	5
Shear Force[3] (kg/g)	2.570[x]	2.599[x]	2.526[x]	2.435[x]	2.544[x]
standard deviation	±0.180	±0.463	±0.172	±0.243	±0.516
Total Cookloss (%)	29.988[x]	34.238[x]	33.288[x]	31.238[x]	31.538[x]
standard deviation	±2.801	±6.061	±3.674	±4.302	±5.485

[1]113 g (4 ounce) patty formulated to 20-22% fat.

[2]Treatments: 1 = pre-rigor CO_2 chill; 2 = pre-rigor brine chill; 3 = pre-rigor 0°C chill; 4 = pre-rigor -29°C chill; 5 = post-rigor conventional chill.

[3]L.E.E. Kramer attachment for Instron Universal Testing Machine.

[x]Means in the same row with different superscripts are significantly different at $P<.05$.

TABLE 11. Mean Shear Force and Cooking Loss for 0% Salt Ground Cow Beef Patties[1] by Replicate

Variable	Replicate 1	Replicate 2
Shear Force[2] (kg/g)	2.826[y]	2.258[x]
standard deviation	±0.309	±0.264
Total Cookloss[3] (%)	34.085[y]	30.030[x]
standard deviation	±5.089	±3.096

[1]113 g (4 ounce) patty formulated to 20-22% fat.

[2]L.E.E. Kramer attachment for Instron Universal Testing Machine.

[xy]Means in the same row with different superscripts are significantly different at $P<.05$.

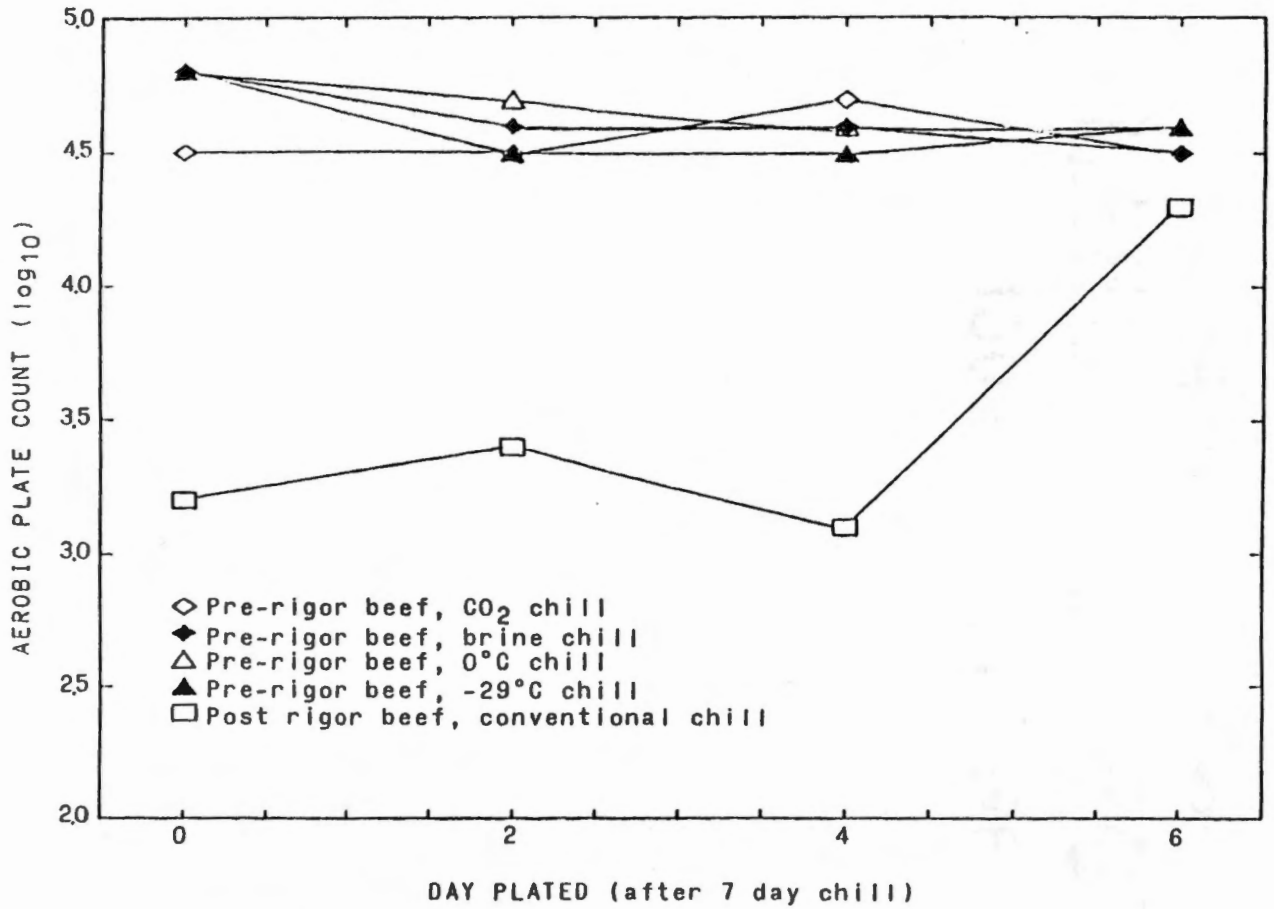

FIGURE 1. Logrithmic growth patterns for mesophiles among treatments containing 0% salt.

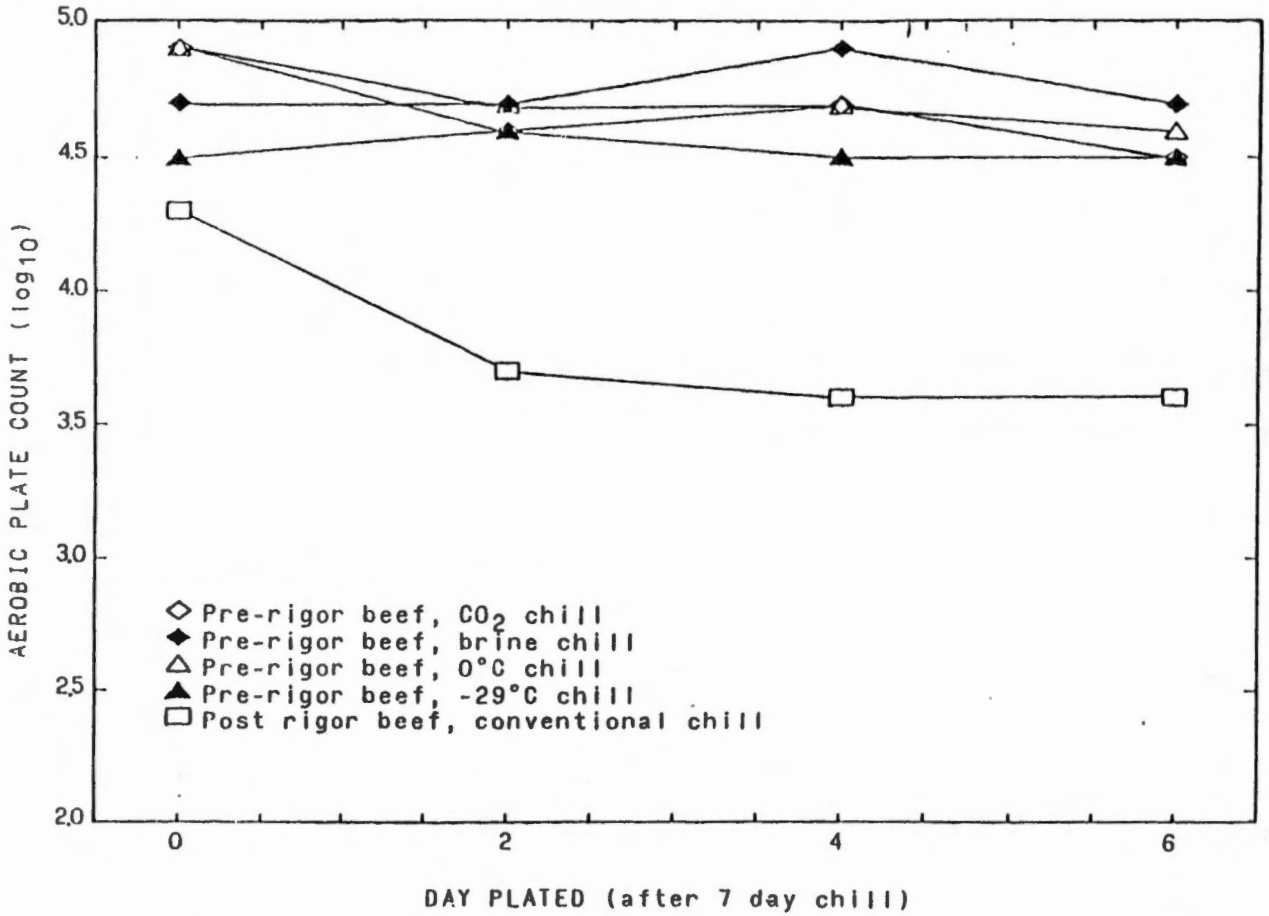

FIGURE 2. Logrithmic growth patterns for mesophiles among treatments containing 4% salt.

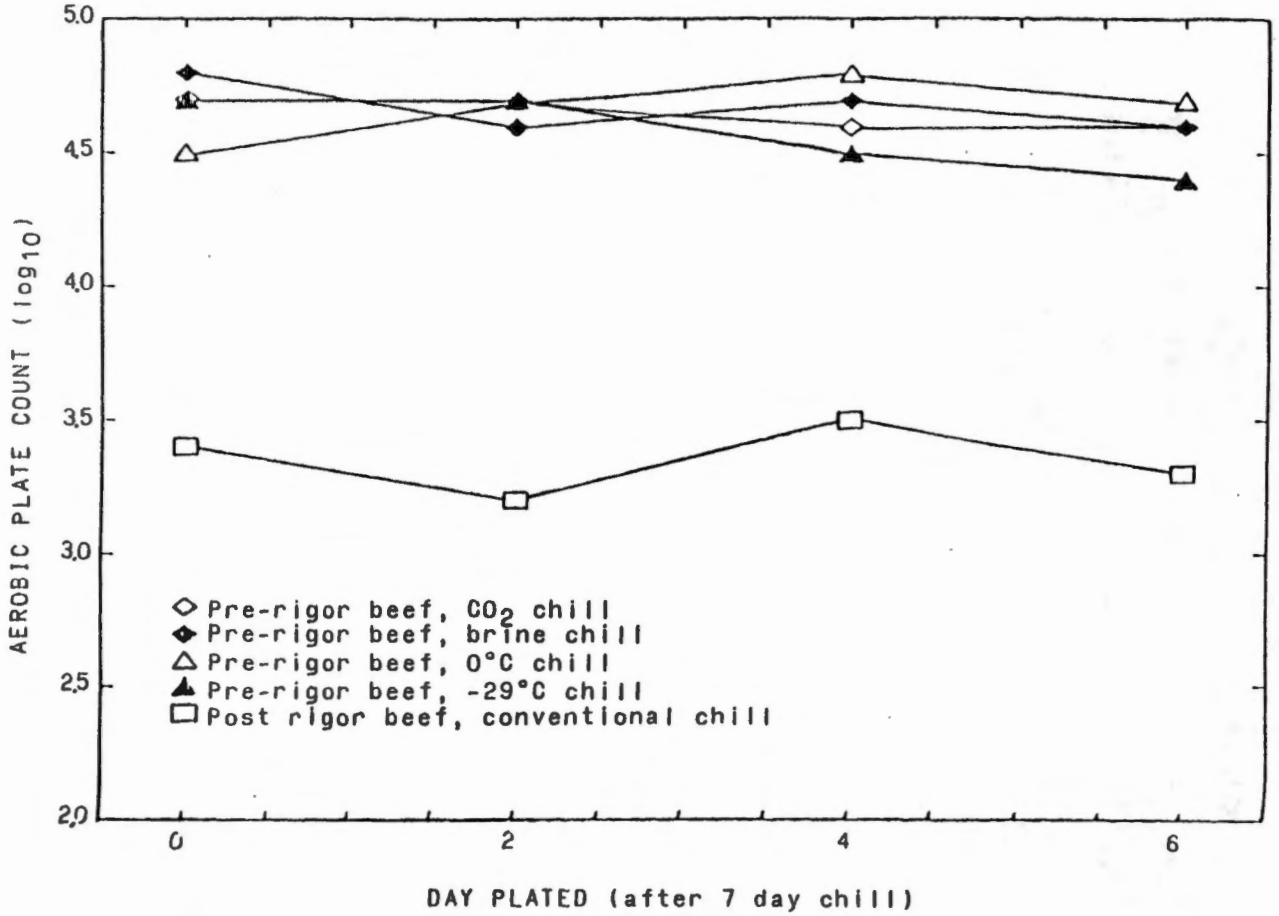

FIGURE 3. Logrithmic growth patterns for mesophiles among treatments containing 8% salt.

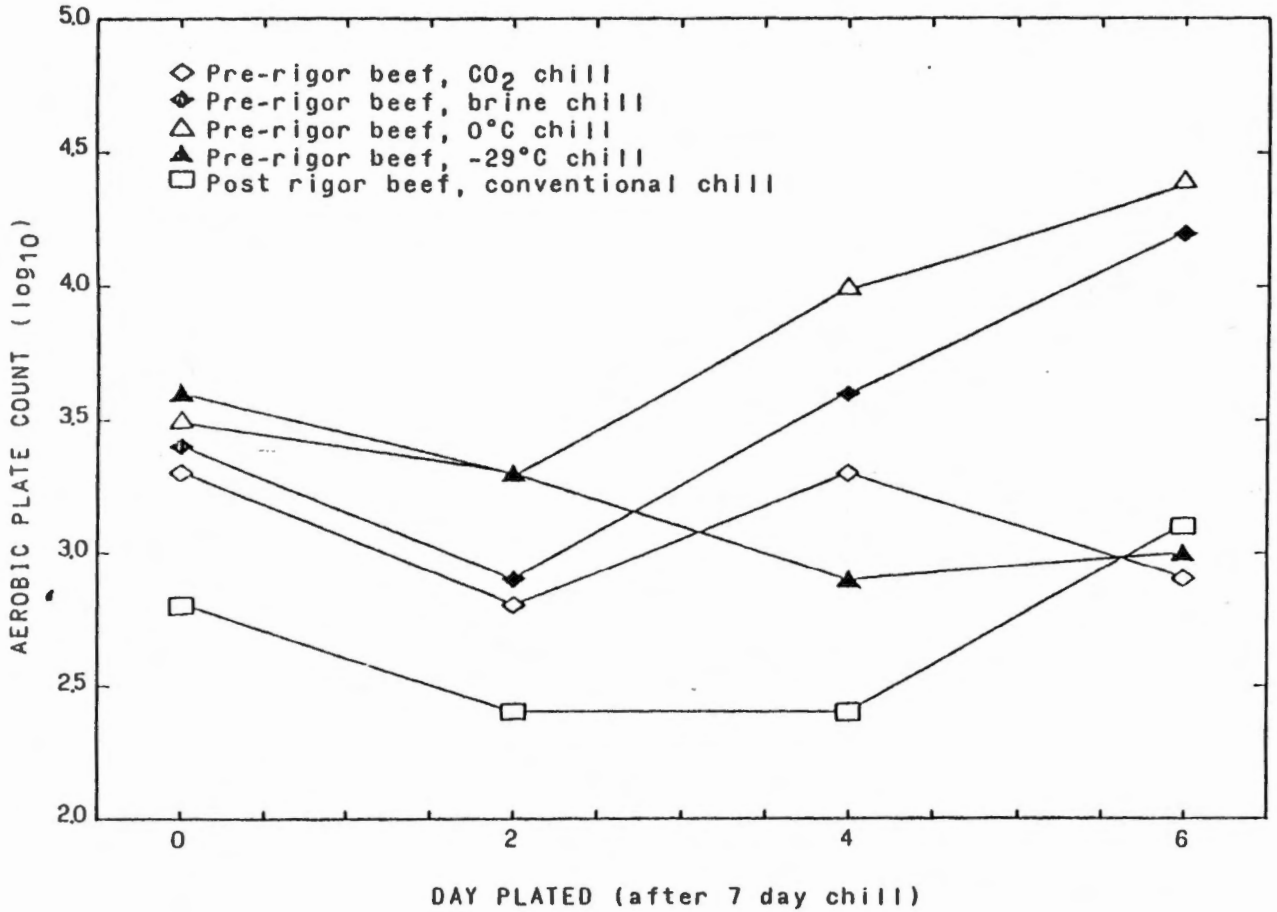

FIGURE 4. Logrithmic growth patterns for psychrophiles among treatments containing 0% salt.

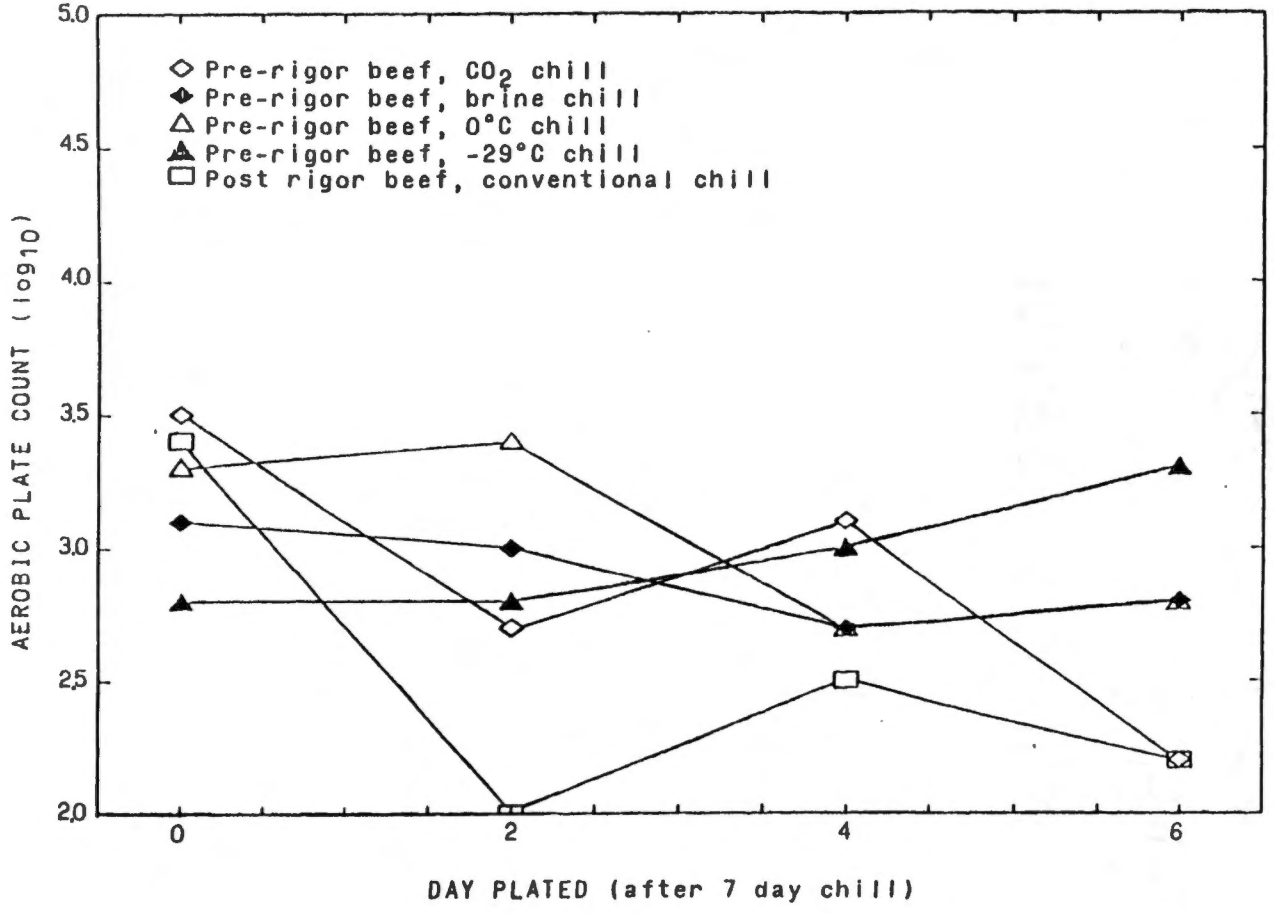

FIGURE 5. Logrithmic growth patterns for psychrophiles among treatments containing 4% salt.

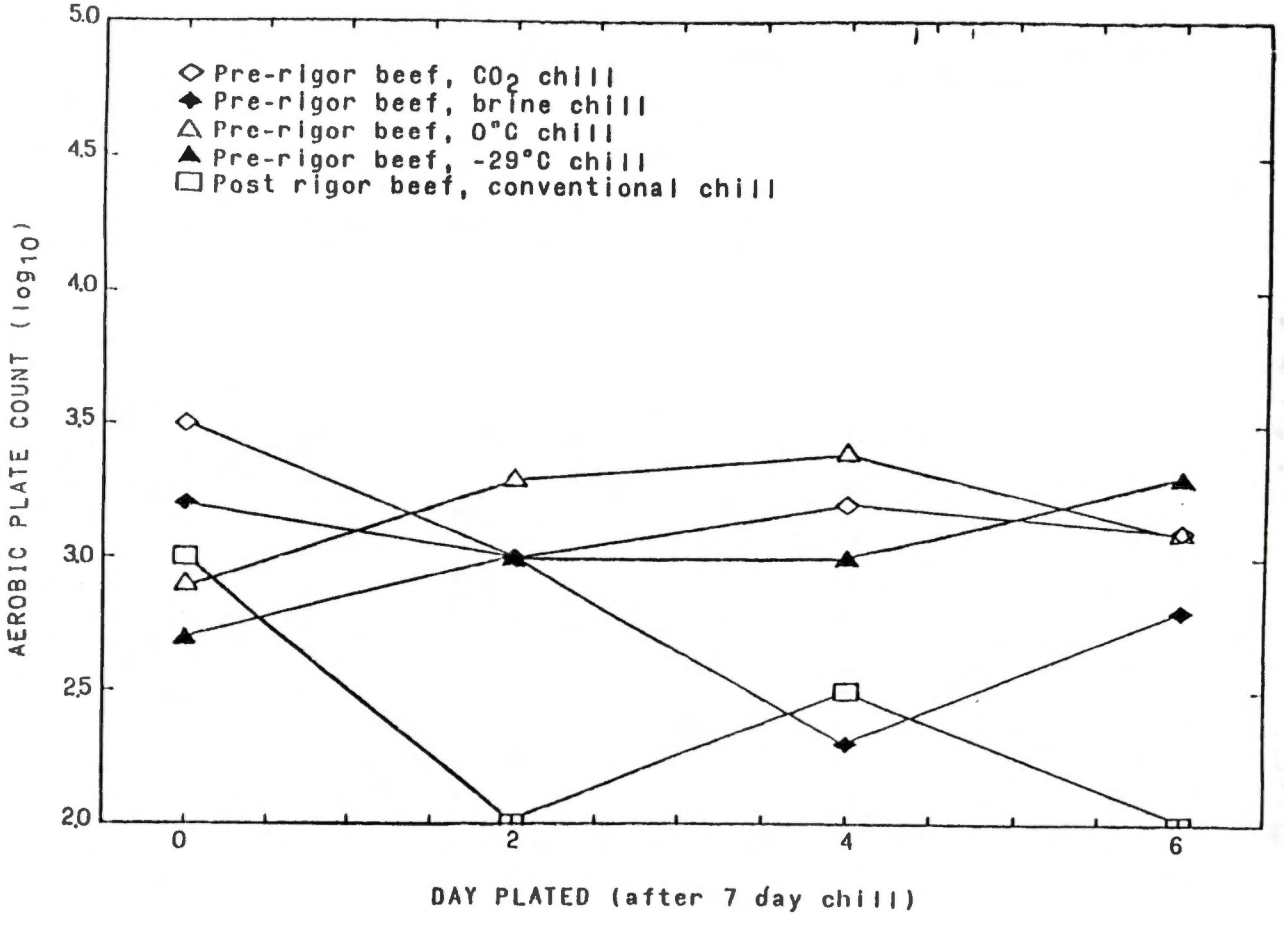

FIGURE 6. Logrithmic growth patterns for psychrophiles among treatments containing 8% salt.

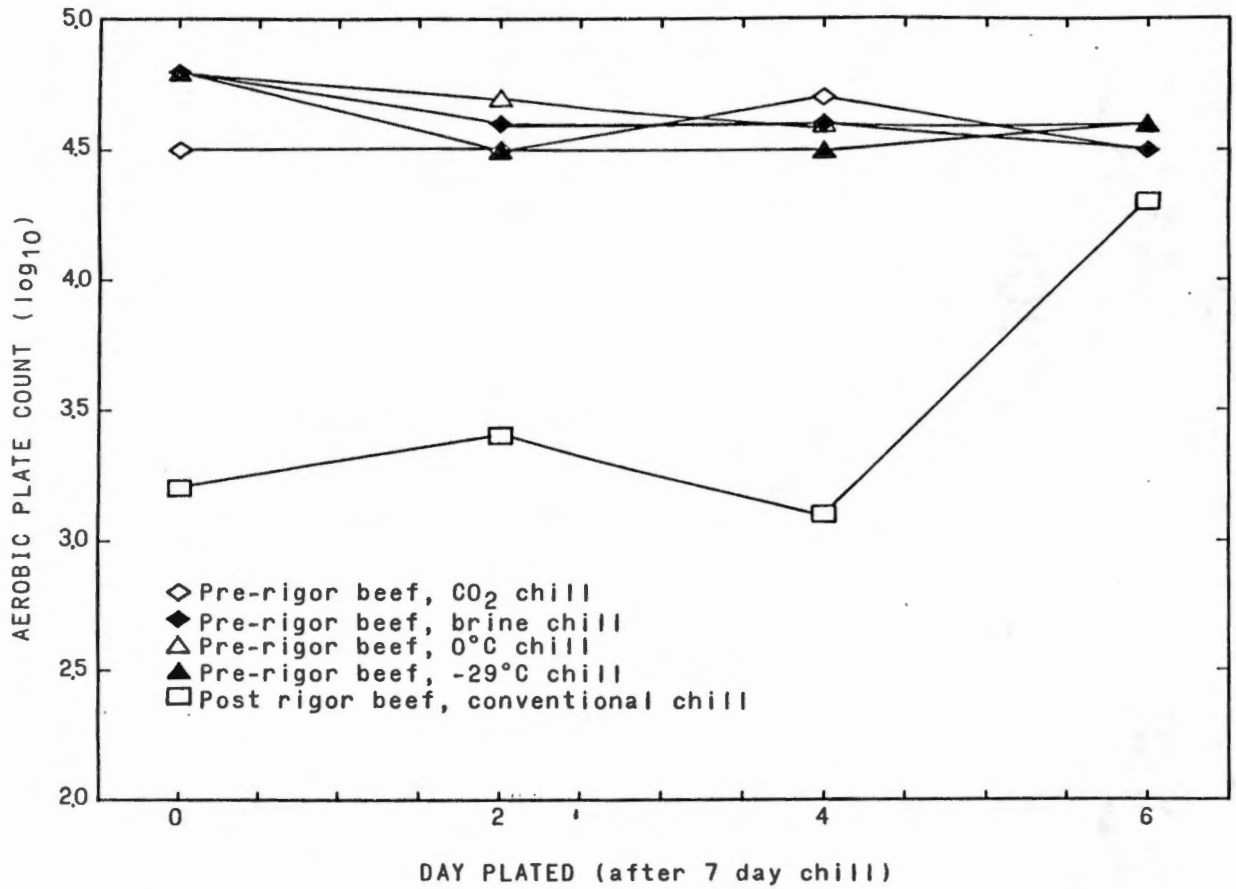

FIGURE 7. Logrithmic growth patterns for lactic acid bacteria among treatments containing 0% salt.

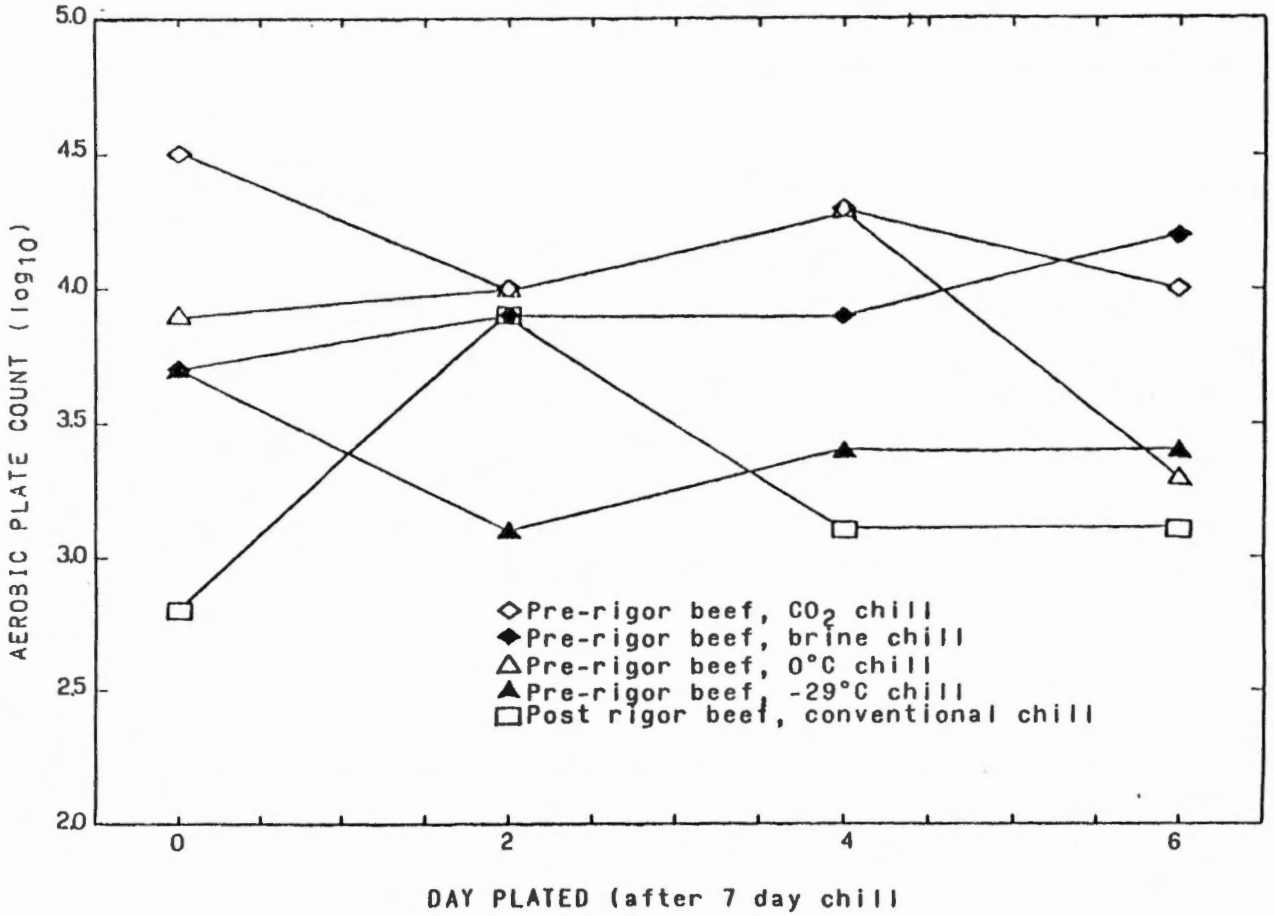

FIGURE 8. Logrithmic growth patterns for lactic acid bacteria among treatments containing 4% salt.

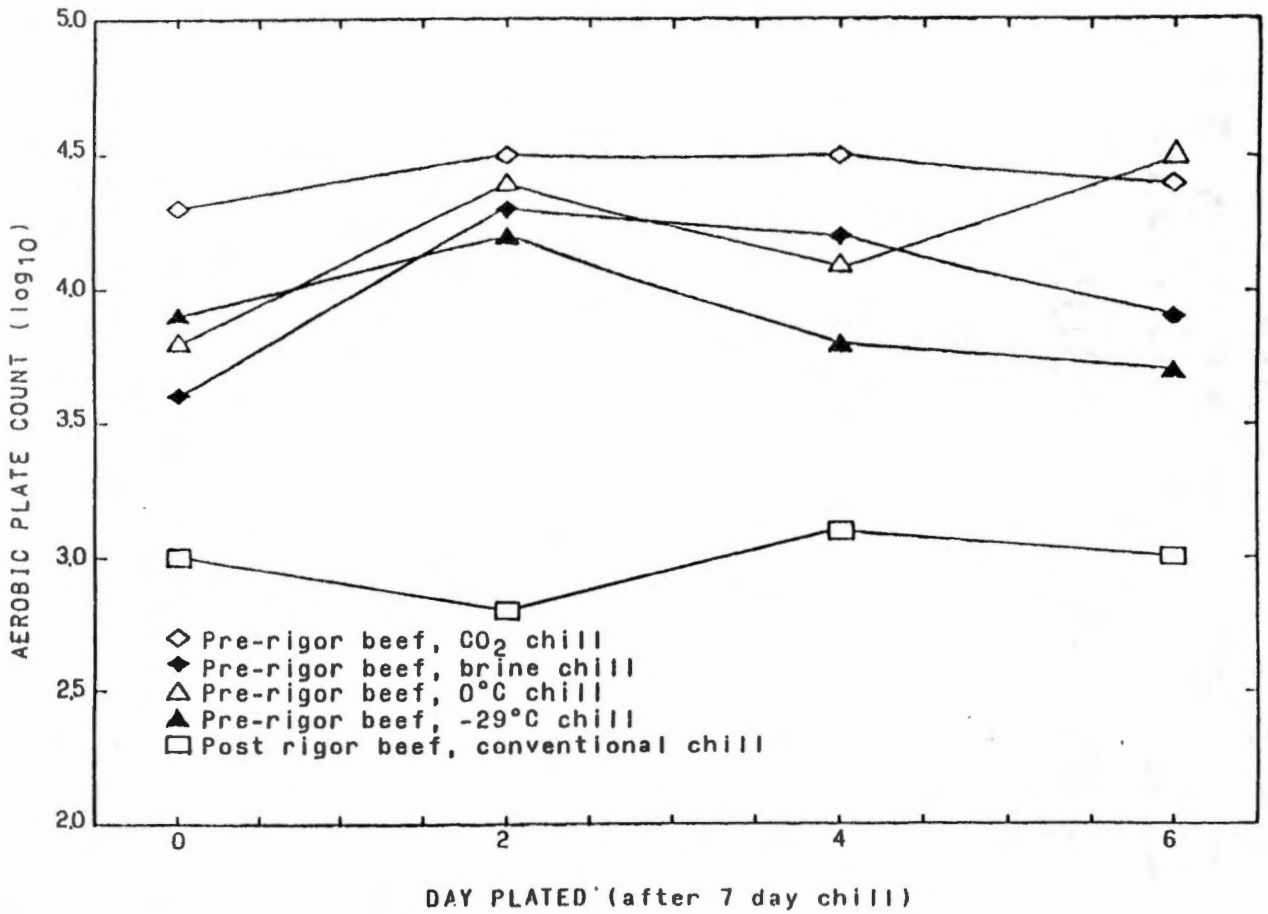

FIGURE 9. Logrithmic growth patterns for lactic acid bacteria among treatments containing 8% salt.

this time to note that microbiological data was collected only on the first replication of the experiment. Results concerning microbiological data can only be referred to as findings of trends since there was no experimental basis for significance testing.

Aerobic plate counts for mesophiles (Figures 1-3, pages 64-66) showed that the post-rigor chilling treatment (treatment 5) had lower mesophile aerobic plate counts than the four pre-rigor chilling treatment and salt level combinations. In fact, it was interesting to note the similarities between the mesophilic aerobic plate counts of the four pre-rigor chilling treatments. Mesophiles remained stable over time reflecting survival rather than growth. The highest mesophilic counts for all treatments were found at the 4% salt level whereas the lowest mesophilic counts for the pre-rigor treatments were found at the 0% salt level, and the lowest mesophilic counts for the post rigor treatment was found at the 8% salt level.

Figures 4 through 6, pages 67-69, show the areobic plate counts for psychrophiles for all chilling treatment and salt level combinations. The post-rigor chilling treatment was once again lower in aerobic plate count than the pre-rigor chilling treatments at all three salt levels. However, the differences between pre-rigor and post-rigor chilling treatments were not as extreme when enumerating these organisms as when enumerating the mesophiles. Regarding all treatment and salt level combinations, the psychrophiles showed much less growth than did the mesophiles. However, this may be a reflection of starting levels of the particular organisms. For example the

average starting level for psychrophiles in Figure 4, page 67, is about $\log_{10}$ 3.32 colonies whereas the average starting level for mesophiles in Figure 1, page 64, is about $\log_{10}$ 4.57 colonies. Starting levels for psychrophiles from all treatments at the 4% and 8% salt levels (Figures 5 and 6, pages 68 and 69) were also much lower than for mesophiles from the same treatments and salt levels (Figures 2 and 3, pages 64 and 65).

The lowest psychrophilic aerobic plate counts for the pre-rigor chilling treatment were found at the 4% salt level (Figure 5, page 68) whereas the lowest psychrophilic aerobic plate count for the post-rigor chilling treatment was found at the 8% salt level (Figure 6, page 69). The highest psychrophilic aerobic plate counts for all the chilling treatments were found at the 0% salt level as seen in Figure 4, page 67. In this figure, the pre-rigor brine chill treatment and the 0°C pre-rigor chill treatment show growth of over one log cycle. Growth reflected by these treatments indicates that the rate of initial temperature drop may not have been severe enough to inhibit the psychrophiles.

Figures 7 through 9 show the aerobic plate counts for lactic acid bacteria (lactics) for all chilling treatment and salt level combinations. General trends once again showed the post-rigor chilling treatment to be lower in microbial counts across all chilling treatment and salt level combinations. Pre-rigor treatment counts were tightly grouped therefore showing no extreme effect of one treatment over another.

The highest lactic acid bacteria aerobic plate counts for the pre-rigor chilling treatment and salt level combinations were found at the 0% salt level (Figure 7), and the highest for the post-rigor treatment was found at the 4% salt level (Figure 8). The lowest lactic acid bacteria counts for the pre-rigor chilling treatments were found at the 4% salt level (Figure 8) whereas the lowest lactic acid bacteria counts for the post-rigor chilling treatment were found at the 8% salt level (Figure 9).

Due to the similar values found for the pre-rigor treatments, it was difficult to make a judgment for one treatment's microbiological superiority over that of another treatment. However, a general trend that can be noticed is treatments 1, 2 and 3 were continuously high in starting microbial load at day 0 after 7 days refrigerated storage. Treatment 3 was higher in initial load more than treatments 1 and 2. Treatment 3 was also the most common treatment to finish the highest in microbial level after the sixth day of plating following the initial 7 days of refrigerated storage. The conventional post-rigor chill treatment consistently produced samples having the lowest microbial counts after 6 days of storage following the initial 7 days of holding in refrigeration at 0°C.

CHAPTER V

CONCLUSION

Two Holstein cows averaging 110 pounds were slaughtered in the conventional manner. The carcasses were split into a hot-processed side and a conventionally processed side. Muscle tissue from the hot-processed sides was formulated with 0%, 4%, and 8% salt. These salt treatments were then chilled by CO_2 gas, brine, 0°C air flow, or -29°C air flow. Variables measured included water holding capacity, emulsification capacity, pH level, color, fat content, moisture content, microbiological growth, cooking loss and shear value. The post rigor conventionally chilled side represented a fifth chilling treatment and was also formulated at 0%, 4%, and 8% salt. The same analytical, microbiological, and textural tests were conducted on this treatment as were conducted on the four pre-rigor chilling treatments.

One of the most noteworthy findings of this study was the reinforcement of the fact that carcasses with different muscle, fat, and moisture levels had different processing capabilities. The fatter replicate (replicate 2) had significantly lower pH, higher emulsifying capacity and higher water holding capacity.

The CO_2 chilling treatment was the most rapid method of chilling the pre-rigor muscle tissue. This method in turn showed higher pH levels and water binding ability. On the other hand, this method

showed darker red color and higher microbial contamination. CO_2 chilling would also obviously offset some of the savings gained through hot processing.

Brine chilling was also a "rapid chill" method as evidenced by relatively high pH levels. This method did show a relatively high cook loss and shear level thus indicating that it may be more desirable for a salt-added pre-blend to be used for further processing.

The 0°C chill also showed a relatively high pH level and although not significant, a water binding ability higher than the post-rigor chill treatment. This method also reflected the highest emulsification capacity of all treatments. This is the method of chilling most often used in the industury today for pre-rigor meat. It was interesting to note the relatively high microbial levels of this treatment which most likely resulted from the slower chill rate.

The -29°C chill method could have been more commonly referred to as "blast frozen." This was a rapid chill method that reflected a significantly higher pH and emulsifying capacity than the post-rigor chill treatment. Although not statistically significant, this treatment's water binding ability values were higher than those for the post-rigor chill treatment. This method of chilling could also be extremely expensive to processors.

The post-rigor conventional chilling method showed significantly lower pH and emulsifying capacity values. However, meat from this treatment was more acceptable in color and especially in microbial content. Water binding ability from this treatment was not significantly different than that of the pre-rigor treatments.

Salt level had a greater effect on the processing characteristics than did chilling treatment. Increasing levels of salt increased the pH, emulsifying capacity, and water holding capacity. Higher salt levels also showed greater redness. Although not quantitatively measured, higher salt level samples showed better protein extraction as evidenced by stickiness of handling. This protein extraction can benefit the formation of emulsions in further processing. Microbiologically, salt level did not dramatically affect aerobic plate count, although the preserving qualities of salt and the ionic atmosphere created by its presence have been known to improve microbial stability.

The results of this study indicate that hot-processing can improve the functional characteristics of cow muscle. Adding salt to pre-rigor processed cow meat creates pre-blends with desirable further processing characteristics. The more rapidly the pre-rigor muscle is chilled, the more functional it becomes for further processing. When formulated into a retailable product, pre-rigor processed cow beef was not significantly different from post-rigor processed cow beef. This study showed that through hot processing, rapid chilling, and salt addition, there is an important place in the meat industry for the low value cow carcass.

REFERENCES

REFERENCES

American Public Health Association. 1980. "Compendium of Methods For the Microbiological Examination of Foods." American Public Health Association, New York, N.Y.

A.O.A.C. 1975. "Official Methods of Analysis." 12th ed. Association of Official Analytical Chemists, Washington, D.C.

Anonymous. 1978. Optimal Methods for hot processed beef carcasses. Progress Report prepared for Packerland International, Inc. Prepared by the Meat Science Research Laboratory, Federal Research, SEA, USDA, Beltsville, MD.

Apple, J. M. 1981. Concepts of packaging pre-rigor meat. Proc. 34th Recip. Meats Conf. 34:85.

Bate-Smith, E. C. 1948. The physiology and chemistry of rigor mortis with special reference to the aging of beef. Adv. in Food Res. 1:1.

Behnke, J. R., Fennema, O. and Haller, R. W. 1973. Quality changes in pre-rigor poultry at -3°C. J. Food Sci. 38:275.

Behnke, J. R. and Fennema, O. 1973. Quality changes in pre-rigor beef muscle at -3°C. J. Food Sci. 38:539.

Bendall, J. R. 1972. Consumption of oxygen by the muscles of beef animals and related species, and its effect on the color of meat. I. oxygen consumption in pre-rigor muscle. J. Sci. Food Agric. 23:61.

Berry, B. W. and Stiffler, D. M. 1981. Effects of electrical stimulation, boning temperature, formulation and rate of freezing on sensory, cooking, chemical and physical properties of ground beef patties. J. Food Sci. 46:1103.

Booren, A. M., Jones, K. W., Mandigo, R. W. and Olson, D. G. 1979. Processing factors influencing binding of meat pieces into restructured, fresh beef steaks. Abstract Proc. 71st Annual Meeting of the Am. Soc. of Anim. Sci., Tucson, AZ. 71:214.

Booren, A. M. and Mandigo, R. W. 1981. Maximizing color in restructured steaks. Meat Ind. Oct. p.36.

Bowling, R. A., Smith, G. C., Dutson, T. R. and Carpenter, J. L. 1978. Effects of pre-rigor conditioning treatments on lamb muscle shortening, pH and ATP. J. Food Sci. 43:502.

Cia, G. and Marsh, B. B. 1976. Properties of beef cooked before rigor onset. J. Food Sci. 41:1259.

Clydesdale, F. M. 1976. Instrumental techniques of color measurement of foods. Food Technol. 30(2):52.

Contreras, S., Harrison, D. L., Kropf, D. H. and Kastner, C. L. 1981. Electrical stimulation and hot boning: cooking losses, sensory properties, and microbial counts of ground beef. J. Food Sci. 46:457.

Cordray, J. C. and Huffman, D. L. 1983. Restructuring of hot-processed meat. Proc. 36th Recip. Meats Conf. 36:74.

Cornforth, D. F. and Egbert, W. R. 1985. Effect of rotenane and pH on the color of pre-rigor muscle. J. Food Sci. 50:34.

Crenwelge, D. D., Dill, C. W., Tybor, P. T. and Landmann, W. A. 1974. A comparison of the emulsification capacities of some protein concentrates. J. Food Sci. 39:175.

Cross, H. R., Berry, B. W., Kotula, A. W., Wells, L., Emswiler, B. S., Tennent, I., Quick, J., Stanfield, M., and Muse, D. 1978a. Optimal Methods for Fabrication of Ground Beef, Prepared for the U.S. Army Natick Research and Development Command. Meat Science Research Laboratory Agriculture Research, S.E.A. U.S. Department of Agriculture, Beltsville, Maryland 20705.

Cross, H. R., Stanfield, Marilyn S. and Franks, W.J. 1978b. Objective measurements of texture in ground beef patties. J. Food Sci. 43:1510.

Cross, H. R., Berry, B. W. and Muse, H. D. 1979. Sensory and cooking properties of ground beef prepared from hot and chilled beef carcasses. J. Food Sci. 44:1432.

Cross, H. R. and Tennet, I. 1981. Effect of electrical stimulation and postmortem boning time on sensory and cookery properties of ground beef. J. Food Sci. 46:293.

Cutaia, A. J. and Ordal, Z. J. 1964. Pigment changes in anaerobically packaged ground beef. Food Technol. 18:757.

Cuthbertson, A. 1979. Hot processing of meat: a review of the rationale and economic implications. Meat and Livestock Commission, Bletchley, Milton Keynes, United Kingdom.

Cuthbertson, A. 1980. Hot processing of meat: a review of the rationale and economic implications. In Developments in Meat Science - 1, Chapt. 3, p. 61. Ed. R. Lawrie. Applied Science Publishers Ltd., London.

Dalrymple, R. H. and Hamm, R. 1975. Post-mortem glycolysis in pre-rigor ground bovine and rabbit muscle. J. Food Sci. 40:850.

Davey, C. L. and Gilbert, K. V. 1974. The mechanism of cold shortening in beef muscle. J. Food Technol. 9:51.

deFremery, D. and Pool, M. F. 1963. The influence of post mortem glycolysis on poultry tenderness. J. Food Sci. 28:173.

Dransfield, E., Brown, A. J. and Rhodes, D. N. 1976. Eating quality of hot deboned beef. J. Food Technol. 11:401.

Draughon, F. A. 1984. Microorganisms Common in Food Products, Resource Book.

Drerup, D. L., Judge, M. D. and Aberle, E. D. 1981. Sensory properties and lipid oxidation in pre-rigor processed fresh pork sausage. J. Food Sci. 46:1659.

Duitschaever, C. L., Arrott, D. R. and Bullock, D. H. 1973. Bacteriological quality of raw refrigerated ground beef. J. Milk Food Technol. 36:375.

Eagerman, B. A., Clydesdale, F. M. and Francis, F. C. 1977. Determination of fresh meat color by objective methods. J. Food Sci. 42:707.

Emswiler, B. S. and Kotula, A. W. 1979. Bacteriological quality of ground beef prepared from hot and chilled beef carcasses. J. Food Prot. 42:561.

Falk, S. N., Hendrickson, R. L. and Morrison, R. D. 1975. Effect of boning beef carcasses prior to chilling on meat tenderness. J. Food Sci. 40:1075.

Ford, A. L., Jones, P. N., Macfarlane, J. J., Schmidt, G. R. and Turner, R. H. 1978. Binding on meat pieces: objective and subjective assessment of restructured steakettes containing added myosin and/or sarcoplasmic protein. J. Food Sci. 43:815.

Froning, G. W. and Neelakantan, S. 1970. Emulsifying characteristics of pre-rigor and postrigor poultry muscle. Poultry Sci. 50:839.

Fung, D. Y. C., Kastner, C. L., Hunt, M. C., Dikeman, M. E. and Kropf, D. H. 1980. Mesophilic and psychrotrophic populations on hot boned and conventionally processed beef. J. Food Prot. 43:547.

Gilbert, K. V. 1978. The processing of accelerated conditioned beef. New Zealand 20th Meat Ind. Res. Conf., Hamilton. 26.

Gill, C. O. and Penney, N. 1979. Survival of bacteria in carcasses. Appl. and Environ, Micro. 37(4):667.

Grau, R. and Hamm, R. 1953. Eine einfache methode zur bestimmung der wasserbindung in muskel. Naturwissenschaften. 40:29.

Hamm, R. 1960. Biochemistry of meat hydration. Adv. Food Res. 10:355.

Hamm, R. 1972. "Kolloïdchemie des Fleisches." Paul Parey Verlag. Berlin, West German.

Hamm, R. 1977. Post mortem breakdown of ATP and glycogen in ground muscle: A review. Meat Sci. 1:15.

Hamm, R. 1982. Post mortem changes in muscle affecting the quality of comminuted meat products. In: "Developments in Meat Science." Applied Publishers, London. p. 93.

Hegarty, G. R., Bratzler, L. J. and Pearson, A. M. 1963. Studies on the emulsifying properties of some intracellular beef muscle proteins. J. Food Sci. 28:663.

Hendrickson, R. L. 1981. Energy aspects of pre-rigor meat. Proc. 34th Recip. Meat Conf. 34:81.

Hiner, R. L. 1954. Munsell disk and color paddles as methods of measuring color in meat. Proc. 7th Recip. Meat Conf. Ntl. Livestock and Meat Board, Chicago.

Honikel, K. O. and Hamm, R. 1978. Influence of cooling and freezing of minced pre-rigor muscle on the breakdown of ATP and glycogen. Meat Sci. 2:181.

Honikel, K. O., Fischer, C., Hamid, A. and Hamm, R. 1981. Influence of postmortem changes in bovine muscle on the water-holding capacity of beef. Postmortem storage of muscle at 20°C. J. Food Sci. 46:1.

Huffman, D. L. 1980. Processing effects on fresh and frozen meat color. Proc. 33rd Recip. Meats Conf. 33:4.

Huffman, D. L., Cross, H. R., Campbell, K. J. and Cordray, J. C. 1981. Effect of salt and tripolyphosphate on acceptability of flaked and formed hamburger patties. J. Food Sci. 46:34.

Hunt, M. C. 1980. Meat color measurements. Proc. 33rd Recip. Meat Conf. 33:41.

Hunter, R. S. 1958. Photoelectric color difference meter. J. Opt. Soc. Am. 48, No. 12, 985-995.

Inklaar, P. A. and Fortuin, J. 1969. Determining the emulsifying and emulsion stabilizing capacity of protein meat additives. Food Technol. 23:103.

Jacobs, D. K. and Sebranek, J. G. 1980. Use of pre-rigor beef for frozen ground beef patties. J. Food Sci. 45:648.

Jeremiah, L. E., Carpenter, A. L. and Smith, G. C. 1972. Beef color as related to consumer acceptance and palatability. J. Food Sci. 37:476.

Kastner, C. L. 1977. Hot processing: Update on potential energy and related economics. Proc. Meat Ind. Res. Conf. Amer. Meat Inst. Foundation. Chicago, Ill. p.43.

Kastner, C. L. and Russell, T. S. 1975. Characteristics of conventionally and hot boned bovine muscle excised at various conditioning periods. J. Food Sci. 40:747.

Kastner, C. L. 1982. Optimal hot-processing systems for beef. symposion on: Utilization of hot boning and electrical stimulation to increase meat quality and hot processing efficiency. Institute of Food Technologists Annual Meeting, 1982, Las Vegas, NV. Food Technol. Submitted for publication.

Kotula, A. W., Ayres, J. C., Huhtanen, C. N., Stern, N. J., Stringer, W. C. and Tompkin, R. B. 1980. Guidelines for microbiological evaluation of meat. Proc. 33rd Recip. Meats Conf. 33:65.

Koneicko, E. S. 1979. "Handbook for Meat Chemists." Avery Publishing Group, Inc., Wayne, New Jersey, p.62.

Kramlich, W. E., Pearson, A. M. and Tauber, F. W. 1980. Processed Meats, Second Edition, The A.V.I. Publishing Company, Inc., Wesport, Connecticut.

Kropf, D. H. 1980. Effects of retail display conditions on meat color. Proc. 33rd Recip. Meats Conf. 33:15.

Lanier, T. C., Carpenter, J. A. and Toledo, R. T. 1977. Effects of cold storage environment on color of lean beef surfaces. J. Food Sci. 42:860.

Lin, Hwei Shen, Topel, D. G. and Walker, H. W. 1979. Influence of prerigor and post rigor muscle on the bacteriological and quality characteristics of pork sausage. J. Food Sci. 44:1055.

Locker, R. H. and Hagyard, C. J. 1963. A cold shortening effect in beef muscle. J. Sci. Food Agric. 14:787.

Macfarlane, J. J., Schmidt, G. R. and Turner, R. H. 1977. Binding of meat pieces: A comparison of myosin, actomyosin and sarcoplasmic proteins as binding agents. J. Food Sci. 47:1603.

Mackinney, G., Little, A. C. and Briner, L. 1966. Visual appearance of foods. Food Technol. 20:1300.

Marsh, B. B. 1964. Meat quality and rigor mortis. In "Carcass Composition and Appraisal of Meat Animals," CSIRO, Melbourne, Paper No. 12.

Marsh, B. B. 1981. Properties and behavior of pre-rigor meat. Proc. 34th Recip. Meat Conf. 34:75.

Marshall, W. H., Dutson, T. R., Carpenter, Z. L. and Smith, G. C. 1975. A Research Note: A simple method for emulsion end-point determinations. J. Food Sci. 40:896.

McMillin, D. J., Sebranek, J. G. and Kraft, A. A. 1981. Microbial quality of hot processed frozen ground beef patties processed after various holding times. J. Food Sci. 46:488.

Mercure, M. 1967. Interpretation de la numeration bacterienne en regard de la qualite de la viande. Can. J. Public Health 58:457.

Miller, E. M. and Harrison, D. L. 1965. Effect of marination in sodium hexametaphosphate solution on the palatibility of loin steaks. Food Technol. Jan. 1965.

Moran, T. and Smith, E. C. 1929. Postmortem changes in animal tissues--the conditioning or ripening of beef. Special Report Food Invest. Board London No. 36.

Newbold, R. P. and Harris, P. V. 1972. The effects of pre-rigor changes on meat tenderness. A review. J. Food Sci. 37:337.

Nusbaum, R. P. 1979. Structural and palatability traits of ground beef hot boned, chilled and frozen muscle. Proc. 32nd Recip. Meats Conf. 32:23.

Ockerman, H. W. 1980. "Quality Control of Post-Mortem Muscle Tissue Volume 4 Microbiology." Ohio State University, p. 400.00, 410.00.

Ockerman, H. W. 1981. Quality Control of Post-Mortem Muscle Tissue. Volume 1 Meat and Additives Analysis. Ohio State University. P. 23.0, 51.0, 200.0.

Ockerman, H. W. and Organisciak, C. S. 1979. Quality of restructured beef steaks after refrigerated and frozen storage. J. Food Prot. 42:126.

Paul, P. C., Bratzler, L. J., Farwell, E. D. and Knight, K. 1952. Studies on tenderness of beef. I. Rate of heat penetration. Food Res. 17:504.

Pearson, A. M., Spooner, A. E., Hegarty, G. R. and Bratzler, L. J. 1965. The emulsifying capacity and stability of soy sodium proteinate, potassium casseinate and nonfat dry milk. Food Technol. 19:1841.

Pepper, F. H. and Schmidt, G. R. 1975. Effect of blending time, salt, phosphates and hot-boned beef on binding strength and cooked yields of beef rolls. J. Food Sci. 40:227.

Ramsbotton, J. M. and Strandine, E. J. 1949. Initial physical and chemical changes in beef as related to tenderness. J. Anim. Sci. 8:398.

Randall, C. J. and Larmond, E. 1977. Effect of method of comminution (flake cutting and grinding) on the acceptability and quality of hamburger patties. J. Food Sci. 42:728.

Saffle, R. L. and Galbreath, J. W. 1964. Quantitative determination of salt-soluble protein in various types of meat. Food Technol. 18(12):119.

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

Siegel, D. G. and Schmidt, G. R. 1979. Ionic, pH and temperature effects on the binding ability of myosin. J. Food Sci. 44:1686.

Schmidt, G. R. and Gilbert, K. V. 1970. The effect of muscle excision before the onset of rigor mortis on the palatability of beef. J. Food Technol. 5:331.

Schmidt, G. R. and Keman, S. 1974. Hot boning and vacuum packaging of eight major bovine muscles. J. Food Sci. 39:140.

Smith, G. C., Juhn H., Carpenter, Z. L., Mattil, K. F. and Cater, C. M. 1973. Efficacy of protein additives as emulsion stabilizers in frankfurters. J. Food Sci. 38:849.

Smith, E. W. 1980. Hot processing: Economic feasibility of hot processing beef carcasses. Bull. 639 Ag. Exp. Station, Kansas State University, Manhatton, Dec.

Snedecor, G. W. and Cochran, W. G. 1967. Statistical Methods (6th Ed.) Iowa State University Press, Ames, Iowa.

Sokal, R. R. and Rohlf, F. J. 1981. Biometry, Second Edition, W. H. Freeman and Company, San Francisco, California.

Solomon, L. W. and Schmidt, G. R. 1980. Effect of vacuum and mixing time on the extractability and functionality of pre- and post-rigor beef. J. Food Sci. 45:283.

Strange, E. D., Benedict, R. C., Gugger, R. E., Metzger, V. and Swift, C. E. 1974. Simplified Methodology for measuring meat color. J. Food Sci. 39:988.

Stringer, W. C., Bilskie, M. E. and Naumann, H. D. 1969. Microbial profiles of fresh beef. Food Technol. 23:97.

Swift, C. E., Lackett, C. and Fryar, A. J. 1961. Comminuted meat emulsions--the capacity of meats for emulsifying fat. Food Technol. 15:468.

Swift, C. E. and Sulzbacher, W. L. 1963. Comminuted meat emulsions. Factors affecting meat proteins as emulsion stabilizers. Food Technol. 17:224.

Taylor, A. A., Shaw, B. G. and MacDougal, D. B. 1981. Hot deboning of beef with and without electrical stimulation. Meat Sci. 5:109.

Trautman, J. C. 1964. Fat-emulsifying properties of prerigor and postrigor pork proteins. Food Technol. 18:1065.

Unger, S. G. 1975. "Energy utilization in the leading energy-consuming food processing industries." Food Tech. 29:33.

U.S. Dept. of Commerce. 1977. Annual Survey of Manufacturers 1976. Bureau of Census.

Van Eerd, J. P. 1972. Emulsion stability and protein extractability of ovine muscle as a function of the time postmortem. J. Food Sci. 37:473.

Viskase, Ltd. 1971. Growing interest in meat tumbling. Food Manufacturing 43:35.

Walker, H. W. 1980. Effects of microflora on fresh meat color. Proc. 33rd Recip. Meats Conf. 33:33.

Webb, N. B., Ivey, F. J., Craig, H. B., Jones, V. A. and Monroe, R. J. 1970. The measurement of emulsifying capacity by electrical resistance. J. Food Sci. 35:501.

Weidemann, J. F., Kaess, G. and Carruthers, L. D. 1967. The histology of pre-rigor and post-rigor ox muscle before and after cooking and its relation to tenderness. J. Food Sci. 32:7.

Well, L. H., Berry, B. W. and Douglass, L. W. 1980. Effects of grinding and mechanical desinewing in the manufacture of beef patties using conventionally chilled and hot boned and rapidly chilled mature beef. J. Food Sci. 45:163.

West, R. L. 1983. Chilling of prerigor meat. Proc. 36th Recip. Meats Conf. 36:82.

Wierbicki, E. and Deatherage, F. E. 1958. Determination of water-holding capacity of fresh meats. J. Agr. Food Chem. 6:387.

Williams, S. C. 1978. Hot Boning. Food Technol. in Australia. Dec. p.495.

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