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EFFECTS OF FREEZING SYSTEM, FREEZING RATE, FILM PERMEABILITY, PACKAGING TIME AND DISPLAY CASE TEMPERATURE ON COLOR STABILITY AND WEIGHT LOSS OF FROZEN BEEF *LONGISSIMUS* AND *PSOAS MAJOR* MUSCLES

by 632

MICHAEL LEWIS SANDBERG

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Approved by:

D H Kropf

Major Professor

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ORGANIZATION OF THE THESIS

This thesis is presented as a series of chapters. Chapter I is a general introduction to the entire thesis including a statement of the problem, reason for studying the topic and the specific purpose of the work. Chapter II includes a comprehensive review of literature pertinent to all topics and subjects included in subsequent chapters.

The two chapters following the general literature review each deal with an individual sub-unit of the total study and are placed in sequence as the study developed. Each of these chapters is written, with few exceptions, in the style form of the journal to which they will be submitted for publication.

Chapter V is a summarization of the entire thesis.

An Appendix is included following Chapter V and consists of additional tables which aid in the comprehension of the thesis.

CHAPTER I

GENERAL INTRODUCTION

Thirty-five billion pounds of red meat were produced in 1969 and it is anticipated that more than 36 billion pounds will be produced in 1970, a large percentage of which will be retailed on a fresh basis. Centralized fabricating and packaging of red meat would allow increased efficiency in the use of labor and equipment, inspection at all levels of production, improved sanitation, reduced transportation tonnage and improved handling properties of shipped product. A modern freezing and packaging operation would easily fit into such a plant by producing a product of acceptable quality and appearance. Freezing may extend the display life of red meat considerably.

Educating consumers in the purchasing of frozen meat appears to be a major task, due to the experience of years of buying fresh meat and because of the natural suspicion consumers have of marketing changes in traditional products. Therefore, the appearance of frozen meat will be an extremely important selling point and the more natural the color the more likely the product will be accepted.

Meat displayed in the frozen state has several advantages over cuts displayed fresh. Most researchers agree that fresh meat color remains stable for approximately 72 hours, with excessive myoglobin oxidation resulting in discoloration after that amount of time. At temperatures above freezing, displayed meat is also subject to bacterial discoloration and spoilage. Freezing and low temperature

storage has been shown to greatly reduce both bacterial spoilage and discoloration. Ramsbottom (1947) reported an increased storage life and color stability in steaks stored at -12.2°C when compared with steaks stored at -3.3°C. Acceptable color was maintained for 90 days in steaks stored at -12.2°C. Lawrie (1966) reported finding edible meat in mammoth carcasses frozen for 20,000 years in Northern Siberia.

Workers have encountered several problems in the freezing of red meat. Two toning within cuts, partial discoloration of muscles, ice crystal formation, desiccation and frost in the packages have all plagued researchers at various times. These problems must be resolved before the meat industry is assured of stable saleable product.

The purpose of this work was to study the effects of freezing system, freezing rate, packaging time, film permeability, and display case temperature on color stability and weight loss of frozen beef longissimus and psoas major muscles.

CHAPTER II

REVIEW OF LITERATURE

Meat Color and its Importance

All factors which influence the visual appearance of meat are rapidly assessed by a consumer and interpreted into a response: to buy or not to buy; to eat or not to eat (Mackinney, Little and Briner, 1966). Color makes up a large part of the overall visual appearance of a cut of meat so it probably is the single greatest appearance factor which determines whether or not that cut will be purchased. Hiner (1954) stated that color of a product has both a psychological and a real effect on a consumer. The psychological effect occurs since color causes an almost immediate positive or negative response and the real effect indicates quality, amount of time held, temperature of holding, and how the product was handled.

Judging color is part of our everyday life (Judd and Wyszecki, 1963). Birren (1963) agreed and stated that everything owns its own color. He found that bright "warm" colors of certain foods tend to stimulate the autonomic nervous system, which affects the digestive system, while soft "cool" colors of other foods tend to suppress it. In further testing, other animals and birds were shown to react in the same manner as humans, so color is a universal means of judging acceptance or rejection of food.

Francis (1963) stated that color in food is important to humans and that it can be divided into two general areas. The first deals

with the addition of coloring agents to various foods while the second deals with the natural pigments, such as myoglobin and hemoglobin, found in meats and their contribution to color. The former can be controlled, so as to present an appealing color, but are illegal to use in many areas. Natural pigment state and concentration is difficult to control due to inherent differences in muscles and animals, and because of the different "physical" characteristics of each animal at the time of slaughter. These include differences in age, sex, nutritional state, ante mortem handling and post mortem treatment all of which could have significant effects on lean meat color.

The importance of meat color was demonstrated by Naumann, McBee and Brady (1957) who said consumers consider two different preferences in their meat purchasing. One is a minimum visual appearance which must be present if the meat cut is to be bought while the other is palatability which is determined by the overall quality of the meat. Certainly consumers have few if any means of estimating the flavor, juiciness and tenderness of a cut of meat while it is in the showcase so they must base their selection on the other preference, visual appearance. Color, of course, makes up much of what the consumer sees while making this choice.

The Chemistry of Muscle Pigments

The chemistry of meat color primarily involves the chemistry of the pigment myoglobin (Giffee et al., 1960). Brooks (1929) noted that the amount of myoglobin in beef muscle, unlike hemoglobin, is independent of the degree of blood removal, but dependent on the type of muscle, age

and condition of the animal. Rickansrud and Henrickson (1967) supported these findings by reporting muscle differences accounted for 84% of the variation in bovine myoglobin while animal differences accounted for 14% of the variation. They reported that 80% of beef longissimus pigment was myoglobin while only 62% of beef psoas major muscle pigment was myoglobin. The remainder of the pigment in both muscles was assumed to be hemoglobin. Earlier research by Shenk, Hall and King (1934) indicated that myoglobin made up more than 90% of fresh beef respiratory pigment, while hemoglobin percentage averaged 3.9%. Fleming, Blumer and Craig (1960) found similar results and reported that beef longissimus contains 95 to 97% myoglobin and 3 to 5% hemoglobin. Ginger, Wilson and Schweigert (1954) and Schweigert (1954) determined that beef longissimus and round muscles contain between 2.26 and 5.41 mg (averaging 3.9 mg) myoglobin per gram of fresh tissue.

Schweigert (1956) stated that myoglobin is a conjugated protein molecule. It contains a heme moity attached to the protein, globin, which functions to accept oxygen from hemoglobin, for use in oxidative energy yielding reactions within muscle cells. Giffee et al. (1960) added that the protein portion of the molecule has a molecular weight of 16,000 to 17,000 and the non peptide portion, the heme, contains both an iron atom and a porphyrin ring. It is the oxidative state of the iron atom and the position of the heme on the globin that determines what color the myoglobin molecule exhibits.

Myoglobin and hemoglobin are identical in their color chemistry (Fox, 1966), with the most important reactions being autoxidation (metmyoglobin formed), reactions with NO (nitrosyl hemochrome formed),

oxygenation (oxymyoglobin formed) and denaturation. He stated that although the reactions are essentially the same, the rates for the two pigments are different. When freshly cut, the surface of meat contains myoglobin in the purple-red reduced state (iron atom in the non oxygenated iron II state). Immediately after exposure to available oxygen, oxygenation of the myoglobin begins which is visually observed as the formation of a bright red color (iron atom in the oxygenated iron II state) while prolonged exposure results in the oxidation of myoglobin to brownish-red metmyoglobin (iron atom in the non oxygenated iron III state) (Grant, 1955). Cutaia and Ordal (1964), using reflectance spectrophotometry, found that after as little as five minutes bloom time, no reduced myoglobin could be found in ground beef.

Many researchers have shown that partial pressure of oxygen, ambient temperature, pH, and enzymatic activity all affect the rate of pigment reactions. Conont and Fieser (1924) established that one hydrogen equivalent of oxidizing agent was required for the conversion of one mole of reduced myoglobin to metmyoglobin, and one hydrogen equivalent of reducing agent was needed for the reverse. Further work by Conont and Fieser (1924) and studies by Neill and Hastings (1925) showed that oxidation of oxymyoglobin to metmyoglobin was encouraged by low partial pressures of oxygen. Oxidation was most complete at a partial pressure low enough to permit one half of the ferrous atoms to be in the deoxygenated state.

George and Stratmann (1952a, b) found that with pH, salt concentration and temperature held constant, the oxidation of reduced myoglobin to metmyoglobin was a first order reaction where no protein

denaturation occurred. They determined the maximum rate of oxidation of myoglobin to occur at partial oxygen pressures between 1 and 1.4 mm Hg but later showed that this maximum rate could be obtained at oxygen pressures up to 20 mm of Hg if the temperature and pH were altered. At oxygen pressures above 20 mm of Hg the oxidation rates leveled off to a constant value. Calculations showed that the reaction changing one mole of myoglobin to metmyoglobin used 2.5 moles of oxygen. Snyder and Ayres (1961) verified the oxidation reaction to be a first order type by finding that when the log-percent of oxymyoglobin was plotted against time, a straight line resulted.

Brown and Mebine (1969) suggested that only 0.25 mole of oxygen in oxymyoglobin is used for oxidation and that 0.75 mole is released. They reasoned that former results could have included errors due to interference by oxidation products of sodium hydrosulfite, a reducing agent, which was not removed from the reaction.

Grant (1955) identified the enzymes found in frozen and thawed meat 18 hours after slaughter. Succinic dehydrogenase, glycerophosphate dehydrogenase and cytochrome oxidase were found to be the only active enzymes present at this time. Urbin and Wilson (1961) reported a uniform use of oxygen during the first 15 hours post mortem through uptake by myoglobin, enzyme systems and a dissolving of oxygen in meat solutions. After 15 hours, however, most of the oxygen use by muscle was due to uptake by enzyme systems. These enzyme systems continually re-reduced metmyoglobin to reduced myoglobin (Stewart et al., 1965b; Watts et al., 1966; Saleh and Watts, 1968). Hutchins, Liu and Watts (1967) found large differences within muscle systems in regard to

their initial reducing activity at different temperatures. Attainment of 50% reduction of metmyoglobin in 30°C took less than one hour. At 9°C it took 7 hours and at 0°C, 48 hours.

Brooks (1931) stated that as the pH of blood decreased, the rate of hemoglobin oxidation increased proportionally to the hydrogen ion concentration. Brown and Mebine (1969) supported the early findings of Brooks (1931), finding a strong dependence of oxidation rates on muscle pH, with a linear relationship existing between pH 5.0 and pH 7.0 with higher rates at 5.0. Urbin and Wilson (1961) disagreed and stated that with increasing muscle pH (6.4 to 8.0) oxygen uptake also increased.

Snyder and Ayres (1961) and Brown and Dolev (1963a) found that temperature has a profound effect on oxidative reaction rates. They reported doubling the rates by increasing the temperature from 0°C to 4°C. Further studies by Brown and Dolev (1963b) attempted to show effects of temperatures below 0°C on oxidation rates. They found that all myoglobin solutions oxidized more slowly at -5°C than at 0°C but when held at -10°C the solutions were frozen and the oxidation rates increased. They concluded that this was due to physical changes involved in freezing, and probably involved adjustment of the physical proximity of the myoglobin and oxygen molecules to a distance more favorable for oxidation reactions to occur. Brown and Mebine (1969) studied temperature effects on oxidative reaction rates and showed 40 to 50 fold slower rates at -2°C than at +22°C.

Brissey (1963) studied factors which affect the stability of meat pigments. It was found that sanitation, temperature, desiccation, packaging material, freezing and lighting could affect discoloration.

Methods of Color Measurement

Pearson (1969) stated that the eye sees color but biases and personality differences make an objective method of color determination necessary. These objective measurements must, however, involve procedures that can be reconciled with visual color perception. The University of Wisconsin (1963) published color standards for fresh pork, thus helping to meet the need for such an objective scale in the pork industry.

Mackintosh (1932) described Munsell disk colorimetry as a practical method of measuring color in beef. He determined that a "score of 40 red units" were needed to reach the lower limit of color acceptability. Nickerson (1946) authored a handbook on the method of disk colorimetry and described many uses of the system. Hiner (1954) further explained the use of the three variables, namely, hue (the color of an object), value (the degree of lightness or darkness), and chroma (the color difference from gray). He stated that by using these variables, the color of any cut of meat could accurately be determined and recorded.

Clydesdale (1969) described the International Commission on Illumination's system of tristimulus values as one using the three primary colors (red (x), green (y) and blue (z)), because all other colors are obtainable by mixing them. Little and Mackinney (1969)

added that all color stimuli with the same tristimulus values, under defined conditions, match each other whether or not they have the same spectral distribution. Under defined conditions of lighting and viewing, only one combination of the three primary colors will match a given set of tristimulus values. They continued, stating that the physical state of a sample will affect the results obtained from this or any other method of color measurement. High correlations, ranging from .769 to .873, were found between tristimulus values and visual beef and pork muscle color scores by Ockerman and Cahill (1969). The Gardner method, another color matching system, also employs three color variables.

Spectrophotometric methods of following pigment changes have been widely used and, in general, involve destruction of sample material. Early work by Austin and Drabkin (1935) described a method of determining heme pigment concentration using absorbency, based on the fact each pigment has a characteristic, reproducible absorption curve when pH and concentration are held constant. Schweigert (1954), however, while studying isolated myoglobin fractions, found several disadvantages with the absorbency method, due to the need to extract pigments and thereby change the chemical state of the sample. Once extracted, samples were not able to be used for further research.

Much work has been done regarding the spectral absorbency distribution of myoglobin derivatives. Each chemical form of myoglobin has its own characteristic spectral curve with easily observable maxima and minima (Snyder, 1965). Shenk et al. (1934) reported that solutions of myoblobin examined by spectrophotometric methods produced curves similar

› spectral curves produced by hemoglobin, but were displaced toward the
:d portion of the spectrum. They found that by using absorbence methods,
:moglobin and myoglobin produced maxima at 547 nm and 577 nm, maxima at
:3 nm and 582 nm, respectively. A minimum for hemoglobin appeared at
:2 nm whereas 564 nm was found to be a minimum for myoglobin. Bowen
949) studied absorption curves with a Beckman DU Spectrophotometer and
und peaks at 555 nm (reduced myoglobin), 544 nm and 582 nm (oxymyoglobin)
d 630 nm (metmyoglobin). Minima were found at 480 nm, 510 nm and 564 nm,
:d 590 nm for the three pigment forms, respectively. Similar peaks were
und by Schweigert (1956), Tappel and Maier (1957) and others, but per-
ps more important were ratios worked out to distinguish between pigment
ates.

An isobestic point for all three myoglobin oxidation forms was
und to be 525 nm whereas reduced myoglobin and oxymyoglobin had an
obestic point at 572 *nm and oxymyoglobin and metmyoglobin had an*
obestic point at 474 nm (Stewart et al., 1965a; Snyder, 1965; Snyder
d Armstrong, 1967). Further work by the aforementioned workers
plained that the ratios R474/R525 nm and R572/R525 nm indicate
anges from reduced myoglobin to oxymyoglobin and oxymyoglobin to
tmyoglobin, respectively. These ratios could then be used to follow
d measure pigment changes in beef, during a storage period.

Broumand, Ball and Steir (1958) used absorbency ratios in fresh
ef studies and found relative *concentrations of oxymyoglobin decreased*
nearly with time when meat (in contact with air) was held at room
mperature for up to 75 minutes. Metmyoglobin concentrations increased
pidly after four days storage at low temperatures.

Dean and Ball (1960b) found low correlations between absorbence and reflectance methods for measuring the proportion of the myoglobin state. After analyzing fresh meat by both methods, they reported values of 22%, 50% and 20% compared to 50%, 30% and 10% for myoglobin, oxymyoglobin and metmyoglobin, respectively, for the two methods. They suggested that reflectance presented a more accurate picture of surface pigment concentration, because myoglobin could be converted from one chemical state to another during extraction (absorbency method). True proportions of actual myoglobin derivatives could therefore not practically be determined. Spectral reflectance is suited to in situ studies of pigment systems where extractive procedures are difficult or impossible, or where they would cause an unwanted change in the pigment (Naughton, Frodyma and Zeitlin, 1957). These workers, however, used plots of the log of absorbence instead of reflectance. They were certain that both the spectral pattern and the maxima and minima of heme derivatives would not change when absorbence, rather than reflectance is used. Hansen and Sereika (1969) used absorbence ratios (A582/A525 and A630/A525) to measure percentages of the three pigment forms and determined fresh meat showed acceptable bloomed color only if a A582/A525 ratio greater than 1.12 and a A630/A525 ratio less than 0.55 was obtained.

Reflectance was observed to be a rapid objective method of measuring muscle color (Ockerman and Cahill, 1969). Correlations of .88 were found between visual panel scores and percent reflectance at 685 nm. Kraft and Ayres (1954) used reflectance wavelengths between 540 nm and 800 nm to estimate color in round steak, and Pirko and Ayres (1957) found absorbence maxima of KCl extracted pigment at 500 nm and 635 nm

Tappel and Maier (1957) found similar results, stating heme containing compounds have characteristic maxima and minima in the regions 500 to 600 nm and 400 to 425 nm. They further stated reflectance was useful because no extraction was necessary. Allen et al. (1969) used reflectance to measure color changes in unfrozen beef longissimus muscle over 10 days (240 hours). Percent reflectance at wavelengths of 474, 525, 538, and 571 nm decreased significantly between 0 time and 5 minutes. Wavelengths of 525, 538, 568 and 571 nm were fairly insensitive to color change, while reflectance at 600, 610, 620 and 630 nm decreased gradually as subjective discoloration occurred. The ratio of R474/R525 nm increased as color deteriorated while that of R571/R525 nm did not change with darkening or discoloration.

A further application of reflectance spectrophotometry was used by Dean and Ball (1960b) who calculated K/S values (K/S equals the absorption coefficiency (K), divided by the light scattering coefficient (S) per unit of sample thickness) of the ratios 507/573 nm and 473/597 nm to estimate the relative amounts of each pigment present in vacuum prepackaged beef. Their data were not sufficient to explain the discoloration patterns that occurred. Stewart et al. (1965a) reported a linear relationship between K/S525/K/S525 and percent total pigment. The plot of raw reflectance at R572/R525 nm and percent total pigment, however, yielded a non linear curve, so graphs could accurately show percentages of the three myoglobin derivatives.

Snyder (1965) suggested adjusting reflectance to a common level at 525 nm to eliminate the effects of uncontrollable variables including marbling and film wrinkles so graphs could accurately show percentages

of the three myoglobin derivatives. When the aforementioned adjustment was made, isobestic points for oxymyoglobin and metmyoglobin and reduced myoglobin and oxymyoglobin were found at 474 nm and 571 nm, respectively. Further work by Snyder and Armstrong (1967) showed the above adjustment to be unnecessary if K/S values were used instead of reflectance values. They made extensive comparisons between absorbence and K/S values and concluded that the K/S system was more suited for studying myoglobin derivatives due to the linearity found when it was plotted against total pigment concentration. Meat reflectance was affected by myoglobin concentration, moisture, fat, connective tissue and degree of contact between the packaging film and the meat surface as well as the chemical state of the myoglobin. Snyder (1968) stated that due to sample heterogeneity film wrinkles, wet and dry sample surfaces, fat presence and small sampling, area reflectance was not a perfect method of determining meat color. It was, however, a quick and flexible means of estimating surface color and pigment concentrations.

Factors Affecting Freezing Rate and Color of Frozen Beef

Freezing rates, methods and drip losses. Meryman (1956) defined freezing rate as the rate of advance of a freezing boundary in a linear direction through the medium. Three characteristics of the medium which influenced the rate of heat transfer included specific heat, thermal conductivity and latent heat of fusion. Rapid freezing, low storage temperature and very rapid thaw increased success of freezing preservation.

Callow (1952) described the theory of freezing and the frozen state. When freezing muscle systems, ice crystals form first outside the fibers and only when rates are fast enough to yield large numbers of crystal centers do they form within fibers. As temperatures decrease, ice forms and salt concentration increases. At high salt concentrations proteins may be denatured. Rapid freezing and thawing and low storage temperatures were found to minimize protein denaturation. Ede (1955) stated cooling of meat proceeds normally until the surface reaches the freezing point. Then the process is retarded because any further decrease in temperature must be accompanied by extraction of latent heat. The freezing boundary penetrates slowly from surfaces, causing the temperature of the unfrozen core to gradually become uniform at the freezing point and remain there while freezing proceeds. Once the entire block is frozen, it cools quickly to the ambient temperature due to the high thermal conductivity of ice (.0050 to .0055 calories/cm^2/sec). Many researchers have shown liquid immersion freezing systems to be more efficient than many other systems and therefore produce a faster freeze.

Moran (1935) found that freezing promoted denaturation of muscle proteins, with maximum rates occurring at -19°C, due to a combined effect of altered pH and increased salt concentration in the liquid phase of partly frozen muscle. At -16°C a maximum production of ice crystals and a larger amount of drip loss were noted. After studying beef rounds frozen in an air blast held at -31.7°C, Ramsbottom, Goeser and Strandine (1949) reported the presence of ice crystals of all sizes, ranging from very small intracellular crystals to very large intercellular crystals. They reported more rapid freezing with increasing

fat percentages and with increasing air velocity from less than 15.25 m^3/min to 61.0 m^3/min to 152.50 m^3/min. No further increase of freezing rate was found when air velocity was over 152.50 m^3/min. Aging or grinding beef did not significantly change freezing rates and rates decreased proportionally with the insulating ability of the package. Steaks frozen at -6.67, -28.8 and -78.8°C produced colors much darker than fresh beef, similar to fresh beef and much lighter than fresh beef, respectively.

Little work has been done in the field of freon freezing of meat. Lawler and Trauberman (1969), however, performed a study on cost figures, efficiency and product acceptability of a freon freezing system. They reported meat and poultry frozen in a continuous immersion spray system to have "superior quality" with essentially no moisture loss. The freezant was a non-toxic, non-flammable, non-corrosive and completely recoverable liquid.

Liquid nitrogen, unlike freon, has been widely used. Gray (1967) found that through the use of liquid nitrogen, "freezer burn" could be eliminated by limiting moisture loss to one percent while blast freezing allowed up to five percent loss. Costello and Henrickson (1964) froze biceps femoris steaks in liquid nitrogen at -12.2, -15.5, -43.3 and -71.1°C and found internal temperature to be reduced linearly with time until the internal temperature reached -2.2°C. The temperature pattern then flattened out between -2.2 and -3.3°C (while the latent heat of fusion was removed) and finally became linear once again as the ambient temperature was reached.

Literature concerning the influence of freezing rate on inherent meat factors and on influence of factors on freezing rate is extensive. In general, faster freezing methods have resulted in less weight (drip) loss upon thawing (Cook et al., 1926; Ramsbottom and Koonz, 1939 and 1941; Brady, Frei and Hickman, 1942; Hiner, Madsen and Hankins, 1945; Wierbicki, Kunkle and Deatherage, 1957). Muscle drip contained approximately nine percent protein (Cook et al., 1926) and was similar in its chemical and physical composition to the free fraction of muscle fluid (Empey, 1933). Wierbicki et al. (1957) stated that thawing loss was decreased by aging of meat prior to freezing and by increasing its salt concentration.

Dunker and Hankins (1953) found rates of freezing and thawing to be affected by type of wrapping material. There was an increase of 103 percent in the time required to freeze and thaw a sample of ground pork wrapped in a polyethylene film when compared to a similar unwrapped sample. Bratzler and Tucker (1963) found similar results and stated that with like pieces of meat, various films and wraps affect freezing rates differently.

Color is very much affected by freezing rates and methods. Ramsbottom and Koonz (1941) stated that slower freezing (-12.2°C vs -34.4°C) caused a darker surface color due to the presence of large ice crystals which scatter less light, while faster freezing caused a lighter color due to smaller ice crystals and more light scattering. Brissey (1963) and Gray (1967) indicated rapidly frozen meat displayed a brighter, more natural red color than meat frozen more slowly. Lawrie (1966) agreed, stating low freezing temperatures enhanced color

(1958) both reported that refreezing meat resulted in a significantly darker color than was present after the original freeze, regardless of the treatment used.

Lentz and L. Van de Berg (1957) and Hamre and Stadelman (1967) reported that as freezing rate increased, the color of diced chicken became lighter. The data of Hamre and Stadelman (1967) indicated that chicken immersed in liquid CO_2 and liquid nitrogen appeared "as white as chalk", while a CO_2 vapor and liquid nitrogen spray produced a light but acceptable color. Propylene glycol immersion, still air freezing (-10°C) and blast freezing (-28.9°C) produced significantly darker colors than previously mentioned systems.

Display temperatures, storage time and frozen weight loss. Low storage temperature depressed enzyme activity, minimized color changes, inhibited oxidation and reduced desiccation and drip (Ramsbottom and Koonz, 1941). These workers stored 32 rib steaks at -12.2°C and -34.5°C, thawing half of each group at four days and half at 365 days. Oxidation occurred faster at the higher storage temperature. Brooks (1938) stated meat appeared visually brown when 60 percent of the myoglobin was in the "met" form. Watts (1954) and Bratzler (1955) added that oxidation rates doubled for every 10°C rise in temperature. Brown and Dolev (1963a, b) supported the previously mentioned work by reporting that oxidation rates increased with increased temperatures (in both beef and tuna fish).

Moran and Hale (1932) thawed steaks held at -3°C, -10°C and -20°C for 7 or 31 days and reported low frozen storage weight losses in steaks held at the lowest temperature for the longer period of time. Brady et al. (1942) studied frozen weight losses after 6 and 39 weeks.

Quick frozen steaks lost 1.8% and 9.8% while slow frozen steaks lost 2.35% and 10.3% for the two time periods, respectively. Ramsbottom (1947) stated that with storage time ranging from 0 days to 365 days that as storage temperature decreased from -3.3°C to -28.9°C, color stability of pork chops increased. At -3.3°C complete discoloration occurred by 60 days while appearance of steaks remained acceptable for 90 days at -12.2°C. The two lower temperatures (-23.3°C and -28.9°C) maintained acceptable color in pork chops stored up to 365 days. In another study Ramsbottom (1947) found complete discoloration in all beef steaks stored at -12.2°C for seven years. Hankins and Hiner (1941) reported the color stability of freshly cut pork stored 10 months at -7.8°C decreased significantly faster than similar cuts stored at -17.8°C. Hunt et al. (1969) investigated color stability of frozen lamb chops displayed under lights at -21°C and -29°C. Over a period of six weeks, color stability was enhanced at the lower display temperature.

Lentz and L. Van De Berg (1957) worked with chicken and turkey muscle and found results similar to those reported for red meat. A storage temperature of -28.8°C maintained a more acceptable color for the entire 12 weeks of the study than a temperature of -18.8°C.

Possibly the extreme example of low temperature storage was reported by Lawrie (1966) who demonstrated the edibility of meat from mammoths frozen for 20,000 years in northern Siberia, under conditions preventing desiccation.

Effects of fluctuating storage temperatures have been studied by several researchers. Hustruld, Winter and Nobel (1949) stored one sample of ground beef at -18.8°C constantly for six months and fluctu-

They reported no significant differences between the two in regard to color, texture, and degree of desiccation. Winter et al. (1952) found fluctuating temperatures between -17.7°C and -12.2°C resulted in decreased color values when compared to a constant storage temperature of -17.7°C. Townsend and Bratzler (1958) and Brissey (1963) indicated decreased color stability in meat stored at fluctuating temperatures and cyclic defrost temperatures, respectively.

Packaging materials. The primary function of a meat package is to present the product to the consumer in the most attractive manner possible and at the same time protect the product from physical damage, microbes and chemical change (Mills and Urbin, 1960). Packages for frozen meats must maintain desired product characteristics at freezer temperatures and be able to hold up for prolonged storage periods. Color, as seen through a film, depends on the physical characteristics of the film including opaqueness, translucence, glossiness, matteness and the degree of wrinkling that occurs when the film is used (Mackinney et al., 1966). Birren (1963) stated package color itself (if not white or transparent) should enhance rather than conflict with the color of the contents.

Rikert, Ball and Stier (1957) found that no single film or other packaging material is best suited for all types of meat. Color of lean ground beef was enhanced by a film made of vinylidene copolymer while fat ground beef color was enhanced by a cellulose acetate package.

Films used for commercial packaging of meat should have gas permeabilities high enough to allow sufficient amounts of oxygen to enter the package and react with myoglobin to form oxymyoglobin (Allen, 1949; Urbain, 1952; Pirko and Ayres, 1957; Townsend and Bratzler, 1958;

indicated similar findings. Davis and Burns (1969) stated that in the presence of more than one gas, the permeability of oxygen through a polymer film depends on the partial pressure of oxygen, not the total pressure surrounding the package. Mechanisms of gas transfer through film pores differ depending on whether a total pressure (one gas present) or partial pressure (two or more gases present) exists between the two ends of the pore. Results of Watts (1954) and Marriott et al. (1967) with fresh beef, however, were in contrast with the aforementioned work. They reported packaging meat in oxygen impermeable films retarded discoloration, thereby maintaining a brighter red color than films of high oxygen permeability. Their conclusions were based on the statement that myoglobin changes to its oxidized form much faster if oxygen is readily available.

Vacuum packaging has been investigated by many researchers. Rikert et al. (1957c) found meat stored under 27 inches of vacuum returned to redness sometime after the initial bloom red was lost. Dean and Ball (1958) and Ball (1959) found similar results and added that frozen samples vacuum sealed in film type packages were darker than samples vacuum sealed in cans. Dean and Ball (1960a) explained that the second red color that occurred in vacuum packaged beef is not a bloom red, but a purple-red color similar to that of reduced myoglobin.

Allen (1949) and Mills and Urbin (1960) stated excessive surface drying leads to discoloration and weight loss. Kraft and Wanderstock (1950) found rubber base films to be the most desirable type of wrapper due to their imperviousness to moisture, their high tensile strength, transparency and ability to be heat sealed. Robertson (1950) added

that packages must be tight, with no air pockets or pin holes to allow condensation. Further work by Kraft and Ayres (1952) and Landrock and Wallace (1955) showed cellophane to be an effective material for maintaining bright red color of bloomed meat, due to its ability to prevent moisture loss while at the same time maintaining high oxygen permeability.

Despite the abundance of research performed to find materials suitable for packaging red meat, Bratzler (1955) stated that packaging of meat (especially fresh) is not adaptable to large efficient centralized operations, due to temperature changes, additional handling, fogging, color degradation and weepage.

Display lighting. Appropriate lighting for meat displays involves three factors including level of illumination, directional quality and color quality of the lights (Clark, 1956). The color of display lights should bring out the natural appetizing appearance of the meat by emitting substantial amounts of red light, thereby giving meat a strong red appearance. Ramsbottom, Goeser and Schultz (1941) indicated 72 hours is the maximum storage time for illuminated fresh display. After that amount of time, light acts as a catalyst with increasing discoloration occurring in proportion to increasing time and light intensity.

Literature involving studies on lighting types and intensities is extensive. Kraft and Wanderstock (1950) stated that the best light source for fresh meat is one that emits very little ultraviolet light, such as ordinary incandescent bulbs. Watts (1954) and Brissey (1963) found more discoloration in meat stored under lamps emitting more of the shorter wavelengths of the visible spectrum. Other work by Townsend and Bratzler (1958) indicated wavelengths of light between

560 and 630 nm (yellow to orange) were responsible for most of the color deterioration, regardless of light source. Brissey (1963) claimed that displaying meat in the frozen state does not reduce its susceptibility to discoloration. Naumann et al. (1957) found stability of color to be related to length of dark storage prior to display, lumens per square meter of illumination and temperature of storage and display.

Investigations into the color rendering properties of various lamps have shown G. E. deluxe cool white, soft white and incandescent tungsten filament bulbs to have high outputs in the red range of the spectrum (Ramsbottom et al., 1951; Clark, 1956; Allphin, 1970). Allphin (1970) stated that standard fluorescent, mercury vapor and metal halide lamps have poor color rendering properties for use in meat displays. Kraft and Ayres (1954) found equal amounts of discoloration in frozen meat samples stored under G. E. soft white fluorescent and white fluorescent bulbs at equal intensities for 12 days.

Rikert et al. (1957b) found that light, in the absence of oxygen, causes little discoloration, indicating an interaction between the two factors. Frozen samples displayed under fluorescent light at -17.8°C discolored slower than samples held in the dark at fluctuating temperatures. However, both Marriott et al. (1967) and Santamaria (1970) indicated opposite findings in that steaks stored in the dark (at constant temperatures) maintained acceptable color for longer periods of time than steaks stored under either fluorescent or incandescent lights (at various intensities).

Santamaria (1970) found a masking of discoloration by Holophane lens altered incandescent light when compared to deluxe cool white

fluorescent light. He compared intensities of 3228, 1614, 1076, 807 and 0 lm/m^2 and reported increasing discoloration with increasing intensity in both types of lights. The incandescent source appeared to promote better color at the lower intensities, while at the highest (3228 lm/m^2), the fluorescent source appeared to be superior. Other workers also reported brighter meat colors after storage under incandescent types of light when compared to fluorescent sources. Hoke and Davis (1970) indicated color scores of beef are significantly affected by type and intensity of light. In contrast with Santamaria (1970), they found meat stored under fluorescent lights at 269, 537 and 1075 lm/m^2 had higher color scores than similar cuts displayed under incandescent sources at the same intensities. Subjective evaluation was performed by a panel of graders.

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CHAPTER III

EFFECTS OF FREEZING SYSTEM AND FREEZING RATE ON COLOR STABILITY OF BEEF STEAKS PACKAGED IN TRANSPARENT FILM

Introduction

America's meat industry must keep pace with the needs of its expanding population. The American Meat Institute predicts that the national production of red meat will reach 36.1 billion pounds in the year 1970. In order to maintain efficient distribution and marketing systems, new ways of processing should be considered. Centralized processing and fabricating operations and distribution of frozen packaged retail cuts should result in more efficient use of time and manpower by all concerned with retailing.

The problem of maintaining acceptable color in frozen meat has been studied by several researchers. Lawler et al. (1969) reported meat and poultry frozen in a continuous freon immersion spray system exhibited "superior quality" and essentially no moisture loss. The freezant was described as being a non-toxic, non-flammable, non-corrosive and completely recoverable liquid. Ramsbottom et al. (1941) stated that freezing at higher temperatures (-12.2°C vs. -34.4°C) resulted in darker surface colors due to the presence of large ice crystals which scatter smaller amounts of light. Brissey (1963), Lawrie (1966) and Gray (1967) indicated that rapidly frozen meat displayed a more natural red color than meat frozen by slow means. Gray (1967) compared sirloin steaks frozen by a blast freezer with steaks frozen in an industrial

The purpose of this work was to study the effects of several liquid nitrogen vapor, freon immersion and blast air freezing treatments on color stability under display lighting of beef longissimus and psoas major muscles packaged in transparent film.

Experimental Procedure - Trial I

Description of steaks and treatments. Six beef loins from animals slaughtered the same day were used. The loins weighed between 24.9 and 27.2 kg, had small to modest amounts of marbling at the thirteenth rib and less than 1.27 cm of fat cover. Nine 2.54 cm thick steaks, T-bone and Porterhouse, were cut from each loin and were then randomly assigned to the nine treatments. Four of the loins provided the steaks used in the various treatments and the remaining two loins provided "dummy" steaks for time-temperature measurements.

Treatments employed liquid nitrogen and freon freezing systems and are presented in Table 1. Liquid nitrogen treated steaks were frozen in an NCG-Ultra-Freeze Simulator Freezer with the steaks placed on edge so that both sides were in equal contact with the nitrogen vapor, until an endpoint of -13.9°C was reached at the center of the half radius of the steak. Freon treated steaks were frozen to the same internal temperature using a Dupont Laboratory Freon Immersion Freezer.

Temperature recording. Temperature recordings were obtained using a 24 point Honeywell Electronik 16 Multipoint Strip Chart Recorder. Thermocouples were inserted into "dummy" steaks at two levels, just below the surface of the meat and at the center of the one-half radius location (Figure 1).

Table 1. Effect of various freezing treatments on visual redness scores.*

Treatment Means

Freezing cycle	Time period					
		Frozen				
	Fresh	Day 0	Day 1	Day 7	Day 14	Avg
Liquid Nitrogen System						
1. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	2.31^{abc}	2.50^{bc}	3.06^{cd}	3.88^{cd}	4.31^{b}	3.21
2. 45 min -26.1°C	2.13^{bcd}	2.06^{ef}	3.00^{cde}	3.50^{de}	3.94^{b}	2.93
3. 30 min -40°C	2.06^{cd}	2.88^{a}	3.38^{bc}	4.00^{bc}	4.25^{b}	3.31
4. 20 min -56.7°C	2.00^{cd}	2.63^{ab}	3.06^{cd}	4.00^{bc}	4.31^{b}	3.20
6. 10 min -40°C and equilibrate -20.6°C case	1.81^{d}	2.31^{de}	3.06^{cd}	3.56^{cde}	4.25^{b}	3.00
7. 10 min -26.1°C and equilibrate -20.6°C case	2.06^{cd}	2.44^{bcd}	3.75^{ab}	4.44^{ab}	4.81^{a}	3.50
Freon Immersion						
8. -30.6°C continuous for 5 min	2.31^{abc}	1.94^{f}	4.06^{a}	4.81^{a}	5.12^{a}	3.65
9. -30.6°C for 1 min, out 1 min, repeat 7 times	2.50^{a}	2.00^{f}	2.69^{de}	3.31^{e}	3.86^{b}	2.87
10. -30.6°C for 30 sec, dip 71.2°C H_2O, repeat 10 times	2.44^{ab}	2.00^{f}	2.50^{e}	3.44^{de}	4.06^{b}	2.89
Avg	2.17	2.30	3.18	3.88	4.33	3.17

abc Means within columns with same superscript letters are not significantly different ($P<.05$).

* Visual Redness Scores: 1 = very bright red; 2 = bright red; 3 = slightly dark red; 4 = very dark red; 5 = extremely dark red.

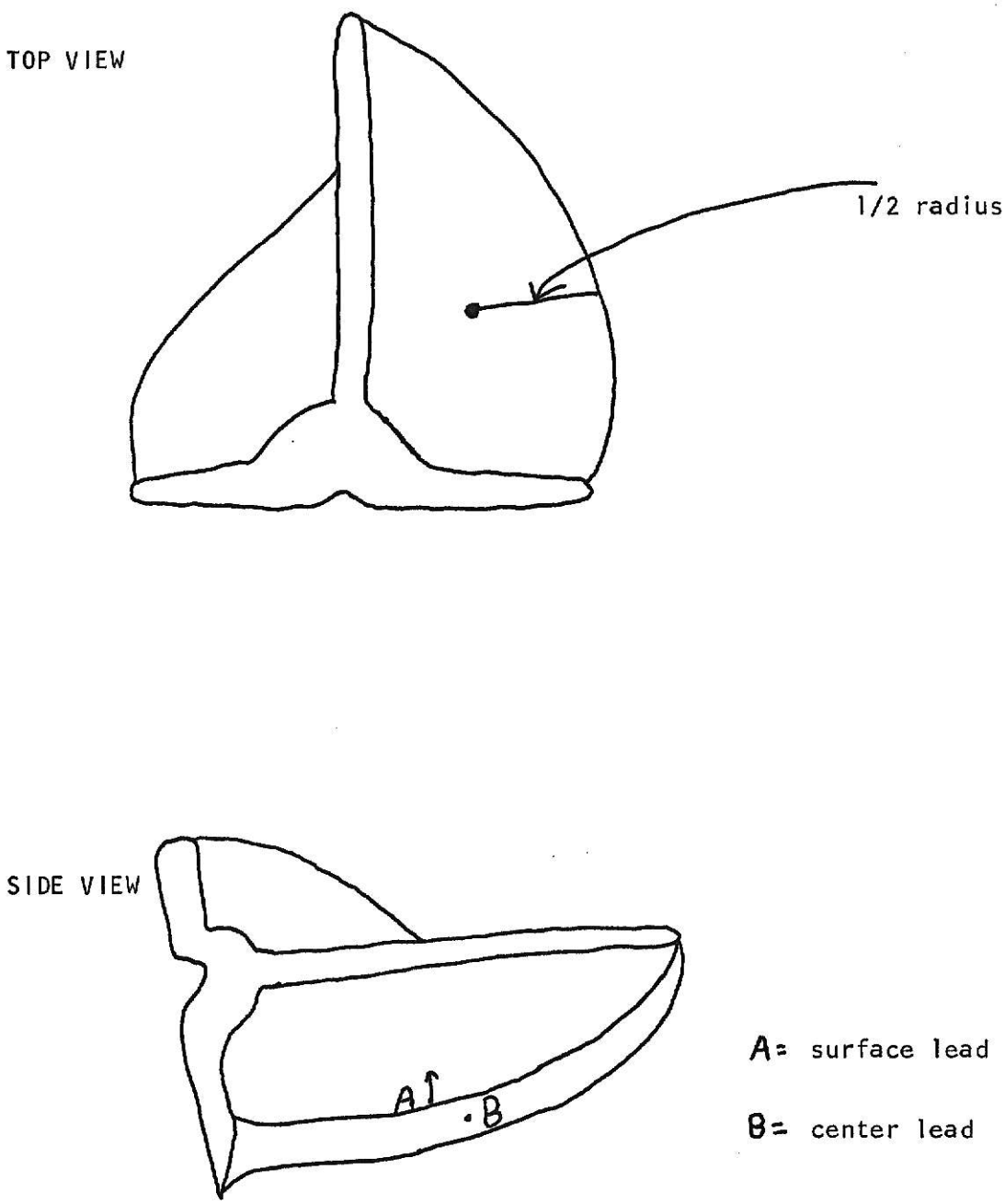

Figure 1. Placement of thermocouple leads for temperature recording.

Packaging. After a thirty minute bloom period all steaks were vacuum sealed in oxygen impermeable saran bags which were heat shrunk for 2-3 seconds at 88°C.

Lighting and case temperature. All steaks were displayed under General Electric Delux Cool White Fluorescent lights at an intensity of 1076 lm/m^2 and stored in Hussman cases maintained at -20.6°C with twice daily defrost cycles.

Color evaluation. Both longissimus and psoas major muscles were evaluated for visual redness and bleach before freezing. Immediately after freezing and after 1, 7 and 14 days of display. Care was taken to expose and evaluate the same surface throughout the study. Objective color measurements were obtained by reflectance spectrophotometry using a Bausch and Lomb Spectronic 600 (scan speed of 250 nm/min) with reflectance attachment, using magnesium carbonate blocks to standardize 100% reflectance. Reflectance scores were recorded for 474, 525, 572, 610, 650, and 685 nm and in addition, the area under the reflectance curves were obtained from 400-700, 650-700 nm and 440-474 nm to represent total, red and blue area reflectance, respectively. Treatment effects were analyzed by analysis of variance within each time period. In addition, correlation coefficients of visual redness and bleach scores with objective color measurements were calculated. Least significant difference analyses were performed to indicate significant differences between treatments ($P<.05$) within each time period. Analyses between time periods were not performed.

Experimental Procedure - Trial II

The experimental procedure for trial II was identical with that of trial I with the following exceptions:

1. Eight treatment combinations were studied and are designated in Table 8.
2. Treatments consisted of various temperature cycles obtained with the liquid nitrogen simulator freezer and mechanical air blast freezing.
3. All steaks were packaged with a Dupont vacuum packaging machine using a skin type film. The packaging material was of medium permeability to oxygen (209.30 cc $O_2/m^2/24$ hr/atm).
4. Steaks were examined for color and bleach prior to freezing, immediately after freezing and after 1, 7 and 20 days of display.

Results and Discussion - Trial I

Longissimus and psoas major visual redness scores (Table 1) indicated brighter lean color in steaks frozen by freon immersion but the amount of bleach (Table 2) produced by freon treatments detracted from their visual appearance. The bleach produced by most of the liquid nitrogen treatments was less than that caused by immersing steaks in liquid freon. Upon examination of the bleach, it was noted that it remained confined to the surface of the steaks frozen in nitrogen while it penetrated more deeply in steaks frozen in freon, probably due to the high thermal conductivity of liquid freon as compared to nitrogen vapor when in contact with muscle surfaces. These findings are in agreement

Table 2. Effect of various freezing treatments on visual bleach scores.*

Treatment Means

Freezing cycle	Time period (Frozen)				
	Day 0	Day 1	Day 7	Day 14	Avg
Liquid Nitrogen System					
1. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	3.38[a]	2.94[b]	2.13[ab]	2.00[ab]	2.29
2. 45 min -26.1°C	1.56[c]	1.75[cd]	1.63[cd]	1.69[bcd]	1.53
3. 30 min -40°C	1.44[cd]	1.44[cde]	1.50[cde]	1.44[cde]	1.36
4. 20 min -56.7°C	1.38[de]	1.19[ef]	1.19[de]	1.38[cde]	1.23
6. 10 min -40°C and equilibrate -20.6°C case	2.44[b]	1.84[c]	1.88[bc]	1.88[abc]	1.61
7. 10 min -26.1°C and equilibrate -20.6°C case	1.00[e]	1.13[ef]	1.31[de]	1.13[e]	1.11
Freon Immersion					
8. -30.6°C continuous	1.00[e]	1.00[f]	1.13[e]	1.13[e]	1.05
9. -30.6°C 1 min, out 1 min, repeat 7 times	3.69[a]	2.81[b]	1.88[bc]	2.00[ab]	2.28
10. -30.6°C 30 sec, dip 71.2°C H_2O, 10 times	3.38[a]	3.44[a]	2.44[a]	3.37[a]	2.51
Avg	2.13	1.95	1.67	1.66	1.68

[a] Means within columns with same superscript letters are not significantly different ($P<.05$).

* Visual bleach scores: 1 = no bleach; 2 = slight bleach; 3 = moderate bleach; 4 = very bleached; 5 = extreme bleach.

with those of Lawler and Trauberman (1969) who indicated that meat frozen by immersion in liquid freon had superior quality and essentially no moisture loss, due to the extremely fast heat transfer of the liquid as compared to a nitrogen vapor freeze. Scores on day 1 indicated a darkening of the red color in all treatments. The largest decrease in visual redness was found in the steaks frozen continuously in liquid freon at -30.6°C. At day 1, the only difference between liquid nitrogen treatments was a darker color in steaks frozen 10 minutes at -26.1°C and equilibrated in a -20.6°C display case, a difference that was found at each evaluation time. This treatment appears to involve too slow freezing for good color retention. By day 7, steaks frozen by cycles 3, 4, 7 and 8 exhibited an arbitrary unacceptable visual color score of 4 or more and by day 14 only steaks frozen in cycles 2 and 9 exhibited acceptable color scores. However, there were no significant differences between the two acceptable groups of steaks and several of the unacceptable groups. Averages of all treatments within time periods indicated that darkening tended to occur at a decreasing rate after day 0.

Means of visual bleach scores partially explain the acceptable color of the freon treated steaks. Increased brightening due to bleaching occurred in treatments 1, 9 and 10 due to the high thermal conductivity of freon and liquid nitrogen (at -129°C). These data support the findings of Lentz et al. (1957) and Hamre et al. (1967) who reported as freezing rate increased, the color of sliced chicken became lighter. Chicken immersed in liquid CO_2 and liquid nitrogen appeared "as white as chalk". Treatments other than the three previously mentioned cycles had only slight amounts of bleach. No reason could

be found to explain why freon cycle 8 did not exhibit the high degree of bleach that was found in freon treatments 9 and 10.

The severity of the bleach caused by freezing was influenced by packaging materials. Dunker et al. (1953) and Bratzler et al. (1963) reported that with similar cuts of meat, packaging films affected rate of heat transfer by increasing the time needed to freeze a muscle sample up to 103 percent. However, all packaging was similar in this study.

Freezing with any of the liquid nitrogen systems appeared to reduce percent reflectance at 650 and 685 nm whereas freezing with freon immersion increased reflectance at these two wavelengths (Tables 3 and 4). On day 0, reflectance at 650 nm was highest in treatments 2, 8, 9 and 10 but after one day, steaks in treatments 9 and 10 exhibited significantly higher ($P<.05$) reflectance when compared to all other steaks. On day 7, many of the reflectance differences had disappeared and by day 14, treatments 1, 2, 6 and 9 appeared to have slightly more red reflectance than the other treatments. The three freon cycles had significantly higher reflectance percentages than all nitrogen cycles at day 0 but by day 1, freon treatment 8 had the lowest percent reflectance. On day 7, steaks in treatments 1, 2 and 3 had reflectance percentages equivalent to the best freon treatment and by day 14 reflectance percentages of nitrogen cycles 1 and 2 were significantly higher than any other treatment. These data suggest that although freon treated steaks were brighter than steaks frozen in liquid nitrogen shortly after freezing, they lose their brightness in a shorter period of time. This phenomenon may be explained by greater bleach resolution

Table 3. Effect of various freezing treatments on percent reflectance at 650 nm.

Treatment Means

Freezing cycle	Time period					
		Frozen				
	Fresh	Day 0	Day 1	Day 7	Day 14	Avg
Liquid Nitrogen System						
1. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, 1 min temper	37.49^{abc}	32.74^{bcd}	29.02^{b}	20.96^{abc}	20.72^{ad}	28.19
2. 45 min -26.1°C	34.94^{bc}	35.77^{abc}	28.99^{b}	24.22^{a}	23.94^{a}	29.57
3. 30 min -40°C	38.26^{ab}	28.25^{d}	25.11^{b}	21.59^{abc}	19.85^{b}	26.61
4. 20 min -56.7°C	37.35^{abc}	30.89^{cd}	24.64^{bc}	19.64^{abc}	19.09^{bc}	26.32
6. 10 min -40°C and equilibrate -20.6°C case	34.32^{c}	30.85^{cd}	24.69^{bc}	19.36^{bc}	20.79^{ab}	26.00
7. 10 min -26.1°C and equilibrate -20.6°C case	38.54^{a}	33.50^{bcd}	20.37^{cd}	18.02^{bc}	18.52^{bc}	25.79
Freon Immersion						
8. -30.6°C continuous	36.00^{abc}	38.29^{ab}	17.47^{d}	17.10^{c}	15.82^{c}	24.94
9. -30.6°C 1 min, out 1 min, repeat 7 times	35.97^{abc}	39.40^{a}	35.42^{a}	22.05^{ab}	20.64^{ab}	30.70
10. -30.6°C 30 sec, dip 71.2°C H_2O 10 times	35.67^{abc}	38.19^{ab}	35.36^{a}	19.79^{abc}	19.05^{bc}	29.61
Avg	36.51	34.28	26.79	20.30	19.83	27.54

^{abc} Means within columns with same superscript letters are not significantly different ($P<.05$).

Table 4. Effect of various freezing treatments on percent reflectance at 685 nm.

Treatment Means

Freezing cycle	Time period					
		Frozen				
	Fresh	Day 0	Day 1	Day 7	Day 14	Avg
Liquid Nitrogen System						
1. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	41.89[a]	38.57[bc]	38.94[bc]	33.19[abc]	32.69[a]	37.06
2. 45 min -26.1°C	44.85[a]	39.20[bc]	40.24[b]	37.15[a]	36.92[a]	39.69
3. 30 min -40°C	42.75[a]	32.34[d]	33.94[d]	32.59[abcd]	30.86[bc]	34.50
4. 20 min -56.7°C	41.77[a]	34.15[cd]	33.14[d]	29.84[cde]	29.36[bc]	33.65
6. 10 min -40°C and equilibrate -20.6°C case	38.52[a]	34.14[cd]	35.42[cd]	31.52[bcd]	31.76[bc]	34.23
7. 10 min -26.1°C and equilibrate -20.6°C case	42.62[a]	38.17[bc]	28.11[e]	27.70[de]	28.04[cd]	32.93
Freon Immersion						
8. -30.6°C continuous	40.32[a]	43.27[ab]	24.07[e]	26.40[e]	24.40[d]	31.69
9. -30.6°C 1 min, out 1 min, repeat 7 times	40.37[a]	45.16[a]	46.44[a]	35.49[ab]	32.02[bc]	39.90
10. -30.6°C 30 sec, dip 71.2°C H_2O, 10 times	40.59[a]	43.65[ab]	45.60[a]	31.75[bcd]	30.49[bc]	38.42
Avg	41.53	38.74	36.21	31.74	30.73	35.79

[a] Means within columns with same superscript letters are not significantly different ($P<.05$).

that occurred in steaks frozen by freon, thereby resulting in a loss of brightness.

Results of total reflectance measurements (Table 5) revealed trends similar to those found in reflectance measurements. Freon treated steaks were slightly higher in total reflectance than steaks treated by liquid nitrogen on day 0 but by day 1, steaks in treatment 8 lost much of their original brightness. All steaks exhibited nearly the same total reflectance at days 7 and 14, suggesting that there is little difference in freezing cycles ability to control total reflectance after two weeks display and supporting the idea of resolution of bleach under display conditions. Immediately after freezing, treatments 2, 8, 9 and 10 reflected more red light (Table 6), with only treatment 9 having significantly more 650-700 nm reflectance than other treatments. On day 1, treatments 2, 9 and 10 had high amounts of red reflectance, while treatments 3, 4, 6, 7 and 8 exhibited a poor amount of red reflectance. Red reflectance (area 2) seemed to support visual redness results, whereas total reflectance (area 1) seemed to be related to bleach.

Simple correlation coefficients between visual redness and bleach scores and the objective variables studied are presented in Table 7. After freezing, significant correlations were found between visual redness scores and 650 nm reflectance (day 7) and 650 nm, 685 nm reflectance and area 2 (day 14). Significant correlations between bleach scores and ratio 2 (day 0) and 685 nm reflectance and area 2 (day 1) were found. These correlations were low, but suggested that

Table 5. Effect of various freezing treatments on total reflectance (area 1*).

Treatment Means

Freezing cycle	Time period					
		Frozen				
	Fresh	Day 0	Day 1	Day 7	Day 14	Avg
Liquid Nitrogen System						
1. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	37.15[a]	33.80[bcd]	35.93[bc]	29.67[ab]	31.15[ab]	33.54
2. 45 min -26.1°C	32.64[bc]	33.48[bcd]	33.73[cd]	34.96[a]	35.15[a]	33.99
3. 30 min -40°C	36.44[ab]	30.32[d]	31.22[de]	31.28[ab]	30.38[ab]	31.93
4. 20 min -56.7°C	35.48[abc]	31.09[cd]	28.38[de]	27.86[ab]	30.44[ab]	30.64
6. 10 min -40°C and equilibrate -20.6°C case	32.12[c]	30.44[d]	29.02[de]	29.28[ab]	32.06[ab]	30.57
7. 10 min -26.1°C and equilibrate 20.6°C case	36.64[a]	31.86[cd]	25.86[ef]	26.57[b]	28.12[b]	29.80
Freon Immersion						
8. -30.6°C continuous	35.28[abc]	37.34[abc]	21.80[f]	27.28[b]	26.90[b]	29.73
9. -30.6°C 1 min, out 1 min repeat 7 times	36.06[abc]	41.28[a]	42.05[ab]	29.99[ab]	30.70[ab]	37.67
10. -30.6°C 30 sec, dip 71.2°C H_2O, 10 times	34.83[abc]	38.96[ab]	43.22[a]	29.02[ab]	29.86[ab]	35.15
Avg	35.22	34.89	32.38	29.60	30.57	32.51

[a] Means within columns with same superscript letters are not significantly different ($P<.05$).

* Area 1 = area 400-700 nm.

Table 6. Effect of various freezing treatments on red reflectance (area 2*).

Treatment Means

Freezing cycle	Time period					
		Frozen				
	Fresh	Day 0	Day 1	Day 7	Day 14	Avg
Liquid Nitrogen System						
1. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	12.84^{bcd}	11.61^{bc}	11.54^{cd}	9.16^{abcd}	8.96^{b}	10.84
2. 45 min -26.1°C	12.06^{cd}	12.32^{abc}	11.80^{bc}	10.51^{a}	10.71^{a}	11.48
3. 30 min -40°C	13.42^{ab}	9.74^{d}	10.13^{e}	9.61^{abc}	8.58^{bc}	10.32
4. 20 min -56.7°C	13.35^{bc}	10.58^{cd}	9.68^{ef}	9.03^{abcd}	9.03^{b}	10.32
6. 10 min -40°C and equilibrate -20.6°C case	11.80^{d}	11.61^{bc}	10.38^{de}	9.09^{abcd}	8.96^{b}	10.38
7. 10 min -26.1°C and equilibrate -20.6°C case	14.45^{a}	11.93^{bc}	8.26^{fg}	8.26^{cd}	8.32^{bc}	10.26
Freon Immersion						
8. -30.6°C continuous	13.03^{bcd}	13.54^{ab}	7.35^{g}	7.55^{d}	7.29^{c}	9.74
9. -30.6°C 1 min, out 1 min repeat 7 times	12.58^{bcd}	13.80^{a}	13.16^{ab}	10.19^{ab}	9.80^{ab}	11.93
10. -30.6°C 30 sec, dip 71.2°C H_2O, 10 times	12.26^{bcd}	13.35^{ab}	13.74^{a}	8.77^{bcd}	8.77^{bc}	11.35
Avg	12.84	17.06	10.71	9.16	8.96	10.77

^{bcd} Means within columns with same superscript letters not significantly different ($P<.05$).

* Area 2 = area 650-700 nm.

Table 7. Simple correlation coefficients between visual redness and bleach scores and objective variables.

Variable	Time period								
	Fresh	Frozen							
		Day 0		Day 1		Day 7		Day 14	
	Vis[3]	Vis[3]	Bl[4]	Vis3	Bl[4]	Vis[3]	Bl[4]	Vis[3]	Bl[4]
474 nm	-.11	-.15	0.06	0.10	-.06	-.08	0.22	0.04	0.21
525 nm	-.26	-.20	0.09	0.12	-.06	-.10	0.21	0.00	0.22
572 nm	-.21	-.18	-.04	0.18	-.09	-.10	0.22	0.02	0.22
610 nm	-.45**	-.30	0.22	-.18	0.24	-.21	0.07	-.26	0.24
650 nm	-.49**	-.32*	0.23	-.31	0.23	-.31	0.10	-.36*	0.26
685 nm	-.41	-.30	0.19	-.28	0.46**	-.32*	0.08	-.40*	0.28
A1[1]	-.28	-.27	0.10	-.06	0.03	-.12	0.15	-.16	0.21
A2[1]	-.38*	-.28	0.20	-.34*	0.38*	-.21	0.07	-.36*	0.19
A3[1]	-.08	-.18	0.04	0.23	-.19	-.07	0.19	0.01	0.22
R1[2]	0.40*	0.26	-.15	-.11	0.01	0.14	0.23	0.27	0.00
R2[2]	0.19	0.08	-.40*	0.37*	-.14	0.05	0.06	0.03	0.09

[1] A1 = Area 400-700 nm; A2 = Area 650-700 nm; A3 = Area 440-474 nm.

[2] R1 = Ratio 474/525 nm; R2 = Ratio 572/525 nm.

[3] Vis = Visual redness.

[4] Bl = Visual bleach.

* = (P<.05).

** = (P<.01).

the red area of the spectrum is the portion to study in order to find an objective measurement that will accurately measure redness of frozen beef.

Results and Discussion - Trial II

Visual redness score means (Table 8) indicated that differences existed between steaks assigned to the various treatments before freezing was accomplished. Immediately after freezing, cycles 4 and 7 displayed significantly lower ($P<.05$) (numerical) scores, indicating the presence of a brighter more natural color. Blast freezing resulted in significantly darker steaks on day 0 and caused an unacceptable color by day 7. On day 1, steaks in all treatments exhibited acceptable color with treatments 4 and 7 again exhibiting the most desirable color. The differences between treatments became more apparent by day 7 but by day 20 the steaks in all treatments appeared to be similar in visual color scores. On day 7, treatment 4 had the brightest color followed by treatments 3 and 7. Aside from blast freezing, nitrogen cycles 1 and 2 were approaching the unacceptable level. The closeness of the visual redness score indicated that a point was reached at about 20 days of display where colors darkened to the same level. Even after 20 days of storage six of the treatments exhibited an arbitrary acceptable color score of less than 4. These results are in agreement with Ramsbottom et al. (1941) who stated that slower freezing caused a darker surface color while fast freezing caused a lighter color due to the presence of smaller ice crystals and more light scattering. Gray (1967) indicated rapidly

Table 8. Effect of various freezing treatments on visual redness scores.*

Treatment Means

Freezing cycle	Time period					
		Frozen				
	Fresh	Day 0	Day 1	Day 7	Day 20	Avg
Liquid Nitrogen System						
1. 45 min -26.1°C	1.81[d]	2.50[b]	2.88[b]	3.81[a]	3.75[ab]	2.95
2. 10 min -40°C and equilibrate -20.6°C case	1.63[d]	2.56[b]	3.38[a]	3.75[a]	4.00[a]	3.06
3. 30 min -40°C	1.75[d]	2.25[b]	2.50[bc]	3.00[cd]	3.50[b]	2.60
4. 20 min -56.7°C	2.56[bc]	1.75[c]	2.25[c]	2.75[d]	3.44[b]	2.55
5. 2 min -26.1°C, 2 min -40°C, -73.4°C till the end point	2.75[bc]	2.56[b]	2.69[bc]	3.25[bc]	3.63[b]	2.98
6. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	3.19[a]	2.44[b]	2.50[bc]	3.38[b]	3.75[ab]	3.05
7. -129°C till the end point	2.86[b]	1.75[c]	2.25[c]	3.19[bc]	3.63[b]	2.74
Mechanical Air Blast						
8. -26.1°C to -28.9°C for 24 hr	2.50[c]	3.06[a]	3.56[a]	4.06[a]	4.06[a]	3.45
Avg	2.39	2.36	2.75	3.40	3.72	2.92

[d] Means within columns with same superscript letters are not significantly different ($P<.05$).

* Visual redness scores: 1 = very bright red; 2 = bright red; 3 = slightly dark red; 4 = very dark red; 5 = extremely dark red.

frozen meat displayed a brighter more natural red color than meat frozen slowly.

Visual bleach scores (Table 9) indicated the presence of only small amounts of bleach after freezing in treatments 5, 6, 7 and 8. The increased ability of the skin-tight film in holding a vacuum, or this film could be a better insulator, resulting in slower freezing, possibly aided in the prevention of a more severe bleach in these treatments, while moderate bleaching occurred in the four remaining groups of steaks. The average of treatment bleach scores decreased slightly during the first day of display, suggesting that resolution of bleach begins immediately after freezing. Steaks blast frozen at -26.1 to -28.9°C exhibited only slight amounts of bleach due to the extremely slow freezing rate inherent in that method. By day 7, no treatment exhibited bleach severe enough to rate it as unacceptable, although significant differences ($P<.05$) in bleach were found between treatments at that time.

Percent reflectance at 650 nm and 685 nm (Tables 10 and 11) immediately after freezing revealed that slower freezing methods resulted in less red reflectance from steak surfaces while the faster method of freezing caused significantly ($P<.05$) more red reflectance. These data support visual score findings and the previously mentioned research by Ramsbottom et al. (1941) and Gray (1967).

At both wavelengths, 650 nm and 685 nm, the higher reflectance percentages found in the steaks frozen by fast methods decreased at a faster rate than did the reflectance of those steaks frozen by

Table 9. Effect of various freezing treatments on visual bleach scores.*

Treatment Means

Freezing cycle	Time period				
	Frozen				
	Day 0	Day 1	Day 7	Day 20	Avg
Liquid Nitrogen System					
1. 45 min -26.1°C	3.63[a]	1.81[d]	1.25[b]	1.19[ab]	1.78
2. 10 min -40°C and equilibrate -20.6° case	3.00[b]	1.63[d]	1.13[b]	1.06[b]	1.56
3. 30 min -40°C	3.00[b]	3.81[a]	1.75[a]	1.38[a]	2.19
4. 20 min -56.7°C	3.44[a]	3.69[a]	2.06[a]	1.38[a]	2.31
5. 2 min -26.1°C, 2 min -40°C, -73.4°C till the end point	2.06[c]	1.69[d]	1.13[b]	1.06[b]	1.39
6. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	2.06[c]	2.75[b]	1.25[b]	1.06[b]	1.62
7. -129°C till the end point	1.56[c]	2.25[c]	1.13[b]	1.25[ab]	1.44
Mechanical Air Blast					
8. -26.1°C to -28.9°C for 24 hr	1.00[c]	1.19[e]	1.06[b]	1.06[b]	1.06
Avg	2.47	2.35	1.35	1.17	1.67

[a] Means within columns with same superscript letters are not significantly different ($P<.05$).

* Visual bleach scores: 1 = no bleach; 2 = slight bleach; 3 = moderate bleach; 4 = very bleached; 5 = extremely bleached.

Table 10. Effect of various freezing treatments on percent reflectance at 650 nm.

Treatment Means

Freezing cycle	Time period					
		Frozen				
	Fresh	Day 0	Day 1	Day 7	Day 20	Avg
Liquid Nitrogen System						
1. 45 min -26.1°C	15.96^{c}	43.94^{bc}	35.42^{bc}	26.59^{ab}	21.06^{abc}	28.59
2. 10 min -40°C and equilibrate -20.6° case	16.84^{c}	33.22^{d}	27.05^{d}	24.84^{bc}	17.24^{d}	23.84
3. 30 min -40°C	24.41^{b}	50.74^{a}	39.50^{ab}	29.25^{a}	21.42^{ab}	33.06
4. 20 min -56.7°C	29.09^{a}	51.84^{a}	42.04^{a}	28.36^{ab}	21.66^{ab}	34.60
5. 2 min -26.1°C, 2 min -40°C, -73.4°C till the end point	30.96^{a}	40.67^{c}	32.51^{c}	27.75^{ab}	22.19^{a}	30.82
6. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	32.70^{a}	49.04^{ab}	36.09^{bc}	26.12^{ab}	19.66^{bcd}	32.72
7. -129°C till the end point	31.93^{a}	52.61^{a}	42.31^{a}	26.94^{ab}	20.82^{abc}	34.92
Mechanical Air Blast						
8. -26.1°C to -28.9°C for 24 hr	31.01^{a}	29.54^{d}	22.60^{e}	21.47^{c}	18.52^{cd}	24.63
Avg	26.61	43.95	34.69	26.42	20.33	30.40

[c] Means within columns with same superscript letters are not significantly different ($P<.05$).

Table 11. Effects of various freezing treatments on percent reflectance at 685 nm.

Treatment Means

Freezing cycle	Time period					
		Frozen				
	Fresh	Day 0	Day 1	Day 7	Day 20	Avg
Liquid Nitrogen System						
1. 45 min -26.1°C	18.42[c]	48.36[b]	44.30[cd]	39.84[bcd]	34.39[ab]	37.06
2. 10 min -40°C and equilibrate -20.6°C case	19.22[c]	37.67[c]	36.50[e]	38.89[cd]	29.31[c]	32.32
3. 30 min -40°C	28.17[b]	55.14[a]	48.89[abc]	44.72[a]	35.71[a]	42.52
4. 20 min -56.7°C	35.42[a]	57.59[a]	51.71[ab]	44.04[ab]	35.89[a]	44.93
5. 2 min -26.1°C, 2 min -40°C, -73.4°C till the end point	36.32[a]	46.85[b]	42.32[d]	43.32[abc]	36.44[a]	41.05
6. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	38.20[a]	54.30[a]	48.12[bc]	43.02[abc]	34.17[ab]	43.56
7. -129°C till the end point	36.92[a]	57.82[a]	53.23[a]	44.35[ab]	37.17[a]	45.89
Mechanical Air Blast						
8. -26.1°C to -28.9°C for 24 hr	37.62[a]	36.19[c]	35.00[e]	35.91[d]	31.64[bc]	36.27
Avg	31.29	49.24	45.01	41.76	34.34	40.32

[c] Means within columns with same superscript letters are not significantly different ($P<.05$).

slower cycles. By day 20, percentages of red reflectance were quite similar in all treatments. At 650 nm, treatment 5 maintained the highest reflectance, followed closely by treatments 4, 3, 1 and 7 while at 685 nm only steaks in cycles 2 and 8 were found to have significantly lower ($P<.05$) reflectance than steaks frozen by the best treatments.

Total reflectance (400 nm to 700 nm) measurements (Table 12) indicated results similar to those found with specific red wavelengths. Faster freezing resulted in more total reflectance immediately after freezing but as time of display increased, the differences between treatments decreased. One exception was found in cycle 5, which immediately after freezing ranked seventh out of the eight cycles studied. However, by day 20, this treatment ranked second. Total reflectance did not appear as effective a measure of red color as percent reflectance at specific wavelengths, especially at day 0, as correlations in Table 14 indicate. Red area reflectance (650 nm to 700 nm) (Table 13) also followed the general trend of increased brightness with increased freezing rate. Treatments 3, 4, 6 and 7 exhibited significantly higher reflectance percentages than the other cycles employed and again, these superior treatments degenerated at a faster rate. These data indicated that the largest decrease in brightness occurred during the first week of display. On day 20, treatments 5 and 7 were superior in amount of red reflectance to other treatments but were significantly higher ($P<.05$) to only cycles 2 and 3.

Table 12. Effect of various freezing treatments on total reflectance (area 1*).

Treatment Means

Freezing cycle	Time period					
		Frozen				
	Fresh	Day 0	Day 1	Day 7	Day 20	Avg
Liquid Nitrogen System						
1. 45 min -26.1°C	19.93[b]	45.54[cd]	41.02[cd]	32.06[abc]	29.41[ab]	33.60
2. 10 min -40°C and equilibrate -20.6°C case	19.87[b]	33.73[e]	30.51[e]	29.41[bc]	26.12[b]	27.93
3. 30 min -40°C	24.06[b]	57.28[ab]	47.66[ab]	34.57[a]	27.99[ab]	38.31
4. 20 min -56.7°C	29.22[a]	59.73[a]	49.92[a]	33.93[ab]	30.32[ab]	40.64
5. 2 min -26.1°C, 2 min -40°C, -73.4°C till the end point	31.15[a]	42.44[d]	37.41[d]	33.73[ab]	30.96[a]	35.15
6. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	33.15[a]	51.47[bc]	43.09[bc]	29.73[bc]	28.32[ab]	37.15
7. -129°C till the end point	31.15[a]	57.79[ab]	48.44[ab]	32.51[abc]	31.60[a]	40.31
Mechanical Air Blast						
8. -26.1°C to -28.9°C for 24 hr	32.12[a]	33.41[e]	28.83[e]	27.99[c]	28.38[ab]	30.12
Avg	27.54	47.66	40.89	31.73	29.15	35.41

[b] Means within columns with same superscript letters are not significantly different ($P<.05$).

* Area 1 = area 400-700 nm.

Table 13. Effect of various freezing treatments on red reflectance (area 2*).

Treatment Means

Freezing cycle	Time period					
		Frozen				
	Fresh	Day 0	Day 1	Day 7	Day 20	Avg
Liquid Nitrogen System						
1. 45 min -26.1°C	8.19^{cd}	15.80^{bc}	17.54^{a}	13.42^{ab}	12.38^{ab}	13.48
2. 10 min -40°C and equilibrate -20.6°C case	7.80^{d}	13.54^{cd}	13.87^{bc}	13.48^{ab}	10.38^{c}	11.80
3. 30 min -40°C	10.58^{bc}	21.03^{a}	19.09^{a}	14.71^{a}	11.03^{bc}	15.29
4. 20 min -56.7°C	11.93^{ab}	19.74^{a}	19.61^{a}	15.09^{a}	12.84^{ab}	15.80
5. 2 min -26.1°C, 2 min -40°C, -73.4°C till the end point	13.35^{a}	16.45^{b}	15.22^{b}	14.84^{a}	13.03^{a}	14.58
6. 1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C, and 1 min temper	14.32^{a}	19.67^{a}	17.67^{a}	13.87^{ab}	11.87^{abc}	15.48
7. -129°C till the end point	12.90^{ab}	21.09^{a}	19.03^{a}	14.77^{a}	13.03^{a}	16.19
Mechanical Air Blast						
8. -26.1°C to -28.9°C for 24 hr	14.25^{a}	11.54^{d}	12.13^{c}	11.80^{b}	11.42^{abc}	12.19
Avg	11.67	17.35	16.77	14.06	12.00	14.38

^{cd} Means within columns with same superscript letters are not significantly different ($P<.05$).

* Area 2 = Area 650 to 700 nm.

Correlations between visual redness and bleach scores and objective variables (Table 14) were significant at some time periods but were low. Significant correlations were found between redness scores and percent reflectance at 610, 650 and 685 nm and area 2 values on day 0, 525, 572, 610 and 685 nm reflectance and area 1 values on day 1 and 610 nm reflectance on day 20. The only significant correlation of an objective variable and bleach occurred on day 0 between visual bleach and ratio 2.

Summary

Beef loin steaks used in Trial I were packaged in oxygen impermeable Saran bags and were randomly assigned to the nine liquid nitrogen and freon immersion freezing treatments. The time-temperature pattern of frozen steaks was recorded. Reflectance percentages at various wavelengths of light and areas (cm^2) of three portions of the reflectance curve (400-700 nm, 650-700 nm and 440-474 nm) were recorded and two ratios of reflectance at specific wavelengths were calculated (474/525 nm and 572/525 nm) to determine color stability of beef loin muscles after 0, 1, 7 and 14 days of frozen display in Trial I and up to 20 days in Trial II. In general, freon freezing resulted in brighter redness scores but also caused a severe surface bleaching while liquid nitrogen cycles resulted in darker visual red scores and only slight amounts of bleach. Liquid nitrogen freezing at -26.1°C for 10 minutes and allowing steaks to equilibrate in a display case at -20.6°C was too slow and produced an arbitrary unacceptable dark color score of 4. Resolution of bleach seemed to occur under display conditions, causing bleach differences to become minimal after 7 days of display.

Table 14. Simple correlation coefficients between visual redness and bleach scores and objective variables.

Variable	Time period								
	Fresh	Frozen							
		Day 0		Day 1		Day 7		Day 20	
	Vis[3]	Vis[3]	Bl[4]	Vis[3]	Bl[4]	Vis[3]	Bl[4]	Vis[3]	Bl[4]
474 nm	0.28	-.07	0.18	-.32	0.29	-.16	0.14	-.28	0.16
525 nm	-.04	-.13	0.20	-.34*	0.30	0.13	0.16	-.28	0.16
572 nm	0.24	-.11	0.22	-.34*	0.33	-.25	0.17	-.22	0.14
610 nm	-.03	-.35*	0.07	-.35*	0.28	-.14	0.24	-.36*	0.24
650 nm	-.01	-.43*	0.04	-.39*	0.26	-.10	0.25	-.32	0.29
685 nm	0.06	-.35*	-.01	-.33	0.02	-.14	0.28	-.32	0.28
A1[1]	0.17	-.24	0.10	-.37*	0.27	-.14	0.26	-.28	0.18
A2[1]	0.21	-.39*	0.02	-.25	0.29	-.09	0.26	-.29	0.04
A3[1]	-.11	0.12	0.02	-.20	0.28	-.15	0.17	-.29	0.20
R1[2]	0.38*	0.33	-.04	0.15	-.04	-.04	-.03	0.02	-.06
R2[2]	0.45*	0.04	0.36*	0.01	0.14	-.14	-.06	0.08	-.03

[1] A1 = Area 400-700 nm; A2 = Area 650-700 nm; A3 = Area 440-474 nm.

[2] R1 = Ratio 474/525 nm; R2 = Ratio 572/525 nm.

[3] Vis = Visual redness.

[4] Bl = Visual bleach.

* = ($P<.05$).

Treatments and packaging material were changed in Trial II. Steaks were packaged in a skin-type film with medium permeability to oxygen. Liquid nitrogen cycles proved superior to blast freezing in maintaining color stability. Generally, all cycles used with the skin-tight film and liquid nitrogen were acceptable except steaks frozen for 10 minutes at -40°C and allowed to equilibrate in a display case at -20.6°C. Blast freezing at -26.1°C to -28.9°C was inadequate with this film.

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CHAPTER IV

EFFECTS OF FILM PERMEABILITY, FREEZING SYSTEM, PACKAGING TIME AND DISPLAY CASE TEMPERATURE ON COLOR STABILITY AND WEIGHT LOSS DURING DISPLAY OF FROZEN BEEF *LONGISSIMUS* AND *PSOAS MAJOR* MUSCLES PACKAGED IN TRANSPARENT FILM

Introduction

In order to keep pace with an "ever" expanding affluent population, America's meat industry must continue to grow and develop more efficient systems of processing and marketing. Centralized processing and fabricating operations and distribution of frozen packaged retail cuts would result in more efficient use of time and manpower and less handling of cuts from slaughter until display in a retail showcase. Modern freezing and packaging would easily fit into such a system by producing a product of acceptable quality and appearance and would extend the display life of red meat to a month or more.

The problem of maintaining acceptable frozen meat color has been studied by many researchers. Lawler *et al.* (1969) reported meat and poultry frozen in a continuous freon immersion spray system exhibited "superior quality" and essentially no moisture loss. The freezant was described as being a non-toxic, non-flammable, non-corrosive, and completely recoverable liquid. Gray (1967) compared beef sirloin steaks frozen by blast air with steaks frozen in an industrial liquid nitrogen tunnel and found the latter to produce a more natural red color. Hamre *et al.* (1967) indicated, however, that chicken immersed in liquid nitrogen appeared "as white as chalk."

Dunker et al. (1953) found rates of freezing to be affected by type and presence of wrapping material. An increase of up to 103 percent was found in the time required to freeze samples of ground pork wrapped in polyethylene film when compared to similar unwrapped samples. Faster freezing was found to promote a brighter surface color (Ramsbottom et al., 1941). Film used for the commercial packaging of meat should have gas permeabilities high enough to allow sufficient amounts of oxygen to enter the package and react with myoglobin to form oxymyoglobin (Allen, 1949; Snyder, 1965; Hunt et al., 1969). Results of Watts (1954) and Marriott et al. (1967), however, were in contrast with the aforementioned work. They reported packaging meat in oxygen impermeable films retarded discoloration, thereby maintaining a brighter red color than films of high oxygen permeability. Their conclusions were based on the fact that myoglobin changes to its oxidized form much faster if oxygen is readily available.

Low temperature display depressed enzyme activity, minimized color changes, inhibited oxidation and reduced desiccation and drip (Ramsbottom et al., 1941). Hunt et al. (1969) investigated color stability of frozen lamb chops displayed at -21°C and -29°C. Over a period of six weeks, color stability was enhanced to a greater extent at the lower display temperature.

The purpose of this work was to study the effects of film permeability, freezing system, packaging time, display case temperature and possible interactions on color stability and weight loss during display of frozen beef longissimus and psoas major muscle packaged in transparent film.

Experimental Procedure

Description of steaks and treatments. Six wholesale beef loins from animals slaughtered the same day were used for each of three replications. The loins weighed between 24.9 and 27.2 kg, had small to modest amounts of marbling at the thirteenth rib and less than 1.27 cm of fat cover. For each replication, six 2.54 cm steaks were cut from each loin from immediately posterior to the point at which the psoas major muscle was large enough to cover the aperture of the spectrophotometer used for color measurement. In addition, extra steaks were cut for purposes of temperature recording during freezing and storage. The thirty-six steaks thus obtained were then randomly assigned to thirty-six treatment combinations. Different tables of random numbers were used for each replication. A flow diagram of all the variable combinations used in this study is presented in Figure 2. Factors studied include three film permeabilities, high (ethylene vinyl acetate, 465.00 cc $O_2/m^2/24$ hr/atm); medium (iolon, 209.30 cc $O_2/m^2/24$ hr/atm); and low (nylon polyethylene, 4.65 cc $O_2/m^2/24$ hr/atm); two freezing systems (liquid nitrogen vapor and freon immersion); two vacuum packaging times (before and after freezing) and three display case temperatures (-28.9°C, -20.6°C, and -12.2°C). T-Bone and Porterhouse steaks were used since they contain both a light colored muscle (longissimus) with a relatively low oxygen requirement and a dark colored muscle (psoas major) with a high oxygen requirement.

Freezing and temperature recording. Liquid nitrogen treated steaks were frozen in an NCG-Ultra-Freeze Simulator Freezer using a freezing

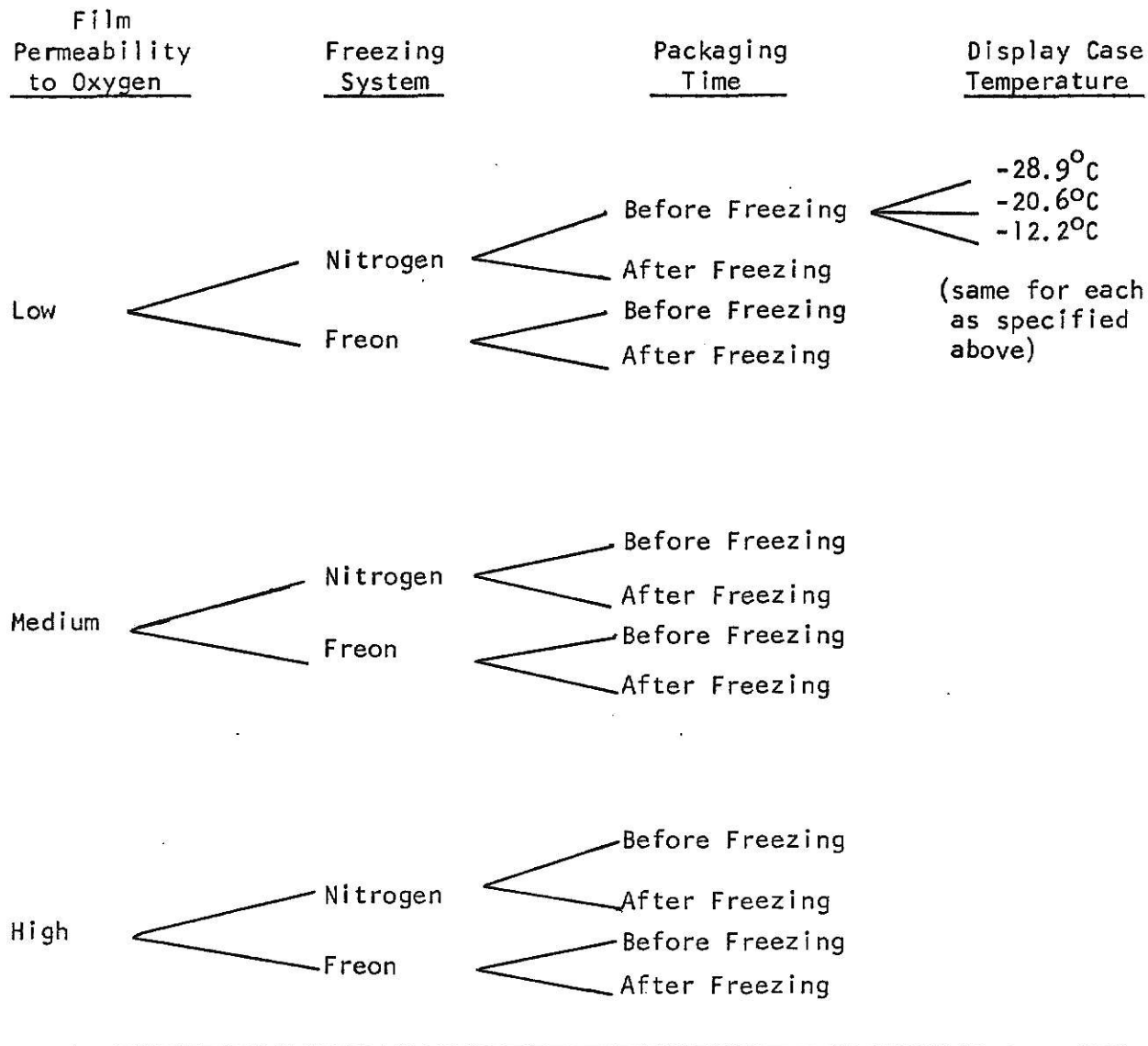

Figure 2. Experimental design.

cycle of -17.8°C for 1/2 minute, -45.6°C for 1/2 minute, -73.4°C for one minute, -101.2°C for one minute, -129°C for one minute and tempering for one minute. Freon treated steaks were frozen in a Dupont Laboratory model freon freezer, at a constant -30.6°C until the center of the steaks reached -5° C (about six minutes).

Temperature recordings during freezing cycles and storage were obtained using a 24 point Honeywell Electronik 16 Multipoint Strip Chart Record, with thermocouples placed at the surface of "dummy" steaks and at the center of the 1/2 radius of the longissimus muscle (Figure 3). Defrost cycles of the display cases were also monitored to find any major variation in internal steak temperatures due to the rise in ambient temperatures at these times. Ambient temperature and relative humidity were recorded throughout the study using a hygrothermograph.

Packaging. After a thirty minute bloom period, one sixth of the steaks in each replication were packaged in each of the three previously mentioned films. Packages were subjected to 13.6 kg of vacuum and heat sealed, so that a skin type package was obtained. Remaining steaks were packaged in the same manner, after freezing.

Display cases and lighting system. Quickold freezer cases (no defrost cycles) were used to display steaks held at -12.2°C and Hussman cases were used for those steaks stored at -20.6°C and -28.9°C. Case covers were placed over the steaks at 7:00 p.m. each night and were removed at 7:00 a.m. each morning, to simulate a twelve hour store operation. General Electric Delux Cool White Fluorescent lights were used at an intensity of 1076 lumens/m^2 at steak surfaces. Room lights

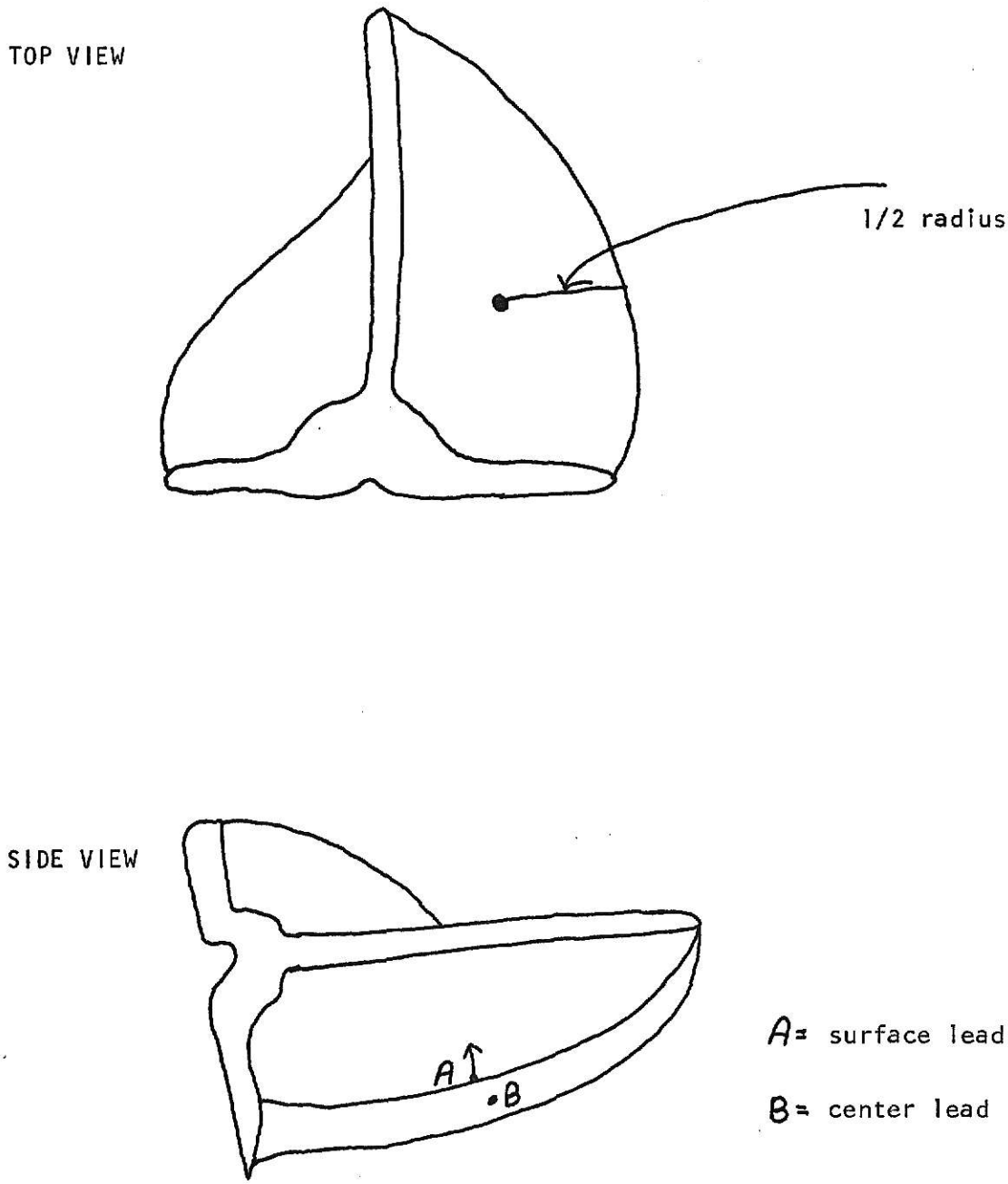

Figure 3. Placement of thermocouple leads for temperature recording.

remained off to remove effects of background lighting. Care was taken to display and evaluate the same surface during the entire study.

Color and weight loss recording. Both longissimus and psoas major muscles were subjectively scored for color and bleach development (Tables 16 and 18)immediately post freezing, and after 1, 7, 21, and 42 days display. Percent reflectance was scanned from 400 to 700 nm with a Bausch and Lomb Spectronic 600 (with magnesium carbonate blocks used for 100% reflectance standard at a scan speed of 250/nm/min). Data used included percent reflectance at 474, 525, 572, 610, and 685 nm. In addition, the areas under the reflectance curves from 400 to 700 nm (total reflectance), 650 to 700 nm (red reflectance), and 440 to 474 nm (blue reflectance) were obtained and reflectance ratios were calculated (R474/R525 nm and R572/R525 nm).

Analysis of variance was performed on main treatments and interactions and correlation coefficients of objective color measurements with subjective scores were calculated on a within time period basis.

Steaks were weighed by Mettler P1200N balance to the nearest 0.01 gm at each time period and weight losses during display were determined as percentages of original frozen weight.

Results and Discussion

Average ambient humidity during the six week study was approximately 33 percent while ambient temperature fluctuated between 18.8°C and 25.5°C and averaged 22.2°C. Freezing unpackaged steaks by immersion in liquid freon took approximately five minutes (steaks reached an

internal temperature of -5°C) while freezing prepackaged steaks took nine minutes to reach the same internal temperature. Steaks frozen by liquid nitrogen vapor were subjected to a seven minute cycle and those steaks that were frozen after packaging reached the -5°C endpoint, while steaks frozen unpackaged reached a somewhat colder internal temperature.

Weight loss and percent loss data (Table 15) indicated a net gain of 0.17 gm or +0.22% during six weeks display. Ice accumulation on the package was the probable cause for the slight gain in weight although every effort was made to remove ice prior to weighing each package.

Main effect means for visual redness scores of longissimus and psoas major muscles are presented in Tables 16 and 17, respectively. Significant differences existed in longissimus visual redness between steaks packaged in low permeability nylon film and steaks packaged in the two higher oxygen permeability films (iolon and ethylene vinyl acetate). A similar trend was found in the psoas major visual redness means for film permeability; however, only differences on day 7 of display exhibited significance. Perhaps greater oxygen demand of psoas major muscle means that even the oxygen permeability of the medium and high films is limiting, consequently no significant differences were found. These results are in agreement with those of Allen (1949), Snyder (1965), and Hunt et al. (1969), and are contradictory with the findings of Watts (1954) and Marriott et al. (1967).

Freezing system means for both muscles indicated that steaks frozen by freon immersion exhibited a brighter color (compared to liquid nitrogen) after one day of display, but lost this advantage by

Table 15. The effect of length of display on product weight loss.

Time	Weight in grams	% Change	Total % change
Day 0	380.88		
		+0.20	
Day 1	380.94		
		-0.04	
Day 7	380.80		+0.22
		-0.07	
Day 21	380.58		
		+0.13	
Day 42	381.05		

Table 16. Main treatment effects on visual redness scores* of frozen beef longissimus.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	1.57^{a}	2.07^{b}	3.72^{b}	3.90^{b}	4.21^{b}
Medium	1.44^{a}	1.57^{a}	3.06^{a}	3.57^{a}	3.97^{a}
High	1.62^{a}	1.74^{a}	3.19^{a}	3.67^{a}	4.04^{a}
FREEZING SYSTEM					
Nitrogen	1.59^{a}	1.94^{b}	3.27^{a}	3.70^{a}	4.02^{a}
Freon	1.50^{a}	1.65^{a}	3.38^{a}	3.72^{a}	4.12^{a}
PACKAGING TIME					
Before	1.56^{a}	1.90^{a}	3.49^{b}	3.80^{b}	4.14^{a}
After	1.54^{a}	1.68^{a}	3.16^{a}	3.62^{a}	4.01^{a}
DISPLAY TEMPERATURE					
-28.9°C	1.47^{a}	1.40^{a}	3.06^{a}	3.47^{a}	3.92^{a}
-20.6°C	1.62^{a}	1.87^{b}	3.32^{b}	3.70^{b}	4.07^{ab}
-12.2°C	1.54^{a}	2.10^{b}	3.60^{c}	3.96^{c}	4.23^{b}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

* Visual redness score code: 1 = very bright red; 2 = bright red; 3 = slightly dark red; 4 = very dark red; 5 = extremely dark red.

Table 17. Main treatment effects on visual redness scores* of frozen beef psoas major.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	3.18^{a}	3.46^{a}	4.19^{b}	4.24^{a}	4.49
Medium	3.07^{a}	3.24^{a}	3.69^{a}	4.03^{a}	4.33^{a}
High	3.12^{a}	3.22^{a}	3.71^{a}	4.10^{a}	4.36^{a}
FREEZING SYSTEM					
Nitrogen	3.36^{b}	3.51^{b}	3.87^{a}	4.13^{a}	4.35^{a}
Freon	2.89^{a}	3.10^{a}	3.86^{a}	4.11^{a}	4.44^{a}
PACKAGING TIME					
Before	3.37^{b}	3.54^{b}	4.01^{b}	4.20^{b}	4.44^{a}
After	2.88^{a}	3.07^{a}	3.72^{a}	4.04^{a}	4.34^{a}
DISPLAY TEMPERATURE					
-28.9°C	3.11^{a}	3.08^{a}	3.68^{a}	3.90^{a}	4.21^{a}
-20.6°C	3.04^{a}	3.29^{ab}	3.87^{ab}	4.07^{b}	4.32^{a}
-12.2°C	3.22^{a}	3.54^{b}	4.04^{b}	4.39^{c}	4.65^{b}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

* Visual redness score code: 1 = very bright red; 2 = bright red; 3 = slightly dark red; 4 = very dark red; 5 = extremely dark red.

the seventh day of display. The higher degree of bleach (Tables 18 and 19) of steaks frozen by freon followed by partial resolution of the bleach during display accounted for part of the aforementioned trend.

Longissimus packaging time means suggested that packaging steak before freezing results in darker surface colors, but significant differences were found only at days 7 and 21. Packaging time data for the psoas major indicated a similar but stronger trend, with means showing significance at every time period, with the exception of day 42. Some significant interactions between film permeability and packaging time were calculated (Tables 20 and 21). After 1 day of display, of longissimus packaged in low oxygen permeability film, that packaged before freezing was darker. After longer display times, namely 21 days for longissimus and 21 and 42 days for psoas major, for steaks packaged in medium and high permeability film, those packaged after freezing were again brighter. The film that was low in oxygen permeability caused a degeneration of the bloomed color in steaks packaged prior to freezing due to the inability of available oxygen to penetrate the package during the time period between packaging and freezing. Oxygen was able to penetrate the permeable films though and in some cases might have reacted with available oxymyoglobin to produce metmyoglobin. This was due to the increased amount of time required to freeze pre-packaged steaks. Lighter color when packaging after freezing may have been partially due to faster freezing of unpackaged steaks with more bleach resulting.

Table 18. Main treatment effects on visual bleach scores* of frozen beef longissimus.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	1.85[a]	1.78[a]	1.51[a]	1.57[a]	1.64[a]
Medium	1.94[a]	1.71[a]	1.33[a]	1.44[a]	1.33[a]
High	1.87[a]	1.64[a]	1.44[a]	1.49	1.53[a]
FREEZING SYSTEM					
Nitrogen	1.20[a]	1.18[a]	1.15[a]	1.14[a]	1.18[a]
Freon	2.57[b]	2.24[b]	1.71[b]	1.86[b]	1.82[b]
PACKAGING TIME					
Before	1.78[a]	1.51[a]	1.30[a]	1.30[a]	1.32[a]
After	2.00[a]	1.91[b]	1.56[b]	1.69[b]	1.68[b]
DISPLAY TEMPERATURE					
-28.9°C	1.80[a]	1.71[a]	1.53[b]	1.64[b]	1.67[b]
-20.6°C	1.90[a]	1.72[a]	1.54[b]	1.61[b]	1.58[b]
-12.2°C	1.96[a]	1.69[a]	1.22[a]	1.25[a]	1.25[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

* Visual bleach score code: 1 = no bleach; 2 = slight bleach; 3 = moderate bleach; 4 = very bleached; 5 = extremely bleached.

Table 19. Main treatment effects on visual bleach scores* on frozen beef psoas major.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	1.96[a]	1.92[a]	1.51[a]	1.54[a]	1.71[a]
Medium	2.17[a]	2.06[a]	1.50[a]	1.57[a]	1.44[a]
High	2.15[a]	1.85[a]	1.50[a]	1.57[a]	1.54[a]
FREEZING SYSTEM					
Nitrogen	1.30[a]	1.29[a]	1.14[a]	1.16[a]	1.18[a]
Freon	2.88[b]	2.59[b]	1.87[b]	1.96[b]	1.94[b]
PACKAGING TIME					
Before	1.92[a]	1.68[a]	1.35[a]	1.36[a]	1.32[a]
After	2.27[b]	2.20[b]	1.66[b]	1.76[b]	1.80[b]
DISPLAY TEMPERATURE					
-28.9°C	2.03[a]	2.00[a]	1.79[b]	1.83[b]	1.79[b]
-20.6°C	2.11[a]	1.90[a]	1.47[a]	1.56[ab]	1.61[b]
-12.2°C	2.14[a]	1.92[a]	1.25[a]	1.29[a]	1.29[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

* Visual bleach score code: 1 = no bleach; 2 = slight bleach; 3 = moderate bleach; 4 = very bleached; 5 = extremely bleached.

Table 20. Interaction effects on visual redness scores of frozen beef longissimus.

Interaction	Time period				
	Day 0	Day 1	Day 7	Day 21	Day 42
FILM PERMEABILITY X PACKAGING TIME					
Low before	N.S.	2.33^{a}	N.S.	3.80^{a}	N.S.
Low after		1.80^{bc}		4.00^{a}	
Medium before		1.75^{bc}		3.78^{a}	
Medium after		1.39^{c}		3.36^{b}	
High before		1.61^{bc}		3.83^{a}	
High after		1.86^{b}		3.50^{b}	

Interaction means within time periods with same superscript letters are not significantly different ($P<.05$).

Table 21. Interaction effects on visual redness scores of frozen beef psoas major.

Interaction	Time period				
	Day 0	Day 1	Day 7	Day 21	Day 42
FILM PERMEABILITY X PACKAGING TIME					
Low before	N.S.	N.S.	N.S.	4.14^{ab}	4.39^{ab}
Low after				4.33^{a}	4.58^{a}
Medium before				4.19^{a}	4.42^{ab}
Medium after				3.86^{c}	4.25^{b}
High before				4.28^{a}	4.53^{a}
High after				3.92^{bc}	4.19^{b}
FREEZING SYSTEM X PACKAGING TIME					
Nitrogen before	N.S.	N.S.	4.13^{a}	4.30^{a}	4.48^{a}
Nitrogen after			3.61^{c}	3.96^{b}	4.22^{b}
Freon before			3.89^{b}	4.11^{b}	4.41^{ab}
Freon after			3.83^{bc}	4.11^{b}	4.46^{a}

Interaction means within time periods with same superscript letters are not significantly different ($P<.05$).

Display case temperature effects on both muscles were apparent early in the study. Steaks held at -28.9°C exhibited significantly brighter longissimus and psoas major colors at all time periods when compared to steaks held at -12.2°C. However, when -28.9°C was compared with -20.6°C, a similar trend was found, but longissimus redness scores were not significantly brighter at all time periods and psoas major redness scores were significantly brighter only on day 21. These results are in agreement with Ramsbottom (1947) who stated that as storage temperature decreased from -3.3°C to -28.9°C, color stability of frozen pork chops increased. Hunt et al. (1969) found that over a period of six weeks, color stability of frozen lamb chops was more stable at the lower of two (-29°C and -21°C) display temperatures.

Main effect means of visual scores indicated that acceptable longissimus colors (mean arbitrary value of less than 4) were maintained in all treatments through day 21 of display but only steaks packaged in medium permeability film or displayed at -28.9°C showed acceptable visual redness values after 42 days of display. Psoas major main effect means indicated that acceptable color was lost at some time between day 7 and day 21 of display. If low permeability film was used, psoas major was unacceptable by day 7 and if packaging occurred before freezing, color also became undesirable by day 7.

Additional interactions occurred between freezing system and packaging time (Table 21). Packaging after freezing with liquid nitrogen vapor maintained a more natural red color than packaging prior to freezing.

Tables 18 and 19 present main effect means of visual bleach scores for longissimus and psoas major muscles. There were no visual bleach differences ($P<.05$) in film permeability means at any time period. Freezing steaks in liquid freon caused significantly more bleach ($P<.05$) in both muscles at all time periods when compared to steaks frozen by liquid nitrogen. Similar findings have been reported by Hamre et al. (1967), who said that the color of diced chicken immersed in liquid nitrogen appeared as "white as chalk", while a CO_2 vapor and liquid nitrogen spray produced a light but acceptable color. This bleach was probably due to the more efficient heat transfer by liquid freon used at its boiling point as compared to the liquid nitrogen freezant used as a vapor spray. The difference in bleach scores between freon and nitrogen frozen steaks tended to decrease with an increase in display time, perhaps due to ice recrystallization.

Packaging prior to freezing prevented much of the bleach caused by freezing prior to packaging.

Display case temperature data indicated that after the first day of display, no difference in visual bleach could be seen, but after one week of display, a significantly higher degree of bleach was present in the coldest display case. This observation was found in both muscles and suggests that during display resolution of surface bleach occurs in "warmer" cases while bleach remains to a greater extent at the lowest temperature.

Reflectance percentages at 685 nm (Tables 22 and 23) did not decrease during the six week display period. Although time was not

Table 22. Main treatment effects on 685 nm reflectance percentages of frozen beef longissimus.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	50.77^{a}	50.07^{a}	47.62^{a}	52.95^{a}	52.69^{a}
Medium	51.58^{a}	52.26^{a}	50.97^{a}	55.02^{a}	49.64^{a}
High	49.61^{a}	51.72^{a}	50.89^{a}	50.64^{a}	50.85^{a}
FREEZING SYSTEM					
Nitrogen	43.36^{a}	45.47^{a}	45.59^{a}	49.19^{a}	47.59^{a}
Freon	57.94^{b}	57.24^{b}	54.06^{b}	56.55^{b}	54.53^{b}
PACKAGING TIME					
Before	48.86^{a}	48.94^{a}	47.68^{a}	50.78^{a}	49.20^{a}
After	52.44^{a}	53.58^{b}	51.97^{b}	54.96^{a}	52.92^{b}
DISPLAY TEMPERATURE					
-28.9°C	50.57^{a}	52.16^{a}	52.60^{b}	57.80^{c}	54.25^{b}
-20.6°C	52.68^{a}	51.16^{a}	50.37^{ab}	52.72^{b}	50.94^{a}
-12.2°C	48.71^{a}	50.74^{a}	46.50^{a}	48.08^{a}	48.00^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Table 23. Main treatment effects on 685 nm percentages of frozen beef psoas major.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	41.54[a]	46.57[b]	44.47[a]	46.43[a]	47.56[a]
Medium	39.41[a]	42.98[ab]	40.93[a]	45.29[a]	44.45[a]
High	40.01[a]	38.85[a]	40.33[a]	45.83[a]	44.22[a]
FREEZING SYSTEM					
Nitrogen	33.86[a]	38.32[a]	38.61[a]	40.47[a]	42.81[a]
Freon	46.76[b]	47.28[b]	45.21[b]	51.23[b]	48.01[b]
PACKAGING TIME					
Before	37.36[a]	40.98[a]	39.05[a]	43.71[a]	42.83[a]
After	43.26[b]	44.61[a]	44.78[b]	47.99[b]	48.00[b]
DISPLAY TEMPERATURE					
-28.9°C	40.15[a]	46.32[b]	46.46[b]	50.72[b]	49.53[b]
-20.6°C	41.31[a]	41.19[a]	40.58[a]	44.10[a]	44.21[a]
-12.2°C	39.50[a]	40.88[a]	38.69[a]	42.73[a]	42.49[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

included in the analysis of variance, the repeatability inherent in this objective measurement allows the above comparison to be made.

Film permeability did not result in significant differences between longissimus 685 nm reflectance percentages within any time period. At day 1, psoas major when packaged in low permeability film exhibited a significantly higher 685 nm reflectance percentage than psoas major packaged in the high permeability film.

Both muscles had significantly more 685 nm reflectance with increasing display time in the steaks frozen by freon immersion. Packaging after freezing also caused more 685 nm reflectance with significant differences occurring at days 1, 7 and 42 and days 0, 7, 21 and 42 for the longissimus and psoas major muscles, respectively.

Results of display case temperature on means of 685 nm reflectance percentages show that with decreasing display temperature more light is reflected by both muscles. After 7 days, steaks displayed at -28.9°C showed significantly more reflectance than steaks stored at -12.2°C. On day 21 significant differences were found between longissimus 685 nm reflectance percentages of all three temperatures while at day 42, the display temperature of -28.9°C caused a higher ($P<.05$) reflectance percentage than the other two temperatures used. Psoas major results were similar, showing that within each time period, steaks displayed at -28.9°C had higher ($P<.05$) 685 nm reflectance percentages than steaks displayed at the two warmer temperatures, supporting the brighter visual redness found for the coldest case.

Main effect means for total reflectance (Tables 24 and 25) indicate that essentially no differences occurred between film permeabilities in

Table 24. Main treatment effects on total reflectance (area 1*) of frozen beef longissimus.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	45.80[a]	49.79[a]	41.54[a]	47.28[a]	48.38[b]
Medium	47.15[a]	46.12[a]	38.57[a]	43.02[a]	37.73[a]
High	43.41[a]	48.76[a]	41.34[a]	40.44[a]	43.09[ab]
FREEZING SYSTEM					
Nitrogen	35.54[a]	40.25[a]	35.02[a]	39.09[a]	39.28[a]
Freon	55.34[b]	56.18[b]	45.92[b]	48.12[b]	46.83[b]
PACKAGING TIME					
Before	43.86[a]	46.18[a]	38.44[a]	42.25[a]	41.22[a]
After	47.02[a]	50.24[a]	42.50[a]	44.96[a]	44.89[a]
DISPLAY TEMPERATURE					
-28.9°C	44.05[a]	50.57[a]	44.76[b]	49.54[b]	47.15[b]
-20.6°C	48.76[a]	48.25[a]	41.67[b]	43.22[b]	44.44[b]
-12.2°C	43.54[a]	45.92[a]	35.02[a]	37.99[a]	37.60[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

* Area 1 = Area 400 to 700 nm in cm^2.

Table 25. Main treatment effects on total reflectance (area 1*) of frozen beef psoas major.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	38.76^{a}	51.21^{b}	42.89^{b}	45.28^{b}	48.76^{b}
Medium	37.80^{a}	41.34^{a}	33.41^{a}	37.73^{a}	36.64^{a}
High	37.34^{a}	39.86^{a}	35.86^{a}	40.64^{ab}	38.96^{a}
FREEZING SYSTEM					
Nitrogen	29.22^{a}	38.89^{a}	32.83^{a}	35.02^{a}	37.99^{a}
Freon	46.76^{b}	49.47^{b}	41.92^{b}	47.41^{b}	44.89^{b}
PACKAGING TIME					
Before	33.22^{a}	41.73^{a}	33.80^{a}	37.22^{a}	37.80^{a}
After	42.76^{b}	46.57^{a}	40.96^{b}	45.21^{b}	45.08^{b}
DISPLAY TEMPERATURE					
-28.9°C	36.96^{a}	49.92^{b}	43.47^{b}	47.60^{b}	45.92^{b}
-20.6°C	39.22^{a}	42.83^{a}	37.02^{a}	38.96^{a}	40.96^{a}
-12.2°C	37.73^{a}	39.73^{a}	31.67^{a}	37.02^{a}	37.34^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

* Area 1 = Area 400 to 700 nm in cm^2.

their abilities to affect the amount of light reflected from the surface of frozen longissimus. However, the low permeability film caused significantly more reflectance in the psoas major muscle. This appears to be in conflict with visual redness scores. No differences in red area reflectance (Tables 26 and 27) due to film permeability were found in either muscle at any time period studied.

Freezing steaks by immersing them in liquid freon resulted in significantly more total and red area reflectance means, when compared to means obtained from steaks frozen in nitrogen vapor. The higher degree of bleach found with freon freezing explains the increased reflectance percentages also found in steaks frozen by this method.

Packaging time means for frozen longissimus muscle indicated that although packaging after freezing tended to result in more total light reflectance at each time period, no significant differences occurred. A similar trend was found in red area reflectance with a significantly higher amount occurring only at day 7 for the longissimus. Psoas major muscle means for total areas indicated that significantly more reflectance occurred in steaks packaged after freezing at every time period except day 1. Red area means for packaging time showed results similar to those of total area means, with every time period except day 1 exhibiting significance. Although packaging after freezing resulted in higher bleach scores, it was also apparent that color stability was enhanced. Freezing prior to packaging probably slowed enzyme reactions within the muscles to a greater extent than freezing

Table 26. Main treatment effects on percent red reflectance (area 2*) of frozen beef longissimus.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	14.19[a]	14.96[a]	13.22[a]	13.67[a]	14.45[a]
Medium	14.58[a]	15.87[a]	14.00[a]	15.16[a]	14.12[a]
High	14.12[a]	15.80[a]	14.96[a]	13.87[a]	14.64[a]
FREEZING SYSTEM					
Nitrogen	12.26[a]	13.80[a]	12.64[a]	13.22[a]	13.48[a]
Freon	16.38[b]	17.29[b]	15.42[b]	15.22[b]	15.35[b]
PACKAGING TIME					
Before	13.80[a]	14.84[a]	13.35[a]	13.74[a]	13.93[a]
After	14.77[a]	16.25[a]	14.77[b]	14.71[a]	14.90[a]
DISPLAY TEMPERATURE					
-28.9°C	14.12[a]	15.67[a]	14.84[b]	15.48[b]	15.42[a]
-20.6°C	15.03[a]	15.42[a]	14.71[b]	14.25[b]	14.25[a]
-12.2°C	13.80[a]	15.54[a]	12.58[a]	12.90[a]	13.54[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

* Area 2 = Area 650 to 700 nm (red portion of spectrum) in cm^2.

Table 27. Main treatment effects on percent red reflectance (area 2*) of frozen beef psoas major.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	11.61[a]	14.12[a]	12.19[a]	12.77[a]	13.61[a]
Medium	10.71[a]	13.09[a]	11.61[a]	12.71[a]	12.90[a]
High	11.22[a]	12.45[a]	12.00[a]	12.77[a]	13.03[a]
FREEZING SYSTEM					
Nitrogen	9.35[a]	12.00[a]	11.09[a]	11.22[a]	12.32[a]
Freon	13.03[b]	14.38[b]	12.77[b]	14.25[b]	14.00[b]
PACKAGING TIME					
Before	10.26[a]	12.38[a]	11.22[a]	12.00[a]	12.45[a]
After	12.06	14.00	12.64	13.48	13.93
DISPLAY TEMPERATURE					
-28.9°C	11.29[a]	14.45[a]	13.03[b]	14.06[b]	14.51[b]
-20.6°C	11.48[a]	12.38[a]	11.87[ab]	12.06[a]	12.71[a]
-12.2°C	10.77[a]	12.77[a]	10.96[a]	12.00[a]	12.26[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

* Area 2 = Area 650 to 700 nm (red portion of spectrum) in cm^2.

after packaging, resulting in decreased enzyme competition for oxygen, allowing the muscle pigment to be more fully maintained in the oxymyoglobin state.

Longissimus area 1 means for display case temperatures show significantly higher total reflectance in the -28.9°C case (as compared to the -12°C case) after 7, 21, and 42 days of display. The fact that no differences were found in this or any other reflectance data at day 0 was expected since steaks were not exposed to their respective cases until after the readings were collected. Area 2 means for the longissimus muscle exhibited a similar trend. However, significance was not exhibited at day 42. In the case of both areas, reflectance obtained from longissimus muscles displayed at -20.6°C were not statistically different as areas obtained from longissimus muscles in the -28.9°C case; at several time periods. Psoas major area 1 and area 2 means also show increased reflectance in the coldest display case when compared to the two warmer cases with significance exhibited at several time periods.

Film permeability means for 474/525 nm reflectance ratios (Tables 28 and 29) indicated that after day 1 of display, steaks packaged in the low permeability film had higher ($P<.05$) ratios indicating possible lower oxymyoglobin percentages in both muscles based on the work of Allen et al. (1969). Partial oxygen pressures below 20 mm of Hg favor oxidation of myoglobin (George et al., 1952a, b). The greater oxidation to metmyoglobin probably accounted for the visually darker appearance of these steaks.

Table 28. Main treatment effects on R474/R525 ratio of frozen beef longissimus.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	0.94[a]	0.97[b]	0.99[b]	1.00[b]	1.00[b]
Medium	0.97[a]	0.91[a]	0.93[a]	0.94[a]	0.97[a]
High	0.94[a]	0.92[a]	0.95[a]	0.95[a]	0.98[a]
FREEZING SYSTEM					
Nitrogen	0.93[a]	0.93[a]	0.96[a]	0.96[a]	0.99[b]
Freon	0.96[b]	0.94[a]	0.96[a]	0.97[a]	0.97[a]
PACKAGING TIME					
Before	0.95[a]	0.94[a]	0.97[b]	0.98[b]	0.99[b]
After	0.94[a]	0.92[a]	0.94[a]	0.95[a]	0.97[a]
DISPLAY TEMPERATURE					
-28.9°C	0.93[a]	0.93[a]	0.96[a]	0.96[a]	0.98[a]
-20.6°C	0.95[a]	0.93[a]	0.96[a]	0.97[a]	0.98[a]
-12.2°C	0.95[a]	0.94[a]	0.95[a]	0.96[a]	0.98[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Table 29. Main treatment effects on R474/R525 ratio of frozen beef psoas major.

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	1.01[a]	0.99[b]	1.02[b]	1.00[b]	1.01[b]
Medium	1.00[a]	0.94[a]	0.94[a]	0.94[a]	0.97[a]
High	0.97[a]	0.95[a]	0.96[a]	0.95[a]	0.97[a]
FREEZING SYSTEM					
Nitrogen	0.99[a]	0.96[a]	0.97[a]	0.96[a]	0.99[a]
Freon	1.00[a]	0.96[a]	0.98[b]	0.97[a]	0.98[a]
PACKAGING TIME					
Before	1.02[b]	0.98[b]	0.98[a]	0.97[a]	0.98[a]
After	0.97[a]	0.95[a]	0.97[a]	0.96[a]	0.98[a]
DISPLAY TEMPERATURE					
-28.9°C	1.00[a]	0.96[a]	0.97[a]	0.97[a]	0.99[a]
-20.6°C	1.00[a]	0.96[a]	0.98[a]	0.96[a]	0.98[a]
-12.2°C	0.98[a]	0.96[a]	0.97[a]	0.96[a]	0.98[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

No consistent effects were produced by freezing system for 474/525 nm reflectance values.

Packaging time means indicate that packaging before freezing resulted in increased R474/R525 ratios in both longissimus and psoas major muscles. Significantly higher values were found at days 7, 21 and 42 in longissimus muscle while the psoas major muscle exhibited significance at days 0 and 1. Complex enzyme systems inherent within psoas major muscle compete with pigment systems for oxygen causing less oxygen to be available for oxymyoglobin formation at the later time periods.

No differences were found between display case temperature means for 474/525 nm reflectance means at any time period.

Simple correlation coefficients between visual redness scores and objective variables (Tables 30 and 31) were generally low for both muscles. Significant correlations were obtained at various time periods between visual redness and percent reflectance at 610, 650, 685 nm, reflectance scan areas and the two ratios. The highest correlations for each muscle occurred between visual redness and 685 nm reflectance and 572/525 nm reflectance ratios. Ockerman et al. (1969) studied fresh beef longissimus color and reported correlations as high as 0.88 between visual color scores (taken by a panel) and percent reflectance at 685 nm. Freezing might have affected spectrophotometric properties of the meat surfaces in some way, causing lower correlations to be found in the present study. A different visual scale was also used which could have affected results, but data suggested that 685 nm reflectance

Table 30. Simple correlation coefficients between visual redness scores and objective variables (longissimus).

Day Variable	0 Vis	1 Vis	7 Vis	21 Vis	42 Vis
474 nm	0.19	-.07	0.02	-.09	0.13
525 nm	0.18	-.01	-.01	-.12	0.10
572 nm	0.19	-.05	0.07	-.06	0.17
610 nm	0.09	0.02	-.24*	-.25*	-.03
650 nm	0.06	-.37*	-.29*	-.28*	-.06
685 nm	0.09	-.47*	-.22*	-.25*	-.12
A-1[1]	0.18	-.39*	-.14	-.16	0.04
A-2[1]	0.09	-.22*	-.21*	-.30*	-.16
A-3[1]	0.24*	-.41*	-.08	-.10	0.13
R-1[2]	0.17	0.02	0.31*	0.42*	0.48*
R-2[2]	0.11	0.38*	0.48*	0.42*	0.42*

[1] A-1 = Area 400-700 nm.
A-2 = Area 650-700 nm.
A-3 = Area 440-474 nm.

[2] R-1 = R474/R525.
R-2 = R572/R525.

* ($P<.05$).

Table 31. Simple correlation coefficients between visual redness scores and objective variables (psoas major).

Day Variable	0 Vis	1 Vis	7 Vis	21 Vis	42 Vis
474 nm	-.08	-.20*	0.01	-.07	0.04
525 nm	- 13	-.22*	-.01	-.08	0.01
572 nm	-.12	-.19	0.04	-.02	0.07
610 nm	-.25*	-.37*	-.20*	-.21*	-.12
650 nm	-.24*	-.43*	-.28*	-.27*	-.19
685 nm	-.16	-.40*	-.17	-.18	-.12
A-1[1]	-.10	-.31*	-.11	-.12	-.06
A-2[1]	-.14	-.36*	-.19	-.18	-.16
A-3[1]	-.11	-.20*	0.03	-.01	0.05
R-1[2]	0.24*	0.18*	0.34*	0.13*	0.17
R-2[2]	0.07	0.21*	0.55*	0.48*	0.45

[1] A-1 = Area 400-700 nm.
A-2 = Area 650-700 nm.
A-3 = Area 440-474 nm.

[2] R-1 = R474/R525.
R-2 = R572/R525.

* ($P<.05$).

is a promising objective variable to study in order to obtain estimates of visual redness in frozen beef.

Correlations between visual bleach scores and objective variables are presented in Tables 32 and 33. Correlations were significant between reflectance percentages and areas and bleach scores but were nonsignificant between bleach scores and the calculated ratios. These results were expected because severely bleached steaks had reflectance percentages higher ($P<.05$) than those obtained from non bleached steaks. Bleach did not affect the ratios because the division of two high reflectance percentages canceled out the effects of the bleach.

Summary

Three beef loin steaks were randomly assigned to each of 36 treatment combinations involving all possible combinations of three film permeabilities (465.0, 209.3 and 4.65 cc $O_2/m^2/24$ hr/atm), two freezing systems (liquid nitrogen vapor and freon immersion), two vacuum packaging times (before and after freezing) and three display case temperatures (-28.9, -20.6 and -12.2°C). Visual redness and bleach scores, steak weights and reflectance percentage (474, 525, 572, 610, 650 and 685 nm) were recorded at each of five time periods (frozen day 0, day 1, day 7, day 21 and day 42). Areas (400 to 700 nm, 650 to 700 nm and 440 to 474 nm) under the reflectance curves were measured in order to determine total reflectance, red reflectance and blue reflectance. Reflectance ratios of 474/525 nm and 572/525 nm were calculated to indicate the relative amount of oxymyoglobin and

Table 32. Simple correlation coefficients between visual bleach scores and objective variables (longissimus).

Day	0	1	7	21	42
Variable	Bl	Bl	Bl	Bl	Bl
474 nm	0.57*	0.55*	0.64*	0.74*	0.76*
525 nm	0.58*	0.58*	0.64*	0.74*	0.77*
572 nm	0.57*	0.56*	0.60*	0.74*	0.74*
610 nm	0.46*	0.54*	0.62*	0.72*	0.78*
650 nm	0.39*	0.44*	0.58*	0.71*	0.77*
685 nm	0.38*	0.39*	0.41*	0.64*	0.67*
A-1[1]	0.18	0.50*	0.48*	0.67*	0.73*
A-2[1]	0.36*	0.03	0.33*	0.55*	0.36*
A-3[1]	0.63*	0.33*	0.39*	0.74*	0.28*
R-1[2]	0.20*	0.01	0.03	-.06	-.02
R-2[2]	0.05	0.14	-.14	-.13	-.20

[1] A-1 = Area 400-700 nm.
A-2 = Area 650-700 nm.
A-3 = Area 440-474 nm.

[2] R-1 = R474/R525.
R-2 = R572/R525.

* ($P<.05$).

Table 33. Simple correlation coefficients between visual bleach scores and objective variables (psoas major).

Day	0	1	7	21	42
Variable	Bl	Bl	Bl	Bl	Bl
474 nm	0.71*	0.42*	0.66*	0.60*	0.62*
525 nm	0.72*	0.45*	0.68*	0.70*	0.64*
572 nm	0.69*	0.42*	0.66*	0.69*	0.64*
610 nm	0.66*	0.46*	0.68*	0.71*	0.60*
650 nm	0.60*	0.43*	0.64*	0.69*	0.57*
685 nm	0.54*	0.30*	0.55*	0.68*	0.52*
A-1[1]	0.67*	0.38*	0.59*	0.66*	0.63*
A-2[1]	0.50*	0.18*	0.37*	0.60*	0.38*
A-3[1]	0.67*	0.20*	0.58*	0.65*	0.56*
R-1[2]	0.07	-.08	-.04	0.01	0.08
R-2[2]	0.20*	0.10	-.08	-.05	-.01

[1] A-1 = Area 400-700 nm.
A-2 = Area 650-700 nm.
A-3 = Area 440-474 nm.

[2] R-1 = R474/R525.
R-2 = R572/R525.

* ($P<.05$).

metmyoglobin. All procedures were performed on both the longissimus and psoas major muscles.

Steak weights did not significantly change over the six week display period. Longissimus and psoas major visual redness scores indicated that a gradual darkening occurred with increasing display time. The steaks that were packaged in oxygen permeable films after being frozen in liquid nitrogen and displayed at -28.9°C exhibited a more acceptable red meat color when compared to the other treatment combinations studied. Some steaks frozen in liquid freon had acceptable frozen meat color; however, most exhibited moderate to severe surface bleach.

Spectrophotometric data indicated that more light was reflected from the surface of freon frozen steaks, but this was due to the high degree of bleach caused by this method of freezing.

The ratios studied suggested that more oxymyoglobin was maintained in steaks packaged in oxygen permeable films after freezing, while more metmyoglobin occurred in steaks that were packaged in the low oxygen permeable film or displayed at the warmer temperatures.

Correlations between visual redness scores and objective variables were significant in some cases but generally low. Correlations between visual bleach scores and objective variables of percent reflectance at all wavelengths or areas under the reflectance scan were high and significant, but those of reflectance ratios were nonsignificant.

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CHAPTER V

GENERAL SUMMARY

The effects of freezing system, freezing cycle, packaging time (before or after freezing), film permeability and display case temperature on color stability of frozen beef loin steaks (longissimus and psoas major muscles) was investigated. Steaks (2.54 cm thick) were cut from choice beef loins which weighed between 25 and 27 kg, had small to modest marbling and less than 1.27 cm of fat cover. Visual redness and bleach scores, steak weights, reflectance percentages at 474, 525, 572, 610, 650 and 685 nm, and three areas under the reflectance curves, namely, 400-700 nm, 650-700 nm and 440-474 nm (total, red and blue reflectance, respectively) were measured.

Two pilot studies were performed to determine the ability of various mechanical air blast, freon immersion and liquid nitrogen vapor freezing cycles to produce acceptable frozen meat color. Freezing at -40°C for 10 minutes and equilibrating in a display case at -20.6°C was inadequate for steaks put in in Saran pouches. Faster freezing of other liquid nitrogen vapor cycles (1/2 min -17.8°C, 1/2 min -45.6°C, 1 min -73.4°C, 1 min -101.2°C, 1 min -129°C and 1 min temper and -26.1°C for 45 min) produced more acceptable red color.

Freon treatments caused high amounts of bleach in steaks packaged in Saran bags. Ice accumulation within these packages (partially due to an incomplete vacuum) contributed to their unacceptability. Correlations between visual redness and bleach scores and objective variables were generally low and insignificant.

When steaks were packaged in skin tight film, blast freezing at -27°C and liquid nitrogen freezing at -40°C for 10 minutes and equilibrating in a display case at -20.6°C produced a darker product than more rapid freezing treatments. Freon immersion freezing caused some bleach problems, although bleach differences became minimal after 7 days of display.

Three steaks were randomly assigned to each of 36 treatments consisting of all possible combinations of two freezing systems (liquid nitrogen system with temperature cycle ranging from -17.8°C to -129°C over 7 minutes and a liquid freon immersion system held at -30.6°C), three film oxygen permeabilities (ethylene vinyl acetate, iolon and nylon/polyethylene, with high, medium and low oxygen permeabilities, 465.0, 209.3 and 4.65 cc $O_2/m^2/24$ hr/atm, respectively), two vacuum packaging times (before and after freezing) and three display case temperatures (-12.2°C, -20.6°C and -28.9°C). Color and weight measurements were taken immediately after freezing and after 1, 7, 21 and 42 days of display at 1076 lm/m^2 of Deluxe Cool White Fluorescent lights. R474/R525 and R572/R525 ratios were also calculated.

Packaging with the low permeability film caused significantly darker visual color at days 1, 7, 21 and 42 for the longissimus and at day 7 for the psoas major. The two higher permeability films maintained visually acceptable (an arbitrary score of less than 4) color for almost 42 days for the longissimus and almost 21 days for the psoas major. Reflectance data indicated similar results. Ratio data for R474/R525 suggested that less ($P<.05$) oxymyoglobin was

present in steaks (both muscles) packaged in the low permeability film than the two more permeable films at every time period after day 0.

Freezing systems caused no significant differences in longissimus or psoas major visual redness scores after 1 day of display. Significantly more bleach, however, was found in both muscles in steaks frozen by freon immersion when compared to steaks frozen in liquid nitrogen vapor. Higher individual reflectance percentages of freon frozen steaks and larger reflectance areas confirmed the greater ($P<.05$) visual bleach.

Due to a combination of increased bleach and freezing rate, packaging after freezing resulted in brighter visual redness compared to packaging before freezing. These visual results were verified by higher ($P<.05$) 685 nm reflectance percentages and increased total and red reflectance at most time periods in both muscles.

Decreasing display case temperatures resulted in increased visual brightness in both muscles. Steaks displayed at -28.9°C showed acceptable visual color through day 21 while steaks displayed at the two warmer temperatures lost much of their brightness between day 7 and day 21. Higher ($P<.05$) percent 685 nm reflectance, total reflectance and red area reflectance found at many time periods in these steaks supported visual results.

No main treatment variable significantly ($P<.05$) affected product weight loss under frozen display conditions during the six week display period.

Interactions were found involving several variables at various time periods and consisted primarily of two way interactions between

film permeability x packaging time and freezing system x packaging time. The former indicated that packaging before freezing at each film permeability caused faster degeneration of red color while the latter indicated that packaging after freezing in liquid nitrogen maintained a more natural red color.

Significant correlations were obtained at various time periods between visual redness and percent reflectance at 610, 750, 685 nm, reflectance scan areas and the two ratios. Correlations between visual bleach scores and reflectance percentages and areas were significant, but between visual bleach score and ratio data were nonsignificant.

APPENDICES

Appendix 1A

Main treatment effects on 474 nm reflectance percentages of frozen beef longissimus

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	16.76[a]	19.20[a]	18.65[a]	21.96[b]	22.64[b]
Medium	18.01[a]	14.78[a]	15.14[a]	16.41[a]	15.44[a]
High	15.38[a]	16.93[a]	15.75[a]	16.80[a]	18.39[ab]
FREEZING SYSTEM					
Nitrogen	11.46[a]	13.29[a]	13.72[a]	15.78[a]	16.56[a]
Freon	21.97[b]	20.65[b]	19.31[b]	21.00[b]	21.08[b]
PACKAGING TIME					
Before	16.05[a]	16.55[a]	15.94[a]	17.87[a]	18.16[a]
After	17.38[a]	17.39[a]	17.00[a]	18.91[a]	19.49[a]
DISPLAY TEMPERATURE					
-28.9°C	15.76[a]	18.17[a]	18.97[b]	21.98[b]	20.94[b]
-20.6°C	18.66[a]	17.70[a]	16.65[ab]	18.27[a]	19.67[b]
-12.2°C	15.72[a]	15.04[a]	13.93[a]	14.92[a]	15.86[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 1B

Main treatment effects on 474 nm reflectance percentages of frozen beef psoas major

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	15.98[a]	21.57[b]	20.33[b]	20.94[b]	23.69[b]
Medium	16.16[a]	15.08[a]	13.26[a]	14.91[a]	15.49[a]
High	14.69[a]	14.81[a]	14.37[a]	17.44[a]	16.48[a]
FREEZING SYSTEM					
Nitrogen	11.40[a]	14.48[a]	13.40[a]	14.39[a]	16.81[a]
Freon	19.82	19.83[b]	18.57[b]	21.14[b]	20.29[b]
PACKAGING TIME					
Before	13.51[a]	16.41[a]	14.43[a]	15.87[a]	16.56[a]
After	17.71[b]	17.90[a]	17.54[b]	19.66[b]	20.55[b]
DISPLAY TEMPERATURE					
-28.9°C	14.69[a]	19.76[b]	19.05[b]	20.97[b]	20.77[a]
-20.6°C	16.71[a]	17.00[ab]	15.73[a]	16.96[a]	18.06[a]
-12.2°C	15.43[a]	14.70[a]	13.17[a]	15.36[a]	16.83[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 2A

Main treatment effects on 525 nm reflectance percentages of frozen beef longissimus

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	17.63^{a}	19.88^{a}	19.01^{a}	22.05^{b}	22.71^{b}
Medium	18.26^{a}	16.07^{a}	16.32^{a}	17.43^{a}	15.98^{a}
High	16.27^{a}	18.10^{a}	16.47^{a}	17.56^{a}	18.84^{a}
FREEZING SYSTEM					
Nitrogen	12.22^{a}	14.14^{a}	14.37^{a}	16.34^{a}	16.77^{a}
Freon	22.55^{b}	21.90^{b}	20.18^{b}	21.68^{b}	21.58^{b}
PACKAGING TIME					
Before	16.69^{a}	17.37^{a}	16.35^{a}	18.31^{a}	18.32^{a}
After	18.08^{a}	18.67^{a}	18.19^{a}	19.72^{a}	20.04^{a}
DISPLAY TEMPERATURE					
-28.9°C	16.64^{a}	19.35^{a}	19.85^{b}	22.74^{b}	21.35^{b}
-10.6°C	19.17^{a}	18.70^{a}	17.25^{ab}	18.80^{a}	20.00^{b}
-12.2°C	16.35^{a}	16.01^{a}	14.71^{a}	15.50^{a}	16.18^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 2B

Main treatment effects on 525 nm reflectance percentages of frozen beef psoas major

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	15.85^{a}	21.84^{b}	20.15^{b}	21.05^{b}	23.42^{b}
Medium	15.93^{a}	15.95^{a}	13.93^{a}	15.76^{a}	15.99^{a}
High	15.21^{a}	15.52^{a}	14.89^{a}	18.22^{a}	16.95^{a}
FREEZING SYSTEM					
Nitrogen	11.44^{a}	14.97^{a}	13.78^{a}	14.90^{a}	16.87^{a}
Freon	19.88^{b}	20.57^{b}	18.86^{b}	21.78^{b}	20.71^{b}
PACKAGING TIME					
Before	13.28^{a}	16.74^{a}	14.62^{a}	16.30^{a}	16.73^{a}
After	18.04^{b}	18.80^{a}	18.02^{b}	20.37^{b}	20.85^{b}
DISPLAY TEMPERATURE					
-28.9°C	14.68^{a}	20.46^{b}	19.43^{b}	21.54^{b}	21.05^{a}
-20.6°C	16.73^{a}	17.54^{ab}	16.06^{a}	17.57^{a}	18.40^{a}
-12.2°C	15.58^{a}	15.31^{a}	13.47^{a}	15.91^{a}	16.92^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 3A

Main treatment effects on 572 nm reflectance percentages of frozen beef longissimus

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	14.66^{a}	18.05^{b}	18.57^{b}	22.24^{b}	23.38^{b}
Medium	14.34^{a}	13.57^{a}	14.98^{a}	16.96^{a}	17.03^{a}
High	13.76^{a}	15.57^{a}	15.14^{a}	16.90^{a}	19.24^{a}
FREEZING SYSTEM					
Nitrogen	9.79^{a}	12.30^{a}	13.51^{a}	16.17^{a}	17.52^{a}
Freon	18.72^{b}	19.16^{b}	18.96^{b}	21.22^{b}	22.25^{b}
PACKAGING TIME					
Before	13.43^{a}	15.26^{a}	15.67^{a}	18.14^{a}	19.19^{a}
After	15.08^{a}	16.21^{a}	16.80^{a}	19.26^{a}	20.58^{a}
DISPLAY TEMPERATURE					
-28.9°C	13.64^{a}	16.86^{a}	18.16^{b}	21.72^{b}	21.20^{b}
-20.6°C	15.71^{a}	16.46^{a}	16.55^{ab}	18.99^{b}	21.35^{b}
-12.2°C	13.42^{a}	13.88^{a}	13.99^{a}	15.38^{a}	17.11^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 3B

Main treatment effects on 572 nm reflectance percentages of frozen beef psoas major

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	13.90^{a}	20.24^{b}	19.56^{b}	20.69^{b}	23.47^{b}
Medium	13.22^{a}	13.97^{a}	12.68^{a}	14.92^{a}	16.03^{a}
High	12.94^{a}	13.81^{a}	13.64^{a}	17.41^{a}	16.77^{a}
FREEZING SYSTEM					
Nitrogen	9.75^{a}	13.52^{a}	12.84^{a}	14.24^{a}	16.87^{a}
Freon	16.96^{b}	18.49^{b}	17.75^{b}	21.11^{b}	20.65^{b}
PACKAGING TIME					
Before	11.15^{a}	15.25^{a}	13.76^{a}	15.75^{a}	16.75^{a}
After	15.57^{b}	16.77^{a}	16.83^{b}	19.60^{b}	20.77^{b}
DISPLAY TEMPERATURE					
-28.9°C	12.53^{a}	18.42^{b}	17.96^{b}	20.25^{b}	20.23^{a}
-20.6°C	14.27^{a}	16.03^{ab}	15.25^{ab}	17.31^{ab}	18.98^{a}
-12.2°C	13.26^{a}	13.57^{a}	12.67^{a}	15.46^{a}	17.06^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 4A

Main treatment effects on 610 nm reflectance percentages of frozen beef longissimus

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	36.68^{a}	34.42^{a}	28.77^{a}	31.82^{a}	31.97^{b}
Medium	39.11^{a}	35.36^{a}	30.34^{a}	31.33^{a}	26.57^{a}
High	35.90^{a}	35.94^{a}	30.53^{a}	29.78^{a}	28.98^{ab}
FREEZING SYSTEM					
Nitrogen	29.04^{a}	29.03^{a}	25.27^{a}	27.27^{a}	25.80^{a}
Freon	45.42^{b}	41.46^{b}	34.49^{b}	34.69^{b}	32.55^{b}
PACKAGING TIME					
Before	35.65^{a}	33.15^{a}	27.58^{a}	29.36^{a}	27.64^{a}
After	38.81^{a}	37.33^{b}	32.18^{b}	32.60^{a}	30.71^{a}
DISPLAY TEMPERATURE					
-28.9°C	36.90^{a}	37.57^{a}	33.70^{b}	36.47^{b}	32.67^{b}
-20.6°C	39.56^{a}	34.81^{a}	29.95^{a}	30.29^{a}	29.40^{ab}
-12.2°C	35.23^{a}	33.34^{a}	25.99^{a}	26.17^{a}	25.44^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 4B

Main treatment effects on 610 nm percentages of frozen beef psoas major

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	27.58^{a}	32.66^{b}	28.95^{a}	29.45^{a}	31.24^{b}
Medium	28.19^{a}	29.00^{ab}	25.03^{a}	26.84^{a}	25.73^{a}
High	27.12^{a}	26.49^{a}	25.18^{a}	28.81^{a}	25.90^{a}
FREEZING SYSTEM					
Nitrogen	20.74^{a}	25.08^{a}	23.12^{a}	23.32^{a}	25.07^{a}
Freon	34.52^{b}	31.84^{b}	29.65^{b}	33.41^{b}	30.18^{a}
PACKAGING TIME					
Before	23.79^{a}	26.92^{a}	23.27^{a}	25.80^{a}	24.90^{a}
After	31.47^{b}	31.84^{b}	29.50^{b}	30.93^{b}	30.35^{a}
DISPLAY TEMPERATURE					
-28.9°C	27.01^{a}	33.20^{b}	31.56^{b}	33.71^{b}	31.88^{b}
-20.6°C	29.01^{a}	27.96^{a}	24.86^{a}	26.33^{a}	26.03^{a}
-12.2°C	26.87^{a}	26.99^{a}	22.74^{a}	25.06^{a}	24.96^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 5A

Main treatment effects on 650 nm reflectance percentages of frozen beef longissimus

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	45.31^{a}	41.18^{a}	32.94^{a}	35.49^{a}	36.33^{a}
Medium	47.64^{a}	44.37^{a}	35.84^{a}	36.51^{a}	31.43^{a}
High	44.65^{a}	44.51^{a}	35.50^{a}	34.52^{a}	33.66^{a}
FREEZING SYSTEM					
Nitrogen	38.15^{a}	37.20^{a}	30.08^{a}	31.74^{a}	30.44^{a}
Freon	53.59^{b}	49.50^{b}	39.45^{b}	39.28^{b}	37.17^{b}
PACKAGING TIME					
Before	44.21^{a}	40.85^{a}	32.14^{a}	33.81^{a}	32.20^{a}
After	47.52^{a}	45.86^{b}	37.38^{b}	37.21^{a}	35.41^{a}
DISPLAY TEMPERATURE					
-28.9°C	45.72^{a}	46.18^{a}	39.72^{b}	41.50^{b}	37.86^{b}
-20.6°C	48.18^{a}	42.50^{a}	34.17^{a}	34.77^{a}	32.74^{a}
-12.2°C	43.70^{a}	41.37^{a}	30.40^{a}	30.27^{a}	29.82^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 5B

Main treatment effects on 650 nm percentages of frozen beef psoas major

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	35.74^{a}	38.99^{a}	34.00^{a}	34.70^{a}	35.97^{b}
Medium	35.24^{a}	35.96^{a}	30.80^{a}	32.76^{a}	31.27^{a}
High	34.72^{a}	33.35^{a}	30.95^{a}	34.23^{a}	31.14^{a}
FREEZING SYSTEM					
Nitrogen	28.73^{a}	31.96^{a}	28.69^{a}	28.97^{a}	30.29^{a}
Freon	41.73^{b}	40.24^{b}	35.14^{b}	38.82^{b}	35.30^{a}
PACKAGING TIME					
Before	31.55^{a}	33.37^{a}	28.86^{a}	31.44^{a}	30.18^{a}
After	38.92^{b}	38.82^{b}	34.97^{b}	36.35^{b}	35.41^{a}
DISPLAY TEMPERATURE					
-28.9°C	34.97^{a}	40.46^{b}	37.73^{b}	39.91^{b}	38.18^{b}
-20.6°C	36.37^{a}	33.98^{a}	30.06^{a}	31.35^{a}	30.67^{a}
-12.2°C	34.36^{a}	33.86^{a}	27.95	30.42^{a}	29.53^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 6A

Main treatment effects on percent blue reflectance (area 3*) of frozen beef longissimus

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	2.32^{a}	3.42^{b}	3.03^{a}	3.61^{b}	5.35^{b}
Medium	2.45^{a}	2.45^{ab}	2.64^{a}	2.45^{a}	2.45^{a}
High	2.19^{a}	2.84^{ab}	2.64^{a}	2.71^{a}	3.10^{a}
FREEZING SYSTEM					
Nitrogen	1.61^{a}	2.45^{a}	2.45^{a}	2.45^{a}	2.84^{a}
Freon	3.03^{b}	3.35^{b}	3.16^{b}	3.42^{b}	4.30^{a}
PACKAGING TIME					
Before	2.19^{a}	2.90^{a}	2.77^{a}	2.84^{a}	3.87^{a}
After	2.45^{a}	2.90^{a}	2.84^{a}	2.97^{a}	3.35^{a}
DISPLAY TEMPERATURE					
-28.9°C	2.13^{a}	3.03^{a}	3.35^{b}	3.55^{b}	3.48^{a}
-20.6°C	2.58^{a}	2.97^{a}	2.84^{ab}	2.97^{ab}	4.71^{a}
-12.2°C	2.26^{a}	2.71^{a}	2.19^{a}	2.19^{a}	2.64^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

* Area 3 = Area 440 to 474 nm (blue area of spectrum) in cm^2.

Appendix 6B

Main treatment effects on percent blue reflectance (area 3*) values of frozen beef psoas major

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	2.26^{a}	4.00^{b}	3.61^{b}	3.68^{b}	4.39^{b}
Medium	2.32^{a}	2.45^{a}	1.94^{a}	2.52^{a}	2.58^{a}
High	2.26^{a}	2.64^{a}	2.39^{a}	2.90^{a}	2.84^{a}
FREEZING SYSTEM					
Nitrogen	1.61^{a}	2.71^{a}	2.19^{a}	2.52^{a}	2.97^{a}
Freon	2.90^{b}	3.35^{a}	3.10^{b}	3.55^{b}	3.55^{a}
PACKAGING TIME					
Before	1.87^{a}	2.97^{a}	2.32^{a}	2.64^{a}	2.90^{a}
After	2.64^{b}	3.10^{a}	2.97^{b}	3.35^{b}	3.68^{b}
DISPLAY TEMPERATURE					
-28.9°C	2.13^{a}	3.48^{a}	3.10^{b}	3.48^{a}	3.55^{a}
-20.6°C	2.39^{a}	3.16^{a}	2.71^{b}	2.97^{a}	3.29^{a}
-12.2°C	2.26^{a}	2.52^{a}	2.13^{a}	2.64^{a}	2.90^{a}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

* Area 3 = Area 440 to 474 nm (blue area of spectrum) in cm^2.

Appendix 7A

Main treatment effects on R572/R525 ratio of frozen beef longissimus

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	0.82^{b}	0.91^{b}	1.00^{b}	1.03^{b}	1.04^{a}
Medium	0.78^{a}	0.84^{a}	0.92^{a}	0.98^{a}	1.08^{b}
High	0.83^{b}	0.84^{a}	0.92^{a}	0.97^{a}	1.03^{a}
FREEZING SYSTEM					
Nitrogen	0.80^{a}	0.86^{a}	0.95^{a}	1.00^{a}	1.06^{a}
	0.82^{a}	0.86^{a}	0.94^{a}	0.99^{a}	1.04^{a}
PACKAGING TIME					
Before	0.80^{a}	0.87^{a}	0.96^{a}	1.00^{a}	1.06^{b}
After	0.83^{b}	0.86^{a}	0.93^{a}	0.98^{a}	1.03^{a}
DISPLAY TEMPERATURE					
-28.9°C	0.82^{a}	0.86^{a}	0.92^{a}	0.95^{a}	1.00^{a}
-20.6°C	0.81^{a}	0.86^{a}	0.97^{b}	1.02^{b}	1.08^{b}
-12.2°C	0.81^{a}	0.87^{a}	0.95^{ab}	1.00^{b}	1.07^{b}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 7B

Main treatment effects on R572/R525 ratio on frozen beef psoas major

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	0.87^{c}	0.92^{b}	0.98^{b}	0.97^{b}	1.00^{a}
Medium	0.82^{a}	0.88^{a}	0.91^{a}	0.95^{a}	1.01^{a}
	0.84^{b}	0.88^{a}	0.91^{a}	0.95^{a}	0.99^{a}
FREEZING SYSTEM					
Nitrogen	0.84^{a}	0.89^{a}	0.93^{a}	0.96^{a}	1.00^{a}
	0.84^{a}	0.89^{a}	0.94^{a}	0.97^{a}	1.00^{a}
PACKAGING TIME					
Before	0.84^{a}	0.90^{a}	0.94^{a}	0.97^{a}	1.00^{a}
After	0.85^{a}	0.89^{a}	0.93^{a}	0.96^{a}	1.00^{a}
DISPLAY TEMPERATURE					
-28.9°C	0.85^{a}	0.89^{a}	0.92^{a}	0.94^{a}	0.96^{a}
-20.6°C	0.84^{a}	0.90^{a}	0.95^{ab}	0.98^{b}	1.04^{c}
-12.2°C	0.84^{a}	0.89^{a}	0.94^{ab}	0.97^{b}	1.00^{b}

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 8

Main treatment effects on weights of frozen beef steaks

	Day 0	1	7	21	42
	Mean	Mean	Mean	Mean	Mean
FILM PERMEABILITY					
Low	385.02[a]	384.82[a]	384.76[a]	384.76[a]	384.72[a]
Medium	376.26[a]	376.46[a]	376.15[a]	376.09[a]	376.09[a]
High	381.39[a]	381.48[a]	381.50[a]	380.85[a]	380.99[a]
FREEZING SYSTEM					
Nitrogen	376.07[a]	376.09[a]	376.05[a]	375.63[a]	375.77[a]
Freon	385.71[a]	385.74[a]	385.56[a]	385.51[a]	385.44[a]
PACKAGING TIME					
Before	379.52[a]	379.58[a]	379.41[a]	379.41[a]	378.44[a]
After	382.26[a]	382.24[a]	382.19[a]	381.72[a]	382.77[a]
DISPLAY TEMPERATURE					
-28.9°C	378.28[a]	378.34[a]	378.40[a]	378.27[a]	378.18[a]
-20.6°C	381.91[a]	381.96[a]	381.82[a]	381.25[a]	381.69[a]
-12.2°C	382.47[a]	382.43[a]	382.18[a]	382.18[a]	381.94[a]

Main effect means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 9A

Interaction effects on 474 reflectance percentages of frozen beef longissimus

Interaction	Time period				
	0 Days	1 Day	7 Days	21 Days	42 Days
FILM PERMEABILITY X PACKAGING TIME					
Low before	N.S.	N.S.	N.S.	23.23^{a}	23.74^{a}
Low after				20.69^{ab}	21.53^{a}
Medium before				16.84^{bc}	15.72^{b}
Medium after				15.98^{bc}	15.16^{b}
High before				13.53^{c}	15.01^{b}
High after				20.08^{ab}	21.78^{a}
FREEZING SYSTEM X PACKAGING TIME					
Nitrogen before	N.S.	N.S.	N.S.	17.14^{b}	N.S.
Nitrogen after				14.41^{b}	
Freon before				18.59^{b}	
Freon after				23.41^{a}	

Interaction means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 9B

Interaction effects on 474 nm reflectance percentages of frozen beef psoas major

Interaction	Time period				
	0 Days	1 Day	7 Days	21 Days	42 Days
FILM PERMEABILITY X PACKAGING TIME					
Low before	N.S.	24.63^{a}	21.30^{a}	21.49^{a}	23.72^{a}
Low after		18.52^{b}	19.36^{a}	20.39^{ab}	23.66^{a}
Medium before		13.90^{bc}	12.19^{bc}	13.04^{c}	13.82^{cd}
Medium after		16.27^{b}	14.32^{b}	16.77^{bc}	17.17^{bc}
High before		10.69^{c}	9.79^{c}	13.07^{c}	12.14^{d}
High after		18.93^{b}	18.94^{a}	21.81^{a}	20.82^{ab}
FREEZING SYSTEM X PACKAGING TIME					
Nitrogen before	11.16^{c}	N.S.	N.S.	N.S.	N.S.
Nitrogen after	11.64^{c}				
Freon before	15.85^{b}				
Freon after	23.78^{a}				

Interaction means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 10A

Interaction effects on 610 reflectance percentages of frozen beef longissimus

Interaction	Time period				
	0 Days	1 Day	7 Days	21 Days	42 Days
FREEZING SYSTEM X PACKAGING TIME					
Nitrogen before	N.S.	N.S.	N.S.	28.11[b]	N.S.
Nitrogen after				26.42[b]	
Freon before				30.61[b]	
Freon after				38.77[a]	

Interaction means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 10B

Interaction effects on 610 reflectance percentages of frozen beef psoas major

Interaction	Time period				
	0 Days	1 Day	7 Days	21 Days	42 Days
FILM PERMEABILITY X PACKAGING TIME					
Low before	N.S.	32.69^{a}_{a}	27.90^{ab}	29.47^{ab}	N.S.
Low after		32.62^{a}	29.99^{a}	29.43^{ab}	
Medium before		27.31^{a}_{a}	23.07^{bc}_{ab}	24.53^{b}_{ab}	
Medium after		30.69^{a}	26.99^{ab}	29.14^{ab}	
High before		20.77^{b}_{a}	18.85^{c}_{a}	23.40^{b}_{a}	
High after		32.20^{a}	31.51^{a}	34.22^{a}	
FREEZING SYSTEM X PACKAGING TIME					
Nitrogen before	20.14^{c}	24.52^{b}_{b}	N.S.	N.S.	N.S.
Nitrogen after	21.34^{c}	25.64^{b}			
Freon before	27.44^{b}_{a}	29.32^{b}_{a}			
Freon after	41.60^{a}	38.03^{a}			

Interaction means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 11A

Interaction effects on 650 nm reflectance percentages of frozen beef longissimus

Interaction	Time period				
	0 Days	1 Day	7 Days	21 Days	42 Days
FREEZING SYSTEM X PACKAGING TIME					
Nitrogen before	N.S.	N.S.	N.S.	32.26[b]	N.S.
Nitrogen after				31.22[b]	
Freon before				35.35[b]	
Freon after				43.20[a]	

Interaction means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 11B

Interaction effects on 650 nm reflectance percentages of frozen beef psoas major

Interaction	Time period				
	0 Days	1 Day	7 Days	21 Days	42 Days
FILM PERMEABILITY X PACKAGING TIME					
Low before	N.S.	N.S.	33.45^{ab}	35.17^{ab}	35.58^{a}
Low after			34.54^{ab}	34.22^{abc}	36.36^{a}
Medium before			28.67^{bc}	30.27^{bc}	29.33^{bc}
Medium after			32.93^{ab}	35.24^{ab}	33.20^{ab}
High before			24.46^{c}	28.86^{c}	25.63^{c}
High after			37.43^{a}	39.59^{a}	36.66^{a}
FREEZING SYSTEM X PACKAGING TIME					
Nitrogen before	28.27^{c}	N.S.	N.S.	N.S.	N.S.
Nitrogen after	29.30^{c}				
Freon before	34.83^{b}				
Freon after	48.64^{a}				

Interaction means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 12A

Interaction effects on R572/R525 ratio of frozen beef longissimus

Interaction	Time period				
	0 Days	1 Day	7 Days	21 Days	42 Days
FILM PERMEABILITY X PACKAGING TIME					
Low before	0.82^{b}	0.93^{a}	N.S.	N.S.	1.02^{bc}
Low after	0.82^{b}	0.88^{b}			1.05^{bc}
Medium before	0.78^{b}	0.84^{c}			1.10^{a}
Medium after	0.78^{b}	0.83^{c}			1.06^{ab}
High before	0.79^{b}	0.83^{c}			1.06^{ab}
High after	0.88^{a}	0.86^{bc}			1.00^{c}

Interaction means within time periods with same superscript letters are not significantly different ($P<.05$).

Appendix 12B

Interaction effects on R572/R525 ratio of frozen beef *psoas major*

Interaction	Time period				
	0 Days	1 Day	7 Days	21 Days	42 Days
FILM PERMEABILITY X PACKAGING TIME					
Low before	0.88^{a}	0.94^{a}	N.S.	0.97^{ab}	N.S.
Low after	0.86^{a}	0.89^{b}		1.00^{a}	
Medium before	0.81^{b}	0.87^{b}		0.97^{ab}	
Medium after	0.83^{b}	0.88^{b}		0.93^{c}	
High before	0.82^{b}	0.88^{b}		0.96^{bc}	
High after	0.86^{a}	0.88^{b}		0.95^{bc}	

Interaction means within time periods with same superscript letters are not significantly different ($P<.05$).

EFFECTS OF FREEZING SYSTEM, FREEZING RATE, FILM PERMEABILITY, PACKAGING TIME AND DISPLAY CASE TEMPERATURE ON COLOR STABILITY AND WEIGHT LOSS OF FROZEN BEEF *LONGISSIMUS* AND PSOAS *MAJOR MUSCLES*

by

MICHAEL LEWIS SANDBERG

B. S., Kansas State University, 1969

AN ABSTRACT OF A MASTER'S THESIS

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Department of Animal Science and Industry

KANSAS STATE UNIVERSITY
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The effects of freezing system, freezing cycle, packaging time (before or after freezing), film permeability and display case temperature on color stability of frozen beef loin steaks (longissimus and psoas major muscles) were investigated. Steaks (2.54 cm thick) were cut from choice beef loins which weighed between 25 and 27 kg, had small to modest marbling and less than 1.27 cm of fat cover. Visual redness and bleach scores, steak weights, reflectance percentages at 474, 525, 572, 610, 650 and 685 nm, and three areas under the reflectance curves, namely, 400-700 nm, 650-700 nm and 440-474 nm (total red and blue reflectance, respectively) were measured.

Two pilot studies were performed to determine the ability of various mechanical air blast, freon immersion and liquid nitrogen vapor freezing cycles to produce acceptable frozen meat color. Freezing at -40°C for 10 minutes and equilibrating in a display case at -20.6°C was inadequate for steaks put up in Saran pouches. When steaks were packaged in skin tight film blast freezing at -27°C and liquid nitrogen freezing at -40°C for 10 minutes and equilibrating in a display case at -20.6°C produced a darker product than more rapid freezing treatments. Freon immersion freezing caused some bleach problems, although bleach differences became minimal after 7 days of display.

Three steaks were randomly assigned to each of 36 treatments consisting of all possible combinations of two freezing systems (liquid nitrogen system with temperature cycle ranging from -17.8°C to -129°C over 7 minutes and a liquid freon immersion system held at -30.6°C), three film oxygen permeabilities (ethylene vinyl acetate, iolon and

nylon/polyethylene, with high, medium and low oxygen permeabilities, 465.0, 209.3 and 4.65 cc $0_2/m^2/24$ hr/atm, respectively), two vacuum packaging times (before and after freezing) and three display case temperatures (-12.2°C, -20.6°C and -28.9°C). Color and weight measurements were taken immediately after freezing and after 1, 7, 21 and 42 days of display at 1076 lm/m^2. R474/R525 and R572/R525 ratios were also calculated.

Packaging with the low permeability film caused significantly darker visual color at days 1, 7, 21 and 42 for the longissimus and at day 7 for the psoas major. The two higher permeability films maintained visually acceptable color longer. Ratio data for R474/R525 indicated less ($P<.05$) oxymyoglobin was present in steaks (both muscles) packaged in the low permeability film than the two more permeable films at every time period except day 0.

Freezing systems caused no significant differences in longissimus or psoas major visual redness scores after 1 day of display. Significantly more bleach, however, was found in both muscles in steaks frozen by freon immersion when compared to steaks frozen in liquid nitrogen vapor. In freon frozen steaks higher individual reflectance percentages and larger reflectance areas confirmed the greater ($P<.05$) visual bleach.

Due to a combination of increased bleach and freezing rate, packaging after freezing resulted in brighter visual redness compared to packaging before freezing. These visual results were verified by

higher ($P<.05$) 685 nm reflectance percentages and increased total and red reflectance at most time periods in both muscles.

Decreasing display case temperatures resulted in increased visual brightness in both muscles. Steaks displayed at -28.9°C showed acceptable color through day 21 while steaks displayed at the two warmer temperatures lost much of their brightness between day 7 and day 21. Reflectance data indicated similar results.

No main treatment variable significantly ($P<.05$) affected product weight loss under frozen display conditions during the six-week display period.