EFFECTS OF DISPLAY LIGHT INTENSITY ON COLOR STABILITY OF FROZEN BEEF CUTS IN TRANSPARENT FILM

by

JORGE ALBERTO SANTAMARIA

D.V.M., Universidad de Antioquia, 1967
Medellin-Colombia

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

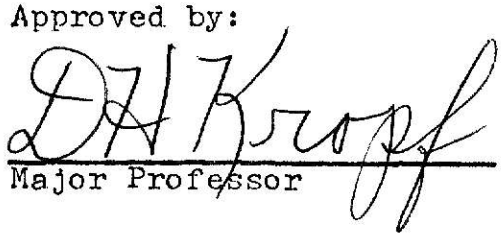
MASTER OF SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1970

Approved by:



Major Professor

ACKNOWLEDGEMENTS

It is a great pleasure to acknowledge my indebtedness to Dr. Donald H. Kropf, my major professor, whose advice, support, understanding and patience during my academic work have been invaluable to me, both professionally and personally.

I also wish to acknowledge my gratitude for the advice, criticism and technical assistance of my other professors, my fellow graduate students, and members of the staff.

And certainly I am most grateful to my parents for their sacrifices and financial support, and for their interest and encouragement in this undertaking.

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX

TABLES PAGE

TABLES PAGE

TABLES PAGE

LIST OF FIGURES

APPENDIX

Chapter 1

INTRODUCTION

The modern meat industry is moving towards centralized cutting and processing. This new approach offers product improvement through stricter and more uniform quality control. Plant management, in regard to labor efficiency and inventory control, is made simpler. From the consumer stand point, an inspected product can reach the markets at better prices, since the lower processing cost and the suitability for most efficient distribution will cut prices at the consumer level.

Despite some earlier unsuccessful attempts at frozen meat retailing, frozen products fit into the centralized processing concept very well. Stores would be able to keep the product for a longer period and deterioration during transport and storage could be lessened.

Many factors affect color of frozen meats displayed in transparent films. Packaging material, freezing temperature, display case temperature, source of light, intensity of illumination, as well as sanitation are included.

Color of frozen product is an important factor affecting salability. Psychic factors are important as dark color is associated with an "old product"; green with a "spoiled" one; and too bright a red with deception. The correct light source, as well as the appropriate light intensity may contribute to the eye appeal of the displayed product. A high level

of illumination may produce too rapid a deterioration of the red meat pigment, thus making the product less attractive to the consumer.

Many unanswered questions face the industry today. Stores vary widely in type and intensity of illumination and no apparent recognition of their effect is evident.

It was considered worthwhile to study the effect of two different light sources, and various light intensity levels on color stability of displayed beef steaks prepackaged in transparent film.

Chapter 2

REVIEW OF LITERATURE

Color and its Measurement.

Color can mean a mixture of light of various wavelengths, its effect on the human eye, or the results of this effect in the mind of the viewer. Color results from physical modification of light by colorants as observed by the human eye and interpreted in the brain (Wright, 1944). From the purely physical point of view, the production of color requires three things: a source of light, an object which it illuminates, and the eye and brain to perceive the color. In addition to a mere physical phenomenon, color is a sensation experienced by an individual when energy in the form of radiation within the visible spectrum falls upon the retina of the eye (Francis and Clydesdale, 1967).

Visible light is a form of energy, part of the family which includes radio waves and x-rays, as well as ultra-violet and infrared light. Light can be described by its wavelength, for which the millimicron (mu) or nanometer (nm) is a convenient unit of length. The relative insensitivity of the eye limits the visible part of the spectrum to a very narrow band of wavelengths between about 380 nm and 750 nm with blue below about 480 nm; green, roughly between 480 and 560 nm; yellow 560 to 590 nm; orange, between 590 and 630 nm; and the red at the wavelengths longer than 630 nm (Judd, 1953).

The light from any source can be described in terms of the "spectral energy distribution curve" which is the relative energy emitted at each wavelength. Light striking an object can be transmitted, absorbed, or reflected. Translucent material both transmits and reflects light but opaque material absorbs or reflects all light and transmits none (Francis and Clydesdale, 1968).

Visual color measurements have been criticized by many scientists because of the problems related to repeatability of results. One of the equally important issues is whether any of the objective instrumentation techniques actually measures the variable of interest, which at the level of the consumer is based on visual appraisal (Enfield, 1968).

The fundamental properties of an object responsible for its color are spectral transmittance for transparent objects and spectral reflectance for opaque objects. The spectral transmittance is the ratio of transmitted to incident radiant flux for one narrow band of the spectrum (Billmeyer and Saltzman, 1967).

Goldring et al. (1953) have examined abnormalties in spectrophotometric measurements and classified these on the basis of chemical factors, instrument factors, operational techniques and mathematical considerations. Of particular concern are errors of which the operator may remain unaware. The case of mechanically insecure elements in the input electro-

meter is cited. As the photocell compartment shutter is opened or closed, there can be a substantial shift in the zero of the photometer system. This is unsuspected when the change in zero is reproducible, the new position being metastable as stated by Mackinney and Chichester (1954).

Meat color appraisal has been attempted by several different methods, including spinning disks (Hiner, 1954); color photographs (University of Wisconsin, 1963); color paddles (Hiner, 1954); pigment extraction (Schweigert, 1954; Tauber and Simon, 1963); and reflectance (Tappel, 1957, 1961; Cutaia and Ordel, 1964; Snyder, 1965; Stewart et al., 1965; Kraft and Ayres, 1954b; Snyder and Armstrong, 1967). Reflectance of tissue color seems to offer promise as an objective non-destructive method of analysis.

Rikert et al. (1957b) noted that probably any one of the Hunter components (L scale, a_L, b_L) could be used satisfactorily as an index to the color changes of meat. They also stated that the highly significant correlations between a_L values and both hue and chroma seemed to qualify this component as a satisfactory index of the color of fresh meat. Arbitrary interpretations of visual color acceptability in terms of a_L values were indicated. The upper value (from 12 and up), marked a desirability of the fresh meat. The lower value (8 and down), arbitrarily designated as undesirable, is that below which the average consumer probably would regard the meat unacceptable. These values constituted

the upper and lower bounds for satisfactory, but not preferred, color. Snyder (1964) using the Gardner color-difference meter showed that a_L values changed appreciably in relation to the other two parameters (L, b_L) of color. When changing from oxymyoglobin or myoglobin to metmyoglobin, a_L value decreased. The two types of change (oxidation; oxygenation) could be distinguished by considering the a_L/b_L ratio. In differentiating between oxymyoglobin and myoglobin, a_L/b_L ratio did not change appreciably, but for a conversion of oxymyoglobin or myoglobin to metmyoglobin, the a_L/b_L ratio decreased considerably.

Dean and Ball (1960), using the Gardner a_L value, showed that cut surfaces of muscle did not bloom to equal redness. The sample of higher bloom (a_L=18.2) was indicated by the reflectance and absorbancy ratio methods, respectively, to have 0 and 9% metmyoglobin, 37 and 0% reduced myoglobin, and 63 and 91% oxymyoglobin. Sample of lowest bloom (a_L=11.7) was indicated by the reflectance and absorbancy ratio methods, respectively, to have 18 and 34% metmyoglobin, 61 and 16% reduced myoglobin, and 21 and 50% oxymyoglobin. They stated that from these factors, it is difficult to say which of the two methods presents the more nearly true picture of the facts.

Reflectance and absorbance methods have been used to follow and/or to measure the changes in the myoglobin pigments. The absorbance method, developed by Broumand *et al.* (1958) was dependent upon pigment extraction. Snyder (1965) stated that

there are practical problems in extracting the pigments from meat to give a clear solution, in selecting the surface volume of meat to be analyzed, and in changes in the form of the pigment during extraction and analysis. Furthermore, reflectance method excludes errors due to extraction since the analysis is done on an intact or ground sample of meat, and no extraction is necessary. However, there is no sound theoretical basis relating reflectance spectra and qualities of pigments. Percent of reflectance will depend upon the concentration of pigment, the amount of intramuscular fat, and the amount of surface moisture of the meat, as well as the oxidation or oxygenation state of the pigment.

Reflectance curves of fresh meat in the visible region were reported (Ginger et al., 1954) and the meat pigments identified in accordance with existing reflectance maxima. These workers stated that the reflectance curves obtained with a spectrophotometer confirmed the presence of discoloration observed visually while absorption curves from pigment extracts of similar samples did not give any indication about the pigment changes on the surface of the meat.

Pirko and Ayres (1957) have stated that four absorption maxima can be seen at the wavelengths 500, 545, 580 and 635 nm; there is also a minimum value shown at 555 nm. According to Bowen (1954), these peaks may be attributed to the pigments metmyoglobin (500 and 635 nm), and oxymyoglobin (545 and 580 nm),

while a minimal value at 555 nm coincides with the absorption spectrum for myoglobin.

Dean and Ball (1960) pointed out that neither the absorbancy ratio nor the reflectance ratio give positive and accurate evidence of the presence of myoglobin derivatives in the reported proportions. Furthermore, no chemical reaction by which it could be possible to check the spectrophotometric methods was reported. These researchers showed that on the surface of freshly cut beef without a blooming period, reduced myoglobin should predominate and reflectance ratio indicated that this was true. Reduced myoglobin was over 50% and metmyoglobin was under 10%. However, absorbancy ratio indicated for the same surfaces that myoglobin was 20%, metmyoglobin about 20% and oxymyoglobin over 50%. This implies that the reflectance method is giving truer values for composition of the meat sample surface.

Snyder (1965) recorded reflectance spectra from 400 to 700 nm. The curves were adjusted to a constant at 525 nm to eliminate uncontrolled variables. The adjustment of the spectra leads to relatively stable and reproducible isobestic points. Isobestic points were reported at 474 nm for metmyoglobin and oxymyoglobin, at 571 nm for myoglobin and oxymyoglobin, and at 525 nm for the three forms of the pigment.

Snyder (1965) also showed that since the variation in reflectance at an isobestic point is small, it appeared possible to measure the amount of pigment present based on reflectance

at two wavelengths. From this information it is possible to plot graphs relating reflectance to the percent of the three myoglobin derivatives. To determine the intermediate points of these graphs, a suspension of non-fat milk, with known mixtures of oxymyoglobin and metmyoglobin was used.

Vodicka (1956) first called attention to the necessity of using K/S values rather than absorbance in studying the pigments of cured meat.

Since 525 nm is isobestic for all three pigments (Stewart et al., 1965), the reflectivity values at this wavelength, expressed as the ratio K/S, might be expected to show some correlation with the total amount of heme pigments in the meat. Stewart and co-workers found a positive correlation between the readings at 525 nm and total pigment. Expressed as absorbance, the relation is definitely non-linear. The ratio of absorbances at 572 nm/525 nm, when plotted against percent of the total pigment as metmyoglobin, gives a straight line, in contrast to the curve obtained for a ratio at 507 nm/573 nm, as was done by Broumand et al. (1958).

Snyder and Armstrong (1967) made reflectance measurements and compared the values and K/S ratios for a series of dry milk suspensions containing mixtures of oxymyoglobin and metmyoglobin. (K=absorbancy coefficient per unit of sample thickness; S=scattering coefficient per unit of sample thickness). Because of the definite curvature of reflectance plotted against concentra-

tion and because of the linearity of K/S plotted against concentration, they recommend that K/S values be utilized in attempts to relate data to the myoglobin concentrations in meat.

Zimmerman and Snyder (1969) stated that reflectance measurements and K/S ratios agree well with ratios reported earlier (Stewart et al., 1965; Snyder and Armstrong, 1967). They found the K/S ratio for metmyoglobin to be 0.59 at 571/525 nm; for oxymyoglobin, K/S equaled 1.36 at 571/525 nm, and 0.88 at 474/525 nm; and for myoglobin K/S was 0.53 at 474/525 nm.

Ockerman and Cahill (1969) indicated that the simplest method of predicting beef visual color was to use the reflectance at 685 nm rather than at 485 nm.

Franke and Solberg (1970) found that the height of the peak at 632 nm absorbance was directly related to the amount of metmyoglobin present on the meat sample. For 100% oxymyoglobin, absorbance at 632 nm was at a minimum. For 100% metmyoglobin the absorbance at this wavelength was at a maximum.

Wrinkles in the transparent film covering the sample, moist or dry meat surfaces and the presence of fat particles can cause variations in the reflectance spectra (Snyder, 1968).

Meat Pigments.

A vital factor in the acceptability of fresh and cured meat is muscle color. The bright-red color of the fresh meat and the pinkish-red color of cured meat, as well as discolora-

tion of various meat products, are due to the chemical state of the pigment called myoglobin. The muscle pigment, myoglobin, differs in chemical structure and reactivity from the blood pigment, hemoglobin.

In the animal tissues, oxygen is transported to the tissues by the iron-porphyrin pigments hemoglobin, myoglobin and chlorocruorin, and by the copper-containing pigment hemocyanin (Guzman, 1954).

The porphyrin molecule can easily accept metals. Thus, iron enters into the center of the square formed by the four nitrogen atoms in the porphyrin ring stabilizing the electrons of the pyrrol nuclei. As a consequence the absorption spectrum of the porphyrin loses some of its complexity: two absorption maxima in the visible light vanish, and fluorescence disappears. This iron completes its Werner coordination complex by ligating by itself two more groups, one above and the other below the plane of the porphyrin molecule, as reported by Guzman (1954).

Work reported by Perutz (1964) showed the hemoglobin molecule is a flattened disk whose shape may be approximated by a right-circular cylinder 34 Å high and 57 Å in diameter. It possesses a two-fold axis of symmetry, perpendicular to the cylinder axis, and appears to consist of four equally-spaced layers of matter. The four iron porphyrins are arranged on the surface of the molecule with their planes parallel to the cylinder axis and the axis of symmetry, and are attached to

identical residues of the protein, so that inherently they are all alike. Barcroft (1928) suggested that the specificity of the protein component is such that fetal and adult hemoglobins have proteins of different amino acid content and different oxygen affinities. In fact Itano (1951) has demonstrated that blood of the same individual may contain different kinds of hemoglobin. However, the iron porphyrin component is identical in all hemoglobins (Guzman, 1954).

Myoglobin is a conjugated, complex protein that contains a heme moiety (iron containing porphyrin compound) attached to the protein, globin. Its function in the live animal is to accept oxygen from the hemoglobin of the blood to use in oxidation energy-yielding reactions to the cell. This is essentially a storage mechanism for oxygen in the cells (Fox, 1968). Shenk et al. (1934) stated that this storage role is reflected in the quantities of myoglobin found in various tissues. These quantities are generally functions of (1) the amount of use of the principally muscular-activity tissue, (2) the blood supply, (3) the oxygen availability, and (4) the age of the animal (Giffee et al., 1960).

It is pertinent to consider the chemical structure of myoglobin and its derivative prior to evaluating factors affecting the stability of the compounds. The oxidation of myoglobin in air proceeds at a rate 4.25 times faster than the oxidation of hemoglobin, and the browning of meat must be due to the

ready formation of metmyoglobin (Guzman, 1954).

Lemberg and Legge (1950) described myoglobin as a complex protein, which means that in addition to the protein portion of the molecule, there is another moiety, non-peptide in nature, complexed to the peptide chain. The protein moiety, the globin, has a molecular weight of 16,000 to 17,000. The non-peptide portion is called the heme, and it is composed of two parts: an iron atom and a large planar ring, the porphyrin. The porphyrin is made up of four subunits, the heterocyclic compound pyrrole, linked together by methene bridges. There are three different kinds of side chains: methyl, vinyl and propyl. The complexes with iron are known as hemes, and when they are bound by the globins the resulting compounds are myoglobin and hemoglobin.

There are, however, two important differences between hemoglobin and myoglobin. First, although hemoglobin has four times the molecular weight of the muscle pigment, its oxygen-binding equivalence is the same because it has four heme groups per molecule. Second, the binding of the heme is not the same in the two compounds and it is found that there is a higher oxygen affinity in the muscle pigment, a factor which facilitates the transfer of oxygen from the blood to the cells in the capillaries (Guzman, 1954).

Kendrew et al. (1960) reported that in myoglobin, the central iron atom is attached with six bonds. In this case the

iron has not contributed any electrons itself but has accepted six pairs from some other atoms, five pairs from nitrogen atoms, and one pair from oxygen. Four of the nitrogen atoms are in the porphyrin ring, and one is in the imidazole group of a histidine molecule in the amino acid chain of the globin. It is the sixth bond orbital which provides for the function of the molecules in that this orbital is available for the complexing of any atom which has an electron pair to donate.

Giffee et al. (1960) stated that various known complexes of heme, globin, and ligands may be grouped in two major classes of ionic and covalent bond types, each of which contains members in which the iron is in either the ferrous (2+) or ferric (3+) state. Insofar as meat color is concerned, the covalent complexes are of the greatest interest for it is in this class that the bright-red pigments so desired in fresh or cured meats are found. Oxymyoglobin, nitrosomyoglobin and carbonmonoxymyoglobin are examples of the ferrous covalent complexes of myoglobin with oxygen, nitric oxide, and carbon monoxide, respectively. Two examples of ferric iron covalent complexes are cyanometmyoglobin and metmyoglobin hydroxide, both of which have the characteristic red color.

Myoglobin and metmyoglobin do not exist uncomplexed in solution, and in the absence of strong covalent complexes they form ionic complexes with water (Fox, 1968).

The oxidation of myoglobin in the presence of reducing agents results in two other heme pigments; both are green but

their essential character differs, depending upon the type of reductant used. If the reductant is a sulfhydryl compound, the resulting green pigment is sulfmyoglobin, a heme pigment which apparently contains sulfur and is characterized spectrally by a strong absorption band at 616 nm in the red portion of the spectrum. If the reductant is ascorbate or some other non-sulfhydryl agent, the principal product is choleomyoglobin, a heme-globin complex in which the porphyrin has been oxidized. Sulfmyoglobin may be converted back to the original myoglobin, but choleomyoglobin cannot be reconverted and rapidly breaks down to yield globin, iron and a tetrapyrrole (Millikan, 1939).

With this information on the chemical structure of myoglobin, and related compounds, it is of interest to consider the chemical reactions involved in the production of desirable or undesirable color changes in fresh or cured meats.

Several generalizations may be made relative to reactions causing color change, as reported by Schweigert (1956). While oxygen is required for the oxygenation of myoglobin to oxymyoglobin, a desired reaction in fresh meats, prolonged exposure to oxygen results in the undesirable formation of metmyoglobin. The presence of reducing conditions not only keeps myoglobin in the reduced state, but will convert metmyoglobin to myoglobin. Myoglobin must be in the reduced state before it will react with nitric oxide to form the cured meat pigment. Nitrite will function as an oxidizing agent in the presence of air to convert

myoglobin to metmyoglobin, an undesirable reaction. When oxidation proceeds to the formation of green compounds, the reactions appear to be irreversible. Green compound formation with an ultimate degradation to colorless compounds, occurs on prolonged exposure to oxygen, by the action of peroxides, by irradiation with gamma rays, and probably by several other oxidizing conditions. The presence of light catalyzes the rate of oxidation of these pigments. Nitric oxide myoglobin is much more susceptible to oxidation changes than is the pigment present after the cured meat is heated (Coleman, 1951; Watts, 1954).

Guzman (1954) suggested that the simplest stoichiometry for the oxidation of ferrous compounds by atmospheric oxygen requires four Fe^{++} equivalents per mole of O_2. In the oxidation of myoglobin, which has one Fe^{++}-porphyrin per mole of protein, George and Stratman (1952a), found an uptake of 2.5 moles, an indication that some oxidizable groups of the proteins were oxidized during this process (tyrosine, tryptophan, serine...). During the oxidation of the Fe^{++} compound there must be formation of intermediates which are strong oxidizing agents. In acid solutions the oxidation of oxymyoglobin is first-order with respect to oxyhemoglobin and hydrogen ions, the rate-determining step involving the production of the perhydroxyl radical (Coryell et al., 1937).

The faster oxidation of hemoglobin and myoglobin when

compared to the oxidation of the oxyhemoglobin and oxymyoglobin is an indication that there is formation of an auxiliary electron accepting group in the unoxidized forms of myoglobin and hemoglobin (Guzman, 1954).

Metmyoglobin, the oxidized form of the pigment, cannot bind oxygen. In the presence of oxygen, therefore, myoglobin is converted to two different pigments, metmyoglobin and oxymyoglobin, the oxidized and oxygenated forms, respectively. The relative proportions of these two forms depend upon the partial pressure of oxygen, the formation of metmyoglobin being favored by low oxygen pressures. Thus, in a piece of fresh meat, the bright-red color of oxymyoglobin on the surface is observed where there is plentiful supply of both oxygen and reducing substances. In the interior myoglobin is in the reduced state and has the dark purple-red color. As long as the tissues' supply of oxidizable substrates lasts, the heme pigments are retained in the reduced state, but as soon as they are used up the reducing power of the muscle is lost, and the iron of the heme pigment is oxidized to the brown metmyoglobin (Brooks, 1929; 1938).

Light-accelerated fading of dyes and other pigments is well known. Muscle pigments also fade and absorbed light energy apparently decomposes the pigment. Blue and green light would be expected to cause the greatest destruction of "heme pigments" since their strongest absorption bands in the visible spectrum

lie in this region, an expectation corroborated by experiments of Archer and Brandfield (1950).

Myoglobin, in its various chemical forms, is not the only pigment in muscle, but is generally the only pigment present in large enough quantities to color the tissue. Myoglobin acts primarily as a storage place for oxygen, and apparently can be all dispended without impairment of muscle function. A number of muscle pigments exist which are of greater importance to the living tissue but which are present in such small quantities that they contribute little or nothing to the total color. Among these are the cytochromes, red heme pigments which contain iron in a similar porphyrin-protein complex structure; vitamin B_{12}, a much more complex structure which contains the same porphyrin ring as the hemes and the cytochromes, but which contains a cobalt atom instead of iron; and the flavins, yellow coenzymes involved with the cytochromes in electron transport in the cell, as stated by Giffee and associates (1960).

Factors Affecting the Stability of Meat Pigments.

Snyder and Ayres (1961) believe that myoglobin is subjected to an autoxidation which is not associated with bacterial contamination. Since the initial discoloration occurs 2-3 mm below the meat surface (Brooks, 1929), it is difficult to understand how surface bacterial growth causes the oxidation of myoglobin at some distance removed, but not in immediately

adjacent areas.

Pronounced surface discoloration can occur in less than one hour if the meat surface is brushed with a heavy bacterial inoculation. Butler et al. (1953), inoculated beef with Pseudomonas and found that the inoculated samples showed greater discoloration than non-inoculated control samples. Naumann et al. (1968) reported that in natural conditions contamination can happen with direct contact with an aged piece of meat, uncleaned blocks or cutting boards, and dirty equipment. Any practice which increases the surface bacterial load on meat cuts will promote surface discoloration.

Rikert et al. (1957a) reported that inoculation with Achromobacter hastened the return of red color. This red color is undoubtedly the purplish red myoglobin reported previously by Butler et al. (1953) as produced by Pseudomonas and later by Robach and Costilow (1961) for Pseudomonas, Achromobacter and Flavobacterium, but no discoloration was noted under the effect of the microaerophile Lactobacillus plantarum.

Cutaia and Ordal (1964) found that initial microbial load had little or no effect upon the rate of metmyoglobin formation and its conversion to reduced myoglobin in anaerobically packaged ground beef.

Microorganisms, both living and dead, and their enzymes on the surface of meat may oxidize both fresh and cured meat pigments to "methemoglobin" (Jensen, 1954). Butler et al.

(1953) postulated that the oxidation of meat pigments is primarily due to the presence of bacteria. The explanations for the effects of bacteria on meat color center upon assumed influences of the bacteria on the oxidation-reduction potential of the meat (Rikert et al., 1957a).

The destruction of heme by bacteria by direct utilization of either the heme or the globin seems to be of little importance, but the action of various by-products of bacterial metabolism causes heme damage. The bacteria causing the greatest discoloration in meats are those which produce hydrogen peroxide, which oxidizes the porphyrin ring to a green compound (possibly choleomyoglobin) that may be oxidized further to colorless compounds (Brissey, 1963).

Since bacterial levels affect meat discoloration, rate of discoloration of meat cuts in the display case is increased with increased storage temperature. Meat cuts displayed at 38-42°F (4-5°C) may maintain excellent color for periods of up to three or four days. In general, the normal spoilage bacteria on cut meat surfaces, at these relative temperatures, will multiply ten times more rapidly with each 5°F (2.78°C) increase in temperature, as reported by Brissey (1963).

The salable life of both fresh and processed meats depends to a great extent on the temperature at which they are stored and displayed. One test (Hockman, 1956) indicated a reduction of 50% in the salable life of a loin steak if it is kept at 40°F (4.5°C) rather than 35°F (1.5°C). Clark (1956)

reported tests by a large grocery chain showing that an illumination of 40 fc. (430.4 lm/m^2) from 150 watt reflector lamps raised the surface temperature of transparent wrapped meats in a self-service display case 2 or 3°F (1.6-2.2°C) above the 35°F (1.5°C) ambient. Fluorescent lamps have only about 1/5 as much radiant heat per foot-candle as filament lamps. This is in agreement with work done by Hockman (1956) who stated that filament lamps emit a relatively large amount of radiant heat that can have the effect of raising the temperature of exposed surfaces of meat in refrigerated show cases.

Clauss et al. (1957) reported that in general, total organoleptic quality, flavor and color of all meats were maintained better at relatively low temperatures. Storage at around 34°F (1°C) was better in prolonging good quality life of fresh lamb from grain-fed animals, than storage at 40°F (4.5°C).

Jensen (1954) showed that meats held under refrigeration may develop a flora of psychrophilic bacteria. These are bacteria that grow at temperatures near freezing, although the growth is slow.

Brissey (1963) stated that an unattractive brick red color results as cut meat surfaces lose surface moisture. Low humidities, excessive air movement and non-moisture-proof packaging material promote surface drying. Pirko and Ayres (1957) indicated that insofar as color changes are concerned, oxygen transmission through the packaging material may be of

more importance than water vapor transmission provided that water losses do not cause the meat to be severly desiccated. Brissey (1963) further added that surface drying does not entirely inhibit surface bacterial growth, but protection against drying may set up a moist surface condition that requires optimum sanitation measures and temperatures if more than one day's display case life is required.

Fresh meat packaging films will maintain the bloom of the meat for several days if proper care is taken to guard against other discoloration factors. With a non-moisture-proof film, a dried surface and hard brick red color is developed in a short time as cited by Brissey (1963).

Mackinney and Little (1962) stated that oxymyoglobin is fairly stable at high oxygen pressures and the question arises whether to package fresh meat in an oxygen-permeable film. Given an impermeable film, the metmyoglobin may be reduced to myoglobin because the meat proteins have some reducing capacity.

Brissey (1963) suggested that with fresh meat the use of a vacuum package and an oxygen impermeable film always produce a dull purple-red color. It is generally accepted that this purple-red color does not have the appeal of the bright red color maintained with proper fresh meat packaging film. However, a vacuum package does provide a longer display-case life. This results because of the fact that the vacuum package, and the oxygen impermeable film provide a nearly oxygen-free

packaging which is not conducive to the growth of the normal spoilage-bacteria found on meat. Jaye et al. (1962) stated that there is a growing utilization of vacuum packages on fresh ground beef. The consumer has found that when the meat is removed from the package, the characteristic red color is quickly formed.

Various packaging materials for fresh meat were studied by Kraft and Ayres (1954a), to determine their ability to preserve the desirable bright-red color of meat. These investigations concluded that packaging materials that preserve the desirable color of meat in the early phases of storage enhanced rapid growth of microorganisms.

Rikert et al. (1957b), reported that no one film is best suited for packaging all types of meat. The best results, as far as color is concerned, are obtained by packaging each type of meat in a specific package. In most cases, the difference between long and short storage, is not significant, but some films were considered better for short rather than long storage.

The replacement of the vacuum by carbon dioxide (Rikert et al., 1957c) or nitrogen (Rikert et al., 1958) yielded results essentially similar to those reported for the vacuum studies. As oxygen replaced nitrogen or carbon dioxide in these same studies the development of metmyoglobin was retarded. Fellers et al. (1963) reported that partial pressures of oxygen

above those in the normal atmosphere were advantageous for preserving the oxymyoglobin redness of meat. Baush (1966) stated that 760 mm of oxygen pressure, or any oxygen pressure above that found in the atmosphere, will keep red meat for an "exceptional" time period. Studies by Snyder (1964) further supported the results previously cited.

Freezing and storage temperatures of frozen meat have a marked effect on color. Color stability of frozen meat is enhanced by freezing and storage treatments that produce and maintain intracellular ice crystals (Lawrie, 1966). Ramsbottom and Koonz (1941) compared freezing temperatures of -12.2°C and -34.4°C and found the slower frozen meat to be darker. Based on histological evidence, they attributed the darkening to large, mostly extracellular ice crystals resulting in less scattering of light.

Frozen meat when stored at relatively high temperatures, 10 to 25°F (-12 to -3°C), will discolor even though it was originally quick-frozen and did originally have a bright-red color. The rate of discoloration can be very rapid, a matter of just a few weeks at temperatures around 25°F (-3°C). Much of the discoloration in fresh meat in freezer display cases is due to the fact that the frozen meat cuts are not held at temperatures of 0°F (-18°C) or lower, as stated by Brissey (1963).

The position of the meat cut in the case can affect the

color of the packaged meat item. Very often the package is placed too high in the case and does not have the advantage of the proper freezer temperatures. In addition, the fluctuation of temperatures due to defrost cycles and surface warming due to radiant heat from high intensity light may contribute to more rapid discoloration in the display case than is found in the closed freezer (Gould, 1963).

Frost accumulation in the package when the film is not in close contact with the meat surface will produce surface meat dehydration as suggested by Brissey (1963). Further, Brissey adds that dehydration detracts from the appearance of the meat and if it continues to develop under prolonged storage, will cause a decrease in the juiciness of the meat and lead to undesirable flavor of meat when cooked.

The effect of temperature on myoglobin in the absence of oxygen was studied by Cutaia and Ordal (1964). In this situation, myoglobin or oxymyoglobin were partially oxidized to metmyoglobin and then reduced again to myoglobin. As the storage temperature was increased from 30° to 68°F (-1° to 20°C), the time for formation of significant levels of metmyoglobin decreased, resulting in a lower maximum quantity of metmyoglobin being observed at the higher temperatures. Thus, it appears that reducing enzymes may be stimulated by temperature increase to convert metmyoglobin to myoglobin at a greater rate than the mechanism converting oxymyoglobin to metmyoglobin. In addition there may be some difference in the rate of the two processes

as a function of the energy requirement effect presented by George and Stratmann (1952b), which showed that oxymyoglobin oxidation required an activation energy of 25 Kcal, while the myoglobin-metmyoglobin reaction had an activation energy of only 19 Kcal.

Susceptibility of frozen meats to fading by light is similar to that of meats kept at temperatures between 32°F (0°C) and 40°F (4.5°C). Cured, smoked, and table-ready meats that have been sliced and frozen are much more susceptible to light discoloration than frozen fresh meats (Ramsbottom et al., 1951).

As reported by Kampschmidt (1955), light is known to cause the dissociation of carbon monoxide hemoglobin. He also demonstrated that light caused the dissociation of nitrosomyoglobin, forming oxymyoglobin, since this compound is not dissociated by light.

Watts (1954) postulated that fresh meats are not materially discolored by display case lighting during a three-day period. Longer display periods may bring about discoloration, primarily a result of microbial development.

Ramsbottom et al. (1951) found that fresh meats became only partially discolored after display for 36 hours under ultraviolet lighting of 60 fc (645.6 lm/m^2) or less illumination.

In displaying the bright, natural colors of meats when the light intensity at the level of display was approximately

the same, "Deluxe Cool White" fluorescent, "Soft White" fluorescent and incandescent-tungsten filament lamps were superior to all others tested (Clark, 1956).

Barr et al. (1952) reported that the "Deluxe Cool White" lamps appeared to define clearly the natural white color of the fatty tissue and the natural bright-red color of the lean meat. The greater amount of red in the illumination of the incandescent and "Soft White" fluorescent lamps gave the fat a yellowish cast. Since fresh meats containing white fat are preferred by the trade, a slight color advantage may be gained by the use of "Deluxe Cool White" fluorescent lamps.

Ramsbottom and co-workers (1951) found that the rate of discoloration of fresh meat exposed to 60 fc (645.6 lm/m^2) was between two and three times as fast as those exposed to 20 fc (215.2 lm/m^2).

In spectral reflectance studies made on sliced bologna, Taylor and Pracejus (1950) reported that the same fading will be produced by 20 fc (215.2 lm/m^2) for 10 hours as is produced by 200 fc (2,152 lm/m^2) for one hour.

There has been considerable speculation as to whether certain wavelengths in the visible spectrum are primarily responsible for discoloring meats. Townsend and Bratzler (1958) stated that steaks stored under orange and red filters and under no filter showed the largest amount of metmyoglobin formation. They showed that wavelengths of light between 560 and 630 nm (yellow and orange portion of the spectrum) seem to

be responsible for color degradation of packaged frozen meat. Frozen meat stored under green and red fluorescent light, seemed to have better color stability.

Data reported by Kampschmidt (1955) showed that the energy absorbed from wavelengths between 350 and 580 nm will result in more dissociation than from the upper range of the visible spectrum.

Archer and Brandfield (1950) used filters selected for their ability to absorb wavelengths in the 400 nm range and interposed them between the fluorescent source and the meat product. They have found a significant increase in the time required for least perceptible discoloration of the meat. Allen (1949) showed no effects on color which could be attributed to the color of light in the visible spectrum.

Hockman (1956) stated that intensity seems to have a greater effect than does the color of light and more fading occurred when the meat was exposed to near ultraviolet and less with yellow light in cured meats. Ramsbottom et al. (1951) showed that meats discolored just as quickly under incandescent light as they did under fluorescent light. These data are in agreement with studies reported by Taylor and Pracejus (1950) who stated that within experimental errors, the fading or color change was identical under the two sources for equal exposure in foot-candles per hour.

Ramsbottom et al. (1951) reported that fluorescent lamps

used in display cases do not emit ultraviolet rays in significant amounts, and discredits statements to the effect that display-case discoloration of meat is caused by ultraviolet rays. By using filters to absorb ultraviolet rays, it was demonstrated that the meat discolored just as quickly with or without the filters, provided the light intensity was the same. These observations are in agreement with those reported by Pracejus (1949).

The earlier statement regarding ultraviolet emission of the fluorescent sources is contradictory in view of recent concepts. Thorington and Parascandola (1967) stated that the Deluxe Cool White fluorescent source emitts roughly 80 microwatts per lumen of ultraviolet radiation.

Ramsbottom et al. (1951) also stated that cured meats were discolored to a lesser extent by a 36 hour exposure to ultraviolet rays, than when exposed for a similar period to fluorescent light of 60 fc (645.6 lm/m^2) intensity. Conversely, fresh meats were not discolored after a 36 hour exposure to fluorescent light, but they did change color after a similar exposure to the ultraviolet rays.

Kraft and Ayres (1954a) studied the intensity of "Soft White" fluorescent light and found that it was unimportant in influencing the course of discoloration of packaged fresh beef or development of the surface organisms. They recommended display of fresh meat in self-service markets using high intensities of "Soft White" fluorescent light without the occurrence

of undue discoloration. These researchers (Kraft and Ayres, 1954a) indicated similar results when round steaks wrapped in MSAT-80 cellophane were subjected to 7 to 10 fc (75.3 to 107.6 lm/m^2) of ultraviolet light at 2.5°C. The reflectance rapidly decreased during a two-day storage and the color became brown compared to red for steaks displayed under fluorescent lights. However, beef wrapped with Visten-C (0.001 in., low transmittance film, particularly below 320 nm) was not affected by the two types of light in the same manner as was meat packaged with MSAT-80 cellophane. It appears that "Soft White" fluorescent light produced greater discoloration than did germicidal ultraviolet light. From display observations it seemed that the intensity of ultraviolet radiation on the surface of beef packaged with Visten-C was not sufficiently great to cause as marked discoloration as that which occurred when the meat was wrapped with the more transparent cellophane.

Further, Kraft and Ayres (1954a) stated that there was a higher moisture loss in steaks under ultraviolet light than those under fluorescent light. Duggan (1936) and Haurowitz (1950) suggested that affinity of proteins for water is decreased as a result of denaturation by ultraviolet radiation.

Beef exposed to ultraviolet light exhibited more drastic changes in color and reflectance than those noted for similarly packaged beef held under fluorescent light (Kraft and Ayres, 1954a). When the beef was displayed under ultraviolet lights,

the reflectance rapidly decreased during storage for two days, and the color of the samples was a dark brown in contrast to the dull red color of the meat displayed under fluorescent light. The reflectance and color changes of beef wrapped in cellophane and displayed under 50 and 150 fc (538 and 1614 lm/m^2) of fluorescent light were similar and corresponded to those observed when cellophane-wrapped beef was stored in the dark. Measurements of spectral reflectance and visible color changes indicated that ultraviolet light caused rapid oxidation to metmyoglobin to produce marked discoloration of fresh beef early in storage, whereas similar discoloration with display under fluorescent light required a longer exposure period and resulted from a combination of desiccation of the meat and oxidation of the pigment.

Voegeli (1952) found that the intensities of light employed, up to 215 fc (2313.4 lm/m^2) did not affect the rate of color change of unwrapped samples under comparable storage temperatures. The increased temperatures from the light sources reduced the shelf life of both wrapped and unwrapped samples. Gould (1963) studied high intensities of illumination and reported that incandescent light contributed to increased surface heating and rapid discoloration of fresh pork chops, but light intensities that did not increase surface temperature had no effect on discoloration of fresh pork chops.

Rikert et al. (1957a) and Clauss et al. (1957) reported

data indicating that light versus dark storage had little effect on the color of fresh meat. The effect of lighted storage upon the color of cured meat was deleterious except in the case of cuts of ham in "film 15" (cellophane-pliofilm laminate, pliofilm inside, with low vapor permeability and 0.019 cc/100 sq. in./24 hrs. [0.0029/1.0 m^2/24 hrs] oxygen permeability) during a long storage period. Clauss et al. (1957) further stated that the organoleptic quality of the product was not altered under light and dark storage.

Marriot et al. (1967) showed that color description and color desirability scores of prepackaged fresh beef steaks changed only slightly during ten days of dark storage at 30°F (-1°C). In contrast, steaks that were continuously displayed under light were scored lower for color and desirability after three days than those stored in the dark and these differences became progressively greater as the display period increased. Likewise, steaks displayed after 3, 5, or 7 days dark storage were scored lower and these differences became progressively greater as the display period increased. No significant difference was observed in color desirability scores attributable to packaging material.

Rate of frozen meat color deterioration is proportional to the amount of light exposure as reported by Ramsbottom et al. (1951) and Taylor and Pracejus (1950).

Lighted display following dark storage stimulated the

growth of bacteria. Whether presence of light, or slight increase in surface temperature due to light radiation stimulated growth of bacteria was not determined (Marriot et al., 1967). Although lower light intensity was used in this study than the study reported by Voegeli (1952), the results obtained further confirm the conclusions that fluorescent light causes discoloration of packaged fresh beef. However, these results do not support the report of Kraft and Ayres (1954a) that Soft White fluorescent light intensity was unimportant in causing discoloration.

Field inspections of meat discoloration by Archer and Brandfield (1950) revealed that at 40°F (4.5°C), a fluorescent source with 93 fc (972.6 lm/m^2) required one hour to produce perceptible discoloration whereas approximately 159 fc (1708 lm/m^2) were needed for tungsten sources. The discrepancies become even greater at lower temperatures, thus at 35°F (1.5°C) the fluorescent source required 135 fc. hr. (1452.6 lm/m^2) and the tungsten source required 300 fc. hr. (3228 lm/m^2) to produce equal amounts of perceptible discoloration. These differences suggested that the yellow and red predominance of tungsten sources was advantageous when considering the display lighting of meat for more reasons than appearance alone. The same researchers found that for prepared meats wrapped in cellophane and exposed to illumination levels between 50 and 150 fc (538-1614 lm/m^2) the time required to produced "least perceptible

discoloration" is a function of time, temperature, quantity of illumination, and the spectral quality of the light.

LITERATURE CITED

Allen, N. 1949. Meat film considerations. Modern Packaging 22, 134.

Archer, H. and Brandfield, R. E. 1950. The discoloration of veal loaf when exposed to high illumination. Illuminating Eng. 45, 429.

Barcroft, J. 1928. The Respiratory Function of the Blood. Vol. II Haemoglobin. Cambridge Univ. Press. pp. 47.

Barr, A. C., Clark, C. N. and Hessler, J. 1952. Evaluation of color rendition by fluorescent lamps. An explanatory study. Illuminating Eng. 47, 649.

Baush, E. R. 1966. Canadian Patent 742,165.

Billmeyer, F. W. and Saltzman, M. 1967. Principles of Color Technology. Interscience Publishers. New York.

Bowen, W. J. 1949. Theabsorption spectra and extinction coefficients of myoglobin. J. Biol. Chem. 179, 235.

Brissey, G. E. 1963. Factors affecting stability of meat pigments. 16th Rec. Meat Conference pp. 93.

Brooks, J. 1929. Post mortem formation of methaemoglobin in red muscle. Biochem. J. 23, 1391.

Brooks, J. 1938. Color of meat. Food Res. 3, 75.

Broumand, H., Ball, C. O. and Stier, E. F. 1958. Factors affecting the quality of prepackaged meat. II E Determining the properties of heme derivatives in fresh meat. Food Technol. 12, 65.

Butler, O. D., Bratzler, L. J. and Mallman, W. L. 1953. The effect of bacteria on the color of prepackaged retail beef cuts. Food Technol. 7, 397.

Clark, C. N. 1956. The basis of appropriate lighting for meat displays. Proc. 8th Res. Conference. AMIF. Univ. of Chicago.

Clauss, W. E., Ball, C. O. and Stier, E. F. 1957. Factors affecting the quality of prepackaged meat. I. Physical and organoleptic tests. C. Organoleptic and miscellaneous physical characteristics of product. Food Technol. 11, 363.

Coleman, H. M. 1951. The mechanism of meat pigment oxidation. The effect of solutes on the hemoglobin-oxygen equilibrium. Food Res. 16, 222.

Coryell, C. D., Stitt, F. and Pauling, L. 1937. The magnetic propreties and structure of ferrihemoglobin (methemoglobin) and some of its compounds. J. Am. Chem.Soc. 59, 633.

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

Dean, R. W. and Ball, C. O. 1960. Analysis of the myoglobin fractions on the surfaces of beef cuts. Food Technol. 12, 271.

Duggan, B. M. 1936. Biological Effects of Radiation. McGraw-Hill Book Co., Inc. New York.

Enfield, F. D. 1968. Problems related to the genetic analysis of differences in meat color. Proc. Meat Ind. Res. Conference. AMIF pp. 4.

Fellers, D. A., Wahba, I. J., Caldano, J. C. and Ball, C. O. 1963. Factors affecting the color of prepackaged retail beef cuts. Origen of cuts, package type and storage conditions. Food Technol. 17, 1175.

Fox, J. B. 1966. The chemistry of meat pigments. J. Agr. Food Chem. 14, 207.

Fox, J. B. 1968. Chemico-physical properties of meat pigments as related to color. Proc. Meat Ind. Res. Conf. AMIF. pp. 12.

Francis, F. J. and Clydesdale, F. M. 1967. Color measurement of foods: I. The nature of light. Food Product Development, Vol. 1, October-November.

Francis, F. J. and Clydesdale, F. M. 1968. Color measurement of foods: II The nature of color. A reprint from Food Product Development, Vol. 2, December-January.

Franke, W. C. and Solberg, M. 1970. The quantitative determination of metmyoglobin and total pigment in an intact meat sample using reflectance photometry. IFT 30th Annual meeting, San Francisco. An abstract, pp. 111.

George, P. and Stratmann, C. J. 1952a. The oxidation of myoglobin to metmyoglobin by oxygen. 1. Biochem. J. 51, 103.

George, P. and Stratmann, C. J. 1952b. The oxidation of myoglobin to metmyoglobin by oxygen. 2. The relation between the first order rate constant and the partial pressure of oxygen. Biochem. J. 51, 418.

Giffee, J. W., Urbin, M. C., Fox, J. B., Landmann, W. A., Siedler, A. J. and Sliwinski, R. A. 1960. Chemistry of animal tissues. In "The Science of Meat and Meat Products". pp. 56-110 W. H. Freeman and Co., San Francisco.

Ginger, I. D., Wilson, G. D. and Schweigert, B. S. 1964. Biochemistry of myoglobin. Quantitative determination in beef and pork muscle. J. Agr. Food Chem. 2, 1037.

Goldring, L. S., Hawes, R. C., Hare, G. H., Beckman, A. D. and Stickney, M. E. 1953. Abnormalies in extinction coefficient measurements. Anal. Chem. 25, 869.

Gould, P. F. 1963. Discoloration of fresh meats as influenced by temperature, microflora and light. M. S. thesis, Univ. of Missouri, Columbia, Missouri.

Guzman-Barron, E. S. 1954. Iron-porphyrins and oxidation-reductions. Proc. 6th AMIF Conference, pp. 5.

Hansen, L. J. and Sereika, H. E. 1969. Factors affecting color stability of prepackaged frozen fresh beef in display cases. Illuminating Eng. 64, 620.

Haurowitz, F. 1950. Chemistry and Biology of Proteins. Academic Press, New York and London.

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

Hockman, R. O. 1956. Problems in packaging meat products. The National Provisioner 114, 76.

Itano, H. A. 1951. A third abnormal haemoglobin associated with hereditary hemolitic anemia. Proc. Natl. Acad. of Sciences 37, 775.

Jaye, M., Kittka, R. S. and Ordal, Z. J. 1962. The effect of temperature and packaging material on the storage life and bacterial flora of ground beef. Food Technol. 16, 95.

Jensen, L. B. 1954. Microbiology of Meats. Garrard Press. Champaign, Illinois.

Judd, D. B. and Wyszecki, G. 1963. Color in Business, Science and Industry. (2nd edition). John Wiley and Sons, Inc. New York.

Kampschmidt, R. F. 1955. Meat color and influence of light. Proc. 7th Res. Conference. AMIF. pp. 42.

Kendrew, J. C., Dickerson, R. E., Strandberg, B. E., Ghart, R., Davies, D. R., Phillips, D. C. and Shore, V. C. 1960. Structure of myoglobin. A three dimensional fourier synthesis at 2 A resolution. Nature 185, 422.

Kraft, A. A. and Ayres, J. C. 1954a. Effect of display case lighting on color and bacterial growth on packaged fresh beef. Food Technol. 8, 290.

Kraft, A. A. and Ayres, J. C. 1954b. Color changes in packaged bologna. Food Technol. 8, 22.

Lawrie, R. A. 1966. Meat Science. Pergamon Press, New York.

Lemberg, R. and Legge, J. W. 1950. Pyrrole pigments. Ann. Rev. Biochem. 19, 431.

Mackinney, G. and Chichester, C. O. 1954. The color problem in foods. Advances in Food Research. 5, 301.

Mackinney, G. and Little, A. C. 1962. Color of Foods. The AVI Publishing Co. Inc.,Westport, Conneticut.

Marriot, N. G., Naumann, H. D., Stringer, W. C. and Hedrik, H. B. 1967. Beef as influenced by pre-display environments. Food Technol. 21, 1518.

Millikan, G. A. 1939. Muscle haemoglobin. Physiol. Rev. 19, 503.

Naughton, J. J., Frodyma, M. K. and Zeitlin, H. 1957. Spectral reflectance applied to the study of heme pigments. Science 125, 121.

Naumann, H. D., McBee, J. L. and Brady, D. E. 1957. Color stability of frozen beef as influenced by illumination, temperature and storage. Food Technol. 11, 31 (Abstr. 127).

Naumann, W., Stringer, W. C. and Gould, P. F. 1968. Handling prepackaged meat in retail stores. Manual 64, reprint 7/68, Univ. of Missouri.

Ockerman, H. W. and Cahill, V. R. 1969. Reflectance as a measure of pork and beef muscle tissue color. J. Anim. Sci. 28, 750.

Perutz, M. F. 1964. The haemoglobin molecule. A reprint from Scientific American, November 1964. W. H. Freeman and Co., San Francisco.

Pirko, P. C. and Ayres, J. C. 1957. Pigment changes in packaged beef during storage. Food Technol. 11, 461.

Pracejus, W. G. 1949. A report on meat fading. Engineers Bulletin. Large Lamp Department. General Electric Co.

Ramsbottom, J. M. and Koonz, C. H. 1941. Freezer storage temperature as related to drip and to color of frozen-defrosted beef. Food Res. 6, 571.

Ramsbottom, J. M., Goeser, P. A. and Schultz, H. W. 1951. How light discolors meat. What to do about it. Food Industry 23, 120.

Rikert, J. A., Ball, C. O. and Stier, E. F. 1957b. Factors affecting quality of prepackaged meat. II Color studies. A Effect of package characteristics upon color of product. Food Technol. 11, 520.

Rikert, J. A., Ball, C. O. and Stier, E. F. 1958. Factors affecting quality of prepackaged meat. II Color studies. D. Effects of nitrogen and carbon dioxide under different pressures upon color of product. Food Technol. 12, 17.

Rikert, J. A., Bressler, L., Ball, C. O. and Stier, E. F. 1957a. Factors affecting quality of prepackaged meat. II Color studies. B. Effects of storage time, storage temperature, antioxidants, bacteria, light, freezing and fat upon color of product. Food Technol. 11, 567.

Rikert, J. A., Bressler, L., Ball, C. O. and Stier, E. F. 1957c. Factors affecting quality of prepackaged meat. II Color studies. C. Effects of air and oxygen under different pressures upon color of product. Food Technol. 11, 625.

Robach, D. L. and Costilow, R. N. 1961. Role of bacteria in the oxidation of myoglobin. Appl. Microbiol. 9, 529.

Schweigert, B. S. 1954. Quantitative chemical measurements of myoglobin. Proc. 7th American Rec. Meat Conference. pp. 77.

Schweigert, B. S. 1956. Chemistry of meat pigments. Proc. 8th Ind. Res. Meat Conference. AMIF. Univ. of Chicago, pp. 61.

Shenk, J. H., Hall, J. L. and King, H. H. 1934. Spectrophotometric characteristics of hemoglobins. I. Beef blood and muscle hemoglobins. J. Biol. Chem. 105,741.

Snyder, H. E. 1964. Measurement of discoloration in fresh beef. J. Food Sci. 29, 535.

Snyder, H. E. 1965. Analysis of pigments at the surface of fresh beef with reflectance spectrophotometry. J. Food Sci. 30, 457.

Snyder, H. E. 1968. The study of myoglobin derivatives in meat samples by reflectance spectrophotometry. Proc. Meat Ind. Res. Conference. AMIF. Univ. of Chicago. pp. 21.

Snyder, H. E. and Ayres, J. C. 1961. The autoxidation of crystallized beef myoglobin. Food Res. 26, 469.

Snyder, H. E. and Armstrong, D. J. 1967. An analysis of reflectance spectrophotometry as applied to meat and model systems. J. Food Sci. 32, 241.

Stewart, M. R., Zipser, M. W. and Watts, B. M. 1965. The use of reflectance spectroscopy for the assay of raw meat pigments. J. Food Sci. 30, 464.

Tappel, A. L. 1957. Reflectance spectral studies of the hematin pigments of cooked beef. Food Res. 22, 404.

Tappel, A. L. 1961. Special measurements of hematin pigments of cooked and cured meats. J. Food Sci. 26, 269.

Tauber, F. W. and Simon, S. 1963. Changes in the color of meat under various processing conditions. Food Technol. 17, 105.

Taylor, A. H. and Pracejus, W. G. 1950. Fading of colored materials by light and radiant energy. Illuminating Eng. 45, 149.

Thorington, L. and Parascandola, L. J. 1967. Ultraviolet emission from light sources used as general illuminants. Illuminating Eng. 62, 674.

Townsend, W. E. and Bratzler, L. J. 1958. Effect of storage conditions on the color of frozen packaged retail beef cuts. Food Technol. 12, 663.

University of Wisconsin. 1963. Pork quality standards. Wisconsin Experiment Station. Special Bulletin No. 9.

Vodicka, V. O. 1956. The nature and properties of the pigment of cured meats. Ph. D. thesis. Rutgers, the State University. New Brunswick, New Jersey.

Voegeli, M. M. 1952. The measurement of fresh beef muscle color changes by disk colorimetry. Ph. D. thesis. Michigan State College. East Lansing, Michigan.

Watts, B. M. 1954. Oxidative rancidity and discoloration in meat. Advances in Food Research 5, 1.

Wright, W. D. 1944. The Measurement of Colour. London, Hilger.

Zimmerman, G. L. and Snyder, H. E. 1969. Meat pigment changes in intact beef samples. J. Food Sci. 34, 258.

Chapter 3

EFFECT OF DISPLAY LIGHT INTENSITY ON COLOR STABILITY OF FROZEN BEEF CUTS IN TRANSPARENT FILM

The modern meat industry is moving towards centralized cutting and processing of products for economic reasons. More efficient use can be made of machinery and work planning is more efficient. Freezing of meats is a logical and necessary step in this integration. Frozen products should have an extended shelf life, as compared to fresh meats, especially under the distribution system needed for central meat cutting.

Central meat cutting also offers greater standardization and improved distribution of individual retail cuts in that each cut could be sent to its highest demand area.

Color is one of the most important factors determining the acceptance of frozen products. Since the bright red color of oxymyoglobin has been identified with fresh, wholesome meat, the consumer relies on the color criterion as a basis for acceptance or rejection. If the color of the meat is not acceptable, there is no point in considering other factors, such as flavor, tenderness, texture, nutritional value, etc.

A wide variation is found in retail stores with regard to meat display case lighting type and intensity. The appropriate source of illumination and the correct intensity level to avoid accelerated darkening of the bright oxymyoglobin pigment should be developed.

This study was undertaken to investigate the effect of two different light sources, and various light intensity levels on display case color stability of beef steaks prepackaged in transparent film.

EXPERIMENTAL PROCEDURES

Sample Selection, Preparation and Display.

Beef loins were purchased at a commercial packing company. Each of the eight replications consisted of paired beef loins, selected to have a "small" *longissimus dorsi* marbling score at the twelfth rib. Ten steaks from each loin pair, each 2.54 cm thick, were randomly assigned to one of ten treatments which consisted of all possible combinations of two light sources: fluorescent (Deluxe Cool White) and incandescent with a Holophane Prismatic Reflectance fixture (Holophane Company, Inc., 1963), and five display light intensities (0, 807, 1076, 1614, and 3228 lm/m^2) at product level. Steaks were required to have a *psoas major* muscle large enough to cover the aperture of the reflectance spectrophotometer.

Other factors such as bloom time, freezing rate, display temperature, and packaging material were carefully standardized for all steaks.

After cutting, steaks were held at room temperature for at least 30 minutes to develop the bright-red oxymyoglobin pigment before being frozen.

The freezer chamber of a liquid nitrogen simulator freezer was pre-chilled to -18°C, before placing steaks on the freezing rack. The system was programmed to go through the following cycle: -18°C for 1/2 min, -60°C for 1/2 min, -87°C for 1 min, -115.7°C for 1 min, -143°C for 1 min, and allow to temper for another 1 minute. Timing at each temperature was begun when chamber temperature reached the prescribed level; consequently the total cycle time was eight to nine minutes. Following the freezing cycle, steaks were allowed to obtain a bright-red surface color again before being packaged.

Skin-tight, transparent packaging material was used. The Iolon/ Iolon (Dupont) film used has a permeability of 4,652-7,752 cc/ m^2/ 24 hrs. (300-500 cc/100 sq. in./ 24 hrs). This permeability is given for room temperature (21°C) and is not available for sub-freezing temperatures.

The open top display case temperatures were maintained at -21°C at the product level and cases were set to defrost twice in a 24 hour period. Product surface temperature never rose above -9.4°C (fluorescent, 3228 lm/m^2) and -7.7°C (incandescent, 3228 lm/m^2), during the defrost cycle. It took from two hours and 40 minutes to three hours for the product to return to its original temperature after initiation of defrost. The air temperature returned to its original level in from 50 min to three hours after initiation of defrost cycle.

Color Determinations.

Subjective color scores and objective color determinations

were taken over a period of 42 days, at the following intervals: immediately post-freezing (Day 0), 24 hours later (Day 1), and after frozen display for 3, 7, 21, and 42 days.

Subjective color score (both the longissimus dorsi and the psoas major) for each steak at each time period was determined under both lighting systems, regardless of display lighting used. All steaks were scored at the same light intensity, namely 1076 lm/m^2 to the nearest 0.5 point on the following scale; 1. very bright; 2. bright; 3. slightly dark; 4. dark; and 5. extremely dark.

A Bausch and Lomb 600 spectrophotometer with reflectance attachment was used to objectively measure the surface color changes. The apparatus was calibrated to read 100% reflectance with a block $MgCO_3$ skin-wrapped in the same packaging material as the cuts, in order to avoid effects due to packaging. Percent of reflectance was measured from 400 to 700 nm at a recording speed of 250 nm/ min. A black rubber gasket slightly larger than the aperture of the reflectance attachment was placed between the package and the reflectance sphere to insure a minimum effect from thawing during the color scan and to reduce the entrance of stray light.

Reflectance values were read to the nearest 0.1% at wavelengths of 474, 525, 572, 582, 600, 630, 650, and 685 nm.

Ratios of reflectance readings at 474/525, 572/525, 582/525, 630/525, 685/525, and 685/474 nm were calculated. Total area under the reflectance scans was measured as well as

areas under the blue portion (450 to 474 nm) and red portion (630 to 700 nm). Ratios of the red area/blue area were also calculated.

Statistical Procedures.

All data were subjected to a two-way analysis of variance and least-significance difference procedure, to detect differences in treatment means. Simple correlation coefficients were computed between the visual score for each reflectance reading, ratios, and areas. These were calculated separately for both the longissimus dorsi and the psoas major muscles and for light sources under which color score was determined.

RESULTS AND DISCUSSION

Display Temperature.

Beef steaks displayed under the incandescent source were subjected to higher surface temperature (Figure 1) than beef steaks displayed under the fluorescent light (Figure 2). Steaks displayed under 3228 lumen/meter^2 (lm/m^2) incandescent, went from -12°C up to -6.5°C during the defrost cycle, whereas the fluorescent-display steaks had a maximum temperature of -9.5°C. Even under 0 light intensity, the incandescent case was about 3°C warmer so adjustment of case temperature was not entirely satisfactory.

Displaying steaks under 1614, 1076, and 807 lm/m^2 did not increase surface temperature noticeably for either of the display

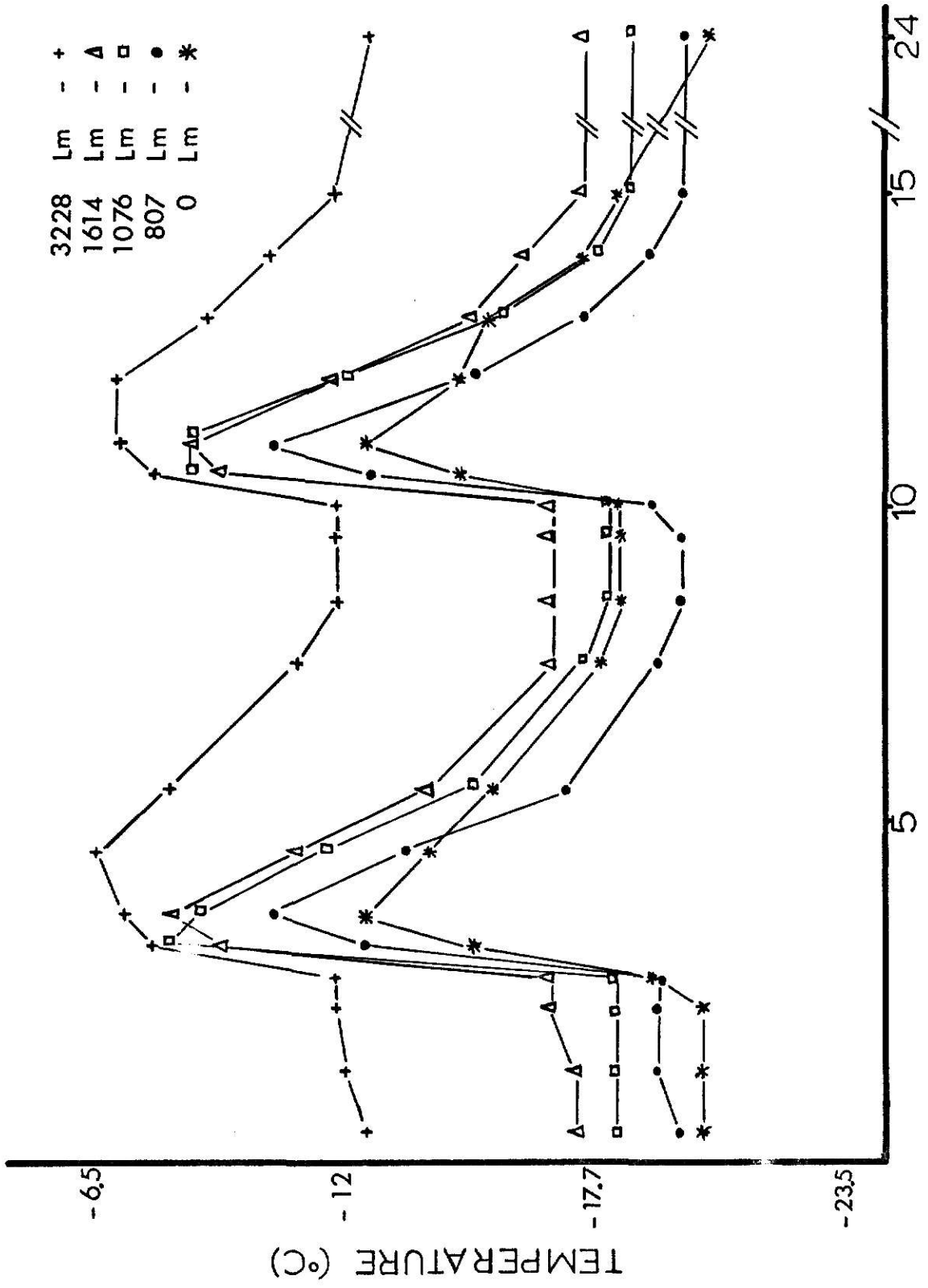


FIGURE 1. Time-surface temperature relationship for the case with the incandescent source.

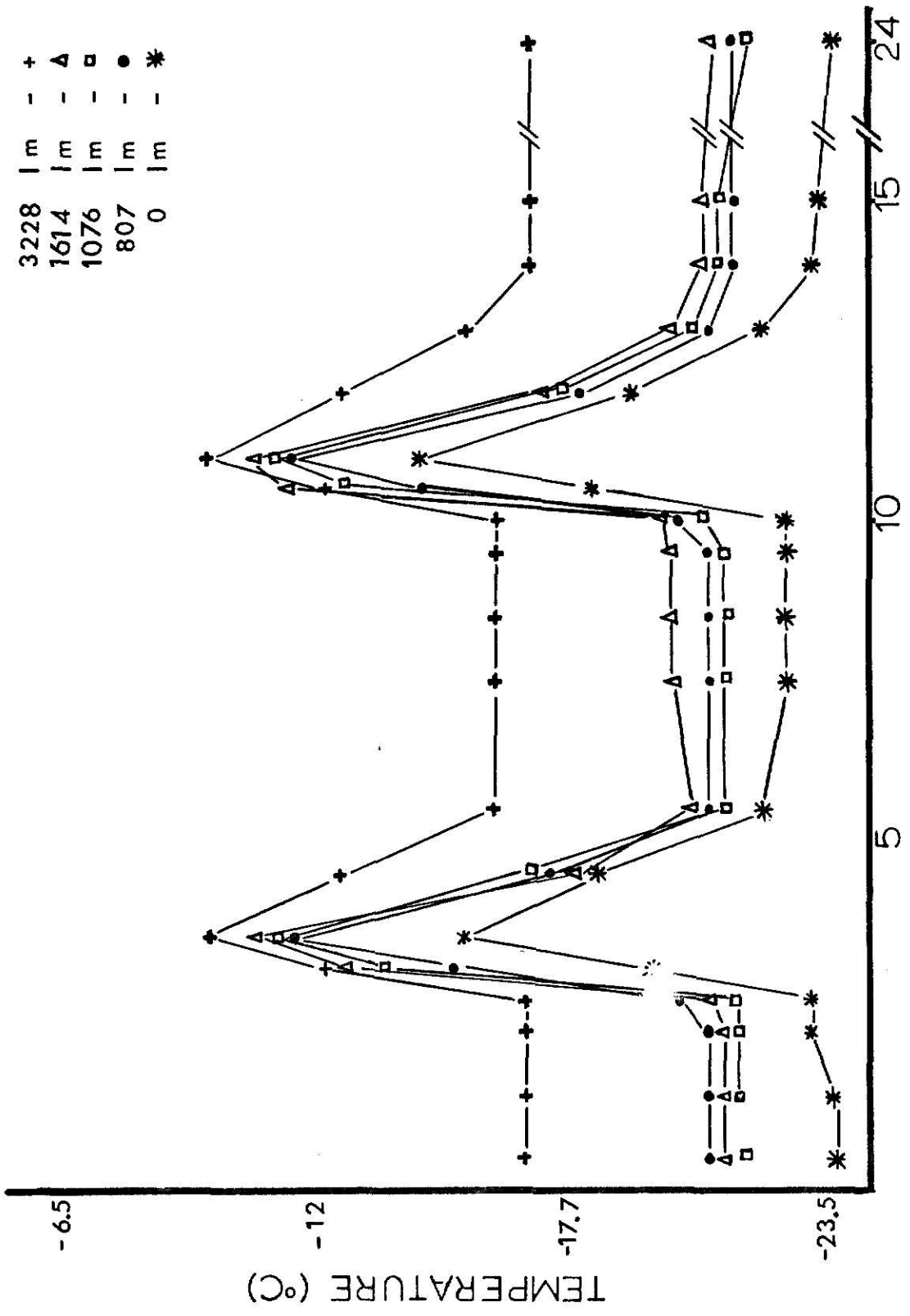


FIGURE 2. Time-surface temperature relationship for the case with the fluorescent source.

sources. Steaks displayed in the dark showed the lowest surface temperature, as expected. Display at 3228 lm/m^2 resulted in the greatest elevation of temperature, roughly $7^{\circ}C$ above dark-display steak temperature in both cases.

Light Source.

Mean visual scores for the longissimus dorsi and psoas major muscles are presented in Table 1. When longissimus dorsi muscles were visually scored under the same lighting they were displayed under, no difference was noted between steaks displayed under incandescent (Holophane Prismatic Reflectance fixture) or Deluxe Cool White fluorescent at 0 time and after 3 or 7 days of display. Those displayed under incandescent were brighter after 1 and 21 days of display and those under fluorescent were brighter after 42 days.

This effect was questioned because the incandescent lighting may have masked color deterioration. Consequently, all steaks were also scored under the opposite lighting system. All color scoring was at light intensity of 1076 lm/m^2. Steaks displayed under fluorescent lighting and scored under incandescent lighting had a brighter color at each time period than those displayed under incandescent and scored under fluorescent. Results for the psoas major color evaluation are similar.

This suggests that fluorescent lighting caused less color deterioration in frozen beef steaks. However, the incan-

Table 1. Mean visual score[1] values of frozen beef longissimus dorsi and psoas major muscles at all time periods[2]

	TIME (DAYS)					
	0	1	3	7	21	42
Longissimus dorsi						
Display lighting[3]						
Incandescent-I I-	1.62	1.31^{a}	1.66	2.03	2.97^{a}	3.36^{a}
Fluorescent -F F-	1.63	1.42^{b}	1.70	2.12	3.17^{b}	3.11^{b}
Evaluation lighting[4]						
Incandescent-F I-	1.28^{a}	1.08^{a}	1.50^{a}	1.85^{a}	2.73^{a}	2.90^{a}
Fluorescent -I F-	1.96^{b}	1.65^{b}	1.85^{b}	2.30^{b}	3.41^{b}	3.58^{b}
Psoas major						
Display lighting						
Incandescent-I I-	2.34	2.30	2.63	2.94	3.75	4.10^{a}
Fluorescent -F F-	2.34	2.26	2.50	3.03	3.86	3.96^{b}
Evaluation lighting						
Incandescent-F I-	1.99^{a}	2.00^{a}	2.44^{a}	2.80^{a}	3.44^{a}	3.76^{a}
Fluorescent -I F-	2.70^{b}	2.45^{b}	2.68^{b}	3.18^{b}	4.17^{b}	4.30^{b}

[1] 1 = very bright red, 5 = extremely dark.

[2] Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

[3] Steaks visually scored under display light at 1076 lm/m^2.

[4] Steaks visually scored under opposite lighting (not display light) at 1076 lm/m^2.

descent source resulted in a brighter color when visually appraised. Hansen and Sereika (1969) indicated that illumination of prepackaged frozen meat accelerated deterioration of color but this rate of deterioration is essentially the same for fluorescent or incandescent light sources. These findings do not concur with what was found in the present study.

The accelerated color deterioration of steaks displayed under incandescent lighting may have been due to the elevated product surface temperatures.

A summary of percent reflectance at 630 nm is presented in Tables 2 and 3. At 0 and 1 day steaks displayed under fluorescent lighting showed greater reflectance at this wavelength and a trend is shown in the same direction after 3 and 7 days. Higher reflectance at 630 nm indicated less metmyoglobin since Hansen and Sereika (1969) reported greater absorbancy at 630 nm to be related to more metmyoglobin.

Ultraviolet radiation, wavelengths shorter than 400 nm, emitted by the Deluxe Cool White fluorescent source, was reported to be around 75 microwatts per lumen (Thorington and Parascandola, 1967). Incandescent sources are regarded as very low emitters of U. V. radiation; in fact less than 0.1% of the input wattage (I.E.S., 1966).

Most infrared radiation is in the near part of the spectrum (shorter wavelength) with relatively little in the far infrared, for the incandescent source (I.E.S., 1966).

Table 2. The effect of display lighting type and intensity on percent reflectance at 630nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	30.04^{a}	26.86^{a}	26.78	24.26	21.48	20.10
Fluorescent (F)	32.28^{b}	30.00^{b}	28.13	25.15	20.28	19.86
0[2]	32.47	38.81^{c}	38.25^{c}	37.27^{c}	31.50^{c}	29.92^{b}
807	29.10	29.09^{b}	26.18^{b}	24.23^{b}	20.78^{b}	17.91^{a}
1076	30.36	26.38^{ab}	24.77^{ab}	20.74^{a}	17.05^{a}	17.85^{a}
1614	31.45	25.00^{a}	25.50^{a}	22.10^{ab}	18.37^{ab}	18.21^{a}
3228	32.39	22.87^{a}	22.60^{a}	19.18^{a}	16.71^{a}	16.02^{a}
I x 0	31.59	36.62	36.75	37.93	33.37	30.36^{c}
I x 807	25.72	26.18	27.12	24.68	21.62	18.95^{ab}
I x 1076	30.35	25.71	25.98	21.31	18.30	19.46^{ab}
I x 1614	30.85	22.81	23.18	19.50	18.37	15.85^{a}
I x 3228	31.68	23.00	20.87	17.87	15.75	15.91^{a}
F x 0	33.36	41.00	39.75	36.61	29.62	29.47^{c}
F x 807	32.48	32.00	25.25	23.78	19.93	16.88^{ab}
F x 1076	30.38	27.06	23.56	20.17	15.81	16.23^{a}
F x 1614	32.06	27.08	27.81	24.70	18.37	20.57^{b}
F x 3228	33.09	22.75	24.31	20.48	17.68	16.13^{a}

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P<0.05$).

[2]Light intensity in lumens/meter^{2}

Table 3. The effect of display lighting type and intensity on percent reflectance at 630nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	26.15	18.14	17.80	16.42	16.40	14.60
Fluorescent (F)	26.72	19.90	19.17	17.12	15.30	13.74
0[2]	25.10	22.50^{b}_{ab}	23.12^{c}_{b}	22.98^{b}	21.87^{c}	17.86^{b}_{a}
807	27.12	19.25_{a}	19.03_{ab}	16.78^{a}	15.68^{b}	13.48_{a}
1076	26.92	18.17_{ab}	16.72_{a}	14.34^{a}	14.78^{ab}	12.08_{a}
1614	26.31	18.90_{a}	16.43_{ab}	15.08^{a}	13.60^{ab}	13.88_{a}
3228	26.73	16.28	17.12	14.67^{a}	13.32^{a}	14.55^{a}
I x 0	24.27	20.62	20.93	22.18	22.37	16.88
I x 807	27.41	18.43	18.81	17.62	16.31	13.81
I x 1076	27.80	16.47	16.32	13.56	14.87	13.08
I x 1614	27.03	18.50	16.43	14.50	13.96	15.12
I x 3228	24.25	16.68	16.50	14.25	14.50	14.10
F x 0	25.93	24.37	25.31	23.78	21.37	18.85
F x 807	26.83	20.06	19.25	15.94	15.06	13.16
F x 1076	26.05	19.87	17.12	15.12	14.68	11.07
F x 1614	25.60	19.31	16.43	15.67	13.25	12.63
F x 3228	29.22	15.87	17.75	15.10	12.15	13.00

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

[2]Light intensity in lumens/meter^2

Radiation amounting to 70% is emitted as infrared and 10% as light (General Electric Company. No date). The energy of the Deluxe Cool White fluorescent lamp includes 36% emitted as infrared radiation and 22% as light output. The rest, 42%, is dissipated as heat.

The smooth curve of the fluorescent source represents the light resulting from phosphorus excitation. Some visible light is generated directly by the mercuric arc, and the bars added to the top of the cu show where this energy is concentrated (Figure 3). Thi urce is high in yellow and somewhat lacking in red, but would have a predominant spectral output near the blue end of the spectrum (General Electric Company, 1970).

Tungsten-incandescent sources are quite deficient in blue, nevertheless are well-balanced to accentuate meat color. The Holophane fixture filters out a large portion of wavelengths between 550 and 650 nm; hence, there should be a larger proportion of wavelengths emitted at 540 to 610 by the fluorescent source. The apparent lack of harmful effect on meat color stability of the fluorescent source, is not in agreement with Townsend and Bratzler (1958) who reported that beef steaks displayed under fluorescent light at wavelengths of 560 to 630 nm were subjected to an accelerated discoloration.

Intensity.

Display light intensity at different levels (Tables 4 and 5)

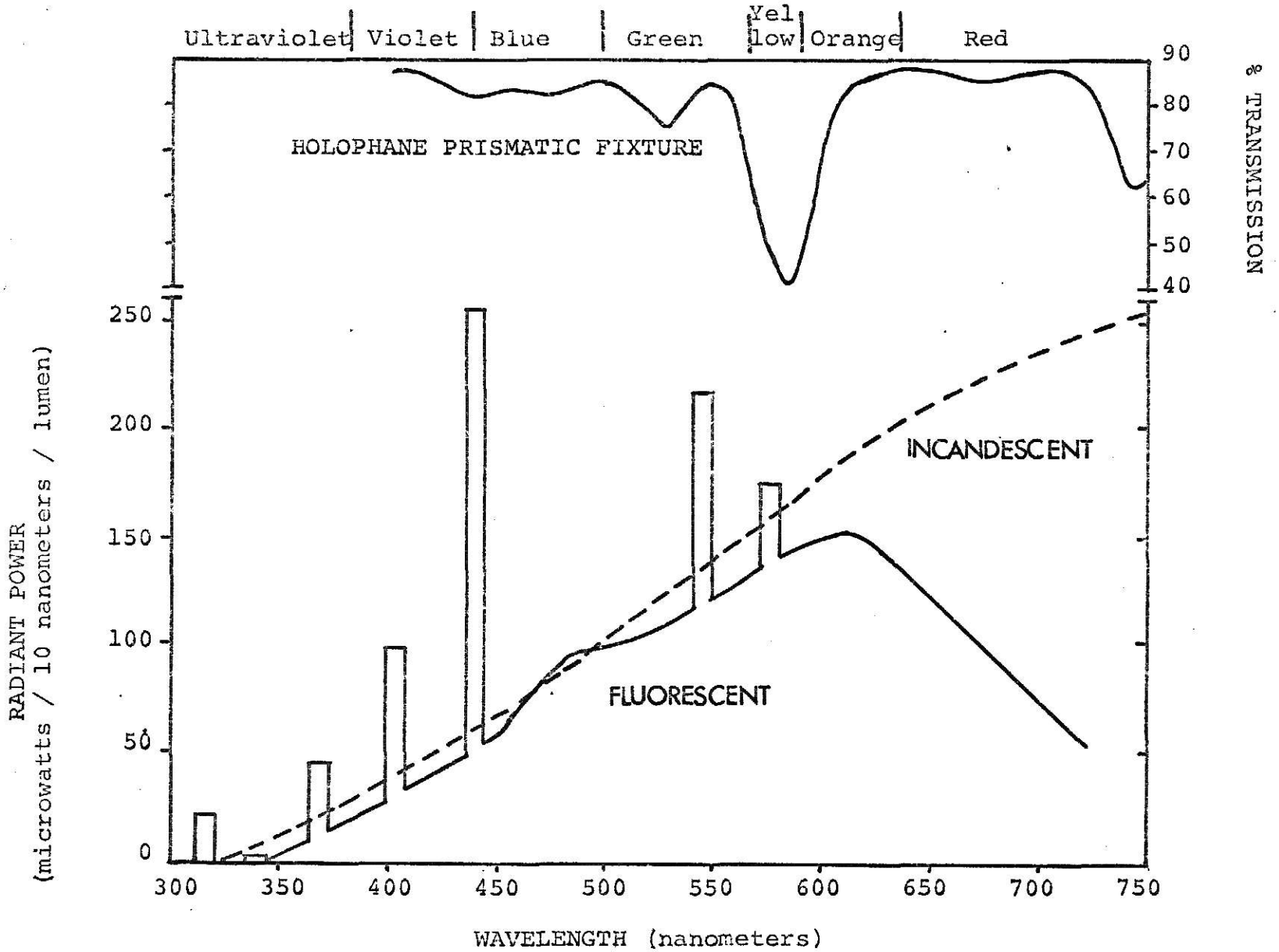


Figure 3. Approximate energy distribution of deluxe cool white fluorescent and incandescent lamps and percent transmission of light by Holophane Prismatic Reflectance Fixture.

Table 4. Effect of display lighting on visual score of frozen beef *longissimus dorsi* muscle (mean value)[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Intensity						
0[2]	1.65	0.70^{a}	0.92^{a}	0.84^{a}	0.81^{a}	1.06^{a}
807	1.67	1.28^{b}	1.65^{b}	2.21^{b}	3.30^{b}	3.56^{b}
1076	1.62	1.48^{c}	1.81^{c}	2.18^{b}	3.40^{b}	3.68^{b}
1614	1.64	1.53^{c}	1.84^{c}	2.32^{b}	3.70^{c}	3.82^{c}
3228	1.54	1.86^{d}	2.17^{d}	2.81^{c}	4.17^{d}	4.06^{d}
Display lighting x Intensity						
I x 0	1.65	0.71^{a}	0.96^{a}	0.71^{a}	0.84^{a}	1.18
F x 0	1.65	0.68^{a}	0.87^{a}	0.96^{a}	0.78^{a}	0.93
I x 807	1.65	1.31^{b}	1.60^{bc}	2.00^{cd}	2.87^{b}	3.65
F x 807	1.68	1.26^{b}	1.71^{b}	2.43^{b}	3.71^{d}	3.46
I x 1076	1.62	1.34^{bc}	1.65^{de}	2.06^{c}	3.10^{c}	3.75
F x 1076	1.62	1.62^{d}	1.96^{cd}	2.31^{c}	3.68^{d}	3.62
I x 1614	1.62	1.53^{cd}	1.87^{bcd}	2.31^{cd}	3.68^{d}	3.93
F x 1614	1.65	1.53^{cd}	1.81^{f}	2.34^{e}	3.71^{d}	3.71
I x 3228	1.56	1.68^{d}	2.21^{e}	3.06^{d}	4.37^{f}	4.28
F x 3228	1.53	2.03^{e}	2.12^{e}	2.56^{d}	3.96^{e}	3.84

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

[2]Light intensity in lumens/meter^2

I = Incandescent, F = Fluorescent (Deluxe Cool White)

Table 5. Effect of display lighting on visual score of frozen beef psoas major muscle (mean value)[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Intensity						
0[2]	2.26	1.92^{a}	1.95^{a}	2.20^{a}	2.11^{a}	2.01^{a}
807	2.35	2.18^{b}	2.46^{b}	2.87^{b}	3.94^{b}	4.32^{b}
1076	2.40	2.20^{bc}	2.62^{b}	3.01^{c}	4.12^{b}	4.45^{bc}
1614	2.32	2.35^{c}	2.73^{b}	3.31^{d}	4.37^{c}	4.60^{c}
3228	2.36	2.48^{d}	3.04^{c}	3.53	4.50^{c}	4.78^{d}
Display lighting x Intensity						
I x 0	2.31	1.96^{a}	2.00	2.21^{a}	2.03^{a}	2.10
F x 0	2.21	1.87^{a}	1.93	2.18^{a}	2.18^{a}	1.93
I x 807	2.31	2.18^{bc}	2.34	2.65^{b}	3.56^{b}	4.34
F x 807	2.40	2.18^{b}	2.56	3.10^{c}	4.31^{d}	4.31
I x 1076	2.34	2.12^{bc}	2.65	2.93^{c}	3.93^{c}	4.50
F x 1076	2.46	2.28^{c}	2.60	3.10^{d}	4.31^{d}	4.40
I x 1614	2.34	2.40^{bc}	2.81	3.31^{d}	4.43^{d}	4.71
F x 1614	2.31	2.31^{bc}	2.65	3.31^{e}	4.31^{d}	4.50
I x 3228	2.40	2.31^{d}	3.34	3.60^{de}	4.81^{e}	4.87
F x 3228	2.31	2.65	2.75	3.46	4.18^{d}	4.68

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

[2]Light intensity in lumens/meter^{2}

I=Incandescent, F=Fluorescent (Deluxe Cool White)

significantly ($P < 0.01$) affected the visual score of the longissimus dorsi muscle from day 1 up to day 42. At all time periods, the brightest visual score was noted for steaks displayed at 0 lm/m^2 intensity whereas those at 3228 lm/m^2 showed a rapid increase in the visual score, from 1.54 to 4.06 (longissimus dorsi) and from 2.36 to 4.78 (psoas major). Color value for steaks stored in the dark display remained quite constant for the entire 42-day display period. Furthermore, these two intensities deviated significantly from 807, 1076 and 1614 lm/m^2. In general, 807 and 1076 were not different nor were 1076 and 1614, but 807 and 1614 lm/m^2 presented variations in all time periods with greater color deterioration at the higher intensity. The same pattern was found for the psoas major muscle.

Reflectance at 630 nm (Tables 2 and 3) generally substantiates visual score results since steaks at 0 light intensity reflected more light at 630 nm and those at higher lighting intensity tended to have less reflectance at this wavelength.

Reported evidence is in agreement with data presented by Voegeli (1952), Townsend and Bratzler (1958), and Hansen and Sereika (1969) who stated that samples kept in dark storage remained unchanged. Levels of illumination above 2152 lm/m^2 (200 fc) caused rapid degradation of frozen meat color as noted by Hansen and Sereika (1969).

Significant interactions between lighting type and inten-

sity with respect to visual score were calculated at 1, 3, 7 and 21 days for the longissimus dorsi and at 1, 7 and 21 days for the psoas major. Muscles displayed under incandescent lighting tended to have brighter scores with lower intensity illumination (807, 1076 lm/m^2) whereas they had darker scores under the highest lighting intensity. Reflectance at 630 nm generally did not show this difference.

Percent Reflectance Changes with Display Time.

Means for various objective measurements at each time period are presented in Tables 6 and 7. Reflectance values at 630 and 650 nm for the longissimus dorsi and psoas major, presented a decrease from day 0 to day 42. These lower values at the end of the display period may indicate larger proportions of metmyoglobin. Mean percent reflectance at 474, 525, and 572 nm did not change much from time period to time period while that at 582 nm tended to increase with display time.

Ratio of reflectance at 630/525 nm showed a progressive decline of the mean values through the display period. The values for the ratios 572/525 nm and 582/525 nm presented an increase from day 0 to day 42. Hansen and Sereika (1969) stated that the absorbancy ratio 630/525 nm would indicate the amount of oxymyoglobin being converted to metmyoglobin, therefore a declining reflectance ratio also indicates this change. The other ratios (572/525 nm and 582/525 nm) were

Table 6. Effect of display time on beef longissimus dorsi muscle mean value for all variables

	TIME (DAYS)					
	0	1	3	7	21	42
Percent Reflectance						
474	8.51±2.18[a]	10.58±2.97	11.24±2.81	10.01±2.84	10.07±2.34	10.03±3.28
525	9.74±2.35	10.07±2.92	11.32±2.75	10.72±2.85	8.93±2.20	10.22±3.36
572	7.45±1.87	9.52±2.27	10.41±2.50	9.85±2.38	10.05±2.43	10.94±3.83
582	6.68±1.57	8.52±2.00	9.51±2.63	10.28±2.97	9.39±2.54	10.68±3.80
600	19.20±4.35	21.19±6.35	21.43±5.10	19.80±5.93	17.75±4.91	10.77±5.65
630	31.16±5.15	28.41±8.64	27.50±7.81	24.70±8.43	20.88±6.83	10.98±6.85
650	35.29±4.87	32.68±9.12	31.03±8.51	28.93±8.73	24.32±7.25	22.85±7.21
685	39.81±4.95	44.57±7.84	46.13±6.96	43.27±7.37	40.36±6.94	38.29±8.32
Reflectance scan area[b]						
Blue	0.15±0.03	0.16±0.04	0.18±0.10	0.16±0.04	0.17±0.04	0.17±0.05
Red	2.39±0.31	2.50±0.50	2.64±0.50	2.31±0.45	2.03±0.35	2.14±0.75
Total	4.65±0.77	5.12±1.14	5.14±0.99	4.69±1.01	4.37±0.93	4.25±1.14
474/525	0.87±0.10	0.97±0.06	0.99±0.06	0.93±0.07	1.02±0.06	0.98±0.03
572/525	0.76±0.07	0.88±0.05	0.92±0.06	0.92±0.08	1.02±0.10	1.07±0.11
685/474	4.86±0.89	4.33±0.66	0.25±0.85	4.46±0.70	4.09±0.63	3.97±0.82
630/525	3.27±0.47	2.62±0.49	2.50±0.80	2.31±0.53	2.13±0.56	1.98±0.46
582/525	0.69±0.09	0.79±0.07	0.84±0.18	0.97±0.20	0.96±0.15	1.04±0.14
685/525	4.21±0.64	4.22±0.68	4.22±0.91	4.15±0.66	4.19±0.66	3.98±0.78
Red/Blue	16.51±3.31	15.74±3.86	16.52±4.74	14.28±3.33	12.47±2.79	12.80±4.50

[a] Mean and standard deviation, respectively.

[b] 1 = 6.25 cm^2

Table 7. Effect of display time on beef psoas major muscle mean value for all variables

	TIME (DAYS)					
	0	1	3	7	21	42
Percent Reflectance						
474	8.07±2.51[a]	9.12±6.83	8.56±1.85	7.53±2.09	8.17±2.58	7.80±2.46
525	9.01±2.67	9.40±6.80	8.71±1.80	8.12±2.25	8.08±2.50	8.05±2.47
572	6.93±2.11	8.58±6.76	8.13±1.74	7.50±2.09	8.11±2.71	8.48±2.90
582	6.38±1.81	7.53±2.08	7.75±1.67	7.64±1.90	7.81±2.70	8.24±2.98
600	16.17±4.48	14.60±10.05	13.80±2.95	12.70±3.56	13.08±2.76	11.67±3.31
630	26.44±4.86	19.00±5.60	18.50±4.40	16.77±5.26	15.85±4.67	14.17±3.64
650	29.71±5.13	21.90±6.06	21.12±4.93	19.37±5.76	18.35±4.97	16.21±3.89
685	34.73±5.03	30.29±5.73	31.21±5.04	29.67±5.23	29.63±5.57	28.47±4.29
Reflectance scan area[b]						
Blue	0.13±0.04	0.13±0.04	0.14±0.03	0.13±0.03	0.13±0.04	0.14±0.05
Red	2.03±0.30	1.74±0.35	1.83±0.34	1.58±0.41	1.60±0.32	1.49±0.27
Total	4.04±0.78	4.20±4.67	3.64±0.66	3.37±0.76	3.45±0.90	3.16±0.74
474/525	0.89±0.10	0.96±0.04	0.98±0.04	0.92±0.05	1.01±0.05	0.96±0.05
572/525	0.77±0.05	0.91±0.05	0.93±0.04	0.92±0.09	1.00±0.08	1.04±0.09
685/474	4.50±0.81	3.67±0.64	3.77±0.83	4.06±0.67	3.80±0.82	3.86±0.91
630/525	3.02±0.46	2.19±0.46	2.18±0.59	2.08±0.44	2.01±0.51	1.81±0.45
582/525	0.71±0.08	0.86±0.16	0.88±0.06	0.94±0.09	0.96±0.10	1.01±0.13
685/525	3.99±0.59	3.54±0.59	3.69±0.76	3.75±0.55	3.83±0.82	3.71±0.80
Red/Blue	15.52±3.85	13.19±3.17	13.57±4.97	12.07±3.15	12.22±3.12	11.46±3.30

[a] Means and standard deviation, respectively.

[b] 1 = 6.25 cm^2

calculated as suggested by Snyder and Armstrong (1967) and Hansen and Sereika (1969) respectively, and should indicate an increase in the concentration of metmyoglobin.

Reflectance scan areas indicate greater or lesser light reflectance in blue and red areas of the spectrum and it was felt that total scan area should be related to lightness or darkness of muscle. A slight decrease in red reflectance was noted with increasing time and total light reflectance tended to decrease in the psoas major but this trend is not apparent for the longissimus dorsi muscle samples. Means of other objective color measurements for the psoas major muscle disclosed the same pattern as the longissimus dorsi.

These results are in agreement with those reported by Kropf et al. (1970) who stated that reflectance at no wavelength studied under 600 nm was significantly correlated to visual score, but wavelengths from 610 to 700 nm were equally correlated to visual score (r from -0.58 to -0.66). A darker color evidenced less reflected light at higher wavelengths.

A correlation coefficient of 0.87 between percent reflectance at 685 nm and visual score for beef was reported by Ockerman and Cahill (1969). Results of this study do not support this high correlation as reflectance at 685 did not change much as discoloration increased. Pirko and Ayres (1957) indicated that minimal reflectance at 635 nm (maximal metmyoglobin content) coincided with higher reflectance readings

for myoglobin and for oxymyoglobin (lower content of these two pigments). Franke and Solberg (1970) have directly related the height of the absorbance peak at 632 nm to metmyoglobin concentration. Furthermore, reflectance minima for metmyoglobin were reported by Ginger *et al.* (1954), at 635 nm which may substantiate the findings of the present study in regard to highest correlations scores being at 630-650 nm percent reflectance.

Visual Score Correlations.

The highest correlation coefficients between visual score values and percent of reflectance appear to be found at wavelengths of 630 nm and 650 nm, for both muscles (*longissimus dorsi* and *psoas major*) at most time periods, as presented in Tables 8 and 9.

The reflectance ratios 630/525 nm and 582/525 nm generally presented the highest correlations with the visual scores for the *psoas major* muscle. However, similar correlations were low and lacking in significance for the reflectance ratios of the *longissimus dorsi* muscle. All correlations generally were low at day 0 when little color variation exists.

In general, reflectance values lower than 600 nm were insensitive to color deterioration. A gradual decrease in reflectance of values above 600 nm was noted as discoloration proceeded. This is in accordance with research reported by Allen and associates (1969) working with fresh beef *longissimus dorsi* muscle. These workers also found that the ratio 474/525 nm

Table 8. Correlation coefficients between visual score and objective color measurements of frozen beef longissimus dorsi muscle

	DAY 0				DAY 1			
	LIGHTING				LIGHTING			
	I I[a]	F F	F I	I F	I I[a]	F F	F I	I F
Percent Reflectance								
474	-0.16	-0.21	-0.16	0.02	-0.27	-0.34	-0.56**	-0.04
525	-0.16	-0.19	-0.24	0.04	-0.24	-0.34	-0.56**	-0.04
572	-0.06	-0.20	-0.17	0.05	-0.21	-0.34	-0.53**	-0.03
582	0.01	-0.20	-0.13	0.31	-0.26	-0.26	-0.52**	-0.06
600	-0.25	-0.20	-0.25	0.04	-0.35	-0.46**	-0.64**	-0.10
630	-0.34	-0.22	-0.31	0.03	-0.44*	-0.51**	-0.67**	-0.09
650	-0.30	-0.20	-0.31	0.06	-0.44*	-0.52**	-0.69**	-0.11
685	-0.31	-0.18	-0.31	0.05	-0.56**	-0.53**	-0.69**	-0.20
Reflectance scan area								
Blue	0.05	-0.12	-0.15	0.20	-0.09	-0.31	-0.48**	0.07
Red	-0.30	-0.21	-0.35	-0.03	-0.53**	-0.45*	-0.60**	-0.15
Total	-0.32	-0.23	-0.31	-0.00	-0.38*	-0.45*	-0.65**	-0.08
474/525	-0.05	-0.01	0.27	-0.02	-0.08	-0.09	-0.09	-0.03
572/525	0.15	-0.01	0.31	0.02	0.27	0.15	0.35	0.08
685/474	0.06	0.12	-0.03	0.00	-0.12	-0.01	0.11	-0.12
630/525	-0.06	-0.02	0.28	-0.02	-0.08	-0.10	-0.09	-0.03
582/525	0.22	0.06	0.44*	0.37*	0.14	0.39*	0.32	0.02
685/525	0.06	0.12	0.14	0.02	-0.13	-0.04	0.10	-0.13
Red/Blue	-0.25	-0.04	-0.09	-0.25	-0.21	0.01	0.12	-0.15

[a]1st letter designates display lighting, 2nd evaluation lighting, I = Incandescent F = Fluorescent (Deluxe Cool White).
*P < 0.05, **P < 0.01.

Table 8 (cont.). Correlation coefficients between visual score and objective color measurements of frozen beef longissimus dorsi muscle

	DAY 3				DAY 7			
	LIGHTING				LIGHTING			
	I I[a]	F F	F I	I F	I I[a]	F F	F I	I F
Percent Reflectance								
474	-0.14	-0.30	-0.57**	-0.38*	-0.23	-0.50**	-0.50**	-0.34
525	-0.17	-0.25	-0.55**	-0.42*	-0.26	-0.53**	-0.51**	-0.39*
572	-0.10	-0.26	-0.55**	-0.40*	-0.26	-0.42*	-0.46**	-0.36*
582	-0.05	-0.25	-0.48**	-0.31	-0.29	-0.33	-0.33	-0.33
600	-0.31	-0.35	-0.62**	-0.41*	-0.32	-0.60**	-0.58**	-0.31
630	-0.44*	-0.45*	-0.63**	-0.50**	-0.48**	-0.66**	-0.61**	-0.49**
650	-0.44*	-0.44*	-0.62**	-0.53**	-0.45*	-0.62**	-0.56**	-0.51**
685	-0.49**	-0.34	-0.55**	-0.49**	-0.33	-0.64**	-0.55**	-0.34
Reflectance scan area								
Blue	-0.07	-0.07	-0.14	-0.38*	-0.09	-0.47**	-0.50**	-0.23
Red	-0.53**	-0.35	-0.60**	-0.54**	-0.30	-0.65**	-0.61**	-0.54**
Total	-0.32	-0.33	-0.56**	-0.48**	-0.33	-0.41*	-0.57**	-0.51**
474/525	0.07	0.32	-0.35	-0.06	0.05	0.16	0.12	0.00
572/525	0.34	0.17	-0.07	0.17	0.21	0.41*	-0.27	0.32
685/474	-0.18	-0.75**	0.35	-0.44*	0.04	0.17	0.24	0.24
630/525	0.07	0.32	-0.35	-0.06	0.05	0.16	0.12	0.00
582/525	0.10	-0.22	0.35	0.71**	-0.06	0.16	0.16	0.05
685/525	-0.14	-0.75**	0.28	-0.45*	0.07	0.21	0.29	0.24
Red/Blue	-0.27	-0.41*	0.03	-0.35	-0.10	0.18	0.24	-0.13

[a]1st letter designates display lighting, 2nd evaluation lighting, I = Incandescent F = Fluorescent (Deluxe Cool White).
*P < 0.05, **P < 0.01.

Table 8 (concluded). Correlation coefficients between visual score and objective color measurements of frozen beef *longissimus dorsi* muscle

	DAY 21				DAY 42			
	LIGHTING				LIGHTING			
	I I[a]	F F	F I	I F	I I[a]	F F	F I	I F
Percent Reflectance								
474	-0.04	-0.30	-0.40*	-0.15	-0.40*	-0.08	-0.48**	-0.08
525	-0.04	-0.29	-0.43*	-0.14	-0.37*	-0.06	-0.45*	-0.05
572	0.03	-0.25	-0.35	-0.06	-0.34	-0.01	-0.39*	0.00
582	0.07	-0.30	-0.33	-0.06	-0.35	-0.02	-0.38*	0.00
600	-0.17	-0.44*	-0.50**	-0.22	-0.48**	-0.17	-0.50**	-0.26
630	-0.34	-0.44*	-0.52**	-0.30	-0.54**	-0.26	-0.60**	-0.35
650	-0.36*	-0.45*	-0.63**	-0.31	-0.58**	-0.27	-0.60**	-0.50**
685	-0.17	-0.40*	-0.60**	-0.07	-0.52**	-0.20	-0.40*	-0.42*
Reflectance scan area								
Blue	0.05	-0.30	-0.41*	0.06	-0.28	-0.01	-0.37*	0.04
Red	-0.25	-0.34	-0.50**	-0.30	-0.42*	0.26	-0.09	-0.36*
Total	-0.16	-0.36*	-0.54**	-0.17	-0.45*	-0.13	-0.50**	-0.23
474/525	-0.03	-0.06	0.02	-0.10	-0.23	-0.18	-0.31	-0.28
572/525	-0.19	-0.13	0.24	0.24	0.24	0.23	0.13	0.27
685/474	-0.06	0.00	0.02	0.13	0.27	-0.05	0.38*	0.02
630/525	-0.03	-0.06	0.03	-0.10	-0.23	-0.18	-0.31	-0.28
582/525	0.22	-0.01	0.17	0.11	0.13	0.19	0.14	0.13
685/525	-0.08	-0.02	0.04	0.10	0.20	-0.10	0.33	-0.12
Red/Blue	-0.10	0.06	0.01	-0.23	-0.10	-0.28	0.18	-0.40*

[a]1st letter designates display lighting, 2nd evaluation lighting, I = Incandescent F = Fluorescent (Deluxe Cool White).
*P < 0.05, **P < 0.01.

Table 9. Correlation coefficients between visual score and objective color measurements of frozen beef psoas major muscle

	DAY 0				DAY 1			
	LIGHTING				LIGHTING			
	I I[a]	F F	F I	I F	I I[a]	F F	F I	I F
Percent Reflectance								
474	-0.08	-0.45*	-0.22	0.00	-0.32	0.03	0.00	-0.26
525	-0.23	-0.40*	-0.16	0.07	-0.32	0.03	0.00	-0.25
572	-0.17	-0.37*	-0.15	0.03	-0.30	0.04	0.02	-0.25
582	-0.01	-0.39*	-0.17	-0.17	-0.29	-0.16	-0.32	-0.27
600	-0.10	-0.52**	-0.12	-0.22	-0.40*	0.01	-0.03	-0.36*
630	-0.17	-0.48**	-0.12	-0.25	-0.46**	-0.24	-0.40*	-0.40*
650	-0.13	-0.51**	-0.11	-0.22	-0.46**	-0.20	-0.42*	-0.41*
685	-0.18	-0.54**	-0.16	-0.17	-0.40*	-0.08	-0.36*	-0.33
Reflectance scan area								
Blue	0.02	-0.30	-0.14	-0.12	-0.15	0.00	-0.11	-0.23
Red	-0.15	-0.51**	-0.15	-0.27	-0.43*	-0.25	-0.50**	-0.42*
Total	-0.13	-0.45*	-0.15	-0.21	-0.05	-0.15	-0.39*	0.03
474/525	0.22	-0.43*	-0.31	-0.14	-0.09	0.06	0.13	0.15
572/525	0.21	-0.11	0.00	-0.15	0.25	0.23	0.34	0.01
685/474	-0.11	0.42*	0.21	-0.05	0.27	-0.11	-0.09	0.03
630/525	0.05	0.21	0.14	-0.30	-0.24	-0.38	-0.33	-0.47**
582/525	0.24	0.08	0.01	-0.29	0.38	-0.21	-0.15	0.01
685/525	0.09	0.26	0.10	-0.20	0.25	-0.10	-0.07	-0.02
Red/Blue	-0.09	0.07	0.11	-0.01	-0.13	-0.23	-0.32	-0.13

[a]1st letter designates display lighting, 2nd evaluation lighting, I = Incandescent F = Fluorescent (Deluxe Cool White).
*P < 0.05, **P < 0.01.

Table 9 (cont.). Correlation coefficients between visual score and objective color measurements of frozen beef psoas major muscle

	DAY 3				DAY 7			
	LIGHTING				LIGHTING			
	I I[a]	F F	F I	I F	I I[a]	F F	F I	I F
Percent Reflectance								
474	-0.08	0.01	0.02	0.25	-0.19	-0.20	-0.09	-0.08
525	-0.15	0.05	0.10	0.29	-0.22	-0.27	-0.19	-0.12
572	-0.10	0.15	0.15	0.24	-0.11	-0.18	-0.10	-0.07
582	-0.02	0.24	0.30	0.26	-0.21	-0.12	-0.06	-0.09
600	0.00	-0.06	-0.05	0.24	-0.40*	-0.34	-0.28	-0.33
630	-0.22	-0.36*	-0.42*	0.22	-0.56**	-0.48**	-0.40*	-0.39*
650	-0.25	-0.37*	-0.41*	0.19	-0.55**	-0.52**	-0.42*	-0.38*
685	-0.19	-0.08	-0.13	0.28	-0.53**	-0.40*	-0.34	-0.42*
Reflectance scan area								
Blue	-0.06	0.15	0.07	0.23	-0.12	-0.19	-0.06	-0.05
Red	-0.30	-0.14	-0.24	0.31	-0.48**	-0.43*	-0.37*	-0.30
Total	-0.16	-0.10	0.01	0.28	-0.35	-0.36*	-0.25	-0.23
474/525	0.36*	0.22	-0.22	0.36*	0.15	0.35	0.48**	0.16
572/525	0.24	0.10	0.16	0.25	0.16	0.49**	0.43*	0.04
685/474	0.12	-0.44*	-0.20	-0.79**	-0.13	-0.08	-0.17	-0.17
630/525	0.12	-0.35	-0.63**	-0.57**	-0.42*	-0.55**	-0.53**	-0.30
582/525	0.40*	0.12	0.40*	0.33	0.17	0.63**	-0.53**	0.25
685/525	0.21	-0.42*	-0.33	-0.77**	-0.08	0.04	-0.01	-0.12
Red/Blue	0.08	-0.24	-0.19	-0.55**	-0.27	-0.28	-0.40*	-0.13

[a]1st letter designates display lighting, 2nd evaluation lighting, I = Incandescent F = Fluorescent (Deluxe Cool White).
*$P < 0.05$, **$P < 0.01$.

Table 9 (concluded). Correlation coefficients between visual score and objective color measurements of frozen beef psoas major muscle

	DAY 21				DAY 42			
	LIGHTING				LIGHTING			
	I I[a]	F F	F I	I F	I I[a]	F F	F I	I F
Percent Reflectance								
474	-0.20	-0.03	-0.33	0.03	-0.32	-0.05	0.15	-0.35
525	-0.15	-0.04	-0.28	0.02	-0.32	-0.05	0.13	-0.37*
572	-0.14	0.02	-0.21	0.09	-0.28	0.08	0.30	-0.34
582	-0.13	0.00	-0.20	0.10	-0.26	0.02	0.18	-0.32
600	-0.29	-0.13	-0.46**	-0.07	-0.42*	-0.31	-0.10	-0.46**
630	-0.39*	-0.28	-0.57**	-0.23	-0.47**	-0.37*	-0.15	-0.56**
650	-0.43*	-0.28	-0.58**	-0.28	-0.52**	-0.38*	-0.22	-0.58**
685	-0.37*	0.05	-0.41*	-0.16	-0.51**	-0.36*	-0.15	-0.64**
Reflectance scan area								
Blue	-0.16	-0.11	-0.39*	-0.02	-0.19	0.12	0.34	-0.34
Red	-0.35	-0.38*	-0.60**	-0.24	-0.48**	-0.23	-0.04	-0.61**
Total	-0.42*	-0.20	-0.48**	-0.09	-0.40*	-0.20	0.02	-0.47**
474/525	-0.33	0.09	-0.20	0.00	0.02	0.36*	0.11	0.16
572/525	0.06	0.32	0.30	0.33	0.26	0.48**	0.57**	0.21
685/474	-0.08	0.07	0.12	-0.16	0.07	-0.36*	-0.30	-0.02
630/525	-0.45*	-0.34	-0.31	-0.54**	-0.24	-0.51**	-0.49**	-0.31
582/525	0.07	0.20	0.30	0.32	0.31	0.19	0.15	0.27
685/525	-0.20	0.09	0.03	-0.17	0.08	-0.24	-0.33	0.02
Red/Blue	-0.12	-0.21	0.00	-0.10	-0.15	-0.35	-0.43*	-0.05

[a]1st letter designates display lighting, 2nd evaluation lighting, I = Incandescent F = Fluorescent (Deluxe Cool White).
*P < 0.05, **P < 0.01.

tended to decline as the color of the fresh beef brightened and increased as color deteriorated, but this observation was not corroborated in this study.

SUMMARY

Display color stability of frozen beef longissimus dorsi and psoas major in transparent film was evaluated using two light sources (Deluxe Cool White fluorescent and incandescent with Holophane Prismatic Reflectance fixture) at five different intensity levels (0, 807, 1076, 1614 and 3228 lm/m^2). Color of the steaks was evaluated under the display lighting source and also under the opposite source. Subjective visual score and objective measurements (reflectance spectrophotometry) were recorded immediately after freezing and packaging and also after display at $-21^{\circ}C$ for 1, 3, 7, 21 and 42 days.

Fluorescent display lighting appeared to cause less discoloration on frozen beef longissimus dorsi and psoas major muscle. However, the incandescent source enhanced the appearance of frozen steaks and may have masked discoloration.

A display intensity of 3228 lm/m^2 was found to accelerate discoloration whereas 0 lm/m^2 resulted in excellent color stability. Intermediate intensities gave no appreciable difference between 807 and 1076 lm/m^2, nor 1076 and 1614 lm/m^2, but at 807 the steaks retained a more desirable color longer than at 1614 lm/m^2.

Interaction between lighting type and intensity with the incandescent source resulted in brighter visual scores after all display periods at lower levels of illumination (807 and 1076 lm/m^2) whereas the fluorescent source was superior at the highest intensity (3228 lm/m^2).

Correlation coefficients between visual score and percent reflectance were higher at wavelengths of 630 nm and up, for both muscles. Correlation coefficients between reflectance ratios and visual scores showed low values for the longissimus dorsi; however, generally high correlations were evident for the psoas major visual scores and percent of reflectance ratios at 582/525 nm and 630/525 nm. The reflectance scan of the red area showed consistent and negative correlations with the visual appraisal over the various display periods (the higher the red reflectance values, the brighter the color). Other areas and ratio of the area, percents of reflectance and reflectance ratios, were not consistently or strongly related to the visual scores.

LITERATURE CITED

Allen, C. C., Kropf, D. H., Tuma, H. J., Covington, R. L. and Grant, D. L. 1969. Bovine maturity and marbling effects on prepackaged longissimus dorsi color as measured by reflectance spectrophotometry. J. Anim. Sci. 29, 119. Abstract.

Franke, W. C. and Solberg, M. 1970. The quantitative determination of metmyoglobin and total pigment in an intact meat sample using reflectance photometry. IFT 30th Annual meeting, San Francisco. Abstract 126, pp. 111.

General Electric Company. No date. Incandescent lamps. Bulletin TP-110. pp. 23.

General Electric Company. 1970. Fluorescent lamps. Bulletin TP-111. pp. 9.

Ginger, I. D., Wilson, G. D. and Schweigert, B. S. 1954. Biochemistry of myoglobin. Quantitative determination in beef and pork muscle. J. Agri. Food Chem. 2, 1037.

Hansen, L. J. and Sereika, H. E. 1969. Factors affecting color stability of prepackaged frozen fresh beef in display cases. Illuminating Eng. 64, 620.

Holophane Company. 1963. Glass for lighting. Rep. LR 23.

I. E. S. 1966. Lighting and air conditioning. Illuminating Eng. 61, 124.

Kropf, D. H., Hunt, M. C. and Dayton, A. D. 1970. Reflectance spectrophotometry for following frozen beef and lamb color changes. J. Anim. Sci. 31, 185. Abstract.

Ockerman, H. W. and Cahill, V. R. 1969. Reflectance as a measure of pork and beef muscle tissue color. J. Anim. Sci. 28, 750.

Pirko, P. C. and Ayres, J. C. 1957. Pigment changes in packaged beef during storage. Food Technol. 11, 461.

Snyder, H. E. and Armstrong, D. J. 1967. An analysis of reflectance spectrophotometry as applied to meat and model systems. J. Food Sci. 32, 241.

Thorington, L. and Parascandola, L. J. 1967. Ultraviolet emission from light sources used as general illuminants. Illuminating Eng. 62, 674.

Townsend, W. E. and Bratzler, L. J. 1958. Effect of storage conditions on the color of frozen packaged retail beef cuts. Food Technol. 12, 663.

Voegeli, M. M. 1952. The measurement of fresh beef muscle color changes by disk colorimetry. Ph. D. thesis. Michigan State College, East Lansing, Michigan.

APPENDIX

APPENDIX A

Visual color score scale, time period identification, and treatment combinations

Visual Score

1. Very Bright
2. Bright
3. Slightly Dark
4. Dark
5. Extremely Dark

Time Periods

1. Frozen day 0
2. Frozen day 1
3. Frozen day 3
4. Frozen day 7
5. Frozen day 21
6. Frozen day 42

Treatment Combinations

1. Fluorescent - 0 lumen/meter^2
2. Fluorescent - 807 lumen/meter^2
3. Fluorescent - 1076 lumen/meter^2
4. Fluorescent - 1614 lumen/meter^2
5. Fluorescent - 3228 lumen/meter^2
6. Incandescent - 0 lumen/meter^2
7. Incandescent - 807 lumen/meter^2
8. Incandescent - 1076 lumen/meter2
9. Incandescent - 1614 lumen/meter^2
10. Incandescent - 3228 lumen/meter^2

APPENDIX B

List of the objective color measurements (*longissimus dorsi* and *psoas major*)

Percent Reflectance

1. 474 nm
2. 525 nm
3. 572 nm
4. 582 nm
5. 600 nm
6. 630 nm
7. 650 nm
8. 685 nm

Reflectance Ratios

9. 474/525
10. 572/525
11. 582/525
12. 630/525
13. 685/525
14. 685/474

Reflectance Scan Area

15. Total area (400-700 nm)
16. Blue area (450-474 nm)
17. Red area (630-700 nm)
18. Area ratio: Red area/Blue area

APPENDIX C-1

Mean square values for treatment effects on visual score of frozen beef *longissimus dorsi*

	TIME (DAYS)					
	0	1	3	7	21	42
Loin	1.68**	0.88**	0.75**	1.49**	0.87**	0.68**
Display lighting	0.001	0.45*	0.05	0.35	1.60**	2.37**
Intensity	0.07	5.85**	6.90**	12.25**	54.92**	48.54**
Evaluation lighting	18.56**	12.94**	4.90*	7.87**	18.22**	18.56**
Display x Intensity	0.005	0.30*	0.25*	1.04**	2.06**	0.11
Display x Evaluation	0.007	0.19	0.90**	0.20	2.50**	2.37**
Intensity x Evaluation	0.001	0.35**	0.46**	0.04	0.90**	0.13
Display x Int. x Evaluation	0.03	0.12	0.05	0.07	0.51**	0.49**
M.S. error	0.11	0.08	0.08	0.10	0.09	0.07

*$P < 0.05$, **$P < 0.01$.

APPENDIX C-2

Mean square values for treatment effects on visual score of frozen beef psoas major

	TIME (DAYS)					
	0	1	3	7	21	42
Loin	0.28*	0.09	0.67	0.70**	0.92**	1.14**
Display lighting	0.00	0.15	0.67	0.30	0.45	0.75**
Intensity	0.08	1.43**	5.06**	8.23**	30.42**	41.80**
Evaluation lighting	19.60**	8.10**	2.40*	6.00**	21.39**	11.55**
Display x Intensity	0.08	0.28*	0.69	0.38**	2.15**	0.04
Display x Evaluation	0.006	0.02	0.04	0.10	1.70**	0.40*
Intensity x Evaluation	0.06	0.09	0.10	0.11	0.71**	0.04
Display x Int. x Evaluation	0.03	0.04	0.65	0.18	0.92**	0.23*
M.S. error	0.10	0.10	0.37	0.10	0.13	0.09

*P < 0.05, **P < 0.01.

APPENDIX D-1

Effect of display and evaluation lighting on visual score of frozen beef *longissimus dorsi* muscle (mean values[1])

Light	TIME (DAYS) 0	1	3	7	21	42
Display x Evaluation						
Inc. x Inc.	1.26	1.00	1.41^{a}	1.77	2.51^{a}	2.90^{a}
Inc. x Fluor.	1.98	1.63	1.91^{c}	2.28	3.43^{c}	3.82^{c}
Fluor. x Inc.	1.31	1.17	1.60^{b}	1.93	2.96^{b}	3.90^{c}
Fluor. x Fluor.	1.95	1.67	1.80^{c}	2.31	3.38^{c}	3.33^{b}
Intensity x Evaluation lighting						
0 Inc.	1.31	0.56^{a}	0.68^{a}	0.68	0.56	0.68
0 Fluor.	2.00	0.84^{a}	1.15^{b}	1.00	1.06	1.43
807 Inc.	1.31	0.87^{a}	1.40^{c}	1.96	2.68	3.28
807 Fluor.	2.03	1.68^{cd}	1.90^{d}	2.46	3.90	3.84
1076 Inc.	1.31	1.12^{b}	1.78^{d}	1.93	3.00	3.37
1076 Fluor.	1.93	1.84^{d}	1.84^{d}	2.43	3.78	4.00
1614 Inc.	1.28	1.25^{b}	1.78^{d}	2.10	3.46	3.53
1614 Fluor.	2.00	1.81^{cd}	1.90^{d}	2.56	3.93	4.12
3228 Inc.	1.21	1.62^{c}	1.87^{d}	2.60	3.96	3.62
3228 Fluor.	1.87	2.09^{e}	2.46^{e}	3.03	4.37	4.50

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

APPENDIX D-2

Effect of display and evaluation lighting on visual score of frozen beef psoas major muscle (mean values[1])

Light	TIME (DAYS) 0	1	3	7	21	42
Display x Evaluation						
Inc. x Inc.	1.98	1.98	2.52	2.72	3.28^{a}	3.78^{a}
Inc. x Fluor.	2.70	2.41	2.73	3.16	4.22^{c}	4.42^{c}
Fluor. x Inc.	2.00	2.02	2.36	2.86	3.60^{b}	3.75^{a}
Fluor. x Fluor.	2.68	2.50	2.64	3.20	4.12^{c}	4.18^{b}
Intensity x Evaluation lighting						
0 Inc.	1.90	1.75	1.84	2.06	1.62^{a}	1.68
0 Fluor.	2.62	2.09	2.10	2.34	2.60^{b}	2.34
807 Inc.	1.96	1.93	2.25	2.65	3.40^{c}	4.06
807 Fluor.	2.75	2.43	2.65	3.10	4.46^{ef}	4.59
1076 Inc.	2.12	1.90	2.53	2.75	3.81^{d}	4.18
1076 Fluor.	2.68	2.50	2.72	3.28	4.43^{ef}	4.71
1614 Inc.	2.00	2.18	2.60	3.10	4.03^{d}	4.37
1614 Fluor.	2.65	2.53	2.87	3.53	4.71^{g}	4.84
3228 Inc.	1.96	2.25	3.00	3.40	4.34^{e}	4.53
3228 Fluor.	2.75	2.71	3.10	3.65	4.65^{f}	5.03

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

APPENDIX E-1

Effect of display light type x intensity x evaluation lighting interactions on visual score of frozen beef *longissimus dorsi* muscle (mean values[1])

		TIME (DAYS)					
		0	1	3	7	21	42
Displaying x Intensity x Evaluation							
Inc. 0	Inc.	1.33	0.32	0.70	0.60	0.40^{a}	0.90^{b}
Inc. 0	Fluor.	1.97	0.97	1.11	0.98	1.01^{b}	1.46^{c}
Inc. 807	Inc.	1.30	0.94	1.50	1.92	2.65^{c}	3.21^{d}
Inc. 807	Fluor.	2.03	1.50	1.76	2.42	3.73^{hij}	4.15^{fg}
Inc. 1076	Inc.	1.24	1.07	1.63	1.90	2.93^{d}	3.34^{d}
Inc. 1076	Fluor.	2.00	1.80	1.95	2.40	3.64^{ghi}	4.27^{gh}
Inc. 1614	Inc.	1.30	1.22	1.60	2.01	3.31^{ef}	3.65^{e}
Inc. 1614	Fluor.	1.97	1.72	2.05	2.54	3.90^{d}	4.24^{gh}
Inc. 3228	Inc.	1.24	1.60	2.00	2.61	3.87^{ij}	4.00^{f}
Inc. 3228	Fluor.	1.84	2.00	2.30	2.92	4.26^{k}	4.37^{h}

APPENDIX E-1 (Continued)

Effect of display light type x intensity x evaluation lighting interactions on visual score of frozen beef longissimus dorsi muscle (mean values[1])

		TIME (DAYS)					
		0	1	3	7	21	42
Fluor. 0	Inc.	1.30	0.51	0.80	0.63	0.54^{a}	0.54^{a}
Fluor. 0	Fluor.	2.02	1.00	1.08	1.15	1.28^{b}	1.34^{c}
Fluor. 807	Inc.	1.36	1.04	1.45	2.07	3.26^{ef}	3.22^{d}
Fluor. 807	Fluor.	2.00	1.62	1.90	2.46	3.53^{gh}	3.65^{e}
Fluor. 1076	Inc.	1.32	1.32	1.64	2.04	3.16^{de}	3.35^{d}
Fluor. 1076	Fluor.	1.92	1.74	2.01	2.42	3.81^{ij}	3.77^{e}
Fluor. 1014	Inc.	1.30	1.26	1.73	2.20	3.41^{fg}	3.32^{d}
Fluor. 1014	Fluor.	2.00	1.90	1.98	2.55	4.18^{k}	4.10^{fg}
Fluor. 3228	Inc.	1.17	1.54	1.98	2.57	3.80^{ij}	3.44^{d}
Fluor. 3228	Fluor.	1.92	2.27	2.39	3.14	4.75^{l}	4.43^{h}

[1]Observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

APPENDIX E-2

Effect of display light type x intensity x evaluation lighting interactions of visual score of frozen beef psoas major muscle (mean values[1])

		TIME (DAYS)					
		0	1	3	7	21	42
Displaying x Intensity x Evaluation							
Inc. 0	Inc.	1.90	1.66	1.83	1.97	1.50^{a}	1.72^{a}
Inc. 0	Fluor.	2.62	2.11	2.23	2.34	2.61^{c}	2.44^{c}
Inc. 807	Inc.	1.96	1.91	2.30	2.50	3.34^{d}	4.10^{d}
Inc. 807	Fluor.	2.75	2.39	2.73	2.06	4.42^{hi}	4.70^{gh}
Inc. 1076	Inc.	2.06	1.91	2.55	2.70	3.81^{ef}	4.20^{de}
Inc. 1076	Fluor.	2.75	2.42	2.82	2.25	4.33^{gh}	4.85^{hi}
Inc. 1614	Inc.	2.03	2.16	2.61	3.06	4.10^{fg}	4.47^{fg}
Inc. 1614	Fluor.	2.62	2.48	3.00	3.46	4.55^{i}	4.88^{hi}
Inc. 3228	Inc.	2.00	2.20	3.23	3.41	4.21^{gh}	4.70^{gh}
Inc. 3228	Fluor.	2.71	2.70	3.00	3.56	4.67^{ij}	5.00^{i}

APPENDIX E-2 (Continued)

Effect of display light type x intensity x evaluation lighting interactions of visual score of frozen beef psoas major muscle (mean values[1])

		TIME (DAYS)					
		0	1	3	7	21	42
Fluor. 0	Inc.	1.92	1.72	1.86	2.04	2.00^{b}	1.76^{a}
Fluor. 0	Fluor.	2.60	2.18	1.95	2.44	2.33^{c}	2.12^{b}
Fluor. 807	Inc.	2.05	2.00	2.36	2.76	3.80^{ef}	4.00^{d}
Fluor. 807	Fluor.	2.66	2.43	2.41	3.07	4.17^{gh}	4.50^{fg}
Fluor. 1076	Inc.	2.05	2.03	2.45	2.95	3.71^{e}	4.17^{de}
Fluor. 1076	Fluor.	2.76	2.43	2.67	3.16	4.64^{i}	4.60^{g}
Fluor. 1014	Inc.	1.92	2.10	2.61	3.16	3.92^{ef}	4.20^{de}
Fluor. 1014	Fluor.	2.73	2.68	2.[illegible]	3.54	4.92^{j}	4.87^{hi}
Fluor. 3228	Inc.	2.01	2.31	2.61	3.26	4.05^{fg}	4.33^{ef}
Fluor. 3228	Fluor.	2.70	2.71	3.35	3.88	5.05^{j}	4.10^{i}

[1]Observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

APPENDIX F-1

Effect of display lighting source and intensity on mean square values of longissimus dorsi muscle

	DAY 0					DAY 1				
	Loin	Light	Inten.	I.xL.[1]	Error	Loin	Light	Inten.	I.xL.[1]	Error
Percent Reflectance										
474	2.85	9.31	5.67	2.37	3.69	26.45**	35.88*	10.84	9.12	6.22
525	6.50	22.89*	4.28	2.57	17.82	28.84**	27.19*	8.82	10.06	5.81
572	1.72	8.06	4.04	1.81	23.70	17.00**	15.38*	3.89	5.95	3.67
582	1.46	4.90	1.52	1.74	2.66	10.82**	18.73*	3.29	5.74	2.92
600	28.33	80.00*	17.46	6.78	17.82	123.85**	309.95**	117.78**	49.87	20.71
630	38.26	100.35*	32.73	27.26	23.70	201.42**	193.18**	618.87**	24.67	26.22
650	38.42	71.82	18.44	15.36	22.23	213.13**	335.96**	699.31**	39.29	27.00
685	36.91	101.02*	20.70	22.94	22.27	200.99**	380.94**	174.49**	34.58	34.86
Reflectance scan area										
Blue	0.001	0.002	0.001	0.001	0.001	0.003*	0.01*	0.005	0.001	0.001
Red	0.15	0.22	0.08	0.12	0.09	0.05**	0.10	1.75**	0.11	0.12
Total	0.92	1.46	0.53	0.53	0.56	4.14**	4.55*	5.73**	1.02	0.66
474/525	0.02**	0.006	0.01	0.001	0.008	0.001	0.006	0.01**	0.009*	0.003
572/525	0.01*	0.005	0.007	0.001	0.005	0.003	0.002	0.003	0.002	0.002
685/474	0.60	0.38	0.70	0.34	0.87	0.94*	0.09	0.12	0.49	0.41
630/525	0.42	0.15	0.11	0.09	0.22	0.03	0.000	3.01**	0.28*	0.08
582/525	0.02**	0.007	0.003	0.001	0.007	0.01	0.000	0.01*	0.006	0.004
685/525	0.48	0.60	0.30	0.13	0.42	0.92*	0.000	0.48	0.88	0.40
Red/Blue	22.10*	0.52	11.11	3.65	10.39	14.17	70.28*	37.60*	10.04	12.96

[1]Interaction of light x intensity.

*P < 0.05, **P < 0.01.

APPENDIX F-2

Effect of display lighting source and intensity on mean square values of longissimus dorsi muscle

	DAY 3					DAY 7				
	Loin	Light	Inten.	I.xL.[1]	Error	Loin	Light	Inten.	I.xL.[1]	Error
Percent Reflectance										
474	15.45*	40.85*	1.54	13.32	6.53	18.88**	1.03	16.81*	17.58*	5.87
525	14.88*	36.57	3.96	9.47	6.42	19.28**	26.91*	15.81*	12.46*	5.83
572	11.95	28.31	4.94	6.18	5.39	12.35**	31.75**	4.54	11.94*	4.19
582	10.65	13.28	12.02	1.55	6.44	12.97	7.14	7.76	35.94**	6.78
600	58.98**	105.56*	73.15*	39.47	17.13	81.79**	65.70	218.54**	30.72	18.14
630	94.06**	36.07	608.99**	41.35	23.51	102.81**	15.84	844.84**	33.76	21.84
650	117.17**	73.40	711.99**	57.93	27.05	109.47**	51.84	936.36**	42.10	24.97
685	97.75**	330.24**	103.26*	52.79	34.50	132.17**	276.76**	240.18**	100.94**	27.42
Reflectance scan area										
Blue	0.009	0.02	0.009	0.004	0.01	0.002	0.004	0.001	0.002	0.001
Red	0.49	0.67	1.50**	0.14	0.14	0.31**	0.33*	1.78**	0.29**	0.08
Total	1.95**	2.51	3.56**	0.77	0.69	1.97**	3.13*	5.34**	1.15	0.60
474/525	0.02	0.000	0.01	0.003	0.004	0.002	0.10**	0.001	0.003**	0.002
572/525	0.005	0.001	0.004	0.01*	0.003	0.003	0.008	0.04**	0.02**	0.004
685/474	0.69	1.09	1.94*	1.63*	0.59	1.05*	1.41	0.77	0.57	0.40
630/525	0.17	1.62**	8.12**	0.62*	0.19	0.14*	0.62**	4.01**	0.20*	0.06
582/525	0.06	0.02	0.03	0.02	0.03	0.02	0.35**	0.03	0.21**	0.02
685/525	0.63	1.30	3.32**	1.62*	0.63	0.89*	0.09	0.49	1.08*	0.34
Red/Blue	32.08	58.33	381.43**	103.26*	33.80	16.11	0.91	51.70**	7.85	8.34

[1]Interaction of light x intensity.

*P < 0.05, **P < 0.01.

APPENDIX F-3

Effect of display lighting source and intensity on mean square values of longissimus dorsi muscle

	DAY 21					DAY 42				
	Loin	Light	Inten.	I.xL.[1]	Error	Loin	Light	Inten.	I.xL.[1]	Error
Percent Reflectance										
474	9.20	2.11	10.98	1.72	5.01	22.35*	0.27	11.01	15.80	9.33
525	9.20	0.35	7.04	0.54	4.57	22.31*	0.04	10.07	17.02	9.95
572	5.41	0.003	12.66	0.76	5.95	23.07	0.09	21.12	18.44	13.37
582	5.45	1.35	17.21*	2.82	6.22	21.54	0.12	33.00*	18.93	12.34
600	34.70**	38.50	209.04**	15.76	11.49	53.76**	2.04	223.79**	40.11	17.23
630	56.99**	28.68	604.02**	19.68	12.25	79.74*	1.20	505.32**	37.51*	15.36
650	87.54**	24.20	624.04**	27.02	14.57	106.14**	0.74	546.04**	51.85*	15.48
685	106.59**	0.11	355.91**	53.45	22.57	117.63**	22.57	558.28**	85.82*	32.63
Reflectance scan area										
Blue	0.002	0.004	0.001	0.000	0.001	0.003	0.000	0.007	0.002	0.003
Red	0.22*	0.01	1.18**	0.13*	0.05	0.99*	0.22	1.96**	0.63	0.43
Total	1.23*	0.10	5.87**	0.36	0.55	3.01**	0.03	5.12**	1.60	0.88
474/525	0.007	0.007	0.004	0.004	0.003	0.001	0.004	0.001	0.000	0.001
572/525	0.01**	0.006	0.10**	0.01	0.004	0.01**	0.000	0.17**	0.01*	0.003
685/474	0.72*	0.33	1.41**	0.27	0.31	1.08*	0.78	3.60**	0.14	0.48
630/525	0.17*	0.21	4.63**	0.10	0.07	0.06	0.01	3.36**	0.06	0.04
582/525	0.01	0.04	0.17**	0.01	0.01	0.01**	0.001	0.30**	0.01*	0.005
685/525	0.63	0.04	1.86**	0.37	0.33	0.87	0.38	3.07**	0.13	0.46
Red/Blue	5.39	17.56	46.86**	5.40	5.58	21.65	1.32	82.45**	25.23	16.06

[1]Interaction of light x intensity.

*P < 0.05, **P < 0.01.

APPENDIX G-1

Effect of display lighting source and intensity on mean square values of psoas major muscle

	DAY 0					DAY 1				
	Loin	Light	Inten.	I.xL.[1]	Error	Loin	Light	Inten.	I.xL.[1]	Error
Percent Reflectance										
474	17.91**	0.21	6.46	5.55	5.15	43.35	46.21	33.68	23.79	49.37
525	9.30	0.79	3.92	6.90	7.20	42.91	44.81	34.73	23.67	48.89
572	9.30*	1.79	4.84	4.72	3.96	47.41	36.81	34.13	24.86	47.83
582	9.71**	0.16	2.63	3.48	2.66	2.59	0.78	5.02	4.78	4.50
600	64.02*	0.18	9.63	22.50	16.05	100.13	293.74	48.46	48.46	104.80
630	57.97**	6.61	10.34	31.22	20.46	42.04	60.67	81.35*	13.99	27.23
650	64.46*	2.73	11.56	26.82	23.37	50.56*	121.79	94.22**	21.54	30.73
685	41.98	7.50	17.63	36.12	23.57	35.13	110.16	21.58	12.39	33.13
Reflectance scan area										
Blue	0.007**	0.04	0.000	0.001	0.001	0.002	0.002	0.001	0.002	0.002
Red	0.12	0.03	0.03	0.15	0.08	0.11	0.17	0.25	0.06	0.12
Total	1.10	0.56	0.22	1.17	0.56	21.28	18.52	22.75	22.95	22.12
474/525	0.05**	0.01	0.006	0.005	0.007	0.001	0.000	0.002	0.001	0.002
572/525	0.01**	0.000	0.006*	0.001	0.002	0.005*	0.006	0.000	0.004	0.002
685/474	3.93**	0.45	0.62	0.28	0.32	0.54	0.51	0.37	0.32	0.40
630/525	0.90	0.000	0.12	0.42	0.16	0.14	0.31	1.68**	0.15	0.13
582/525	0.01*	0.007	0.003	0.001	0.007	0.02	0.000	0.02	0.03	0.02
685/525	1.08**	0.002	0.18	0.17	0.29	0.39	0.47	0.52	0.36	0.33
Red/Blue	76.50**	20.22	2.63	3.88	9.37	15.94	5.07	19.79	15.22	8.54

[1] Interaction of light x intensity.

*P < 0.05, **P < 0.01.

APPENDIX G-2

Effect of display lighting source and intensity on mean square values of psoas major muscle

	DAY 3					DAY 7				
	Loin	Light	Inten.	I.xL.[1]	Error	Loin	Light	Inten.	I.xL.[1]	Error
Percent Reflectance										
474	4.10	5.92	4.76	6.75	3.02	10.62*	1.65	5.08	2.02	3.82
525	2.56	7.98**	4.62	6.72	2.91	10.51*	0.33	6.11	4.15	4.57
572	2.60	2.00	6.24	7.17*	2.61	8.26	0.78	3.19	1.41	4.30
582	1.74	4.37	6.98*	6.21*	2.39	57.43*	19.80*	17.82	4.47	2.96
600	7.81	38.82*	9.86	14.36	7.80	20.87	14.87	35.67*	2.37	10.96
630	32.26**	37.09	122.94**	12.09	11.28	49.77**	9.79	207.05**	7.50	15.42
650	41.57**	74.61*	155.59**	12.81	13.66	61.94**	23.21	241.77**	7.50	18.56
685	15.46	183.23**	66.09*	19.21	21.78	28.24	72.77	110.87**	14.39	22.13
Reflectance scan area										
Blue	0.001	0.001	0.003	0.001	0.001	0.003**	0.000	0.001	0.001	0.001
Red	0.11	0.43*	0.67**	0.10	0.08	0.21	0.11	0.87**	0.08	0.12
Total	0.53	0.55	0.58	0.35	0.41	0.97	0.11	1.83**	0.12	0.49
474/525	0.004**	0.000	0.002	0.002	0.001	0.002	0.05**	0.001	0.008**	0.002
572/525	0.004*	0.01**	0.003	0.002	0.002	0.01*	0.001	0.01	0.01	0.008
685/474	0.55	0.11	4.44**	1.60**	0.42	1.11**	2.96**	1.91**	0.39	0.24
630/525	0.08	0.24	3.92**	0.52**	0.14	0.23**	0.000	2.53**	0.17*	0.05
582/525	0.003	0.000	0.01**	0.002	0.004	0.005	0.36**	0.002	0.42**	0.002
685/525	0.25	0.15	4.05*	1.33*	0.35	0.83**	0.34	1.37**	0.56*	0.17
Red/Blue	25.13	1.35	152.00**	19.97	17.20	10.80	0.05	64.41**	17.00*	6.09

[1]Interaction of light x intensity.

*P < 0.05, **P < 0.01.

APPENDIX G-3

Effect of display lighting source and intensity on mean square values of psoas major muscle

	DAY 21					DAY 42				
	Loin	Light	Inten.	I.xL.[1]	Error	Loin	Light	Inten.	I.xL.[1]	Error
Percent Reflectance										
474	9.70	35.51*	2.53	7.35	6.13	5.80	26.22*	23.98**	8.62	4.47
525	8.50	30.62*	2.69	6.77	5.82	7.41	23.11*	20.20**	10.46	4.56
572	9.71	30.50*	6.65	9.68	6.64	6.53	33.80*	44.72**	13.79*	5.56
582	7.77	43.07*	9.05	9.51	6.45	6.85	42.77**	59.14**	10.97	5.31
600	16.84	45.75*	56.31**	5.16	11.28	19.04*	56.28*	19.17*	19.86	8.30
630	30.37*	24.20	195.51**	2.57	11.08	29.49**	14.70	75.90**	12.04	7.56
650	39.20*	16.38	228.31**	3.33	11.76	37.93**	11.10	95.67**	11.71	7.83
685	24.20	8.00	166.50**	13.21	24.69	37.02**	25.31	60.58**	43.29**	11.97
Reflectance scan area										
Blue	0.002	0.01**	0.001	0.002	0.001	0.001	0.01*	0.01**	0.004	0.001
Red	0.13*	0.03	0.77**	0.01	0.06	0.14**	0.02	0.44**	0.05	0.05
Total	0.86	3.05*	2.29*	0.45	0.69	0.94*	1.26	1.20*	0.76	0.44
474/525	0.002	0.000	0.003	0.003	0.003	0.002	0.003	0.007*	0.003	0.002
572/525	0.01	0.002	0.03**	0.01*	0.004	0.01**	0.001	0.10**	0.01**	0.002
685/474	1.30**	4.62**	2.47**	0.87	0.41	0.37	0.99	8.92**	0.44	0.39
630/525	0.21**	0.39*	3.54**	0.10	0.06	0.09*	0.05	3.20**	0.08*	0.03
582/525	0.01	0.005	0.07**	0.01	0.007	0.02**	0.01	0.19**	0.003	0.005
685/525	1.14**	4.39**	3.00**	0.80	0.40	0.42	0.41	6.14**	0.63	0.31
Red/Blue	12.02*	43.57**	81.10**	4.46	4.80	7.43	6.35	116.15**	6.32	5.02

[1] Interaction of light x intensity.

*P < 0.05, **P < 0.01.

APPENDIX H-1

The effect of display lighting type and intensity on percent reflectance at 474nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	8.17	9.92^{a}	10.50$^{a}_{b}$	9.89	10.23	9.97
Fluorescent (F)	8.85	11.27^{b}	11.95	10.12	9.91	10.09
0*	8.81	11.87	11.21	11.26$^{c}_{bc}$	10.97	10.82
807	7.67	10.98	11.00	10.68	10.50	9.12
1076	8.09	10.12	10.86	8.65^{a}	8.78	9.70
1614	9.00	10.18	11.65	10.03^{abc}	8.90	11.00
3228	8.96	9.84	11.40	9.42^{ab}	10.15	9.54
Inc. x 0	8.50	10.68	9.56	12.31^{d}	11.50	10.67
I x 807	6.81	9.50	11.12	11.18^{bcd}	10.50	9.33
I x 1076	8.28	10.25	11.17	8.62^{a}	9.25	10.62
I x 1614	8.77	9.18	10.06	8.31^{a}	10.00	9.31
I x 3228	8.47	10.00	10.62	9.06^{ab}	9.93	9.95
Fluor. x 0	9.12	13.06	12.87	10.21^{abcd}	10.43	10.97
F x 807	8.53	12.43	10.87	10.18^{abcd}	10.62	8.91
F x 1076	7.90	10.00	10.56	8.68^{a}	8.31	8.76
F x 1614	9.23	11.18	13.25	11.76^{cd}	9.81	12.70
F x 3228	9.46	9.68	12.18	9.78^{abc}	10.37	9.14

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX H-2

The effect of display lighting type and intensity on percent reflectance at 525nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	9.20	10.30^{a}	10.63	10.14	9.90	10.24
Fluorescent (F)	10.27	11.47^{b}	12.00	11.30	9.76	10.19
0*	10.41	11.75	10.96	11.95^{c}	10.43	11.04
807	9.17	11.60	10.93	11.24^{bc}	10.28	9.38
1076	9.27	10.40	10.96	9.38^{a}	8.76	9.86
1614	10.01	10.62	11.96	10.89^{abc}	9.68	11.08
3228	9.83	10.06	11.75	10.13^{ab}	10.00	9.71
Inc. x 0	9.85	10.25	9.56	11.43^{bcd}	10.56	10.97
I x 807	9.10	10.31	11.06	11.62^{cd}	10.24	9.70
I x 1076	9.32	10.62	11.00	9.16^{ab}	9.06	10.90
I x 1614	9.53	10.06	10.43	8.87^{a}	9.81	9.40
I x 3228	9.22	10.25	11.12	9.62^{abc}	9.81	10.22
Fluor. x 0	10.97	13.25	12.37	12.47^{d}	10.31	11.12
F x 807	10.25	12.87	10.81	10.87^{abcd}	10.31	9.06
F x 1076	9.22	10.18	10.93	9.61^{abc}	8.46	8.82
F x 1614	10.48	11.18	13.50	12.91^{d}	9.56	12.76
F x 3228	10.45	9.87	12.37	10.65^{abcd}	10.18	9.21

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX H-3

The effect of display lighting type and intensity on percent reflectance at 572nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	7.13	9.10^{a}	9.80	9.22^{a}	10.05	10.97
Fluorescent (F)	7.76	9.97^{b}	11.00	10.48^{b}	10.06	10.91
0*	7.87	10.15	9.90	10.11	9.53	9.90
807	6.93	9.96	10.09	10.09	10.12	10.34
1076	6.96	9.16	10.00	8.60	8.84	11.01
1614	8.02	9.31	10.87	10.15	10.78	12.86
3228	7.45	9.06	11.12	10.00	11.00	10.60
Inc. x 0	7.58	9.06	9.06	10.24^{bcd}	9.87	9.91
I x 807	6.22	9.00	10.06	9.93^{abc}	9.93	10.43
I x 1076	7.15	9.20	9.87	8.43^{ab}	8.81	11.94
I x 1614	7.76	8.81	9.31	8.06^{a}	10.81	11.13
I x 3228	6.93	9.37	10.68	9.43^{abc}	10.81	11.46
Fluor. x 0	8.16	11.25	10.74	9.97^{abc}	9.18	9.88
F x 807	7.65	10.93	10.12	10.24^{bcd}	10.31	10.25
F x 1076	6.77	9.12	10.12	9.37^{abc}	8.87	10.08
F x 1614	8.28	9.81	12.43	12.24^{d}	10.74	14.60
F x 3228	7.96	8.75	11.56	10.57^{cd}	11.18	9.72

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX H-4

The effect of display lighting type and intensity on percent reflectance at 532nm of frozen beef longissimus dorsi muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	6.43	8.04$^{a}_{b}$	9.08	10.58	9.26	10.63
Fluorescent (F)	6.93	9.01^{b}	9.90	9.98	9.52	10.56
0*	6.94	9.00	8.91	11.33	8.31$^{a}_{ab}$	8.88$^{a}_{a}$
807	6.22	8.96	9.04	10.62	9.57^{a}	9.90^{ab}
1076	6.51	7.91	8.70	9.80	8.35^{ab}	10.74^{b}
1614	6.93	8.44	10.76	10.00	10.07^{ab}	12.80^{ab}
3228	6.80	8.31	10.01	9.64	10.64^{b}	10.66^{ab}
Inc. x 0	6.71	8.00	8.11	14.00^{c}	8.41	8.91
I x 807	5.63	7.86	9.10	11.43^{bc}	9.02	9.81
I x 1076	6.81	7.70	8.39	9.60^{ab}	8.13	11.76
I x 1614	6.61	7.96	10.23	8.93^{ab}	10.54	11.11
I x 3228	6.41	8.67	9.56	8.93^{ab}	10.18	11.60
Fluor. x 0	7.17	10.01	9.71	8.67^{a}	8.22	8.56
F x 807	6.81	10.06	9.00	9.81^{ab}	10.12	10.00
F x 1076	6.22	8.12	9.00	10.01^{ab}	8.56	9.72
F x 1614	7.25	8.92	11.30	11.07^{ab}	9.60	14.47
F x 3228	7.20	7.95	10.47	10.34^{ab}	11.10	9.73

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

APPENDIX H-5

The effect of display lighting type and intensity on percent reflectance at 600nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	18.19^{a}	19.23^{a}	20.23^{a}	18.90	18.45	16.93
Fluorescent (F)	20.19^{b}	23.20^{b}	22.56^{b}	20.71	17.06	16.61
0*	19.73	25.84^{b}	24.81^{b}	25.86^{c}	23.59^{c}	23.17^{b}
807	17.88	21.06^{a}	21.46^{a}	20.00^{b}	17.71^{b}	15.50^{a}
1076	18.31	20.36^{a}	20.43^{a}	17.11^{ab}	15.03^{a}	15.67^{a}
1614	19.68	20.03^{a}	21.28^{a}	19.50^{ab}	16.60^{ab}	16.20^{a}
3228	20.35	18.78^{a}	19.00^{a}	16.55^{a}	14.84^{a}	13.33^{a}
Inc. x 0	19.06	22.37	23.00	26.37	25.75	23.10
I x 807	15.81	17.12	22.00	19.75	19.56	16.62
I x 1076	17.77	19.97	21.00	16.87	15.75	17.33
I x 1614	19.12	17.87	18.00	16.50	16.93	13.78
I x 3228	19.20	18.81	16.50	15.00	14.25	13.83
Fluor. x 0	20.40	29.31	26.62	25.35	21.43	23.25
F x 807	19.96	25.00	20193	20.25	17.87	14.37
F x 1076	18.85	20.75	19.87	17.36	14.31	14.00
F x 1614	20.25	22.18	23.87	22.50	16.25	18.62
F x 3228	21.51	18.75	21.50	18.10	15.43	12.83

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX H-6

The effect of display lighting type and intensity on percent reflectance at 650nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	34.35	30.63^{a}	30.01	27.50	24.87	22.95
Fluorescent (F)	36.24	34.76^{b}	31.95	29.05	23.77	22.76
0*	36.21	43.71^{a}	42.65^{c}	41.50^{c}_{b}	34.96^{c}	33.25^{b}
807	34.06	33.43^{c}	29.50^{b}	27.50^{a}	24.68^{b}	20.36^{a}
1076	34.36	30.54^{bc}	28.36^{ab}	23.86^{ab}	20.28^{a}	20.40^{a}
1614	35.38	28.96^{ab}	28.71^{ab}	25.93^{a}	21.84^{a}	20.92^{a}
3228	36.46	26.81^{a}	25.68^{a}	22.46^{a}	19.84^{a}	19.34^{a}
Inc. x 0	35.33	41.56	40.75	42.12	37.25^{d}_{b}	33.60^{d}_{abc}
I x 807	31.52	29.37	30.37	27.12	24.93^{b}_{ab}	21.56^{bc}
I x 1076	34.47	29.28	29.72	24.56	21.37^{ab}	22.28^{a}_{ab}
I x 1614	34.86	26.06	26.18	23.00	22.25^{a}	18.12^{ab}
I x 3228	35.55	26.87	23.06	20.43	18.56^{c}_{b}	19.18^{d}
Fluor. x 0	37.10	45.87	44.56	40.87	32.68^{b}_{a}	32.91^{ab}
F x 807	36.60	37.50	28.62	27.87	24.43^{a}_{ab}	19.16^{ab}
F x 1076	34.25	31.81	27.00	23.17	19.18^{ab}	18.50^{c}_{ab}
F x 1614	35.90	31.87	31.24	28.87	21.44^{a}	23.72^{ab}
F x 3228	37.37	26.75	28.31	24.50	21.12^{a}	19.50^{ab}

[1] Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX H-7

The effect of display lighting type and intensity on percent reflectance at 685nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	38.68	42.37^{a}	44.06^{a}	41.41^{a}	40.40	38.82
Fluorescent (F)	40.93	46.77^{b}	48.16^{b}	45.13^{b}	40.32	37.76
0*	40.77	50.28^{b}	50.37^{b}	49.73^{b}	40.25^{c}	48.01^{c}
807	38.35	44.46^{a}	46.18^{a}	43.43^{a}	42.81^{b}	37.78^{b}
1076	38.81	42.87^{a}	45.35^{a}	40.86^{a}	36.43^{a}	36.18^{b}
1614	40.45	43.25^{a}	44.93^{a}	42.48^{a}	39.31^{a}	37.48^{b}
3228	40.66	42.00^{a}	43.71^{a}	39.83^{a}	36.00^{a}	31.98^{a}
Inc. x 0	40.15	48.93	48.87	51.00^{e}	50.18	48.58^{e}
I x 807	35.48	39.87	45.74	42.00^{bc}	42.18	39.93^{cd}
I x 1076	39.18	42.06	45.02	40.50^{abc}	36.18	38.96^{bcd}
I x 1614	38.91	40.68	40.75	37.68^{ab}	39.50	34.31^{abc}
I x 3228	39.70	40.31	39.94	35.87^{a}	33.93	32.31^{a}
Fluor. x 0	41.40	51.62	51.87	48.47^{de}	44.31	47.43^{e}
F x 807	41.22	49.06	46.62	44.87^{cd}	43.43	35.62^{abcd}
F x 1076	38.43	43.68	45.68	41.22^{bc}	36.68	33.41^{ab}
F x 1614	41.98	45.81	49.12	47.28^{de}	39.12	40.66^{d}
F x 3228	41.62	43.68	47.50	43.80^{cd}	38.06	31.66^{a}

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P<0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX H-8

The effect of display lighting type and intensity on reflectance scan blue area of frozen beef *longissimus dorsi* muscle[1,2]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	0.14	0.15[a]	0.16	0.16	0.17	0.17
Fluorescent (F)	0.15	0.17[b]	0.20	0.17	0.16	0.18
0*	0.15	0.17	0.15	0.17	0.16	0.17
807	0.14	0.17	0.17	0.16	0.17	0.15
1076	0.15	0.16	0.22	0.15	0.15	0.16
1614	0.14	0.16	0.19	0.17	0.17	0.21
3228	0.16	0.15	0.18	0.17	0.17	0.17
Inc. x 0	0.15	0.16	0.12	0.16	0.18	0.17
I x 807	0.12	0.14	0.18	0.16	0.17	0.15
I x 1076	0.15	0.15	0.18	0.15	0.15	0.17
I x 1614	0.14	0.15	0.17	0.14	0.18	0.19
I x 3228	0.15	0.16	0.17	0.16	0.18	0.18
Fluor. x 0	0.15	0.18	0.18	0.17	0.15	0.17
F x 807	0.14	0.19	0.16	0.17	0.17	0.16
F x 1076	0.14	0.16	0.26	0.14	0.15	0.15
F x 1614	0.15	0.17	0.20	0.20	0.16	0.23
F x 3228	0.17	0.15	0.20	0.17	0.16	0.16

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

[2]1 = 6.25 cm^2

APPENDIX H-9

The effect of display lighting type and intensity on reflectance scan red area of frozen beef *longissimus dorsi* muscle[1,2]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	2.34	2.46	2.54	2.25^{a}	2.02	2.09
Fluorescent (F)	2.44	2.53	2.73	2.38^{b}	2.05	2.19
0*	2.47	3.06^{c}	3.16^{b}	2.88^{c}	2.48^{c}	2.76^{b}
807	2.29	2.52^{b}	2.60^{a}	2.33^{b}	2.09^{b}	1.94^{a}
1076	2.35	2.33^{ab}	2.53^{a}	2.13^{ab}	1.85^{a}	1.93^{a}
1614	2.40	2.36^{ab}	2.53^{a}	2.18^{ab}	1.95^{ab}	2.00^{a}
3228	2.45	2.23^{a}	2.35^{a}	2.04^{a}	1.81^{a}	2.07^{a}
Inc. x 0	2.45	3.05	3.02	2.91^{e}	2.57^{e}	2.84
I x 807	2.10	2.39	2.59	2.37^{cd}	2.10^{d}	2.02
I x 1076	2.40	2.36	2.56	2.16^{bcd}	1.89^{abcd}	2.03
I x 1614	2.35	2.24	2.40	1.95^{ab}	1.85^{abc}	1.84
I x 3228	2.38	2.28	2.15	1.85^{a}	1.69^{a}	1.71
Fluor. x 0	2.50	3.07	3.30	2.85^{e}	2.39^{e}	2.68
F x 807	2.48	2.65	2.62	2.30^{cd}	2.07^{cd}	1.87
F x 1076	2.29	2.30	2.50	2.10^{abc}	1.80^{ab}	1.83
F x 1614	2.44	2.47	2.66	2.42^{d}	2.05^{cd}	2.16
F x 3228	2.51	2.17	2.56	2.24^{cd}	1.93^{bcd}	2.42

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

[2]1 = 6.25 cm^2

APPENDIX H-10

The effect of display lighting type and intensity on reflectance scan total area of frozen beef *longissimus dorsi* muscle[1,2]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	4.51	4.88[a]	4.95	4.49	4.40	4.27
Fluorescent (F)	4.78	5.36[b]	5.31	4.88	4.33	4.23
0*	4.82	6.12[c]	5.93[b]	5.64[b]	5.33[c]	5.19[b]
807	4.40	5.22[b]	5.10[a]	4.73[a]	4.56[b]	3.88[a]
1076	4.52	4.86[ab]	4.95[a]	4.23[a]	3.80[a]	4.02[a]
1614	4.70	4.82[ab]	5.01[a]	4.60[a]	4.15[ab]	4.34[a]
3228	4.80	4.61[a]	4.67[a]	4.24[a]	4.00[a]	3.81[a]
Inc. x 0	4.67	5.71	5.59	5.60	5.58	5.28
I x 807	4.03	4.67	5.16	4.72	4.50	4.00
I x 1076	4.67	4.81	5.00	4.20	3.95	4.33
I x 1614	4.57	4.55	4.57	3.97	4.11	3.82
I x 3228	4.62	4.68	4.46	3.95	3.90	3.93
Fluor. x 0	4.98	6.53	6.27	5.68	5.08	5.10
F x 807	4.76	5.77	5.04	4.73	4.63	3.77
F x 1076	4.38	4.91	4.92	4.25	3.66	3.71
F x 1614	4.82	5.08	5.45	5.23	4.20	4.86
F x 3228	4.98	4.53	4.87	4.53	4.10	3.70

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

[2]1 = 6.25 cm^2

APPENDIX H-11

The effect of display lighting type and intensity on reflectance ratio 474/525nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	0.88	0.96	0.99	0.97^{a}	1.03	0.97
Fluorescent (F)	0.86	0.98	0.99	0.89^{b}	1.01	0.99
0*	0.84	1.01^{b}	1.02	0.94	1.05	0.97
807	0.83	0.94^{a}	1.00	0.94	1.02	0.97
1076	0.87	0.97^{a}	0.98	0.92	1.00	0.98
1614	0.89	0.95^{ab}	0.97	0.92	1.02	0.99
3228	0.91	0.97^{ab}	0.96	0.93	1.01	0.98
Inc. x 0	0.85	1.04^{c}	1.02	1.06^{d}	1.08	0.97
I x 807	0.84	0.92^{a}	1.00	0.95^{c}	1.02	0.96
I x 1076	0.88	0.96^{ab}	1.01	0.94^{bc}	1.02	0.97
I x 1614	0.92	0.92^{ab}	0.97	0.94^{bc}	1.02	0.99
I x 3228	0.91	0.97^{b}	0.95	0.94^{bc}	1.01	0.97
Fluor. x 0	0.83	0.99^{bc}	1.03	0.81^{a}	1.01	0.98
F x 807	0.83	0.96^{ab}	1.00	0.93^{bc}	1.02	0.98
F x 1076	0.86	0.97^{b}	0.96	0.90^{b}	0.98	0.99
F x 1614	0.87	0.99^{cb}	0.98	0.91^{bc}	1.03	0.99
F x 3228	0.91	0.98^{b}	0.98	0.90^{bc}	1.01	0.99

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX H-12

The effect of display lighting type and intensity on reflectance ratio 572/525nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	0.77	0.88	0.92	0.91	1.01	1.07
Fluorescent (F)	0.75	0.87	0.91	0.93	1.03	1.07
0*	0.75	0.87	0.90	0.84^{a}	0.91^{a}	0.89^{a}
807	0.76	0.86	0.92	0.91^{b}	0.99^{b}	1.10^{b}
1076	0.75	0.88	0.91	0.95^{cd}	1.01^{b}	1.11^{b}
1614	0.80	0.88	0.90	0.93^{bc}	1.11^{c}	1.16^{b}
3228	0.75	0.90	0.95	0.98^{d}	1.10^{c}	1.09^{b}
Inc. x 0	0.76	0.88	0.95^{cd}	0.89^{bc}	0.93	0.89^{a}
I x 807	0.76	0.87	0.91^{abc}	0.87^{b}	0.97	1.09^{bc}
I x 1076	0.76	0.87	0.90^{ab}	0.92^{bcde}	0.97	1.08^{bc}
I x 1614	0.82	0.87	0.89^{ab}	0.91^{bcd}	1.08	1.18^{e}
I x 3228	0.75	0.92	0.96^{d}	0.98^{ef}	1.10	1.12^{cd}
Fluor. x 0	0.74	0.86	0.86^{a}	0.79^{a}	0.88	0.88^{a}
F x 807	0.75	0.85	0.93^{bcd}	0.95^{cdef}	1.00	1.12^{c}
F x 1076	0.74	0.89	0.92^{bcd}	0.98^{ef}	1.04	1.14^{d}
F x 1614	0.78	0.88	0.92^{bcd}	0.95^{def}	1.13	1.14^{d}
F x 3228	0.76	0.88	0.93^{bcd}	1.00^{f}	1.09	1.06^{b}

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX H-13

The effect of display lighting type and intensity on reflectance ratio 685/474nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	4.93	4.37^{a}	4.37	4.32	4.03	4.07
Fluorescent (F)	4.80	4.30^{b}	4.13	4.59	4.15	3.87
0*	4.74	4.35	4.87^{b}	4.59	4.43^{b}	4.66^{c}
807	5.21	4.18	4.27^{a}	4.21	4.12^{b}	4.22^{b}
1076	4.90	4.34	4.23^{a}	4.76	4.15^{b}	3.92^{a}
1614	4.74	4.40	3.97^{a}	4.40	4.14^{b}	3.60^{a}
3228	4.71	4.38	3.97^{a}	4.31	3.61^{a}	3.47^{a}
Inc. x 0	4.88	4.64	5.50^{b}	4.39	4.51	4.82
I x 807	5.34	4.25	4.21^{a}	3.86	4.04	4.38
I x 1076	4.86	4.23	4.11^{a}	4.74	3.92	3.98
I x 1614	4.62	4.49	4.07^{a}	4.54	4.19	3.74
I x 3228	4.95	4.23	3.97^{a}	4.08	3.48	3.43
Fluor. x 0	4.60	4.06	4.15^{a}	4.79	4.35	3.46
F x 807	5.08	4.11	4.33^{a}	4.56	4.20	4.05
F x 1076	4.95	4.46	4.36^{a}	4.78	4.40	3.87
F x 1614	4.86	4.32	3.86^{a}	4.27	4.09	3.47
F x 3228	4.47	4.53	3.97^{a}	4.54	3.74	3.51

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX H-14

The effect of display lighting type and intensity on reflectance ratio 630/525nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	3.31	2.62	2.64^{a}	2.39^{a}	2.18	2.00
Fluorescent (F)	3.22	2.62	2.35^{b}	2.22^{b}	2.08	1.97
0*	3.15	3.37^{c}	3.73^{c}	3.17^{c}	3.06^{c}	2.77^{c}
807	3.25	2.53^{b}	2.40^{b}	2.19^{b}	2.01^{b}	1.92^{b}
1076	3.34	2.55^{ab}	2.25^{ab}	2.21^{ab}	1.93^{b}	1.85^{a}
1614	3.23	2.37^{a}	2.14^{a}	2.06^{a}	1.95^{b}	1.68^{a}
3228	3.72	2.30^{a}	1.94^{a}	1.90^{a}	1.68^{a}	1.67^{a}
Inc. x 0	3.24	3.60^{e}	4.21^{e}	3.41^{e}	3.21	2.86
I x 807	3.22	2.56^{bc}	2.49^{c}	2.16^{c}	2.11	1.95
I x 1076	3.30	2.44^{abc}	2.36^{bc}	2.32^{c}	2.01	1.85
I x 1614	3.28	2.26^{a}	2.21^{abc}	2.20^{c}	1.96	1.68
I x 3228	3.51	2.26^{a}	1.90^{a}	1.87^{a}	1.62	1.60
Fluor. x 0	3.06	3.15^{d}	3.25^{d}	2.94^{d}	2.92	2.70
F x 807	3.28	2.50^{abc}	2.32^{abc}	2.22^{c}	1.92	1.87
F x 1076	3.37	2.66^{c}	2.15^{abc}	2.10^{abc}	1.85	1.85
F x 1614	3.18	2.48^{abc}	2.06^{ab}	1.91^{a}	1.95	1.68
F x 3228	3.23	2.30^{ab}	1.97^{ab}	1.92^{ab}	1.75	1.74

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX H-15

The effect of display lighting type and intensity on reflectance ratio 582/525nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	0.70	0.79	0.86	1.03^{a}	0.93	1.04
Fluorescent (F)	0.68	0.79	0.83	0.90^{b}	0.98	1.04
0*	0.67	0.77^{a}	0.82	0.95	0.80^{ab}	0.80^{a}
807	0.68	0.77^{a}	0.83	0.95	0.93^{b}	1.06^{b}
1076	0.70	0.77^{a}	0.80	1.05	0.95^{b}	1.08^{c}
1614	0.70	0.80^{ab}	0.92	0.94	1.03^{c}	1.15^{bc}
3228	0.70	0.83^{b}	0.85	0.96	1.06^{c}	1.10^{a}
Inc. x 0	0.68	0.78	0.85	1.21^{d}	0.81	0.81^{bc}
I x 807	0.70	0.76	0.82	1.00^{bc}	0.88	1.02^{bcd}
I x 1076	0.72	0.75	0.78	1.04^{bc}	0.90	1.06^{f}
I x 1614	0.70	0.80	1.00	1.00^{bc}	1.05	1.18^{e}
I x 3228	0.69	0.86	0.86	0.93^{a}	1.05	1.14^{a}
Fluor. x 0	0.65	0.76	0.78	0.69^{bc}	0.80	0.79^{cde}
F x 807	0.67	0.78	0.84	0.91^{c}	1.00	1.10^{bcde}
F x 1076	0.68	0.80	0.82	1.06^{b}	1.01	1.09^{de}
F x 1614	0.70	0.80	0.84	0.87^{bc}	1.02	1.13^{bcd}
F x 3228	0.70	0.81	0.85	0.99^{bc}	1.08	1.06

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX H-16

The effect of display lighting type and intensity on reflectance ratio 685/525nm of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	4.30	4.21	4.35	4.18	4.16	3.96
Fluorescent (F)	4.12	4.21	4.10	4.11	4.21	3.82
0*	3.98	4.41	4.96^{b}	4.27	4.63^{c}_{b}	4.52^{e}_{d}
807	4.34	3.94	4.28^{a}	4.00	4.20_{b}	4.10^{c}
1076	4.28	4.20	4.17^{a}	4.40	4.16_{bc}	3.86_{b}
1614	4.21	4.21	3.86^{a}	4.06	4.25_{a}	3.58^{a}
3228	4.25	4.30	3.83^{a}	4.02	3.68	3.41
Inc. x 0	4.15	4.82	5.65^{b}	4.63^{d}	4.85	4.66
I x 807	4.45	3.94	4.23^{a}	3.70^{a}	4.14	4.23
I x 1076	4.28	4.05	4.16^{a}	4.47^{cd}	4.00	3.88
I x 1614	4.18	4.12	3.96^{a}	4.25^{abcd}	4.28	3.71
I x 3228	4.41	4.13	3.77^{a}	3.87^{ab}	3.55	3.33
Fluor. x 0	3.80	4.01	4.27^{a}	3.91^{abc}	4.42	4.37
F x 807	4.22	3.95	4.34^{a}	4.27^{abcd}	4.27	3.97
F x 1076	4.27	4.35	4.19^{a}	4.32^{bcd}	4.33	3.83
F x 1614	4.23	4.30	3.78^{a}	3.88^{ab}	4.23	3.46
F x 3228	4.08	4.45	3.90^{a}	4.18^{abcd}	3.81	3.48

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX H-17

The effect of display lighting type and intensity on reflectance ratio red/blue of frozen beef *longissimus dorsi* muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	16.60	16.71^{a}	17.37	14.38	12.00	12.66
Fluorescent (F)	16.43	14.81^{b}	15.65	14.17	12.94	12.92
0*	16.46	18.32^{b}	25.12^{b}	17.17^{b}	15.32^{c}	16.37^{b}
807	17.50	15.41^{a}	15.83^{a}	14.36^{a}	12.44^{b}	12.62^{a}
1076	16.06	15.78^{a}	14.17^{a}	14.23^{a}	12.13^{ab}	12.17^{a}
1614	17.11	15.00^{a}	13.82^{a}	13.16^{a}	12.72^{ab}	10.07^{a}
3228	15.40	14.30^{a}	13.60^{a}	12.47^{a}	10.76^{a}	12.71^{a}
Inc. x 0	16.65	19.28	30.40^{c}	17.94	15.20	17.10
I x 807	17.00	16.97	14.78^{ab}	14.78	12.28	13.50
I x 1076	15.76	17.68	14.51^{ab}	14.15	12.22	12.35
I x 1614	17.45	15.01	14.12^{ab}	13.61	10.83	9.90
I x 3228	16.07	14.58	13.04^{a}	11.44	4.49	10.47
Fluor. x 0	16.26	17.36	19.84^{b}	16.41	15.44	14.64
F x 807	18.01	13.86	16.88^{ab}	13.95	12.60	11.74
F x 1076	16.35	13.88	13.83^{a}	14.30	12.04	12.00
F x 1614	16.77	14.97	13.52^{a}	12.70	12.61	10.24
F x 3228	14.74	14.01	14.17^{ab}	13.50	12.03	15.00

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX I-1

The effect of display lighting type and intensity on percent reflectance at 474nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	8.02	8.34	8.30	7.68	8.83[a]	8.37[a]
Fluorescent (F)	8.12	9.87	8.85	7.39	7.50[b]	7.22[b]
0*	7.33	8.09	7.96	7.89	8.34	6.53[a]
807	7.91	8.68	8.62	7.37	7.84	7.03[a]
1076	8.88	8.13	8.28	6.63	8.21	7.21[a]
1614	7.68	9.00	8.56	7.75	7.83	8.93[a]
3228	8.56	11.62	9.43	8.03	8.71	9.28[b]
Inc. x 0	7.13	7.81	6.68	7.75	8.93	6.16
I x 807	8.07	8.00	8.06	7.62	7.94	7.06
I x 1076	9.48	7.65	8.31	6.50	8.37	8.12
I x 1614	7.83	9.43	8.68	7.78	8.43	10.38
I x 3228	7.58	8.81	9.75	8.74	10.50	10.12
Fluor. x 0	7.52	8.37	9.25	8.03	7.75	6.91
F x 807	7.76	9.37	9.18	7.12	7.75	7.00
F x 1076	8.27	8.62	9.25	6.76	8.06	6.31
F x 1614	7.53	8.56	8.43	7.72	7.02	7.47
F x 3228	9.53	14.42	9.12	7.32	6.93	8.44

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX I-2

The effect of display lighting type and intensity on percent reflectance at 525nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	8.91	8.64	8.40[a]	8.05	8.70[a]	8.60[a]
Fluorescent (F)	9.11	10.15	9.03[b]	8.18	7.46[b]	7.51[b]
0*	8.43	8.28	8.15	8.60	8.00	7.00[a]
807	9.16	8.84	8.65	7.87	7.75	7.34[a]
1076	9.64	8.54	8.37	7.17	8.21	7.40[a]
1614	8.60	9.37	8.84	7.29	7.71	9.07[b]
3228	9.23	11.93	9.56	8.67	8.71	9.45[b]
Inc. x 0	8.32	7.87	6.81	7.87	8.37	6.40
I x 807	9.37	8.12	8.12	7.93	7.81	7.41
I x 1076	10.02	8.08	8.44	6.93	8.50	8.28
I x 1614	8.86	9.93	8.75	8.20	8.37	10.54
I x 3228	8.00	9.18	9.87	9.35	10.43	10.31
Fluor. x 0	8.53	8.68	9.50	9.33	7.62	7.60
F x 807	8.96	9.56	9.18	7.81	7.68	7.27
F x 1076	9.27	9.00	8.31	7.41	7.93	6.51
F x 1614	8.34	8.81	8.93	8.38	7.06	7.60
F x 3228	10.46	14.68	9.25	8.00	7.00	8.60

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX I-3

The effect of display lighting type and intensity on percent reflectance at 572nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	6.78	7.90	8.03	7.40	8.73^{a}	9.13^{a}
Fluorescent (F)	7.08	9.26	8.35	7.58	7.50^{b}	7.83^{b}
0*	6.39	7.53	7.46	7.60	7.62	6.38^{a}
807	6.63	8.00	8.06	7.36	7.68	7.70^{a}
1076	7.68	7.76	7.92	6.78	8.24	8.00^{a}
1614	6.60	8.46	8.34	8.76	7.84	9.90^{b}
3228	7.33	11.12	9.15	7.84	9.18	10.45^{b}
Inc. x 0	6.33	7.12	6.31^{ab}	7.06	8.37	5.95^{a}
I x 807	6.45	7.50	7.56^{bc}	7.50	7.56	7.47^{abc}
I x 1076	8.02	7.60	8.15^{bc}	6.68	8.36	8.97^{bc}
I x 1614	6.80	8.93	8.43^{c}	7.66	8.31	11.58^{d}
I x 3228	6.28	8.31	9.68^{c}	8.04	11.06	11.68^{d}
Fluor. x 0	6.45	7.93	8.62^{bc}	8.13	6.87	6.81^{ab}
F x 807	6.81	8.50	8.56^{bc}	7.22	7.81	7.91^{abc}
F x 1076	7.33	7.93	7.68^{ab}	6.87	8.12	7.01^{abc}
F x 1614	6.41	8.00	8.25^{bc}	8.07	7.37	8.21^{abc}
F x 3228	8.38	13.93	8.62^{bc}	7.63	7.31	9.22^{c}

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX I-4

The effect of display lighting type and intensity on percent reflectance at 582nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	6.34	7.43	7.52	8.13	8.55^{a}	8.97^{a}
Fluorescent (F)	6.43	7.63	8.00	7.14	7.08^{b}	7.51^{b}
0*	6.00	7.10	6.83^{a}	8.04	7.25	5.89^{a}
807	6.13	7.66	7.72^{ab}	7.53	7.30	7.11^{ab}
1076	6.96	7.32	7.60^{b}	6.76	7.63	7.80^{b}
1614	6.18	8.45	7.95^{b}	7.84	7.70	9.95^{c}
3228	6.65	7.12	8.66^{b}	8.01	9.10	10.05^{c}
Inc. x 0	5.95	6.67	5.62	8.68	8.06	5.55
I x 807	6.05	7.16	7.27	8.18	7.12	7.21
I x 1076	7.38	7.10	7.67	7.00	8.02	8.83
I x 1614	6.45	8.27	7.93	8.03	8.51	11.61
I x 3228	5.86	8.00	9.08	8.77	11.02	11.66
Fluor. x 0	6.05	7.53	8.03	7.40	6.43	6.23
F x 807	6.21	8.16	8.17	6.87	7.48	7.02
F x 1076	6.53	7.56	7.53	6.53	7.23	6.76
F x 1614	5.91	8.63	7.96	7.65	7.07	8.30
F x 3228	7.43	6.27	8.25	7.25	7.17	9.23

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX I-5

The effect of display lighting type and intensity on percent reflectance at 600nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	16.12	12.65	13.08[a]	12.26	13.83[a]	12.51[a]
Fluorescent (F)	16.22	16.51	14.48[b]	13.12	12.32[b]	10.84[b]
0*	15.33	14.28	14.53	15.09[b]	16.21[b]	12.75[b]
807	17.20	13.84	14.60	12.90[ab]	13.18[a]	11.19[ab]
1076	16.73	13.10	13.00	11.07[a]	12.68[a]	10.00[a]
1614	15.62	14.06	12.97	12.19[a]	11.59[a]	12.33[b]
3228	15.98	17.62	13.84	12.20[a]	11.71[a]	12.11[b]
Inc. x 0	15.03	12.43	12.18	14.31	16.87	11.93
I x 807	18.33	12.62	13.93	13.12	13.68	11.56
I x 1076	17.26	11.62	12.72	10.43	12.81	12.10
I x 1614	15.97	13.81	13.00	11.75	12.43	13.78
I x 3228	14.02	12.74	13.56	11.68	13.37	13.20
Fluor. x 0	15.62	16.12	16.87	15.87	15.56	13.56
F x 807	16.06	15.06	15.25	12.68	12.68	10.82
F x 1076	16.20	14.56	13.25	11.71	12.56	7.91
F x 1614	15.27	14.31	12.93	12.63	10.75	10.87
F x 3228	17.95	22.50	14.12	12.71	10.06	11.02

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX I-6

The effect of display lighting type and intensity on percent reflectance at 650nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	29.53	20.67	20.14[a]	18.83	18.80	16.59
Fluorescent (F)	29.90	23.16	22.08[b]	19.91	17.89	15.84
0*	28.40	25.62[b]	26.25[c]	26.14[b]	24.78[c]	20.40[b]
807	30.60	22.12[ab]	21.93[b]	19.12[a]	18.43[b]	15.43[a]
1076	30.27	21.18[a]	19.25[a]	16.91[a]	17.20[ab]	13.97[a]
1614	29.45	21.78[a]	18.71[a]	17.73[a]	15.77[a]	15.77[a]
3228	29.83	18.87[a]	19.40[ab]	16.95[a]	15.56[a]	15.50[a]
Inc. x 0	27.77	23.50	23.75	24.93	25.25	19.50
I x 807	30.77	21.00	21.43	19.68	19.00	16.00
I x 1076	31.27	18.62	18.57	16.02	17.10	15.25
I x 1614	30.20	20.93	18.50	17.37	16.00	16.68
I x 3228	27.62	19.31	18.43	16.12	16.68	15.51
Fluor. x 0	29.03	27.74	28.75	27.35	24.31	21.31
F x 807	30.42	23.25	22.43	18.56	17.87	14.87
F x 1076	29.27	23.75	19.93	17.77	17.31	12.68
F x 1614	28.71	22.62	18.93	18.10	15.56	14.85
F x 3228	32.05	18.43	20.37	17.78	14.43	15.50

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

THIS BOOK CONTAINS NUMEROUS PAGES THAT ARE BLURRY DUE TO DOUBLE PRINTING IN THE TEXT.

THIS IS AS RECEIVED FROM THE CUSTOMER.

APPENDIX I-7

The effect of display lighting type and intensity on percent reflectance at 685nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	34.42	29.13	29.66^{a}	28.72	29.95	29.03
Fluorescent (F)	35.04	31.50	32.71^{b}	30.63	29.31	27.91
0*	33.08	31.31	33.96^{b}	33.81	34.75^{c}	31.81^{b}
807	35.80	31.34	32.78^{ab}	30.65	30.06^{b}	28.05^{a}
1076	35.42	29.74	29.60^{a}	27.57	29.46^{ab}	27.26^{a}
1614	34.51	30.60	29.90^{a}	28.74	27.56^{ab}	28.31^{a}
3228	34.85	28.60	29.68^{a}	27.60	26.32^{a}	26.94^{a}
Inc. x 0	31.75	24.25	30.75	32.37^{cd}	34.81	30.25^{cd}
I x 807	35.60	30.00	30.75	31.37^{bcd}	31.25	28.10^{bc}
I x 1076	36.90	27.86	28.80	26.37^{a}	28.93	30.22^{cd}
I x 1614	35.26	29.87	28.87	27.50^{ab}	27.06	29.37^{bc}
I x 3228	32.62	28.68	29.12	26.00^{a}	27.68	27.25^{abc}
Fluor. x 0	34.41	33.37	37.18	35.26^{d}	34.68	33.37^{d}
F x 807	36.00	32.68	34.81	29.93^{abc}	28.87	28.00^{bc}
F x 1076	33.95	31.62	30.37	28.77^{abc}	30.00	24.31^{a}
F x 1614	33.76	31.31	30.93	29.98^{abc}	28.06	27.25^{abc}
F x 3228	37.07	28.50	30.25	29.20^{abc}	24.96	26.63^{ab}

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX I-8

The effect of display lighting type and intensity on reflectance scan blue area of frozen beef psoas major muscle[1,2]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	0.13	0.13	0.14	0.13	0.15[a]	0.15[a]
Fluorescent (F)	0.14	0.14	0.15	0.13	0.12[b]	0.13[b]
0*	0.13	0.13	0.12	0.13	0.12	0.11[a]
807	0.14	0.14	0.15	0.12	0.13	0.12[a]
1076	0.14	0.14	0.13	0.13	0.13	0.12[a]
1614	0.13	0.14	0.14	0.14	0.13	0.16[b]
3228	0.14	0.12	0.16	0.14	0.15	0.17[b]
Inc. x 0	0.12	0.12	0.11	0.12	0.13	0.11
I x 807	0.13	0.12	0.14	0.11	0.14	0.12
I x 1076	0.14	0.14	0.14	0.12	0.14	0.12
I x 1614	0.13	0.13	0.14	0.14	0.14	0.19
I x 3228	0.12	0.14	0.16	0.15	0.18	0.20
Fluor. x 0	0.13	0.14	0.14	0.14	0.11	0.12
F x 807	0.14	0.16	0.17	0.12	0.12	0.12
F x 1076	0.15	0.14	0.13	0.13	0.12	0.11
F x 1614	0.13	0.15	0.13	0.13	0.13	0.13
F x 3228	0.16	0.11	0.16	0.13	0.11	0.15

[1]Means of the same set of observations within the same column bearing similaror no superscript letters are not significantly different ($P<0.05$).

*Light intensity in lumens/meter^2

[2]1 = 6.25 cm^2

APPENDIX I-9

The effect of display lighting type and intensity on reflectance scan red area of frozen beef psoas major muscle[1,2]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	2.00	1.70	1.75^{a}	1.55	1.61	1.50
Fluorescent (F)	2.05	1.79	1.90^{b}	1.62	1.57	1.47
0*	1.96	1.92	2.12^{c}	1.96^{c}	1.96_{b}	1.76_{b}^{c}
807	2.09	1.76	1.95^{bc}	1.65^{b}	1.62_{ab}	1.48^{b}
1076	2.05	1.66	1.68^{a}	1.37^{a}	1.53_{ab}	1.32^{a}
1614	2.03	1.79	1.62^{ab}	1.53^{ab}	1.47^{a}	1.46^{ab}
3228	2.02	1.59	1.75^{ab}	1.41^{ab}	1.40^{a}	1.41^{ab}
Inc. x 0	1.91	1.81	1.94	1.90	1.96	1.71
I x 807	2.07	1.72	1.88	1.71	1.67	1.46
I x 1076	2.15	1.57	1.70	1.38	1.53	1.41
I x 1614	2.01	1.76	1.62	1.45	1.46	1.53
I x 3228	1.85	1.64	1.62	1.28	1.44	1.41
Fluor. x 0	2.00	2.04	2.31	2.01	1.96	1.82
F x 807	2.11	1.80	2.01	1.59	1.57	1.50
F x 1076	1.94	1.76	1.68	1.36	1.52	1.23
F x 1614	2.01	1.82	1.63	1.60	1.48	1.40
F x 3228	2.18	1.54	1.87	1.54	1.34	1.40

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

[2]1 = 6.25 cm^2

APPENDIX I-10

The effect of display lighting type and intensity on reflectance scan total area of frozen beef psoas major muscle[1,2]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	4.01	4.75	3.56	3.33	3.65[a]	3.29
Fluorescent (F)	4.06	3.78	3.72	3.41	3.26[b]	3.03
0*	3.85	3.91	3.89	3.94[b]	4.11[b]	3.21[ab]
807	4.12	3.76	3.74	3.36[a]	4.41[a]	2.89[a]
1076	4.13	6.43	3.44	3.03[a]	3.28[a]	2.86[a]
1614	4.01	3.84	3.45	3.27[a]	3.16[a]	3.42[b]
3228	4.07	3.38	3.69	3.26[a]	3.30[a]	3.42[b]
Inc. x 0	3.72	3.62	3.54	3.82	4.38	3.04
I x 807	4.09	3.56	3.70	3.43	3.42	2.88
I x 1076	4.45	9.09	3.45	2.94	3.37	3.09
I x 1614	4.12	3.83	3.47	3.18	3.34	3.79
I x 3228	3.66	3.64	3.63	3.30	3.73	3.63
Fluor. x 0	3.97	4.20	4.23	4.06	3.84	3.38
F x 807	4.16	3.97	3.79	3.28	3.41	2.91
F x 1076	3.82	3.77	3.43	3.12	3.20	2.62
F x 1614	3.90	3.84	3.43	3.35	2.98	3.05
F x 3228	4.48	3.11	3.74	3.23	2.86	3.21

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

[2]1 = 6.25 cm^2

APPENDIX I-11

The effect of display lighting type and intensity on reflectance ratio 474/525nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	0.91	0.96	0.98	0.95^{a}	1.01	0.97
Fluorescent (F)	0.88	0.96	0.97	0.90^{b}	1.00	0.96
0*	0.87	0.97	0.97	0.91	1.03	0.93^{a}
807	0.90	0.98	0.99	0.93	1.01	0.95^{ab}
1076	0.91	0.95	0.98	0.92	1.00	0.97^{b}
1614	0.89	0.95	0.96	0.93	1.00	0.98^{b}
3228	0.91	0.96	0.98	0.93	1.00	0.98^{b}
Inc. x 0	0.86	0.99	0.97	0.98^{e}	1.05	0.96
I x 807	0.92	0.98	0.99	0.95^{de}	1.01	0.95
I x 1076	0.94	0.94	0.98	0.93^{bcd}	0.98	0.97
I x 1614	0.88	0.94	0.98	0.95^{cde}	1.00	0.98
I x 3228	0.94	0.95	0.98	0.94^{bcd}	1.00	0.98
Fluor. x 0	0.87	0.96	0.97	0.85^{a}	1.01	0.90
F x 807	0.86	0.98	1.00	0.91^{b}	1.00	0.9[illegible]
F x 1076	0.88	0.95	0.99	0.91^{bc}	1.02	0.97
F x 1614	0.90	0.96	0.93	0.92^{bcd}	0.99	0.98
F x 3228	0.89	0.96	0.98	0.91^{bcd}	0.99	0.98

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^{2}

APPENDIX I-12

The effect of display lighting type and intensity on reflectance ratio 572/525nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	0.76	0.91	0.95^{a}	0.92	0.99	1.05
Fluorescent (F)	0.77	0.90	0.92^{b}	0.93	1.00	1.04
0*	0.75^{ab}	0.91	0.91	0.88	0.93^{a}	0.91^{a}
807	0.74^{a}	0.90	0.93	0.93	0.99^{b}	1.04^{b}
1076	0.79^{abc}	0.91	0.94	0.95	1.00^{b}	1.08^{c}
1614	0.76^{bc}	0.91	0.94	0.95	1.02^{bc}	1.09^{c}
3228	0.78^{bc}	0.90	0.95	0.91	1.06^{c}	1.10
Inc. x 0	0.76	0.90	0.92	0.89	0.97^{b}	0.92^{a}
I x 807	0.73	0.92	0.92	0.94	0.96^{b}	1.00^{b}
I x 1076	0.80	0.94	0.96	0.96	0.98^{b}	1.08^{c}
I x 1614	0.76	0.91	0.96	0.93	0.99^{bc}	1.10^{c}
I x 3228	0.78	0.90	0.98	0.86	1.06^{d}	1.1^{d}
Fluor. x 0	0.75	0.91	0.90	0.86	0.89^{a}	0.89^{a}
F x 807	0.75	0.88	0.93	0.92	1.01^{bcd}	1.08^{c}
F x 1076	0.78	0.88	0.93	0.93	1.02^{cd}	1.07^{c}
F x 1614	0.76	0.91	0.92	0.96	1.05^{cd}	1.08^{c}
F x 3228	0.78	0.91	0.93	0.96	1.05	1.08^{c}

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX I-13

The effect of display lighting type and intensity on reflectance ratio 685/474nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	4.43	3.59	3.80	3.86^{a}	3.56^{a}	3.75
Fluorescent (F)	4.58	3.75	3.72	4.25^{b}	4.04^{b}	3.97
0*	4.67	3.90	4.61^{c}	4.47	4.40^{c}	4.96^{c}
807	4.65	3.69	3.82^{b}	4.20	3.86^{b}	4.07^{b}
1076	4.27	3.68	3.64^{b}	4.21	3.70^{ab}	3.90^{b}
1614	4.62	3.59	3.56^{ab}	4.80	3.71^{ab}	3.33^{a}
3228	4.30	3.49	3.18^{a}	3.61	3.31^{a}	3.03^{a}
Inc. x 0	4.57	3.80	5.19^{d}	4.26	4.12	4.94
I x 807	4.50	3.83	3.84^{abc}	4.14	3.96	4.10
I x 1076	4.03	3.66	3.56^{abc}	4.11	3.58	3.92
I x 1614	4.68	3.38	3.41^{a}	3.65	3.30	3.00
I x 3228	4.37	3.29	3.00^{c}	3.16	2.82	2.78
Fluor. x 0	4.77	4.00	4.02^{bc}	4.68	4.67	5.00
F x 807	4.81	3.56	3.80^{bc}	4.25	3.77	4.05
F x 1076	4.51	3.71	3.72^{bc}	4.30	3.83	3.88
F x 1614	4.57	3.80	3.71^{ab}	3.95	4.12	3.67
F x 3228	4.24	3.69	3.36^{ab}	4.06	3.80	3.28

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX I-14

The effect of display lighting type and intensity on reflectance ratio 630/525nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	3.02	2.12	3.80	2.08	1.94^{a}	1.80
Fluorescent (F)	3.02	2.25	3.72	2.08	2.08^{b}	1.84
0*	3.02	2.72^{c}	4.61^{c}	2.73^{c}	2.80^{d}	2.57^{dc}
807	3.09	2.20^{b}	3.82^{b}	2.13^{b}	2.03^{c}	1.84^{b}
1076	2.89	2.09^{ab}	3.64^{b}	1.99^{a}	1.84^{b}	1.65^{a}
1614	3.11	2.04^{ab}	3.56^{ab}	1.81^{a}	1.80^{b}	1.55^{a}
3228	3.00	1.87^{a}	3.18^{a}	1.73^{a}	1.60^{a}	1.46^{a}
Inc. x 0	2.97	2.64	5.19^{d}	2.85^{f}	2.72	2.64^{f}
I x 807	3.13	2.29	3.84^{bc}	2.22^{d}	2.08	1.87^{e}
I x 1076	2.83	2.00	3.56^{abc}	1.96^{bc}	1.78	1.60^{bc}
I x 1614	3.13	1.86	3.41^{abc}	1.77^{b}	1.70	1.45^{ab}
I x 3228	3.03	1.82	3.00^{a}	1.58^{a}	1.43	1.40^{a}
Fluor. x 0	3.08	2.81	4.02^{c}	2.62^{e}	2.90	2.50^{f}
F x 807	3.05	2.11	3.81^{bc}	2.04^{cd}	1.98	1.81^{de}
F x 1076	2.94	2.18	3.72^{bc}	2.02^{cd}	1.90	1.70^{cde}
F x 1614	3.08	2.22	3.71^{bc}	1.85^{bc}	1.90	1.66^{cd}
F x 3228	2.96	1.92	3.36^{ab}	1.87^{bc}	1.76	1.53^{bc}

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX I-15

The effect of display lighting type and intensity on reflectance ratio 582/525nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	0.72	0.86	0.89	1.07^{a}	0.97	1.03
Fluorescent (F)	0.70	0.86	0.88	0.88^{b}	0.95	1.00
0*	0.71	0.86	0.83^{a}	0.94	0.89^{a}	0.84^{a}
807	0.69	0.87	0.89^{b}	0.95	0.94^{a}	0.97^{b}
1076	0.72	0.85	0.91^{b}	0.95	0.92^{a}	1.05^{c}
1614	0.72	0.92	0.89^{b}	0.95	1.01^{b}	1.10^{c}
3228	0.72	0.81	0.90^{b}	0.93	1.05^{b}	1.10^{c}
Inc. x 0	0.71	0.85	0.81	1.10^{f}	0.94	0.87
I x 807	0.69	0.88	0.89	1.03^{e}	0.91	0.97
I x 1076	0.74	0.87	0.90	1.01^{e}	0.93	1.07
I x 1614	0.73	0.85	0.90	0.99^{d}	1.02	1.10
I x 3228	0.74	0.86	0.92	0.94^{cd}	1.06	1.13
Fluor. x 0	0.71	0.87	0.84	0.80^{a}	0.84	0.81
F x 807	0.69	0.85	0.89	0.88^{b}	0.97	0.98
F x 1076	0.71	0.84	0.91	0.89^{b}	0.91	1.04
F x 1614	0.70	1.00	0.89	0.92^{bc}	1.01	1.09
F x 3228	0.70	0.76	0.89	0.91^{bc}	1.04	1.08

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX I-16

The effect of display lighting type and intensity on reflectance ratio 685/525nm of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	4.00	3.46	3.73	3.70	3.60^{a}	3.64
Fluorescent (F)	4.00	3.61	3.64	3.82	4.07^{b}	3.78
0*	4.00	3.81	4.46^{cb}	4.07^{b}	4.50^{cb}	4.60^{dcb}
807	4.10	3.61	3.81^{b}	3.91^{b}	3.91^{ab}	3.90^{b}
1076	3.85	3.49	3.60^{ab}	3.88^{b}	3.72^{ab}	3.80^{a}
1614	4.08	3.42	3.41^{ab}	3.56^{a}	3.72^{ab}	3.30^{a}
3228	3.93	3.34	3.13^{a}	3.35^{a}	3.31^{a}	3.00^{a}
Inc. x 0	3.88	3.77	5.01^{d}	4.19^{d}	4.31	4.76
I x 807	4.10	3.75	5.82^{bc}	3.96^{cd}	4.01	3.90
I x 1076	3.77	3.44	3.48^{abc}	3.84^{bcd}	3.50	3.82
I x 1614	4.10	3.18	3.36^{abc}	3.48^{b}	3.33	2.97
I x 3228	4.10	3.15	2.96^{a}	2.97^{a}	2.84	2.75
Fluor. x 0	4.11	3.84	3.91^{c}	3.95^{cd}	4.70	4.44
F x 807	4.10	3.47	3.80^{bc}	3.86^{bcd}	3.81	3.90
F x 1076	3.92	3.54	3.72^{bc}	3.92^{bc}	3.94	3.75
F x 1614	4.08	3.67	3.47^{abc}	3.64^{bc}	4.11	3.60
F x 3228	3.77	3.54	3.29^{ab}	3.72^{bc}	3.79	3.23

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

APPENDIX I-17

The effect of display lighting type and intensity on reflectance ratio red/blue of frozen beef psoas major muscle[1]

	TIME (DAYS)					
	0	1	3	7	21	42
Incandescent (I)	16.02	13.43	13.44	12.04	11.48^{a}_{b}	11.18
Fluorescent (F)	15.02	12.92	13.70	12.09	12.95	11.74
0*	15.95	14.56	18.93^{b}_{a}	14.62^{b}_{b}	15.90^{c}_{b}	15.58^{c}_{b}
807	15.83	12.50	12.59^{a}	13.77^{a}	12.29^{ab}	12.32^{b}
1076	14.93	11.83	13.00^{a}	10.91^{a}	11.90^{a}	11.15^{a}
1614	15.55	14.08	12.27^{a}	11.03^{a}	11.06	9.51
3228	15.34	12.90	11.06^{a}	10.01^{a}	9.92	8.73
Inc. x 0	15.68	14.93	20.42	15.22^{e}	15.07	15.56
I x 807	16.86	13.55	13.11	14.60^{bc}	11.96	12.57
I x 1076	15.71	11.38	12.50	11.50^{abc}	11.33	11.37
I x 1614	15.97	15.38	11.11	10.50^{a}	10.71	8.87
I x 3228	15.90	11.90	10.07	8.40^{de}	8.32	7.52
Fluor. x 0	16.23	14.20	17.45	14.03^{cde}	16.73	15.60
F x 807	14.80	11.43	12.06	12.94^{ab}	12.61	12.10
F x 1076	14.16	12.29	13.51	10.32^{bcd}	12.47	10.94
F x 1614	15.13	12.78	13.43	11.57^{bcd}	11.42	10.15
F x 3228	14.78	13.90	12.06	11.61	11.53	9.95

[1]Means of the same set of observations within the same column bearing similar or no superscript letters are not significantly different ($P < 0.05$).

*Light intensity in lumens/meter^2

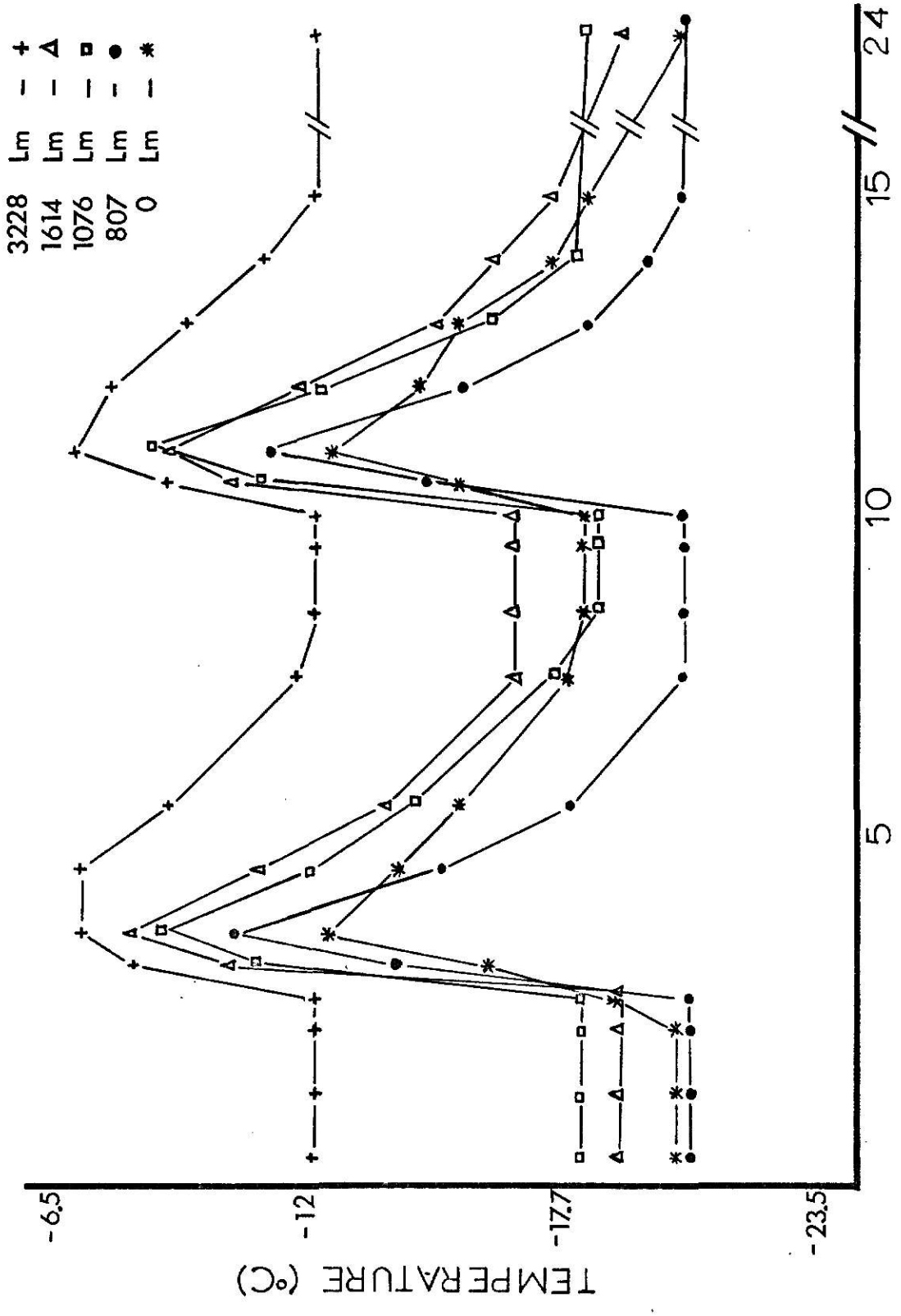


FIGURE 4. Time-1/2 radius probes temperature relationship for the case with the incandescent source.

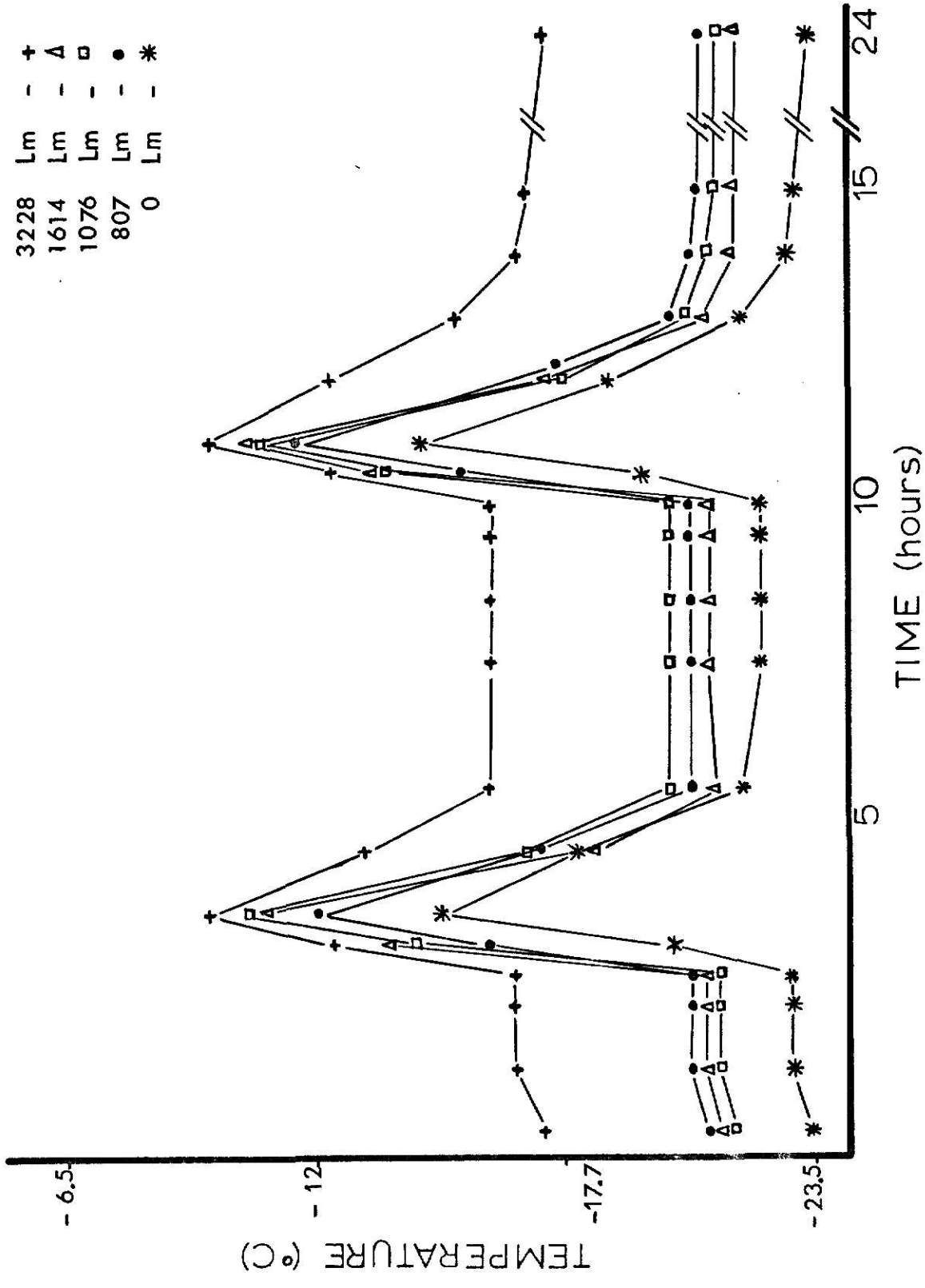


FIGURE 5. Time-1/2 radius probes temperature relationship for the case with the fluorescent source.

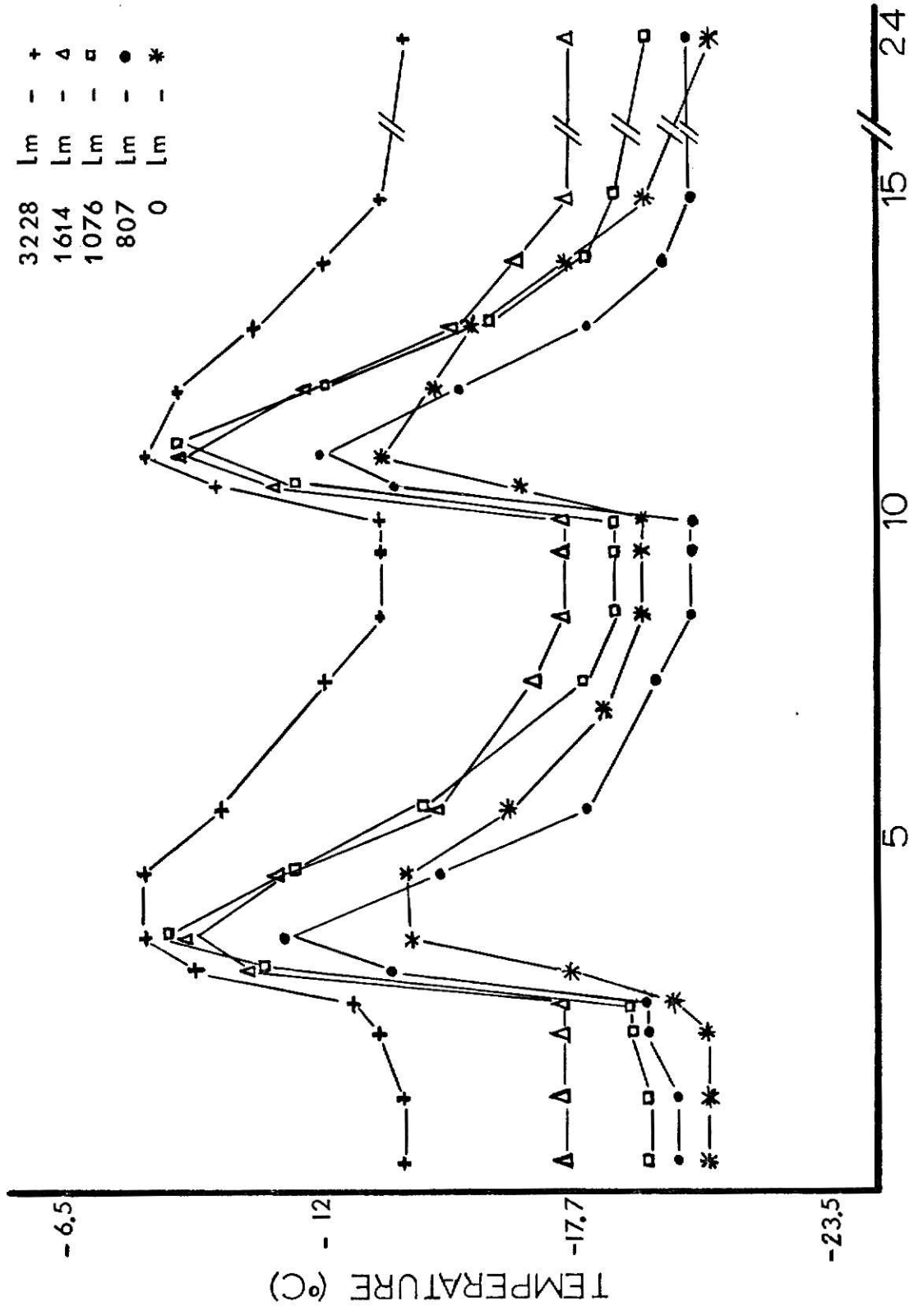


FIGURE 6. Time-bottom temperature relationship for the case with the incandescent source.

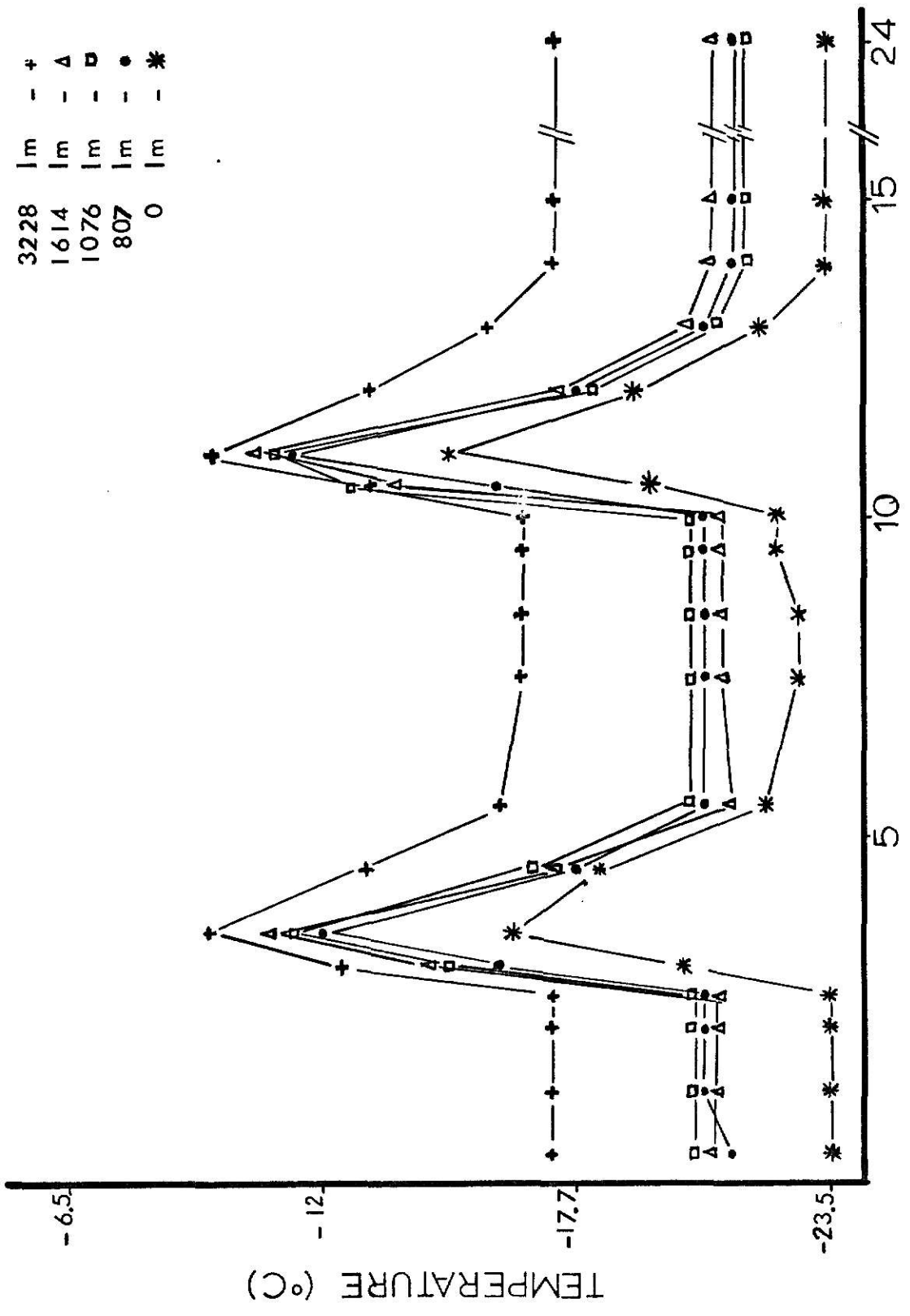


FIGURE 7. Time-bottom temperature relationship for the case with the fluorescent source.

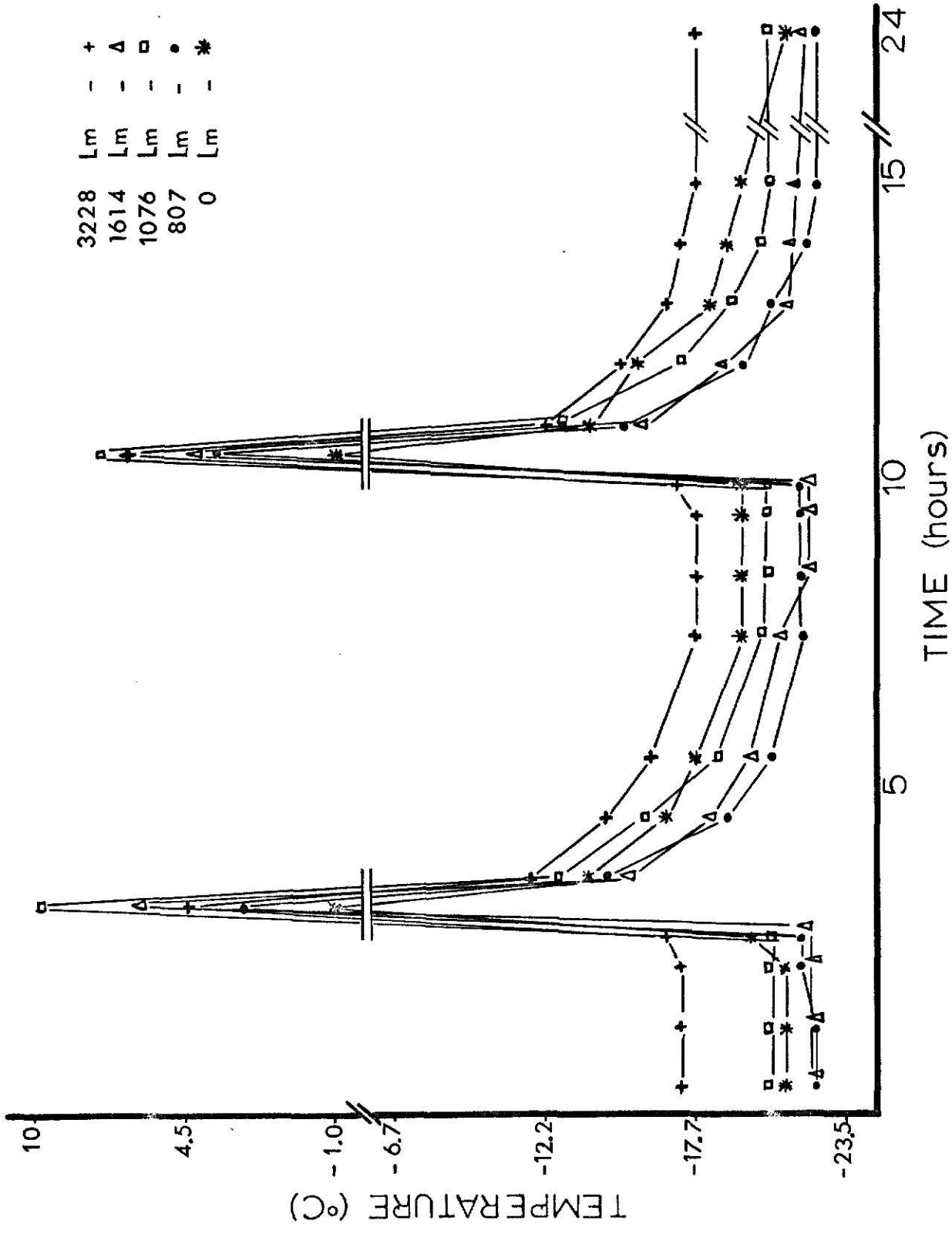


FIGURE 8. Time-air temperature relationship for the case with the incandescent source.

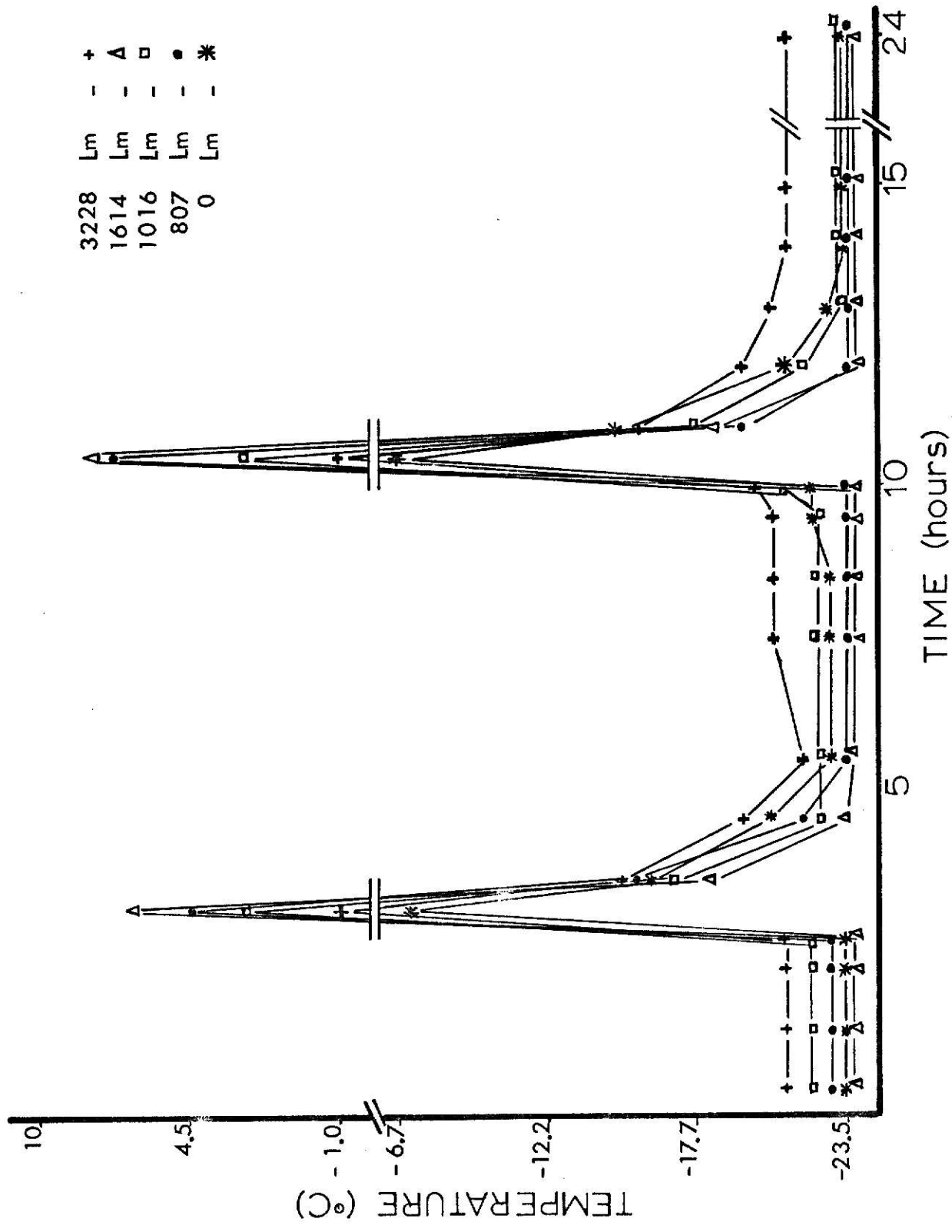


FIGURE 9. Time-air temperature relationship for the case with the fluorescent source.

EFFECT OF DISPLAY LIGHT INTENSITY ON COLOR STABILITY OF FROZEN BEEF CUTS IN TRANSPARENT FILM

by

JORGE ALBERTO SANTAMARIA

D.V.M., Universidad de Antioquia, 1967
Medellin-Colombia

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1970

Frozen beef steaks were stored at -21°C and the color stability during display was evaluated. Two light sources (Deluxe Cool White fluorescent and incandescent with Holophane Prismatic Reflectance fixture) and five intensity levels (0, 807, 1076, 1614 and 3228 lm/m^2) were compared during a display period of 42 days. Objective and subjective color measurements (reflectance spectrophotometry and visual score, respectively) were recorded immediately after freezing, and then at day 1, 3, 7, 21 and 42. Evaluation were made on both the longissimus dorsi and psoas major muscles.

Fluorescent display lighting caused less color deterioration in frozen beef steaks. However, the incandescent source resulted in a brighter color when visually appraised, due to some masking of the deterioration by the light.

A pronounced effect on meat color deterioration was observed with a light intensity of 3228 lm/m^2, whereas 0 lm/m^2 showed no effect and resulted in excellent color stability. Intensities of 807 and 1076 lm/m^2 were found not significantly different ($P < 0.05$), nor were 1076 and 1614, but the difference was significant between 807 and 1614 lm/m^2 with the discoloration greater at the higher intensity.

Significantly different ($P < 0.05$) interactions between lighting type and intensity were found. The incandescent source produced brighter color scores at low intensities (807, 1076 lm/m^2), but at the highest intensity (3228 lm/m^2) the fluorescent

source appeared to be superior.

Percent of reflectance at 630 nm and 650 nm indicated larger proportions of metmyoglobin at the end of the display period. Correlation coefficients between the objective measurements and visual score were low at day 0 when little color variation exists, but greater values were found at 630-650 nm for both muscles, at most time periods. Visual appraisal score and percent of reflectance correlations at 474, 525, 572, 582 and 600 nm, were low and non significant. The ratios 474/525, 572/525, 685/525 and 685/474 nm failed to show any relationship with visual score, nor did the percent reflectance scan areas, blue (450-474 nm), red (630-700 nm) and total (400-700 nm), and the ratio red/blue area.

The mean of all reflectance values of 630 and 650 nm decreased whereas the mean value at 582 nm tended to increase from day 0 to day 42. Progressive decline of the ratio 630/525 nm and an increase for the ratios 572/525 nm and 582/525 nm was observed during the display time. This pattern was found for the longissimus dorsi as well as for the psoas major muscle.