EFFECT OF TEMPERATURE, STORAGE CONDITIONS AND LIGHT ON THE COLOR OF PREPACKAGED FROZEN MEAT

By

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AN ABSTRACT

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EFFECT OF TEMPERATURE, STORAGE CONDITIONS AND LIGHT ON THE COLOR OF PREPACKAGED FROZEN MEAT

Freezing as a method for preserving meat has been used since the early 1900's. During the past few years, frozen meat products have become very prominent because of certain conditions produced by World War II. The development of locker plants, home freezer storage units and display type freezer cases has helped to accelerate the wide spread acceptance of frozen meats. In 1947 (1954), only 13 frozen meat processors were in the country. By 1953, the number increased to 138, an increase of more than 950%. Output of frozen meats increased from five million pounds in 1938 to 250 million pounds in 1956 (1956).

Frozen storage of prepackaged frozen meat will be of economic value to both the producer and the consumer. Prepackaging frozen meat will give greater recovery of bones, fat, etc. There will be a difference in transportation, storage, handling costs in favor of either packer, producer or processor.

Packaging frozen meat produced problems that have proven to be difficult to solve. They are concerned with temperature, storage conditions (which include temperature, air movement, humidity), packaging materials and methods (which include visibility, neatness of cut and tightness of wrap), and display under light. A major factor affecting the attractiveness of prepackaged frozen retail meat is the color of the exposed lean.

Myoglobin, the muscle pigment, is chiefly responsible for the color of lean meat, which under various conditions changes from oxymyoglobin

(the desirable red color) to metmyoglobin (the brown color so characteristic of meat color degradation). Review of the literature reveals some information concerning the effect of various conditions on discoloration in prepackaged frozen meat, but little information concerning the character of this discoloration.

The main purpose of this study was to attempt to characterize the chemical state of myoglobin as affected by various storage conditions.

The Longissimus dorsi muscle from U.S. Good and Choice grade beef ribs was used throughout this study. Boneless rib steaks 1 inch thick were cut from the wholesale rib cut. Steaks were placed in Cry-O-Wrap plastic bags, vacuumized, closed with a Cry-O-Wrap clip, dipped into boiling water which reduced the size of the bag approximately one-third, thus giving the steaks a tight wrap. Prepackaged frozen steaks used in the various studies were stored in a self-service case or in a circulating cold air walk-in type freezer.

Steaks stored in the self-service frozen food case under the influence of light were kept under fluorescent lamps delivering 56 ftc. of illumination. Various colored filters were used in the study concerning the attribute of light that may be responsible for color degradation. Steaks stored under colored fluorescent lamps deliverying 20 ftc. of illumination were kept in the 0°F walk-in freezer.

Measurements of surface color of meat were made by the use of Munsell spinning disks as given by Voegeli (1952). Estimation of the percent metmyoglobin was essentially as applied by Mangel (1951) and Butler (1953).

Temperature variations in a self-service frozen food case affects the appearance of prepackaged frozen meat packaged in transparent oxygen impermeable wrapping materials. Prehandling conditions and rate of freezing affects initial color degradation of prepackaged frozen meat. Repeated freezing and thawing in an oxygen impermeable wrapper has a marked affect on the color of prepackaged meat. With alternate freezing and thawing cycles, there was an increase or decrease of metmyoglobin formation. Display of prepackaged frozen meat under incandescent or fluorescent lighting causes degradation of color. Temperature of display of prepackaged frozen meat under fluorescent lighting had an effect on color degradation. Samples stored under fluorescent light at 0°F showed less discoloration and metmyoglobin formation than samples stored in darkness at the same temperature in the self-service case in which there was considerable temperature fluctuation.

Wave lengths of light between 560 and 630 mu (yellow and orange portion of the spectrum) seem to be responsible for color degradation of prepackaged frozen meat. Frozen meat stored under green and red fluorescent lamps has better color stability but these lights give meat an unfamiliar appearance. It would appear that the light from the yellow portion (580 mu region) of the spectrum emitted by white fluorescent lamps commonly used for frozen food display cases is responsible for color degradation of prepackaged frozen meat. The formation of metmyoglobin is the primary cause of discoloration when prepackaged frozen meat in a transparent wrapper is exposed to light.

References

Anonymous. 1954. Packaging Shift Seen Spur To Frozen Meats. Quick Frozen Foods, 16(6):99.

Anonymous. 1956. The Outlook For Frozen Foods. U.S.D.A. Agricultural Marketing Service. A.M.S. - 154.

Butler, O. D., Bratzler, L. J., and Mallman, W. L. 1953. The Effect of Bacteria on the Color of Prepackaged Retail Beef Cuts. Food Technology, Vol. 7(10)397.

Mangel, Margaret. 1951. The Determination of Methemoglobin in Beef Muscle Extracts. I. A Study of Spectrophometric Methods. II. Factors Affecting Metmyoglobin Formation In Frozen Beef. University of Missouri Research Bulletin. 474. 24 pages.

Voegeli, M. 1952. The Measurement of Fresh Beef Muscle Color Change by Dish Colorimetry. Unpublished Ph.D. Thesis. Michigan State College. 125 pages.

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INTRODUCTION

Freezing as a method for preserving meat has been used since the early 1900's. During the past few years frozen meat products have become very prominent because of certain conditions produced by World War II. The development of locker plants, home freezer storage units and display type freezer cases has helped to accelerate the wide spread acceptance of frozen meats. In 1947 (Anonymous, 1954), only 13 frozen meat processors were in the country. By 1953, the number had increased to 138, an increase of more than 950%. Output of frozen meats increased from five million pounds in 1938 to 125 million pounds in 1952, and to 250 million pounds in 1956 (Anonymous, 1956). This indicates that the program for experimental adjustment of prepackaged frozen meat and the ground work for the "evolution" of frozen meat is slowly being laid by gradual introduction of frozen steaks, chops, etc.

Freezer storage offers a means toward equalizing the supply of fresh meats available at all seasons of the year. This is of economic value to both the producer and the consumer. Prepackaging frozen meat will give greater recovery of bones, fat, and trimmings which can be converted into more useful and valuable products. There will be a difference in transportation, storage, handling, and packaging costs in favor of either the packer, producer or processor. Centralized cutting, trimming, freezing and packaging of meat at the packing plant would eliminate shipment of bulk carcasses and save freight costs in favor of the consumer, producer or processor.

However, the method of packaging frozen meat gave rise to many problems, though they seem to be fewer, but more difficult to solve. These

problems are concerned with temperature, storage conditions (which include temperature, air movement, humidity), packaging materials and methods (which include visibility, neatness of cut and tightness of wrap) and display under light. A major factor affecting the attractiveness of prepackaged frozen retail meat cuts is the color of the exposed lean. The color of meat and meat products is of great importance in our system of meat marketing. Changes in color are largely utilized by the retailer and the meat trade as an indication of meat quality. Consumers are very critical of meat color and discriminate against meat cuts that show discoloration.

Myoglobin, the muscle pigment, is chiefly responsible for the color of lean meat, which under various conditions changes from oxymyoglobin (the desirable red color) to metmyoglobin (the brown color so characteristic of meat color degradation.

In reviewing the literature on the color of meat, it becomes apparent that reports dealing with color degradation of prepackaged frozen meat per se are limited, and since it has been shown by Allen (1948) that color is very important factor in prepackaged meat sales, it would seem that any study of the factors involved would be beneficial to the meat industry.

REVIEW OF LITERATURE

A review of the literature revealed some investigations on discoloration of frozen meat. Much of the research has been done with ground beef. The investigators believed that if there were going to be color changes, it would be accelerated by the large surface area exhibited by ground beef. Studies concerning the discoloration of prepackaged frozen meat in the form of steaks as displayed under store conditions are rather limited. In order to understand the effect of various conditions on the color change of meat, it is essential that one have a thorough knowledge of the chemistry of the muscle pigment (myoglobin).

The bright red color of fresh, cured, and frozen meat, as well as color degradation, is due to the chemical state of the pigment called myoglobin (formerly referred to as muscle hemoglobin). It was interesting to go through the literature and note the many interesting theories regarding the true character of a pigment connected with the muscular substance. As early as the beginning of the eighteenth century, inquiries were made regarding the origin of the color of the muscle. Boerhave (1739) was of the opinion that it was derived from blood and could be washed away with it. Hilderbrandt (1789) maintained that the color of the muscular tissue was connected with its great quantity of blood vessels, but also pointed out that the stronger the "body" the redder the muscle and blood. Bichat (1803) pursued the same line of thought, and stated that the muscle did not take its color from the circulating blood, but from that which became deposited in the tissue.

From 1803 to 1886 many theories were developed regarding the nature of the muscle pigment. During the years 1886 to 1890, a great interest developed regarding the nature of the pigment in muscle. MacMunn (1886) demonstrated that a pigment could be extracted from muscles, and that this pigment gave rise to decomposition products which were related to hemoglobin, but nevertheless not identical with the decomposition products of this latter substance. He applied the term "myohematin" to this substance. He also assumed that this new substance had something to do with the storing of oxygen in fresh muscle.

In 1897, K. A. H. Morner (1897) was able to report that he had proved that the absorption spectrum of muscle pigment was not identical with that of hemoglobin, and that these two substances were quite different. Morner (1897), through his water extracts on muscles of dogs, cattle, and horses, showed the displacement to the red part of the spectrum of myoglobin as compared to hemoglobin. Gunther (1921), as a result of his findings, was convinced that muscle pigment was not identical with hemoglobin, and suggested and used throughout the rest of his work, for the first time, the term "myoglobin". In 1926, Whipple (1926) did many extraction techniques, in order to get an estimate on the myoglobin content of muscles.

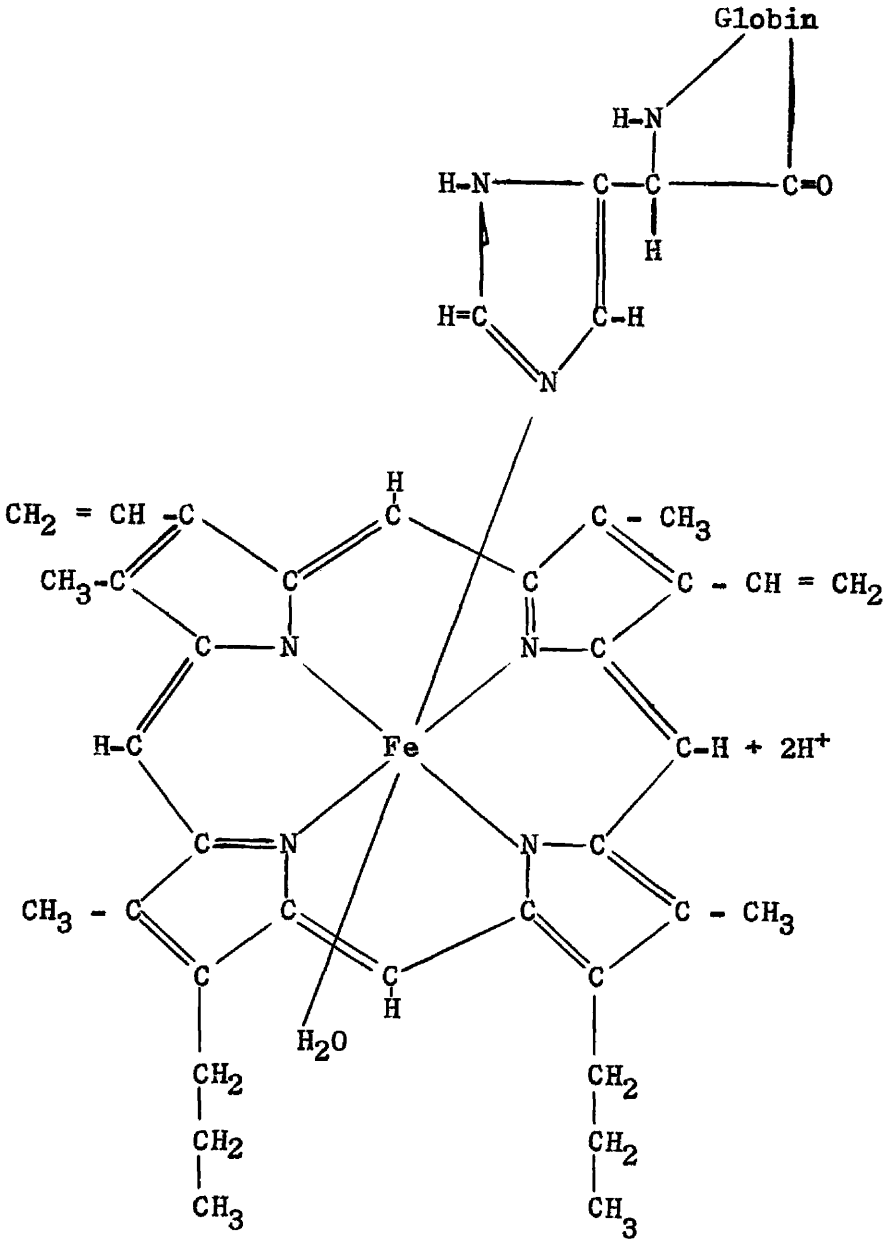
During the next few years, a series of publications followed in which the occurrence of myoglobin and its chemical conditions were subjected to more comprehensive analysis. Theorell's (1932, 1934) conclusive contributions to the research regarding the nature of myoglobin were presented in 1932 and 1934. It was in 1932 that Theorell succeeded in crystallizing myoglobin which gave chemists and physiologists new grounds for continued

research. Schenk, Hall and King (1934) found in their work that the myoglobin content in ribeye muscle of beef did not disclose any parallelism with the hemoglobin content. During the years between 1934 to the present time much research has been going on to better understand the chemical changes that occur in muscle due to this pigment "myoglobin" and its various derivatives.

Chemistry of Myoglobin

Myoglobin and hemoglobin belong to the group of hemo-proteins, comprising a prosthetic group, protoporphrin and a protein component, viz, globin. The former consists of four pyrrol rings in the center of which an iron atom is coupled to the four nitrogen atoms, thus making the porphyrin an iron porphyrin. Bound to this iron atom is the function, essential to the hemo-proteins, of a respiratory pigment. The structure of the heme part of the molecule is shown in Figure 1 (1956). Only four of the six valences of the iron atom are connected with the nitrogen of the pyrrol rings. The other two seem to be bound to the protein component, Kendrew (1949). Theorell's works (1932, 1934 and 1947) offered comprehensive knowledge of the chemistry of myoglobin. His works showed that the iron content of myoglobin was identical with that of hemoglobin, viz, 0.345 percent.

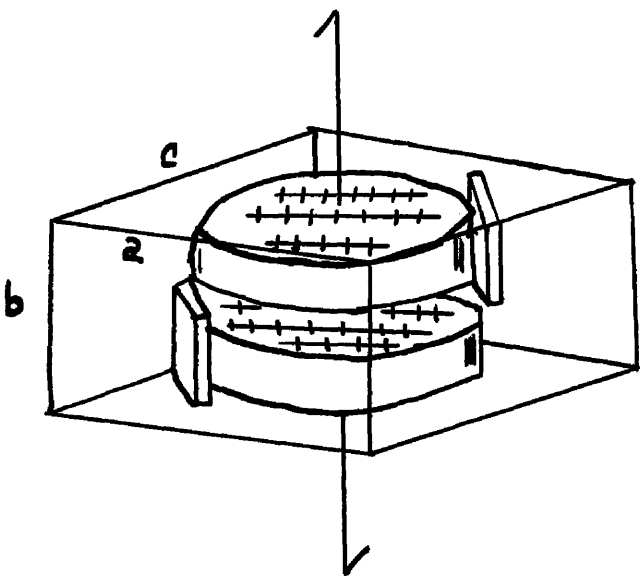
Kendrew (1949) proposed the following structure of myoglobin as shown in Figure 2. He believed that the structure of myoglobin is constituted by two discs, 57Å diameter and 9Å thick, parallel to each other and perpendicular to their axis, separated by a layer of liquid of crystallization 6.6Å thick. Each of the discs is formed by one polypeptide chain, folded



Heme Structure of Myoglobin

Figure 1

Schweigert, B. S. 1956. Proc. of the Eighth Research Conference, Univ. of Chicago, Chicago, Illinois. pg 61-64.



Structure of Myoglobin

Figure 2.

on itself in four equal sections. The prosthetic group (protoferroheme) is perpendicular to the plane of each disc and extends above and below it, its thickness being about 15Å greater than that of the disc itself. He found in Svedberg's ultracentrifuge a sedimentation constant for myoglobin of 2.0×10^{-13}. The molecular weight of 34,000 reported by Theorell (1932) was later corrected by Svedberg (1939) to a molecular weight of about 17,000, which conformed with those of Polson (1937), and Roche (1940). Bowen (1948) reported a molecular weight of 16,400 and an iron content of 0.323 percent. The isoelectric point of myoglobin was found to be pH 6.99.

The composition of the globin component of the different species of animals has been analyzed by Rossi-Fanelli (1940, 1941, 1942, 1947, 1948, 1954, 1955 and 1956). He noticed that myoglobin had isoleucine but no cystine in the globin portion, as contrasted with hemoglobin which contains

cystine but no isoleucine. Rather than to give a further discussion on the physio-chemical constants of myoglobin and hemoglobin, the author believes that more information can be derived from observation of the following Tables I and II.

Table I. Physio-chemical Constants of Myoglobin and Hemoglobin

Physio-chemical Constant	Myoglobin (Mb)	Hemoglobin (Hb)
Prosthetic Group	Protoferroheme	Protoferroheme
Molecular Weight	17,000	68,000
Iron Content	0.34%	0.34%
Form of Dissociation Curve	Hyperbolic	Sigmoid
Effect of pH on the Dissociation Curve	Little	Moderate
Oxidation to "Met"	Very Easily	Less Easily
Oxygen Affinity	Large	Moderate
Rapidity of Fixation at pH 7.4, 20°C, millimole^{-1} sec^{-1}	CO.....300 O_2.....19,000	130 4,000
Rapidity of Dissociation at pH 7.4, 20°C sec^{-1}	CO.....0.04 O_2.....37	0.004 40
Isoelectric Point	6.99	6.78
Solubility In$(NH_4)_2SO_4$	Very soluble	Less soluble
Resistance to Denaturation By Alkalii	Large	Small

Taken from "Les Pigments Musculaires: physiopathologie" by Alessandro Rossi-Fanelli (1950).

Table II. Characteristics of Myoglobin and Some of Its Derivatives

Name	Distinguishing Chemical Characters	Color	Absorption Peaks (mu)
Myoglobin	MbH_2O (Fe^{+2})	Purplish Red	555
Oxymyoglobin	MbO_2 (Fe^{+2})	Bright Red	544,582
Metmyoglobin	MMbOH (Fe^{+3})	Brownish Red	510,635
Nitric Oxide Myoglobin	MbNO (Fe^{+2})	Pinkish Red	544,575
Carboxymyoglobin	MbCO (Fe^{+2})	Red	540,570
Sulfmyoglobin	Mb.S (Fe^{+2})	Green	(540),617,620

Taken from "Chemistry of Meat Pigments" by B. S. Schweigert (1950).

Physiological Function of Myoglobin

The advances in the nineteen-twenties and thirties, in the field of respiration physiology, naturally involved a closer study of the role of myoglobin as a respiratory pigment. Fundamental facts were presented by Theorell (1934) and Hill (1933, 1936), and further investigated by Millikan (1936-1939). No really new viewpoint has been added to the discussion since Millikan's studies. Figure 3 illustrates schematically the interpretation of the role of myoglobin (Biorck, 1949).

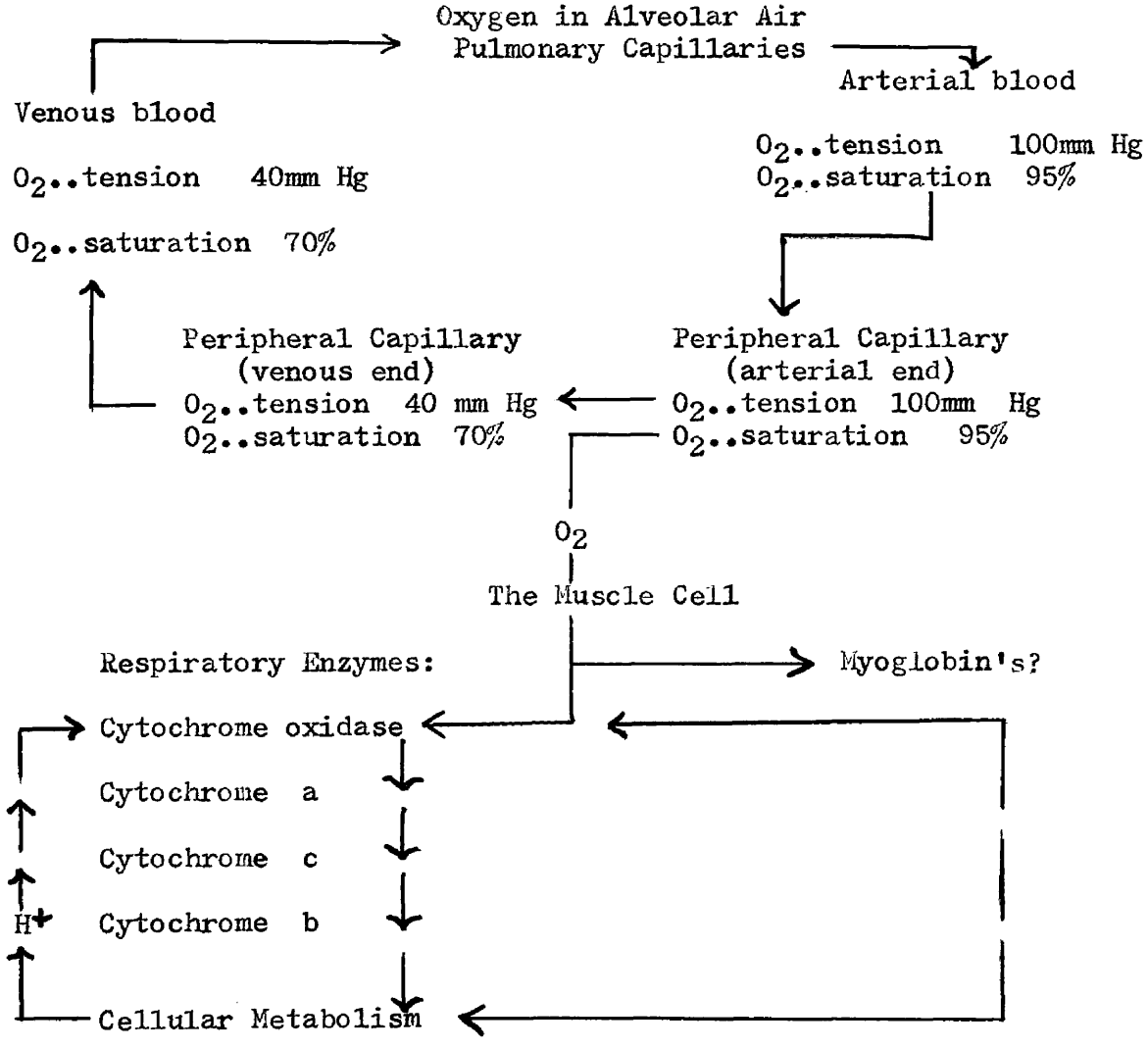


Figure 3

The Color of Fresh Meat

The color of fresh meat and the mechanism of the reactions which cause various discolorations, mainly metmyoglobin (brown), have been reported by the following authors, only to mention a few of them: Allen, 1948; Baker, 1954; Brooks, 1929; 1931, 1933, 1935, 1937, 1948, 1955; Butler, 1953; Coleman, 1951; Heiss, 1933; Hoagland, 1914; Kennedy and Whipple, 1926; Kraft, 1952; Landrock, 1955; Lavers, 1948; Moran, 1935; Penrod, 1954; Rikert, 1952; Urbain, 1952; Whipple, 1926 a and b; and Winkler, 1939 a and b.

The Color of Frozen Meat

Meat when frozen after it has been oxygenated has a desirable red color that the consumer prefers in a piece of meat. However, this desirable red color does not last long due to various factors, such as, type of wrapper, storage conditions (such as light, temperature, rate of freezing, etc.). Further explanation will be given in the section on factors influencing the discoloration of prepackaged frozen meat.

Moran and Brooks (1932) pointed out that when muscle is frozen very rapidly, e.g., in liquid air, it is pale and yellow to pink in color in the frozen state, whereas if it is frozen slowly, e.g., in air at -3°C, it is deep red. The difference in color is really an optical effect due to differences in the size of ice crystals. When the crystals are small there is less penetration of the incident light due to reflection and refraction at the interfaces between the crystals and the surrounding medium. They established the following schematic diagram in order to show this phenomena:

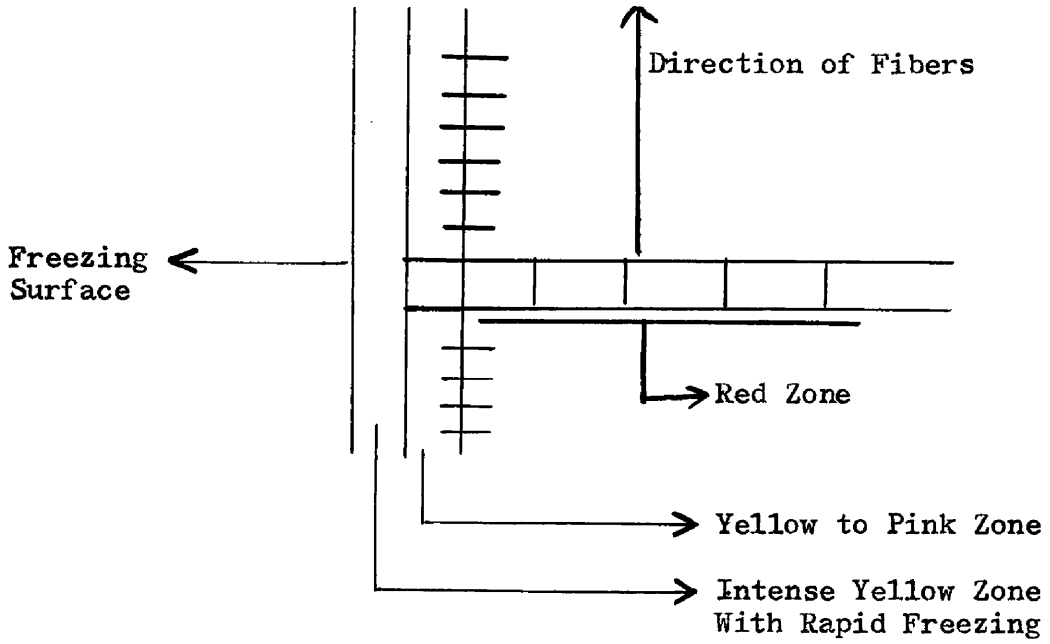


Figure 4.

Moran (1935) further stated that in frozen meat the loss of color is thought to be due to the scattering of light by the minute air bubbles in the tissue originally occupied by the ice crystals.

Chemistry of Color Change In Frozen Meat

The oxymyoglobin⇌myoglobin⇌metmyoglobin reaction plays an important part in the packaging of frozen meats (Bratzler, 1955). Myoglobin combines reversibly with oxygen to form the bright red oxymyoglobin (Watts, 1954). In this compound the heme (iron) remains in the ferrous (Fe^{++}) form. Two types of oxidative changes may be responsible for the abnormal brown discoloration of meat (Watts, 1954). One involves the oxidation of the ferrous iron in the heme compound to the ferric condition, the second is a direct attack by oxygen on the porphyrin ring. The most commonly encountered type of

discoloration is that of the "met" pigment formed by oxidation of the iron in the heme to the ferric (Fe^{+++}) state, known as metmyoglobin.

Heiss and Hohler (1933) stated that color changes in meat during storage may originate in three ways:

1. The oxidation of red myoglobin to brown metmyoglobin.
2. The loss of moisture from the meat surface with consequent increase in concentration of the colored constituents at the surface.
3. The disintegradation of the globin components.

Brooks (1929, 1930, 1931) stated that the pigment of muscular tissue, myoglobin, is present at the surface as oxymyoglobin, which can change gradually during cold storage to metmyoglobin. Winter (1952) stated that meat may darken due to oxidative reactions with the red colored pigments.

Factors Influencing the Color Changes of Frozen Meat

1. Oxygen Pressure and Penetration

Neill (1925) has shown that there was no evidence that methemoglobin was formed in the complete absence of oxygen since in this condition there were no oxidizing agents formed to oxidize hemoglobin to methemoglobin. Brooks (1929) also showed that when hemoglobin was stored in pure nitrogen storage there was no formation of methemoglobin. From this work it was apparent that oxygen was necessary for the formation of methemoglobin, the dark colored pigment of meat. Robertson (1950) stated that since discoloration is actually an oxidative reaction, the elimination of air controls discoloration. He stated that low oxygen transmission rate film is very essential to increase frozen meat qualities. He also stated that

one of the limiting factors in meat freezer storage life is to be found in the degree of oxygen protection offered by the packaging material.

The relation between oxygen pressure and the rate of methemoglobin formation was responsible for the rapid discoloration of tissue stored at 32°F in gases containing a small amount of oxygen according to Brooks (1929). He found that tissue had a small oxygen uptake so that, given sufficient time, a "steady state" was reached where the depth of oxygen penetration was determined by the rate of diffusion of oxygen into the tissues and the oxygen consumption of the tissue. He showed that the depth of oxygen penetration was determined by the oxygen pressure in atmospheres at the surface of the tissue, the diffusion coefficient of oxygen through the tissue, and the oxygen uptake of the tissue. Brooks (1935) found that the depth of oxygen penetration showed a slow increase with time, and a rise in temperature decreased the depth. He found that the depth of oxygen penetration varied from 2 to 5 mm and that the depth of penetration was proportional to the square root of the oxygen pressure in atmospheres.

Brooks (1929) gave the following formula for finding the depth of oxygen penetration:

$$d = \sqrt{\frac{2\, c_o\, D}{A}}$$

where d = depth of oxygen penetration; c_o the pressure of oxygen at the surface of the tissue and $\underline{D}$ and $\underline{A}$ are respectively the coefficients of its diffusion through the tissue and consumption. Therefore, the dissolved oxygen was present only in a superficial layer a few mm thick. Discoloration was confined to the superficial layer. Freezing and thawing the tissue

had no significant effect on oxygen penetration, but did accelerate methemoglobin formation in the region of oxygen penetration.

2. Packaging Methods and Materials

Robertson (1950) stated that visibility and tightness of wrap are a necessary requirement for frozen meat. He gave the essential features of a package material as follows: low oxygen transmission rate and low moisture vapor transmission to prevent dehydration. He stated that a packaging material with low moisture vapor transmission rate is essential because meat bloom is an effect of surface moisture over red meat color. He further mentioned that various color effects can be observed as surface dehydration proceeds on the packaged product in storage. A gray or dark color can be noticed in the later stages of dehydration. Ordinarily, this late stage of dehydration is known as "freezer burn". Robertson (1950) stated that the wrapping of the product should be so well done that it is free of air pockets, which cause the loss of visibility when moisture condenses in the cavity forming a snow or frost.

Weisman (1947) stated that by wrapping the product tightly in a material possessing a low moisture vapor transmission rate, the tendency for moisture to travel outward is minimized. Air pockets must be avoided as much as possible because where air is present within a package, there is a certain amount of moisture loss resulting in frost formation on the inner surface of the package. Close adherence of the product also prevents harmful oxidative changes. He further stated that proper packaging of frozen meats is also of material aid in reducing "cavity ice" formation within a package. "Cavity ice" is a term coined by Sayles (1946) to designate the formation of ice in the air spaces inside a package. Therefore,

by use of certain packaging materials which provide insulation and thus reduce temperature gradients between the product and the packaging surface, the tendency for cavity ice to form is lessened.

Moran (1935) stated that simple desiccation, particularly of frozen meats, leads to apparent discoloration. Lavers (1948) stated that in using an oxygen impermeable wrap, the supply of oxygen is cut off and the rate of oxidation to methemoglobin, i.e., the rate of discoloration, is greatly increased. Methemoglobin is formed rapidly when the pressure of oxygen around the meat is reduced by the packaging material. Robertson (1950) stated that fresh meat color and color stability will sometimes change at different rates in different materials and that color may be readily lost in the wrapped package if the package is not sent directly to the freezer.

3. Methods of Freezing

There are several methods of freezing meat. Among these are:

1. Freezing in low temperature rooms in still air.
2. Freezing in low temperature rooms in an air blast.
3. Freezing on coils.
4. Plate freezing.
5. Freezing in liquid air, brine, etc.

Robertson (1950) has discussed each one of these methods. He stated that still air freezing resulted in a very dark colored meat surface. This was a situation in which the surface did not fracture, but the rate of freezing was so slow that all of the original red meat color was lost. Once the product is satisfactorily frozen and held at sub-zero temperatures,

the color changes are slow. He also stated that plate freezing at -50°F although very rapid, resulted in almost complete loss of the surface color and appearance. The surface was described as having been freezer burned, but that this characteristic was due to the fracture of the frozen surface layer. He stated that blast freezing gave similar results. He noted that when still air was used for freezing at 0°F, the meat was dark in color. He concluded that the dark color in meat frozen by still air was due to the fact that the rate of freezing was so slow that all of the original meat color was lost.

Jensen (1949), on the other hand, reported that a temperature of -10°F or lower resulted in a satisfactory color when freezing by the blast method. Brooks (1929, 1930, 1931) reported that because of the unsightly appearance of the thawed surface due to the effect of freezing in concentrated salt solution, this type of freezing has not been adopted commercially. Collier's (1956) stated that freezing meats in liquid nitrogen at temperatures as low as -320°F showed better color than those frozen at -20°F.

4. Effect of Time, Temperature and Relative Humidity

At 14°F Brooks (1937) found no visible discoloration of lean meat stored for sixteen weeks. At 29.5°F there was no discoloration owing to the formation of methemoglobin until 40-50 days from killing. Mangel (1951) stored samples at temperatures ranging from 10.4°F to -11.2°F. She found that methemoglobin formation was slower in samples stored at the higher temperature than in samples stored at the lower temperature. Ramsbottom's work (1947) would indicate the opposite. He stored fresh beef at six different temperatures ranging from -20°F to 26°F packaged in DuPont 300 M.S.A.T. #87 cellophane. The product stored at 26°F was discolored in less than

thirty days, whereas the product stored at -20°F was still scored good in color and appearance after one year's storage. He concluded that the lower the temperature of storage, the longer the storage life. Tressler and Evers (1947) stated that frozen meat changes in color from the red to brown color at a higher temperature of storage. At 29°F, discoloration of beef was noticeable after eight weeks, whereas at 14°F there was no noticeable change in color until after 12 weeks.

Ramsbottom and Koonz (1941) determined the relative concentration of oxyhemoglobin and methemoglobin in the surface of tissue stored for one year at 10°F and -30°F. They plotted spectra curves from extracts of the surface tissue from spectrophotometric readings. The curves for the steaks stored at 10°F for one year were quite similar to the curve for methemoglobin. The curves for steaks stored at -30°F indicated a mixture of oxyhemoglobin and methemoglobin. This indicated that a greater oxidation, and consequently, darker beef, occurred in the tissue at 10°F than at -30°F. Jensen (1949) stated that freezing should be done at a rate which gave meat a bright color. A temperature of -10°F or lower resulted in a satisfactory color when freezing by the blast freezing method. He agreed with Robertson in that slowly frozen meats were dark in color.

Brooks (1929) noted that the formation of methemoglobin in frozen meat was less important (unless the time of storage was long) than the loss of color due to excessive drying. He said that crystals of ice in the superficial layer evaporate, and the small bulbs of air left behind scatter the incident light.

Robertson (1950) discussed the influence of temperature on the condensation of moisture in the cavities of meat. He stated that air at 60°F contains 77.29 grains of moisture per pound of air, whereas at -10°F the air contains 3.206 grains of moisture per pound of air. He also noted that the moisture content of the entrapped air can fluctuate with changes in the storage temperature. Wiesman (1947) gave further explanation on the subject of "cavity ice" which interfered with visibility of the product. When a product is stored under fluctuating temperatures, there is a certain increment of the total water in meat which is being continually thawed and frozen. The presence of "cavity ice" is an indication that a certain amount of dehydration of the product has taken place since moisture is necessary for the formation of ice. According to him, water moves from the contents of the product to the side walls of the package either by convection currents established because of a difference in the temperature between the air and the colder side wall, or because of an alternate rise and fall in temperature. During a fall in temperature and the subsequent loss of water holding capacity of the ice, ice will be deposited on the coldest surface existing at the time. If the coldest surface is the package contents, ice will be deposited on the contents, which in effect means no cavity ice formation. When the temperature inside the package rises, it will absorb water from the food content and any previously existing "cavity ice". If there is no temperature change within the package, no frost will form. This may be regarded as a "pumping action". A reduction in temperature reduces the moisture-vapor in the air and causes a precipitation in the form of ice. An increase in temperature increases

the moisture-vapor capacity of the atmosphere, thus causing a flow of the moisture-vapor from the product into surrounding atmosphere resulting in deterioration and freezer burn.

5. Effect of Biological Agents

Voegeli (1952) and Butler (1953) have summarized the studies of the workers who studied the effect of biological agents on the color of fresh meat. Voegeli (1952) mentioned that these workers found that Pneumococci reduced methemoglobin to hemoglobin in complete absence of oxygen and that anaerobic bacilli have the ability to oxidize hemoglobin. Butler (1953) in his work, found that bacteria commonly found on meat cuts caused discoloration. The main effect, an increase in the rate of metmyoglobin formation, was the greatest during the logarithmic growth phase.

According to Tanner (1944), microbial development was markedly retarded but not entirely eliminated by freezing. Sulzbacher (1950) stated that the popularity of frozen food during the past two decades has occasioned considerable interest in the growth and survival of microorganisms during freezing and frozen storage. Haines (1931) recognized that the growth of Pseudomonas sp at sub-freezing temperatures was likely to play a part in meat spoilage.

6. Effect of Storage In Different Atmospheres

Mangel (1951) stored samples under atmospheres of nitrogen, oxygen, and carbon dioxide, with air as the control. She found no significant difference, but the methemoglobin formation tended to be slower when the tissue was stored under oxygen, than under nitrogen, carbon dioxide or air,

Robertson (1950) stated that nitrogen may be used to displace the air in a package and thereby prevent discoloration. Brooks (1935) noted that the rate of oxidation of hemoglobin in muscle was not affected to a significant extent by concentrations of carbon dioxide below 20%. Hence, if other conditions of storage are the same, the color change of meat in air and in air containing 20% carbon dioxide should be the same.

Rikert (1952) flushed packaged samples with carbon dioxide and nitrogen before evacuating. This resulted in less initial darkening than that which occurred in samples evacuated without flushing. He also stored samples at atmospheric pressure in carbon dioxide and nitrogen. This had a detrimental effect on the top surface color but improved the bottom color when compared with samples stored in air.

Experiments conducted by the author (1955) indicated that relatively short exposure of meat to an atmosphere of 40% or less carbon monoxide gave excellent color stability in frozen storage for periods of six months or longer.

7. Effect of Light

Discolorations caused by exposure to light become a particularly serious problem because of modern merchandizing methods which require exposure of retail cuts in lighted display cases.

A review of the literature revealed very limited information concerning the effect of light on prepackaged frozen meat packaged in a transparent wrapper.

Nauman (1957) stated that stability of color of frozen beef vacuum packed in flexible transparent film under 20-50 foot-candles of illumination was related to length of dark storage, foot-candle hours of illumination and temperature. He stored samples in the dark at 0°F for 0, 1, 2 and 4 weeks prior to illuminated display.

Cured, smoked and table ready meats when exposed to light become "faded" or discolored. There have been several studies conducted to study the causes of this type of discoloration (Pracejus, 1949; Archer, 1950; Taylor, 1950; Ramsbottom, 1951; Kampschmidt, 1955 and Hockman, 1956). These studies were conducted in order to better understand its relationship to radiant flux density (or illumination) spectral distribution, and time of exposure. In some cases other variables not directly related to radiant energy, such as temperature, humidity, wrapping materials, etc., were also considered. It may be worthwhile to summarize the results of the various tests that were conducted by the above investigators.

1. When temperature and other factors are held constant, rate of fading will be the same under either incandescent or any of several white fluorescent lamps, providing illumination is the same for both.
2. The degree of discoloration of a particular processed meat sample is a function of exposure in foot-candle hours. The reciprocity law was found to apply over a range of 20-200 foot-candles, for bacon, bologna, and sliced ham. Illumination levels outside this range were not reported.

3. The maintained temperature of the meats may have a significant effect on their susceptibility to fading. In a series of tests by Archer (1950), raising the temperature of the meat from 34°F to 40°F resulted in an approximate 50% reduction in the exposure for minimum perceptible fading.

Fresh meats, on the other hand, appear to be relatively unaffected under normal display conditions of light. Kraft (1954) reported that the intensity of soft white fluorescent light was unimportant in influencing the course of discoloration of packaged fresh beef. Measurements of spectral reflectance and visible color changes indicated that ultra-violet light caused rapid oxidation of myoglobin to produce marked discoloration of fresh beef early in storage. Ramsbottom (1951) reported that display case lighting does not significantly discolor fresh meat within the usual display periods up to 3 days. Longer display periods may bring about discoloration that is a factor of microbial development. Voegeli (1952) noted that the intensities of light employed, 20-215 foot-candles, did not affect the rate of color change of unwrapped samples under comparable storage temperatures. Sources of light that increased the storage temperature reduced the saleable storage time of both wrapped and unwrapped samples.

PURPOSE OF STUDY

A review of the literature reveals some information concerning the effect of various conditions on discoloration in prepackaged frozen meat, but there is little information concerning the character of this discoloration.

The main purpose of this investigation was to attempt to characterize the chemical state of myoglobin as affected by various storage conditions.

One major cause of discoloration in prepackaged frozen meats packaged in a transparent package is that of light. This effect has been suspected by several investigators, but supporting evidence as to what property of light causes the discoloration has been incompletely presented or entirely absent. Accordingly, experiments were designed and conducted to study what property of light causes this discoloration and to characterize the chemical state of myoglobin as affected by light.

EXPERIMENTAL PROCEDURE

I. Sampling Procedure and Methods of Freezing

The Longissimus dorsi muscle from U.S. Good and Choice grade beef ribs were used throughout this study.

Boneless rib steaks approximately one inch thick were cut from the wholesale rib cut. All steaks were allowed to bloom for 30 minutes and then a 3mm slice was removed for spectrophotometric estimation of metmyoglobin. The steaks were then placed in a -20°F freezer to harden for approximately one hour. This was done to facilitate packaging.

After removal from the freezer, the steaks were placed in Cry-O-Wrap plastic bags. The bags were vacuumized, closed with a Cry-O-Wrap clip, dipped into boiling water which reduced the size of the bag approximately one-third, thus giving the steaks a tight wrap. The steaks were then returned to a -20°F freezer for 24 hours. After freezing, measurement of surface color was made by use of Munsell spinning disks in the freezer. This method will be discussed under color measurements.

After surface color measurements were made, the steaks were removed from the freezer and subjected to the various storage conditions of this investigation. These storage conditions will be discussed in more detail under results and discussion.

II. Storage

A. Temperature

The prepackaged frozen steaks used in the various studies were stored in a self-service case or in a circulating cold air walk-in type freezer

except in the study concerning the effect of repeated freezing and thawing on metmyoglobin formation. The steaks used in this study were stored in a -20°F freezer.

A Sherer self-service frozen food case was used to store those steaks observed under self-service conditions. The temperature of the case and freezer were measured by the use of a Foxboro filled system recording thermometer. Records obtained were as shown in Figures 5 and 6. A Honeywell recording twelve point potentiometer was used to measure temperature variations in various points of the self-service case.

B. Repeated Freezing and Thawing

Twelve steaks were packaged in Cry-O-Wrap plastic bags and twelve steaks were packaged in aluminum foil. These steaks were frozen twenty-four hours. Steak #1 from each type of wrap was taken from the freezer and allowed to thaw for two hours to facilitate slicing for extraction purposes. After the wrappers were removed, surface color measurements were made by the use of Munsell spinning disks and estimation of metmyoglobin by the use of the spectrophotometer. Steaks #2 through #11 were allowed to thaw for twenty-four hours and then refrozen for twenty-four hours. Steaks #2 were removed after thawing and refrozen once. Steaks #3 removed after thawing and refrozen twice, and so forth until Steaks #11 were thawed and refrozen ten times. pH and absorption spectra determinations were made on all steaks.

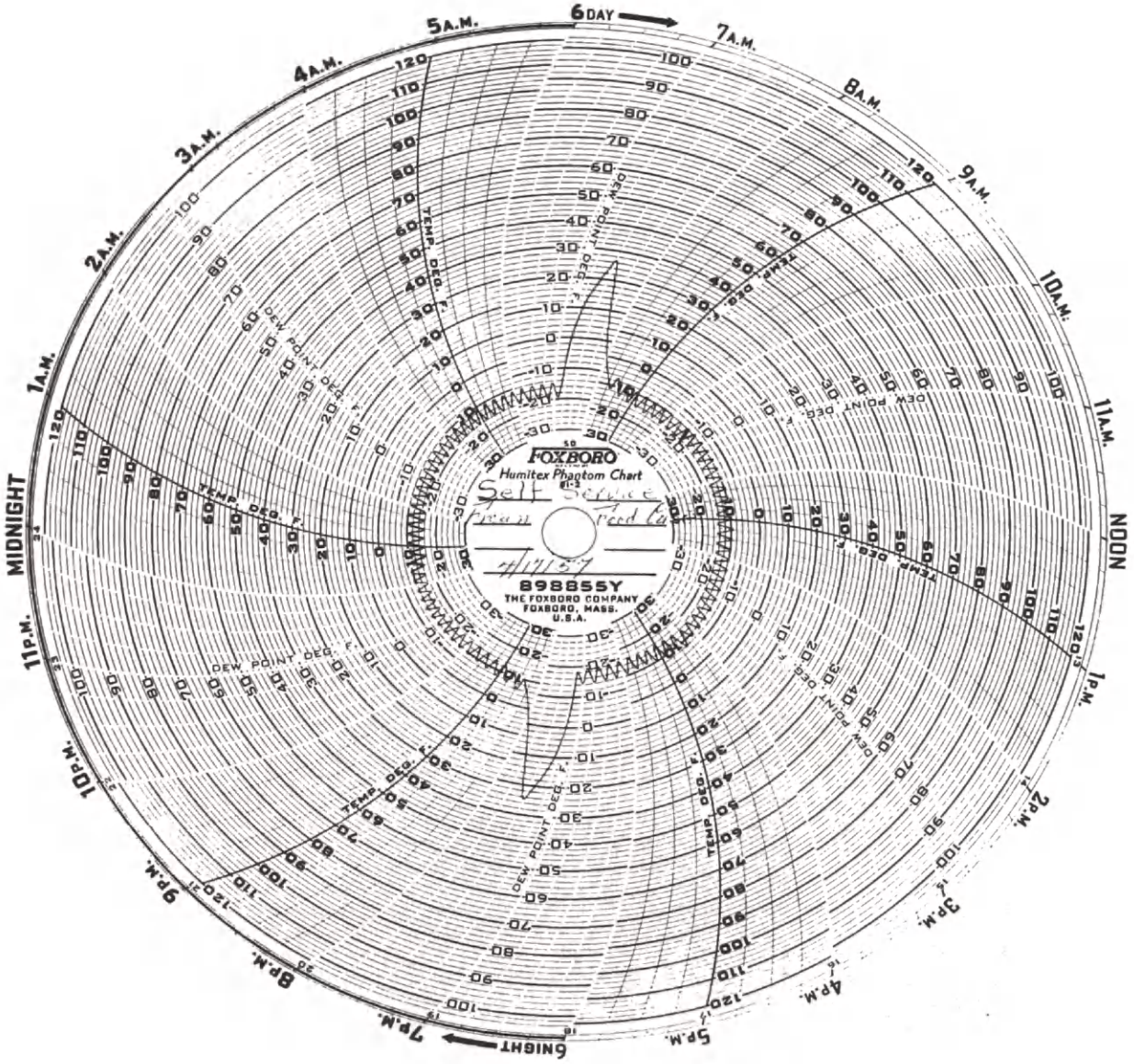


Figure 5. Temperature of Self-Service Frozen Food Display Case

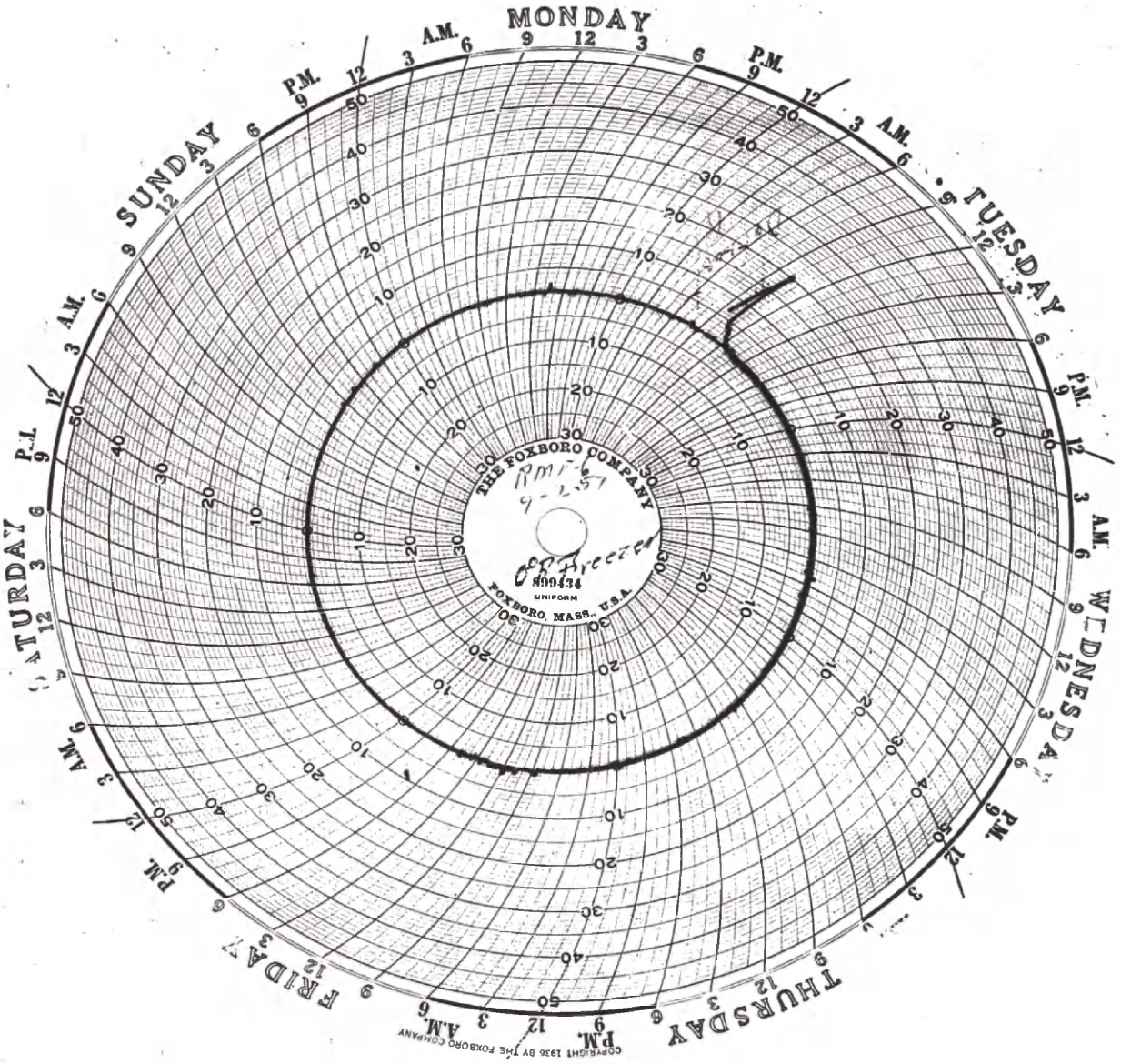


Figure 6. Temperature of 0°F Freezer

C. Effect of Light

Steaks stored in the self-service frozen food case under the influence of light were kept under fluorescent lamps delivering 56 foot-candles of illumination. Various colored filters were used in the study concerning the attribute of light that may be responsible for color degradation. Steaks stored in the 0°F freezer under the influence of light were kept under fluorescent and incandescent lamps delivering 56 foot-candles of illumination, except in one study where the steaks were kept under various colored fluorescent lamps delivering 20 foot-candles of illumination.

III. Color Measurement

Detailed instructions were given by Voegeli (1952) on the application of disk colorimetry for the measurement of the surface color of meats by use of Munsell spinning disks.

The standard color employed for calculation of the index of fading (I) by the formula of Nickerson (1946), as applied by Voegeli (1952) was 7.0 Red in Hue, 4.0 in Value, and 8.0 in Chroma. The selected standard for the plotting of color readings of frozen meat was the color of some very bright steaks obtained by Butler (1953) following treatment with oxygen under pressure. By using the Nickerson (1946) formula, it was possible to find the position of subsequent sample readings in relation to the standard. These positions were plotted against time to show the discoloration of prepackaged frozen meat during storage.

Estimation of the percent metmyoglobin was essentially as applied by Mangel (1951) and Butler (1953). A slice three mm in thickness was removed

with a Hobart Model 300 slicing machine. The slice was weighed on a balance to the nearest 1/10 gram. After weighing, the slice was transferred to a chilled Waring Blendor jar and distilled water at 34°F was added to give a dilution of 1 to 8, which gave a solution of approximately 0.02 to 0.03 millimolar concentration. Solutions of such concentrations had optical densities falling on a desirable area of the optical density scale.

Extracted myoglobin is somewhat unstable, and metmyoglobin may increase or decrease depending on the conditions under which it is handled before the optical densities are taken. Mangel (1951) stated that the percent of metmyoglobin increases with time. At any rate, it is very necessary to standardize the extraction procedure. In these studies, optical density readings were taken within approximately one hour from the time of extraction of the pigment.

Optical density was measured in a Beckman Model DU spectrophotometer at wave lengths of 544 and 582 millimicrons. The total pigment concentration was obtained by conversion of the pigments to the CN derivative by adding a drop of 2% solution of potassium ferricyanide and a drop of 0.5% potassium cyanide to each cubit after readings were obtained. The resultant metmyoglobin cyanide derivative was measured at 540 millimicrons and the millimolar extinction coefficient of 11.3 given by Bowan (1949) for metmyoglobin cyanide was used to calculate the concentration.

The calculation of concentration of the solution whose optical density was measured was based on the Lambert-Beer law as given by Bowen (1949).

$$\log_{10} \frac{I_0}{I} = d = \Sigma c l$$

Where I_0 = intensity of incident light

I = intensity of emergent light

d = density from spectrophotometer

Σ = molar extinction coefficient

c = molar concentration

l = length of light path through the solution in cm(= 1.0 for the cell used).

$$\therefore c = \frac{d}{\Sigma} \text{ where } l = 1.0$$

and for this study

$$c = \frac{d}{11.3 \times 10^3}$$

To estimate the percent metmyoglobin, the difference between the extinction coefficients of oxymyoglobin and metmyoglobin at 544 and 582 millimicrons were taken as maximum possible change at these wavelengths. These figures were 9.6 at 544 mu and 12.1 at 582 mu as given by Bowen (1949). At each wavelength, the change due to metmyoglobin was equal to the Σ of oxymyoglobin minus that of the sample. By dividing the figure obtained by the total change in Σ from oxymyoglobin and metmyoglobin and multiplying by 100, an estimation of the percent metmyoglobin was obtained. The estimations of the percent metmyoglobin at 544 mu and 582 mu were averaged to obtain the final estimate of the percent metmyoglobin.

RESULTS AND DISCUSSION

A. Temperature

Temperature has been found in many studies to have a marked effect on color degradation in frozen meats. (Brooks, 1937; Mangel, 1951; Ramsbottom, 1947; Tressler and Evers, 1947; and Jensen, 1949). Therefore, it is essential that one have some information concerning the effect of temperature on color degradation of prepackaged frozen meat. In order to derive some information on color degradation as related to temperature, it was decided to do this phase of the study in three parts, namely, 1.) temperature variation in the self-service case; 2.) temperature variation in the self-service case when loaded to capacity and 3.) the effect of prehandling conditions and the rate of freezing on initial color degradation.

1. Temperature Variation in Self-Service Case

Thermocouples were placed in several steaks in three locations as follows: 1.) bottom of steak next to the bottom of the case; 2.) center of the steak and 3.) top of the steak. Results of this phase of the study may be represented in Figure 7 on page 34, which shows the arrangement of the steaks in the self-service case. The diagram represents an aerial view of the self-service case.

Temperature fluctuations within the self-service case itself varied from -4.0°F to +5.0°F depending on the stage of the cycling of the compressor furnishing the refrigerant. The temperature varied nine degrees from one side of the case to the other side of the case. It was noticed that the surface of the steaks occasionally reached a temperature equal to that of the bottom of the steak. This may be explained by the fact that there was

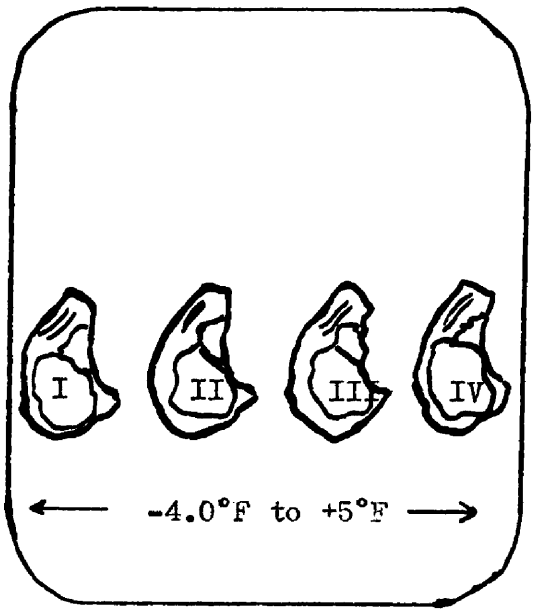


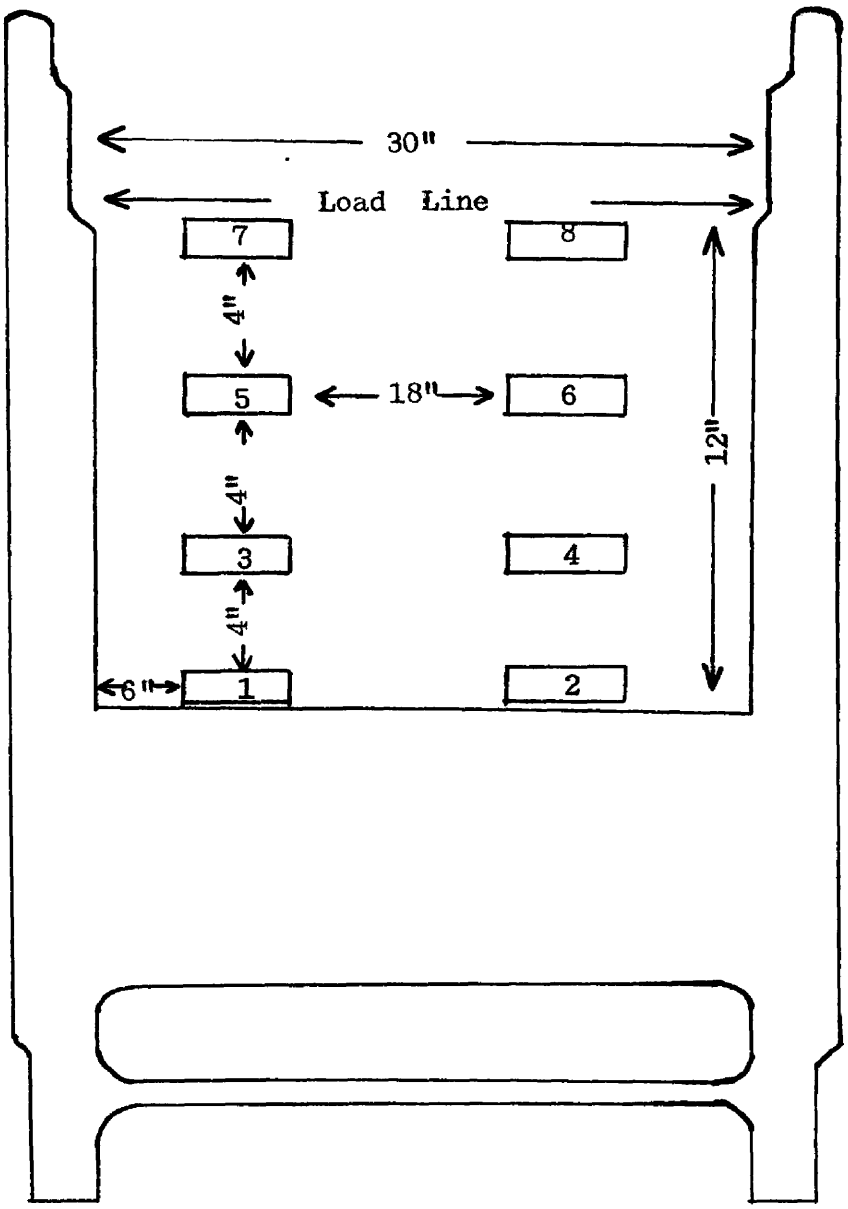
Figure 7

condensation of moisture from the atmosphere on the surface of the steak causing further cooling of the product and thus lowering the surface temperature of the steak. Table III summarizes temperature variations in the self-service case.

2. Temperature Variations in Packaged Frozen Steaks when Stored in a Self-Service Case Loaded to Capacity

Eight steaks were used in this study and arranged as represented in the end view of the self-service case as shown in Figures 8 and 9.

Thermocouples were placed in each steak. Temperature measurements were made by the use of a twelve point Honeywell recording potentiometer. These steaks were stored for a period of ten days after which surface color measurements were made by the use of Munsell spinning disks and estimation of the per cent metmyoglobin by the use of the spectrophotometer.



End View of Self-Service Case

Figure 8

Steak No.	Temperature	Steak No.	Temperature
7	11.3°F to 24°F	8	7.0°F to 10.0°F
5	7.0°F to 9.5°F	6	11.0°F to 17.0°F
3	2.0°F to 8.0°F	4	-3.0°F to -1.0°F
1	10.0°F to 2.0°F	2	-4.0°F to -1.0°F

Figure 9

Results of this study are summarized in Table IV on page 38. They showed variation in temperature from one side of the case to the other side as well as variation in temperature of the steaks stored at various levels in the self-service case. It was thought that those steaks stored at the higher levels in the case would have a higher percentage of metmyoglobin than those steaks stored on the bottom of the self-service case. This was not borne out in this study. The results of this study showed that there was not too much difference in the percent metmyoglobin formation in steaks stored at various levels in the self-service case except at the top level where the steaks were exposed to light and higher temperatures. Perhaps a study should have been made to see if there would be an increase in metmyoglobin formation without the influence of light or whether it was due to the effect of light. The surface color of the steaks was relatively good where they were not exposed to light, but the steaks on the top level became discolored in about 2-3 days.

Table III. Summarized Temperature Variations In Self-Service Case

Steak I	
Top of steak	-1°F to -2.8°Fo
Center of steak	-3.5°F to -5.0°F
Bottom of steak	-1.0°F to -3.0°F
During Defrosting Cycle	+3.5°F to +20°F
Steak II	
Top of steak	-1.5°F to -3.0°F
Center of steak	0°F to -2.0°F
Bottom of steak	-0.5°F to +2.5°F
During Defrosting Cycle	+4.0°F to +19.5°F
Steak III	
Top 1/4 inch of steak	0°F to +2°F
Bottom 1/4 inch of steak	0°F to +5°F
During Defrosting Cycle	+5.0°F to +14.5°F
Steak IV	
Top of steak	0.2°F to +8°F
Center of steak	+1.0°F to +13°F
Bottom of steak	+4.0°F to +5.5°F
During Defrosting Cycle	+30°F to +26°F

Table IV

Steak No.	Temperature Variation	Percent Metmyoglobin Before and After Storage		Index of Fading Before and After Storage	
		Before	After	Before	After
1	-10°F to -2°F	0.79	8.98	14.0	14.5
2	- 4°F to -1°F	0.79	9.68	20.8	19.0
3	+2.0°F to +8°F	0.79	6.65	20.0	15.7
4	-3.0°F to -1°F	0.79	9.83	18.9	11.7
5	+7.0°F to +9.5°F	0.79	9.95	17.0	12.7
6	+11.0°F to +17.0°F	0.79	10.10	22.8	17.0
7	+11.5°F to +24°F	0.79	35.10	16.5	22.6
8	+7.0°F to +10°F	0.79	47.80	14.7	28.4

Figure 10 shows the index of fading of these eight steaks. The steaks which were not exposed to light did not discolor to any extent. There were some steaks that even showed better color than when placed in storage as indicated by index of fading. Steaks #7 and #8 changed from 16.5 to 22.5; and from 14.7 to 28.4 units from Standard, respectively.

3. Prehandling Conditions and Rate of Freezing

In this study, two steaks each were used and subjected to the following three cold storage conditions: 1.) cooler at 34°F; 2.) freezer at 0°F and 3.) freezer at -20°F. Thermocouples were placed in each steak. Rate of freezing was recorded by use of a recording potentiometer. Measurements of surface color were made every two or three hours for twelve hours and then left overnight, with a final reading made at 24 or 28 hours by the use of Munsell spinning disks. Estimations of metmyoglobin were made before and after treatment.

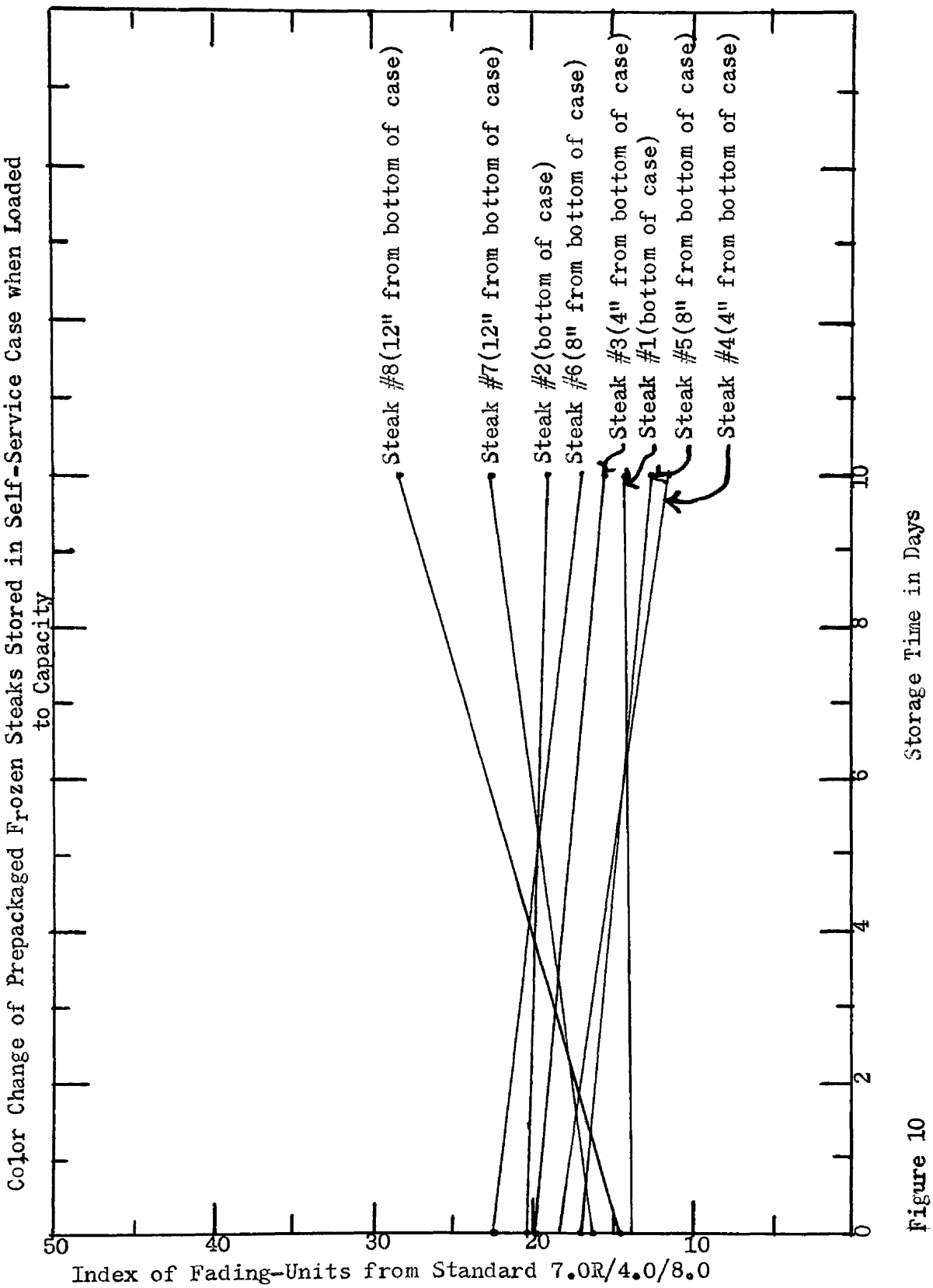

Color Change of Prepackaged Frozen Steaks Stored in Self-Service Case when Loaded to Capacity
Steak #8(12" from bottom of case)
Steak #7(12" from bottom of case)
Steak #2(bottom of case)
Steak #6(8" from bottom of case)
Steak #3(4" from bottom of case)
Steak #1(bottom of case)
Steak #5(8" from bottom of case)
Steak #4(4" from bottom of case)
50
40
30
20
10
0
2
4
6
8
10
Index of Fading-Units from Standard 7.0R/4.0/8.0
Storage Time in Days

Figure 10

a.) Cooler Temperature of 34°F - The purpose of this study was to see how long it would take for the color of oxymyoglobin to be reduced back to the color of reduced myoglobin when packaged in a transparent oxygen impermeable wrapper. After "blooming", the steaks had a very desirable red color characteristic of that of oxymyoglobin. During the first hour that the steaks were in the Cry-O-Wrap, there was not too much change in color. At the end of two hours the steaks started to discolor. At the end of 3, 4, 5 and 6 hours there was considerable discoloration of the steaks. At the end of seven hours, the steaks were comparable in color to the steaks when first cut. At the end of nine hours the steaks showed greater discoloration than when first cut. The control steak which was not wrapped, but left exposed to air discolored at about the same rate, but did not discolor to the same extent as those steaks wrapped in Cry-O-Wrap. Surface color changes are shown in Figure 11. This index of fading graph shows very well the change of reduced myoglobin to the red color of oxymyoglobin and then the change back to the color of reduced myoglobin when stored in an oxygen impermeable wrapping material. After twenty-eight hours, the wrapper was removed from one steak to see if it would "bloom" (return to the red color of oxymyoglobin) again. It was found that when the wrapper was removed the steak changed from 25 units from standard to 19 units from standard. This indicated that the steak did brighten. Percent metmyoglobin formation increased from 0% before the steaks were packaged to 19.86% and 16.85% after twenty-eight hours of storage. The steak which was not packaged and served as a control changed from 0% metmyoglobin to 5.63% metmyoglobin. The larger percent of metmyoglobin in the first two steaks seems to be related to Brook's (1935) observation that as the surface tension of oxygen is lowered to about 4-20mm Hg, that there is faster change of reduced myoglobin to metmyoglobin.

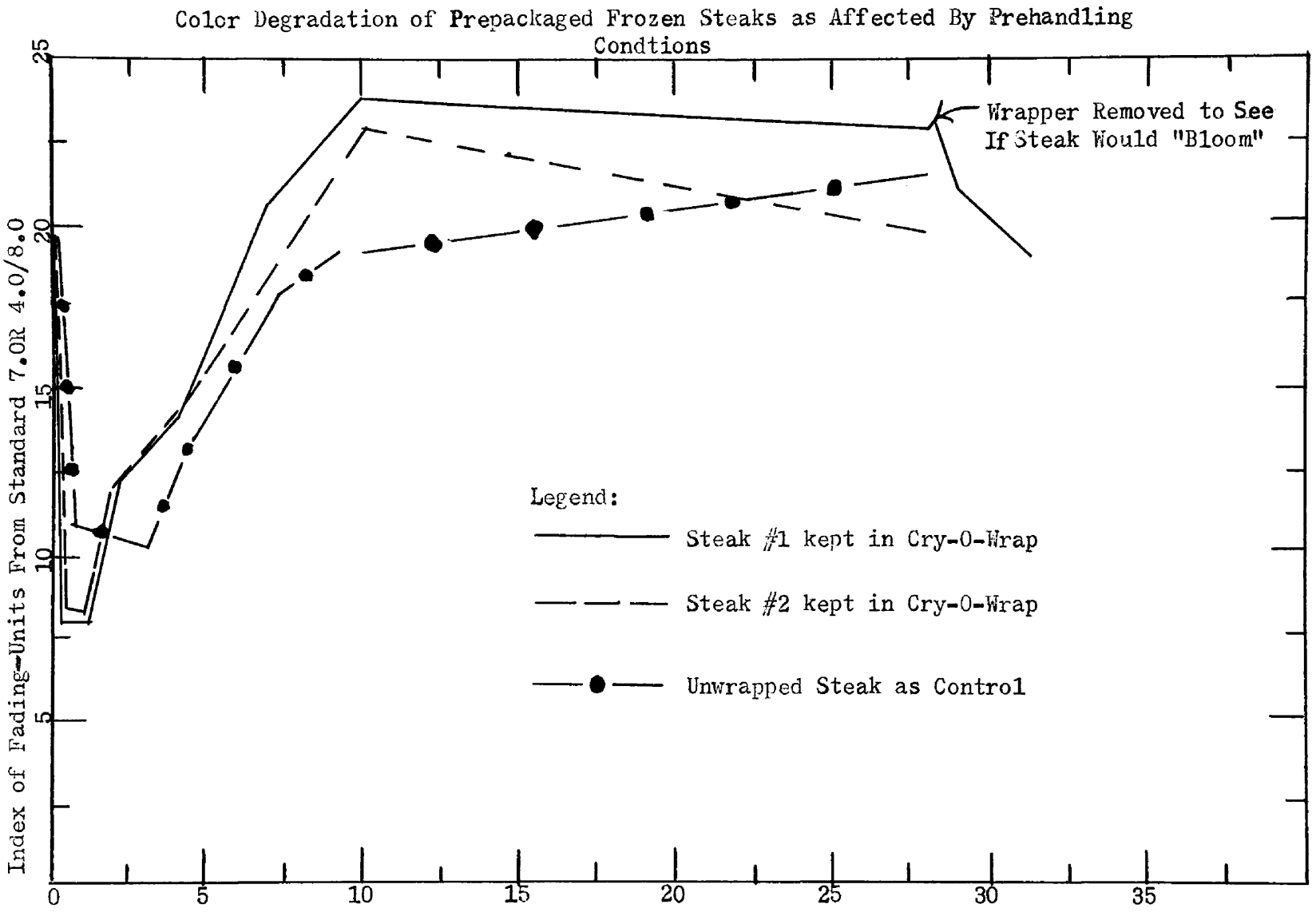

Color Degradation of Prepackaged Frozen Steaks as Affected By Prehandling Condtions
Index of Fading-Units From Standard 7.OR 4.0/8.0
25
20
15
10
5
0
5
10
15
20
25
30
35
Storage Time In Hours
Wrapper Removed to See If Steak Would "Bloom"
Legend:
Steak #1 kept in Cry-O-Wrap
Steak #2 kept in Cry-O-Wrap
Unwrapped Steak as Control

Figure 11.

b.) Rate of Freezing - Robertson (1950) stated that still air freesing resulted in a very dark color surface. This was a condition in which the surface did not fracture, but the rate of freezing was so slow that all of the original red meat color was lost. Jensen (1949), on the other hand, reported that a temperature of -10°F or lower resulted in a satisfactory color when freezing was done by the blast freezing method.

The results of this study showed that steaks frozen at 0°F and at -20°F discolored at about the same rate as indicated by the index of fading graph in Figure 12. The initial discoloration of the steak in the 0°F freezer was more gradual than those frozen in the -20°F freezer. This sudden discoloration in the -20°F freezer might be due to surface fracture such as was reported by Robertson (1950).

Figure 13 shows the rate of freezing of one and one-fourth inch steaks in the 0°F freezer and the -20°F freezer. It should be noted that the steaks frozen at 0°F required about three to four hours to reach the "zone of crystallization". It took only one hour for the steaks in the -20°F to reach the "zone of crystallization" of meat. As a matter of interest, it took about eleven hours for those steaks frozen in the 0°F freezer to come at equilibrium with the temperature of the freezer. It took only seven hours for the temperature of the steaks frozen in the -20°F to come to equilibrium with the temperature of the freezer. It was usually observed that the following muscles: Spinalis dorsi, Longissimus costarum and Trapezius discolored very quickly during the freezing process, whereas the color of the Longissimus dorsi muscle was very slow to show any discoloration. The author believes that prehandling conditions (such as length of "blooming" period,

Color Degradation of Prepackaged Frozen Steaks as Affected by Rate of Freezing in 0°F and -20°F Freezer

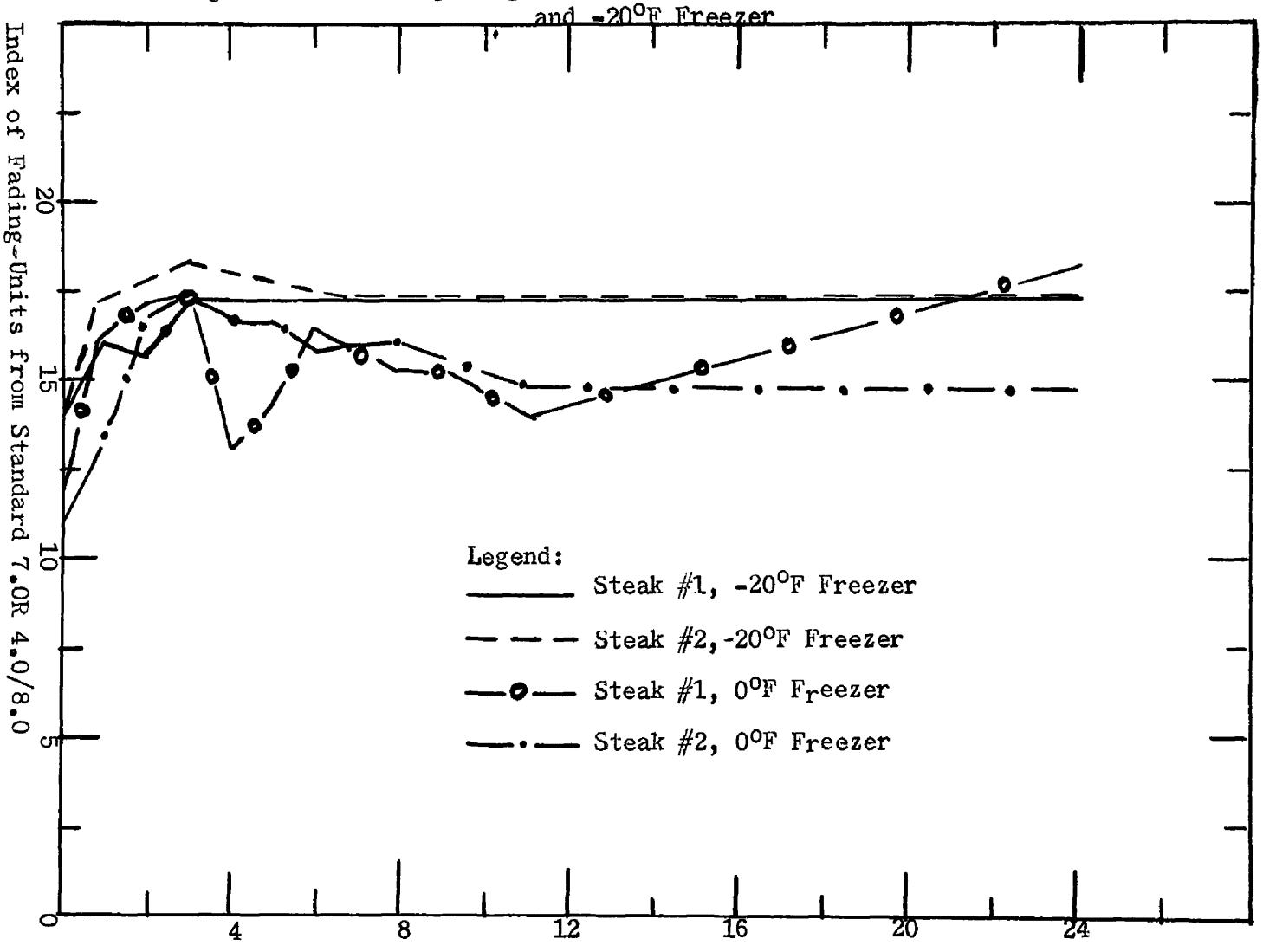


Figure 12.

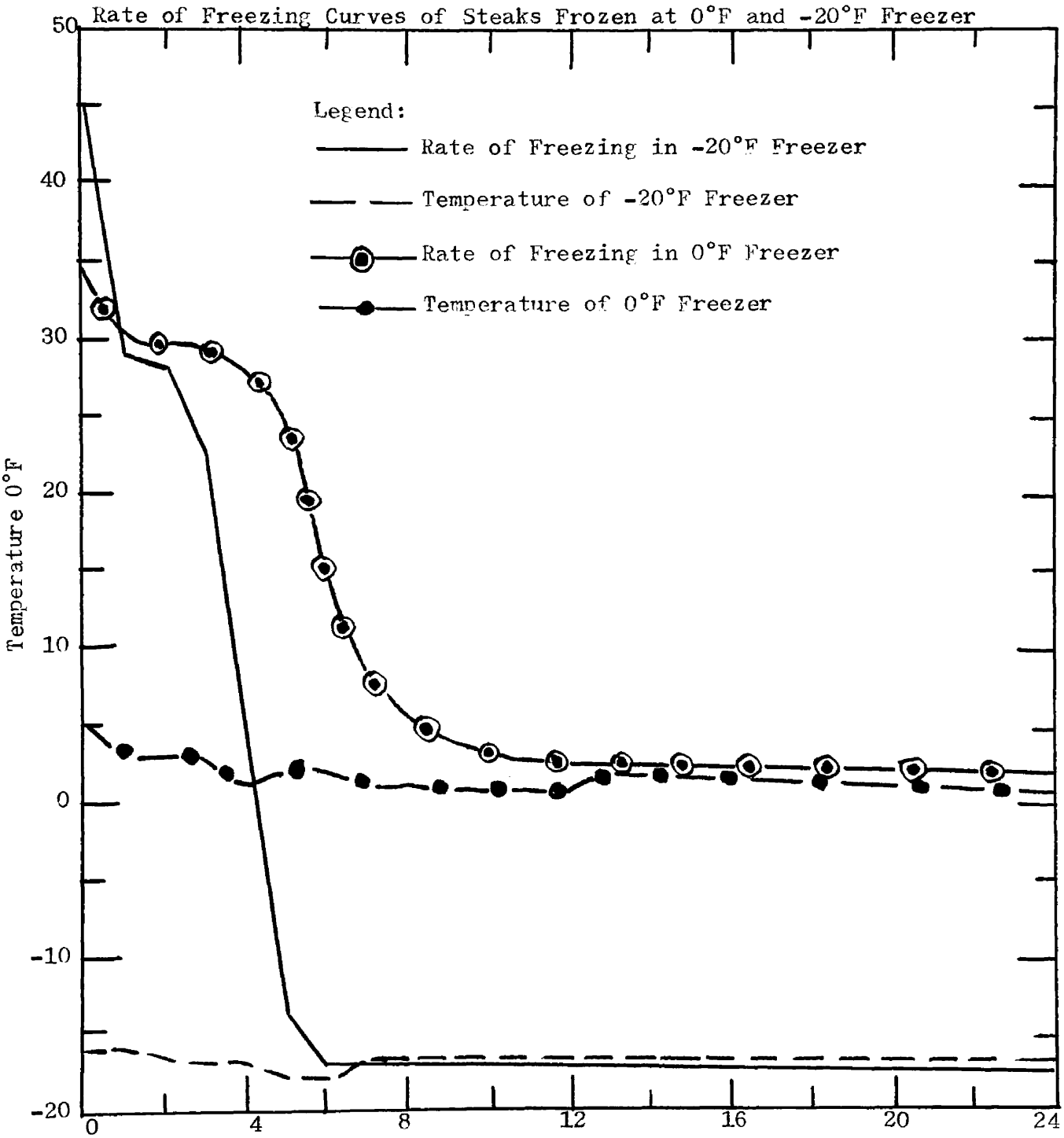

Rate of Freezing Curves of Steaks Frozen at 0°F and -20°F Freezer
Legend:
Rate of Freezing in -20°F Freezer
Temperature of -20°F Freezer
Rate of Freezing in 0°F Freezer
Temperature of 0°F Freezer
Temperature 0°F
50
40
30
20
10
0
-10
-20
0
4
8
12
16
20
24
Time In Hours

Figure 13.

time interval before the package is placed into the freezer, and the rate of freezing) has a marked effect on the initial discoloration of prepackaged frozen meats. The initial color degradation may be due to the effect of temperature on enzymatic activity in meat. Gortner (1949) has shown that enzymatic activity is related to temperature. With a fall in temperature, enzymatic activity is slowed down. Fairley (1957) stated that the cytochrome-oxidase system represents about 90% of the oxygen uptake by the tissue. Cytochrome-oxidase takes up oxygen from myoglobin which acts as an oxygen reservoir in the tissue. In this reaction, oxygen may be picked up from myoglobin by the cytochrome-oxidase system to carry on the rest of the metabolic functions of muscle metabolism. The discoloration of the steaks kept in the cooler in an oxygen impermeable wrap was believed to be due to the enzymes in the meat picking up the residual oxygen in the package and reducing oxymyoglobin to reduced myoglobin, whereas in those steaks that were frozen, the enzymatic activity was slowed down due to the fall in temperature. If steaks are quick frozen as was suggested by Jensen (1949), the enzymatic activity is slowed down faster than the oxygen uptake by the enzymes and oxymyoglobin is not reduced to myoglobin.

The important fact to be derived from these studies in order to observe what effect they have on initial discoloration of prepackaged frozen meat is the manner in which the meat product is handled before being sent to the freezer and the rate of freezing of the product. These studies pointed out the necessity of sending meat products to the freezer as soon as possible after it is packaged, especially in an oxygen impermeable wrap. These studies also point out the necessity of quick freezing at -20°F or lower in order to maintain the original color of oxymyoglobin.

B. Effect of Repeated Freezing and Thawing on Myoglobin of Prepackaged Frozen Meat.

A review of the literature revealed no information concerning the effect of repeated freezing and thawing on the pigment myoglobin when packaged in an oxygen impermeable transparent plastic wrapper and aluminum foil. Mangel (1951) found that when samples were allowed to thaw from one to five times the methemoglobin formation did not increase with repeated thawing. Samples thawed three and four times showed the lowest percent metmyoglobin formation. She did mention that all samples thawed more than once showed surface darkening. Brooks (1929) reported that freezing and thawing had no significant effect on oxygen penetration, but did accelerate methemoglobin formation in the region of oxygen penetration.

Results of this study showed considerable variation in the percent of metmyoglobin formation as shown in Figure 14. Steaks after having been frozen for twenty-four hours exhibited a color characteristic of oxymyoglobin, with a percent metmyoglobin formation of 0.36 and 2.02 percent metmyoglobin from steaks packaged in Cry-O-Wrap and aluminum foil, respectively. The perdent metmyoglobin formation changed very little after the steaks were frozen for twenty-four hours. After the first thawing cycle, those steaks packaged in Cry-O-Wrap exhibited red and purplish blotches characteristic of oxy- and reduced myoglobin. After the second thawing cycle, the steaks packaged in Cry-O-Wrap plastic bags showed much discoloration. The side of the steaks next to the non-fold side of the aluminum foil package showed a color much the same as that exhibited by those steaks packaged in Cry-O-Wrap. This seems to indicate that aluminum foil is somewhat oxygen impermeable. The side of the steak next to the fold side of the package

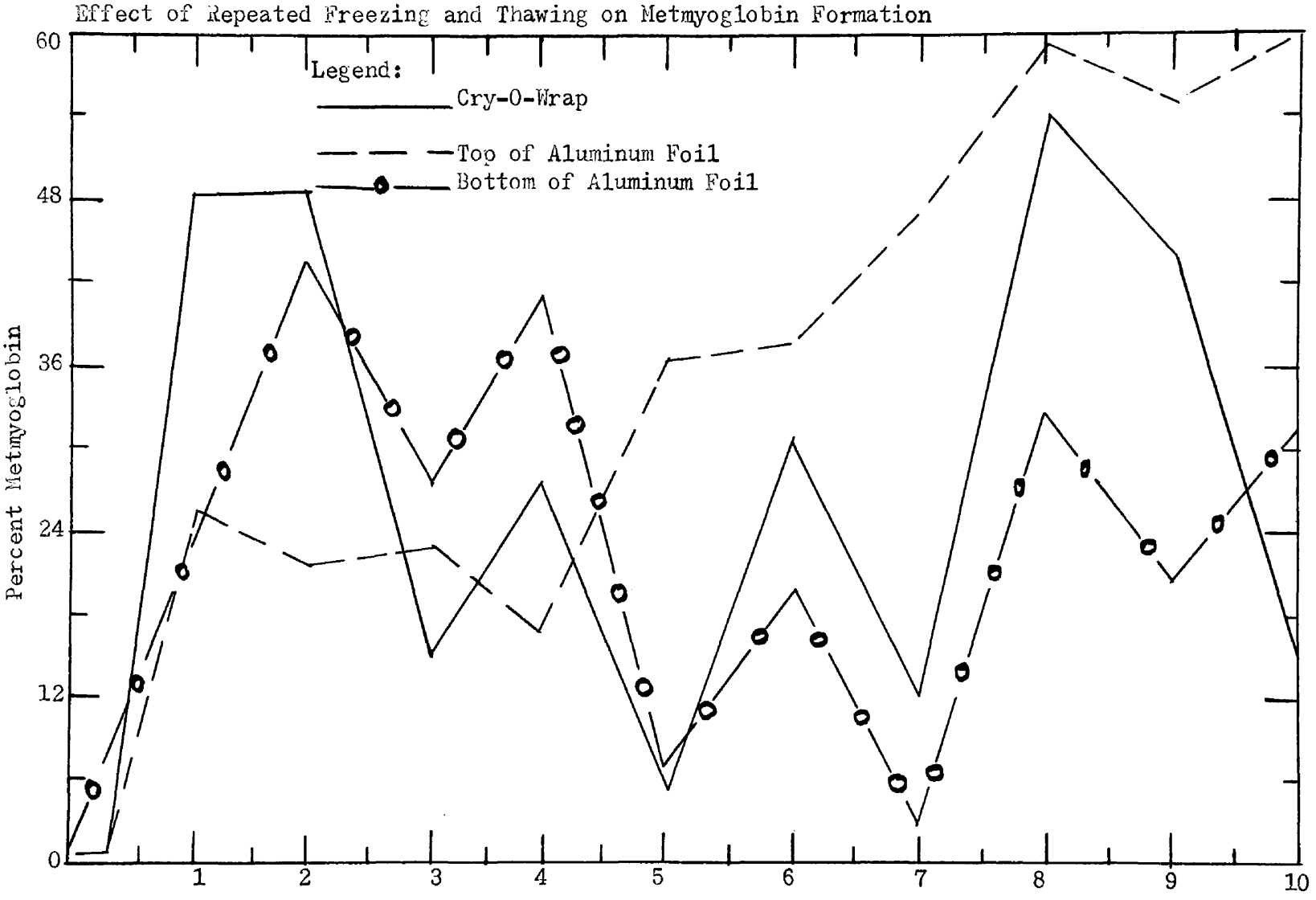

Effect of Repeated Freezing and Thawing on Metmyoglobin Formation
Legend:
Cry-O-Wrap
Top of Aluminum Foil
Bottom of Aluminum Foil
Percent Metmyoglobin
0
12
24
36
48
60
1
2
3
4
5
6
7
8
9
10
Number of Cycles

Figure 14.

exhibited a red color characteristic of oxymyoglobin up to the fourth thawing and refreezing cycle, after which it started to discolor. Figure 14 shows an alternate increase and decrease of percent metmyoglobin formation with alternate thawing and freezing cycles. Those steaks packaged in aluminum foil showed about the same percent metmyoglobin formation as those steaks packaged in Cry-O-Wrap. The side of the steaks packaged in aluminum foil next to the package fold in which there was some air showed a progressive increase in percent metmyoglobin formation.

Figure 15 shows that those steaks packaged in Cry-O-Wrap and the side of the steaks in aluminum foil not next to the package fold discolored at about the same rate, whereas those steaks next to fold side of the aluminum foil package did not discolor until about the fourth thawing and refreezing cycle. No attempt was made to study further the relationship of enzymatic activity as related to thawing and refreezing of meat.

C. The Effect of Light on Color Degradation of Prepackaged Frozen Meat.

In order to properly analyze the results of the effect of light on color degradation of prepackaged frozen meat, it is necessary to become acquainted with the subject of photochemistry. Blum (1941) stated that photobiological processes are essentially photochemical processes. Photochemistry is the study of chemical reactions produced directly or indirectly by means of radiation. It is possible to activate molecules with an external source of energy, as for example, by introducing a beam of light having the proper frequency to be absorbed and sufficient energy in each photon to affect the reaction. A photon of radiation is a unit of radiation which possesses one quantum of energy. Frequently, the term quantum is used interchangeably with the term photon. In the primary photochemical process each molecule

Effect of Repeated Freezing and Thawing On Metmyoglobin Formation

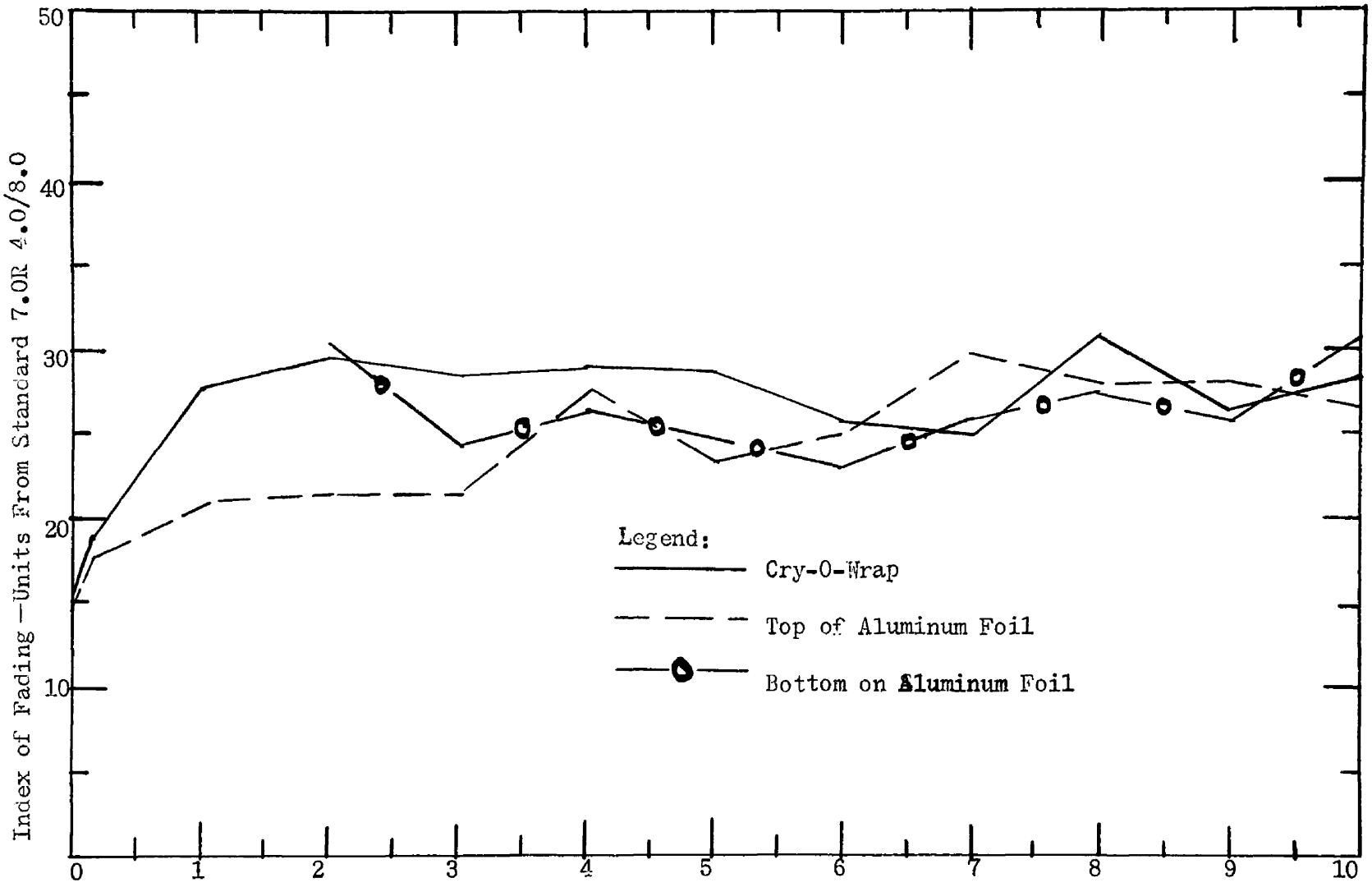


Figure 15.

is activated by the absorption of one photon.

Daniels (1948) stated that if there is no possible electronic, atomic, or molecular change that can use the exact amount of energy contained in the photon of radiation, there will be no interaction and no chemical or physical changes will result. However, if there is within the molecule some change which is not in conflict with the quantum restrictions and which corresponds to the energy of the photon, there may be a transfer of energy, and the photon is "absorbed". The only difference between the ultraviolet and visible spectra is that greater energies and larger displacements are involved in ultraviolet absorption, 35,000 to 71,000 calories per mole being required for absorption in the visible region and 71,000 to several hundred thousand calories for absorption in the ultraviolet. Daniels (1948) further stated that energies required for most chemical reactions range from about 10,000 to 100,000 calories. He stated that only that radiation which is absorbed can produce chemical change. He also mentioned that Grotthus pointed out in 1818 that there cannot be a photochemical reaction unless radiation is absorbed.

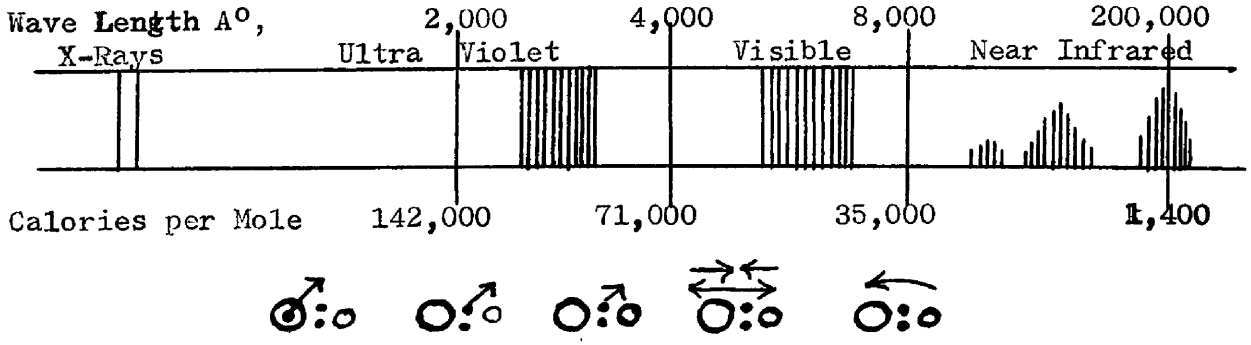
Light is ordinarily made up of many wave lengths. When composed of virtually only one wave length, it is called monochromatic. We distinquish the kinds of radiant energy according to wave length. Wave length can be defined adequately only by a technical description of how it is measured. The wave lengths of light preceived by the human eye are called visible. Visible radiant energy is confined to wave lengths between about 380 mu and 760 mu or 380 to 760 millionths of a millimeter. The following ranges of wave lengths correspond to the indicated colors:

Violet	380 mu to 450 mu
Blue	450 mu to 490 mu
Green	490 mu to 560 mu
Yellow	560 mu to 590 mu
Orange	590 mu to 630 mu
Red	630 mu to 760 mu

The energy of quantum may be transformed in several different ways summarized as follows:

1. Heat- the temperature of the absorbing system is raised.
2. Dissociation- the molecule undergoes a chemical breakdown.
3. Ionization
4. Fluorescence

A molecule may be excited in several different ways, depending on the frequency of radiation absorbed. These different methods of absorbing radiation in the different parts of the spectrum and the energies involved are summarized in Figure 16.



Taken from "Outlines of Physical Chemistry" by Farrington Daniels, (1948), p. 595.

Figure 16

In the upper half of the figure are given the general types of spectra together with the wave length regions and energy of the radiation in calories per mole. In the lower part is given a crude representation of what happens when the radiation is absorbed. The black dots represent electrons, and the large circles represent atoms in the molecule. In the visible and ultraviolet region of the spectrum, the absorption consists in displacing an outer electron in the molecule. Absorption spectra for extracts from prepackaged frozen meat stored under light were determined to see if light caused any deviation from that of the normal absorption spectra curves of mixed pigment extracts containing myoglobin, oxymyoglobin and metmyoglobin.

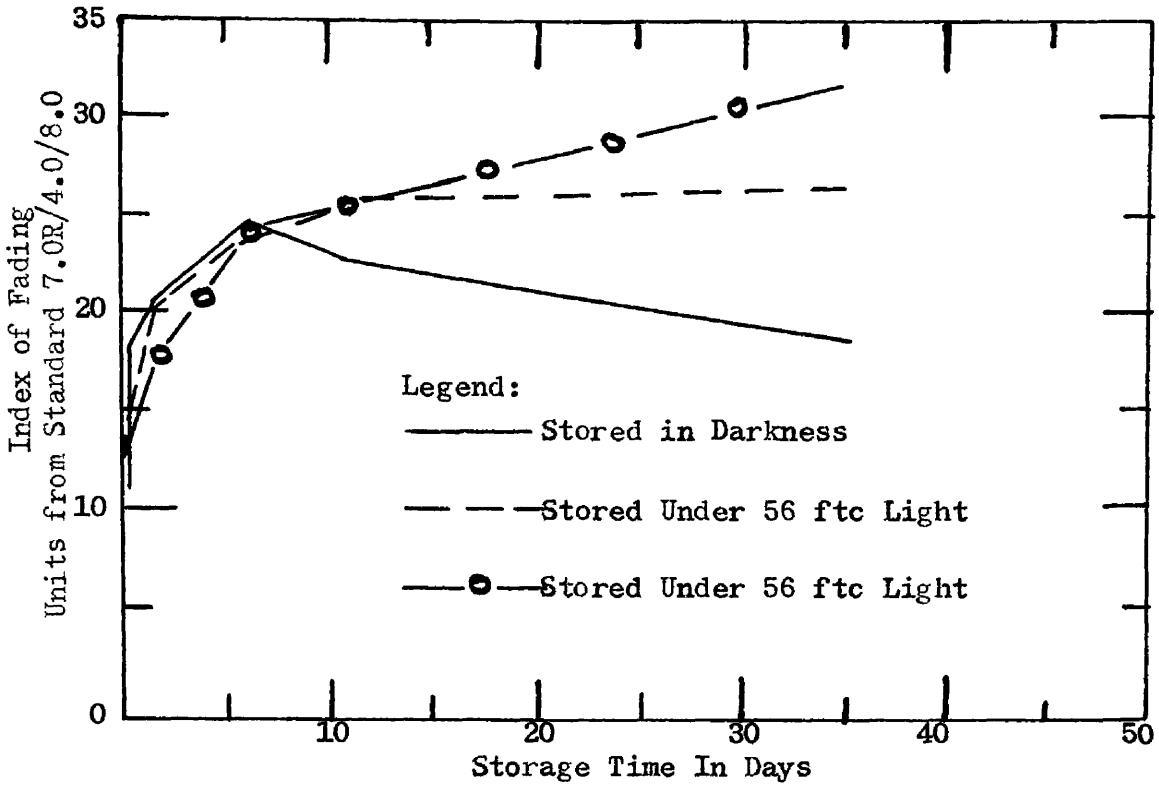
1. The Effect of Incandescent Light on Color Degradation of Prepackaged Frozen Meat.

Three samples were used in this study. One steak was placed under opaque paper to provide darkness. The other two steaks were stored under 56 foot-candles of incandescent tungsten filament illumination. Surface color measurements were made at various intervals of time for a period of five weeks. Estimations of metmyoglobin were made before and after storage. pH and absorption spectra determinations were made. This part of the study was done to see if this type of light had any effect on color degradation of prepackaged frozen meat. Results of this study showed that this type of light caused considerable darkening as compared to the control sample. The index of fading changed from 15 to as high as 24.8 units from standard. The change from 24.8 units to 18.9 units from standard for the last reading was due to the fact that the last reading was taken with the wrapper removed for spectrophotometric analysis. Steaks two and three which were kept under 56 foot-

candles of light changed from 12.2 to 26.9 units from standard for steak No. 2, and 11.7 to 31.4 units from standard for steak No. 3. The greatest change in Munsell renotations seem to be in hue and chroma. The graph showing the index of fading is shown in Figure 17 on page 54. The percent metmyoglobin changed from 0.91% to 31.33% for the steak stored in darkness. Steaks two and three changed from 0.91% to 57.02% and 52.48% metmyoglobin, respectively. A review of the absorption spectra curves in Figure 18 on page 55 shows typical absorption spectra curves for extracts containing mixed pigments. This agrees with the work reported by Mangel (1951). One should note the absorption spectra curves for the samples stored under light. At about 502-505 mu, there is an increase in the slope of the absorption curve which is typical for extracts which contain a considerable amount of metmyoglobin as shown by Mangel (1951).

2. Color Degradation of Prepackaged Frozen Meat Displayed Under Fluorescent Light. - A Preliminary Study.

Twenty-four steaks packaged in Cry-O-Wrap were used in this study. Twelve steaks were kept in darkness and twelve steaks were kept under 56 foot-candles of standard white fluorescent illumination. These steaks were stored in a Sherer self-service frozen food case, with steaks being removed from the case at various intervals of storage up to thirty-five days. As each steak was removed from the case, it was allowed to thaw for two hours, after which the wrapper was removed and surface color measurements were made by use of Munsell spinning disks. A three mm thick slice was sliced off with a Hobart Model 300 slicer for spectrophotometric estimation of metmyoglobin.



Effect of Incandescent Illumination on Color Degradation and Metmyoglobin Formation of Prepackaged Frozen Steaks

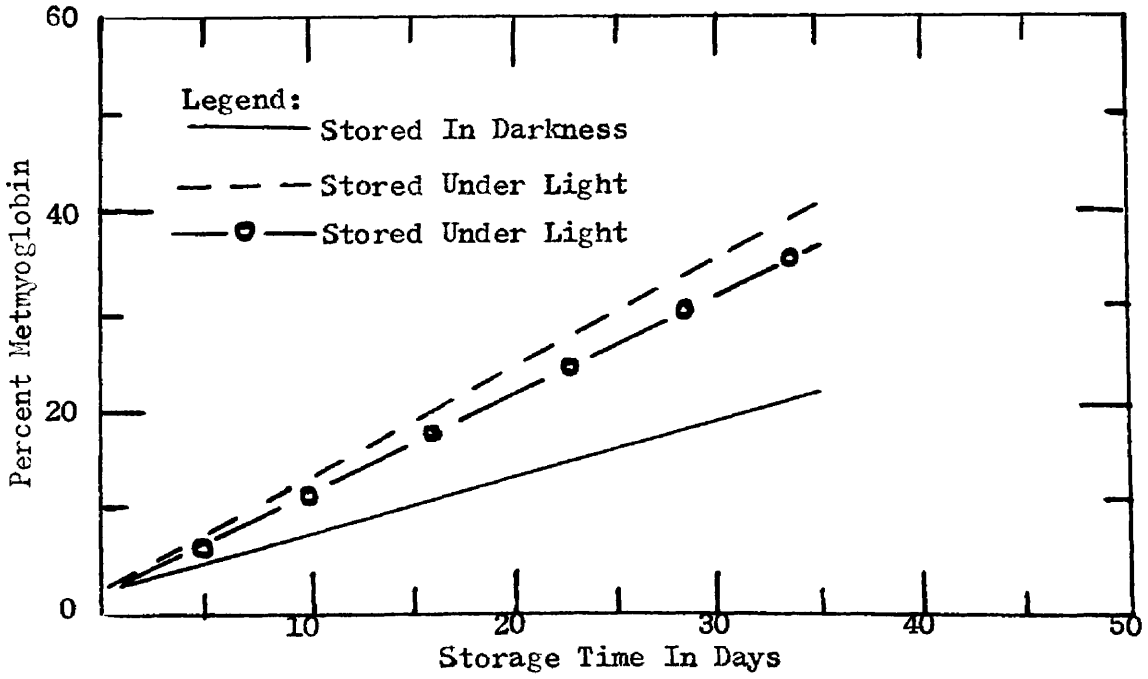


Figure 17.

Absorption Spectra For Extracts From Prepackaged Frozen Steaks Stored In Darkness and Under 56 Foot-Candles of Incandescent Illunination.

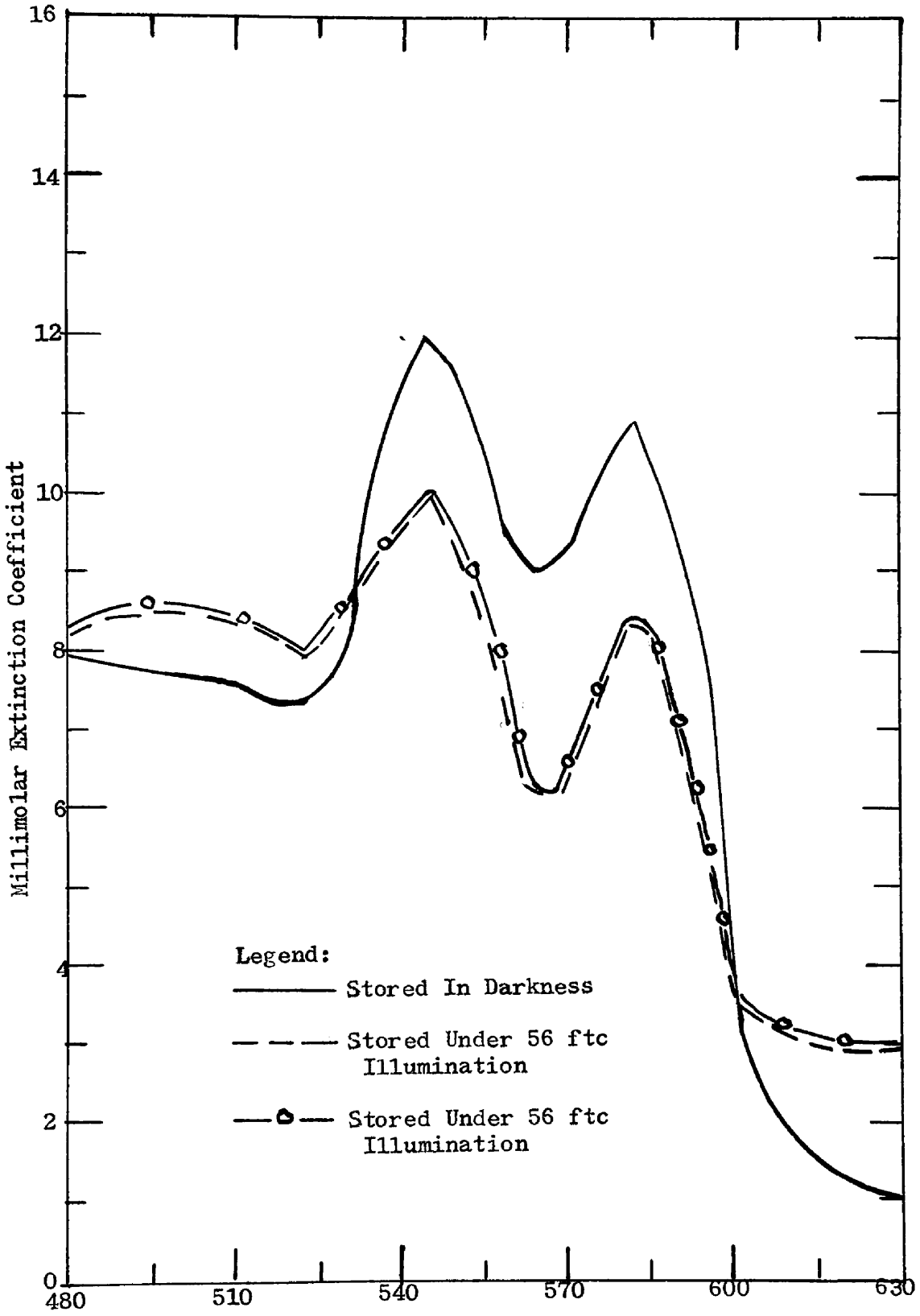


Figure 18.

Each steak was turned over and surface color measurements again made. The steak was then placed in a Cry-O-Wrap plastic bag for four hours to see if there was an increase of oxymyoglobin formation. After the four hour blooming period, surface color measurements were again made and a three mm thick slice removed for spectrophotometric estimation of metmyoglobin. Determinations for pH were also made.

Results of this study showed that fluorescent lighting caused color degradation of prepackaged frozen meat when displayed in a self-service frozen food case. Figure 19 shows that those steaks stored in darkness were only 15.6 units from standard at the beginning of the study and increased to 28.0 units from standard at the end of the storage period. Those steaks stored under light changed from 15.2 units from standard to 26.0 units from standard. Figure 19 also shows that those steaks stored in darkness "brightened" when allowed to "bloom" for four hours, however, those steaks stored under light did not brighten when allowed to "bloom" for four hours.

The change in percent metmyoglobin formation showed considerable variation. This probably was due to the fact that a strict schedule was not followed in exposing each side of the steak to the same period of illumination. Figure 20 shows in general that those steaks stored in darkness contained less metmyoglobin than those steaks stored under light. Figure 21 shows the absorption spectra curves for extracts from frozen steaks stored in darkness and under 56 foot-candles of fluorescent illumination for one day and thirty-five days of storage. Steaks stored in darkness and under light for one day follow about the same absorption curve, however, after thirty-five days storage, the presence of metmyoglobin can readily be distinguished as affected by darkness and light.

Color Change of Prepackaged Frozen Steaks Stored In Darkness and Under 56 Foot-Candles of Illumination.

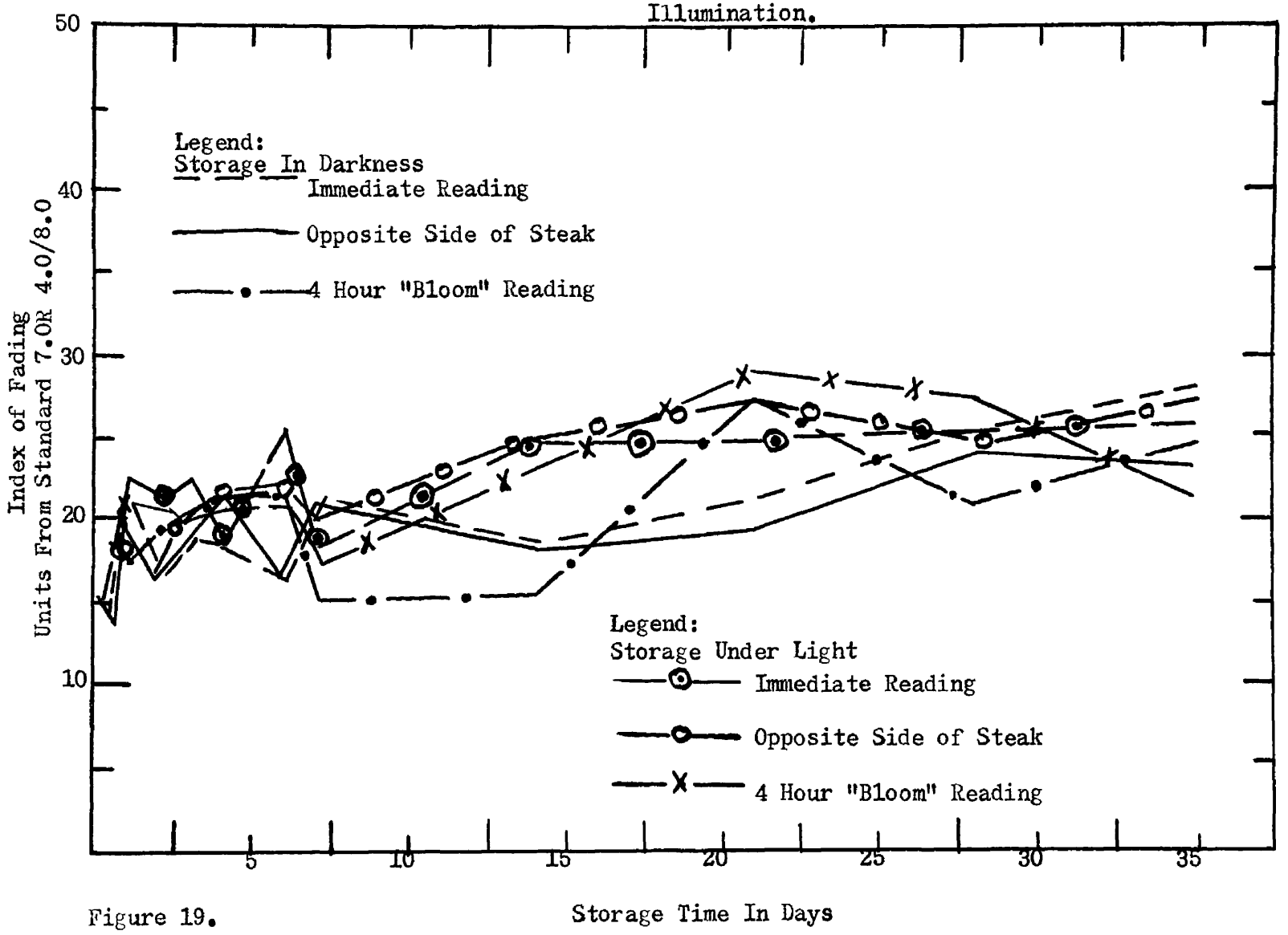


Figure 19.

Percent Metmyoglobin Formation In Prepackaged Frozen Steaks Stored In Darkness and Under 56 Foot-Candles of Illumination.

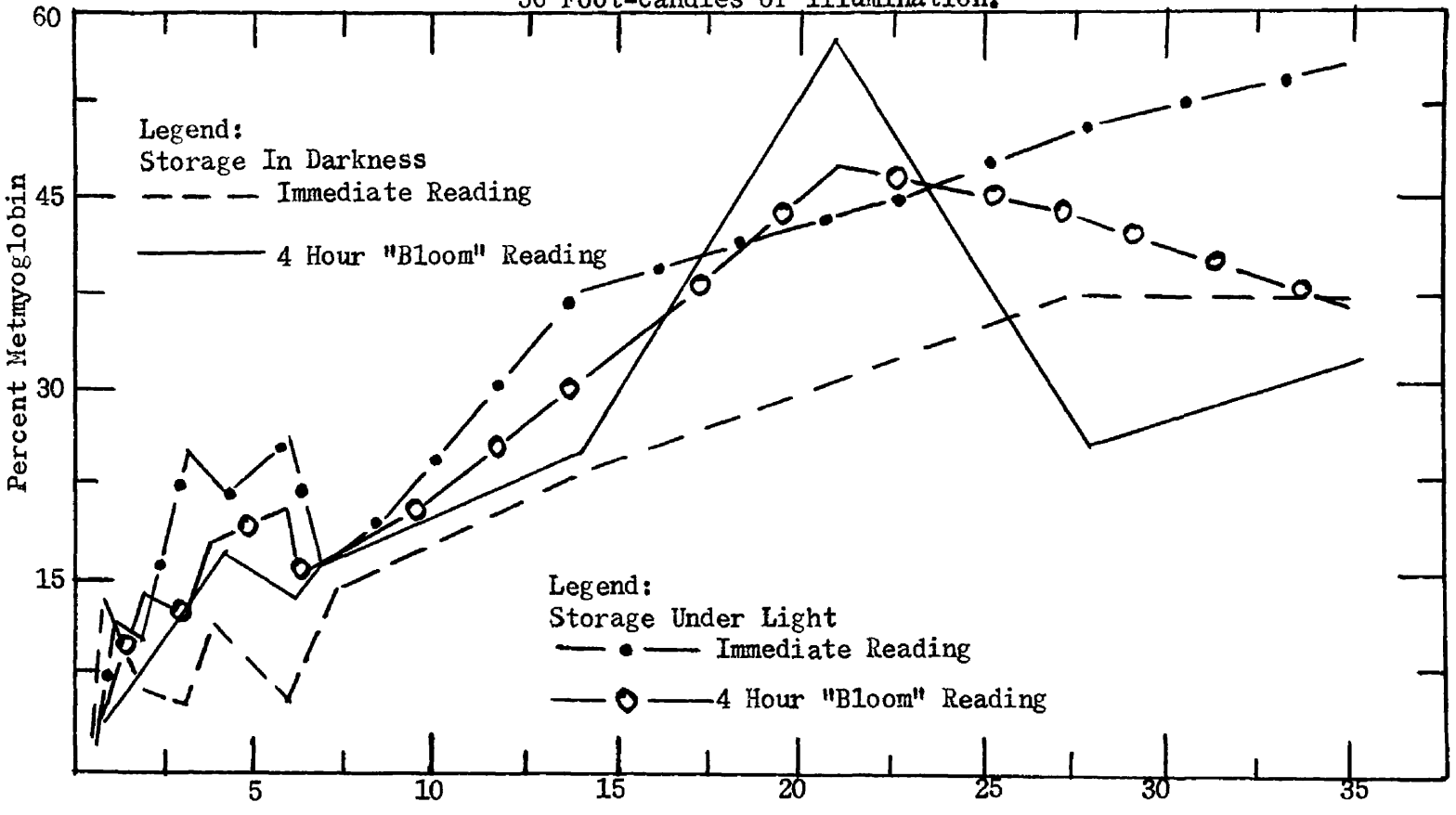


Figure 20.

Absorption Spectra For Extracts From Frozen Steaks Stored In Darkness And Under 56 Foot-candles of Fluorescent Illumination

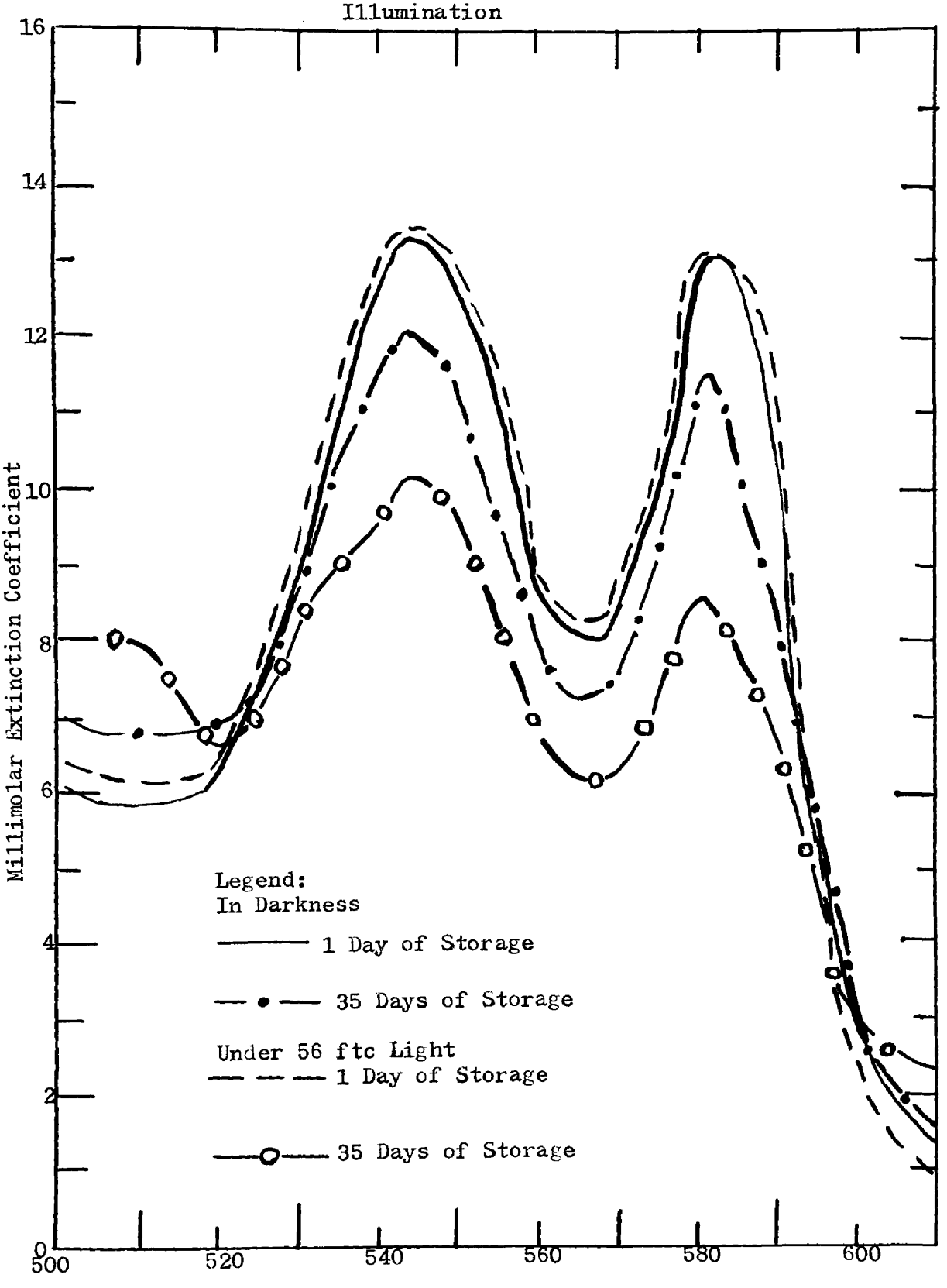


Figure 21.

3. Color Degradation of Prepackaged Frozen Meat Under the Same Level of Illumination at Two Different Temperatures

This study was conducted to see what effect 56 foot-candles of illumination at two different temperatures would have on degradation of color in prepackaged frozen meat.

A total of thirty-six steaks were used in this study. These were divided into four groups of nine steaks each. These groups were as follows:
Group I. Stored in the Sherer self-service case in darkness.
Group II. Stored in the self-service case under 56 foot-candles of illumination. It was necessary to turn these steaks over each day at a specific time in order that both sides of the steak receive equal exposure to light.
Group III. Stored in a 0°F freezer under 56 foot-candles of illumination. These steaks were treated in the same manner as those in Group II.
Group IV. These steaks were stored in a freezer in darkness at 0°F.

Steaks were removed at various intervals of time, with the last steak being removed at the end of five weeks. Surface color measurements and spectrophotometric estimations of metmyoglobin formation were made in the same manner as described in the preliminary study.

Figures 22, 23 and 24 show the results of the effect of the same level of illumination at two different temperatures on color degradation of prepackaged frozen meat. Immediate Munsell readings as shown in Figure 22 show that those steaks stored in darkness in the 0°F freezer did not discolor to the same extent as those steaks stored in the self-service case under light and darkness as well as the steaks stored in the freezer under light. After a four-hour "bloom" period, Figure 23 showed that those steaks stored in darkness in the freezer, and steaks stored under light in the

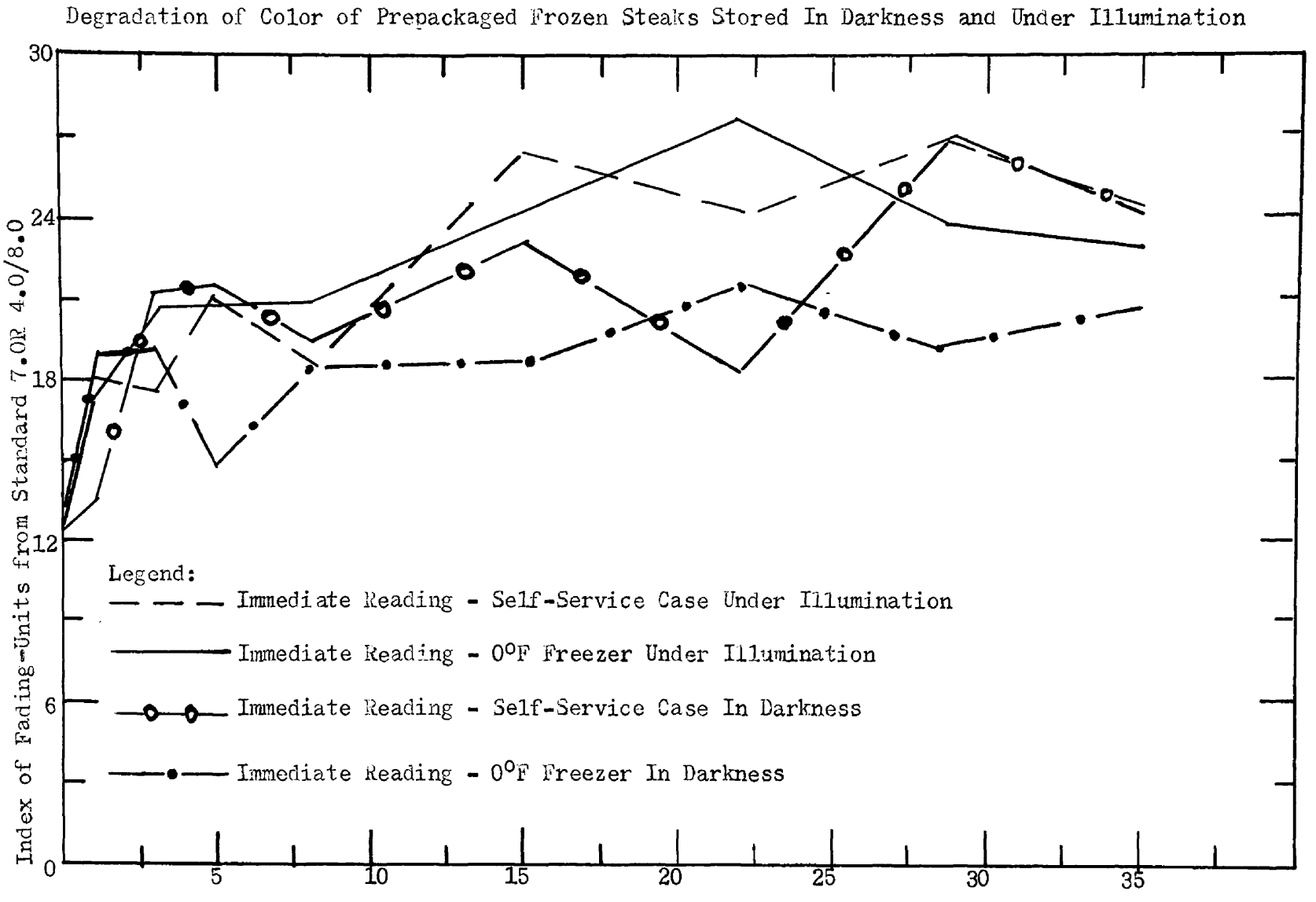


Figure 22. Storage Time In Days

4 Hr. "Bloom Period" of Prepackaged Frozen Steaks Stored In Darkness and Under Illumination

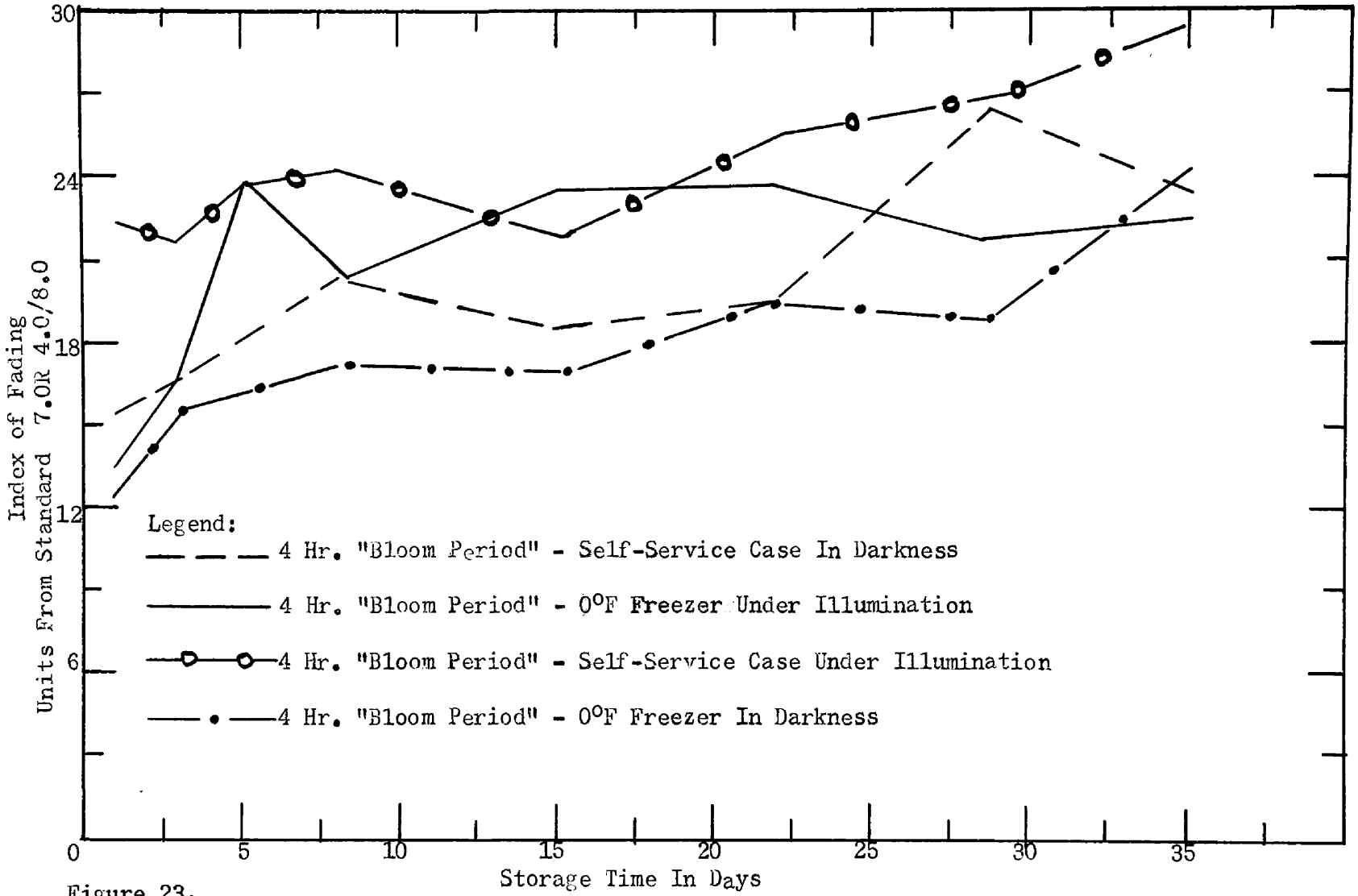


Figure 23.

freezer brightened after a four hour "blooming period". Those steaks stored in the self-service case did not brighten to any extent after a four hour "blooming period". Figures 24 and 24a show the effect of the same level of illumination at two different temperatures on the formation of metmyoglobin. Steaks stored in darkness in the freezer showed the least increase in the formation of metmyoglobin when both immediate and four hour readings were made, however, there was an increase of metmyoglobin from those steaks after a four hour "blooming period". Steaks stored under light in the freezer showed less metmyoglobin formation than those steaks stored in the self-service case in darkness. There was relatively little change in metmyoglobin formation as a result of the "blooming period".

Steaks stored under light in the self-service case showed the greatest amount of metmyoglobin formation, however, when allowed to "bloom" for four hours there was a decrease in metmyoglobin formation. In general the results may be summarized as follows:

1. Meat stored in the freezer in darkness showed the least formation of metmyoglobin, but an increase of metmyoglobin after the four hour "blooming period".
2. Meat stored under light in the freezer showed less metmyoglobin formation than steaks stored in darkness in the self-service case. There was no significant change in the percent metmyoglobin after a four hour "blooming period" for those steaks stored in the freezer under light, but there was a decrease in metmyoglobin formation for those steaks kept in the self-service case in the dark.

Metmyoglobin. Prepackaged Frozen Steaks Stored In Darkness and Under Fluorescent Illumination at Two Different Temperatures.

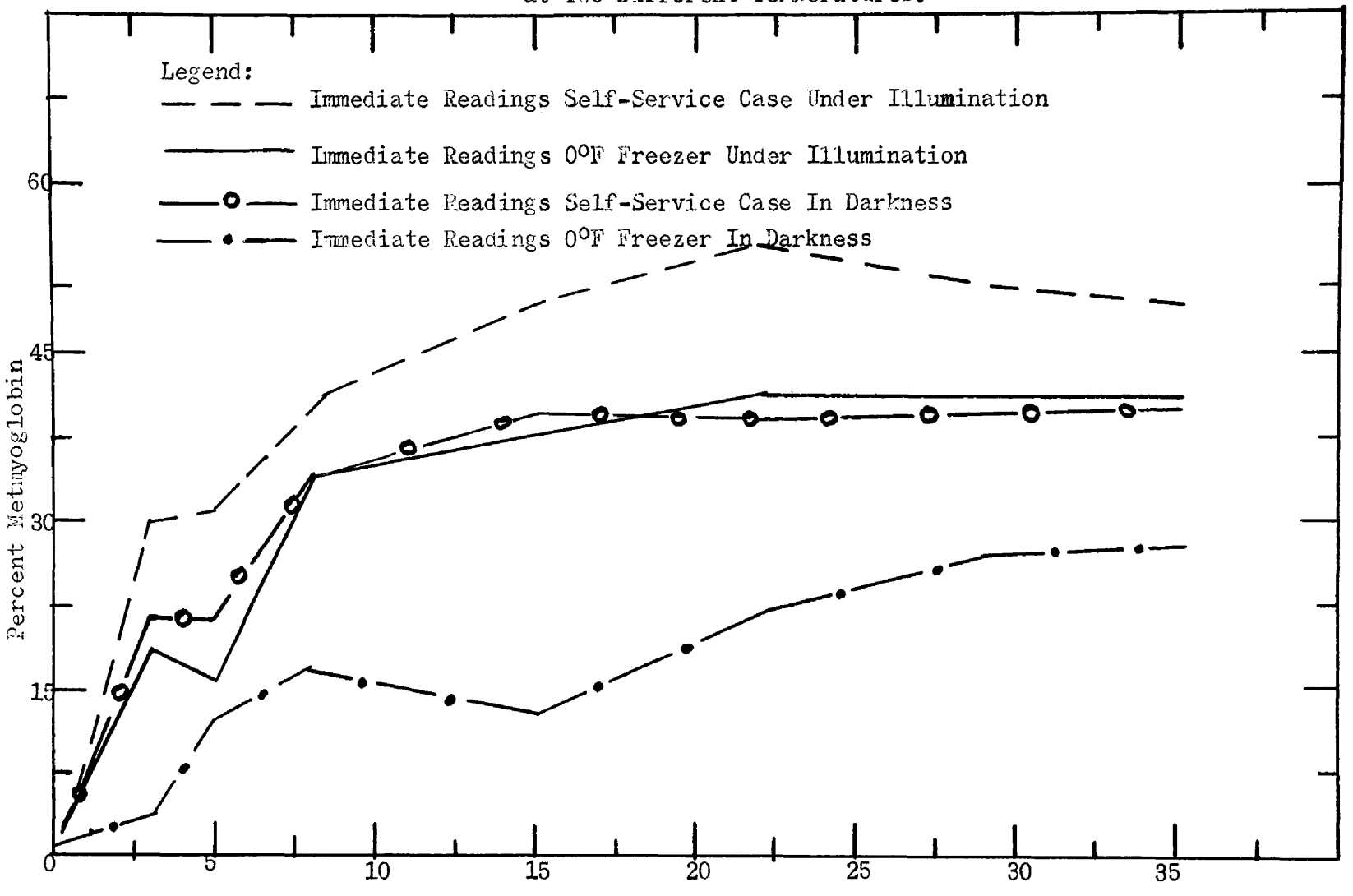


Figure 24.

Metmyoglobin: Prepackaged Frozen Steaks Stored in Darkness and Under Fluorescent Illumination at Two Different Temperatures

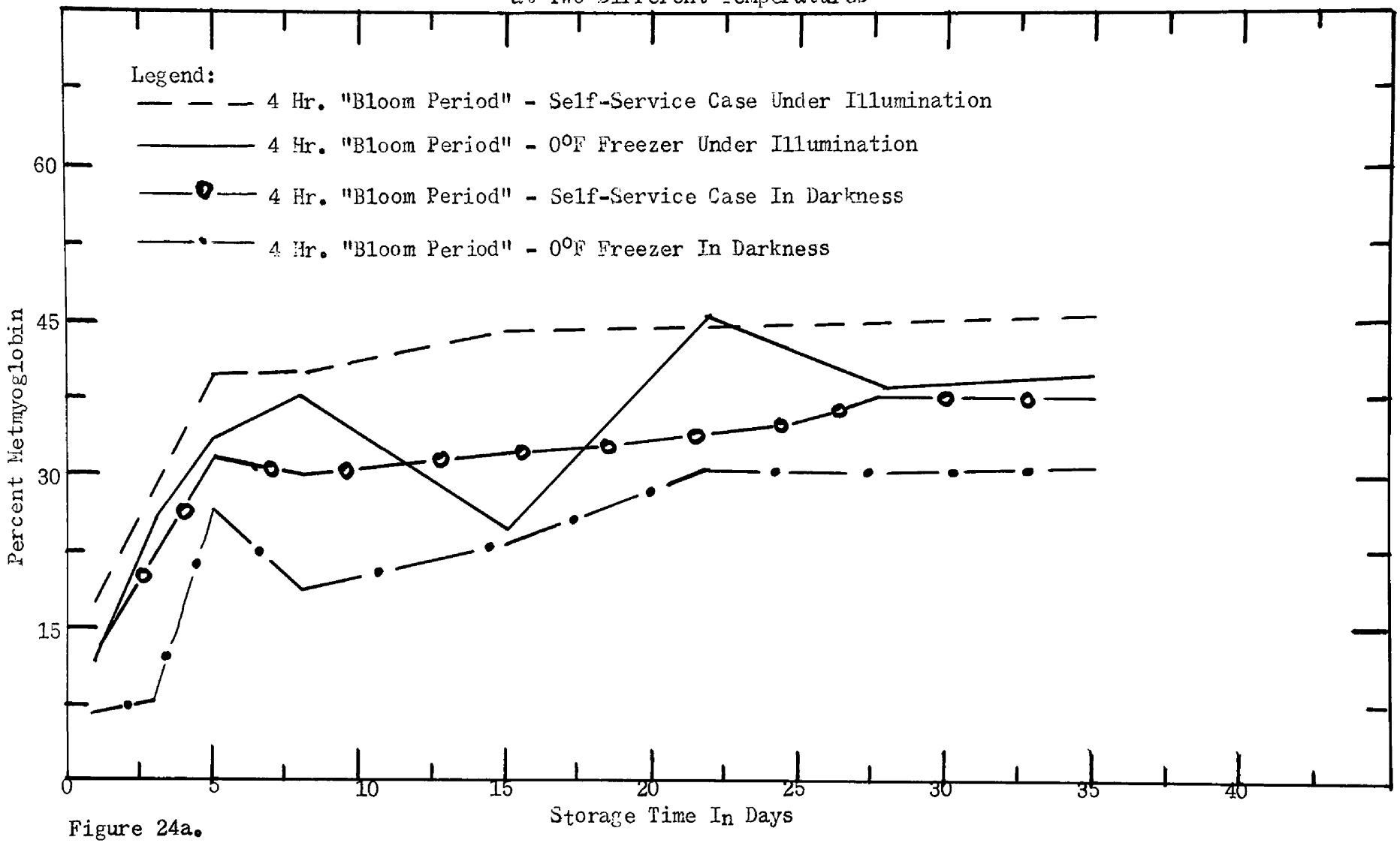


Figure 24a.

3. Steaks stored under light in the self-service case showed the greatest formation of metmyoglobin, however, there was a decrease after a four hour "blooming period".

4. Color Degradation of Prepackaged Frozen Meat Stored Under Various Colored Filters

Results of the two preceding studies indicated that light was detrimental to the color of prepackaged frozen meat. Therefore, it was decided to further exploit the attribute of light which is responsible for this degradation of color.

It has been shown by Kampschmidt (1955) and Taylor (1950) that wave-length is one of the most important factors causing fading or discoloration of colored materials, such as colored textiles and processed meats (such as bologna, veal loaf and boiled ham, etc.). Kampschmidt (1955) reported that for cured meats there are specific wave-lengths of light which are absorbed to a greater extent by cured meats and bring about its discoloration. He stated that the effective spectra distribution curve is higher in the region between 400 mu and 550 mu than wave-lengths above 550 mu. With these thoughts in mind, a study was planned using various colored filters which would allow certain wave-lengths of light to pass through them. This first study was more or less a preliminary study. No attempt was made in this study to maintain the same level of illumination on the steaks.

Eight steaks packaged in Cry-O-Wrap were used in this study. One sample was placed under each of the following light filters: purple, blue, green, yellow, orange and red. One steak was held in darkness and one steak stored under Standard Cool fluorescent lighting. External illumination of 56 foot-

candles was used with the following light intensities falling on the steak after passing through the filter. These were as follows:

Purple	5 footcandles
Blue	2 footcandles
Green	4 footcandles
Yellow	44 footcandles
Orange	14 footcandles
No filter	56 footcandles
Darkness	0 footcandles

Storage was for a period of five weeks. Surface color measurements were taken at various intervals of storage time by the use of Munsell spinning disks. Spectrophotometric estimations of metmyoglobin formation were taken before and after storage. pH determinations were made.

Results of this study seemed to show that the wave-lengths of light between 560 mu and 630 mu (yellow and orange portion of the spectrum) are responsible for the degradation of the color of prepackaged frozen meat. Table V shows the effect of light that has passed through various colored filters on the formation of metmyoglobin.

It should be noted that those steaks stored under the orange and yellow filters showed the largest increase in metmyoglobin formation, whereas those steaks stored under the green and purple filter showed the least amount of metmyoglobin formation of those steaks stored under various filters. Figure 25 shows about the same type of relationship. A review of the absorption spectra curves in Figure 26 shows that those steaks stored under no filter and under the orange and yellow filter gave a small absorption peak in the absorption spectra curves at about 505 mu which is characteristic of metmyoglobin.

Table V

Color of Filter	Percent Metmyoglobin
Purple	38.49
Blue	46.56
Green	38.04
Yellow	53.71
Orange	60.26
Red	45.59
Under light (no filter)	59.40
Under no light	32.52

Under normal extraction procedures, a three mm slice removes the majority of the pigment in the superficial layer. This did not happen when slices were removed from those steaks stored under the orange and yellow filters. After the first three mm slice was removed, it was noticed that there were some brownish areas underneath the first slice. Several three mm slices were removed before there were no more brownish areas. Depth of discoloration was estimated to be at a depth of one-half inch.

5. Color Degradation of Prepackaged Frozen Meat Stored Under Various Colored Filters at the Same Level of Illumination.

After analyzing the data in the preceding study, it was decided to use the green, orange and red light filters in this study. Results of the previous study showed no large differences in the formation of metmyoglobin between the purple, blue and green filters.

Discoloration of Prepackaged Frozen Steaks Stored Under Various Colored Filters In Self-Service Case

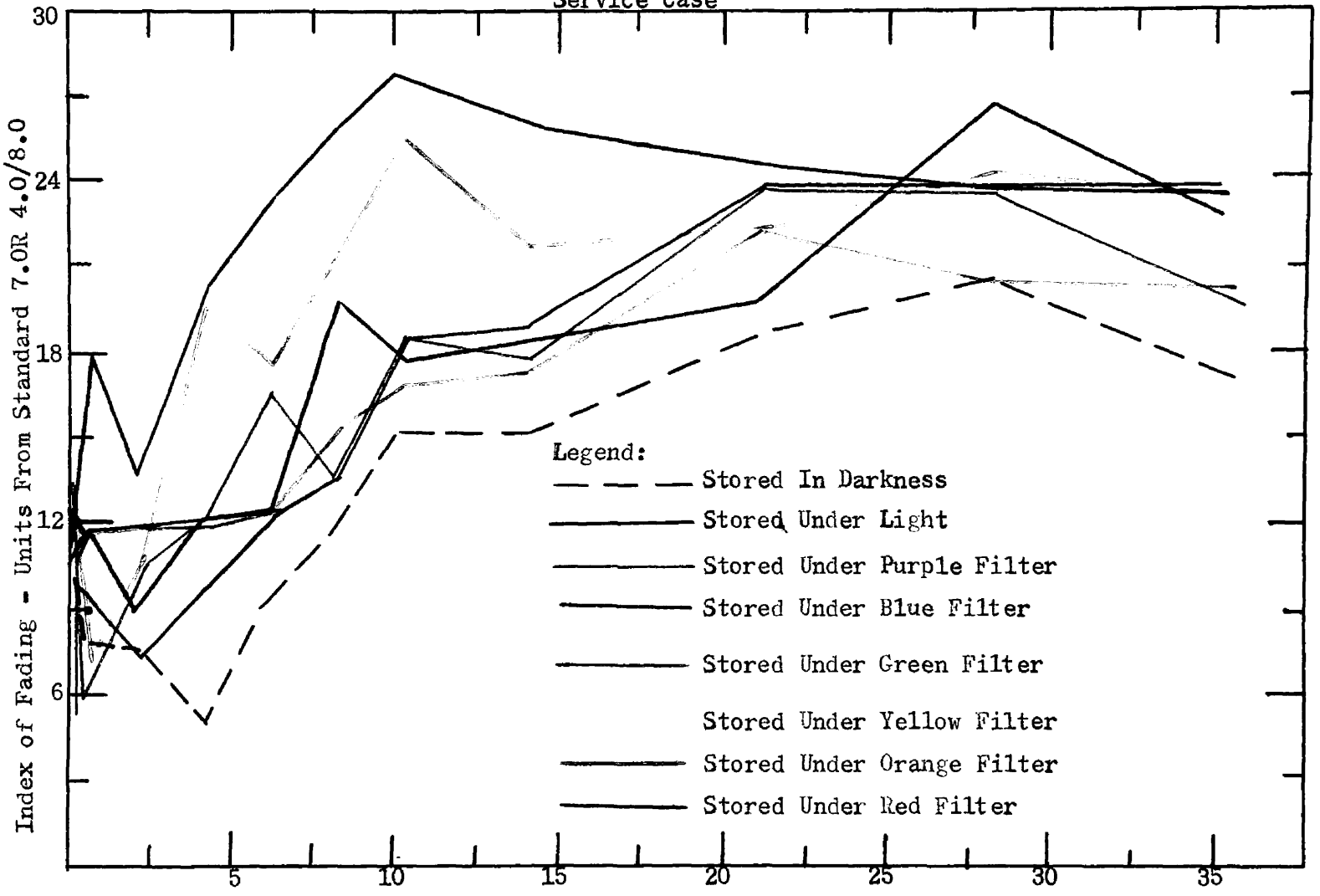


Figure 25.

Absorption Spectra for Extracts From Prepackaged Frozen Steaks Held Under Various Colored Filters

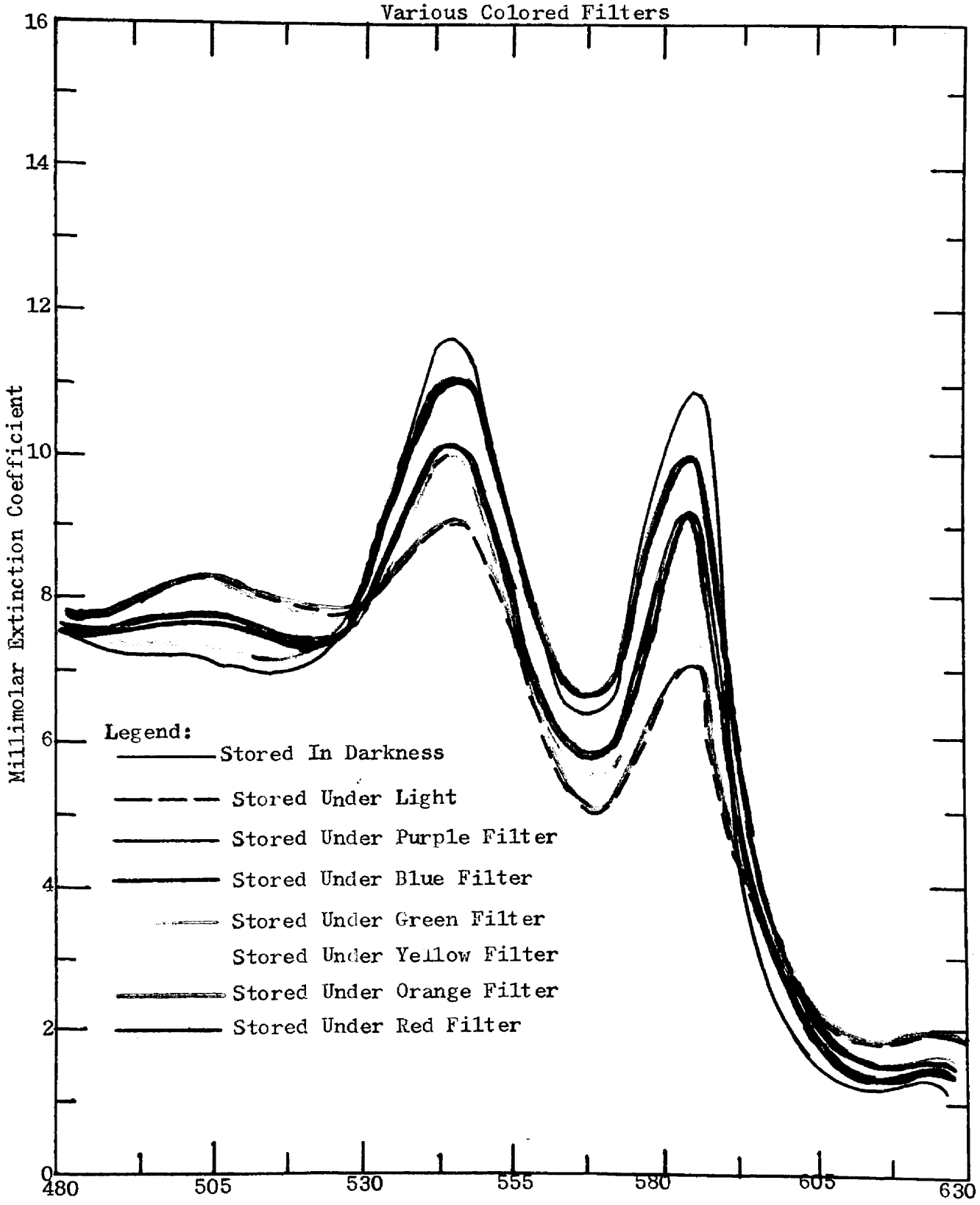


Figure 26.

Five steaks packaged in Cry-O-Wrap were used in this study. One steak was placed under each filter, one steak was placed in darkness and one steak was placed under Standard Cool fluorescent lighting. The filters were so adjusted to give the same level of illumination on each steak. Storage was for a period of five weeks. Surface color measurements were taken at various intervals of time by use of Munsell spinning disks. Spectrophotometric estimations of metmyoglobin formation were made before and after storage. pH determinations were also made.

Results of this study showed that those steaks stored under no filter and under the orange and red filter showed the largest amount of metmyoglobin formation. Table VI shows the percent metmyoglobin formed under the various treatments.

Table VI

Treatment	Percent Metmyoglobin
Orange filter	21.86
Green filter	14.56
Red filter	25.17
Stored in darkness	14.21
Stored under light (no filter)	25.33

The steaks stored under the green filter and in darkness showed the least amount of metmyoglobin formation. Figure 27 shows the color change of steaks stored under various light filters. Figure 28 shows the change in metmyoglobin formation of steaks stored under various filters. Figure 29 shows the absorption spectra for extracts from steaks stored under various filters. In general, this study agreed with the results of the prelim-

Color Degradation of Prepackaged Frozen Steaks Held Under Various Colored Filters at the Same Light Intensity of 2-3 Foot-candles of Fluorescent Illumination

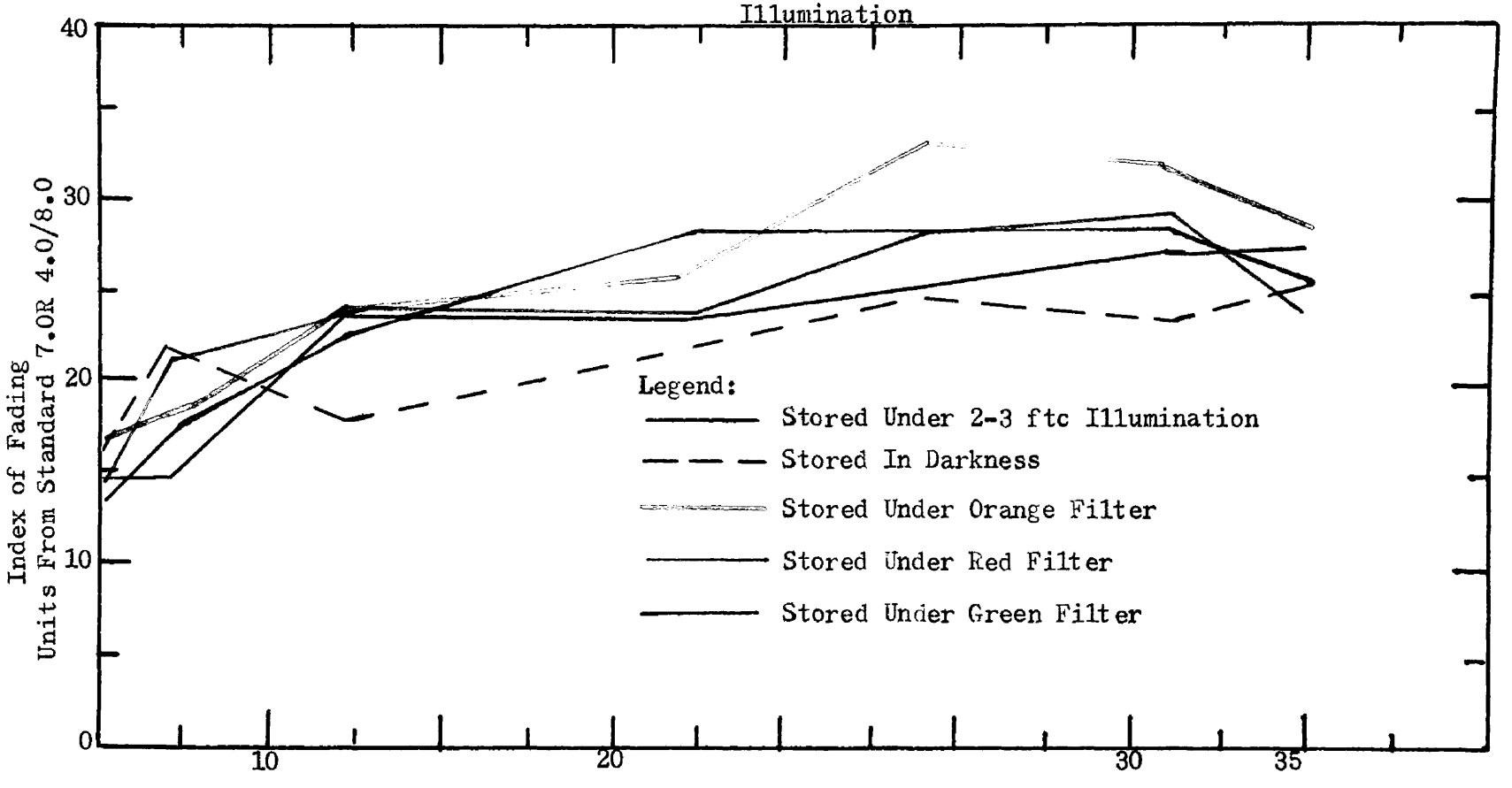


Figure 27.

Color Degradation of Prepackaged Frozen Steaks Held In Darkness and Under Various Colored Filters at the Same Light Intensity

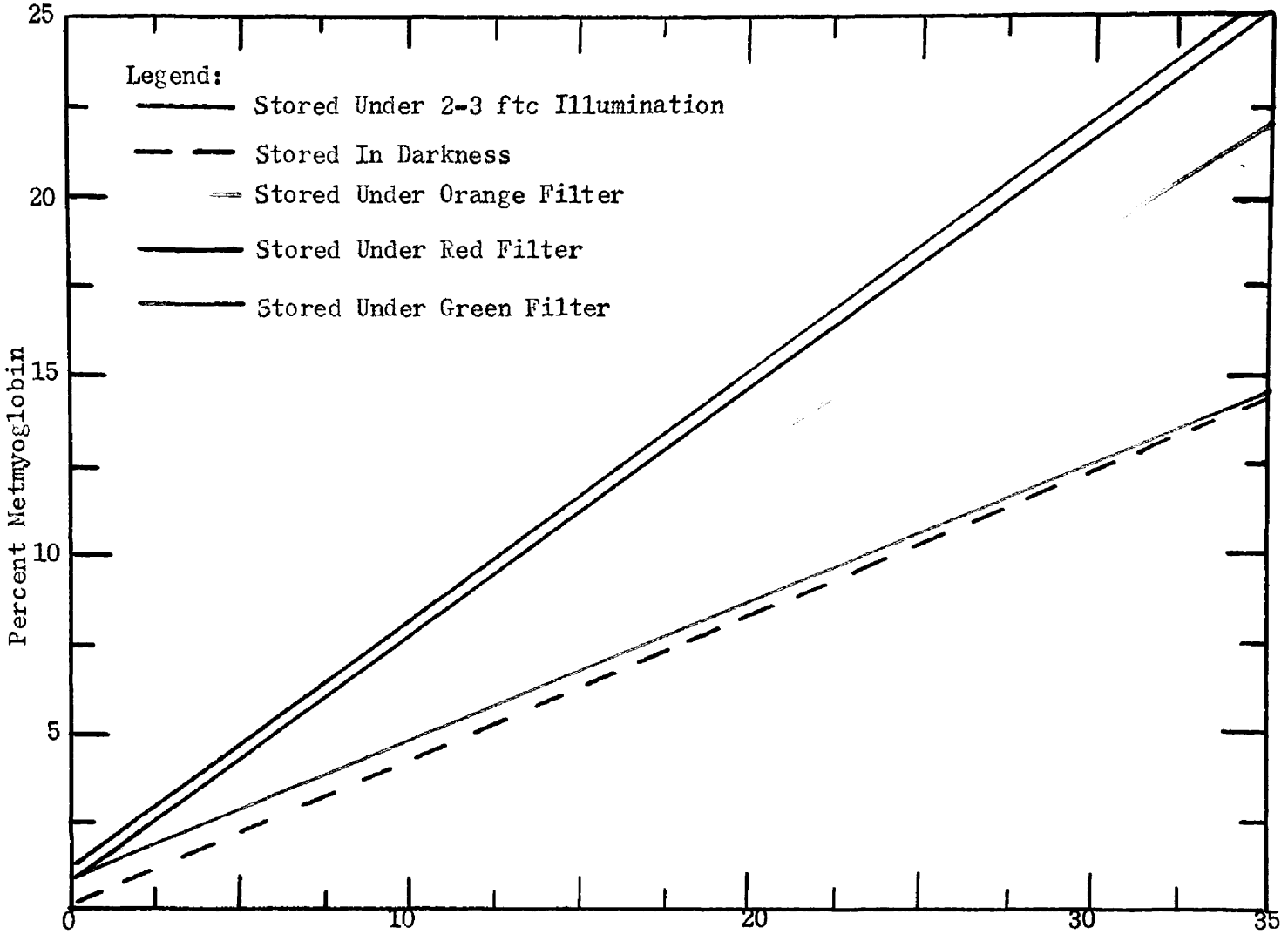


Figure 28.

Absorption Spectra For Extracts From Prepackaged Frozen Steaks Held Under Various Colored Filters At Same Illumination

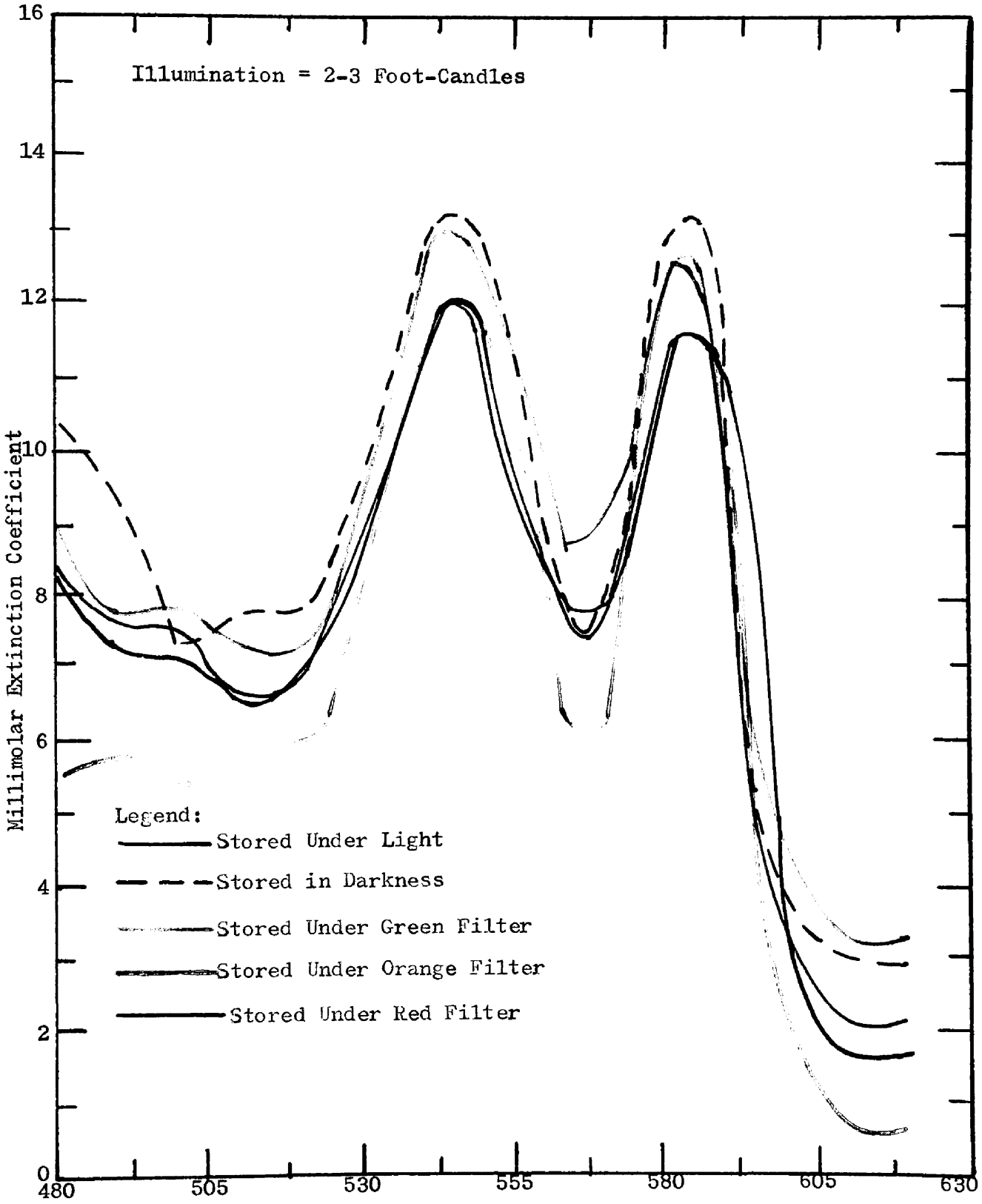


Figure 29.

inary study, in that it seems to be those wave-lengths between 560 mu and 630 mu which are responsible for the degradation of color in prepackaged frozen meat.

6. Color Degradation of Prepackaged Frozen Meat Stored Under Various Colored Fluorescent Lamps

A total of twenty steaks packaged in Cry-O-Wrap plastic bags were used in this study. Four G.E. colored fluorescent lamps were chosen, namely, red, green, white, and yellow. These fluorescent lamps were used because they emitted dominant wave-lengths as shown in Table VII. All steaks were stored in the 0°F freezer.

Table VII

Color of Lamp	Phosphorus Compound Used for Coating Inside of Lamp	Dominant Wave-length
White	Silicate and magnesium	5810
Yellow	Zinc beryllium silicate	5840
Green	Zinc silicate	5280
Red	Cadmium borate	6230

Taken from "Fluorescent Lighting", by A.D.S. Atkinson. New York: Chem. Pub. Co., 1946.

These lamps were so adjusted to give a level of illumination of 20 foot-candles on the steaks. Four steaks were placed under each kind of light and four steaks were stored in darkness. A steak was removed each week for surface color measurements and spectrophotometric estimations of metmyoglobin for a total period of four weeks. pH determinations were also made.

Results of this study are shown in Figures 30 and 31. Figure 30 shows clearly the effect of various colored fluorescent lamps which emit certain wave-lengths of light on the degradation of color of prepackaged frozen meat. Figure 30 shows that steaks stored in darkness show relatively little change in color, while those steaks stored under the yellow fluorescent lamp and white fluorescent lamp showed the greater color changes. Steaks stored under the red and green fluorescent lamps showed color changes intermediate between these steaks stored in darkness and under the white and yellow fluorescent lamps. Results of this study further indicate that light of wave-lengths around 580 mu are responsible for the degradation of color in prepackaged frozen meat. It also would seem to indicate that it is the yellow part of the spectrum (which emits wave-lengths of light of about 5800 Å) in white fluorescent lamps that are commonly used in display cases and stores that is causing the degradation of color in prepackaged frozen meat.

The results of these studies concerning the effect of light on color degradation of frozen meat seem to indicate that wave-lengths of 5800 Å, with the radiation and energy concerned with it are absorbed by the meat pigment myoglobin and as a result produces a photochemical reaction changing oxymyoglobin to metmyoglobin.

D. Comparison of Spinning Disk Method With Spectrophotometric Estimation of Metmyoglobin for Determinations of Surface Color of Frozen Meat.

Butler (1953) found that during the period of increasing formation of metmyoglobin, there was a high correlation between the index of fading calculated from Munsell hue, value, and chroma determined by disk colorimetry,

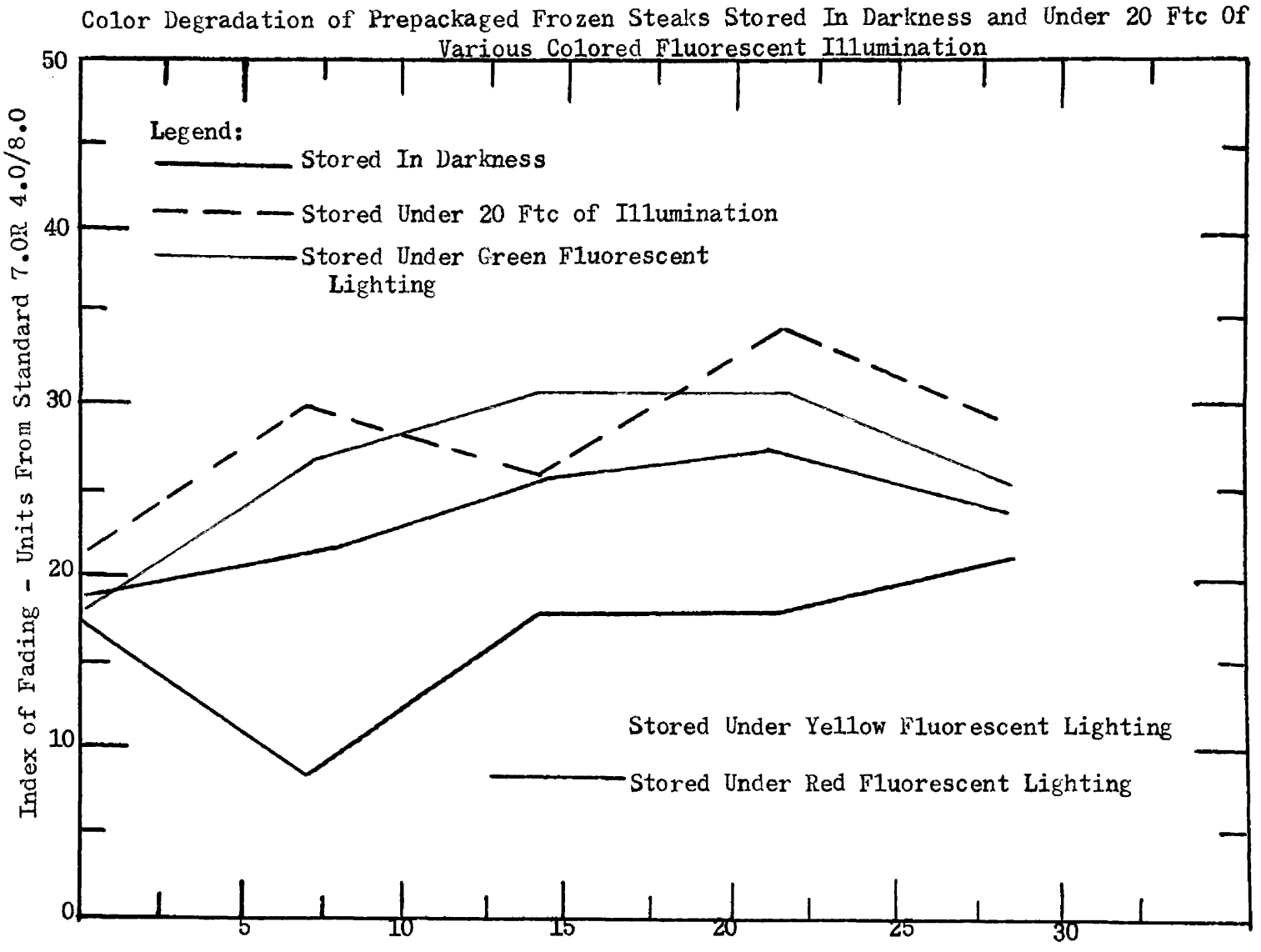

Color Degradation of Prepackaged Frozen Steaks Stored In Darkness and Under 20 Ftc Of Various Colored Fluorescent Illumination
Legend:
Stored In Darkness
Stored Under 20 Ftc of Illumination
Stored Under Green Fluorescent Lighting
Stored Under Yellow Fluorescent Lighting
Stored Under Red Fluorescent Lighting
Index of Fading - Units From Standard 7.0R 4.0/8.0
0
10
20
30
40
50
5
10
15
20
25
30
Storage Time In Days

Figure 30.

Metmyoglobin Formation: Prepackaged Frozen Steaks Stored In Darkness and Under 20 Ftc of Various Colored Fluorescent Illumination

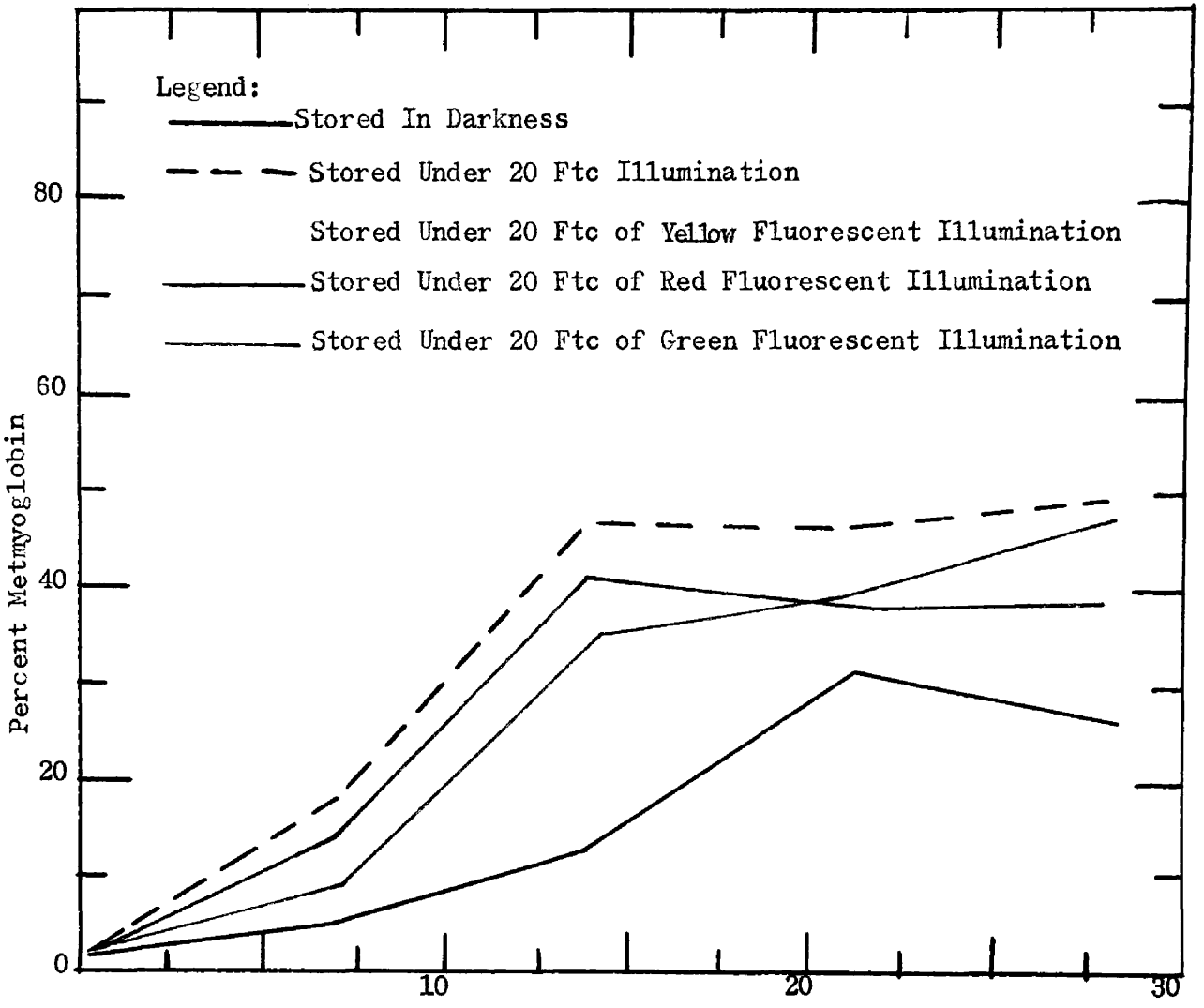


Figure 31.

and the percent metmyoglobin determined spectrophotometrically for determination of surface color of fresh meats. In a total of 114 samples, he found correlation coefficients between the index of fading and the percent metmyoglobin ranging from 0.830 to 0.882. He also pointed out factors responsible for part of the uncorrelated variability observed.

Correlation coefficients were determined to see if there was any correlation between index of fading and percent metmyoglobin for determination of surface color of frozen meat. Figures 32 through 35 present comparative data from 40 samples. Correlation coefficients between index of fading and percent metmyoglobin were obtained by the method of Snedecor (1946), and ranged from 0.777 to 0.930 . These values agree well with those of Butler (1953) and indicate that with the period of increasing formation of metmyoglobin, there is a relatively high relation between index of fading and percent metmyoglobin determined spectrophotometrically for prepackaged frozen meat.

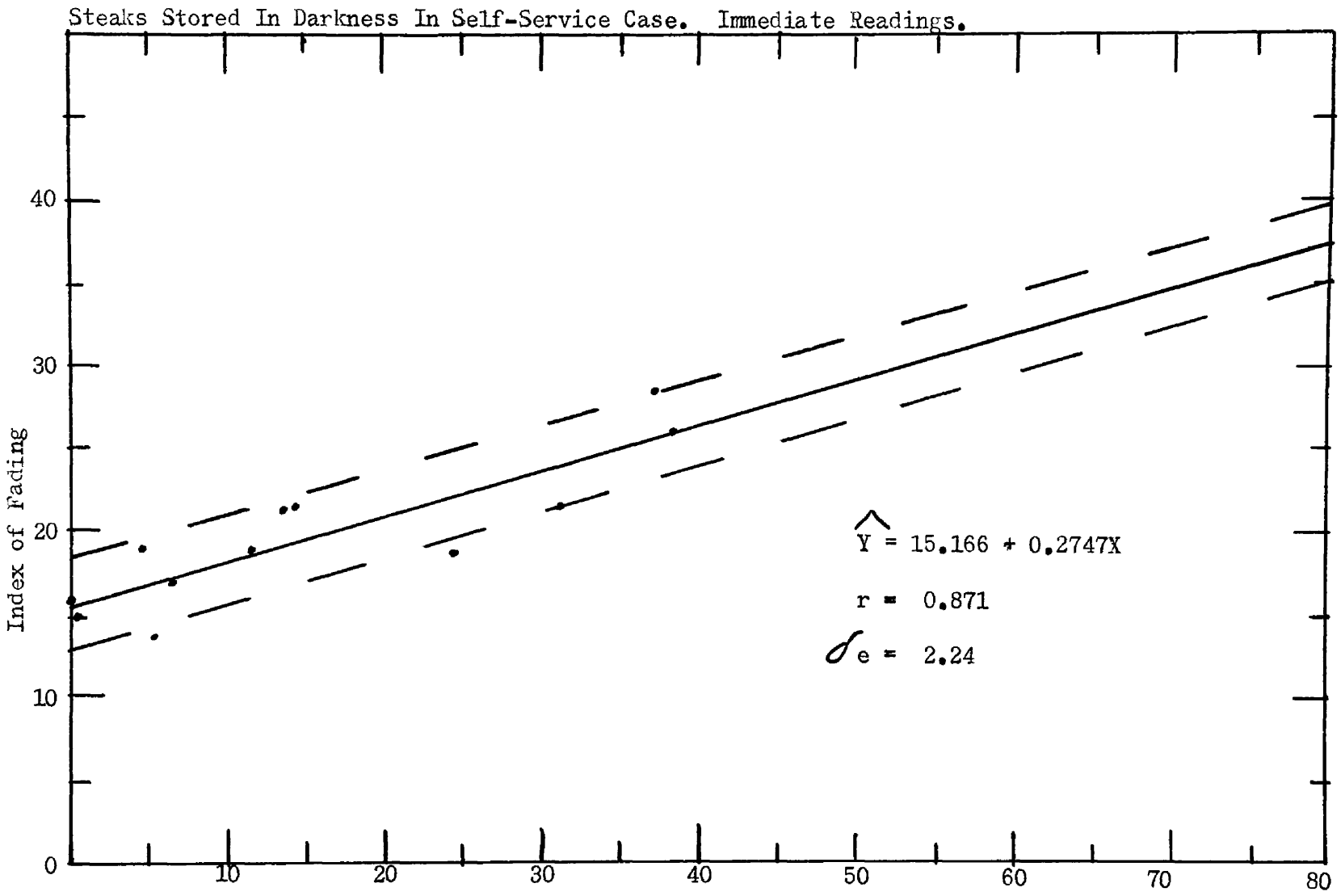


Figure 32. Correlation Between Index of Fading and Percent Metmyoglobin

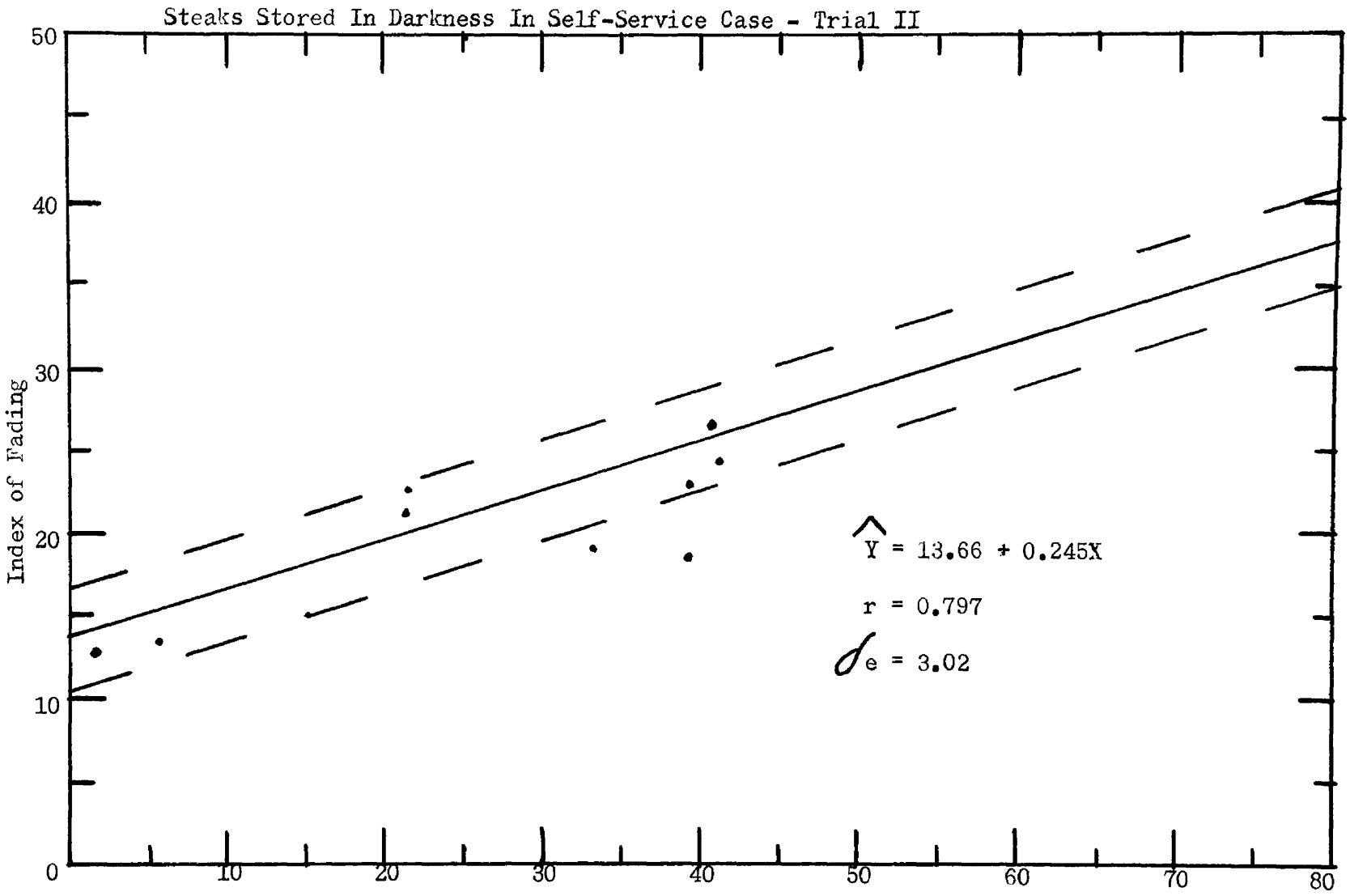


Figure 33. Correlation Between Index of Fading and Percent Metmyoglobin

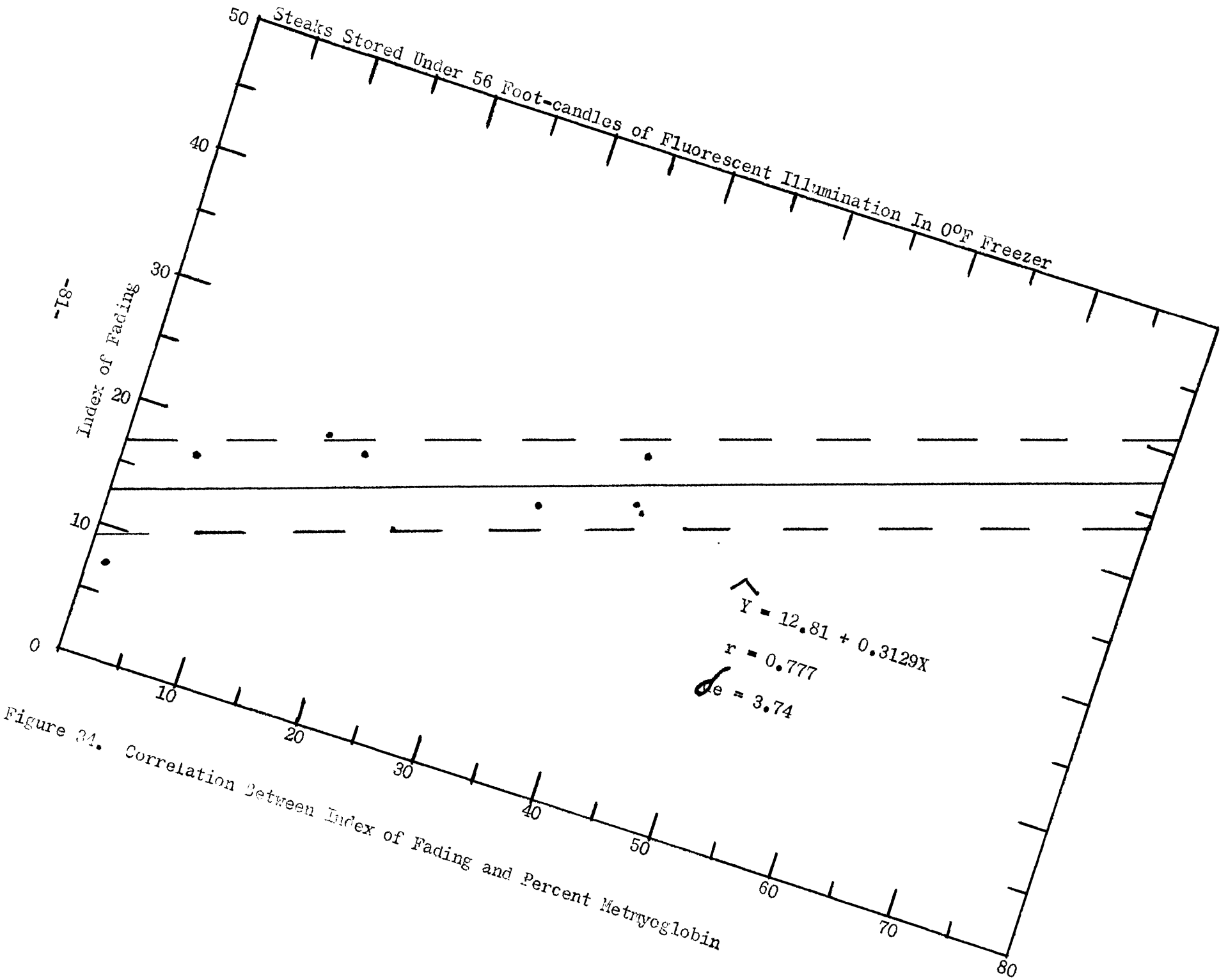


Figure 34. Correlation Between Index of Fading and Percent Metmyoglobin

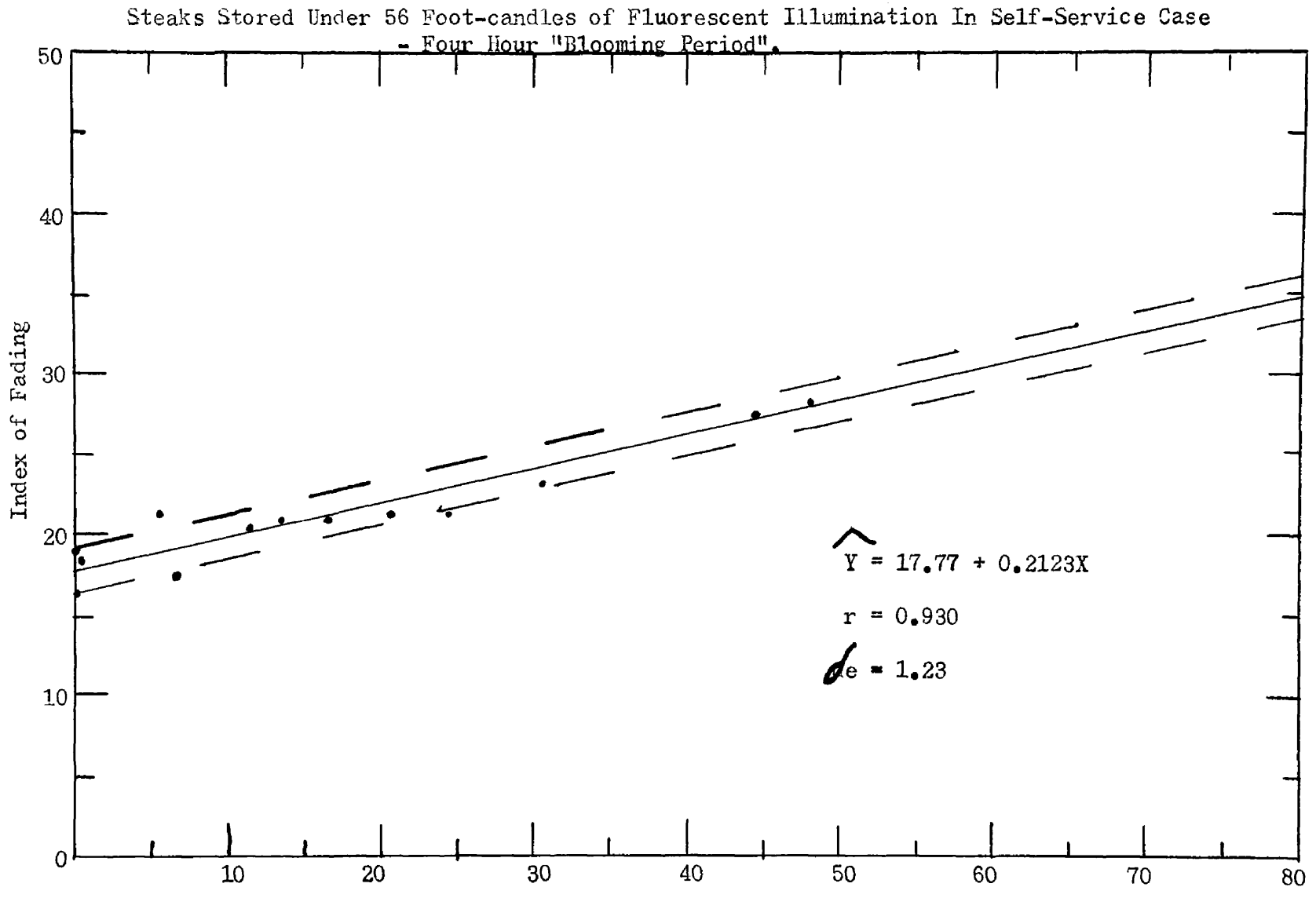


Figure 35. Correlation Between Index of Fading and Percent Metmyoglobin

SUMMARY AND CONCLUSIONS

1. Temperature variations in a self-service frozen food case affect the appearance of prepackaged frozen meat packaged in transparent oxygen impermeable wrapping materials.
2. Prehandling conditions and rate of freezing affect initial color degradation of prepackaged frozen meat.
3. Repeated freezing and thawing in an oxygen impermeable wrapper has a marked effect on the color of prepackaged frozen meat. With alternate freezing and thawing cycles, there was an increase or decrease of metmyoglobin formation.
4. Display of prepackaged frozen meat under incandescent or fluorescent lighting causes degradation of color. Temperature of display of prepackaged frozen meat under fluorescent lighting of the same level of illumination had an effect on color degradation. Samples stored under fluorescent lighting at 0°F showed less discoloration and metmyoglobin formation than samples stored in darkness in the self-service case in which there was considerable temperature fluctuation.
5. Wave-lengths of light between 560 mu and 630 mu (yellow and orange portion of the spectrum) seem to be responsible for color degradation of prepackaged frozen meat.
6. Frozen meat stored under green and red fluorescent lighting seem to give better color stability of prepackaged frozen meat, but gives meat an unfamiliar appearance when displayed under such lighting.

7. It would appear that the yellow portion (560 mu region) of the spectrum emitted by white fluorescent lamps commonly used for frozen food display cases and markets is responsible for color degradation of prepackaged frozen meat.

8. The formation of metmyoglobin is the primary cause of discoloration when prepackaged frozen meat in a transparent wrapper is exposed to light.

Appendix A. Data Collected On Temperature Variation In The Self-Service Case

Time In Hours	Temperature (^{o}F)										
	Steak No. 1			Steak No. 2			Steak No. 3		Steak No. 4		
	Top	Center	Bottom	Top	Center	Bottom	Upper $\frac{1}{4}$ Inch	Bottom $\frac{1}{4}$ Inch	Top	Center	Bottom
0	- 1.0	- 3.5	- 1.0	+ 2.0	+ 1.0	+ 2.5	+ 4.5	+ 2.0	+ 8.0	+10.5	+ 5.5
1	0.0	- 4.0	- 2.8	- 2.5	+ 1.0	+ 1.0	+ 2.0	+ 2.0	+ 2.0	+ 2.2	+ 5.2
2	- 2.0	- 4.5	- 3.0	- 3.0	- 0.5	- 0.5	0.0	0.0	0.0	0.0	0.0
3	- 1.0	- 3.5	- 2.2	- 2.0	0.0	0.0	+ 2.0	+ 1.0	+ 0.2	+ 1.0	+ 4.5
4	0.0	- 4.0	- 3.0	- 2.8	+ 1.0	+ 1.0	+ 1.8	+ 1.5	+ 5.8	+13.0	+ 5.0
5	0.0	- 4.5	- 2.0	0.0	+ 0.5	+ 2.0	+ 5.0	+ 1.5	+ 2.0	+ 3.0	+ 4.0
6	- 1.0	- 5.0	- 3.0	- 1.5	0.0	+ 1.0	+ 6.0	+ 1.0	+11.5	+15.0	+ 4.0
7	+ 3.5	+ 4.0	+ 6.0	+ 6.5	+ 4.0	+ 4.0	+ 5.0	+ 5.0	+ 5.0	+ 6.0	+14.0
Defrost											
7.5	+20.5	+18.0	+21.5	+21.5	+19.0	+20.0	+21.5	+20.0	+23.0	+26.5	+25.0
8	+14.0	+ 9.0	+13.5	+18.0	+15.5	+18.5	+18.5	+17.0	+21.0	+26.0	+15.2
9	0.0	- 2.5	+ 1.0	+ 3.0	+ 3.0	+ 5.0	+ 6.0	+ 4.0	+ 8.5	+12.0	+ 9.0
10	- 2.8	- 5.0	- 4.0	- 4.0	- 0.5	- 0.5	+ 1.0	+ 1.0	+ 1.0	+ 2.0	+ 6.0
11	- 4.5	- 8.0	- 8.0	- 8.0	- 3.5	- 3.5	- 1.0	- 1.0	- 1.0	0.0	+ 3.0
12	- 4.2	- 9.5	- 8.0	- 7.0	- 4.0	- 4.0	- 2.0	- 2.5	- 0.5	0.0	+ 3.3
13	- 4.0	- 6.5	- 6.0	- 6.0	- 2.0	- 2.0	0.0	0.0	0.0	0.0	+ 3.5
14	- 2.0	- 4.0	- 1.0	+ 1.0	0.0	+ 1.5	- 0.2	+ 1.0	+ 3.0	+ 4.0	+ 5.0
15	- 1.8	- 5.0	- 1.0	+ 3.0	0.0	+ 1.5	- 2.0	+ 2.0	+ 3.0	+ 5.0	+ 5.0
16	- 2.0	- 5.5	- 4.5	- 4.0	- 0.5	0.0	+ 2.0	+ 1.0	+ 2.0	+ 3.0	+ 4.0
17	- 1.8	- 4.0	- 2.0	0.0	0.0	+ 1.0	+ 3.0	+ 1.5	+ 4.0	+ 6.5	+ 5.0
18	- 1.0	- 4.5	- 3.5	- 3.0	0.0	0.0	+ 1.5	+ 1.5	+ 1.5	+ 2.0	+ 5.0
19	+ 1.5	- 1.0	+ 1.0	+ 1.0	+ 2.0	+ 2.0	+ 4.0	+ 4.0	+ 5.0	+ 7.0	+11.5
# 20	+15.0	+10.0	+11.0	+11.0	+16.5	+16.5	+18.0	+18.0	+18.0	+19.5	+15.8
21	+ 1.5	- 2.0	0.0	0.0	+ 4.0	+ 5.0	+ 6.0	+ 6.0	+ 2.5	+10.0	+ 9.0
22	- 1.5	- 4.0	- 4.0	- 4.0	+ 1.0	+ 1.0	+ 2.2	+ 2.2	+ 2.2	+ 3.0	+ 6.0
23	0.0	- 4.0	- 4.0	- 4.0	0.0	0.0	+ 1.8	+ 1.8	+ 1.8	+ 2.0	+ 5.0
24	- 2.0	- 5.5	- 5.5	- 5.5	0.0	0.0	+ 1.0	+ 1.0	+ 1.0	+ 1.2	+ 3.5

#Increase in temperature due to second defrost cycle.

Appendix B. Data Collected On Temperature Variation In Self-Service Case When Loaded To Capacity

Time In Hours	Temperature (°F) Steak No's. 1	2	3	4	5	6	7	8
0	- 8.5	- 2.5	+ 2.5	- 1.5	+ 8.9	+13.0	+ 5.0	+12.0
1	- 8.5	- 3.0	+ 3.0	- 1.5	+ 8.9	+14.0	+ 7.0	+13.0
2	- 8.5	- 3.0	+ 5.0	- 2.0	+ 8.5	+25.0	+17.0	+33.0
3	- 9.0	- 3.5	+ 7.0	- 2.5	+ 8.0	+17.0	+ 9.0	+19.0
4	- 9.0	- 3.5	+ 8.0	- 2.5	+ 8.0	+18.0	+10.0	+22.0
5	- 9.5	- 3.8	+ 7.0	- 3.0	+ 8.0	+16.5	+7.8	+17.5
6	- 9.5	- 3.8	+ 8.0	- 3.0	+ 7.5	+17.0	+ 8.0	+18.5
Defrost								
6.5	+14.0	+11.0	+20.0	- 1.8	+10.0	+17.0	+37.0	+42.0
7	+11.0	+11.5	+19.0	- 1.0	+10.0	+17.0	+17.0	+24.0
8	- 2.0	+ 3.0	+ 8.0	0.0	+10.0	+15.0	+11.0	+17.0
9	- 6.0	0.0	+ 4.0	+ 1.0	+ 9.5	+14.0	+ 8.0	+14.0
10	- 7.0	- 1.5	+ 5.5	0.0	+ 9.5	+15.5	+ 6.0	+13.0
11	- 8.0	- 2.0	+ 5.0	0.0	+ 9.0	+15.0	+ 3.0	+10.0
12	- 9.0	- 2.0	+ 4.0	0.0	+ 9.0	+15.5	+ 7.5	+15.0
13	- 9.0	- 3.0	+ 4.0	- 1.0	+ 9.0	+15.0	+9 .0	+15.0
14	- 8.5	- 3.0	+ 4.0	- 1.0	+ 9.5	+14.0	+ 9.5	+14.0
15	- 8.0	- 3.0	+ 3.0	- 1.5	+ 8.5	+13.0	+ 7.5	+10.0
16	- 8.0	- 2.8	+ 3.5	- 1.5	+ 9.0	+13.5	+ 8.0	+11.0
17	- 8.5	- 3.0	+ 2.5	- 2.0	+ 7.0	+11.0	+ 4.0	+ 6.0
18	- 9.0	- 3.5	+ 2.0	- 2.0	+ 8.0	+12.0	+ 1.5	+ 7.0
*19	+10.0	+11.0	+14.0	+13.0	+ 7.0	+12.0	+10.0	+15.0
*20	- 5.0	+ 1.5	+ 9.0	+15.0	+ 6.0	+10.0	+ 8.0	+16.0
21	- 8.0	- 1.0	+ 3.0	- 1.5	+ 9.0	+13.0	+ 2.0	+16.5
22	- 8.5	- 2.0	+ 5.0	0.0	+ 8.5	+14.0	+ 4.0	+ 5.0
23	- 8.5	- 2.5	+ 7.0	- 1.0	+ 8.0	+13.0	+ 3.0	+11.0
24	- 8.0	- 3.0	+ 8.0	- 1.0	+ 7.0	+17.0	+13.0	+18.0

Steak No.	Storage 0 Time H	V	C	I	% mmb	10 Days H	V	C	I	% mmb
1	9.2R	4.9	5.0	14.0	0.79	0.2YR	3.9	5.7	14.5	8.98
2	9.9R	5.0	4.8	20.8	0.79	1.7YR	3.9	5.0	19.0	9.68
3	9.1R	5.0	4.6	20.0	0.79	0.2YR	4.2	5.5	15.7	6.65
4	0.3YR	4.6	5.1	18.9	0.79	9.0R	3.9	5.9	11.7	9.83
5	0.3YR	4.8	4.7	17.0	0.79	9.8R	4.0	6.0	12.7	9.95
6	9.8R	5.1	4.1	22.8	0.79	9.8R	4.3	4.6	17.0	10.10
7	9.3R	4.6	5.4	16.5	0.79	3.1YR	4.1	3.5	22.6	35.10
8	9.3R	4.5	5.8	14.7	0.79	3.7YR	4.9	3.0	28.4	47.80

*Increase in temperature due to second defrost cycle.
H = Hue, V = Value, C = Chroma, I = Index of Fading, % MMb = Percent metmyoglobin.

Appendix C. Data Collected On Prehandling Conditions

Time of Munsell Readings	Sample														
	No. 1 Cry-O-Wrap					No. 2 Cry-O-Wrap					No. 3 No Wrapper				
	H	V	C	I	% MMb	H	V	C	I	% MMb	H	V	C	I	% MMb
Freshly Cut Steak	2.4YR	4.1	4.0	21.2	0.0	1.7YR	4.1	3.2	20.6	0.0	0.8YR	4.0	4.0	22.1	0.0
2 Hr.Bloom	8.3R	4.0	6.4	8.2		8.2R	4.1	6.9	8.5		1.0R	4.0	7.3	11.1	
In Wrapper															
1 hour	8.3R	4.0	6.4	8.2		8.2R	4.2	6.7	8.2						
2 hours	10.0R	4.1	6.7	12.3		9.6R	4.3	6.4	11.8						
3 hours	9.7R	4.3	6.3	13.4		9.7R	4.3	6.3	13.4		0.3YR	4.1	8.0	10.2	
4 hours	9.9R	4.3	6.2	14.2		9.9R	4.3	6.1	14.5		0.5YR	4.1	7.5	12.6	
7 hours	1.5YR	3.9	3.1	20.7		9.8R	3.9	3.1	18.7		1.7YR	4.0	5.9	17.7	
9 hours	2.7YR	3.9	2.7	23.3		2.7YR	3.9	2.7	23.3		2.0YR	4.0	5.6	19.3	
10 hours	3.3YR	3.8	2.6	23.7		2.0YR	3.7	2.3	22.9		2.0YR	4.0	5.6	19.3	
28 hours	3.7YR	4.0	2.2	22.8		2.2YR	4.1	2.0	19.8		2.9YR	3.9	5.9	21.1	5.63
Wrapper Removed	4.8YR	3.9	3.0	23.0		2.2YR	4.1	2.0	19.8	16.85					
1 hr.Bloom	3.0YR	3.9	3.9	21.0				.	.	.					
3 hr.Bloom	1.3YR	3.9	4.6	19.1	19.86										

H = Hue, V = Value, C = Chroma, I = Index of Fading
% MMb = Percent metmyoglobin

Appendix D. Data Collected On Rate of Freezing In 0°F and -20°F Freezer

Rate of Freezing in -20°F Freezer

Time In Hours	Temperature of Freezer (°F)	Temperature of Steaks (°F) Steak No. 1	Steak No. 2
0	-16°F	+44	+43
1	-16°F	+29	+30
2	-17°F	+28	+29
3	-17°F	+22	+22
4	-17°F	-5.0	-5.0
5	-18°F	-13.5	-13.5
6	-18°F	-15.0	-15.0
7	-17°F	-17.0	-17.0
24	-17°F	-17.0	-17.0

Time of Munsell Reading	Steak No. 1 H	V	C	I	% MMb	Steak No. 2 H	V	C	I	% MMb
0 Hour	8.8R	4.4	5.5	13.9	1.41	9.2R	4.3	5.8	13.7	1.32
1 Hour	8.8R	3.8	4.0	16.0		9.8R	4.1	4.0	17.1	
2 Hour	8.9R	3.8	4.2	15.6		8.8R	3.9	4.0	15.4	
3 Hour	8.6R	4.4	3.8	17.2		8.6R	4.5	3.6	18.4	
4 Hour										
5 Hour										
6 Hour										
7 Hour	8.5R	4.4	3.7	17.4	4.43	8.5R	4.4	3.7	17.4	5.31
24 Hour	8.5R	4.4	3.7	17.4		8.5R	4.4	3.7	17.4	

Rate of Freezing in 0°F Freezer

Time In Hours	Temperature of Freezer (°F)	Rate of Freezing (°F) Steak No. 1	Steak No. 2
0	+5.0	+34.5	+34.5
1	+3.0	+30.0	+30.0
2	+3.0	+29.8	+29.8
3	+3.0	+29.5	+29.3
4	+1.0	+28.3	+28.0
5	+2.5	+25.0	+26.0
6	+2.0	+14.0	+15.0
7	+1.0	+ 8.0	+ 7.0
8	+1.5	+ 5.5	+ 5.8
9	+1.0	+ 4.0	+ 4.0
10	+1.0	+ 3.0	+ 3.0
11	+1.0	+ 3.0	+ 3.0
12	+1.0	+ 2.5	+ 2.5
13	+2.0	+ 2.0	+ 2.2
24	+1.0	+ 2.0	+ 2.0

Appendix D. (continued)

Time of Munsell Reading	Steak No.									
	Steak No. 1					Steak No. 2				
	H	V	C	I	% MMb	H	V	C	I	% MMb
0 hour	9.6R	4.1	6.3	11.9	1.29	9.6R	4.0	6.7	10.7	
1 hour	7.7R	4.4	3.7	16.4		8.5R	3.9	4.7	13.2	.92
2 hour	8.0R	4.3	3.3	17.3		8.2R	4.1	3.1	16.7	
3 hour	8.2R	4.1	2.9	17.3		9.0R	4.2	3.5	17.5	
4 hour	8.9R	4.0	4.2	13.3		8.6R	4.1	3.4	16.6	
5 hour	8.9R	4.0	4.2	14.4		8.6R	4.1	3.4	16.6	
6 hour	9.3R	3.9	3.3	16.5		8.8R	4.2	4.1	15.8	
7 hour	8.8R	3.9	3.9	15.8		8.8R	4.2	4.0	16.1	
8 hour	9.3R	3.9	3.8	15.3		8.8R	4.2	4.0	16.1	
9 hour	9.3R	3.9	3.8	15.3		9.3R	4.1	3.5	17.3	
11 hour	8.7R	4.3	4.6	14.1		8.5R	4.1	4.1	14.7	
24 hour	8.8R	4.0	3.8	18.1	9.40	8.9R	4.1	4.1	14.8	11.00

H = Hue, V = Value, C = Chroma, I = Index of fading, % MMb = Percent metmyoglobin.

Appendix E. Data Collected On Repeated Thawing and Freezing of Prepackaged Frozen Steaks

Steak No.	Time of Munsell and Spectrophotometric Readings	Steaks Packaged In Cry-O-Wrap					
		H	V	C	I	% MMb	pH
CTF-0	Before Freezing	0.3YR	3.7	6.4	15.2	0.36	5.70
CTF-1	After Freezing - 24 Hrs.	9.5R	4.7	4.7	18.6	1.70	5.70
	Thawing and Freezing Cycle						
CTF-2	1	3.8YR	3.2	3.1	27.7	48.38	5.60
CTF-3	2	4.4YR	2.9	2.7	29.9	48.83	5.70
CTF-4	3	5.0YR	3.3	2.6	28.4	15.85	6.00
CTF-5	4	6.9YR	3.6	3.1	29.0	28.16	6.00
CTF-6	5	2.6YR	2.8	3.8	28.8	55.08	6.00
CTF-7	6	4.7YR	4.2	2.9	25.7	31.09	6.00
CTF-8	7	4.3YR	3.7	3.1	25.3	12.12	6.00
CTF-9	8	7.5YR	3.5	2.9	30.9	54.26	5.80
CTF-10	9	3.7YR	3.4	3.0	26.6	45.25	5.80
CTF-11	10	4.4YR	3.4	2.8	28.1	15.18	5.80

H = Hue, V = Value, C = Chroma, I = Index of Fading
% MMb = Percent metmyoglobin

Appendix E. (continued)

Steak No.	Time of Munsell and Spectrophotometric Readings	Steaks Packaged In Aluminum Foil H	V	C	I	% MMb	pH
ATF-0	Before Freezing	0.8YR	3.8	7.0	14.8	2.02	5.70
ATF-1	After Freezing	9.8R	3.3	5.3	17.9	.72	5.70
	Thawing and Freezing Cycle						
ATF-2	1	0.6YR	3.1	5.3	20.7	25.94	5.69
ATF-3	2	2.1YR	3.6	4.6	21.6	22.65	5.50
		*3.7YR	2.9	2.8	30.2	43.08	
ATF-4	3	2.1YR	3.7	4.2	21.4	23.58	5.80
		*5.0YR	3.2	3.7	24.7	28.77	
ATF-5	4	3.6YR	3.1	3.7	27.5	16.80	5.80
		*3.1YR	3.2	3.7	26.9	41.40	
ATF-6	5	3.4YR	3.8	4.1	23.1	36.24	6.00
		*2.8YR	3.4	3.2	24.9	6.00	
ATF-7	6	3.1YR	3.4	4.5	25.1	37.98	6.00
		*3.4YR	4.1	3.9	23.1	20.60	
ATF-8	7	5.0YR	3.0	3.2	30.0	47.06	6.00
		*2.9YR	3.3	3.5	26.0	3.44	
ATF-9	8	5.2YR	3.5	2.9	28.1	59.98	6.00
		*3.8YR	3.2	3.1	27.7	33.76	
ATF-10	9	3.9YR	3.1	3.6	28.3	55.72	5.90
		*1.7YR	3.0	3.5	26.0	21.60	
ATF-11	10	5.3YR	3.7	3.5	26.8	59.22	5.90
		*5.3YR	3.1	4.0	30.7	32.38	

*Bottom of Steaks
H = Hue, V = Value, C = Chroma, I = Index of fading
% MMb = Percent metmyoglobin

Appendix F.

Discoloration Of Prepackaged Frozen Meat Stored In Darkness and Under 56 Foot-candles of Incandescent Illumination. Cutting Temperature 34°F. Freezing Temperature -20°F. Storage Temperature 0°F. Standard 7.0R 4.0/8.0. Munsell Renotation Represented by H = Hue, V = Value, C = Chroma and I = Index of Fading.

Time of Munsell and Spectrophotometric Readings	H	V	C	I	Percent (MMb)	pH
	Stored In Darkness					
Before Freezing	0.7YR	4.0	5.7	15.0	0.91	
After Freezing	0.1YR	4.4	4.2	18.8		
2 days in storage	0.9YR	4.7	3.3	21.4		
6 days in storage	2.2YR	4.5	2.8	24.8		
10 days in storage	3.0YR	4.1	3.0	22.8		
35 days in storage	1.0YR	3.7	3.9	18.9	31.33	5.90
	Stored Under 56 Foot-candles of Illumination					
Before Freezing	9.0R	4.0	5.4	12.2	0.91	
After Freezing	9.9R	4.4	4.1	18.7		
2 days in storage	9.3R	4.4	2.7	21.1		
6 days in storage	9.9R	5.4	4.3	24.7		
10 days in storage	2.6YR	4.5	2.0	25.8		
35 days in storage	4.0YR	3.5	3.3	26.9	57.02	5.50
	Stored Under 56 Foot-candles of Illumination					
Before Freezing	9.0R	3.4	5.9	11.7	0.91	
After Freezing	9.6R	4.4	5.0	16.6		
2 days in storage	0.8YR	4.0	3.3	19.4		
6 days in storage	3.6YR	3.9	2.8	24.1		
10 days in storage	3.7YR	3.9	2.1	25.0		
35 days in storage	6.7YR	3.1	2.2	31.4	52.48	5.50

Appendix G. Data Collected From Steaks Stored In The Self-Service Case In Darkness and Under Fluorescent Illumination

Steak No.	Time of Munsell and Spectrophotometric Readings	Immediate Reading						Steaks Turned Over				Four Hour Bloom				
		*H	V	C	I	% MMb	pH	H	V	C	I	H	V	C	I	% MMb
RD-1	Before Freezing	1.0YR	3.9	6.2	15.6	0.0	5.61									
RD-3	After Freezing	0.5YR	3.6	7.4	14.7	0.60	5.61	0.2YR	3.7	7.0	13.8	1.3YR	3.5	6.2	18.7	.65
RD-5	1 day in case	1.2YR	3.5	5.7	21.2	14.07	5.61	0.5YR	3.3	5.7	19.5	0.3YR	3.4	6.0	17.5	
RD-7	2 days in case	0.8YR	3.6	6.5	16.8	6.51	5.60	0.5YR	3.7	6.0	16.2	0.8YR	3.7	5.9	19.6	9.06
RD-9	3 days in case	1.0YR	3.7	5.3	18.7	4.60	5.79	1.2YR	3.5	6.1	18.5	2.2YR	3.6	6.0	20.9	9.85
RD-11	4 days in case	1.1YR	3.6	5.6	18.6	11.87	5.60	2.0YR	3.5	5.1	21.7	2.6YR	4.8	4.9	21.7	17.79
RD-13	6 days in case	9.5R	4.1	5.8	13.2	5.41	5.69	0.5YR	3.8	5.6	16.1	1.6YR	3.6	5.2	21.2	13.56
RD-15	7 days in case	2.4YR	4.1	4.4	21.1	13.69	5.55	2.6YR	4.1	4.3	20.7	0.2YR	4.0	5.1	15.1	16.41
RD-17	14 days in case	9.6YR	3.5	4.4	18.5	24.06	5.75	0.4YR	3.7	4.6	18.1	9.7YR	3.6	5.7	15.8	24.50
RD-19	21 days in case	1.3YR	3.6	4.0	21.3	31.05	5.70	1.6YR	4.0	3.9	19.7	6.5YR	3.9	3.2	27.3	57.78
RD-21	28 days in case	3.9YR	4.5	4.0	25.8	38.32	5.72	2.1YR	4.5	3.3	24.2	7.3YR	3.8	3.0	21.4	26.64
RD-23	35 days in case	5.0YR	4.5	3.4	28.0	37.31	5.75	3.1YR	4.3	4.1	23.3	4.0YR	3.9	4.2	24.9	32.46

*H = Hue
V = Value
C= Chroma
I = Index of Fading
% MMb = Percent Metmyoglobin

Appendix G. (continued)

Steak No.	Time of Munsell and Spectrophotometric Readings	Immediate Reading						Steaks Turned Over				Four Hour Bloom					
		H	V	C	I	% MMb	pH	H	V	C	I	H	V	C	I	% MMb	
RL-2	Before Freezing	0.2YR	3.7	6.3	15.2	0	5.62										
RL-4	After Freezing	0.2YR	3.7	7.0	13.8	0	5.61	0.4YR	3.7	6.9	14.6	1.3YR	3.5	6.2	18.7	0.21	
RL-6	1 day in case	2.3YR	3.4	5.5	22.8	12.80	5.61	0.8YR	3.3	5.5	20.1	2.5YR	3.6	6.1	21.3	5.27	
RL-8	2 days in case	1.2YR	3.3	5.3	21.5	10.40	5.90	0.6YR	3.6	6.0	17.0	2.1YR	3.7	5.6	21.0	13.42	
RL-10	3 days in case	2.1YR	3.7	4.3	22.1	25.40	5.80	1.2YR	3.3	5.5	20.9	2.0YR	3.4	5.5	20.2	11.34	
RL-12	4 days in case	1.2YR	3.8	4.7	18.7	21.94	5.79	2.0YR	3.5	5.1	21.7	2.1YR	3.5	5.1	21.0	16.82	
RL-14	6 days in case	5.0YR	3.9	3.3	25.9	26.48	5.75	1.7YR	3.3	5.2	22.0	1.2YR	3.4	4.9	21.3	20.58	
RL-16	7 days in case	1.1YR	3.9	4.5	18.5	15.61	5.86	1.6YR	3.5	5.9	20.3	9.8R	3.2	6.0	17.5	6.79	
RL-18	14 days in case	3.4YR	3.7	3.3	24.9	38.66	5.80	2.4YR	3.4	3.8	24.8	1.9YR	3.4	4.1	23.1	30.47	
RL-20	21 days in case	4.1YR	3.8	2.9	25.0	44.81	5.80	4.2YR	3.4	3.5	27.1	7.5YR	4.2	2.8	29.4	48.05	
RL-22	28 days in case	6.5YR	4.1	2.3	25.3	52.78	5.80	4.8YR	4.2	2.1	25.1	3.2YR	3.9	3.9	27.7	44.54	
RL-24	35 days in case	6.2YR	4.0	3.0	26.0	56.33	5.80	6.8YR	4.2	3.1	27.7	2.4YR	4.1	4.0	21.2	24.27	

H = Hue, V = Value, C = Chroma, I = Index of fading, % MMb = Percent metmyoglobin

Appendix H. Data Collected From Steaks Stored In Darkness and Under 56 Foot-candles of Fluorescent Illumination At Two Different Temperatures

Time of Munsell and Spectrophotometric Readings	Sample No.	Immediate Reading H	V	C	I	% MMb	pH	Steaks Turned Over H	V	C	I	4 hr. Bloom H	V	C	I	% MMb
						0°F Freezer In Darkness										
Before Freezing	RD-0°	0.3YR	4.2	7.0	13.4	0.91	5.4									
1 day	RD-1°	9.8R	4.5	4.3	18.6	2.21	5.4	0.1YR	3.9	5.7	14.3	9.8R	3.9	6.3	12.4	6.59
3 days	RD-2°	0.8YR	4.4	4.5	19.2	3.73	5.8	0.3YR	4.2	4.5	17.6	0.2YR	3.8	5.8	15.5	8.53
5 days	RD-3°	0.7YR	4.2	4.2	14.7	12.27	5.70	1.9YR	3.6	4.6	21.4	3.4YR	4.0	3.5	22.5	26.53
8 days	RD-4°	0.9YR	4.2	4.6	18.4	17.97	5.68	0.1YR	4.3	4.6	17.6	1.2YR	4.0	5.4	17.0	18.89
15 days	RD-5°	1.1YR	4.0	4.0	18.6	13.38	5.40	0.8YR	3.4	4.2	21.1	0.6YR	4.0	4.5	17.0	23.62
22 days	RD-6°	0.7YR	4.5	3.8	21.5	21.20	5.20	0.6YR	4.4	4.0	20.2	0.7YR	4.2	4.0	19.1	30.33
29 days	RD-7°	9.9R	3.3	4.9	19.3	26.90	5.60	9.6R	3.4	4.6	19.5	9.5R	3.5	4.3	18.6	30.31
35 days	RD-8°	1.5YR	3.7	4.5	20.4	27.80		2.1YR	3.7	3.9	22.3	1.9YR	3.6	4.6	24.4	31.22
						0°F Freezer Under Light										
Before Freezing	RL-0°	9.5R	4.2	7.2	7.1	1.45	5.4									
1 day	RL-1°	9.9R	4.1	5.4	17.1	5.89	5.5	1.9YR	3.7	5.6	22.8	0.1YR	3.9	5.7	13.3	11.99
3 days	RL-2°	2.0YR	3.6	4.7	21.3	18.77	5.8	0.1YR	3.8	4.5	17.3	0.5YR	3.9	5.1	16.3	25.83
5 days	RL-3°	2.2YR	3.7	4.1	21.8	15.67	5.6	2.1YR	3.8	3.8	22.0	3.4YR	3.9	2.9	23.6	24.95
8 days	RL-4°	2.3YR	3.8	3.6	21.8	33.17	6.0	3.8YR	4.0	3.4	23.3	2.5YR	4.1	4.7	20.4	37.84
15 days	RL-5°	Sample not used						4.8YR	3.4	3.4	27.4	3.0YR	3.6	3.8	23.4	24.91
22 days	RL-6°	5.8YR	3.7	2.9	27.7	40.07	5.3	5.8YR	3.8	2.8	27.4	3.4YR	3.8	3.1	23.6	45.27
29 days	RL-7°	2.2YR	3.6	3.3	23.8	40.92	5.4	1.6YR	3.6	3.5	22.3	1.5YR	3.8	3.3	21.6	38.49
35 days	RL-8°	5.6YR	4.2	3.0	23.5	41.03	5.4	1.8YR	3.8	4.0	20.9	2.3YR	3.7	4.0	22.3	39.37

H = Hue, V = Value, C = Chroma, I = Index of fading, % MMb = Percent metmyoglobin

Appendix H. (continued)

Time of Munsell and Spectrophotometric Readings	Sample No.	Immediate Reading H	V	C	I	% MMb	pH	Steaks Turned Over H	V	C	I	4 hr. Bloom H	V	C	I	% MMb
		Self-Service Case Under Light 56 ftc.														
Before Freezing	RL-0^S	0.4YR	4.1	7.2	12.5	1.00	5.4									
1 day	RL-1^S	1.0YR	4.2	4.8	18.0	8.38	5.4	3.2YR	4.1	4.0	22.5	2.7YR	4.4	4.6	22.9	17.54
3 days	RL-2^S	0.9YR	3.9	4.6	17.8	30.00	5.59	1.1YR	4.0	4.2	18.0	3.0YR	4.1	4.5	21.9	28.03
5 days	RL-3^S	1.2YR	3.7	3.4	21.5	30.98	5.59	1.2YR	3.7	3.5	21.2	3.4YR	3.9	2.9	23.6	39.74
8 days	RL-4^S	0.3YR	4.0	3.1	18.7	41.19	6.1	2.5YR	4.3	3.0	22.2	2.6YR	4.3	2.8	24.1	39.60
15 days	RL-5^S	5.8YR	4.1	3.0	26.2	50.04	6.0	3.3YR	4.4	2.8	25.6	2.3YR	4.2	3.2	22.0	44.52
22 days	RL-6^S	4.4YR	3.9	3.1	24.2	55.81	5.5	5.5YR	4.0	2.9	25.7	3.3YR	4.6	3.1	25.9	43.83
29 days	RL-7^S	5.3YR	4.3	3.4	26.3	51.01	5.6	5.3YR	4.3	3.4	26.3	5.2YR	4.2	3.6	26.8	45.49
35 days	RL-8^S	7.3YR	3.5	2.4	24.5	49.75	5.5	7.0YR	4.4	2.7	30.3	7.1YR	4.3	2.9	29.2	45.43
		Self-Service Case In Darkness														
Before Freezing	RD-0^S	0.4YR	4.2	7.5	12.9	1.51	5.4									
1 day	RD-1^S	9.2R	3.9	5.3	13.5	5.90	5.5	1.0YR	4.1	5.0	17.6	0.1YR	4.3	5.5	15.1	12.33
3 days	RD-2^S	1.6YR	3.7	4.3	21.2	21.23	5.91	1.0YR	3.8	4.8	16.2	0.8YR	3.9	5.1	16.9	20.22
5 days	RD-3^S	2.2YR	3.6	4.0	22.7	21.40	5.75	3.1YR	3.8	3.2	22.9	0.3YR	4.0	3.2	18.4	32.23
8 days	RD-4^S	9.7R	4.5	4.3	19.0	33.35	6.20	0.1YR	4.4	4.3	19.1	0.5YR	4.4	3.6	20.5	30.42
15 days	RD-5^S	2.9YR	4.1	2.9	23.0	39.16	5.85	1.2YR	3.7	4.0	20.5	10 R	4.1	3.2	18.6	31.83
22 days	RD-6^S	0.3YR	4.0	3.1	18.7	39.45	5.40	2.3YR	4.1	3.2	21.4	1.1YR	4.1	3.9	19.5	34.88
29 days	RD-7^S	4.6YR	3.6	2.9	26.8	40.83	5.40	4.3YR	3.8	2.9	25.3	5.3YR	4.3	3.4	26.3	37.59
35 days	RD-8^S	3.5YR	3.9	2.7	24.3	41.32	5.50	3.6YR	4.0	2.7	23.8	3.6YR	4.0	2.8	23.5	37.18

H = Hue, V = Value, C = Chroma, I = Index of fading, % MMb = Percent metmyoglobin

Appendix I. Data Collected From Prepackaged Frozen Steaks Stored In Darkness and Under Various Colored Filters. Cutting Temperature 34°F. Freezing Temperature -20°F. Storage In Self-Service Case. Standard 7.0R 4.0/8.0. Munsell Renotation Represented by H = Hue, V = Value, C = Chroma, and I = Index of Fading. MMb = Percent Metmyoglobin.

Time of Munsell and Spectrophotometric Readings	H	V	C	I	% MMb	pH
Stored Under 56 Foot-candles of Fluorescent Illumination						
Before Freezing	0.5YR	4.2	7.4	8.3		
After Freezing	9.4R	4.8	5.2	18.0		
2 days in case	8.5R	4.0	4.3	13.5		
4 days in case	9.9R	4.1	2.4	20.3		
6 days in case	1.8YR	4.3	2.5	23.2		
8 days in case	3.9YR	3.6	2.4	26.1		
10 days in case	4.2YR	4.0	2.6	27.7		
14 days in case	3.9YR	3.6	2.4	26.1		
21 days in case	4.3YR	4.1	2.4	24.7		
28 days in case	4.2YR	4.0	2.5	23.7		
35 days in case	3.1YR	4.2	2.1	23.8	59.40	4.9
Stored In Darkness						
Before Freezing	0.2YR	4.0	7.8	10.2		
After Freezing	7.1R	4.3	6.1	8.7		
2 days in case	7.9R	3.9	6.4	7.6		
4 days in case	7.6R	3.9	6.7	5.1		
6 days in case	8.0R	3.9	5.8	9.4		
8 days in case	9.1R	3.9	5.8	11.8		
10 days in case	9.8R	3.8	5.2	15.2		
14 days in case	9.9R	3.8	5.2	15.4		
21 days in case	0.6YR	3.7	4.5	18.8		
28 days in case	1.8YR	3.8	4.0	20.9		
35 days in case	0.1YR	3.8	4.5	17.3	32.52	5.0
Stored Under Purple Filter						
Before Freezing	0.2YR	4.0	7.8	5.4		
After Freezing	7.5R	4.2	5.7	9.2		
2 days in case	7.8R	4.0	6.1	7.6		
4 days in case	8.0R	3.8	5.9	9.9		
6 days in case	8.7R	3.6	6.1	12.2		
8 days in case	8.6R	3.7	5.2	13.4		
10 days in case	9.8R	3.3	5.2	18.2		
14 days in case	9.7R	3.5	4.2	18.7		
21 days in case	2.0YR	3.4	3.9	23.8		
28 days in case	2.3YR	3.5	3.5	23.9		
35 days in case	1.9YR	3.6	3.4	23.8	38.49	5.6

Appendix I. (continued)

Time of Munsell and Spectrophotometric Readings	H	V	C	I	% MMb	pH
		Stored Under Blue Filter				
Before Freezing	2.0YR	4.0	7.7	10.5		
After Freezing	7.1R	4.5	6.1	11.9		
2 days in case	7.4R	4.4	5.2	11.6		
4 days in case	7.9R	4.2	5.0	12.0		
6 days in case	6.8R	4.1	4.2	12.3		
8 days in case	0.1YR	4.3	3.3	19.6		
10 days in case	0.3YR	4.0	3.9	17.6		
14 days in case	0.8YR	3.9	3.8	18.5		
21 days in case	0.7YR	4.0	2.6	19.9		
28 days in case	2.4YR	3.2	2.1	26.8		
35 days in case	1.6YR	4.3	2.5	22.9	46.56	6.1
		Stored Under Green Filter				
Before Freezing	9.9R	4.1	7.5	10.8		
After Freezing	8.5R	4.2	5.8	11.4		
2 days in case	7.6R	4.1	5.8	8.5		
4 days in case	9.2R	3.8	6.1	12.2		
6 days in case	8.4R	3.7	5.6	12.1		
8 days in case	8.6R	3.7	5.4	15.5		
10 days in case	9.4R	3.5	5.0	16.8		
14 days in case	0.3YR	3.7	4.8	17.4		
21 days in case	2.2YR	3.6	4.5	22.3		
28 days in case	1.2YR	3.7	3.7	20.6		
35 days in case	0.9YR	3.7	3.9	20.3	38.04	5.6
		Stored Under Yellow Filter				
Before Freezing	9.9R	4.4	7.0	13.5		
After Freezing	7.6R	4.1	6.0	8.0		
2 days in case	8.2R	3.9	5.5	10.7		
4 days in case	9.2R	3.8	4.0	16.7		
6 days in case	1.8YR	3.8	3.2	21.4		
8 days in case	0.7YR	3.5	2.8	21.8		
10 days in case	2.7YR	3.7	3.1	24.2		
14 days in case	4.6YR	3.5	3.3	26.8		
21 days in case	4.9YR	3.4	3.0	27.2		
28 days in case	3.0YR	3.6	2.5	24.6		
35 days in case	3.5YR	3.9	3.7	23.6	53.71	5.6

Appendix I. (continued)

Time of Munsell and Spectrophotometric Readings	H	V	C	I	% MMb	pH
	Stored Under Orange Filter					
Before Freezing	0.2YR	4.0	7.8	10.2		
After Freezing	8.0R	4.1	6.9	6.7		
2 days in case	8.3R	3.7	6.2	10.2		
4 days in case	0.6YR	3.7	4.0	19.6		
6 days in case	9.8R	3.8	3.4	17.5		
8 days in case	0.7YR	3.5	3.2	21.8		
10 days in case	3.0YR	3.4	3.1	25.5		
14 days in case	2.3YR	3.4	3.8	21.8		
21 days in case	1.5YR	3.5	3.6	22.5		
28 days in case	2.0YR	3.5	2.8	24.6		
35 days in case	3.2YR	3.8	2.5	23.9	60.26	5.1
	Stored Under Red Filter					
Before Freezing	9.9R	4.4	7.0	13.5		
After Freezing	6.6R	4.0	5.7	5.5		
2 days in case	8.3R	3.7	6.1	10.6		
4 days in case	8.4R	3.7	5.6	12.0		
6 days in case	9.3R	3.5	5.0	16.6		
8 days in case	8.6R	3.8	4.9	13.7		
10 days in case	9.6R	3.4	4.1	18.2		
14 days in case	0.3YR	3.8	4.3	17.6		
21 days in case	1.4YR	3.3	3.2	23.9		
28 days in case	1.3YR	3.3	3.2	23.8		
35 days in case	2.6YR	3.7	3.0	19.9	45.59	6.0

Appendix J. Data Collected From Prepackaged Frozen Steaks Stored In Darkness and Under Various Colored Filters at the Same Light Intensity. Cutting Temperature 34°F. Freezing Temperature -20°F. Storage In Self-Service Case. Standard 7.0R 4.0/8.0. Munsell Renotation Represented by H = Hue, V = Value, C = Chroma, and I = Index of Fading.

Time of Munsell and Spectrophotometric Readings	H	V	C	I	% MMb	pH
Stored Under 2-3 Foot-candles of Fluorescent Illumination						
Before Freezing	0.4YR	4.1	6.0	14.8	0.91	
2 days in case	9.6R	4.4	4.4	17.9		
7 days in case	1.2YR	4.9	4.5	23.5		
17 days in case	1.9YR	4.7	3.8	23.6		
24 days in case	2.6YR	4.8	3.8	25.2		
31 days in case	3.6YR	4.8	3.2	27.1		
35 days in case	4.9YR	4.4	4.0	27.0	25.33	5.38
Stored In Darkness						
Before Freezing	0.4YR	4.2	5.9	15.6	0.91	
2 days in case	0.4YR	4.9	4.8	21.8		
7 days in case	7.6R	4.9	4.1	18.1		
17 days in case	1.4YR	4.2	2.8	22.1		
24 days in case	3.0YR	4.4	2.5	24.9		
31 days in case	3.9YR	4.4	2.3	24.0		
35 days in case	2.9YR	4.7	3.7	25.4	14.21	5.50
Stored Under Orange Filter						
Before Freezing	9.8R	4.4	5.4	16.4	0.91	
2 days in case	8.5R	4.8	4.5	18.0		
7 days in case	1.0YR	5.0	4.2	23.8		
17 days in case	2.6YR	4.9	3.7	26.1		
24 days in case	6.7YR	5.2	3.2	33.2		
31 days in case	5.7YR	5.1	3.0	32.0		
35 days in case	5.6YR	4.5	3.4	28.8	21.86	5.00
Stored Under Red Filter						
Before Freezing	9.3R	4.2	5.6	13.5	0.91	
2 days in case	8.6R	4.8	4.7	17.6		
7 days in case	1.2YR	4.8	4.8	22.8		
17 days in case	2.3YR	5.1	3.3	28.1		
24 days in case	2.9YR	5.0	3.4	28.1		
31 days in case	3.2YR	5.1	3.2	28.4		
35 days in case	2.7YR	4.8	3.7	25.7	25.2	5.00

Appendix J. (continued)

Time of Munsell and Spectrophotometric Readings	H	V	C	I	% MMb	pH
		Stored Under Green Filter				
Before Freezing	9.3R	4.2	5.6	13.5	0.91	
2 days in case	9.9R	5.1	5.1	21.1		
7 days in case	1.2YR	4.9	4.5	23.5		
17 days in case	1.8YR	4.6	3.9	23.6		
24 days in case	4.4YR	4.7	4.1	28.5		
31 days in case	3.9YR	5.0	3.4	29.5		
35 days in case	3.2YR	4.4	4.0	24.3	14.6	5.20

Appendix K. Data Collected From Prepackaged Frozen Steaks Stored In Darkness and Under Various Colored Fluorescent Lamps, Emitting 20 Foot-candles of Illumination. Cutting Temperature 34°F. Freezing Temperature -20°F. Storage In 0°F Freezer. Standard 7.0R 4.0/8.0. Munsell Renotation Represented by H = Hue, V = Value, C = Chroma, and I = Index of Fading. MMb = Percent Metmyoglobin.

Time of Munsell and Spectrophotometric Readings	H	V	C	I	% MMb	pH
			Stored In Darkness			
0 days	9.2R	4.8	4.9	18.5	1.21	5.7
7 days	10.R	4.0	5.2	14.4	5.19	5.6
14 days	0.6YR	3.6	4.9	18.9	12.34	5.4
21 days	1.4YR	4.1	4.9	18.7	31.74	5.5
28 days	1.4YR	3.8	4.3	20.2	26.49	5.6
			Stored Under White Fluorescent Lamp			
0 days	9.5R	4.9	4.5	20.5	1.21	5.6
7 days	3.0YR	3.6	3.7	24.9	28.50	5.8
14 days	2.3YR	4.2	2.5	23.0	47.69	6.0
21 days	5.9YR	3.8	2.9	27.2	46.54	6.0
28 days	4.6YR	3.9	2.7	24.7	50.00	6.2
			Stored Under Green Fluorescent Lamp			
0 days	9.8R	4.7	5.0	18.8	1.21	5.6
7 days	3.6YR	3.9	3.7	23.3	8.56	5.7
14 days	3.5YR	3.7	3.2	25.3	34.56	5.6
21 days	4.3YR	4.1	2.9	25.3	38.24	5.8
28 days	3.9YR	4.0	2.7	22.8	46.14	5.6
			Stored Under Yellow Fluorescent Lamp			
0 days	9.2R	4.8	4.9	18.7	1.21	5.6
7 days	1.4YR	4.0	4.0	19.0	18.62	5.9
14 days	3.1YR	3.7	2.9	23.8	46.62	6.0
21 days	7.5YR	3.5	2.9	30.9	50.07	6.2
28 days	5.2YR	3.8	2.4	26.2	61.37	6.1
			Stored Under Red Fluorescent Lamp			
0 days	9.4R	4.8	4.6	19.3	1.21	5.4
7 days	1.8YR	4.2	4.1	20.6	14.32	5.6
14 days	2.5YR	3.8	3.7	22.9	40.88	5.8
21 days	3.5YR	3.8	4.0	23.6	38.72	5.7
28 days	2.4YR	4.0	3.3	21.7	38.59	5.6

BIBLIOGRAPHY

Allen, N. 1948. Color Changes In Fresh Meat. Pre Pack Age. November.

Anonymous. 1954. Packaging Shift Seen Spur To Frozen Meats. Quick Frozen Foods, 16 (6):99.

Anonymous. 1956. The Outlook For Frozen Foods. U.S.D.A. Agricultural Marketing Service. AMS-154.

Archer, H. and Bandfield, R. E. 1950. The Discoloration of Veal Loaf When Exposed To High Level Illumination. Illuminating Engineering, Vol. 45:429-432.

Atkison, A. D. S. 1946. Fluorescent Lighting. New York, Chemical Publishing Co.

Baker, Merl and Penrod, E. B. 1954. Influence of Storage Conditions on Drying and Discoloration of Beef. Food Technology, Vol. 8: 511-514.

Biorck, Gunnar. 1949. On Myoglobin and Its Occurrence In Man. Acta Medical Scan, Supplement 226, p 915.

Bichat, X. 1803. Allgemeine Anatomie, angewandt auf die Physiologie und Arzneywissens-schaft. II:1. Translated by C. H. Pfaft, Leipzig.

Blum, H. F. 1941. Photodynamic Action and Diseases Caused by Light. Reinhold Publishing Corporation. N.Y.

Boerhave, H. 1739. Institutions de Medecine I, p 275.

Bowen, W. J. 1949. The Absorption Spectra and Extinction Coefficients of Myoglobin. J. Biol. Chem. Vol. 179: 235-245.

Bratzler, L. J. 1955. Technical Problems In Prepackaged Fresh and Frozen Meats. Proc. of the Seventh Research Conference. Univ. of Chicago, Chicago, Illinois. pg. 62-64.

Brooks, John. 1929. Post-mortem Formation of Methaemoglobin in Red Muscle. Biochemical Jour., Vol. 23: 1391-1400.

Brooks, John. 1930. The Effect of Freezing In A Concentrated Solution of Sodium Chloride on the Colour of Red Muscle. Biochemical Jour., Vol. 24: 1379-1383.

Brooks, J. 1931. The Oxidation of Haemoglobin To Methaemoglobin by Oxygen. Proc. Royal Soc. London, s.B. Vol. 109: 35-50.

Brooks, J. 1933. The Effect of Carbon Dioxide on the Color Changes or Bloom of Lean Meat. Jour. Soc. Chem. Ind. Vol. 52: 17T-19T.

Brooks, J. 1935. The Oxidation of Haemoglobin To Methaemoglobin by Oxygen. II. The Relation Between The Rate of Oxidation and Partial Pressure of Oxygen. Proc. Roy. Soc. London, s.B. Vol. 118: 560-577.

Brooks, J. 1937. Color of Meat. Food Research, Vol. 3: 75-78.

Brooks, J. 1948. The Oxidation of Haemoglobin to Methaemoglobin by Oxygen. Jour. of Physiology. Vol. 109: 332-335.

Brooks, J. 1955. The Colour of Meat. Institute of Meat Bulletin. London.

Butler, O. D., Bratzler, L. J. and Mallman, W. L. 1953. The Effect of Bacteria on the Color of Prepackaged Retail Beef Cuts. Food Technology, Vol. 7 (10) 397.

Coleman, Harold M. 1951. Mechanism of Meat-Pigment Oxidation. The Effect of Solutes on the Hemoglobin-oxygen Equilibrium. Food Research, Vol. 16: 222-229.

Collier's Reference Department. 1956. Personal Communication. N.Y.

Daniels, F. 1948. Outlines of Physical Chemistry. John Wiley and Sons, Inc., New York, N. Y.

Fairley, J. 1957. Personal Communication, Michigan State University, East Lansing, Michigan.

Gortner, R. A. Jr. and Gortner, W. A. 1949. Outlines of Biochemistry 3'rd Ed. John Wiley and Son, Inc., New York.

Gunther, H. 1921. Uber den Muskelfarbstoff. Virchows Arch., Vol. 230: 146-178.

Haines, R. B. 1931. Growth of Microorganisms on Chilled and Frozen Meat. Jour. Soc. Chem. Ind., Vol. 50: 223.

Heiss, R. and Hohler, E. 1933. The Discoloration of Chilled Meat. Ice and Cold Storage, Vol. 36: 93-94, 121-122.

Hilderbrandt, C. F. 1789. Lehrbuch der Anatomie des Menchen. II. Braunschweig, 1789.

Hill, R. 1933. Oxygen Affinity of Muscle Haemoglobin. Nature, Vol. 132: 897-898.

Hill, R. 1936. Oxygen Dissociation Curves of Muscle Haemoglobin. Proc. Roy. Soc. London, s.B. Vol. 120: 472-483.

Hoagland, R. 1914. Coloring Matter of Raw and Cooked Salted Meats. Journal of Agricultural Research, Vol. 3: 211-226.

Hockman, R. O. 1956. Problems In Packaging Meat Products. The National Provisioner. April 20, 1956, p. 76.

Jensen, L. B. 1949. Meat and Meat Foods. The Ronald Press Co., New York, N. Y.

Kampschmidt, R. F. 1955. Effect of Wavelength of Light on Discoloration of Cured Meats. Agricultural and Food Chemistry, Vol. 3: 510.

Kendrew, J. C. 1949. Haemoglobin. Burrerworths Scientific Publications. London. pg. 149.

Kennedy, R. P. and Whipple, G. H. 1926. The Identity of Muscle Haemoglobin and Blood Haemoglobin. Amer. Journ. of Physiology, Vol. 76: 685-692.

Kraft, A. A. and Wonderstock, J. J. 1950. Meat-Color Problem Is Closer to Solution. Food Industries, Vol. 22: 65-69.

Kraft, A. A. and Ayres, John C. 1952. Post-mortem Changes In Stored Meats. IV. Effect of Packaging Materials on Keeping Quality of Self-Service Meats. Food Technology, Vol. 6: 8-12.

Kraft, A. A. and Ayres, J. C. 1954. Effect of Display Case Lighting on Color and Bacterial Growth on Packaged Fresh Beef. Food Technology, Vol. 8: 290-295.

Landrock, A. H. and Wallace, G. A. 1955. Discoloration of Fresh Red Meat and Its Relationship to Film Oxygen Permeability. Food Technology, Vol. 9 (4) 194-196.

Lavers, C. G. 1948. Discoloration of Prepackaged Red Meat. Modern Packaging, Vol. 21 (5): January, 1948.

MacMunn, C. A. 1886. Further Observations on Myohaematin and The Histohaematins. Phil. Trans. Roy. Soc. London, Vol. 177: 235-266.

Mangel, Margaret. 1951. The Determination of Methamoglobin In Beef Muscle Extracts. I. A Study of Spectrophotometric Method. II. Factors Affecting Methemoglobin Formation In Frozen Beef. University of Missouri Research Bulletin 474. 24 pages.

Millikan, G. A. 1936. The Role of Muscle Haemoglobin. Jour. Physiology, Vol. 87: 38-39.

Millikan, G. A. 1936. The Kinetics of Muscle Haemoglobin. Proc. Royal Soc. London, s.B. Vol. 120: 366-388.

Millikan, G. A. 1939. Muscle Haemoglobin. Physiological Reviews, Vol. 19: 503-523.

Moran, T. 1932. Rapid Freezing: Critical Rate of Cooling. Jour. Soc. Chem. Ind., Vol. 51: 16T-20T.

Moran, T. 1935. Post-mortem and Refrigeration Changes In Meat. Jour. Soc. Chem. Ind., Vol. 54: 149T-151T.

Morner, K. A. H. 1897. Beobachtungen uber den Muskelfarbstoff. Nord. Med. Arkiv., Vol. 30: 1-8.

Nauman, H. D., BcBee, J. L. Jr., and Brady, D. E. 1957. Color Stability of Frozen Beef As Influenced by Illumination, Temperature and Storage. Food Technology, Vol. 11: No. 4. Abstract.

Neill, James M. and Hastings, A. Baird. 1925. The Influence of The Tension of Molecular Oxygen Upon Certain Oxidations of Hemoglobin. Jour. Biol. Chem., Vol. 63: 479-492.

Nickerson, Dorothy. 1946. Color Measurements and Its Application To The Grading of Agricultural Products. U. S. Department of Agriculture. Misc. Publication #580.

Penrod, E. B. and Baker, Merl. 1954. Effect of Storage Conditions on Drying and Discoloration of Beef. University of Kentucky. Engineering Experiment Station Bulletin, 9: 43 pages.

Polson, A. G. 1937. Researches on the Diffusion Constants of the Proteins. Nature, Vol. 139: 1051.

Pracejus, W. G. 1949. A Report on Meat Fading. Engineers Bulletin. Large Lamp Department, General Electric Company. June, 1949.

Rikert, J. A. 1952. Color Changes of Fresh Meats As Influenced by Some Antioxidant, Temperature and Atmospheric Variations. Rutgers University Thesis. Typewritten publication, 57 pgs.

Ramsbottom, J. M. and Koonz, G. H. 1941. Freezer Storage Temperature As Related to Drip and To Color In Frozen-Defrosted Beef. Food Research, Vol. 6: 571-580.

Ramsbottom, J. M. 1947. Freezer Storage Effect on Fresh Meat Quality. Refrigeration Engineering, Vol. 54: 19-23.

Ramsbottom, J. M., Goeser, P. A. and Schultz, H. W. 1951. How Light Discolors Meat: What To Do About It. Food Industries, Feb. 1951, pg 120-124, 222.

Robertson, E. J. 1950. Prepackaged Frozen Meat. Refrigeration Engineering, Vol. 58: 771.

Roche, J. and Vieil, H. 1940. Preparation et poids moleculaire de la myoglobine de cheval (hemoglobine musculaire) cristallisee. Compt. rend. Acad. d. sc., Vol. 210: 314-316.

Rossi-Fanelli, A. 1940. Sulla constituzion chemica della mioglobina. Arch. di. Sc. Biol., Vol. 26: 244-264 (Summary in English).

Rossi-Fanelli, A. and Travia, L. 1941. Specifecita e composizione chemica di mioglobine di specie diverse Nota I. Boll. d. Soc. Ital. biol. Sperim, Vol. 16: 768-770.

Rossi-Fanelli, A. and Vesica, A. 1942. Specificita e composiziene chemica di mioglobine e emoglobine di specie diverse. Nota II. Boll. d. Soc. Ital. Sperim, Vol. 17: 291.

Rossi-Fanelli, A. and Perri, C. G. 1947. Mioglobina u mona cristallizzato. I. Forma cristallina, solubilita, contemito in Fe e in N. Boll. d. Soc. Ital. Biol. Sperim. Vol. 23: 1-2.

Rossi-Fanelli, A. 1948. Crystalline Human Myoglobin: Some Physio-chemical Properties and Chemical Composition. Science, Vol. 108: 15-16.

Rossi-Fanelli, A. 1950. Les Pigment Musculaires: physio pathologie (French Translation with summary in English). pg. 1-26.

Rossi-Fanelli, A. 1954. Amino Acid Composition of Crystallized Human Myoglobin and Haemoglobin. Experientia, Vol. 10: 72.

Rossi-Fanelli, A. 1955. Le mioglobine. Giornate Biochimiche. italo-franco-elretiche. pgs, 43-95 (Summary in English)

Rossi-Fanelli, A. 1956. Heterogeneity of Human Myoglobin. Archives of Biochemistry and Biophysics, Vol. 65: 587-590.

Sayles, C. I., Gortner, W. A., and Volz, Frances E. 1946. Frozen Food Packaging. -- A Preliminary Study of Cavity Ice. Food Freezing, Sept. 1946.

Schenk, J. H., Hall, J. L., and King, H. H. 1934. Spectrophotometric Characteristics of Hemoglobins. I. Beef Blood and Muscle Hemoglobin. Jour. Biol. Chem., Vol. 105: 741-752.

Schweigert, B. S. 1956. Chemistry of Meat Pigments. Proc. of the Eighth Research Conference. University of Chicago, Chicago, Illinois. pg. 61-64.

Snedecor, George W. 1946. Statistical Methods. Ed. 4, Iowa State College Press, Ames, Iowa, 485 pp.

Sulzbacher, Wm. L. 1950. Survival of Microorganisms In Frozen Meat. Food Technology, Vol. 4: 386-390.

Svedberg, T. 1939. A Discussion on the Protein Molecule. Proc. Royal Soc. of London, s.B. Vol. 127: 1-56.

Tanner, F. W. 1944. The Microbiology of Foods. The Gerrard Press, Champain, Ill. 1196 pp.

Taylor, A. H. and Pracejus, W. G. 1950. Fading of Colored Materials by Light and Radiant Energy. Illuminating Engineering, Vol. 45: 149-151.

Theorell, H. 1932. Kristallinisches Myoglobin. I. Kritallisieren und Reinigung des Myoglobin, sowie vor - laufige Mitteilung uber sein Molekular gewicht. Biochem. Zeitschr., Vol. 252: 1-7.

Theorell, H. 1934. Kristallinisches Myoglobin. II. Sedimentations Konstante und Molekulargewicht des Myoglobins. Biochem. Zeitschr., Vol. 268: 46-54.

Theorell, H. 1934. Kristallinisches Myoglobin. III. Die Absolute Lichtabsorbtion von Oxy-, CO-, Meta- und reduz Myoglobin. Biochem. Zeitschr., Vol. 268: 55-63.

Theorell, H. 1947. Crystalline Human Myoglobin from Heart Muscle and Urine. Arch. Biochem., Vol. 12: 113-24.

Townsend, W. E. 1955. The Stabilization of Color of Prepackaged Frozen Meat By the Use of Carbon Monoxide. Unpublished M.S. Thesis. Michigan State College. 74 pages.

Tressler, D. K. and Eyers, C. F. 1947. The Freezing Preservation of Foods. 2'nd Ed. Avi Publishing Company, Inc.

Urbain, W. M. 1952. Facts about Meat Color. Oxygen is Key to the Color In Meat. The National Provisioner, October 18, 140-144.

Voegeli, Marvin. 1952. The Measurement of Fresh Beef Muscle Color Change by Disk Colorimetry. Unpublished Ph.D. Thesis. Michigan State College, 125 pages.

Watts, Betty M. 1954. Oxidative Rancidity and Discoloration in Meat. Advances In Food Research, Vol. 5: 1-52.

Weisman, Clarence F. 1947. Factors Influencing Quality of Frozen Meats. Ice and Refrigeration, pp. 21-24.

Whipple, G. H. 1926a. The Hemoglobin of Striated Muscle. I. Variation Due to Age and Exercise. Amer. Jour. of Physiology, Vol. 76: 693-707.

Whipple, G. H. 1926b. The Hemoglobin of Striated Muscle. II. Variations Due to Anemia and Paralysis. Amer. Jour. of Physiology, Vol. 76: 708-714.

Winkler, C. A. 1939a. Colour of Meat. I. Apparatus for its Measurement, and Relation Between pH and Colour. Can. Journ. Research, Vol. 17D: 1-7.

Winkler, C. A. 1939b. Colour of Meat. II. Effect of Desiccation on the Colour of Cured Pork. Can. Journ. Research, Vol. 17D: 29-34.

Winter, J. D. 1952. Changes That Occur During The Freezing and Storage of Foods. The Science Counselor, pp. 1-4.