N.Y.

THE MEASUREMENT OF FRESH BEEF MUSCLE COLOR CHANGES BY DISK COLORIMETRY

By

Marvin Mathias Voegeli

A THESIS

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Animal Husbandry

1952

ACKNOWLEDGMENT

The author wishes to express his very sincere appreciation and grateful thanks to Lyman J. Bratzler, Associate Professor of Animal Husbandry, for his guidance, constructive criticism, assistance and constant encouragement in the conduct of this study. His high qualities will always be an inspiration to greater achievement.

The writer wishes to thank E. I. du Pont de Nemours and Company for supplying the film used in packaging the meat.

To Dorothy, his wife, he is deeply indebted for her encouragement, sacrifices and many hours spent at the typewriter in the course of this advanced work.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

The color of lean beef is an important factor in the grading and salability of beef carcasses and cuts. The range in beef color is recognized in the retail cuts by the consumer, and his preferences are projected into the standards for grades. The following expressions concerning beef color are frequently used: dark pink, very light cherry red, light cherry red, slightly dark cherry red, moderately dark cherry red, dark red, and very dark red. These descriptive terms are difficult to apply because different individuals may have varied conceptions of the color described. The development of an objective color measurement that could be applied to meats research and also to meat grading would eliminate different conceptions of meat color.

The color of fresh meat is subject to change. Under commercial retailing, discoloration is the major factor in determining the shelf life of prepackaged meats. The Production and Marketing Administration of the United States Department of Agriculture (50) states that discoloration of red meats is accelerated by high temperature, too much moisture, and too much oxygen. To help prevent discoloration, this report (50) suggests a "blooming period" of 15 to 30 minutes between cutting and wrapping. During this period the desirable bright red color develops and excess free liquid which causes unattractive appearance is removed.

Consumers are very critical of meat color and discriminate against meat cuts that show discoloration. Kramer (26) found that 10 per cent of the packages presented for sale daily in self-

service meat counters were rewrapped packages. The report of the Production and Marketing Administration (50) states that 8 per cent were rewrapped. The major cause for removal and rewrapping of packages was discoloration. This one cause accounted for 20 per cent of the packages reworked.

Methods for promoting and maintaining desirable, appealing color in self-service meat packages would minimize reworking and increase sales, for in self-service, each package is its own salesman.

Many customers have eagerly accepted prepackaged meat. On April 1, 1948, there were 178 stores offering 100 per cent self-service (45). Three years later there were 3,972 stores (25).

Numerous surveys have been made to find consumer and retailer reactions to prepackaged meats. These studies by Anonymous (2,4,6,7), Kramer (29,26), Ranta (42), Teitelman (47) and the United States Department of Agriculture (49) have shown that most store operators experienced an immediate increase in sales after converting to self-service meat retailing, not only in meats, but also in other items. Naturally, these operators were in favor of prepackaged meats. Favorable comments made by consumers concerning prepacked self-service meat retailing were:

1. They could shop quicker as there was no waiting.
2. The weight and total price were given on the packages and they could purchase to suit the household budget.
3. They could examine the meat more closely and know just what they were buying.

The reasons some consumers did not prefer prepackaged meats were:

1. They wanted the advice of the butcher.
2. They preferred to see the meat cut, because they did not know how long prepackaged meat had been packaged.
3. They preferred to see both sides of the meat.

This new method gave rise immediately to technical problems. Several technical studies have sought solutions for these. Weisman and Hagen (57) published a guide to retailers who were considering converting to prepackaged meat. The United States Department of Agriculture Production and Marketing Administration (49,50), E. I. duPont de Nemours and Company (3), Armour and Company (5) and other agencies have published several reports on technical problems. Baker (6) and Gilchrist (16) have presented reports of similar problems. Allied industries, such as the paper companies and self-service refrigerated case manufacturers have done a considerable amount of research work. The experiment stations of Michigan, Missouri and New Jersey have been engaged in cooperative studies. Results of these studies have been published by Chamberlain and Bratzler (15), Gowland (19), and Voegeli (52) of the Michigan Station and Rikert (43) of the New Jersey Station. Few of these studies have emphasized the color changes of fresh meat.

Since the color of meat has been shown to be of great importance, the following study applies disk colorimetry in the objective measurement of beef color. Color changes as affected by various treatments were investigated using this method.

REVIEW OF LITERATURE

In reviewing the literature on the color of meat, it immediately becomes apparent that reports dealing with color changes of meat as such are scarce. Considerable work has been done with solutions of hemoglobin, one of the meat pigments. Kennedy and Whipple (23) made a study to determine if there was any significant difference between blood and muscle hemoglobin. These authors found that muscle hemoglobin was almost indistinguishable from blood hemoglobin. They found evidence that the pigment fraction of muscle and blood hemoglobin was identical but that there were differences in the globin fractions. Spectrophotometrically, the two are quite similar. Many authors have made no attempt to differentiate blood hemoglobin from muscle hemoglobin. It is thought that the reactions of hemoglobin may be applied toward an understanding of meat color changes, since hemoglobin and muscle hemoglobin, usually called myoglobin, are similar in their reactions and the latter compound is the chief pigment of fresh meat. The term hemoglobin will be used to include both blood hemoglobin and muscle hemoglobin in this review.

A. Methods Used to Measure Color

Reference has been made to both subjective and objective methods of color measurement.

Ramsbottom (40) used a committee of three judges to rate the color of beef which had been stored. An arbitrary scale from 1 to 10 was established, 1 being extremely poor and 10 excellent.

Kraft and Wanderstock (24) modified the strictly subjective method by matching meat color with Munsell color panels (meat scale A). The panels were used as a standard and the grading was on a scale from 1 to 10 in order of increasing darkness.

Nickerson (39) has stated that if a standard that actually matches the project can be established, color panels or charts are often useful. Ridgeway charts, Maerz and Paul Dictionary of Color, and Munsell charts have all been used for this purpose.

Objective color measurements have been made using spectrophotometry, colorimetry, and more recently, the Hunter Color Difference Meter.

1. Spectrophotometry - The color may be measured indirectly by specifying the stimulus, completely or partially, in terms of reflectance or transmittance at each wave length in the visible spectrum.
2. Colorimetry - Color may be matched by the use of secondary standards such as filters or disks.

3. Hunter Color Difference Meter - This instrument is a tristimulus colorimeter that measures color on three scales:

   L scale - visual lightness.

   a scale - redness when plus, gray when zero, and greenness when minus.

   b scale - yellowness when plus, gray when zero, and blueness when minus.

B. Methods Used to Express Results of Color Measurement

Nickerson (39) has listed three methods of color notation which are widely used in reporting color measurements.

1. International Commission on Illumination method of color notation - The results of instrument measurements are reduced directly into terms of the standard observer and coordinate system of colorimetry. The data are expressed as the absolute (X,Y,Z) and fractional (x,y,z) amounts of three imaginary red, green and blue lights necessary for an imaginary standard observer to match a given sample under a given illuminant.

2. Homogeneous-Heterogeneous Method of Color Notation - In this method of color notation the results of color measurements are reduced through conversion from I.C.I. notation into terms of the homogeneous-heterogenous system in which a mixture is made or calculated for the amount of spectrum light of a

homogeneous nature and the amount of heterogeneous light needed to match a given sample. Luminous reflectance or transmittance is measured separately. The wave length of the homogeneous light needed to match the sample is called the dominant wave length of the sample; and the purity is the relative amount of neutral light needed to desaturate the homogeneous spectrum light to match the sample under a chosen illuminant.

3. Munsell Method of Color Notation - This method may be used directly if measurements are made by comparison to Munsell charts, or it may be used indirectly by converting I.C.I. notations into Munsell notations. Color is expressed in units of visual difference of three psychological attributes; hue, lightness, and saturation. Results are expressed in terms of color order rather than color mixture and allow an interpretation of results directly in terms of the visual qualities known in the Munsell system as hue, value and chroma.

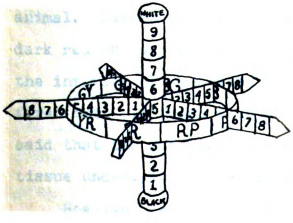
Munsell hue is that attribute of certain colors in respect to which they differ characteristically from a gray of the same lightness and which permits them to be classed as reds, yellows, greens, blues, or purples. The Munsell circuit is divided into 10 major hues:

R - red	BG - blue green
YR - yellow red	B - blue
Y - yellow	PB - purple blue
GY - green yellow	P - purple
G - green	RP - red purple

Munsell value is that attribute of all colors which permits them to be classed as equivalent to some member of a series of grays that are equally spaced under the standard conditions for which the scale was derived. The Munsell scale of grays extends from 0, black, to 10, white.

Munsell chroma is that attribute of all colors possessing hue which determines their degree of difference from a gray of the same value. The notation is numerical, with 0 at gray, extending outward from the neutrals toward 10 or more for the strong colors.

It is important in color work to thoroughly understand the three-dimensional concept of color. The following diagram illustrates hue, value and chroma in their relation to one another.



The circular band represents the hues in proper sequence; the vertical center axis represents the scale of value; the paths outward from the center represent scales of chroma, increasing in strength in the direction indicated by the numbers. (Drawing by F. G. Cooper, from Munsell Book of Color.)

Diagram 1

C. The Color of Fresh Lean Meat

Brooks (13) stated that the color of meat was due to the presence of a complex and relatively unstable compound known as hemoglobin. Brooks (9) reported that hemoglobin was present as muscle hemoglobin, and also in any blood corpuscles remaining in the capillaries. In another paper, Brooks (11) confirmed that the reddish color (hue) of fresh lean meat was due to the pigment muscle hemoglobin found within the muscle fibers. The depth of color (which corresponds roughly to the two other attributes of color, brilliance and saturation) depended on the concentration of hemoglobin and on the thickness of tissue from which light was reflected to the eye by optical heterogeneities within the muscle. The thicker the surface layer and the greater the concentration of pigment, the deeper was the color. Whipple's work (55,56) showed that the amount of muscle hemoglobin present appeared to be independent of the degree of blood removed and dependent on the type of muscle, as well as the breed, age, and condition of the animal. Lavers (29) stated that the color of hemoglobin was dark red or purple and was responsible for the dark color in the interior of meat seen on the exposed surface when it is first cut. In fresh lean meat exposed to air, Brooks (11) said that the purplish reduced hemoglobin was found in the tissue underlying the surface layer.

Hoagland (21) stated that the red color of fresh lean meat was due to oxyhemoglobin, which is one of the constituents

of the blood remaining in the tissues, and to a similar compound which is a normal constituent of the muscles. Lavers (29) found that oxyhemoglobin was bright red and was responsible for the attractive bright red color of meat. According to Brooks (11) the red oxyhemoglobin was found only in a well defined surface layer.

The dark brown color in meat is due to methemoglobin (29). Brooks (13) found that the color of lean meat was brownish when about 60 per cent of the hemoglobin present in the superficial layer was in the form of methemoglobin.

Drying, or dehydration, also caused a color change. Brooks (11) offered the following explanation for the cause of this color. The rate of evaporation of water from muscle depended on the rate of movement of water through the muscle up to the evaporating surface and the rate of diffusion of water vapor from this surface into the outer atmosphere. With large muscles there appeared to be a sufficient difference between these to give a sharp concentration gradient of water near the exposed surface of drying.

D. Chemistry of the Color Change

Haurowitz (20) has reported that hemoglobin consists of two components, a prosthetic group called protoheme, and a protein group called globin. He stated that the prosthetic group is the same for all hemoglobins and myoglobins and shows the structural formula for this to be as follows:

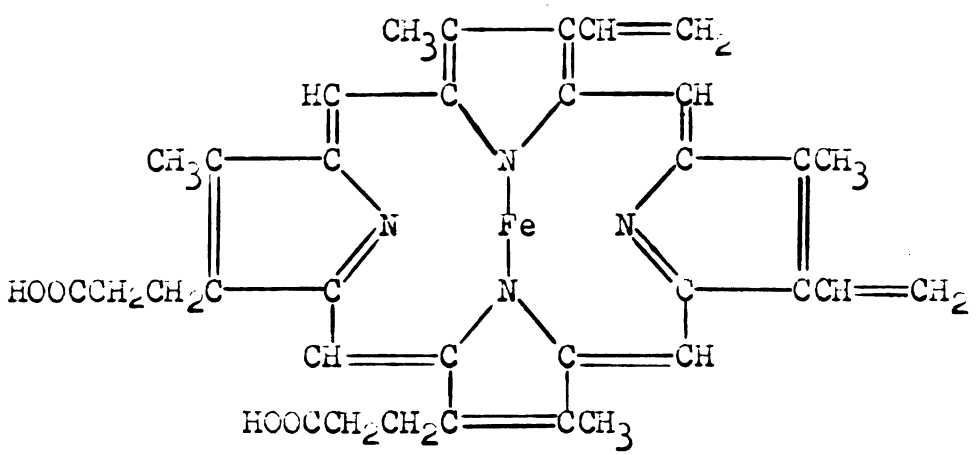
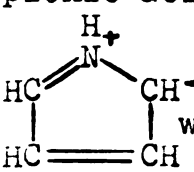
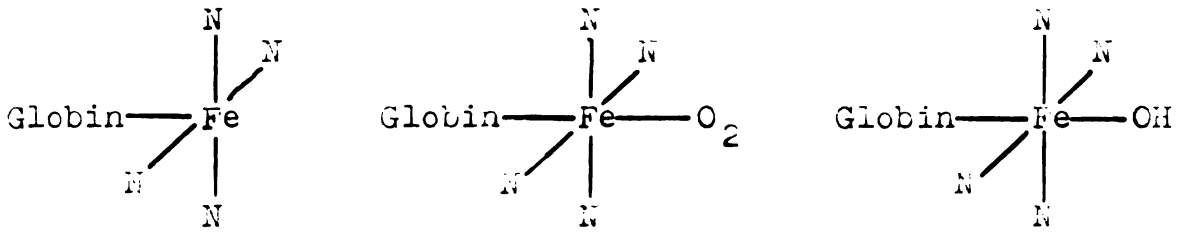


Diagram 2 - Protoheme

This compound is made up of four methyl groups (CH_3), two vinyl groups ($CH{=}CH_2$), two propionic acid radicals (CH_2CH_2COOH), and four pyrrole rings  which make up the porphyrin ring in combination with iron (Fe).

There are three main forms of hemoglobin which explain the color changes of meat: hemoglobin (purple), oxyhemoglobin (red), and methemoglobin (brown). The color of the meat is greatly influenced by the relative concentrations of these compounds.

Firie, according to Haurowitz (20), has illustrated the structure of hemoglobin and important reactions of the iron atom by the following formula. The porphyrin ring is symbolized by the four nitrogen atoms of the pyrrole rings.

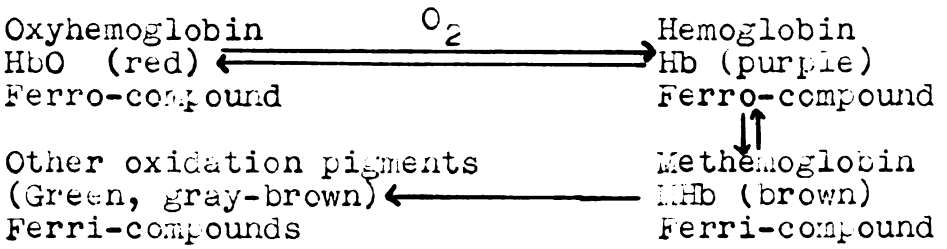


Hemoglobin Oxyhemoglobin Methemoglobin

The iron is in the ferrous (Fe^{++}) state in hemoglobin (29). In oxynemoglobin the iron is also in the ferrous (Fe^{++}) state, but the compound contains more oxygen than reduced hemoglobin. The oxygen is held only in loose combination. Only oxygenation of hemoglobin and not true oxidation has taken place when oxyhemoglobin is formed, since there is no change in valence of the iron. In methemoglobin the iron has been oxidized to the ferric (Fe^{+++}) state.

Lavers (29) stated that oxyhemoglobin is not an intermediate in the formation of methemoglobin. He gave the path of the discoloration reaction as: oxyhemoglobin ⟶ reduced hemoglobin ⟶ methemoglobin.

Using only the portion of Jensen's (22) diagram which pertains to fresh meat, the color change is shown diagramatically as:



E. Factors Influencing the Color of Meat

(I) Hemoglobin Content of the Tissue

Shenk, Hall and King (44) made a study to determine the hemoglobins in beef muscle tissue. They found that muscle hemoglobin in animals full fed grain while on pasture averaged about 16 per cent higher than in animals full fed in dry lot. Animals on pasture alone averaged 37 per cent higher than the animals full fed in dry lot. These authors felt that the difference was not due to nutrition but was due to the increased exercise that the pasture animals were required to take in obtaining their food.

Whipple (55), in a study of striated muscles of the dog, found that the leg and back muscles showed a great range in their muscle hemoglobin content. This variation appeared to depend upon exercise and it determined largely the latent muscular power. Whipple also found that as the animal grew older the muscle hemoglobin content increased. Adult dogs had considerably more hemoglobin present than young dogs and the adult dogs varied all the way from 400 mgm. per 100 grams hemoglobin in a quiet house dog to 1000 mgm. per 100 grams hemoglobin in an active, trained hunting dog.

Whipple (56) also studied the variations in hemoglobin content in striated dog muscle due to anemia or paralysis. He found that severe anemia may reduce the level of muscle hemoglobin slowly. If the original hemoglobin content was high he found that the reduction due to anemia might even

amount to 30 or 40 per cent. Muscular paralysis was followed by a fairly rapid loss of muscle hemoglobin. After a period of seven weeks some paralyzed muscles contained only one-half as much muscle hemoglobin as normal muscles. This showed the relationship between muscle hemoglobin and exercise and that exercise was more important than anemia in determining the level of muscle hemoglobin.

According to Millikan (32) about one-fourth of the living body's hemoglobin is in the form of muscle hemoglobin. The muscle hemoglobin is generally found in large quantities in those muscles requiring slow, repetitive activity of considerable force. Examples are the heart muscles of larger mammals, breast muscles of the larger flying birds, and leg muscles of running animals such as the horse and dog. The same muscles may vary widely in redness from individual to individual and from time to time, depending upon the amount of use to which they are put.

Watson (53) measured the concentrations of hemoglobin in different muscles of the same animal and in animals of different breeds. He found the muscle hemoglobin made up a high percentage of the total hemoglobin in beef muscle. In sheep and pig muscle the percentage of muscle hemoglobin was considerably less. This would account for the darker color in beef muscle than in sheep or pig muscle.

The results of these workers would indicate that the amount of hemoglobin in meat is dependent on the type of

muscle, exercise, age, breed, and condition of the animal.

(II.) Effect of Oxygen Pressure

Neill (37) 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 (9) 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.

The reaction in the formation of methemoglobin was from oxyhemoglobin ⟶ reduced hemoglobin ⟶ methemoglobin. Brooks (12) found that at 30°C (86°F) oxyhemoglobin dissociated rapidly to reduced hemoglobin as the oxygen pressure dropped below 80 mm. mercury. Since the formation of methemoglobin was dependent on the formation of hemoglobin from oxyhemoglobin one would expect discoloration to proceed rapidly at an oxygen pressure below 80 mm. mercury. Neill and Hastings (38) have substantiated this. Working with hemoglobin solutions, these workers found that at 30°C (86°F) the rate of methemoglobin formation was greatest when the partial pressure of oxygen was about 20 mm. of mercury. Brooks (9) found this to be true for the oxidation of hemoglobin in muscle. He found that at this oxygen pressure the concentration of hemoglobin nearly equals the oxyhemoglobin concentration. The rate of

methemoglobin formation was monomolecular with respect to the hemoglobin concentration at a constant oxygen pressure. At 0°C (32°F) Brooks (13) found the rate of methemoglobin formation was greatest when the partial pressure of oxygen was 4 mm. of mercury. It would seem that the oxygen pressure required for optimum methemoglobin formation is dependent on the temperature.

Brooks (12) found that in muscle tissue the concentration of oxygen decreases with increasing distance from the muscle surface. In air the rate of oxidation in the oxygen region increases with increasing distance from the surface. The smaller the pressure of oxygen in the gas in which the tissue was stored, the nearer to the surface was the region where methemoglobin was most rapidly formed, since the depth of oxygen region was proportional to the square root of the oxygen pressure.

The relation between oxygen pressure and the rate of methemoglobin formation was responsible for the rapid discoloration of tissue stored at 0°C (32°F) in gases containing a small amount of oxygen. Brooks (11) found that methemoglobin formed directly on or very near to the surface altered the color of reflected light to a greater extent than the same amount of pigment produced in the same time but some distance (2 mm. or more) below the surface. In tissues that were still reddish on the surface, Brooks (9) found that the difference in rate at different distances from the surface was great

enough to form a yellow brown zone (containing mainly methemoglobin) immediately adjoining the region of reduced hemoglobin.

(III.) Depth of Oxygen Penetration

Since methemoglobin was slowly formed on exposure of hemoglobin to oxygen the formation of methemoglobin in muscle exposed to air was confined to a thin surface layer. Brooks (9) found that the 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 tissue and the oxygen consumption. He showed that the depth of the 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 (9) found that any factor which altered the depth of the penetration of oxygen into the tissue also affected the discoloration of the tissue. The discoloration of the tissue was confined to the thin superficial layer where oxygen had penetrated.

Brooks (11) found that different fresh ox-muscles in air at 0°C (32°F) from the same animal showed values of depth of oxygen penetration varying from 2 to 5 mm. The depth of oxygen penetration showed a slow increase with time, and a rise in temperature decreased the depth. The depth of oxygen

penetration was proportional to the square root of the oxygen pressure of the atmosphere.

(IV.) Effect of Time, Temperature, and Relative Humidity

Since it has been shown that oxygen penetration of the tissue is necessary for the formation of methemoglobin, factors which affect oxygen penetration affect discoloration. Brooks (13) has shown that the depth to which oxygen penetrated the tissue decreased with increasing temperature. Penetration increased slowly with time but rarely exceeded one centimeter even after very long periods of storage.

The onset of discoloration is closely connected with the factors governing the loss of water from the meat. At high humidities, 99 per cent relative humidity at 0°C (32°F), Brooks (13) found that exposed muscle was discolored by methemoglobin in 20 to 30 days. At low humidities where there was excessive drying, there was a dark appearance due to the optical changes in the tissue very quickly.

At 0°C (32°F) Brooks (10) found that the rate of oxidation in ox-muscle was slow but that over long periods of storage it produced a marked brown discoloration of the tissue. After the tissue had stood a few hours, Brooks (9) measured the depth of oxygen penetration and found it to be approximately 2 mm. After 100 hours the depth had increased linearly to approximately 4 mm. In 6-8 weeks the oxidation in ox-muscle was complete in a surface layer of tissue which in extreme

cases was 1 cm. thick.

At -10°C (14°F) Brooks (13) found no visible discoloration of lean meat stored for 16 weeks. At -1.4°C (29.5°F) there was no discoloration owing to the formation of methemoglobin until 40 to 45 days from killing.

Brooks (9) has shown that freezing and thawing meat appeared to increase the rate of methemoglobin formation compared to control tissue which had not been frozen. Mangel (31) included thawing experiments in her work. She found that samples allowed to thaw from one to five times did not show that methemoglobin formation had been increased with repeated thawing and freezing.

Mangel (31) stored samples at temperatures ranging from -12°C (10.4°F) to -24°C (-11.2°F). She found that methemoglobin formation was slower in samples stored at the higher temperature than in samples stored at the lower temperatures. Ramsbottom's (40) work would indicate the opposite. He stored fresh beef at six different temperatures ranging from -20°F to 26°F packaged in Du Pont 300 MSAT #87 cellophane. The product stored at 26°F was discolored in less than 30 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 storage temperature the longer the storage life.

Ramsbottom and Koonz (41) determined the relative concentration of oxyhemoglobin and methemoglobin in the surface

tissues of steaks stored for one year at 10°F and -30°F. The absorption spectra curves on extracts of the surface tissue were plotted from spectrophotometer readings. The curve found for steaks stored at 10°F for one year was quite similar to the curve for methemoglobin. The curve 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 superficial lean tissues at 10°F than occurred at -30°F.

Rikert (43) found that when unpackaged meat was stored at 34°F, 54°F, and 85°F the rate of initial darkening increased as the storage temperature increased. When meat was packaged under vacuum, Rikert (43) found an initial decrease in redness followed by a return to redness which had in many cases a higher redness value than the original. The time required for the return of the red color in the packaged meat was also shortened as the storage temperature increased.

(V.) Effect of Antioxidants

Kraft and Wanderstock (24) dissolved antioxidants in a filtered cocoanut oil carrier and brushed this on the surface of meats. The meats were packaged and stored. They found that antioxidants were most effective for checking undesirable color changes in beef round steaks during the first 24 to 48 hours. Nordihydroguaiaretic acid in 0.01 per cent concentration inhibited color changes in round steaks for 144 hours.

All of the antioxidant treated samples retained color better than did the untreated ones. Rikert (43) concluded that the effect of 0.05 per cent nordihydroguaiaretic acid was not consistently toward either improvement or degradation of the meat color.

When hemoglobin solutions were shaken in air with the addition of ascorbic acid, Lemberg, Legge, and Lockwood (30) noted the formation of green bile pigments. Vestling (51) demonstrated that if controlled conditions were used, ascorbic acid could be used in reducing methemoglobin to hemoglobin at 0°C (32°F). Chang and Watts (16) found that at 45°C (113°F) the addition of .1 per cent ascorbic acid to hemoglobin caused oxidation of the red color followed by conversion of the hemoglobin to a green hemochromogen. Watts and Lehman (54) concluded that ascorbic acid protected hemoglobin solutions when it was added in low concentrations at low temperatures. At high concentrations and high temperatures it brought about discoloration.

Lavers (29) treated wrapping material with ascorbic acid and sodium bisulfite. He found that ascorbic acid was of little value in preventing discoloration while sodium bisulfite was quite effective.

(VI.) Effect of Storage in Different Atmospheres

Brooks (11) investigated the effect of carbon dioxide at 0°C under conditions where there was little or no drying of the tissue. He stated that there were two possible effects

of carbon dioxide.

1. A change in the depth of oxygen penetration into the tissue in addition to the decrease caused by the diminution of oxygen pressure in the gas mixtures.
2. A change in the rate of methemoglobin formation.

Brooks (11) found that in concentrations of carbon dioxide below 20 per cent the rate of oxidation of hemoglobin in muscle was not affected to a significant extent. If other conditions of storage were the same, the color changes of lean meat in air and in air containing 20 per cent carbon dioxide were the same.

Mangel (31) 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 the other gases.

Rikert (43) 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 surface color when compared with samples stored in air.

(VII.) Effect of Biological Agents

Neill (34) made an investigation of the oxidation-reduction activities of Pneumococcus based upon the

physical-chemical relations between oxyhemoglobin, hemoglobin and methemoglobin.

Suspension of living cells and relatively large amounts of sterile Pneumococcus extract respectively were added to sterile solutions of methemoglobin which were then sealed from the air. Analysis proved the complete absence of both oxyhemoglobin and molecular oxygen. In the absence of air, Neill found that living Pneumococci and sterile cell extracts prepared from them reduced methemoglobin to hemoglobin. When oxygen was present, the extract formed oxidizing agents which oxidized hemoglobin to methemoglobin.

Neill (35) made a similar study using anaerobic bacilli. He found that anaerobic bacilli have the ability to oxidize hemoglobin or reduce methemoglobin. The optimum conditions were provided when the oxygen tension was sufficient for the formation of an active concentration of oxidizing agents without preventing the necessary oxygen dissociation of the oxyhemoglobin. In the absence of oxygen, anaerobes did not oxidize hemoglobin to methemoglobin.

Autoxidizable substances formed during the autoxidation of pure oleic and linoleic acids and of substances present in turpentine, cod liver oil and linseed oil have been shown by Neill (36) to oxidize hemoglobin to methemoglobin. Autoxidizable substances were extracted by alcohol from meat infusion and from potato juice. Mixtures of the alcohol soluble substances from either the animal or plant juices consumed

molecular oxygen with the formation of oxidizing agents capable of oxidizing hemoglobin to methemoglobin.

Hemoglobin is oxidized to methemoglobin if oxygen is present while the reverse reaction is induced if oxygen is excluded. The presence or absence of molecular oxygen determines the direction of the reaction induced by these autoxidizable substances.

Neills' studies have shown that "spontaneous" formation of methemoglobin which occurs in sterile drawn blood or in sterile hemoglobin solutions can be prevented by maintaining the hemoglobin system rendered oxygen-free by biological reducing agents. Since methemoglobin is known to be the oxidation product of hemoglobin it would seem certain that its "spontaneous" formation is an oxidation.

Neill (37) has shown that the presence of oxygen is necessary for the "spontaneous" formation of methemoglobin in blood or in hemoglobin solutions either at ordinary temperatures or at 55°C.

(VIII.) Effect of Packaging Material

Lavers (29) tested several packaging materials and found that discoloration was not a function of any particular packaging material. The cause of discoloration was the change of the oxyhemoglobin to hemoglobin and this to methemoglobin.

Lavers (29) stated that when an oxygen-impermeable film was placed on meat, conditions suitable to rapid discoloration

were present. This was due to the supply of oxygen from the air being cut off and a lowered oxygen pressure beneath the film due to diffusion and bacterial action.

Allen (1) relates that Du Pont laboratory research has shown that in addition to oxygen permeability, low water-vapor permeability and a certain degree of water-absorptive power are important in maintaining desirable color. A suitable film must have a proper balance of these properties.

Du Pont 300 MSAT #80 cellophane has been shown to be effective in holding the color of fresh meat for periods of 72 hours and longer when stored at 34°F to 40°F.

This film is characterized by having a "wettable" surface which must be kept in contact with the meat. The oxygen permeability is relatively low as is its water-vapor permeability. The low water-vapor permeability is important in maintaining color because excessive drying of the meat surface contributes to change in color. The relative humidity of self-service cases may average as low as 60 per cent, therefore, films with high water-vapor permeability may cause excessive loss in weight of the packaged meat.

Temperature affects bacterial and enzymatic action which may also play important parts in the retention of color. Allen (1) relates results from an independent laboratory in which 300 MSAT #80 cellophane was one of the films used.

On the average, the meat wrapped in 300 MSAT #80 cellophane remained bright and salable for seven to nine days.

Steaks in other films were generally discolored at the end of two or three days. There was no bacteriostatic action as the counts were high on all steaks.

Kraft and Wanderstock (24) used four different films in their study with antioxidants. They found that a rubber base film gave the best color retention in beef round steaks. Round steaks packaged in films which gave greater retention of color also responded to a greater extent to antioxidant treatment than did the samples packaged in films allowing greater color change.

Rikert (43) found that his control samples underwent, in general, the same color change when packaged in cans, polyethylene film and cellophane-pliofilm laminate film.

(IX.) Effect of Fat Content

Mangel (31) added from zero per cent fat up to 25 per cent fat to ground lean beef. For comparison with the ground beef to which no fat was added, one pound unground pieces of the same beef were used. Mangel (31) found that samples containing more than 15 per cent fat showed higher methemoglobin content than those containing less than 15 per cent fat. She observed no difference in the all lean ground samples and the unground samples. This would indicate that the amount of fat in a muscle may influence discoloration.

PURPOSE

The main purpose of this investigation was to study the application of disk colorimetry as an objective measurement of fresh beef color.

Using this method, it was the purpose to gain information on the color changes as affected by:

I. Color Difference due to Animal
II. Aging
III. Storage in a Film
IV. Light
V. Freezing
VI. Delayed Wrapping

EXPERIMENTAL PROCEDURE

A. Sampling Procedure

Beef was the only meat used in this study. It was secured from animals killed in the Michigan State College meats laboratory. The animals were killed in the usual manner and placed in the laboratory cooler at approximately 34°F for chilling.

Seven different animals were used to secure samples:

Animal	Description	Grade	No. of Samples
I	2 year old Hereford steer	Average prime	1
II	2 year old Angus steer	Average prime	6
III	2 year old Hereford steer	Average choice	4
IV	18 month old Angus steer	High choice	4
V	2 year old Hereford steer	High commercial	8
VI	20 month old Hereford heifer	Low choice	2
VII	18 month old Hereford steer	Low choice	18

The longissimus dorsi muscle was used exclusively throughout this study. After the carcasses had been chilled at least 48 hours the wholesale rib portion was removed. At the beginning of each sample run, the rib cut was taken from the cooler to the meat laboratory cutting room. The cutting room temperature ranged from 55 to 70°F, being mostly about 64°F. The longissimus dorsi muscle was removed and cut into steaks three-quarters of an inch in thickness to be measured for color.

B. Method of Color Measurement

The instrument used to measure the color is shown on pages 30 and 31. The matching booth was made from plywood

and painted with blackboard paint to minimize light reflectance.

The other equipment used for disk colorimetry in the matching booth were as follows:

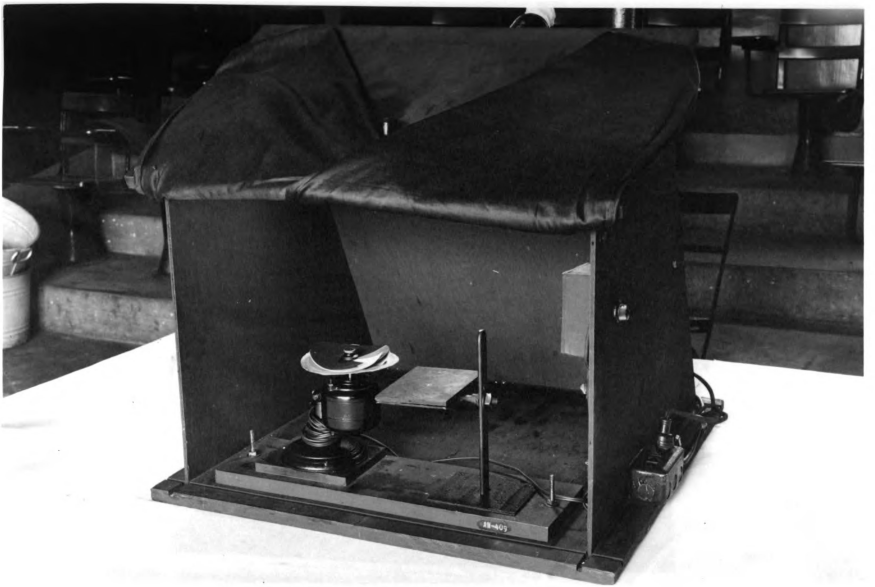
1. Electric motor and controls with Munsell disks.
2. Sample standard.
3. Baush and Lomb optical eyepiece.
4. Mac Beth 300 watt daylight lamp.
5. Black curtains.

The Mac Beth 300 watt daylight lamp produces a color temperature of approximately 6800° Kelvin. This is just a few degrees different from Illuminant C, the light specification set up by the International Commission on Illumination under which colors should be matched. This lamp was mounted on the sloping back of the matching booth so that the angle of the light on the meat surface was 30 degrees.

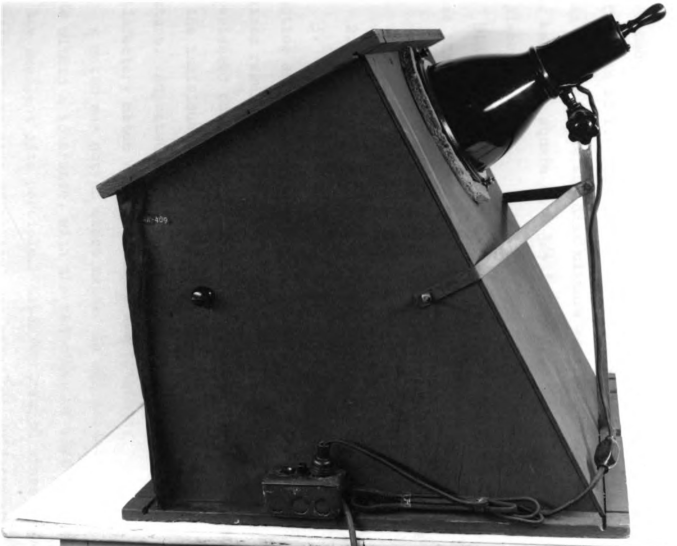
The Munsell disks were backed by a calibrated heavy cardboard disk so that the percentage of each disk used could be read directly. Red, yellow, white, and black disks were used as suggested by Nickerson (38) and had the following Munsell notation:

	Renotation	Production No.
Red - 5R4/14	5.5R 4.16/13.1	3605
Yellow - 5Y8/12	5.5Y 8.13/12.0	3636
White - N9	N8.80/(Y 0.3)	3551
Black - N1	N1.11/(PB 0.2)	3556

The prepared sample was mounted upon a fitted plywood



Front View of Matching Booth



Side View of Matching Booth

backing piece before placing it on the sample stand. This made it possible to remove and replace the sample and still have the same sample area viewed in matching the color. This was found important as different areas of a muscle gave different results depending upon the concentration of intramuscular fat. By adjusting the sample so that the top surface was at the same level as the disks, equal viewing areas of the sample and disk mixture were obtained. This area was 2 cm. square at 8 3/4 inches from the optical eyepiece base.

Since color is three dimensional, to match a sample, these three points were considered:

1. Are the spinning disks redder or yellower than the sample?
2. Are they brighter or darker than the sample?
3. Are they stronger or weaker than the sample?

Practice and experience were important in obtaining the desired result when adjustment of disk mixtures was made. The experienced observer knows what the addition or subtraction of the individual colors will do to the resulting color mixture. Adjustment of the disks was continued until a satisfactory match with the sample was obtained.

A match was not an exact matter in all cases. It was made within a tolerance, with the reduction of that tolerance to the smallest size possible. Cases were found where the addition of one unit of yellow, for example, would change

the disk mixture from slightly lacking in yellow to too much yellow. In such cases the lesser units of yellow were always used in the reading. Since this study was one of comparison of the same samples over a period of time, as long as this was followed results seemed valid.

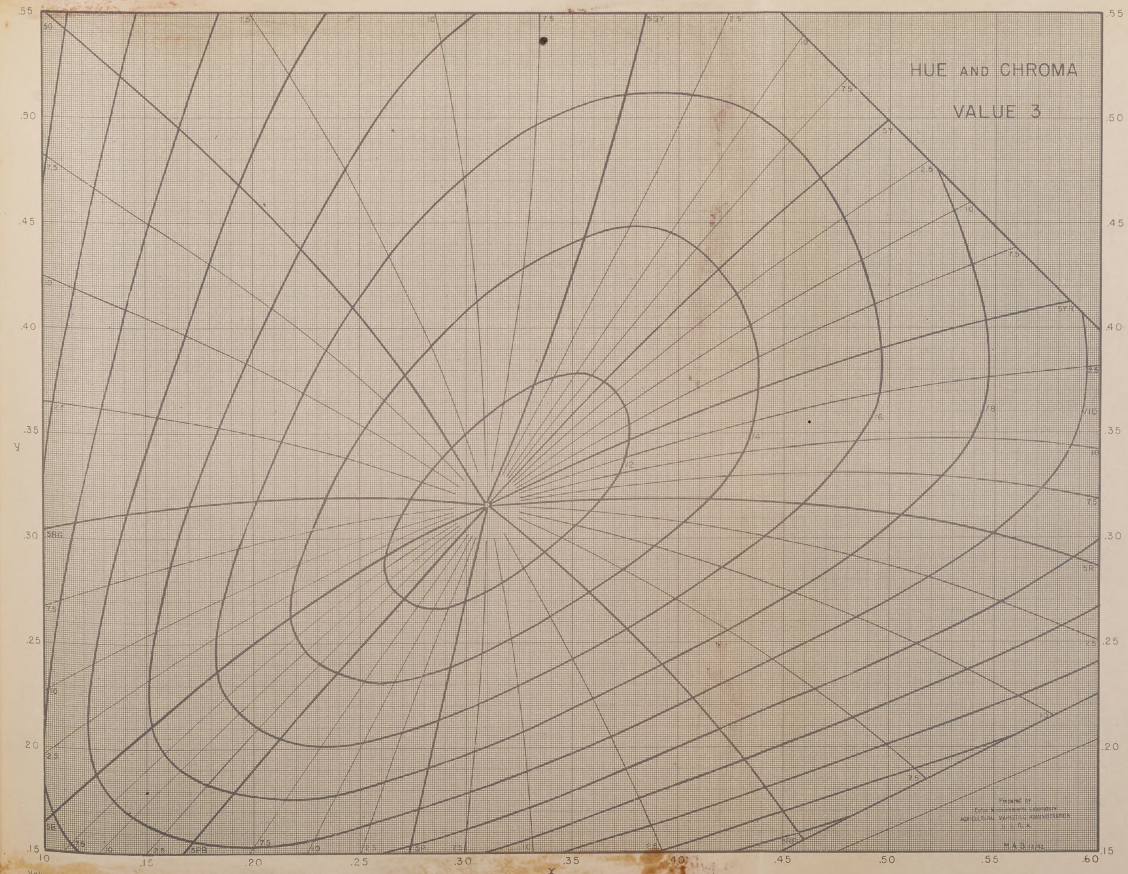
Upon reaching a satisfactory match of the sample the areas of the disk mixture were recorded. By knowing the International Commission on Illumination (I.C.I.) tristimulus values (X,Y,Z) of the individual disks and knowing the number of units used in the match, it was possible to calculate the Munsell renotation.

	Production No.	X	Y	Z
Red disk - 5R4/14	3605	.2283	.1305	.0554
Yellow disk - 5Y8/12	3630	.5794	.6143	.0865
White disk - N9	3551	.7264	.7435	.8409
Black disk - N1	3556	.0133	.0136	.0173

Suppose that the sample required 32 per cent of the red, 5 per cent of the yellow, 2 per cent of the white, and 61 per cent of the black to match the meat sample. The tristimulus values (X,Y,Z) for this color were obtained as weighted means of the (X,Y,Z) data for each disk used, the weights being proportional to the disk area.

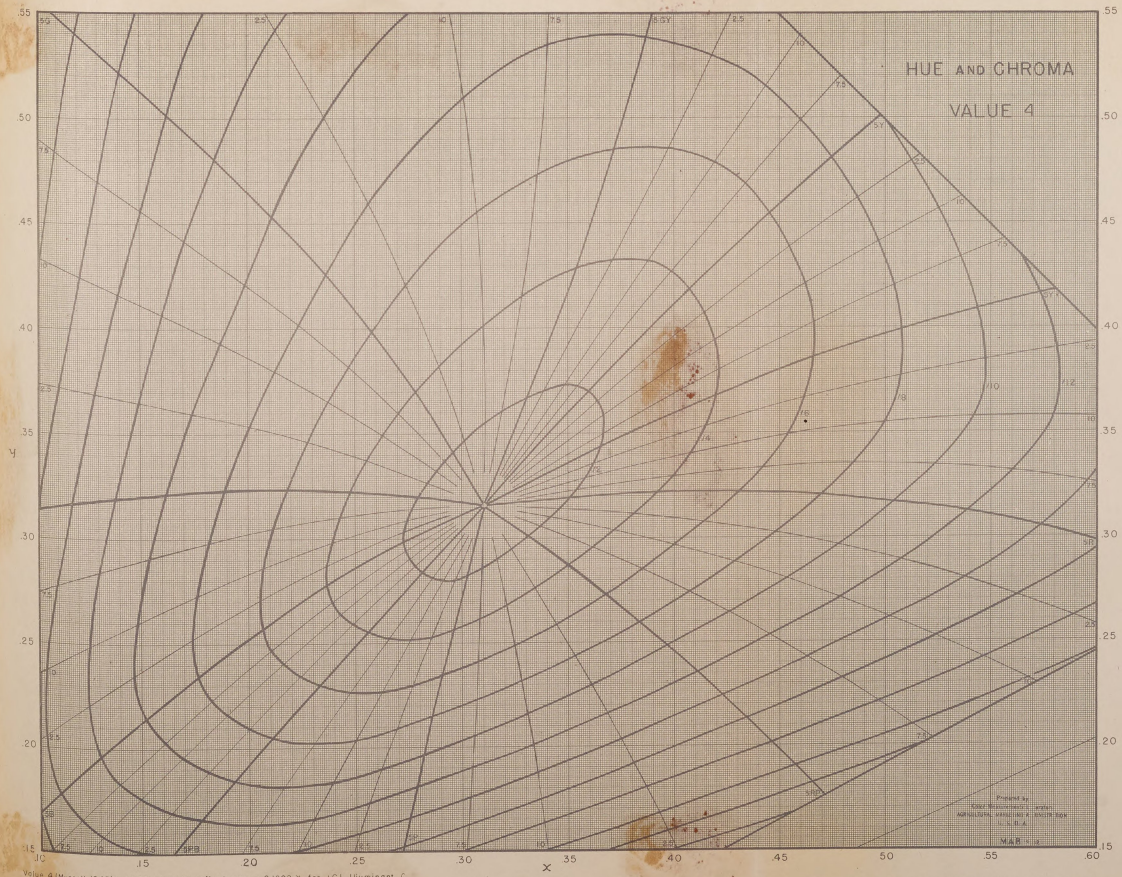
	X	Y	Z
32%(X,Y,Z) red disk	.0731	.0418	.0177
5%(X,Y,Z) yellow disk	.0290	.0307	.0043
2%(X,Y,Z) white disk	.0145	.0149	.0168
61%(X,Y,Z) black disk	.0081	.0083	.0106
Tristimulus values of sample color	.1247	.0957	.0494
Fractional values (x,y,z)	x=.462	y=.355	z=.183

1. To convert these data to the Munsell notation it was necessary to refer to a table of I.C.I. (Y) equivalents of the recommended Munsell value scale (V) from 0/ to 10/. From this table, for Y = .0957 it was found that Munsell value (V) was 3.60.
2. Since V = 3.60/, Munsell hue and chroma were found by interpolation between the charts for value 3/ and 4/ (See pages 35 and 36) to locate the hue and chroma loci at this value. At value 3/ for x = 0.462 and y = 0.355, the Munsell hue was 1.5YR and the chroma was /5.0. At value 4/ for x = 0.462 and y = 0.355, the hue was 0.6YR and the chroma was /6.2.
3. Since 3.60 is 0.6 of the distance between 3/ and 4/, the interpolated hue will be that of value 3/ minus 0.6 of the difference between the hue read from values 3/ and 4/. Since the hue on the 3/ chart was 1.5YR and on 4/chart was 0.6YR the interpolated hue was found to be 1.5 - (0.6(1.5-0.6)) = 1.0YR. The interpolated chroma will be that at value 3/ plus 0.6 of the difference between the chromas read from values 3/ and 4/. Since the chroma on the 3/ chart was 5.0 and on 4/ chart was 6.2 the interpolated chroma was found to be 5.0 - (0.6(5.0-6.2)) = 5.7.
4. The complete notation for the meat sample was found to be 1.0YR 3.60/5.7.



Value 3 (Munsell 1943) = 6.555 percent reflectance = 0.06555 Y for ICI Illuminant C.
Hue is indicated near the end of each radiating hue line.
Chroma is indicated in steps of 2, the inner ovoid being /2

From "Final Report of the O.S.A. Subcommittee on the Spacing of the Munsell Colors," (J. Opt. Soc. Am. 33, 385-418, 1943).



Value 4 (Munsell 1943) = 12.00 percent reflectance = 0.1200 Y for ICI Illuminant C.
Hue is indicated near the end of each radiating hue line.
Chroma is indicated in steps of 2, the inner ovoid being /2.

From "Final Report of the O.S.A. Subcommittee on the Spacing of the Munsell Colors," (J. Opt. Soc. Am. 33, 385-418, 1943).

The procedure followed by making a single color reading and then obtaining the Munsell renotation of that reading has been presented. In this study a series of readings from the same sample area were made to measure the color changes that occurred during the storage of that sample. To discover the relation between successive readings, they were plotted.

Since color is three-dimensional, no two-dimensional diagram will reveal all relations. Nickerson (38) suggests that by plotting hue (horizontally) against value (vertically) on one graph and then chroma (horizontally) against value (vertically) on another graph the significance of the color relations should become apparent.

To express color differences in terms of a single number instead of in three numbers (hue, value and chroma) color difference formulae have been devised. Sample readings are compared to a standard. Nickerson (38) based a small color difference formula on Munsell scales of hue, value and chroma. Judd, Scofield and Adams (38) have also presented formulae for this purpose. The Nickerson formula is easy and quick to apply. It is as follows:

$$I \text{ (index of fading)} = \frac{C}{5}(2\Delta H) + 6\Delta V + 3\Delta C$$

C = chroma of sample
ΔH = difference in hue between sample and standard
ΔV = difference in value between sample and standard
ΔC = difference in chroma between sample and standard

To show the relationship between successive readings

this formula was used. The standard used for readings of meat taken through cellophane was 1YR 4.0/6.0. The standard used for readings of the meat surface direct was 10R 4.0/7.0. The difference in the standards was due to the effect of the cellophane.

Since the sample used in computing the example Munsell renotation was wrapped in cellophane its standard was 1YR 4.0/6.0.

Standard notation - 1.0YR 4.0/6.0
Sample notation 1.0YR 3.60/5.7

$C = 5.7$ $\quad \Delta V = 0.4$
$\Delta H = 9$ $\quad \Delta C = 0.3$

$$I = \frac{C}{5}(2\Delta H) + 6\Delta V + 3\Delta C$$

$$I = \frac{5.7}{5}(2 \times 0) + (6 \times 0.4) + (3 \times 0.3)$$

$$I = (1.14 \times 0) + 2.4 + 0.9$$

$$I = 3.3$$

By use of this formula, it has been shown that the sample reading was 3.3 units from the standard. By following this procedure, 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 color changes of the sample by a single number instead of hue, value, and chroma quantities.

C. Accuracy of Color Match

It has been estimated that at least one male out of every ten is affected by color blindness to some degree (38). It is therefore important that one working with color should have some check on his accuracy in matching colors. The following procedure was used to check the author's accuracy.

Instead of the metal standard to hold the muscle sample, a second motor with spinning disks was mounted. The disks used on the two adjacent motors were the same. The disks on the second motor were set by an operator at percentages unknown to the author. The motor with this disk mixture was set to spinning. The author then came to the matching booth and attempted to match this mixture by altering the disk percentages of the first motor.

Definite settings of the unknown disks were made in the following ranges:

Red - 14 to 28 units
Yellow - 5 to 14 units
White - 2 to 8 units
Black - 50 to 72 units

The author was able to match the unknown disk mixture exactly in all cases but one. In the case where the match was not exact, the error was only 1 unit of the red disk which resulted in an error of only 0.3 hue steps and 0.3 chroma steps, a rather insignificant variance. It is the author' belief that color matches of the meat samples were reasonably accurate.

D. Method of Obtaining Color Reading During Storage

After the steak sample was prepared and placed in storage, following a procedure to be described later, color matches were made with the spinning disks. The matching booth was installed in the refrigerated storage room.

Several color measurements from the same area of the sample were made during the first few hours immediately after placing the sample in storage. Throughout the remainder of storage the color reading was obtained at approximately 24 hour intervals.

In many cases, sample storage was continued beyond the time when the sample was considered unsalable. On several occasions 2 or 3 judges viewed the sample to determine whether it was still salable from the standpoint of color. However, it was impossible to have this done throughout the study, and the time of unsalability as reported was the estimate of the author.

Samples which were stored wrapped in a transparent film were matched through the film.

E. Conditions of Storage

Three general conditions of storage were held as constant as possible throughout the study. Temperature, relative humidity, and air movement varied only to the degree prevailing in the meats laboratory cooler. The wholesale rib cut from which the individual steaks to be matched were cut, and the steaks studied were held under these same conditions.

The temperature was recorded by means of a Honeywell Recording Potentiometer. This machine automatically records the temperature by use of thermocouples, and these were distributed in the cooler. Readings from this instrument showed that the temperature varied from 30°F to 36°F throughout the period of this study.

The relative humidity was recorded by use of a Foxboro Dynalog Dewpoint Temperature Recorder. This instrument records dry bulb and dew point temperatures, from which the relative humidity can be determined. The relative humidity varied considerably, depending upon how much the cooler was being used. It varied from 65 to 90 per cent throughout the study. The most common relative humidity range was 75 to 85 per cent.

Air movement was determined by use of a Hastings Air Meter. This instrument records air movement in feet per minute. Readings showed that the air movement across the samples was 15 to 20 feet per minute.

F. Conditions of Sample Comparisons

(1) Color Difference due to Animal

Samples of the longissimus dorsi muscle of different animals were treated similarly to determine if there were color differences in the same muscle of different animals.

(II) Effect of Aging

It was necessary in this study to limit the number of samples placed in storage at one time. Since the time in storage of some samples was for a period of two weeks, considerable time elapsed after removing the first sample from the wholesale rib cut until removing the last sample. Comparisons of color changes in samples cut at different intervals of time and then held under similar conditions of storage showed the effect of aging on the color change.

(III) Effect of Storage in a Film

The primary difference between the retailing of meat prepackaged and butcher style is the storing of the retail cut in a transparent film. Prepackaged meat is wrapped soon after the retail cut is made and stored in this condition. In the butcher style of retailing meat, the retail cut is made and placed on trays unwrapped until sold, or cuts are made as demanded. To determine the effect on color of storage in a film compared to storage unwrapped the following procedure was followed:

Three-quarter inch steak samples were cut. Some were placed unwrapped in storage immediately after cutting. Others were wrapped with cellophane (300 MSAT #80 Du Pont) before placing in storage.

To wrap a sample the steak was first placed on a Rodeo (brand) Backing Board, so cut that the edges did not extend beyond the steak. The wettable surface of the cellophane was placed against the meat and a tight wrap was made. The film was sealed on the Rodeo Backing Board side by means of transparent adhesive tape.

(IV) Effect of Light

A survey of markets in the locality offering prepackaged meat showed a variation in light intensity upon the product. The market operators felt that light was a factor in the discoloration of fresh meat as well as cured meat. It is well established that light causes a fading of cured meats. No report has been noted by this author in which light has been shown to affect the color of fresh meat significantly.

The intensity of light on the meat products was measured by means of a Weston Foot Candle Meter which measured the light in foot candles. The variations found were:

Market 1 - averaged 60 foot candles
Market 2 - averaged 30 foot candles
Market 3 - averaged 15 foot candles

All of these markets were using white fluorescent light over the fresh meat products. Markets 1 and 2 had lights mounted in the meat cases, and also fluorescent lights mounted from the ceiling above the cases. Market 3 had only fluorescent lights mounted from the ceiling.

To duplicate commercial conditions, a battery of fluorescent lights was installed in the sample storage room. By altering the distance of the lights above the samples, different intensities of light were obtained upon the samples. Samples were stored under the following light intensities:

1. Darkness - The sample was exposed only to the light required when matching the sample.
2. Thirty foot candles - Storage was under thirty foot candles of white fluorescent light.
3. Sixty foot candles - Storage was under sixty foot candles of white fluorescent light.
4. Two hundred and fifteen foot candles - Storage was under two hundred and fifteen foot candles obtained by fluorescent light as well as two hundred and fifteen foot candles obtained by incandescent light.

A thermometer was placed under the lights to determine if the lights were causing a rise in storage temperature of the samples. Any temperature rise at the sample surface caused by the addition of the lights was noted.

(V) Effect of Freezing

A portion of the rib cut of animal VII was frozen and stored at 0°F for 3 weeks. After thawing at 34°F for 2 days, steaks were obtained to observe the color change of the thawed frozen samples over a period of storage.

(VI) Effect of Delayed Wrapping

The United States Department of Agriculture Production and Marketing Administration (50) has suggested that prepackaged meat should have a "blooming period" of 15 to 30 minutes before wrapping to help prevent discoloration of the product.

It is the opinion of the author that immediate wrapping is more efficient if a desirable color can be obtained and maintained for a suitable length of time. The author's personal observations of markets in operation have shown that efficiency of operation is lost when there is a time delay between cutting and wrapping.

To determine whether the "blooming period" was advantageous in preventing discoloration, color measurements

were made of samples wrapped immediately after cutting and of samples which were allowed a "blooming period" and then wrapped.

RESULTS AND DISCUSSION

Two graphic methods of color data presentation have been described in the experimental procedure. To compare these methods, data from a sample stored unwrapped in darkness are presented. These data are shown in tabular form on page 50.

Figure 1 illustrates the relationship between hue and value. The sample color renotation 5 minutes after cutting was approximately at the midpoint (5.1YR) of the yellow red hue range at a value of 4.2. After 24 hours of storage the sample color was 5.3 hue steps redder, being in the red hue range (9.8R) and 0.4 value steps darker. With continued storage a maximum redness hue was reached after 111 hours of storage. This was 7.9 hue steps redder than the initial color of the sample. The change in hue was greatest during the first 24 hours of storage as it was 5.3 hue steps redder than the initial color after 24 hours and only 7.9 hue steps redder after 111 hours of storage. After 111 hours of storage the sample color returned toward the yellow red hue range. At 183 hours of storage it was 2.6 hue steps yellower than the color at 111 hours. This was the same hue as the 24 hour color. However, the color was 1.5 value steps darker than the 24 hour color. From the initial reading after cutting until the end of storage the color darkened 1.9 value steps.

Figure 1a illustrates the relationship between chroma

and value. The initial color of the sample was weak as indicated by a chroma of only 3.5. The color became stronger during the first 29 hours of storage as the chroma increased 4.0 chroma steps to a chroma of 7.5. The increase in the strength of the color was greatest during the first 150 minutes of storage. After 31 hours of storage the chroma weakened. At the end of storage the color was 0.4 chroma steps weaker and 1.9 value steps darker than it was at the beginning of storage.

In the review of literature it was established that the color of fresh meat was greatly influenced by the relative concentrations of the three main forms of hemoglobin; oxyhemoglobin, reduced hemoglobin, and methemoglobin (20,23,39). Oxyhemoglobin was described as being red in color, reduced hemoglobin purple and methemoglobin brown (11,13,21,29). The color change of the sample illustrated in figures 1 and 1a indicated that:

1. During the first 24 hours of storage there was an increase in the concentration of oxyhemoglobin indicated. This is evidenced by a color change of 5.3 hue steps redder and 3.5 chroma steps stronger. The most rapid increase occurred during the first 150 minutes of storage.
2. From 24 hours until 111 hours of storage there was an apparent increase of reduced hemoglobin. This is evidenced by a change of only 2.6 hue steps redder,

1.0 value steps darker and 1.2 chroma steps weaker.

3. After 111 hours of storage, methemoglobin was the main form of hemoglobin indicated. Brooks (13) found that the color of lean meat was brownish when about 60 per cent of the hemoglobin present in the superficial layer was in the form of methemoglobin. The indicated increase of methemoglobin is evidenced by a change in hue of 2.6 hue steps yellower.

Unwrapped Sample Stored in Darkness
Trial G - Low Choice 10 Month Old Hereford Steer
Sample cut from rib 3 weeks after slaughter
Cutting temperature - 64°F, Cooler temperature - 35°F
Standard 10R 4.0/7.0

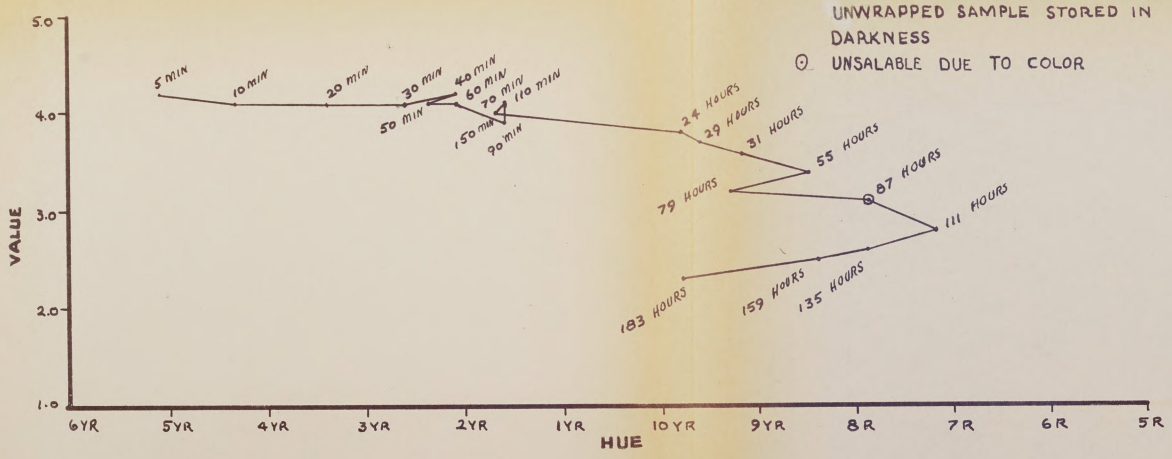
Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
5 Minutes	5.1YR	4.2	3.5	18.8
10 "	4.3YR	4.1	3.9	16.6
20 "	3.4YR	4.1	4.6	14.1
30 "	2.6YR	4.1	4.9	12.0
40 "	2.1YR	4.2	5.2	11.0
50 "	2.4YR	4.1	5.4	10.6
60 "	2.1YR	4.1	5.6	9.5
70 "	1.8YR	4.0	5.4	8.7
90 "	1.6YR	3.9	5.8	7.9
110 "	1.6YR	4.1	6.2	7.0
150 "	1.7YR	4.0	6.4	3.6
23½ Hours	9.8R	3.8	7.0	1.8
28½ "	9.6R	3.7	7.5	4.5
30½ "	9.2R	3.6	7.5	6.3
55 "	8.5R	3.4	7.1	8.2
79 "	9.3R	3.2	6.2	8.9
87 "	7.9R	3.1	6.3	12.8*
111 "	7.2R	2.8	5.8	16.3
135 "	7.9R	2.6	4.8	19.0
159 "	8.4R	2.5	4.1	20.3
183 "	9.8R	2.3	3.1	22.2

* Unsalable

VALUE	VALUE

FIGURE 1 HUE AND VALUE RELATIONSHIPS OF UNWRAPPED SAMPLE STORED IN DARKNESS

⊙ UNSALABLE DUE TO COLOR



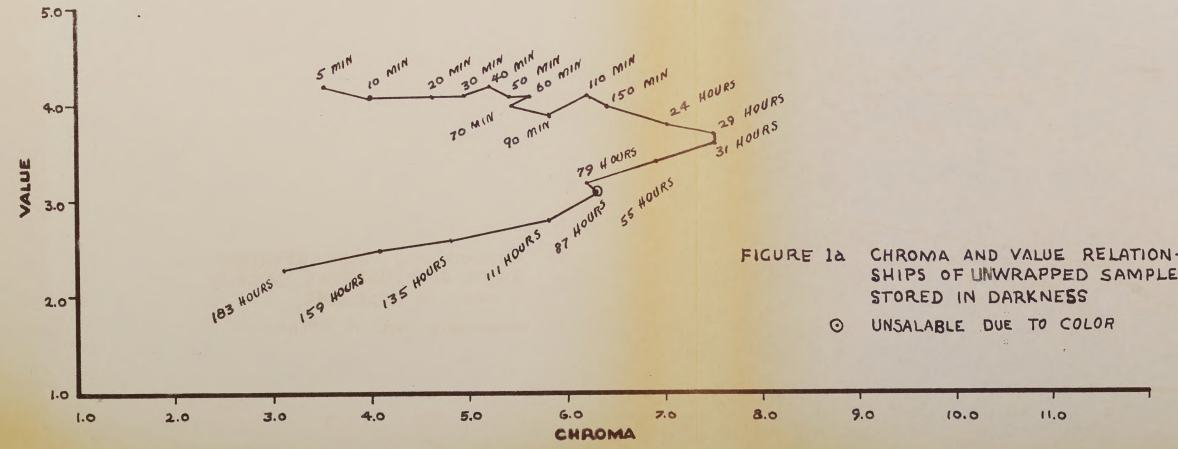


FIGURE 1a CHROMA AND VALUE RELATIONSHIPS OF UNWRAPPED SAMPLE STORED IN DARKNESS

⊙ UNSALABLE DUE TO COLOR

Figures 2 and 2a illustrate the color differences of the same sample in terms of a single number. To use this method it was necessary to select a standard to compare with the color reading. The author made visual observation of several samples in an attempt to select the most desirable color of meat to be used as the standard. These samples were then matched in the matching booth and their color renotated. It was found that the most desirable color renotation of unwrapped meat was near 10R 4.0/7.0. This color renotation was used as the standard for unwrapped meat. The standard for wrapped meat was determined by the same means. This was 1YR 4.0/6.0.

It should be pointed out that the observed color of lean beef would be somewhat different from the color of color chips or panels having the above notations. When lean beef is viewed by eye the color of the lean and fat are distinct. The color of the lean and fat are blended into a single color when the sample is viewed through the optical eyepiece. Conditions of illumination also affect the sample color. Viewing the sample under the daylight lamp in the matching booth resulted in a different color than when viewed under ordinary conditions of illumination.

Comparison of successive sample color measurements with the standard show the color changes during the storage period. The initial color measurement after cutting was 16.9 units

from the standard. The sample color rapidly brightened during the first 150 minutes, being only 3.6 units from the standard at this time. After 24 hours of storage the sample color measurement most nearly equalled the color standard. Subsequent sample color readings showed darkening. This increased throughout storage until 183 hours of storage when the sample color measurement was 22.2 units from the standard.

This method shows the combined effect of hue, value, and chroma in brightening and darkening in relation to a color standard. In this method it is impossible to see the relationship of the individual attributes. It is possible for two very different colors to be of equal distance from the standard. To emphasize this, after 87 hours of storage the sample color measurement was 12.8 units from the standard. The sample color measurement was 12.0 units from the standard after only 30 minutes of storage. However, the Munsell renotation of this sample at these periods of storage was considerably different. The sample color renotation after 30 minutes was 2.6YR 4.1/4.9. This had changed to 7.9R 3.1/6.3 after 87 hours of storage, a change of 4.7 hue steps redder, 1.0 value steps darker, and 1.4 chroma steps stronger.

To simplify the presentation of the data obtained in this study, the latter method was used. For a more complete analysis of the individual attributes of the color change, the reader is referred to the appendix.

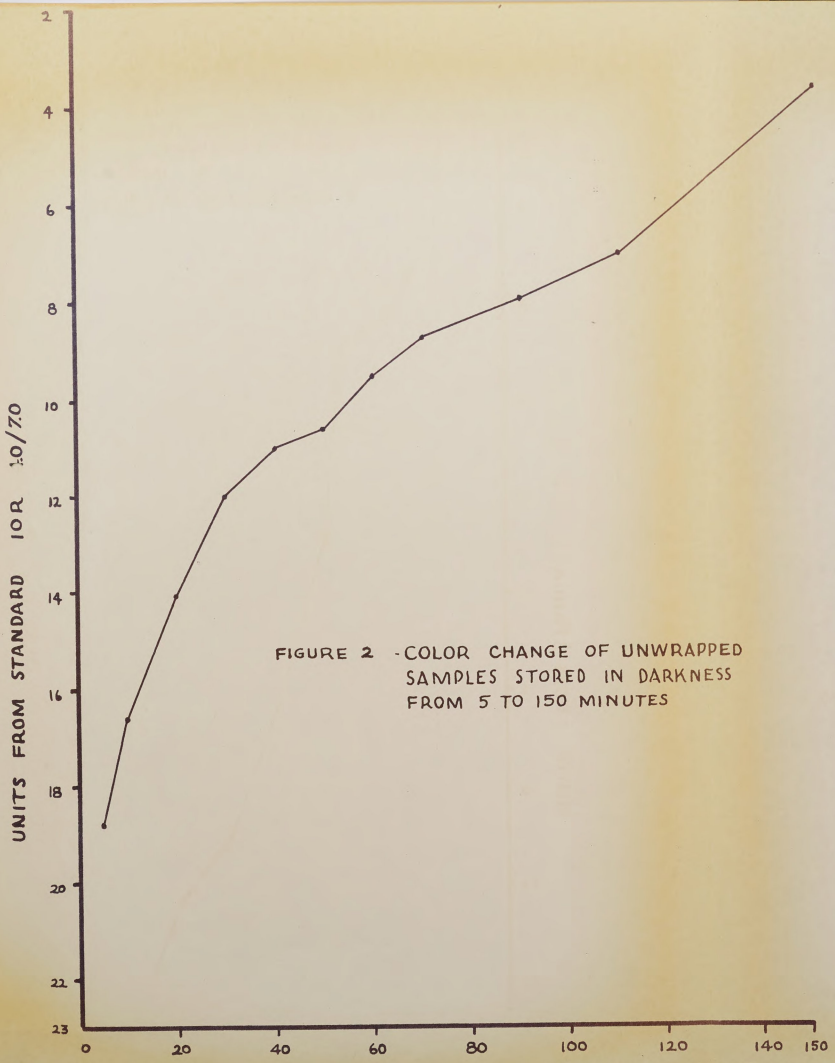


FIGURE 2 - COLOR CHANGE OF UNWRAPPED SAMPLES STORED IN DARKNESS FROM 5 TO 150 MINUTES

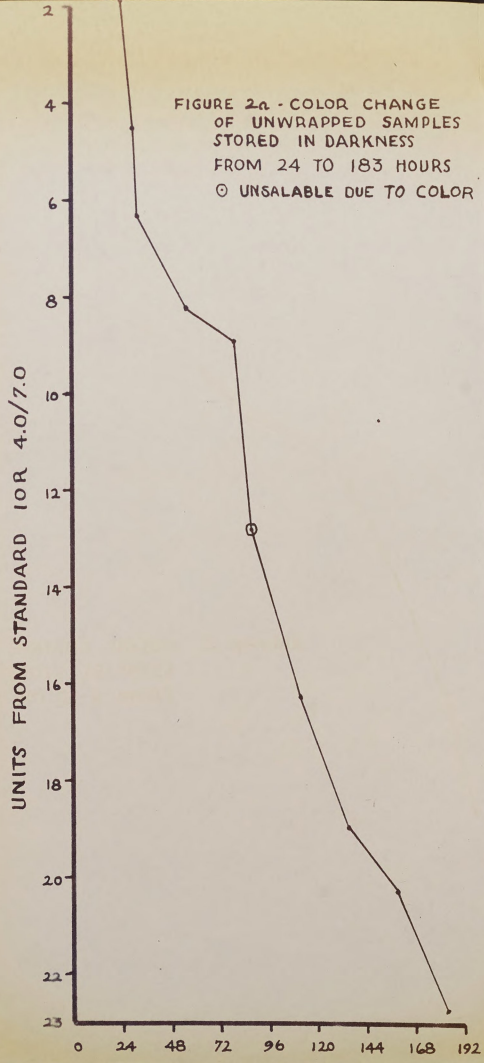


FIGURE 2a - COLOR CHANGE OF UNWRAPPED SAMPLES STORED IN DARKNESS FROM 24 TO 183 HOURS
⊙ UNSALABLE DUE TO COLOR

(I.) Color Difference Due to Animal

Reference was made to studies (32,44,53,55,56) that indicated that the amount of hemoglobin in meat was dependent on the type of muscle, exercise, age, breed, and condition of the animal. We would therefore expect color differences in meat of different animals. Figures 3 and 3a illustrate the color changes of samples obtained from different animals. The animals compared represent the extreme in the grades used in this study. One animal was a 2 year old Angus steer graded average prime, the other was a 2 year old Hereford steer graded high commercial. This comparison is not meant to characterize the color of meat in these grades, but is offered to show that there are differences in color.

The rate of the color change of these samples was similar for the first 125 minutes of storage. The prime sample darkened rapidly after 24 hours of storage while the commercial sample fluctuated during the interval 30 to 244 hours. After 244 hours the commercial sample darkened rapidly. The prime sample was considered salable until 168 hours compared with 316 hours for the commercial sample.

These results are contrary to common belief. The higher grades of beef are generally considered to maintain a more desirable color for a longer time than the lower grades of beef. Within the grades of meat there are color differences so that this one comparison does not characterize the color change of these grades.

Tabular data are shown in Appendix A for these samples. The initial color reading of the prime sample shows it to be 1.4 hue steps yellower, .56 value steps brighter, and .6 chroma steps weaker than the initial color of the commercial sample.

Since different animals show color differences, the following comparisons are made with samples from the same muscle (longissimus dorsi) and from the same animal.

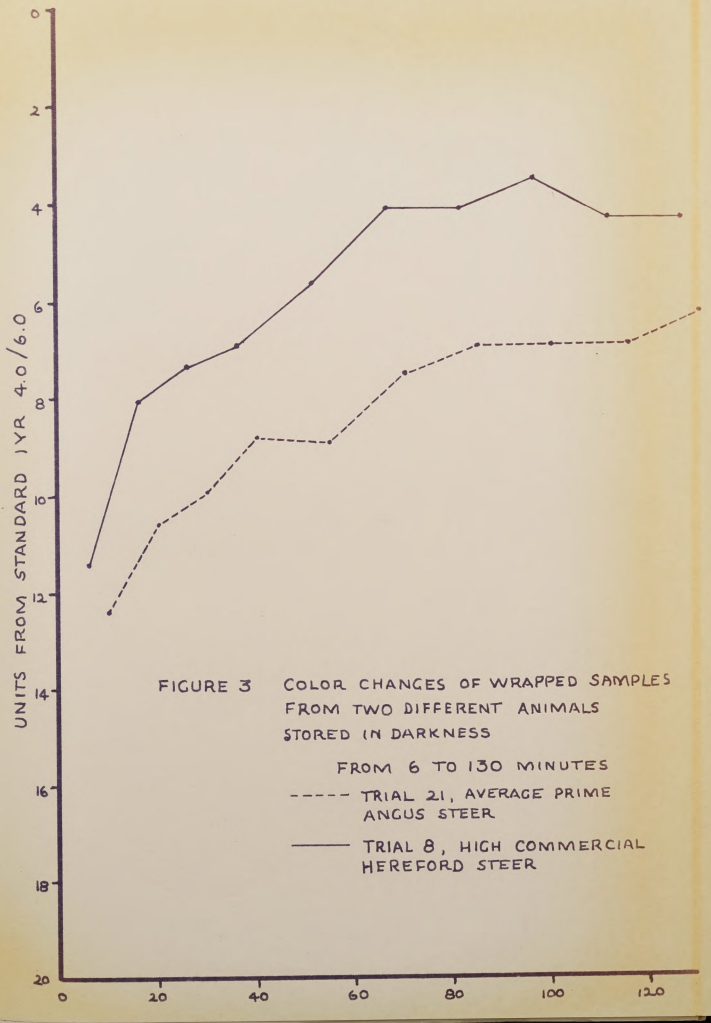


FIGURE 3 COLOR CHANGES OF WRAPPED SAMPLES FROM TWO DIFFERENT ANIMALS STORED IN DARKNESS

FROM 6 TO 130 MINUTES

----- TRIAL 21, AVERAGE PRIME ANGUS STEER

——— TRIAL 8, HIGH COMMERCIAL HEREFORD STEER

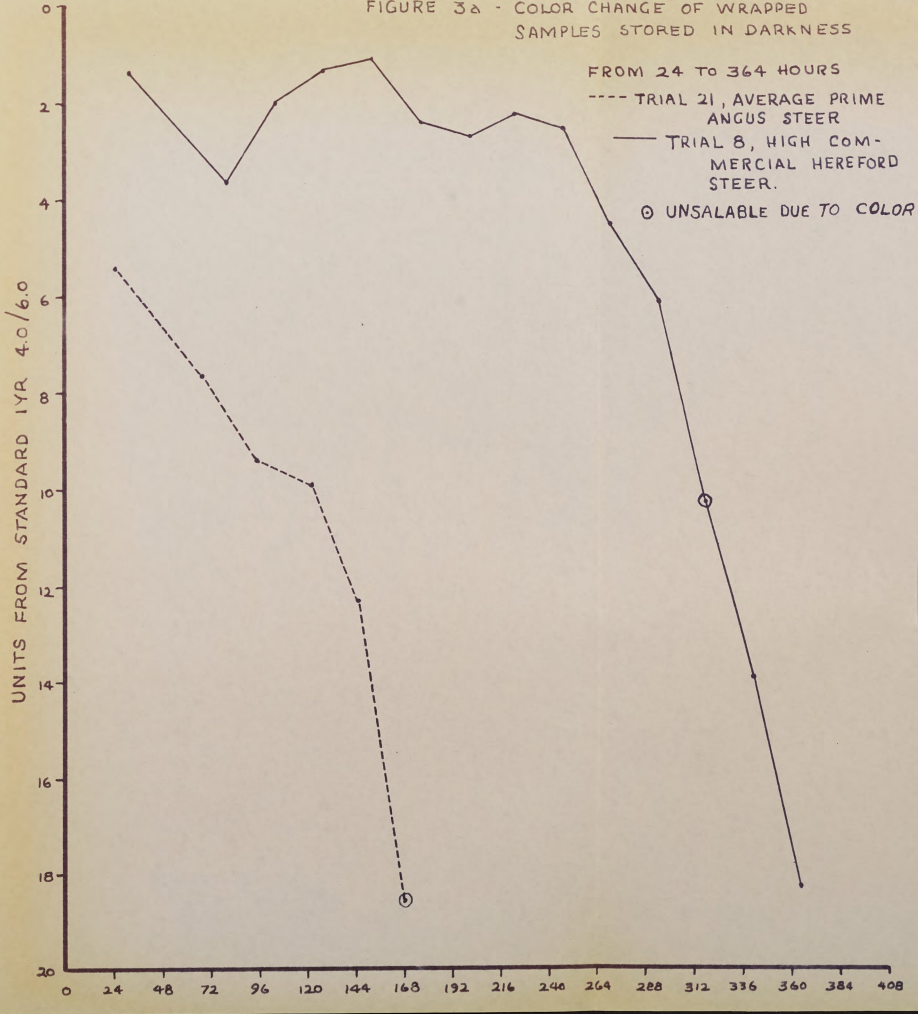


FIGURE 3a - COLOR CHANGE OF WRAPPED SAMPLES STORED IN DARKNESS

FROM 24 TO 364 HOURS

---- TRIAL 21, AVERAGE PRIME ANGUS STEER

—— TRIAL 8, HIGH COMMERCIAL HEREFORD STEER.

⊙ UNSALABLE DUE TO COLOR

II. Effect of Aging

Since it was impossible to place all of the necessary samples in storage at one time, the effect of aging the rib cut on the color of samples cut at different times was tested. Figure 4 illustrates the color changes of unwrapped samples during the first 6 hours of storage. Samples were taken 1 week, 2 weeks, and 4 weeks after slaughter. Tabular data are shown in Appendix B.

Differences in the initial color of the samples would indicate that the longer the aging the darker the color. However, this difference in color could be accounted for in the amount of intramuscular fat in the area of the sample viewed. Since the optical eyepiece blended the lean and fat color, variations were found within a single sample depending upon the amount of intramuscular fat within the area being viewed. The rate of the color change of these three samples was quite similar. The samples cut after aging increased in brightness slightly faster but this difference was not great.

Neill (37), Brooks (9), and others have shown that methemoglobin is not formed in the absence of oxygen. Brooks (9) measured the depth of oxygen penetration in ox muscle and found that at 0°C (32°F) oxidation (methemoglobin formation) was complete in the surface layer which in extreme cases was only 1 cm. thick in 6 to 8 weeks. Therefore, aging would affect only the color of the exposed surfaces of the

rib cut. The exposed surfaces were not used in obtaining samples to be measured for color. From this information it would seem that aging does not affect the color of the sample providing the exposed surfaces are removed. Therefore, the effect of aging is not considered in the comparison of treatments which follow.

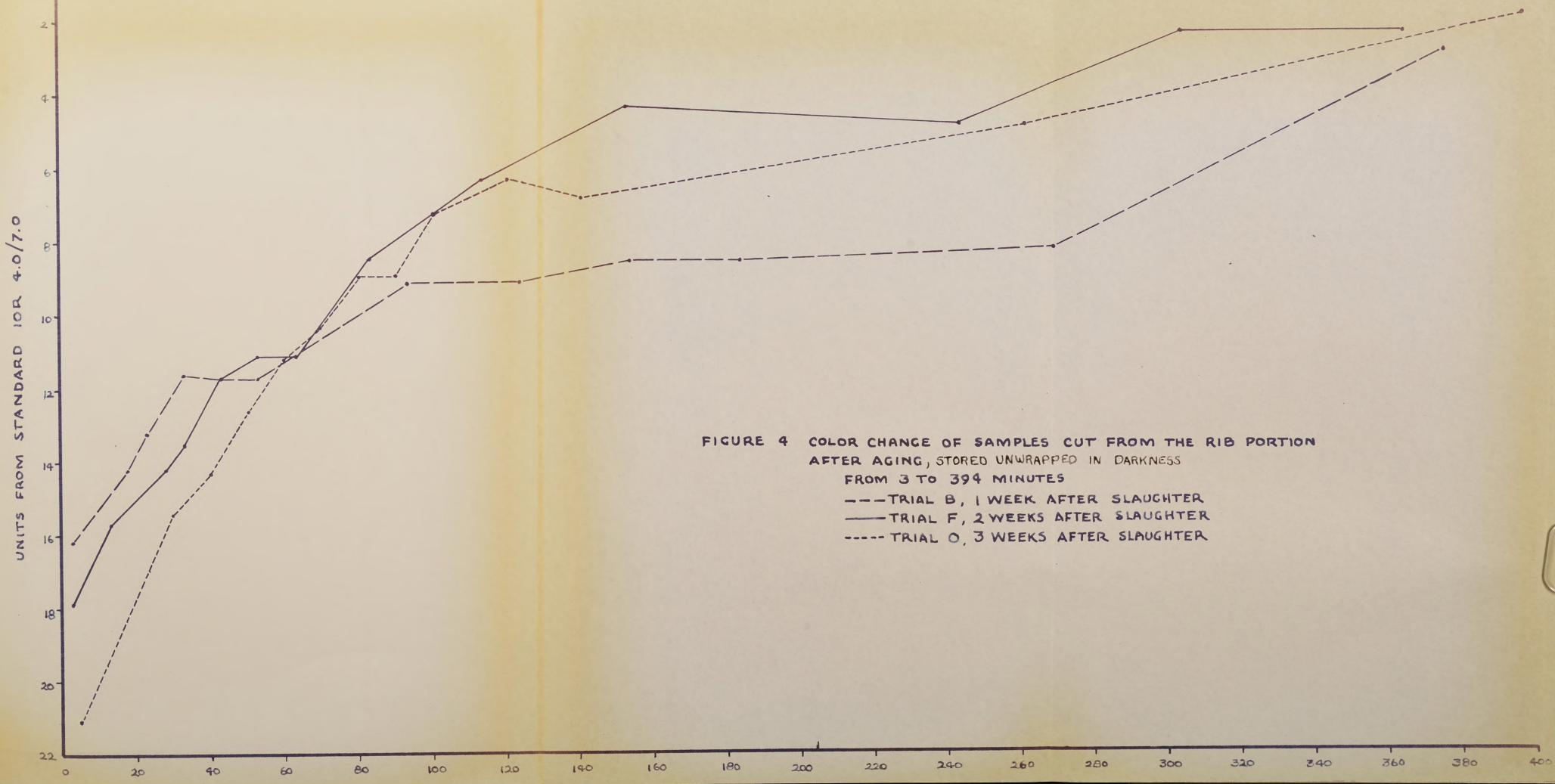


FIGURE 4 COLOR CHANGE OF SAMPLES CUT FROM THE RIB PORTION AFTER AGING, STORED UNWRAPPED IN DARKNESS FROM 3 TO 394 MINUTES

– – – TRIAL B, 1 WEEK AFTER SLAUGHTER

——— TRIAL F, 2 WEEKS AFTER SLAUGHTER

----- TRIAL O, 3 WEEKS AFTER SLAUGHTER

(III.) Effect of Storage in a Film

Figures 5 and 5a are graphic presentations to compare the effect of storage in a film with storage unwrapped on the color of the meat. Figure 5 shows the color change during the first 150 minutes of storage while figure 5a shows the color change over a period of hours. The film used for all packaged meat was Du Pont cellophane, identified as 300 MSAT #80. This is a film developed especially for prepackaged fresh meats.

The rate of color change of the wrapped and unwrapped samples was approximately equal during the first 60 minutes of storage. After 60 minutes, the color change of the wrapped sample was slower than the unwrapped sample. At 139 minutes of storage of the wrapped sample and 150 minutes of storage of the unwrapped sample their colors were 4.7 and 3.6 units respectively from their standards. The color of these samples more nearly approximated their standards after 24 hours of storage. The color of the unwrapped sample changed rapidly after 24 hours of storage. The color had darkened enough to be considered unsalable after 87 hours of storage. At this time it was 12.8 units from the standard. After 24 hours, the color of the wrapped sample changed very little until 190 hours of storage. The color change was rapid after 190 hours. At 310 hours of storage the color of this sample was considered unsalable. This is compared with 87 hours when the unwrapped sample was considered unsalable.

Brooks (13) found that discoloration is closely connected with the factors governing the loss of water from the meat. It should be expected that the unwrapped sample would lose moisture faster than the wrapped sample since Allen (1) related that the film (300 MSAT #60 Du Pont cellophane) used on the wrapped sample has a low water vapor permeability and a wettable surface. From this standpoint, discoloration should be faster on the unwrapped sample.

Brooks (13) also found that at 0°C (32°F) the rate of methemoglobin formation was greatest when the partial pressure of oxygen was 4 mm. of mercury. Allen (1) stated that the oxygen permeability of the cellophane used was relatively low. Therefore, if the oxygen pressure in the wrapped package was low, rapid discoloration should have resulted. This did not occur.

Lavers (29) found that packaging fresh meat in an oxygen-impermeable film caused rapid discoloration. He found that this was due to a lowered oxygen pressure beneath the film due to diffusion into the meat and bacterial oxygen demand.

The results obtained with the wrapped sample are in agreement with results related by Allen (1) where meat wrapped in 300 MSAT #80 cellophane remained bright and salable for seven to nine days.

The loss of water from the samples seemed to be more important than the low oxygen pressure in causing the discoloration of these samples. Tabular data of these samples are shown in Appendix C.

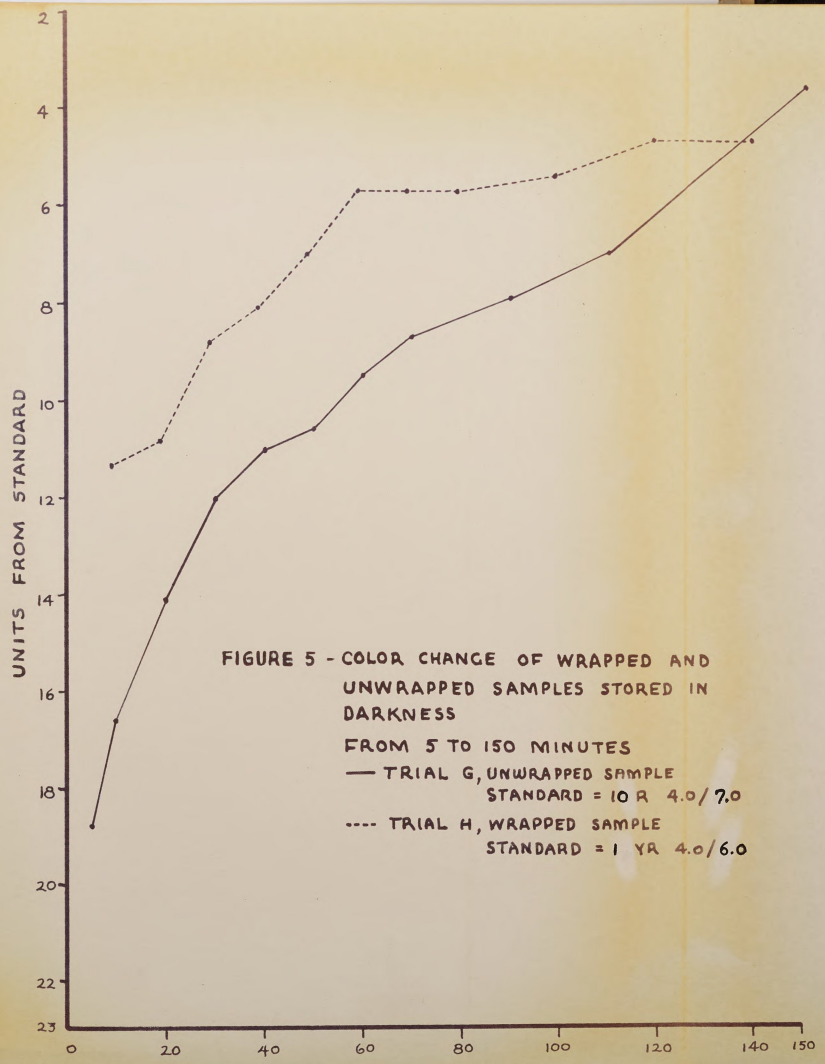


FIGURE 5 - COLOR CHANGE OF WRAPPED AND UNWRAPPED SAMPLES STORED IN DARKNESS

FROM 5 TO 150 MINUTES

— TRIAL G, UNWRAPPED SAMPLE STANDARD = 10 R 4.0/7.0

---- TRIAL H, WRAPPED SAMPLE STANDARD = 1 YR 4.0/6.0

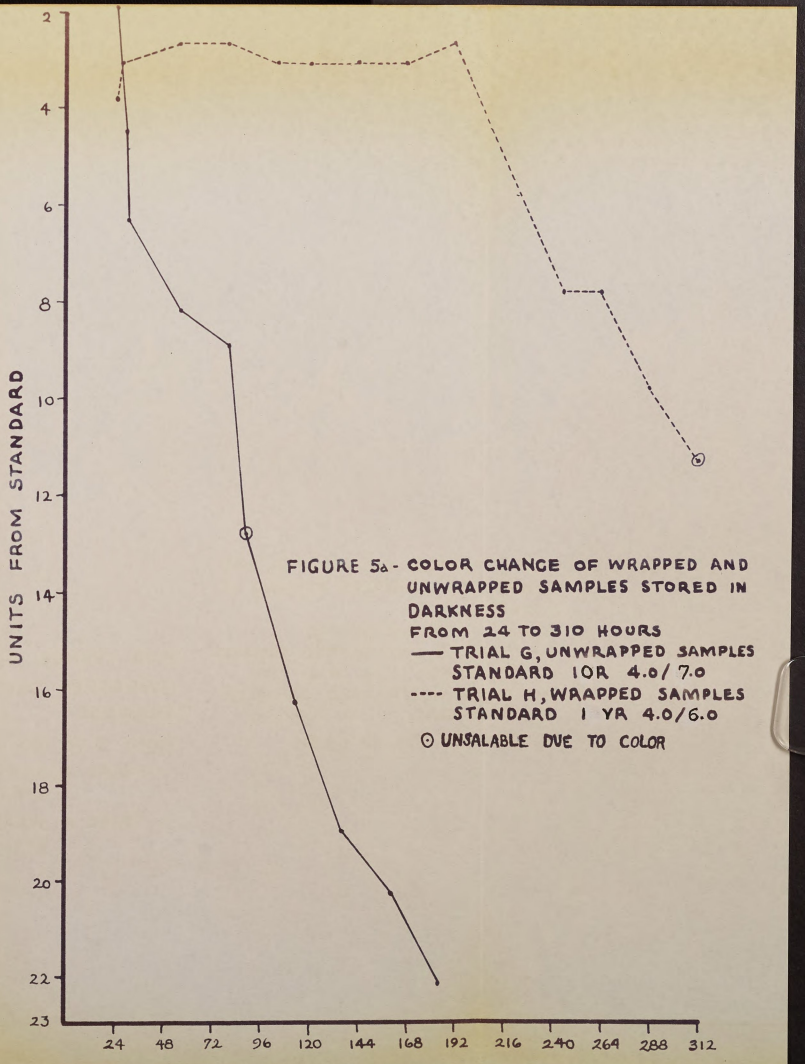


FIGURE 5a - COLOR CHANGE OF WRAPPED AND UNWRAPPED SAMPLES STORED IN DARKNESS

FROM 24 TO 310 HOURS

— TRIAL G, UNWRAPPED SAMPLES STANDARD 10R 4.0/7.0

---- TRIAL H, WRAPPED SAMPLES STANDARD 1 YR 4.0/6.0

⊙ UNSALABLE DUE TO COLOR

(IV.) Effect of Light

Figures 6 and 6a show the effect of light on the color change of fresh meat stored unwrapped. Tabular data are shown in Appendix D.

The rate of color change of the samples stored under 215 foot candles of light compared to darkness was approximately the same during the first 120 minutes of storage. Considerable differences were found at 24 hours of storage. The color of the sample stored under 215 foot candles of fluorescent light was more desirable as it was only 3.2 units from the standard. The color of the samples stored under 215 foot candles of incandescent light was very undesirable as indicated by its being 27 units from the standard. The color of the sample stored in darkness had changed to a less desirable color also. After 24 hours of storage the color of the sample stored in darkness and the sample stored under 215 foot candles of fluorescent light changed at approximately the same rate. The color of the sample stored under 215 foot candles of fluorescent light was considered unsalable after 50 hours of storage compared to 72 hours of storage for the sample stored in darkness and the sample stored under 215 foot candles of incandescent light show little difference (see Appendix D). The initial color attributes of the sample stored under 215 foot candles of fluorescent light were 1.8 hue steps yellower, .43 value steps brighter, and .9 chroma steps weaker than the

sample stored in darkness. This difference may be accounted for in the amount of intramuscular fat within the area viewed.

A thermometer was placed at the meat surface to determine if the lights were causing an increase in temperature. The light used to supply 215 foot candles of incandescent light caused an increase in temperature of 15°F at the meat surface. The storage room temperature was 34°F so that with the 15°F increase caused by the light, the meat sample storage temperature was 49°F. The temperature of the sample stored under 215 foot candles of fluorescent light was increased 3°F above that of the storage room temperature. This sample was therefore stored at a temperature of 37°F.

To account for the rapid discoloration of the sample stored under 215 foot candles of incandescent light, the following explanation is offered. As pointed out, incandescent light caused a storage temperature increase of 15°F. Brooks (13) has shown that the depth to which oxygen penetrated the tissue decreased with increasing temperature. Brooks (11) also found that methemoglobin formed directly on or very near the surface darkened the color to a greater extent than the same amount of pigment produced in the same time but some distance below the surface. Therefore, the increase in temperature would cause the formation of methemoglobin to be closer to the surface and consequently a darker color when compared to the sample stored in darkness at the lower temperature. Rikert (43) found that the rate of darkening

of unpackaged meat increased with an increase in temperature. The sample also evidenced a loss of moisture. This could account for the dark color of the sample since Brooks (13) has shown that excessive drying causes a dark appearance due to the optical changes in the tissue. No doubt a combination of these factors caused the rapid discoloration.

Comparing the sample stored in darkness with the sample stored under 215 foot candles of fluorescent light, the storage temperature difference was 3°F. Other than the color change after 130 minutes, until 24 hours, the change of these two samples was similar. This would indicate that light did not affect the color change of the samples.

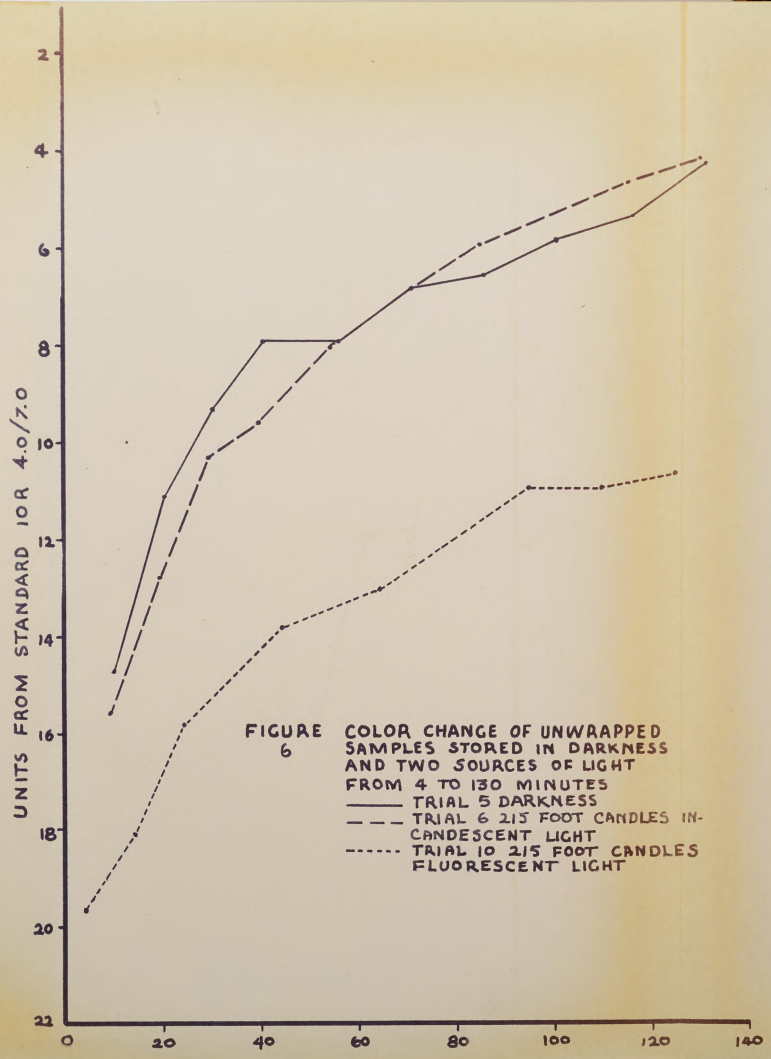


FIGURE 6 COLOR CHANGE OF UNWRAPPED SAMPLES STORED IN DARKNESS AND TWO SOURCES OF LIGHT FROM 4 TO 130 MINUTES

——— TRIAL 5 DARKNESS

– – – TRIAL 6 215 FOOT CANDLES INCANDESCENT LIGHT

----- TRIAL 10 215 FOOT CANDLES FLUORESCENT LIGHT

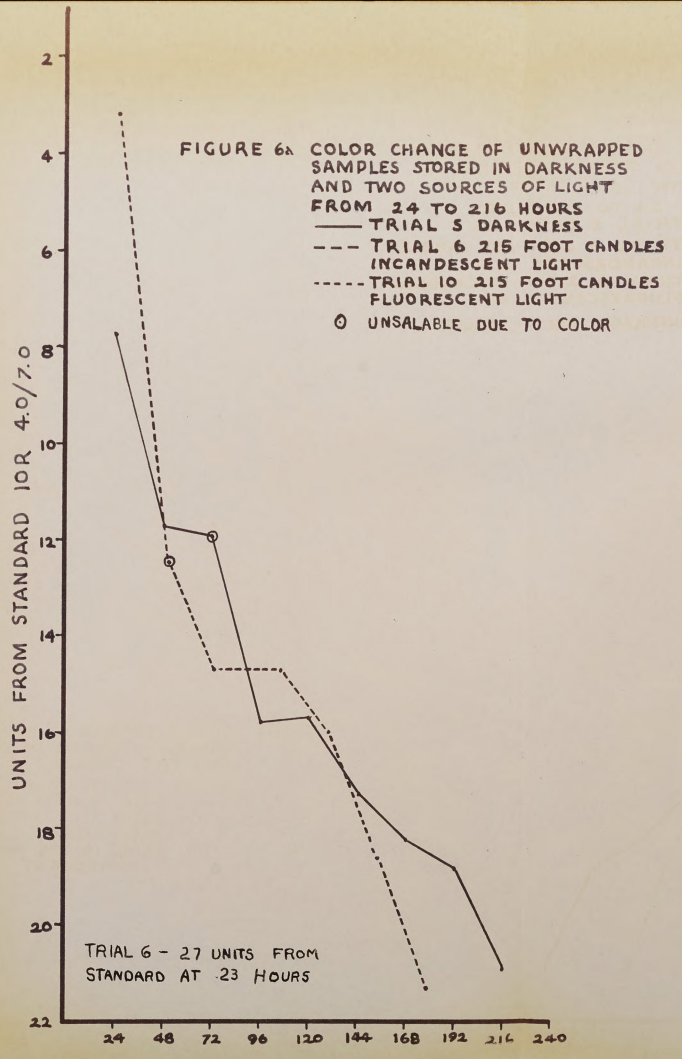


FIGURE 6A COLOR CHANGE OF UNWRAPPED SAMPLES STORED IN DARKNESS AND TWO SOURCES OF LIGHT FROM 24 TO 216 HOURS

——— TRIAL 5 DARKNESS

– – – TRIAL 6 215 FOOT CANDLES INCANDESCENT LIGHT

----- TRIAL 10 215 FOOT CANDLES FLUORESCENT LIGHT

⊙ UNSALABLE DUE TO COLOR

The unwrapped sample stored under 215 foot candles of incandescent light previously discussed, showed a very rapid discoloration due to the increase in temperature caused by the light. Figures 7 and 7a compare color changes of a wrapped sample stored under 215 foot candles of fluorescent light and one stored under 215 foot candles of incandescent light. The color attributes of these samples are shown in Appendix E.

The rate of color change of the samples was similar during the first 130 minutes of storage. After 24 hours of storage there was considerable difference in the rate of the color change. The sample stored under 215 foot candles of incandescent light changed color rapidly. This sample was considered unsalable after 55 hours of storage. The sample stored under 215 foot candles of fluorescent light did not change color as rapidly. It was considered salable until 274 hours of storage.

Allen (1) has related that the cellophane (300 MSAT #80 Du Pont) used has a low water vapor permeability. The unwrapped sample shown in figures 6 and 6a was unsalable in less than 24 hours compared to a time between 31 and 55 hours for the wrapped sample (figures 7 and 7a) stored under the same conditions. The film prevented excessive water loss in the wrapped sample, therefore, discoloration was not due to this.

The effects of temperature on the color change were discussed for samples illustrated in figures 6 and 6a. The temperatures similarly affected the color change of these samples.

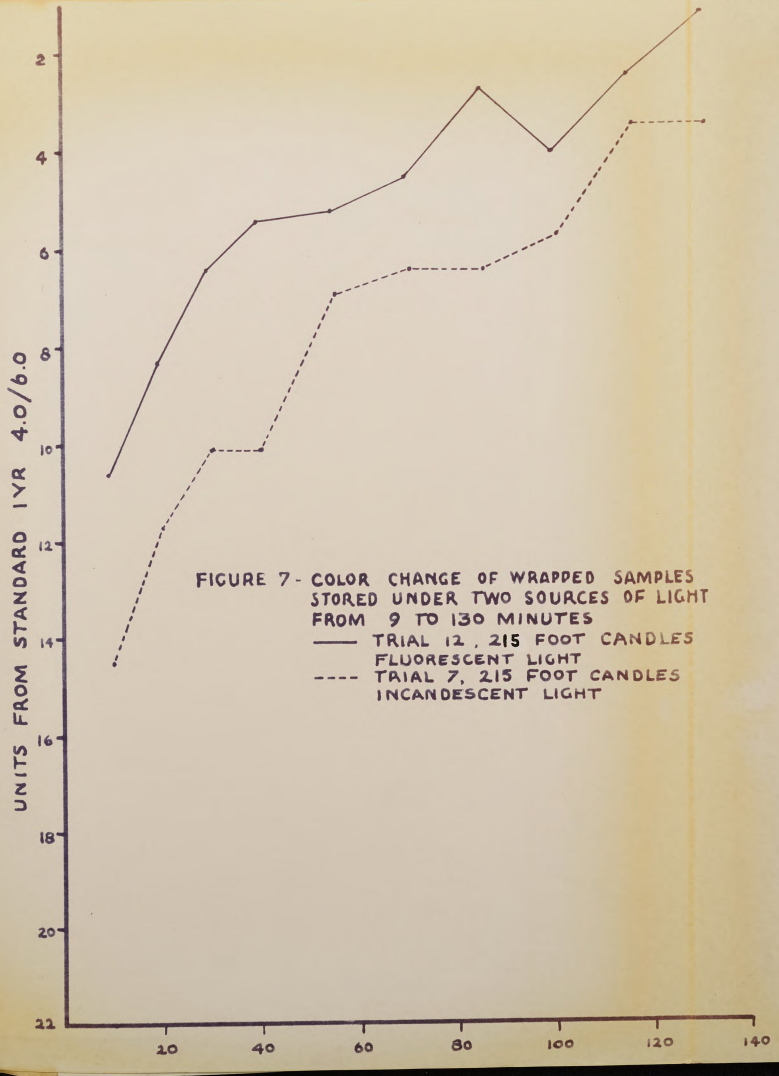


FIGURE 7 - COLOR CHANGE OF WRAPPED SAMPLES STORED UNDER TWO SOURCES OF LIGHT FROM 9 TO 130 MINUTES
—— TRIAL 12, 215 FOOT CANDLES FLUORESCENT LIGHT
---- TRIAL 7, 215 FOOT CANDLES INCANDESCENT LIGHT

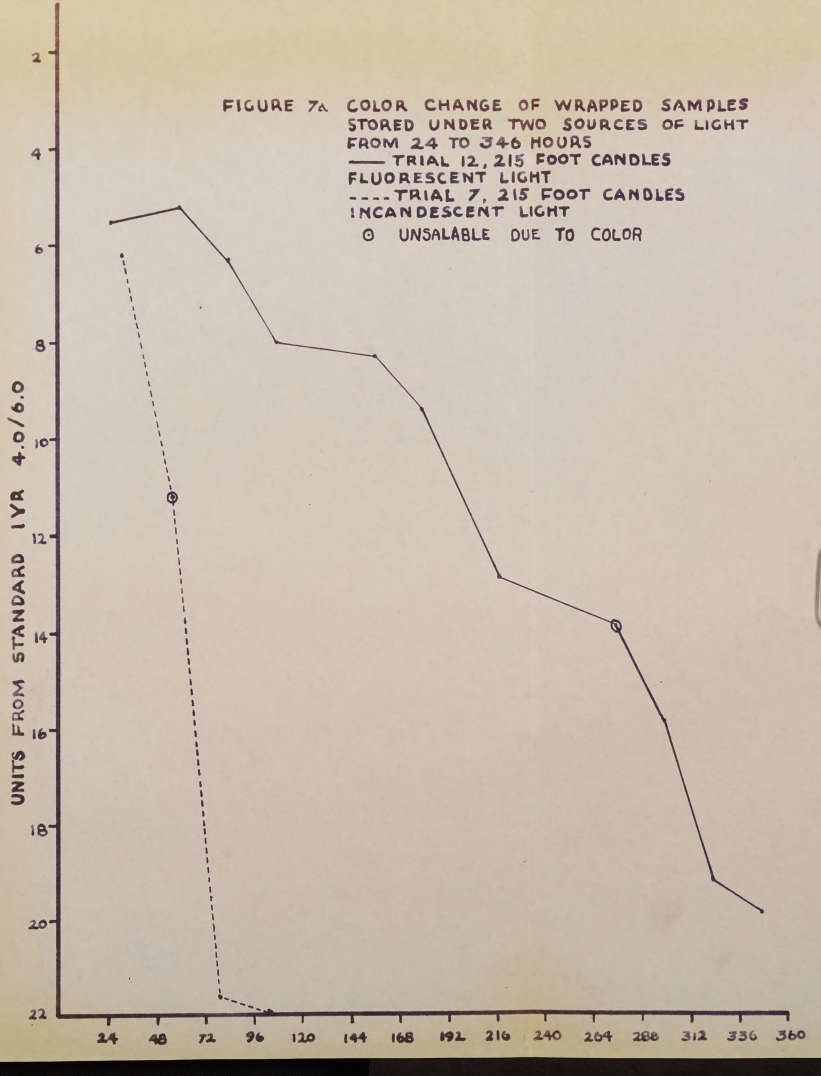


FIGURE 7A COLOR CHANGE OF WRAPPED SAMPLES STORED UNDER TWO SOURCES OF LIGHT FROM 24 TO 346 HOURS
—— TRIAL 12, 215 FOOT CANDLES FLUORESCENT LIGHT
----TRIAL 7, 215 FOOT CANDLES INCANDESCENT LIGHT
⊙ UNSALABLE DUE TO COLOR

To investigate the effect of different intensities of light on wrapped samples, one sample was stored under 60 foot candles of fluorescent light and a second sample was stored under 215 foot candles of fluorescent light. The color changes of these samples are illustrated in figures 8 and 8a. Tabular data are shown in Appendix F.

The rate of the color change during the first 135 minutes of storage was similar for both samples. The darkening after 24 hours of storage was much faster in the sample stored under 60 foot candles of fluorescent light. This sample was unsalable at 168 hours of storage compared with 300 hours for the sample stored under 215 foot candles of fluorescent light.

The beef steaks used were from the rib eye of the same wholesale cut, but the measurements were not made simultaneously.

While fluorescent lights normally used for lighting self-service meat cases are known to cause fading of color of cured meats, the effect on color of fresh meat cuts has not been established.

It seems unreasonable to expect that light should affect the color of wrapped samples, as it did not affect the color of the unwrapped samples (figures 6 and 6a) as long as the storage temperature was not appreciably altered by the light. Further investigations seem advisable.

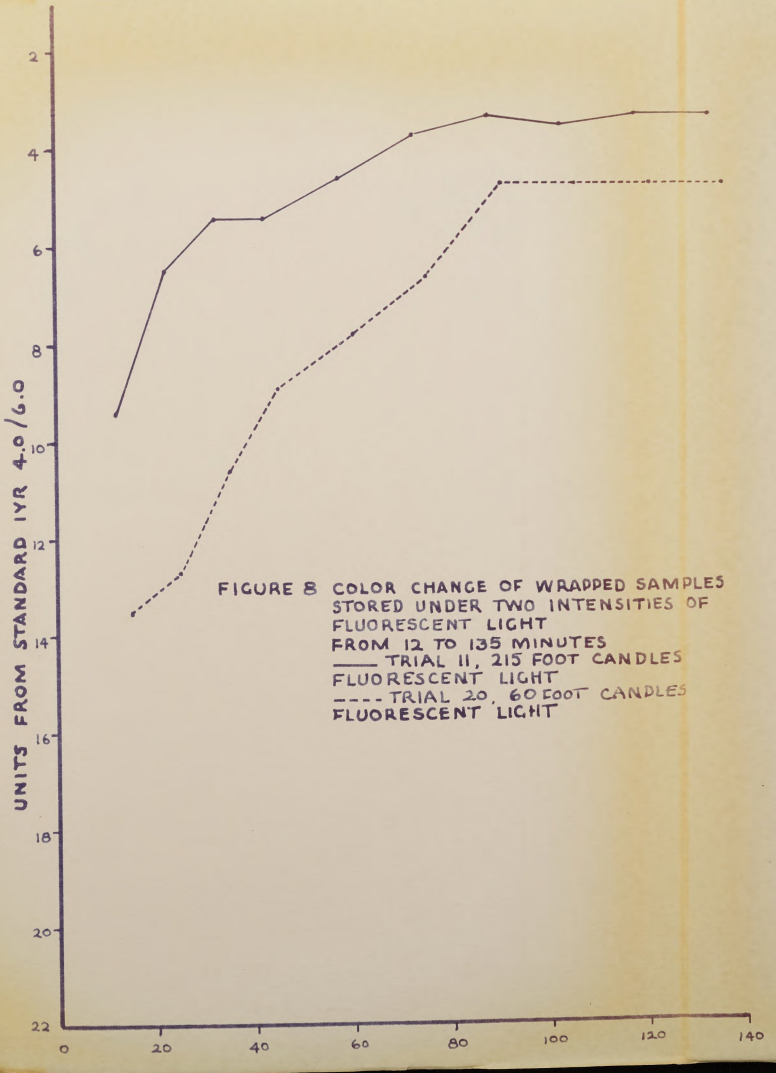


FIGURE 8 COLOR CHANGE OF WRAPPED SAMPLES STORED UNDER TWO INTENSITIES OF FLUORESCENT LIGHT FROM 12 TO 135 MINUTES
—— TRIAL 11, 215 FOOT CANDLES FLUORESCENT LIGHT
---- TRIAL 20, 60 FOOT CANDLES FLUORESCENT LIGHT

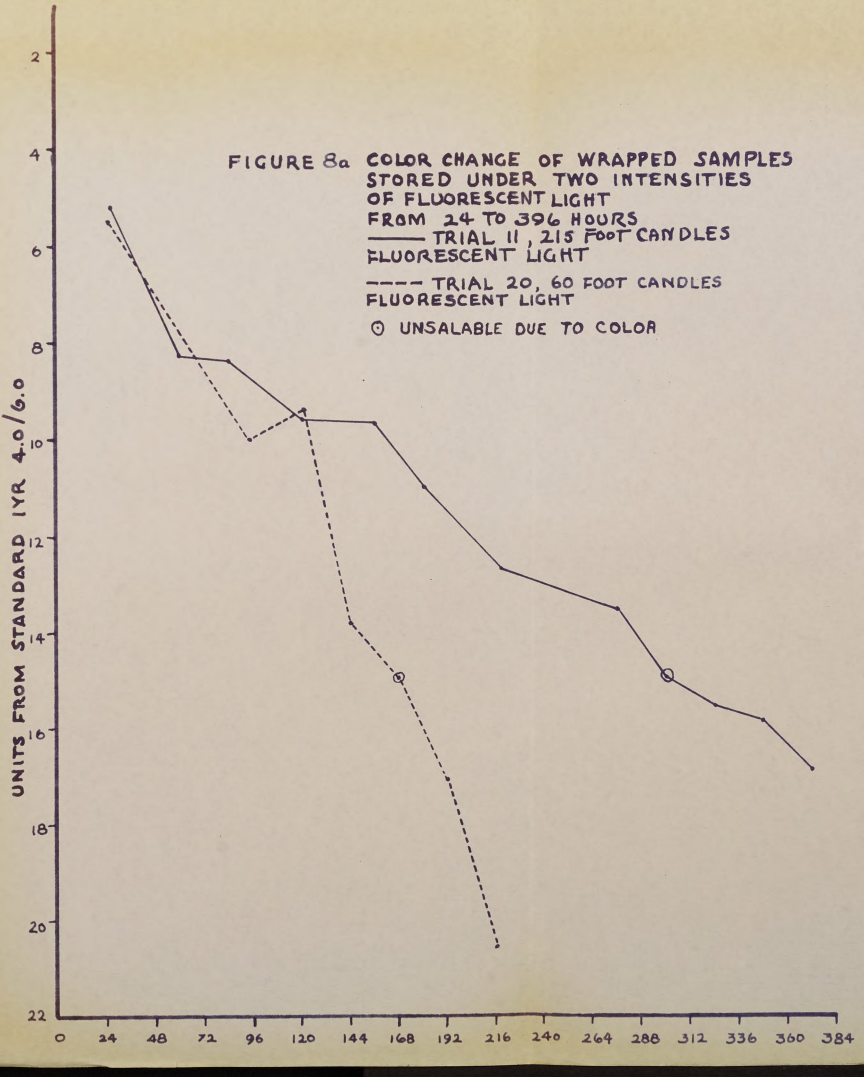


FIGURE 8a COLOR CHANGE OF WRAPPED SAMPLES STORED UNDER TWO INTENSITIES OF FLUORESCENT LIGHT FROM 24 TO 396 HOURS
—— TRIAL 11, 215 FOOT CANDLES FLUORESCENT LIGHT
---- TRIAL 20, 60 FOOT CANDLES FLUORESCENT LIGHT
⊙ UNSALABLE DUE TO COLOR

(V.) Effect of Freezing

To show the effect of freezing on the color changes, a portion of the wholesale rib cut was frozen and held for a period of 3 weeks at 0°F. After thawing 2 days at 34°F a sample was removed to compare the color changes with a sample from the same cut that had not been frozen. Figures 9 and 9a illustrate the results of these samples stored unwrapped in darkness. Tabular data are shown in Appendix G.

The rate of the color change of the sample which had been frozen was much slower than the rate of the color change of the unfrozen sample during the first 120 minutes of storage. The color of the unfrozen sample more nearly equalled that of the standard at 19 hours of storage. After 19 hours of storage the color of the unfrozen sample darkened rapidly. This sample was considered unsalable at 71 hours of storage. The color of the sample that had been frozen increased in desirability until 36 hours of storage. After this, the sample began to darken until it was considered unsalable at 84 hours of storage. After 84 hours the rate of darkening was faster.

Brooks (9) found that freezing and thawing of meat appeared to increase the rate of methemoglobin formation compared to control tissue which had not been frozen. Mangel (31) was unable to verify this, as her samples allowed to thaw from one to five times did not show increased rate of methemoglobin formation. The results presented in figures

9 and 9a indicate that the rate of oxyhemoglobin formation was slower in the sample which had been frozen compared to the unfrozen sample, but the rate of methemoglobin formation (discoloration) was not increased.

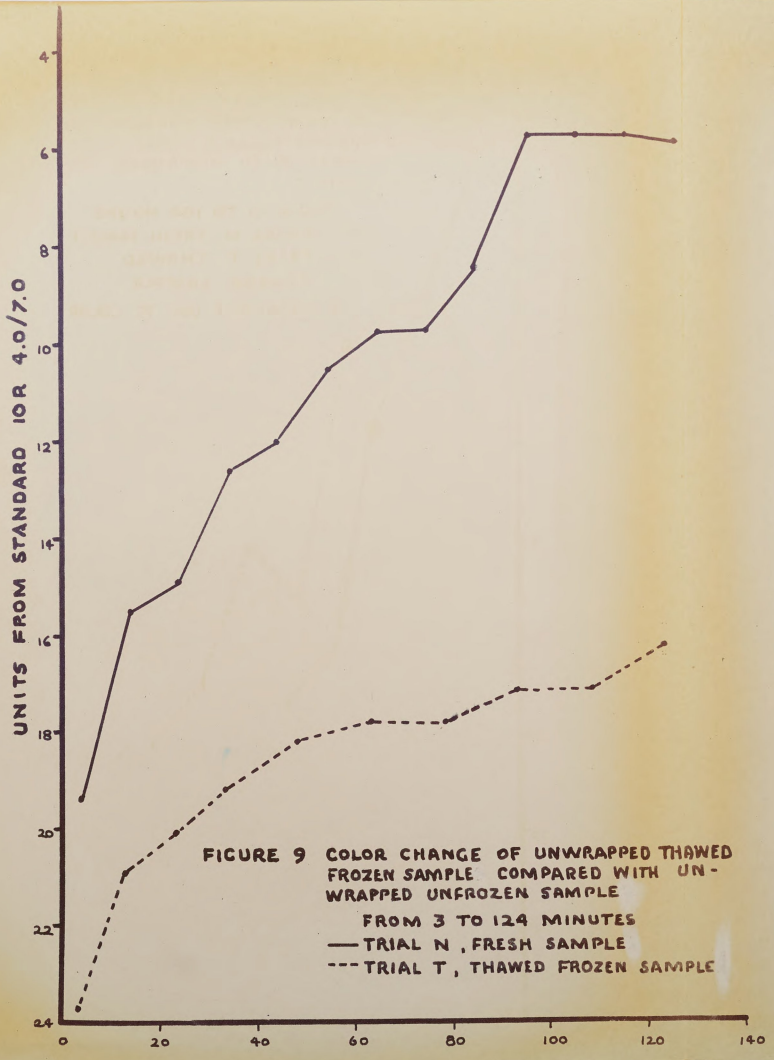


FIGURE 9 COLOR CHANGE OF UNWRAPPED THAWED FROZEN SAMPLE COMPARED WITH UNWRAPPED UNFROZEN SAMPLE

FROM 3 TO 124 MINUTES

—— TRIAL N, FRESH SAMPLE

---- TRIAL T, THAWED FROZEN SAMPLE

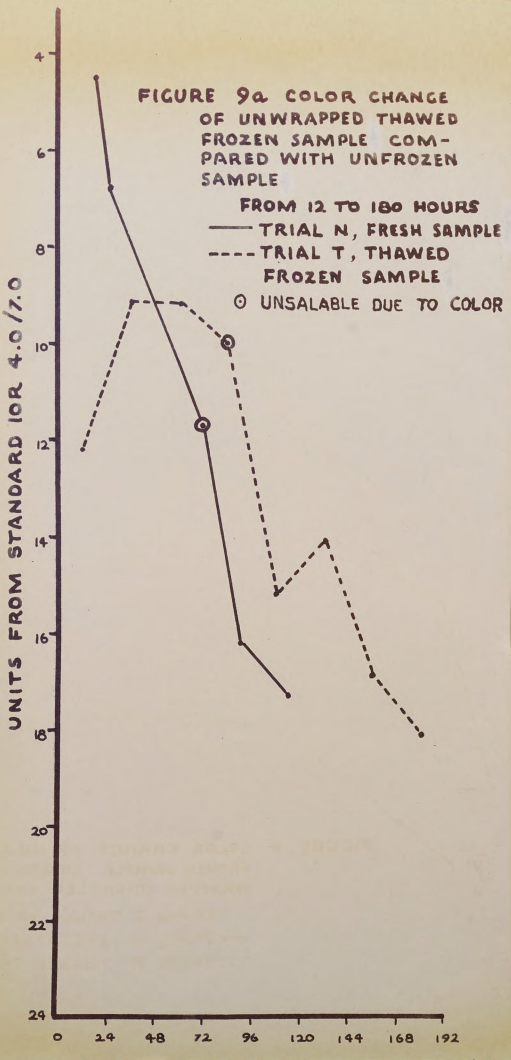


FIGURE 9a COLOR CHANGE OF UNWRAPPED THAWED FROZEN SAMPLE COMPARED WITH UNFROZEN SAMPLE

FROM 12 TO 180 HOURS

—— TRIAL N, FRESH SAMPLE

---- TRIAL T, THAWED FROZEN SAMPLE

⊙ UNSALABLE DUE TO COLOR

(VI.) Effect of Delayed Wrapping

Figures 10 and 10a show the effect of a "blooming period" on the color change. A pair of samples was cut at the same time. One sample was wrapped 3 minutes after cutting and the other was wrapped 30 minutes after cutting. These samples were stored under 30 foot candles of white fluorescent light. Tabular data are shown in Appendix H.

The color of the sample wrapped 30 minutes after cutting did not show any appreciable change until 30 hours of storage, whereas the color of the sample wrapped 3 minutes after cutting brightened rapidly during the first hour. After 60 minutes of storage the color of the sample wrapped 3 minutes after cutting was nearly the same as the color of the sample wrapped 30 minutes after cutting. The color of the sample wrapped 30 minutes after cutting was most desirable after 30 hours of storage compared with 82 hours of storage for the sample wrapped 3 minutes after cutting. After 200 hours darkening was noticeable and the rate of the color change of these samples was very similar throughout the remainder of storage. The sample wrapped 3 minutes after cutting was unsalable after 444 hours of storage compared with 420 hours for the sample wrapped 30 minutes after cutting.

The Production & Marketing Administration of the United States Department of Agriculture (50) suggests that pre-packaged meat retailers allow for a "blooming period" of 15 to 30 minutes after cutting as one of several measures to slow discoloration. The sample wrapped 3 minutes after

cutting obtained a desirable color within one hour and remained salable as long as the sample wrapped after 30 minutes. This would indicate that the blooming period does not necessarily prolong salable storage time.

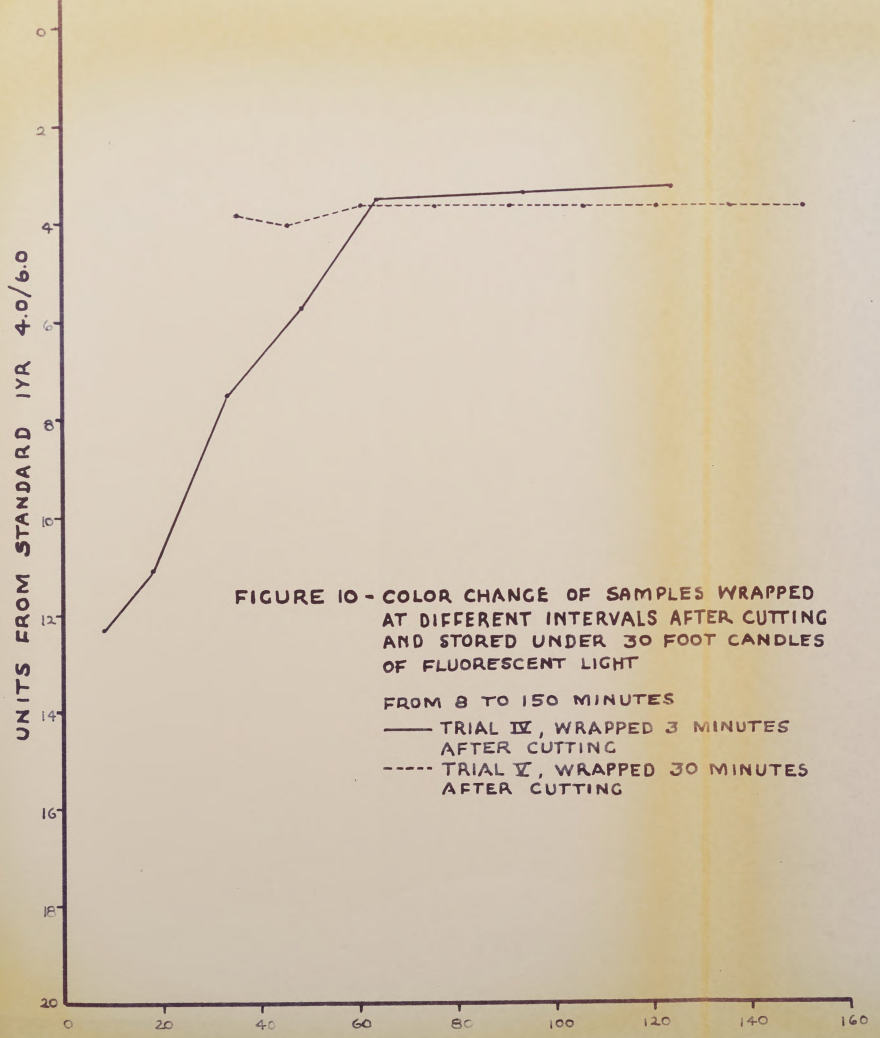


FIGURE 10 - COLOR CHANGE OF SAMPLES WRAPPED AT DIFFERENT INTERVALS AFTER CUTTING AND STORED UNDER 30 FOOT CANDLES OF FLUORESCENT LIGHT

FROM 8 TO 150 MINUTES

—— TRIAL IV, WRAPPED 3 MINUTES AFTER CUTTING

----- TRIAL V, WRAPPED 30 MINUTES AFTER CUTTING

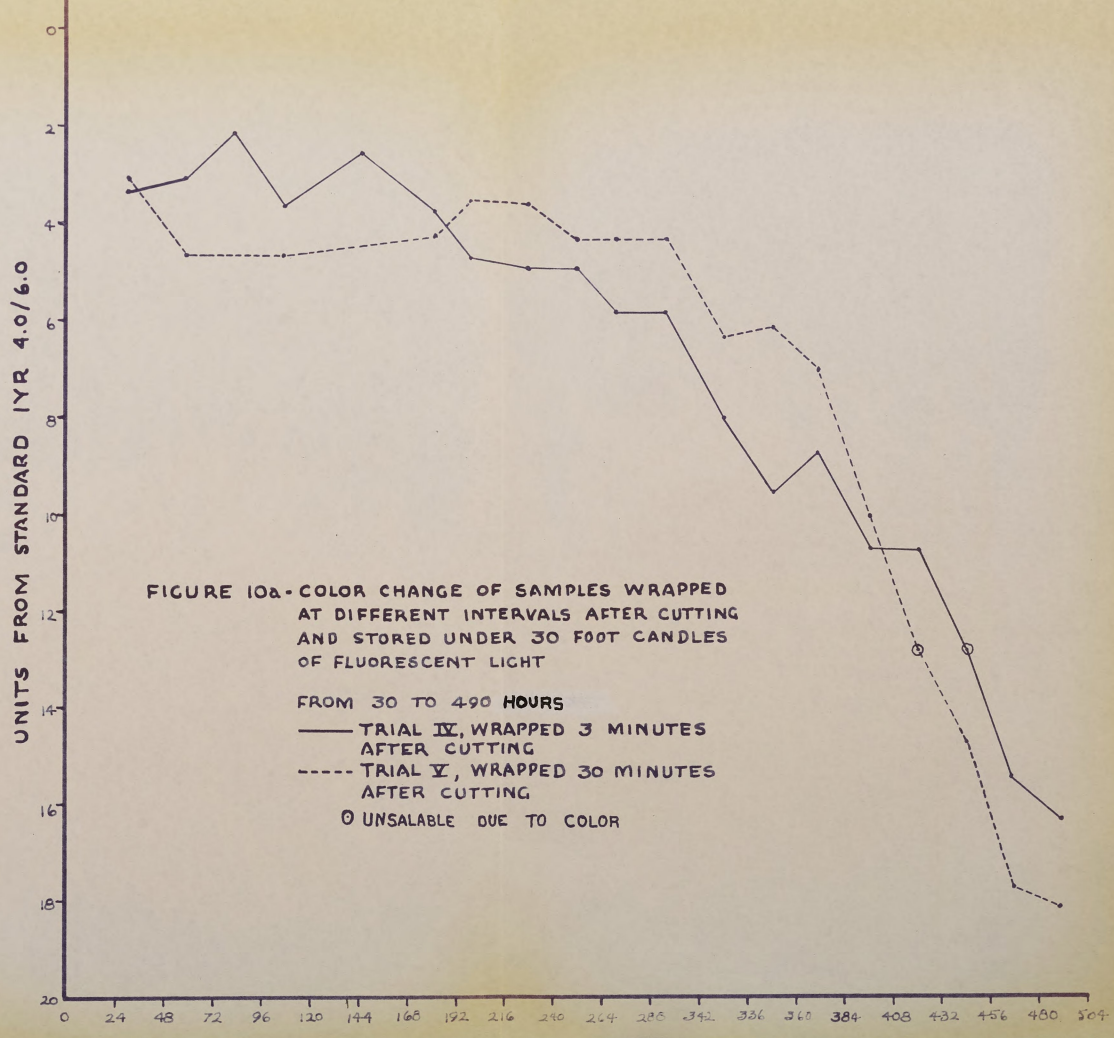


FIGURE 10a - COLOR CHANGE OF SAMPLES WRAPPED AT DIFFERENT INTERVALS AFTER CUTTING AND STORED UNDER 30 FOOT CANDLES OF FLUORESCENT LIGHT

FROM 30 TO 490 HOURS

—— TRIAL IV, WRAPPED 3 MINUTES AFTER CUTTING

----- TRIAL V, WRAPPED 30 MINUTES AFTER CUTTING

O UNSALABLE DUE TO COLOR

A second pair of samples from another animal was treated similarly. These samples were stored under 215 foot candles of fluorescent light. The color changes are illustrated in figures 11 and 11a. Tabular data are shown in Appendix I.

The color of the sample wrapped 3 minutes after cutting indicated a peculiar color change. The color brightened rapidly during the first 35 minutes. At this time the color was brighter than the color of the sample wrapped 30 minutes after cutting. After 35 minutes, the color of the sample wrapped 3 minutes after cutting, showed a slow but steady darkening until 125 minutes of storage. No other sample showed this darkening in color during the first two hours of storage. The sample wrapped after 30 minutes increased in color desirability during this period of storage. The rate of the color change of these samples was very similar after 24 hours of storage.

Both samples were considered to be unsalable after 240 hours of storage.

These results also indicate that the blooming period was not necessary, as the sample wrapped without a blooming period remained salable as long as the sample wrapped after a blooming period.

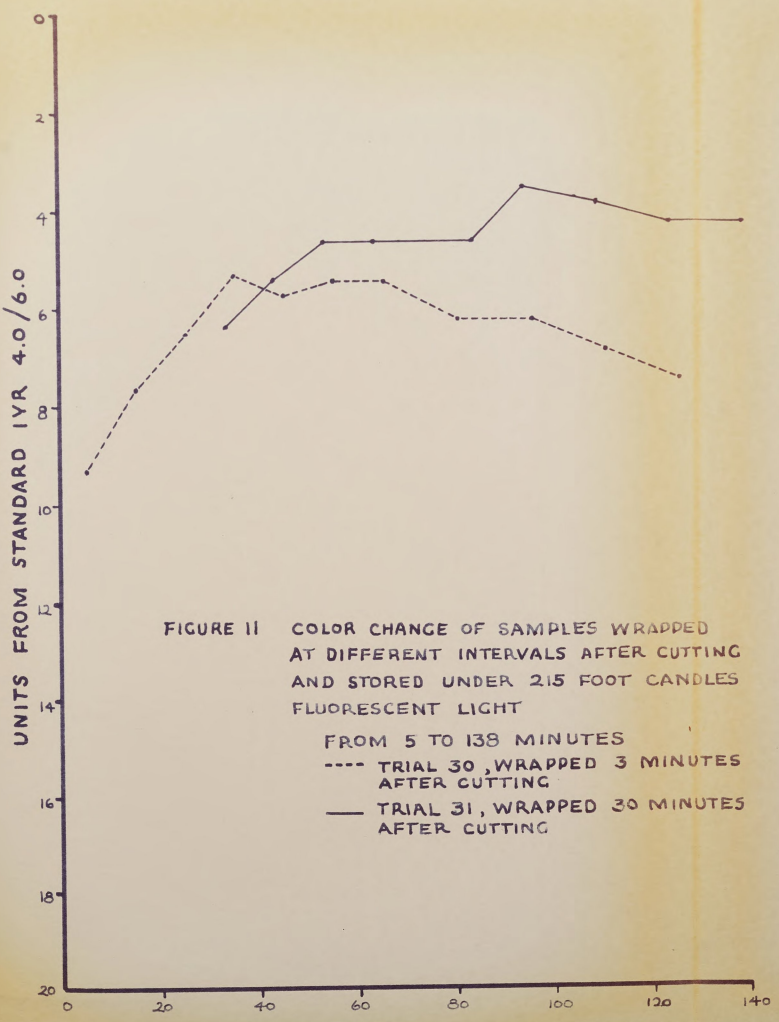


FIGURE II COLOR CHANGE OF SAMPLES WRAPPED AT DIFFERENT INTERVALS AFTER CUTTING AND STORED UNDER 215 FOOT CANDLES FLUORESCENT LIGHT

FROM 5 TO 138 MINUTES

---- TRIAL 30, WRAPPED 3 MINUTES AFTER CUTTING

—— TRIAL 31, WRAPPED 30 MINUTES AFTER CUTTING

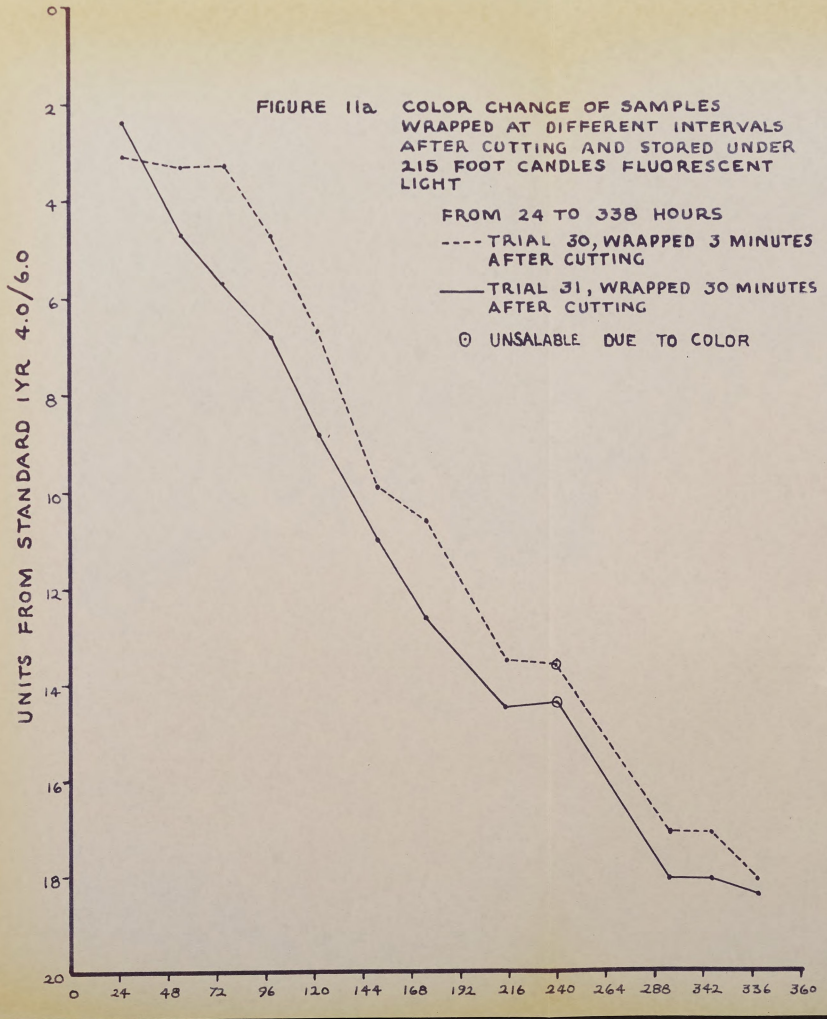


FIGURE IIa COLOR CHANGE OF SAMPLES WRAPPED AT DIFFERENT INTERVALS AFTER CUTTING AND STORED UNDER 215 FOOT CANDLES FLUORESCENT LIGHT

FROM 24 TO 338 HOURS

---- TRIAL 30, WRAPPED 3 MINUTES AFTER CUTTING

—— TRIAL 31, WRAPPED 30 MINUTES AFTER CUTTING

⊙ UNSALABLE DUE TO COLOR

A third pair of samples was treated similarly and stored in darkness. The color changes of these samples are illustrated in figures 12 and 12a. Tabular data are shown in Appendix J.

The rate of color change of these samples was nearly equal until 150 minutes of storage. The color of the sample wrapped 30 minutes after cutting was most desirable at 24 hours of storage. The color of this sample then decreased in desirability as storage time continued. This change was slow until 163 hours of storage, after which the rate increased. The color of the sample wrapped 5 minutes after cutting did not obtain its maximum desirability until 120 hours of storage. There was little change in the color after 80 hours until 144 hours. Darkening began after 144 hours and the rate of color change was approximately equal to that of the sample wrapped 30 minutes after cutting. The color of both samples was rapidly approaching an unsalable color at the end of storage, about 300 hours.

The results from this pair of samples again indicate that the sample wrapped 30 minutes after cutting obtained its most desirable color sooner than the sample wrapped 5 minutes after cutting. However, comparing the color of the two samples at equal times after cutting showed little difference in color. The color of the sample wrapped 5 minutes after cutting was as desirable as the sample wrapped 30 minutes after cutting at the end of storage.

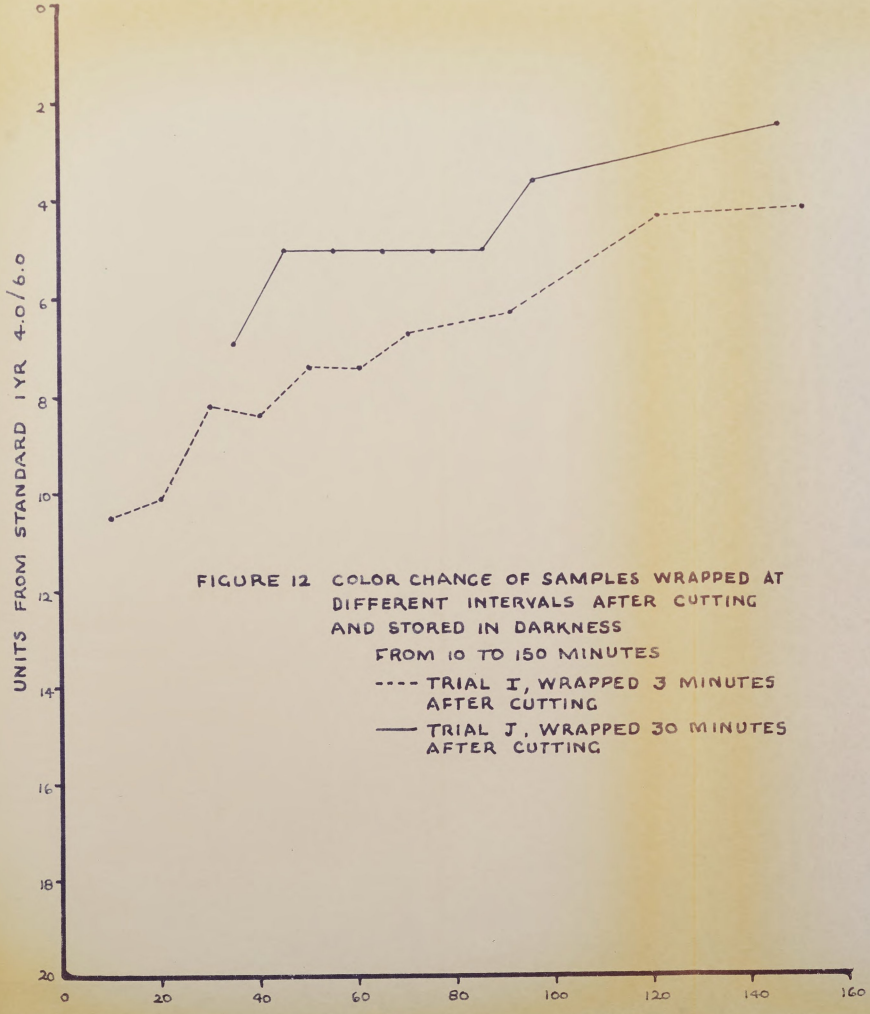


FIGURE 12 COLOR CHANGE OF SAMPLES WRAPPED AT DIFFERENT INTERVALS AFTER CUTTING AND STORED IN DARKNESS

FROM 10 TO 150 MINUTES

---- TRIAL I, WRAPPED 3 MINUTES AFTER CUTTING

—— TRIAL J, WRAPPED 30 MINUTES AFTER CUTTING

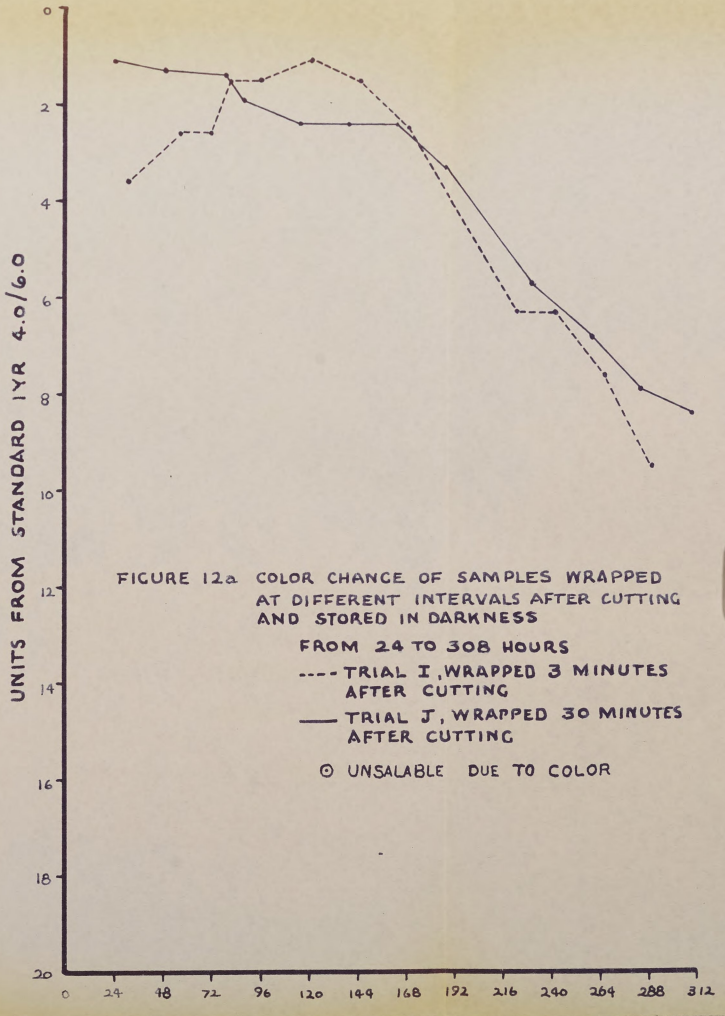


FIGURE 12a COLOR CHANGE OF SAMPLES WRAPPED AT DIFFERENT INTERVALS AFTER CUTTING AND STORED IN DARKNESS

FROM 24 TO 308 HOURS

---- TRIAL I, WRAPPED 3 MINUTES AFTER CUTTING

—— TRIAL J, WRAPPED 30 MINUTES AFTER CUTTING

⊙ UNSALABLE DUE TO COLOR

To determine the effect of freezing on the color change of wrapped samples, a portion of the same rib cut, from which the samples illustrated in figures 12 and 12a were obtained, was frozen 3 weeks at 0°F. After thawing 2 days at 34°F, samples were removed and wrapped at different times to determine if a blooming period delayed discoloration of samples which had been frozen. The results are shown in figures 13 and 13a.

The initial rate of the color change of the thawed samples which had been frozen was approximately the same as the initial rate of the color change of the unfrozen sample (compare figures 12 and 12a with 13 and 13a). After 24 hours, however, the samples which had been frozen, regardless of time of wrapping after cutting, all darkened in color much faster than the unfrozen samples. The blooming period on the samples which had been frozen did not increase the salable storage time. The sample wrapped 60 minutes after cutting was considered unsalable after 148 hours of storage compared with 172 hours of storage for the sample wrapped 30 minutes after cutting and 163 hours for the sample wrapped 4 minutes after cutting. Comparing these periods with the unfrozen samples in figures 12 and 12a, the samples which had been frozen were unsalable much sooner.

Brooks (9) and Mangel (31) have reported conflicting results on the effect of freezing and thawing of meat on the rate of methemoglobin formation. Brooks (9) found that this

increased the rate of methemoglobin formation while Mangel (31) found that it did not increase the rate of methemoglobin formation. The results of the unwrapped thawed frozen sample (illustrated in figures 9 and 9a) previously discussed indicated that freezing and thawing did not increase the rate of methemoglobin formation. The results of the wrapped thawed frozen samples illustrated in figures 13 and 13a indicate that the freezing and thawing did increase the rate of methemoglobin formation when these are compared to wrapped unfrozen samples illustrated in figures 12 and 12a.

Tabular data of these samples are shown in Appendix K.

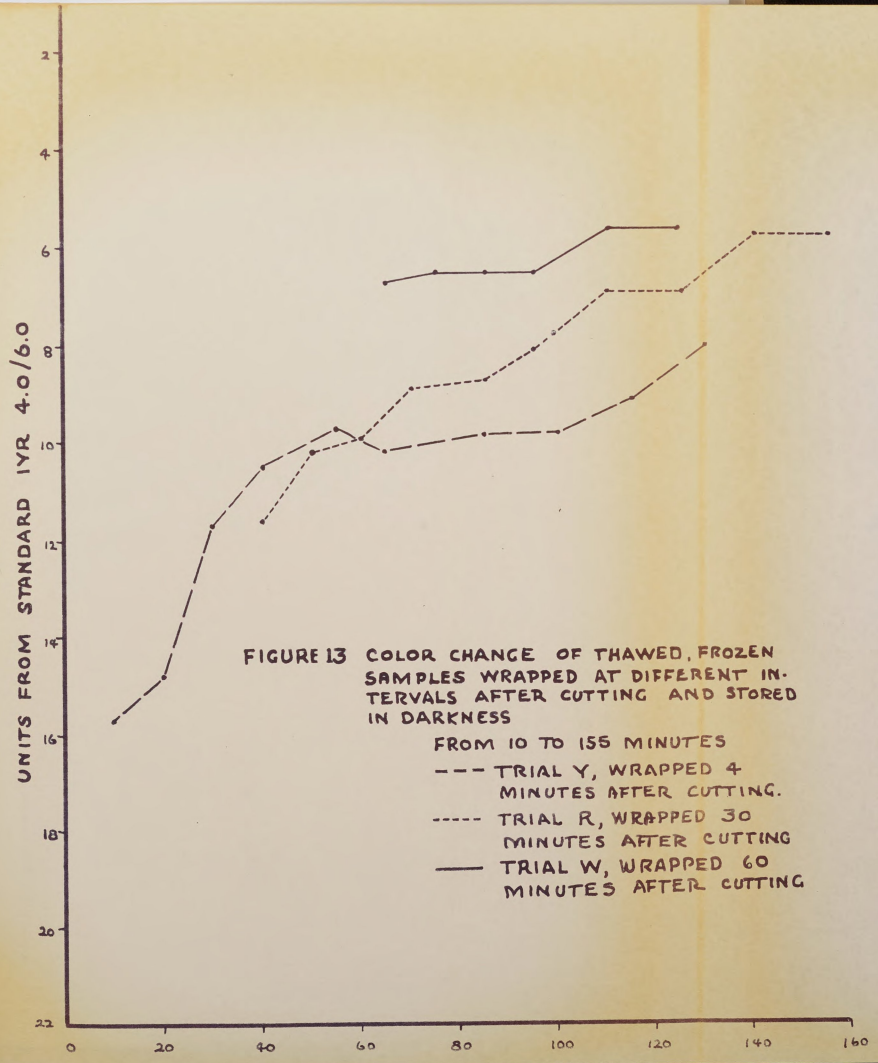


FIGURE 13 COLOR CHANGE OF THAWED, FROZEN SAMPLES WRAPPED AT DIFFERENT INTERVALS AFTER CUTTING AND STORED IN DARKNESS

FROM 10 TO 155 MINUTES

--- TRIAL Y, WRAPPED 4 MINUTES AFTER CUTTING.

----- TRIAL R, WRAPPED 30 MINUTES AFTER CUTTING

—— TRIAL W, WRAPPED 60 MINUTES AFTER CUTTING

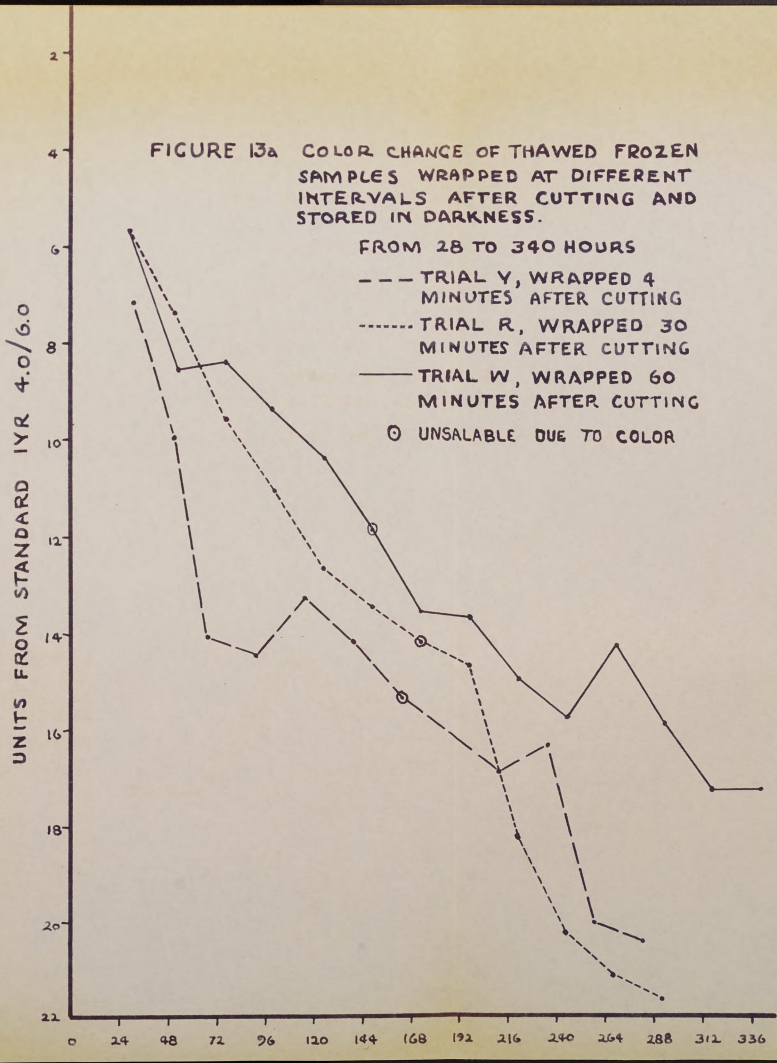


FIGURE 13a COLOR CHANGE OF THAWED FROZEN SAMPLES WRAPPED AT DIFFERENT INTERVALS AFTER CUTTING AND STORED IN DARKNESS.

FROM 28 TO 340 HOURS

--- TRIAL Y, WRAPPED 4 MINUTES AFTER CUTTING

------ TRIAL R, WRAPPED 30 MINUTES AFTER CUTTING

—— TRIAL W, WRAPPED 60 MINUTES AFTER CUTTING

⊙ UNSALABLE DUE TO COLOR

SUMMARY

The application of disk colorimetry as an objective measurement of color changes of fresh beef muscle has been presented.

Color differences were found in the longissimus dorsi muscle of different animals. Differences were also noted in different areas of the same sample.

Aging of the rib portion before cutting the steak samples did not alter the rate of the color change.

Under similar conditions of storage, samples wrapped in Du Pont 300 MSAT #80 cellophane maintained a salable color longer than unwrapped samples. Many wrapped samples maintained a salable color in excess of 10 days. It should be noted, however, that there was no stacking and handling of the samples after placing in storage.

Under the conditions of this study the samples brightened rapidly during the first two hours after cutting. The color change of the samples was approximately twice as great during the first one hour as it was during the second hour. Subsequent desirable color changes occurred at a slower rate.

The intensities of light employed 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 salable storage time of

both wrapped and unwrapped samples.

Freezing and thawing of the rib cut before cutting the steak samples reduced the salable storage life of wrapped samples. This did not, however, reduce the salable storage life of unwrapped samples.

A blooming period before wrapping did not extend the salable storage life when compared with samples wrapped immediately. It did, however, shorten the time necessary for the development of optimum color.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Allen, N.
   1949 Meat Film Consideration. Modern Packaging. January 1949.

2. Anonymous
   1948 Self-Service Meat. E. I. Du Pont de Nemours and Company, Wilmington, Delaware. 45 pp.

3. Anonymous
   1948 How To Prepackage Meat. E. I. Du Pont de Nemours and Company, Wilmington, Delaware. 24 pp.

4. Anonymous
   1949 Housewives Prefer Self-Service, USDA Survery Shows; Some Shoppers Miss Personal Contacts. The National Provisioner, 121: December 25:19.

5. Anonymous
   1949 Prepackaged Self-Service Meats. 1949 Report, Armour & Company. 31 pp.

6. Anonymous
   1950 Boon Continues, Survey Shows. Reported by Armour & Company in The National Provisioner, 122: June 23:14.

7. Anonymous
   1950 More Meats, Other Items Sold in Super Markets Having 100% Prepak Meat Units, Survey Shows. The National Provisioner, 122: March 10:40.

8. Baker, Jim
   1949 Packaging Problems and Solutions. Reprint of a speech presented at the National Independent Meat Packers Association meeting reported in The National Provisioner, 120: June 23:120-142.

9. Brooks, John
   1929 Post-mortem Formation of Methemoglobin in Red Muscle. Biochemical Journal, 23: 1391-1400.

10. Brooks, John
    1931 The Oxidation of Hemoglobin to Methemoglobin by Oxygen. Proceedings of the Royal Society of London, (B), 109: 35-50.

11. Brooks, John
1933 The Effect of Carbon Dioxide on the Color Changes or Bloom of Lean Meat. Journal of the Society of Chemical Industry, 52: 17T-19T.

12. Brooks, John
1935 The Oxidation of Hemoglobin to Methemoglobin by Oxygen. II. The Relation Between the Rate of Oxidation and the Partial Pressure of Oxygen. Proceedings of the Royal Society of London, (B), 118: 560.

13. Brooks, John
1937 Color of Meat. Food Research, 3: 75-77.

14. Brooks, John
1948 The Oxidation of Hemoglobin to Methemoglobin by Oxygen. Journal of Physiology, 107: 332-335.

15. Chamberlain, C. C. and Bratzler, L. J.
1948 Report on Hope-Flannagan Project 1-A, 1947-1948, Michigan Agricultural Experiment Station, Animal Husbandry Department, mimeographed publication. 13 pp.

16. Chang, I. and Watts, B. M.
1949 Antioxidants in the Hemoglobin Catalyzed Oxidation of Unsaturated Fats. Food Technology, 3: 332.

17. Gilchrist, F. W.
1948 An Analysis of Pre-Packaged and Self-Service as a Means of Lowering Costs of Retailing Meat and Delicatessen Products. A copy of a dissertation presented to the faculty of the Department of Economics, University of Southern California, Los Angeles, June, 1948. 10 pages.

18. Gilchrist, F. W.
1949 Self-Service Retailing of Meat. The Journal of Marketing, 13(3): 295-304.

19. Gowland, J. S.
1949 Technical and Operational Problems of Self-Service Meat Merchandising. Michigan State College Thesis, typewritten publication. 58 pages.

20. Haurowitz, Felix
1950 Chemistry and Biology of Proteins. Academic Press Inc. New York, New York. 374 pp.

21. Hoagland, R.
1915 Coloring Matter of Raw and Cooked Salted Meats. Journal Agricultural Research, 3: 211.

22. Jensen, L. B.
1945 Microbiology of Meats. The Garrard Press, Champaign, 389 pp.

23. Kennedy, R. P. and Whipple, G. H.
1926 The Identify of Muscle Hemoglobin and Blood Hemoglobin. American Journal of Physiology, 76: 685-692.

24. Kraft, A. A. and Vanderstock, J. J.
1950 Meat Color Problem is Closer to Solution. Food Industries, 22(1): 65.

25. Kramer, R. C.
1949 Consumer Response to Prepackaged Fresh Meats. Michigan Agricultural Experiment Station Quarterly Bulletin, 32(1): 12-16.

26. Kramer, R. C.
1951 An Economic Analysis of Prepackaged Meat. Merchandising with Particular Emphasis Upon Sales, Consumer Reaction, and Operational Efficiency, Michigan State College Thesis, typewritten publication.

27. Kramer, R. C.
1952 Increasing Labor Efficiency in Prepackaging Meat. Mimeographed copy of Journal Article No. 1322, Michigan Agricultural Experiment Station. 7 pages.

28. Kraybill, H. R.
1951 New Developments in Meat Products. Food Technology, 5: 485.

29. Levers, C. G.
1948 Discoloration of Packaged Red Meat. Modern Packaging, 21(5): January 1948.

30. Lemberg, R., Legge, J. W., and Lockwood, W. H.
1939 Coupled Oxidation of Ascorbic Acid with Hemoglobin. Biochemical Journal, 33: 754.

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

32. Millikan, G. A.
1939 Muscle Hemoglobin. Physiological Reviews, 19: 503-523.

33. Moran, T.
1935 Post-Mortem and Refrigeration Changes in Meat. Journal of the Society of Chemical Industry, 54: 149T-151T.

34. Neill, James M.
1925 Studies on the Oxidation-Reduction of Hemoglobin to Methemoglobin. I. The Changes Induced by Pneumococci and by Sterile Animal Tissue. Journal of Experimental Medicine, 41: 299-313.

35. Neill, James M.
1925 Studies of the Oxidation-Reduction of Hemoglobin to Methemoglobin. II. The Oxidation of Hemoglobin and Reduction of Methemoglobin by Anaerobic Bacilli and by Sterile Plant Tissue. Journal of Experimental Medicine, 41: 535-549.

36. Neill, James M.
1925 Studies on The Oxidation-Reduction of Hemoglobin and Methemoglobin. III. The Formation of Methemoglobin during the Oxidation of Autoxidizable Substances. Journal of Experimental Medicine, 41: 551-560.

37. Neill, James M.
1925 Studies on the Oxidation-Reduction of Hemoglobin and Methemoglobin. IV. The Inhibition of "Spontaneous" Methemoglobin Formation. Journal of Experimental Medicine, 41: 561-570.

38. Neill, James M. and Hastings, A. B.
1925 The Influence of the Tension of Molecular Oxygen Upon Certain Oxidations of Hemoglobin. Journal of Biological Chemistry, 63: 479.

39. Nickerson, Dorothy
1946 U. S. Department of Agriculture. Color Measurement and Its Application to the Grading of Agricultural Products. Washington: Government Printing Office, 1946. 62 pp.

40. Ramsbottom, J. M.
1947 Freezer Storage Effect on Fresh Meat Quality. Refrigerating Engineering, 53: 19-23.

41. Ramsbottom, J. M. and Koonz, C. H.
1941 Freezer Storage Temperature as Related to Drip and to Color in Frozen-Defrosted Beef. Food Research, 6: 571-580.

42. Ranta, R. R.
1951 An Analysis of Consumer Reaction to Prepackaged Meat. Michigan State College Thesis, typewritten publication. 173 pages.

43. Rikert, J. A.
1952 Color Changes of Fresh Meats as Influenced by Some Antioxidant, Temperature and Atmospheric Variations Rutgers University Thesis, typewritten publication. 57 pages.

44. Shenk, J. H., Hall, J. L., and King, H. H.
1934 Spectrophotometric Characteristics of Hemoglobin. I. Beef Blood and Muscle Hemoglobins. Journal of Biological Chemistry, 105: 741-752.

45. Teitelman, Sam
1946 Pre-Packaged Self-Service Meats. Armour & Company, Chicago. 36 pp.

46. Teitelman, Sam
1949 Self-Service Meats. The National Provisioner, 120: May 14:36.

47. Teitelman, Sam
1949 Packer Survey Trends in Self-Service Meats. The National Provisioner, 120: May 21:15.

48. Teitelman, Sam
1949 Pre-Packaged Self-Service Meats. Armour & Company, Chicago. 31 pp.

49. U. S. Department of Agriculture. Retailing Prepackaged Meats. Washington: Government Printing Office, 1949. 27 pp.

50. U. S. Department of Agriculture. Costs of and Reasons for Rewrapping Prepackaged Meats, Poultry and Cheese. Washington: Government Printing Office, 1951. 34 pp.

51. Vestling, S.
1941 The Reduction of Methemoglobin by Ascorbic Acid. Proceedings of the American Society of Biological Chemistry in Journal Biological Chemistry, 140: 135.

52. Voegeli, M. M.
1950 Flow Sheets of Prepackaged Fresh Meat. Michigan State College Thesis, typewritten publication. 96 pages.

53. Watson, Rodger H.
1935 CCLII. Some Observations on the Estimation of Muscle Hemoglobin. Biochemical Journal, 29(2): 2114-2121.

54. Watts, B. M. and Lehmann, B. T.
1952 The Effect of Ascorbic Acid on the Oxidation of Hemoglobin and the Formation Nitric Oxide Hemoglobin. Food Research, 17: 100-108.

55. Whipple, G. H.
1926 The Hemoglobin of Striated Muscle. I. Variations Due to Age and Exercise. American Journal of Physiology, 76: 693-707.

56. Whipple, G. H.
1926 The Hemoglobin of Striated Muscle. II. Variations Due to Anemia and Paralysis. American Journal of Physiology, 76: 708-714.

57. Wiesman, C. K.
1947 Packaging Supplies, Equipment, and Product Care of Meats for Retail Self-Service. Armour & Company, mimeographed publication, 12 pages.

58. Wiesman, C. K. and Hagen, R. F.
1949 Technical Aspects of Self-Service Meats. Armour & Company, mimeographed publication, 21 pages.

APPENDIX

APPENDIX A

Wrapped Sample Stored in Darkness
Trial 21 - Average Prime 2 Year Old Angus Steer
Cutting temperature - 64°F, Cooler temperature - 34°F
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
10 Minutes	4.3YR	4.06	3.7	12.4
20 "	4.0YR	3.98	4.1	10.6
30 "	3.7YR	4.0	4.2	9.9
40 "	3.3YR	4.0	4.4	8.8
55 "	3.1YR	4.06	4.5	8.9
70 "	2.3YR	4.21	4.7	7.5
85 "	2.1YR	4.23	4.8	6.9
100 "	1.9YR	4.25	4.9	6.9
115 "	1.9YR	4.25	4.9	6.9
130 "	1.7YR	4.26	5.0	6.2
24½ Hours	1.7YR	4.42	5.5	5.4
68 "	2.0YR	4.61	5.4	7.6
95 "	3.1YR	4.43	5.1	9.4
121 "	2.8YR	4.40	4.6	9.9
144 "	3.9YR	4.32	4.1	12.3
168 "	8.0YR	4.23	2.9	18.6*
192 "	9.4YR	4.18	2.6	20.1

* Unsalable

Wrapped Sample Stored in Darkness
Trial 8 - High Commercial 2 Year Old Hereford Steer
Sample cut from rib 2 weeks after slaughter
Cutting temperature - 64°F, Cooler temperature - 33°F
Wrapped 3 minutes after cutting
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
6 Minutes	2.9YR	3.50	4.3	11.4
16 "	1.9YR	3.58	4.7	8.0
26 "	1.7YR	3.61	4.8	7.3
36 "	1.6YR	3.63	4.9	6.9
51 "	1.4YR	3.65	4.0	5.6
66 "	0.9YR	3.69	5.3	4.1
81 "	0.9YR	3.69	5.3	4.1
96 "	1.1YR	3.56	5.7	3.5
111 "	1.8YR	3.71	5.8	4.3
126 "	1.8YR	3.71	5.8	4.3
30 Hours	0.6YR	3.96	6.1	1.3
78 "	10.0R	4.23	6.0	3.6
102 "	0.4YR	4.09	6.0	2.0
126 "	0.6YR	3.96	6.1	1.3
150 "	1.1YR	3.90	5.9	1.1
174 "	1.4YR	3.87	5.7	2.4
196 "	1.4YR	3.85	5.6	2.7
220 "	1.2YR	3.96	5.4	2.2
244 "	1.8YR	3.98	5.8	2.5
268 "	2.2YR	3.94	5.6	4.5

Trial 8 - continued

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
292 Hours	2.1YR	3.77	5.1	6.1
316 "	3.8YR	3.89	4.4	10.3*
340 "	5.1YR	3.79	3.9	13.9
364 "	7.4YR	3.68	3.3	18.3

* Unsalable

APPENDIX B

Unwrapped Sample Stored in Darkness
Trial B - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 1 week after slaughter
Cutting temperature - 64°F, Cooler temperature - 36°F
Standard 10R 4.0/7.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
3 Minutes	3.4YR	4.2	3.6	16.2
18 "	2.6YR	4.3	4.4	14.2
23 "	2.1YR	4.4	4.7	13.2
33 "	1.5YR	4.4	4.9	11.6
43 "	1.6YR	4.3	4.7	11.7
53 "	1.6YR	4.3	4.7	11.7
63 "	1.4YR	4.3	4.8	11.1
93 "	1.1YR	4.2	5.1	9.1
123 "	1.1YR	4.2	5.1	9.1
153 "	0.9YR	4.3	5.4	8.5
183 "	0.9YR	4.3	5.4	8.5
268 "	1.2YR	4.1	5.3	8.2
373 "	0.3YR	4.1	5.5	2.8

APPENDIX B - continued

Unwrapped Sample Stored in Darkness
Trial F - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 2 weeks after slaughter
Cutting temperature - 65°F, Cooler temperature - 34°F
Standard 10R 4.0/7.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
3 Minutes	4.7YR	4.1	3.3	17.9
13 "	3.5YR	4.1	3.7	15.7
28 "	2.6YR	4.2	4.1	14.2
33 "	2.3YR	4.2	4.2	13.5
43 "	1.9YR	4.2	4.7	11.7
53 "	1.7YR	4.2	4.8	11.1
63 "	1.7YR	4.2	4.8	11.1
83 "	1.5YR	4.1	5.5	8.4
113 "	0.4YR	4.1	5.4	6.3
152 "	0.3YR	4.0	5.8	4.3
242 "	0.6YR	3.9	6.1	4.8
302 "	0.2YR	4.0	6.4	2.3
362 "	0.2YR	4.0	6.4	2.3

Unwrapped Sample Stored in Darkness
Trial O - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 4 weeks after slaughter
Cutting temperature - 68°F, Cooler temperature - 32°F
Standard 10R 4.0/7.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
5 Minutes	5.2YR	4.56	3.8	21.1
20 "	4.0YR	4.46	4.5	17.7
30 "	3.5YR	4.41	5.0	15.4
40 "	3.5YR	4.33	5.3	14.3
50 "	2.7YR	4.27	5.3	12.6
60 "	2.3YR	4.32	5.6	11.2
70 "	2.0YR	4.34	5.7	10.3
80 "	1.4YR	4.28	5.7	8.9
90 "	1.4YR	4.28	5.7	8.9
100 "	1.0YR	4.33	6.0	7.2
120 "	1.1YR	4.23	6.2	6.3
140 "	1.2YR	4.14	6.6	6.8
260 "	1.0YR	4.16	6.7	4.8
394 "	0.4YR	4.04	7.2	1.8

APPENDIX C

Unwrapped Sample Stored in Darkness
Trial G - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 3 weeks after slaughter
Cutting temperature - 64°F, Cooler temperature - 35°F
Standard 10R 4.0/7.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
5 Minutes	5.1YR	4.2	3.5	18.8
10 "	4.3YR	4.1	3.9	16.6
20 "	3.4YR	4.1	4.6	14.1
30 "	2.6YR	4.1	4.9	12.0
40 "	2.1YR	4.2	5.2	11.0
50 "	2.4YR	4.1	5.4	10.6
60 "	2.1YR	4.1	5.6	9.5
70 "	1.8YR	4.0	5.4	8.7
90 "	1.6YR	3.9	5.8	7.9
110 "	1.6YR	4.1	6.2	7.0
150 "	1.7YR	4.0	6.4	3.6
23½ Hours	9.8R	3.8	7.0	1.8
28½ "	9.6R	3.7	7.5	4.5
30½ "	9.2R	3.6	7.5	6.3
55 "	8.5R	3.4	7.1	8.2
79 "	9.3R	3.2	6.2	8.9
87 "	7.9R	3.1	6.3	12.8*
111 "	7.2R	2.8	5.8	16.3
135 "	7.9R	2.6	4.8	19.0
159 "	8.4R	2.5	4.1	20.3
183 "	9.8R	2.3	3.1	22.2

* Unsalable

APPENDIX C

Wrapped Sample Stored in Darkness
Trial H - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 3 weeks after slaughter
Cutting temperature - 65°F, Cooler temperature - 35°F
Wrapped 4 minutes after cutting
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
9 Minutes	3.8YR	3.9	3.9	11.3
19 "	3.6YR	3.9	4.0	10.8
29 "	3.2YR	4.0	4.3	8.8
39 "	2.9YR	4.1	4.7	8.1
49 "	3.0YR	4.0	5.0	7.0
59 "	2.4YR	4.1	5.3	5.7
69 "	2.4YR	4.1	5.3	5.7
79 "	2.4YR	4.1	5.3	5.7
99 "	2.4YR	4.1	5.4	5.4
119 "	2.2YR	4.1	5.5	4.7
139 "	2.2YR	4.1	5.5	4.7
24 Hours	1.9YR	4.1	5.6	3.8
27 "	1.7YR	4.1	5.7	3.1
53 "	1.5YR	4.2	5.7	2.7
78 "	1.5YR	4.2	5.7	2.7
102 "	1.7YR	4.1	5.7	3.1
118 "	1.7YR	4.1	5.7	3.1
142 "	2.3YR	4.3	5.8	3.1
166 "	1.3YR	4.3	5.8	3.1
190 "	1.9YR	4.0	5.8	2.7

Trial H - continued

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
244 Hours	2.7YR	3.8	4.9	7.8
262 "	2.7YR	3.8	4.9	7.8
286 "	3.3YR	3.7	4.8	9.8
310 "	4.0YR	3.7	4.7	11.3*

* Unsalable

APPENDIX D

Unwrapped Sample Stored in Darkness
Trial 5 - High Commercial 2 Year Old Hereford Steer
Sample cut from rib 2 weeks after slaughter
Cutting temperature - 64°F, Cooler temperature - 33°F
Standard 10R 4.0/7.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
10 Minutes	3.2YR	3.89	4.0	14.7
20 "	2.1YR	3.98	4.6	11.1
30 "	1.5YR	3.92	5.1	9.3
40 "	1.4YR	3.85	5.6	7.9
55 "	1.4YR	3.85	5.6	7.9
70 "	1.1YR	3.88	5.8	6.8
85 "	1.1YR	3.90	5.9	6.5
100 "	0.9YR	3.92	6.0	5.8
115 "	0.8YR	3.94	6.1	5.3
130 "	0.6YR	3.96	6.1	4.2
24 Hours	8.2R	3.58	6.9	7.7
48 "	7.4R	3.40	6.6	11.7
72 "	7.6R	3.25	7.0	11.9*
96 "	6.4R	3.21	6.4	15.8
120 "	7.0R	2.97	6.3	15.7
144 "	7.2R	2.80	5.8	17.3
168 "	7.5R	2.71	5.3	18.2
192 "	7.9R	2.62	4.9	18.8
216 "	7.7R	2.72	3.8	20.9

* Unsalable

Unwrapped Sample Stored in Light
Trial 10 - High Commercial 2 Year Old Hereford Steer
Sample cut from rib 4 weeks after slaughter
Cutting temperature - 65°F, Cooler temperature - 34°F
215 foot candles white fluorescent light
Rise in temperature at meat surface due to light 3°F
Standard 10R 4.0/7.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
4 Minutes	5.0YR	4.32	3.1	19.7
14 "	4.2YR	4.48	3.7	18.1
24 "	3.2YR	4.36	4.4	15.8
34 "	2.8YR	4.40	4.6	14.8
49 "	2.5YR	4.43	4.8	13.8
64 "	2.4YR	4.36	5.1	13.0
79 "	2.0YR	4.38	5.2	12.0
94 "	1.7YR	4.41	5.4	10.9
109 "	1.7YR	4.41	5.4	10.9
124 "	1.7YR	4.42	5.5	10.6
25 Hours	9.9R	3.86	6.2	3.2
50 "	7.9R	3.26	5.9	12.5*
73 "	7.9R	3.41	4.6	14.7
106 "	8.6R	3.46	3.8	14.7
130 "	9.4R	3.41	2.9	16.0
154 "	7.9R	3.47	2.5	18.6
178 "	9.2R	3.05	1.9	21.3

* Unsalable

Unwrapped Sample Stored in Light
Trial 6 - High Commercial 2 Year Old Hereford Steer
Sample cut from rib 2 weeks after slaughter
Cutting temperature - 64°F, Cooler temperature - 33°F
215 foot candles incandescent light
Rise in temperature at meat surface due to light 15°F
Standard 10R 4.0/7.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
9 Minutes	3.5YR	3.75	4.1	15.6
19 "	2.4YR	3.73	4.9	12.8
29 "	1.9YR	3.67	5.6	10.3
39 "	1.8YR	3.71	5.8	9.6
54 "	1.6YR	3.75	6.0	8.0
69 "	1.4YR	3.66	6.5	6.9
84 "	1.2YR	3.70	6.7	5.9
114 "	0.5YR	3.60	6.7	4.6
129 "	0.4YR	3.62	6.8	4.1
23 Hours	6.5R	2.10	3.4	27.0*

* Unsalable

APPENDIX E

Wrapped Sample Stored in Light
Trial 7 - High Commercial 2 Year Old Hereford Steer
Sample cut from rib 2 weeks after slaughter
Cutting temperature - 64°F, Cooler temperature - 33°F
Wrapped 3 minutes after cutting
215 foot candles incandescent light
Rise in temperature at meat surface due to light 15°F
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
10 Minutes	3.8YR	3.44	3.8	14.5
20 "	3.1YR	3.36	4.6	11.7
30 "	2.5YR	3.41	4.8	10.1
40 "	2.5YR	3.41	4.8	10.1
55 "	1.7YR	3.50	5.2	6.9
70 "	1.6YR	3.52	5.3	6.4
85 "	1.6YR	3.52	5.3	6.4
100 "	1.4YR	3.54	5.4	5.7
115 "	1.1YR	3.56	5.7	3.4
130 "	1.1YR	3.56	5.7	3.4
31 Hours	0.9YR	3.38	5.2	6.2
55 "	2.0YR	3.37	4.0	11.2*
79 "	5.0YR	2.79	2.6	21.6
103 "	5.2YR	2.76	2.5	21.9

* Unsalable

Wrapped Sample Stored in Light
Trial 12 - High Commercial 2 Year Old Hereford Steer
Sample cut from rib 4 weeks after slaughter
Cutting temperature - 65°F, Cooler temperature - 34°F
Wrapped 4 minutes after cutting
215 foot candles white fluorescent light
Rise in temperature at meat surface due to light 3°F
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
9 Minutes	4.0YR	3.98	4.1	10.6
19 "	3.0YR	3.94	4.7	8.3
29 "	2.7YR	3.98	5.0	6.4
39 "	2.4YR	3.90	5.4	5.4
54 "	2.4YR	3.92	5.5	5.2
69 "	2.2YR	3.94	5.6	4.5
84 "	1.9YR	3.96	5.8	2.7
99 "	1.6YR	3.83	5.5	4.0
114 "	1.4YR	3.87	5.7	2.4
129 "	1.1YR	3.90	5.9	1.1
25 Hours	2.4YR	4.17	5.6	5.5
59 "	2.4YR	3.92	5.5	5.2
83 "	3.1YR	4.00	5.4	6.3
107 "	3.0YR	3.94	4.8	8.0
155 "	3.0YR	3.94	4.7	8.3
179 "	3.5YR	4.02	4.3	9.4
216 "	5.0YR	4.06	4.1	12.9
274 "	5.7YR	4.00	3.7	13.9*
298 "	7.0YR	3.95	3.5	15.9
322 "	9.0YR	4.08	3.2	19.2
346 "	9.6YR	4.07	3.0	19.9

* Unsalable

APPENDIX F

Wrapped Sample Stored in Light
Trial 20 - Average Prime 2 Year Old Angus Steer
Cutting temperature - 65°F, Cooler temperature - 34°F
Wrapped 7 minutes after cutting
60 foot candles white fluorescent light
Rise in temperature at meat surface due to light 1-2°F
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
15 Minutes	4.3YR	3.57	4.1	13.5
25 "	4.0YR	3.61	4.3	12.7
35 "	3.4YR	3.65	4.5	10.6
45 "	2.7YR	3.69	4.7	8.9
60 "	2.4YR	3.73	4.9	7.8
75 "	2.3YR	3.75	5.1	6.6
90 "	1.8YR	3.79	5.4	4.7
105 "	1.8YR	3.81	5.4	4.7
120 "	1.8YR	3.81	5.4	4.7
135 "	1.8YR	3.81	5.4	4.7
25 Hours	2.4YR	4.17	5.6	5.5
58 "	2.8YR	4.23	5.1	7.6
95 "	3.6YR	4.16	4.7	10.0
121 "	3.9YR	4.02	4.7	9.4
144 "	5.5YR	3.91	4.0	13.8
168 "	6.1YR	3.87	3.8	15.0*
192 "	6.6YR	3.72	3.5	17.1
216 "	9.2YR	3.72	2.7	20.6

* Unsalable

Wrapped Sample Stored in Light
Trial 11 - Average Prime 2 Year Old Angus Steer
Cutting temperature - 65°F, Cooler temperature - 34°F
Wrapped 5 minutes after cutting
215 foot candles white fluorescent light
Rise in temperature at meat surface due to light 3°F
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
12 Minutes	3.4YR	3.81	4.8	9.4
22 "	2.8YR	3.87	5.3	6.5
32 "	2.4YR	3.90	5.4	5.4
42 "	2.4YR	3.90	5.4	5.4
57 "	2.3YR	3.82	5.9	4.6
72 "	2.3YR	3.85	6.0	3.7
87 "	2.0YR	3.86	6.1	3.3
102 "	1.8YR	3.90	6.3	3.5
117 "	1.6YR	3.92	6.4	3.3
132 "	1.6YR	3.92	6.4	3.3
26 Hours	2.4YR	3.92	5.5	5.2
60 "	3.0YR	3.94	4.7	8.3
84 "	3.1YR	3.83	5.0	8.4
108 "	3.5YR	3.79	4.8	9.6
156 "	3.0YR	3.79	4.3	9.7
180 "	3.5YR	3.75	4.1	11.0
218 "	4.6YR	3.93	3.8	12.7
276 "	5.1YR	3.91	3.7	13.6
300 "	6.1YR	3.87	3.8	15.0*

Trial 11 - continued

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
324 Hours	6.5YR	3.85	3.8	15.6
348 "	7.0YR	3.95	3.5	15.9
372 "	7.3YR	3.93	3.5	16.9
396 "	8.5YR	3.88	3.2	18.6

* Unsalable

APPENDIX G

Unwrapped Sample Stored in Darkness
Trial N - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 4 weeks after slaughter
Cutting temperature - 64°F, Cooler temperature - 32°F
Standard 10R 4.0/7.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
4 Minutes	4.5YR	4.37	3.3	19.4
14 "	2.8YR	4.39	4.2	15.5
24 "	2.9YR	4.31	4.3	14.9
34 "	2.3YR	4.26	4.9	12.6
44 "	2.1YR	4.29	5.0	12.0
54 "	1.7YR	4.33	5.3	10.5
64 "	1.3YR	4.36	5.5	9.7
74 "	1.3YR	4.37	5.5	9.7
84 "	0.9YR	4.39	5.7	8.4
94 "	0.5YR	4.22	5.9	5.7
104 "	0.5YR	4.22	5.9	5.7
114 "	0.5YR	4.23	5.9	5.7
124 "	0.4YR	4.25	6.0	5.8
19 Hours	9.1R	3.85	7.4	4.5
26 "	8.5R	3.76	7.4	6.8
71 "	7.6R	3.20	6.9	11.7*
91 "	6.6R	3.01	6.6	16.2
115 "	7.1R	2.84	5.9	17.3

* Unsalable

Unwrapped Thawed Frozen Sample Stored in Darkness
Trial T - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 9 weeks after slaughter
Frozen 3 weeks (5-6), Thawed 1 week
Cutting temperature 70°F, Cooler temperature - 34°F
Standard 10R 4.0/7.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
3 Minutes	7.7YR	4.35	3.6	23.7
13 "	6.3YR	4.32	4.0	20.9
23 "	5.4YR	4.47	4.6	20.1
33 "	5.0YR	4.50	4.8	19.2
48 "	4.6YR	4.53	5.0	18.2
63 "	4.5YR	4.46	5.2	17.8
78 "	4.5YR	4.46	5.2	17.8
93 "	4.0YR	4.36	5.4	17.1
108 "	4.6YR	4.36	5.4	17.1
123 "	4.3YR	4.39	5.6	16.2
12 Hours	2.9YR	4.40	6.1	12.2
36 "	1.6YR	3.72	5.8	9.1
60 "	1.6YR	3.83	5.5	9.2
84 "	0.6YR	3.41	5.3	10.0*
108 "	2.5YR	3.52	4.4	15.2
132 "	1.3YR	3.54	4.0	14.1
156 "	2.4YR	3.46	3.5	16.9
180 "	2.7YR	3.44	3.4	18.1

* Unsalable

APPENDIX H

Wrapped Sample Stored in Light
Trial IV - Low Choice 20 Month Old Hereford Heifer
Sample cut from rib 9 days after slaughter
Cutting temperature - 65°F, Cooler temperature - 35°F
Wrapped 3 minutes after cutting
30 foot candles white fluorescent light
No measureable rise in temperature due to light
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
8 Minutes	3.2YR	3.48	4.1	12.3
18 "	2.8YR	3.39	4.6	11.1
33 "	1.9YR	3.47	5.1	7.5
48 "	1.4YR	3.54	5.4	5.7
63 "	1.1YR	3.56	5.7	3.5
93 "	1.0YR	3.60	5.7	3.3
123 "	0.8YR	3.62	5.9	3.2
30 Hours	0.6YR	3.68	6.2	3.4
58 "	0.6YR	3.66	6.1	3.1
82 "	1.4YR	3.77	6.0	2.2
106 "	0.7YR	3.62	5.8	3.7
145 "	1.6YR	3.75	6.0	2.6
180 "	1.6YR	3.72	5.8	3.8
199 "	1.8YR	3.81	5.4	4.7
227 "	1.9YR	3.67	5.6	5.0
251 "	1.9YR	3.67	5.6	5.0
271 "	2.2YR	3.65	5.5	5.9
295 "	2.2YR	3.65	5.5	5.9
324 "	3.1YR	3.73	5.4	8.1

APPENDIX H - continued

Trial IV - continued

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
348 Hours	3.6YR	3.69	5.2	9.6
370 "	2.8YR	3.58	5.1	8.8
396 "	3.3YR	3.54	4.9	10.8
420 "	3.3YR	3.54	4.9	10.8
444 "	4.6YR	3.71	4.4	12.9*
468 "	4.9YR	3.41	4.2	15.6
490 "	5.4YR	3.51	3.7	16.4

* Unsalable

Wrapped Sample Stored In Light
Trial V - Low Choice 20 Month Old Hereford Heifer
Sample cut from rib 9 days after slaughter
Cutting temperature - 65°F, Cooler temperature - 35°F
Wrapped 30 minutes after cutting
30 foot candles white fluorescent light
No measureable rise in temperature due to light
Standard 1YR 4.0/o.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
35 Minutes	1.4YR	3.94	5.2	3.8
45 "	0.4YR	3.86	5.3	4.0
60 "	0.3YR	3.90	5.5	3.6
75 "	0.1YR	3.92	5.7	3.6
90 "	0.1YR	3.92	5.7	3.6
105 "	0.1YR	3.92	5.7	3.6
135 "	9.7R	3.96	5.8	3.6
150 "	9.7R	3.96	5.8	3.6
30 Hours	9.7R	3.96	6.0	3.1
58 "	9.5R	4.10	5.8	4.7
82 "	9.5R	4.10	5.8	4.7
106 "	9.7R	4.07	5.6	4.7
180 "	0.2YR	4.02	5.2	4.3
199 "	0.4YR	4.0	5.2	3.6
227 "	0.5YR	3.98	5.1	3.7
251 "	1.4YR	4.06	5.0	4.4
271 "	1.4YR	4.04	4.8	4.4
295 "	1.4YR	4.04	4.8	4.4
324 "	2.3YR	4.11	4.9	6.4

APPENDIX H - continued

Trial V - continued

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
348 Hours	2.1YR	3.98	4.6	6.2
370 "	2.3YR	3.95	4.4	7.1
396 "	3.2YR	3.89	4.0	10.1
420 "	4.1YR	3.82	3.6	12.9*
444 "	5.2YR	3.76	3.3	14.8
468 "	6.8YR	3.70	3.0	17.8
490 "	7.1YR	3.68	2.9	18.2

* Unsalable

APPENDIX I

Wrapped Sample Stored in Light -
Immediate versus Delayed Wrapping

Trial 30 - Average Choice 2 Year Old Hereford Steer
Sample Cut from rib 13 days after slaughter
Cutting temperature - 67°F, Cooler temperature - 34°F
Wrapped 3 minutes after cutting
215 foot candles white fluorescent light
Rise in temperature at meat surface due to light 3°F
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
5 Minutes	1.5YR	3.29	4.6	9.3
15 "	1.2YR	3.19	5.2	7.6
25 "	0.9YR	3.24	5.5	6.5
35 "	0.9YR	3.26	5.7	5.3
45 "	0.8YR	3.28	5.8	5.7
55 "	0.5YR	3.31	6.0	5.4
65 "	0.5YR	3.31	6.0	5.4
80 "	0.2YR	3.38	6.2	6.2
95 "	0.2YR	3.38	6.2	6.2
110 "	0.1YR	3.40	6.3	6.8
125 "	10.0R	3.42	6.4	7.4
25 Hours	0.8YR	3.66	6.1	3.1
54 "	1.0YR	3.60	5.7	3.3
76 "	1.0YR	3.58	5.7	3.3
98 "	1.1YR	3.67	5.1	4.7
122 "	1.5YR	3.63	4.9	6.7
150 "	3.1YR	3.67	4.6	9.9
174 "	3.4YR	3.65	4.5	10.6
213 "	4.3YR	3.57	4.1	13.5

APPENDIX I - continued

Trial 30 - continued

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
239 Hours	4.4YR	3.70	3.8	13.6*
295 "	6.0YR	3.60	3.3	17.1
316 "	6.0YR	3.60	3.3	17.1
338 "	6.7YR	3.57	3.2	18.1

* Unsalable

Wrapped Sample Stored in Light -
Immediate versus Delayed Wrapping

Trial 31 - Average Choice 2 Year Old Hereford Steer
Sample cut from rib 13 days after slaughter
Cutting temperature - 67°F, Cooler temperature - 34°F
Wrapped 30 minutes after cutting
215 foot candles white fluorescent light
Rise in temperature at meat surface due to light 3°F
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
33 Minutes	1.7YR	3.38	5.6	6.4
43 "	1.5YR	3.40	5.8	5.4
53 "	1.3YR	3.42	5.9	4.6
63 "	1.3YR	3.42	5.9	4.6
73 "	1.3YR	3.45	5.9	4.6
83 "	1.3YR	3.45	5.9	4.6
93 "	1.1YR	3.47	6.1	3.5
108 "	1.1YR	3.49	6.2	3.8
123 "	0.9YR	3.51	6.3	4.2
138 "	0.9YR	3.51	6.3	4.2
25 Hours	1.5YR	3.75	6.0	2.4
54 "	1.8YR	3.81	5.4	4.7
76 "	2.0YR	3.77	5.2	5.7
98 "	2.2YR	3.85	4.7	6.8
122 "	2.7YR	3.81	4.5	8.8
150 "	3.5YR	3.75	4.1	11.0
174 "	3.9YR	3.71	3.9	12.6
213 "	4.8YR	3.66	3.6	14.5

APPENDIX I - continued

Trial 31 - continued

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
239 Hours	5.0YR	3.78	3.4	14.4*
295 "	7.0YR	3.68	2.9	18.1
316 "	7.6YR	3.80	3.1	18.1
338 "	7.8YR	3.78	3.0	18.4

* Unsalable

APPENDIX J

Wrapped Sample Stored in Darkness -
Immediate versus Delayed Wrapping
Trial I - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 3 weeks after slaughter
Cutting temperature - 63°F, Cooler temperature - 34°F
Wrapped 5 minutes after cutting
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
10 Minutes	4.0YR	3.9	4.5	10.5
20 "	3.9YR	3.9	4.6	10.1
30 "	3.4YR	4.0	4.8	8.2
40 "	3.5YR	3.9	5.1	8.4
50 "	3.2YR	3.9	5.3	7.4
60 "	3.2YR	3.9	5.3	7.4
70 "	3.0YR	3.9	5.4	6.7
90 "	2.9YR	3.9	5.5	6.3
120 "	2.5YR	4.0	5.7	4.3
150 "	2.5YR	4.0	5.8	4.1
31 Hours	2.3YR	4.0	5.8	3.6
56 "	1.6YR	3.9	5.8	2.6
72 "	1.6YR	3.9	5.8	2.6
80 "	1.1YR	4.1	5.8	1.5
96 "	1.1YR	4.1	5.8	1.5
120 "	0.9YR	4.1	5.9	1.1
144 "	1.1YR	4.1	5.8	1.5
168 "	0.8YR	3.9	5.5	2.5
222 "	1.8YR	3.8	4.8	6.3
241 "	1.8YR	3.8	4.8	6.3
265 "	2.3YR	3.7	4.9	7.6
289 "	2.7YR	3.6	4.7	9.5

Wrapped Sample Stored in Darkness -
Immediate versus Delayed Wrapping
Trial J - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 3 weeks after slaughter
Cutting temperature - 63°F, Cooler temperature - 34°F
Wrapped 30 minutes after cutting
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
35 Minutes	2.9YR	4.2	5.5	6.9
45 "	2.7YR	4.2	5.7	5.0
55 "	2.4YR	4.2	5.8	5.0
65 "	2.4YR	4.2	5.8	5.0
75 "	2.4YR	4.2	5.8	5.0
85 "	2.4YR	4.2	5.8	5.0
95 "	1.9YR	4.1	5.7	3.6
145 "	1.5YR	4.2	6.0	2.4
26 Hours	0.8YR	4.1	6.0	1.1
50 "	1.1YR	4.1	5.8	1.3
79 "	0.8YR	4.1	5.9	1.4
87 "	1.3YR	4.0	5.6	1.9
115 "	1.5YR	4.2	6.0	2.4
139 "	1.5YR	4.2	6.0	2.4
163 "	1.5YR	4.2	6.0	2.4
187 "	1.7YR	4.0	5.4	3.3
229 "	1.6YR	3.8	4.9	5.7
259 "	1.9YR	3.8	4.7	6.8
283 "	2.2YR	3.8	4.5	7.9
308 "	2.5YR	3.8	4.5	8.4

* Unsalable

APPENDIX K

Wrapped Thawed Frozen Sample Stored in Darkness - Immediate versus Delayed Wrapping
Trial Y - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 8 weeks after slaughter - Frozen the last 3 weeks
Cutting temperature - 63°F, Cooler temperature - 34°F
Wrapped 4 minutes after cutting
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
10 Minutes	4.3YR	4.56	3.5	15.7
20 "	3.9YR	4.60	3.7	14.8
30 "	3.1YR	4.48	4.3	11.7
40 "	3.0YR	4.38	4.5	10.5
55 "	2.8YR	4.41	4.7	9.7
70 "	3.0YR	4.52	4.9	10.2
85 "	2.9YR	4.53	5.0	9.8
100 "	2.7YR	4.55	5.1	9.8
115 "	2.5YR	4.56	5.2	9.1
130 "	2.5YR	4.49	5.4	8.0
29 Hours	2.6YR	4.38	5.6	7.2
50 "	3.3YR	4.41	5.0	10.0
67 "	4.6YR	4.51	4.4	14.1
91 "	4.8YR	4.49	4.4	14.5
115 "	4.4YR	4.41	4.3	13.3
139 "	4.8YR	4.38	4.2	14.2
163 "	4.9YR	4.46	3.9	15.4*
211 "	6.1YR	4.42	3.6	16.9
235 "	6.2YR	4.30	3.7	16.4
259 "	8.3YR	4.42	3.3	20.1
283 "	8.6YR	4.40	3.2	20.5

* Unsalable

Wrapped Thawed Frozen Sample Stored in Darkness -
Immediate versus Delayed Wrapping
Trial R - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 8 weeks after slaughter -
Frozen the last 3 weeks
Cutting temperature - 63°F, Cooler temperature - 32°F
Wrapped 60 minutes after cutting
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
65 Minutes	3.3YR	3.86	5.7	6.7
75 "	3.3YR	3.88	5.8	6.5
85 "	3.3YR	3.88	5.8	6.5
95 "	3.3YR	3.88	5.8	6.5
110 "	3.0YR	3.92	5.9	5.6
125 "	3.0YR	3.92	5.9	5.6
250 "	3.0YR	3.92	5.9	5.6
28 Hours	2.9YR	4.02	5.5	5.7
52 "	3.5YR	4.05	5.0	8.6
76 "	3.4YR	4.07	5.0	8.4
100 "	3.9YR	4.02	4.7	9.4
124 "	4.3YR	3.98	4.5	10.4
148 "	4.6YR	4.06	4.3	11.9*
172 "	5.5YR	4.13	4.2	13.6
196 "	6.0YR	4.02	4.3	13.7
220 "	6.7YR	3.98	4.1	15.0
244 "	6.7YR	4.10	3.9	15.8
268 "	6.0YR	3.99	3.7	14.3
292 "	7.0YR	3.95	3.5	15.9
316 "	8.0YR	4.03	3.5	17.3
340 "	7.5YR	4.05	3.2	17.3

* Unsalable

Wrapped Thawed Frozen Sample Stored in Darkness -
Immediate versus Delayed Wrapping
Trial W - Low Choice 18 Month Old Hereford Steer
Sample cut from rib 8 weeks after slaughter -
Frozen the last 3 weeks
Cutting temperature - 63°F, Cooler temperature - 34°F
Wrapped 30 minutes after cutting
Standard 1YR 4.0/6.0

Time of Reading after Cutting	Hue	Value	Chroma	Units from Standard
40 Minutes	3.5YR	3.6	4.4	11.6
50 "	3.3YR	3.7	4.6	10.2
60 "	3.1YR	3.7	4.6	9.9
70 "	2.8YR	3.7	4.7	8.9
85 "	2.7YR	3.7	4.8	8.7
95 "	3.1YR	3.7	5.4	8.1
110 "	3.0YR	3.8	5.6	6.9
125 "	3.0YR	3.8	5.6	6.9
140 "	2.6YR	3.8	5.7	5.7
155 "	2.6YR	3.8	5.7	5.7
28 Hours	2.6YR	3.8	5.7	5.7
50 "	2.5YR	3.6	5.4	7.4
76 "	3.5YR	3.8	4.8	9.6
100 "	4.1YR	3.8	4.6	11.1
124 "	4.0YR	3.6	4.3	12.7
148 "	4.4YR	3.6	4.2	13.5
172 "	4.6YR	3.6	4.0	14.2*
196 "	5.1YR	3.8	3.3	14.7
220 "	7.4YR	3.68	3.3	18.3
244 "	8.4YR	3.64	3.1	20.3
268 "	9.2YR	3.60	2.9	21.2
292 "	9.7YR	3.57	2.8	21.7

* Unsalable

ROOM USE ONLY

MAR 10 1961

nt 3/22/61

JUN 10 1961