DETERMINATION OF OXYGENATION RATES IN PORK, BEEF, AND LAMB BY MUNSELL AND REFLECTANCE COLORIMETRY

Thesis for the Degree of M. S.

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Martin Charles Haas

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This is to certify that the

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DETERMINATION OF OXYGENATION RATES IN PORK, BEEF, AND LAMB BY MUNSELL AND REFLECTANCE COLORIMETRY

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ABSTRACT

DETERMINATION OF OXYGENATION RATES IN PORK, BEEF, AND LAMB
BY MUNSELL AND REFLECTANCE COLORIMETRY

by Martin Charles Haas

An experiment was conducted to determine the rate of oxygenation known in the meat industry as "blooming" using the longissimus dorsi (L.D.) muscle of pork, beef, and lamb. The rate studies were made by Munsell Colorimetry and the Gardner Color Difference Meter. The procedure involved making an initial reading on a cross section of the L.D. followed by readings at fifteen minute intervals up to two hours on pork and lamb and three hours on beef. Maximum oxygenation was considered to be the color evaluation at twenty-four hours. Upon obtaining Munsell hue, value, and chroma renotations by disk colorimetry, conversions were made to Index of Fading. Color Difference Meter measurements were interpreted by a_L, a_L/b_L ratio, and total light difference. According to Index of Fading, 87% of the color change in pork occurred in one hour. In beef, 45% of the color change was obtained in one hour, 74% in two hours, and 90% in three hours. In lamb, 67% of the change occurred in one hour and 95% in two hours. According to reflectance, 55% of the color change in pork occurred in one hour based on change of a_L. In beef, 74% of the change occurred in one hour, 88% in two hours, and 96% in three hours. In lamb, 78% of the change occurred in one hour and 86% in two hours.

Several useful relationships were found employing Munsell and reflectance colorimetry. In reflectance, a_L was shown to compare closely

with total light difference on a percent color change basis. Thus, the use of a_L as an indication of color change eliminates the labor involved in calculating $\sqrt{\Delta L^2 + \Delta a_L^2 + \Delta b_L^2}$. A highly significant negative correlation was also found between Index of Fading of the Munsell system and a_L of the Gardner system. Therefore, a_L could be used as indication of oxygenation rates.

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By

MARTIN CHARLES HAAS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF GRAPHS

LIST OF APPENDIX TABLES

INTRODUCTION

Color is an important attribute of meat recognized as a criterion of quality (Bull, 1951). Meat color is known to develop through definite changes depending upon the status of the pigment myoglobin (Brooks, 1929). When initially exposed to the air, a purple red pigmentation is observed due to the presence of myoglobin in its reduced form. After a short time the meat will become increasingly red due to the formation of oxymyoglobin. This process is called oxygenation, which involves the addition of an oxygen atom to the myoglobin (Lavers, 1948). Oxygenation is known commercially as "bloom" and is exceedingly important in consumer acceptance. During long exposure to the air, a brown pigment called metmyoglobin is formed which is the result of an electron exchange and is very undesirable in appearance to the consumer (Lavers, 1948). There are many factors which influence bloom, including concentration of myoglobin in the tissue, oxygen pressure and penetration, relative humidity, temperature, light, bacteria, and enzymes.

The objectives of this investigation were to determine the actual rates of oxygenation of surface pigment in pork, beef and lamb using Munsell Colorimetry and the Gardner Color and Color Difference Meter. These data can then be employed as a basis for characterizing the color of freshly cut meat. Another purpose was to evaluate the advantages and limitations of these two methods of meat color analysis.

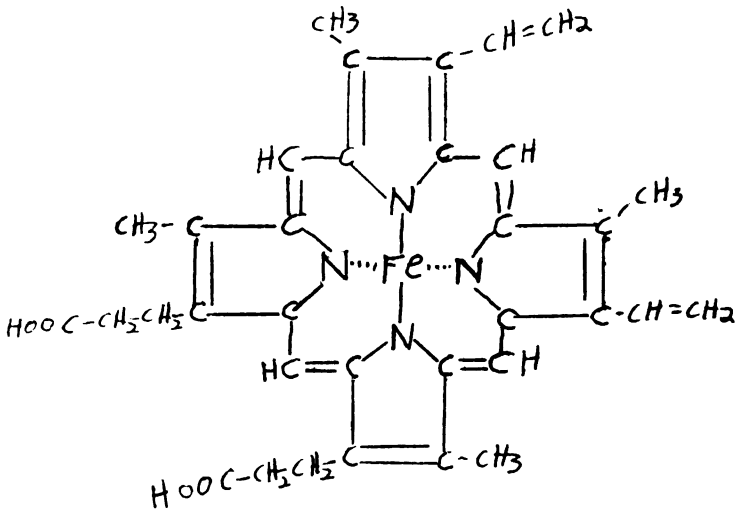
REVIEW OF LITERATURE

The Identity of Myoglobin

The color in meat muscle tissue is primarily due to the pigment myoglobin. According to The Science of Meat and Meat Products (1960), myoglobin accounts for only 10% of the total iron in the live animal. However, this text also reports that in well bled beef skeletal muscle, approximately 95% of the iron has been determined as myoglobin. The remaining 5% of pigmentation was stated to consist of cytochromes, red heme pigments, vitamin B_{12} (which contains the same porphyrin ring as the heme but contains cobalt rather than iron) and flavins. Morner (1897) presented the first evidence demonstrating the existence of a muscle pigment separate from blood hemoglobin on the basis of a study on muscle extracts from dogs, cattle, and horses. He compared the absorption spectra and showed that there was a slight displacement of myoglobin toward the red part of the spectrum. In 1932 Theorell succeeded in crystallizing myoglobin from horse heart, proving that there was a protein in muscle resembling the hemoglobin of blood but distinct from it. Shenk, Hall, and King (1934) contributed further evidence that muscle and blood pigments were separate entities by use of spectrophotometry and reported that the maximum absorption for blood hemoglobin occurred at 517 and 542 mu, while for muscle hemoglobin the similar peaks were at 583 and 543 mu. They also indicated that the myoglobin content in longissimus dorsi of beef could not be correlated with hemoglobin content in blood.

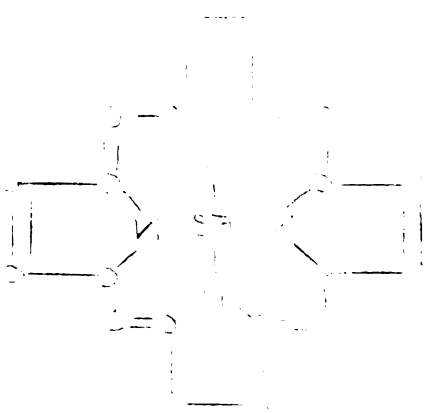
Structure and Composition of Myoglobin

Both hemoglobin and myoglobin are heme-proteins. Schweigert (1956) indicated that a heme protein is comprised of a heme moiety which is an iron containing porphyrin compound attached to a globin protein. The heme consists of four pyrrole rings in the center of which is an iron atom coupled to the four nitrogen atoms. The heme also contains four methyl groups (CH_3), two vinyl groups ($-CH_2 = CH_2$), two propionic acid radicals ($-CH_2\ CH_2\ COOH$), and four pyrrole rings (C_4H_5N) which in combination with the iron comprise the iron porphyrin ring as illustrated below.



The Iron Porphyrin Ring or Heme (Schweigert, 1956)

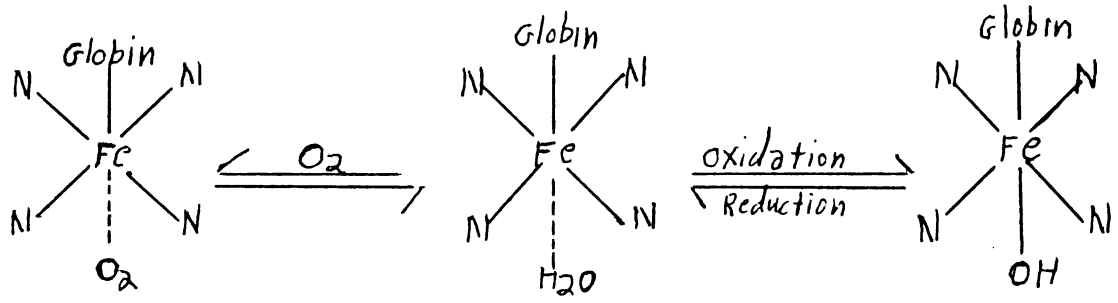
The iron bound in the center of the porphyrin ring has six valences, but only four are connected with the nitrogen atoms of the pyrole. Another valence is bound to the protein component, globin, by means of an imidazole group of a histidine molecule in the amino acid chain of the globin (Kendrew, 1949). The sixth bond orbital provides for the complexing of an atom which has an electron pair to donate to the iron as stated by Granick and Gilder (1947). Thus, in oxygenation, oxygen is the electron donator.



Kendrew (1949) established the physical shape of a myoglobin molecule as two disks which are 57°A in diameter and 9°A thick, lie parallel to each other, and are separated by a layer of crystallization about 6.6°A thick. Each of the disks is formed by one polypeptide chain folded on itself in four equal sections to form a flat disc of 43°A X 35°A X 23°A, which was determined in Xray analysis by Kendrew (1958). The prosthetic ferroheme is perpendicular to the plane of each disc and extends above and below it.

There are many physical constants important in the characterization of myoglobin. Kendrew (1949) established a sedimentation constant of 2.0×10^{-3}. Bowen (1948) reported a molecular weight of 16,400, iron content of .323 percent, and isoelectric point of 6.99.

The color changes occurring in meat are the result of the three forms of myoglobin and their relative concentrations. These forms include myoglobin (purple), oxymyoglobin (red), and metmyoglobin (brown). The changes of myoglobin have been illustrated by Brown and Tappel (1958), in which the porphyrin ring is symbolized by the four nitrogen atoms of the pyrrole rings.



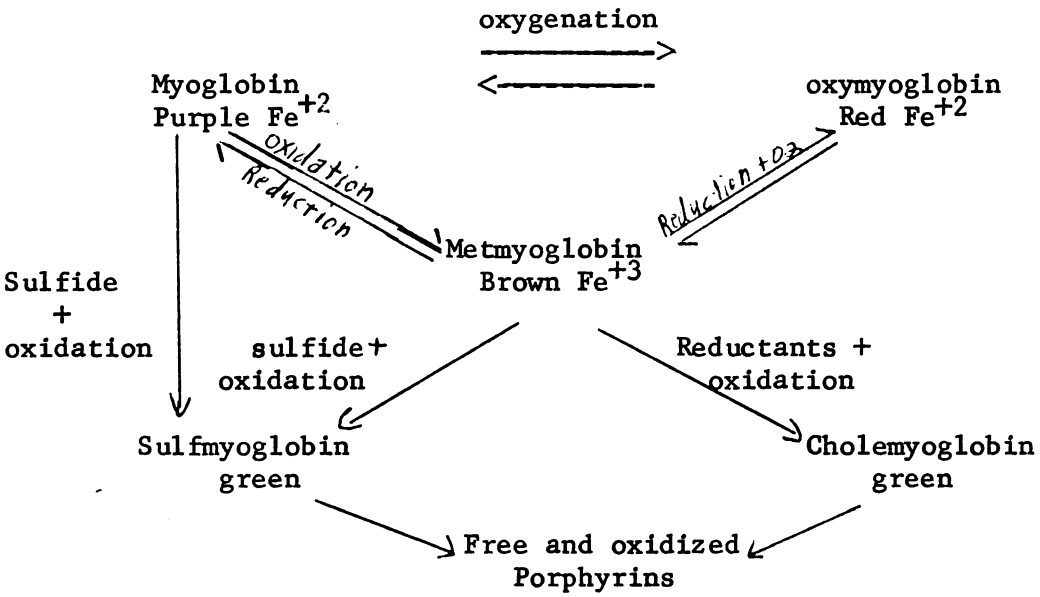
oxymyoglobin reduced myoglobin metmyoglobin

These authors further observed that the combination of oxygen with myoglobin to form oxymyoglobin was a reversible step and was primarily dependent on high oxygen availability. The formation of oxymyoglobin involved a transfer of an oxygen atom and hence is called oxygenation. At low partial pressures of oxygen, there will be a transfer of electrons and metmyoglobin will be formed. Schweigert (1956) stated that the presence of reducing conditions maintained myoglobin in the reduced state and also converted metmyoglobin to myoglobin. An important factor governing the color of pigment is the valence state of iron. As can be observed, the iron is in the reduced state in myoglobin. In oxymyoglobin the iron is also in the reduced ferrous state, but contains more oxygen held in loose combination. In metmyoglobin, the iron has been oxidized to the ferric state due to decrease in one electron. Lavers (1948) stated that oxymyoglobin is not an intermediate in the formation of metmyoglobin and has presented the pathway of discoloration as follows:

oxymyoglobin ------> reduced myoglobin ------> metmyoglobin

Brooks (1929) affirmed that oxymyoglobin must be dissociated into oxygen and myoglobin before metmyoglobin could be formed.

The total pathway of fresh pigment color changes has been determined as follows according to The Science of Meat and Meat Products.



Brooks (1929, 1931, 1935, 1948) extensively studied the oxidation of both hemoglobin and myoglobin. He stated that the conversion of myoglobin to metmyoglobin involves a valence change of the iron atom and required one hydrogen equivalent of oxidizing agent for each atom of iron in the myoglobin molecule. The establishment of an equilibrium between oxygen, myoglobin, and oxymyoglobin is very rapid in comparison with rate of oxidation. Furthermore, this oxidation to metmyoglobin occurs at the maximum rate when oxygen partial pressure is low. He stated there are three possible pathways postulated for the reaction between myoglobin and oxygen depending on oxygen tension. These include:

1. Spontaneous decomposition of oxymyoglobin to metmyoglobin.
2. Oxygenation of reduced myoglobin to oxymyoglobin at high oxygen partial pressure.
3. Oxidation of reduced myoglobin at low oxygen pressure.

Brooks has also stated that the pigment of muscular tissue is present at the surface as oxymyoglobin, which gradually changes during cold storage to metmyoglobin which is brown. The brown discoloration re-

sults from metmyoglobin formation, loss of moisture from the surface, and disintegration of the globin components.

Theory of Oxygenation

In Fruton and Simmonds (1959), the physiological importance of hemoglobin and myoglobin is explained to lie in their ability to combine reversibly with oxygen. Hemoglobin acts as a transport for oxygen from air to the tissue of animals by means of the red corpuscles in the circulatory system. They also state that on a stoichiometric basis one gram of iron will combine with 400.9 ml of molecular oxygen at standard temperature and pressure. Accordingly, there is a shift in the absorption spectrum for the conversion of myoglobin to oxymyoglobin. An interesting aspect discussed by these authors in this conversion is the change in electron status. Both myoglobin and oxygen are paramagnetic, which means that an electron is unpaired. The unopposed spin of this unpaired electron confers a magnetic moment on the molecule and is attracted by an external magnetic field. Oxymyoglobin is diamagnetic, because all the electrons in the molecule are paired as indicated by a repulsion in an external magnetic field. Thus, there is a covalent bonding of the iron and oxygen atoms. This equilibrium may be expressed in symbols by:

$$Mb + O_2 \rightleftharpoons MbO_2$$

$$K_{assoc} = \frac{(MbO_2)}{(Mb)\ (O_2)}$$

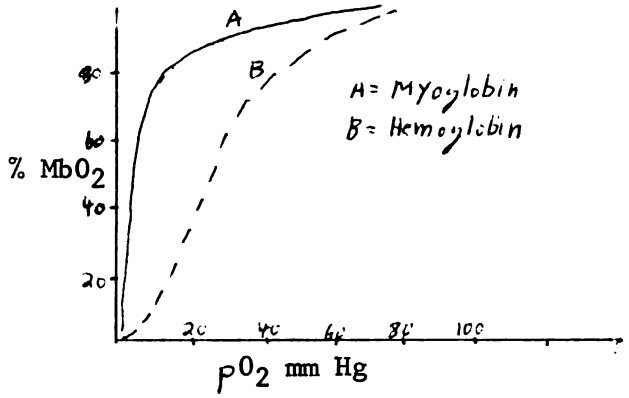
Since the concentration of oxygen is proportional to the partial pressure of the gas according to Henry's Law, the term for concentration of oxygen

may be replaced by pO_2. The following relationship may then be established, which is termed Hüfner's equation. Details concerning this equation are

$$\frac{(Mb\ O_2)}{(Mb)} = K_{assoc} \times pO_2$$

thoroughly explained in Lemberg and Legge's text, Hematin Compounds and Bile Pigments.

If the percent of the total oxymyoglobin concentration is plotted against the partial pressure of oxygen, Millikan (1937) demonstrated that the curve will be a rectangular hyperbola. Such data are derived by equilibration of a solution of myoglobin with a gas phase having a known partial pressure of oxygen followed by analytical determination of oxygen in the gas and liquid phases. Correction for the dissolved oxygen unbound must be made. The rate of oxygenation will then follow the course illustrated in the graph below.



Rate of oxygenation of myoglobin in aqueous extract

Factors Determining the Rate of Oxygenation

1. Myoglobin concentration of tissue

The darkness of color depends on the concentration of myoglobin in the tissue. Lawrie (1950) reported that wide variations occur between muscles of the same animal. This was demonstrated by .465% in longissimus dorsi, .610% in the diaphragm, and .705% in the psoas in beef. Shenk,

Hall, and King (1934) indicated that exercise may be a greater factor than nutrition for myoglobin concentration. Millikan (1939) demonstrated that high concentrations of myoglobin are generally found in muscles requiring slow repetitive activity of considerable force such as the heart muscles of large animals, and leg muscles of running animals. Whipple (1926) showed that age increased the myoglobin concentration. For example, beef contains a range of 4 to 10 mg of myoglobin per gram of tissue, while veal has about 1 to 3 mg/g. Mineral supplementation has produced contradictory effects. In a study conducted by Niedermeier (1959) and substantiated by Bray (1959), iron and copper additions to the feed were shown to greatly influence the myoglobin concentration in veal muscle. In pork, however, Henry (1959) demonstrated that zinc, iron, calcium, and copper supplementation produced no significant effect on myoglobin concentration, as indicated by greater difference within treatment than between treatments. Lawrie (1950) reported that pork muscle can vary in color and still have the same myoglobin content. He indicated that muscles appear much darker at the pH 7.0 than at 6.3.

2. Oxygen pressure and penetration

Neil (1925) reported that no metmyoglobin can be formed in the complete absence of oxygen because no oxidizing agents are available to oxidize the myoglobin to metmyoglobin. Brooks (1929) also indicated that no metmyoglobin is formed from myoglobin stored in pure nitrogen storage. Thus, the presence of an oxidizing agent such as oxygen is an obligate requirement for the formation of the brown pigment metmyoglobin. Neil

and Hastings (1925) 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 Hg. Brooks (1929) also worked with hemoglobin solutions and found that at 20 mm Hg pressure, the concentration of hemoglobin and oxyhemoglobin were nearly equal. The rate of methemoglobin formation was monomolecular with respect to the hemoglobin at constant oxygen pressure.

Brooks (1935) reported that the concentration of oxygen in the muscle tissue decreases in proportion to distance from the surface. Brooks (1929) found that tissue generally has a small oxygen uptake. As a result a "steady state" will be reached in a sufficient amount of time where the depth of oxygen penetration can be determined by the rate of diffusion of oxygen into the tissues and the oxygen consumption of the tissues. He further reported that the depth of oxygen penetration was determined by the oxygen pressure in atmospheres at the surface of the tissue, the diffusion coefficient of oxygen through the tissue, and the oxygen uptake of the tissue. In 1935 he stated that the depth of oxygen penetration showed a slow increase with time and decrease in temperature. He further found that the depth of penetration was proportional to the square root of the oxygen pressure.

3. Effect of relative humidity.

The production of undesirable pigment change can be closely related to factors controlling loss of moisture from the surface of the meat. In a study conducted by Brooks (1937), high humidities at 0°C produced discoloration by metmyoglobin in less than one month. At low humi-

dities browning occurred much more rapidly due to dehydration of the surface and formation of metmyoglobin.

4. Effect of temperature

Probably the most important factor determining rate of oxygenation is temperature. Brooks (1937) indicated that the oxygen pressure required for optimum methemoglobin formation is dependent on the temperature. Even the depth of oxygen penetration is inversely related to temperature. Ramsbottom and Koonz (1941) determined the relative concentration of oxymyoglobin and metmyoglobin on the surface of steaks stored for one year at 10°F and -30°F. By preparing extracts of the surface tissue and determining absorption spectra, the sample stored at 10°F was found to yield a curve similar to metmyoglobin. The curves obtained from samples stored at -30°F indicated a mixture of oxymyoglobin and metmyoglobin. Rikert (1952) found that meat stored at 34°F, 54°F, and 85°F resulted in greater darkening as the temperature increased. The time required for the return of the red color in the packaged meat was decreased as the temperature increased.

5. Effect of light

Fresh meats, in comparison to cured meats, appear to be relatively unaffected under normal display conditions of light according to a study performed by Kraft (1954). He reported that the intensity of soft white fluorescent light was unimportant in influencing the course of discoloration of packaged fresh beef. Measurements of spectral reflectance

as well as visible color changes indicated that ultra-violet light causes rapid oxidation of myoglobin to metmyoglobin. Ramsbottom (1951) reported that display case lighting does not significantly discolor fresh meat within the usual display periods up to three days provided that there is no significant microbial development. In a study by Voegeli (1952), an intensity of light range of 20-215 foot-candles did not affect the rate of color change of unwrapped samples under proper storage temperature. In cases where light increased storage temperature, there was a proportionate discoloration.

Kampschmidt (1955) reported that wavelength is one of the most important factors causing fading, particularly in cured meat products. Townsend (1958), by use of color filters, indicated that the wavelengths of light between 560 and 630 mu (yellow and orange portion of the spectrum) are responsible for the degradation of the color of prepackaged frozen meat. Also, those steaks stored under green and purple filters showed the least amount of metmyoglobin formation.

6. Effect of bacteria

According to Robach (1955), the addition of cell suspensions of aerobic bacteria to steaks greatly increased the rate of discoloration. Sparsely populated suspensions produced a more rapid appearance of metmyoglobin than did high cell concentrations, which created reducing conditions forming the purple color of myoglobin. The visible changes in color were found to be associated with the oxygen demand of the surface tissue including the demand of possible contaminating microorganisms. Inhibitors

of respiratory activity slow the rate of metmyoglobin formation. Thus, it was concluded that the primary role of bacteria in meat discoloration is in the reduction of the oxygen tension in the surface tissue. Neill (1925) reported that pneumococci cause reduction of metmyoglobin to myoglobin under exclusion of molecular oxygen. Upon the introduction of small amounts of molecular oxygen, the reverse reaction was demonstrated due to the production of peroxides.

7. Effect of enzymes

Grant (1955) reported that oxidative changes of myoglobin were intimately related to the functioning of enzyme systems related to oxygen. He stated that succinic dehydrogenase, alpha glycerophosphate dehyrogenase and cytochrome oxidase have appreciable activity in beef. Brown and Tappel (1958) reported that in the interior of fresh meat, respiratory enzymes such as succinoxidase consume oxygen and tend to deoxygenate oxymyoglobin to the reduced form. Lawrie (1953) demonstrated that the succinic dehydrogenase-cytochrome system catalyzes intracellular oxygen uptake and he found a correlation between percent myoglobin and activity of cytochrome oxidase.

Color Measurements as an Analytical Tool

The science of color is a complex and broad field and according to Webster may be defined as a "sensation evoked as a response to the stimulation of the eye and its attached nervous mechanisms by radiant energy of certain wave-lengths and intensities." Livingston (1959) has explained the broad ramifications and developments of color analysis. Color definition may be utilized in food inspection as a criteria on quality of raw material, which must satisfy specifications of the U.S.D.A. For example,

under undesirable storage, color variations may be detected before flavor alterations. As an analytical tool, colorimetry enables the food chemist to perform quantitative analysis on numerous food constituents such as vitamins, minerals, and pesticides. Although the human eye can frequently be employed in color appraisal, there are many variables introduced including departures from normal vision, lighting, sample presentation, observer fatigue, and acuity of color memory.

In order to standardize color analysis many instruments have been adapted to the food industry (Livingston, 1959). Important techniques of color analysis are comparators such as the Wesson Tintometer using mixtures of oil colors to match a sample and the Lovibond Tintometer applying the addition and subtraction of filters from a white light source in order to obtain a match. The Ridgeway Charts and the Maery and Paul Dictionary of Color may also be employed as a comparative technique in the identification. A major advance in color analysis was the development of a photoelectric colorimeter, which replaces an observer with a photoelectric cell. The spectrophotometer was then developed, which measures light of a particular wave-length by use of a prism and can be used to characterize a food component by means of an absorption curve. In addition to methods utilizing transmission of light, there are many other colorimetric techniques based on emission and flouresence.

1. Munsell Disk Colorimetry

Munsell disk colorimetry has been established on the basis that color is composed of three dimensions: hue, value, and chroma (Nickerson,

1946). Hue may be defined as the quality by which one may distinguish one color from another such as red from green. Value is defined as the relative lightness and darkness of the color. Chroma is the strength or intensity of the color. The Munsell system may be pictured in the form of a sphere whose circumference is composed of ten major hues which radiate out like spokes on a wheel from a vertical scale. The hues include red, yellow-red, yellow, green-yellow, green, blue-green, blue, purple-blue, purple, and purple-red. Each division is subdivided into ten steps for accurately matching a given color that does not fall exactly on a major division. Value is the vertical axis consisting of a scale extending from black (0) at the bottom to white (10) at the top with a range of nine intermediate greys. The chroma scale is horizontal and extends from a grey on the vertical axis outward. The chroma of red has the greatest range of intensity. By employing the spinning disk which contains adjustable proportions of the achromic colors (black and white) and chromic colors (red and yellow), a color can be notated in terms of hue, value, and chroma. The percentage of colors used are determined by matching the disk, which is rotated at constant speed by a motor, with the sample by observation through an eye piece. After obtaining the match, the percentage of each color is converted into the tristimulus criteria X, Y, and Z, tabulated, and finally converted into Munsell renotations by use of graphs.

2. Gardner Color and Color Difference Meter

The Gardner Color and Color Difference Meter is an instrument employing reflectance of light and consists of an exposure unit and

a measuring unit (Instruction Manual Gardner Laboratory, Inc.). The exposure unit consists of a light source, mounting for specimens, and means of viewing the specimens with photocells. Two light beams from a single source are directed along separate paths to two photo cells. One beam of light is divided into sections which strike the sample at 45° angle of incidence. The light is diffused perpendicularly from the sample and passes through a fluted lens onto a photocell. There is also another photocell called a standard against which the sample is compared by means of the other beam of light. The standard is based on reflectance from magnesium oxide, a nearly perfect white which has 98% reflectance. The current generated by the photocell containing the sample is conducted to the measuring unit where various current levels from the standard photocell are measured against it. Thus, two photocells operate together in each reflectance measurement so that temperature effects will be balanced.

The measuring unit consists of potentiometer rheostats, switches, and recording values of photocell current on scales proportional to the color. The reflected light from the exposure unit impinges on the photocells and creates a current proportional to its intensity. The signal is then transmitted to the measuring unit, where three motor driven potentiometers called helipots balance the signal generated by the two photocells. Duodials mounted on the front panel are directly coupled to the helipots, and the readings obtained from them give the colorimetric specification of the sample. Thus, test currents obtained from the exposure unit are measured with three potentiometer rheostats relative to current obtained

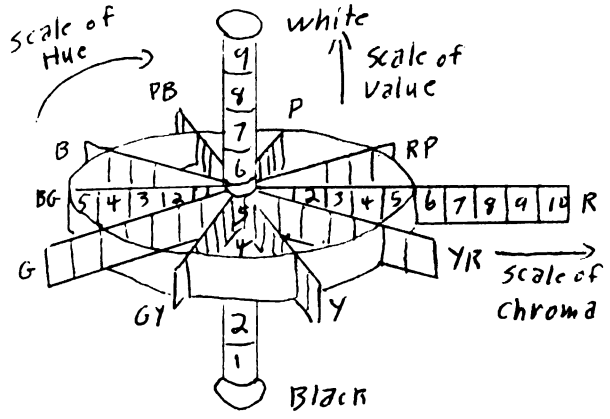
from a constantly illuminated comparison photocell.

The Color Difference Meter presents three dials for each color measured, including numbers for L, a_L, and b_L. The L scale is indicative of the relative lightness and darkness of the sample and corresponds with value in the Munsell system. A sample which appears about halfway between black and white will have a reading of 50. The other two readings are a_L and b_L, which are defined in terms of the tristimulus criteria X, Y, and Z and are rectangular coordinates of chromaticity in any place intersecting the color solid perpendicular to the black and white axis. Both a_L and b_L may be either positive or negative. The a_L scale measures redness and greenness, which are complementary colors. The b_L scale measures yellowness and blueness, which are also complementary colors. For the evaluation of meat color the a_L scale is set positive to measure redness and the b_L scale is also set positive to measure yellowness. In the illustration below, both the Munsell and reflectance color solids are represented.

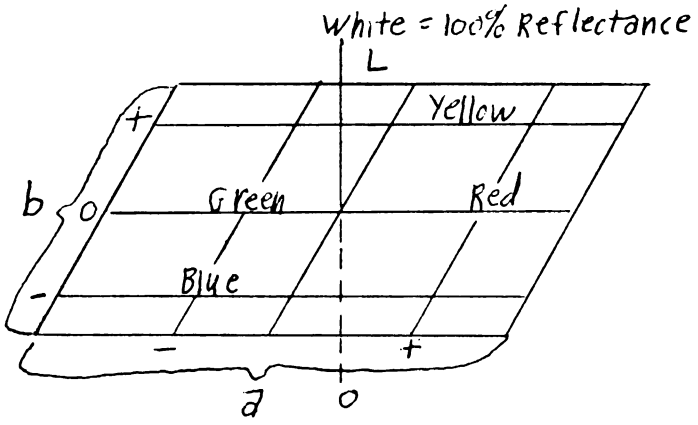
3. Spectrophotometry

A third method applied to analysis of color is spectrophotometry (Beckman Instruction Manual). This method is based on the diffraction of white light by a prism, which is passed through a narrow slit onto a grating and then through a photocell containing the solution to be measured. This causes a current change in the galvanometer proportional to the transmittancy of the solution. When the desired absorption band is located, the instrument can be set for this wave-length and the concentration of

The Munsell and Reflectance Color Solids



Three dimensional color scale defining hue, value, chroma. Munsell Color Co., Inc. Reprint Munsell Book of Color, page 1



Three dimensional color scale defining L, a_L, b_L. Gardner Laboratory, Inc. Reprint Industrial Quality Control (Vol. 17, page 3, 1960).

absorbing material determined on the basis of the percent transmission. In order to determine concentration, the Law of Lambert and Beer is employed, which states that the absorbance or optical density is equal to the product of extinction coefficient, photocell length in cm, and concentration. A complete outline for the determination of myoglobin is presented in the procedure. In addition to the determination of concentration of a chromophoric component, the spectrophotometer may be used as an indication of purity by plotting wave-length against absorption.

EXPERIMENTAL PROCEDURE

Source of Meat

Pork and beef were obtained from Michigan State University Meat Laboratory and lamb from a local meat distributor.

Sampling Procedure

The longissimus dorsi muscle was removed from the beef rib, pork loin, and lamb rack and trimmed of most external fat. Color measurements for each muscle were completed within five days. Ten pork loins were sampled in triplicate. Five replications from each of five beef ribs were studied. For lamb, triplicate samples of five single racks were employed. All meat was stored and studied within a temperature variance of 30-36°F, relative humidity of 75-85%, and air movement of 15-20 feet per minute.

Color Measurements

Surface color of pork, beef, and lamb was determined by Munsell colorimetry and by the Gardner Color and Color Difference Meter. Oxygenation was allowed to progress in total darkness except for when color measurements were made. A spectrophotometric estimation of myoglobin was also performed on lamb.

1. Munsell Disk Colorimetry

The Munsell spinning disk evaluation was employed at periodic time intervals and renotated on the basis of hue, value, and chroma. A

prepared sample was mounted upon a fitted wooden support before placing on the stand. Thus, a sample was easily removed and replaced while still observing the same region for the successive readings. Voegeli (1952) demonstrated that different areas of a muscle will result in different renotations depending upon the concentration of intramuscular fat and myoglobin concentration of the region. The sample was adjusted so that the top surface was at the same level as the disks, allowing equal viewing areas. This area was about two cm^2 at about 8 3/4 inches from the optical eye piece base. In evaluating the color of the sample, such factors as the red-yellow relationship, lightness and darkness, and intensity of the color were considered. Since experience was required for the adjustments of disk combinations, practice trials were conducted on pork, beef, and lamb until satisfactory proficiency was obtained. Although there was a need for as accurate and rapid matches as possible, an exact match could not be made in all cases. For example, the addition of one unit of yellow would change the disk mixture from slightly deficient in yellow to excessive yellow. In such cases, the lesser units of yellow were taken for renotation. Upon obtaining a satisfactory match of the sample, the percentage 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 the number of units used in the match, the Munsell renotation was calculated. The tristimulus values for color were obtained as a weighted percentage of each disk used with the weights being proportional to the disk area (Nickerson, 1958). The following disks were employed.

Specifications for Disks used in Munsell Colorimetry

Lamb and Beef			Pork		
Color	Renotation	Prod. #	Color	Renotation	Prod.#
Red	5R 4/14	3987	Brown	8YR 6.4/11.2	884
Yellow	5Y 8/12	4848	Red	5R 4/14	3987
Black	N1	4174	Black	N1	4174
White	N8	4757	White	N8	4757

Since a rate study on oxygenation of pork, beef, and lamb was conducted, a series of readings were taken. The procedure involved an initial observation on a cross section of the muscle followed by readings at fifteen minute intervals for two hours on pork and lamb and for three hours on beef. Maximum oxygenation was considered as the color evaluation at twenty-four hours.

In order to express color differences in terms of a single number rather than as hue, value, and chroma, a standard color was determined. This involved the direct oxygenation of longissimus dorsi cross-sections of pork, beef, and lamb in a chamber, which was evacuated and filled with pure oxygen. An exposure of two hours in darkness at 32°F was taken as the standard with which air oxygenated samples were compared. The following standards were used:

Standards

*Beef	7.0R 4.0/8.0
Lamb	8.4R 3.8/6.5
Pork	2.4YR 4.8/5.3

*Established by M. M. Voegeli Ph.D. thesis M.S.U. 1952

After determining the standards, the Index of Fading formula (Nickerson, 1946) was employed for the determination of color change in terms of a single number. The formula is as follows:

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

I = Index of Fading

C = Chroma of the sample

H = Difference in hue between sample and standard

V = Difference in value between sample and standard

C = Difference in chroma between sample and standard

A plot of Indexes at each time interval was then made to determine the rate of oxygenation.

2. Gardner Color and Color Difference Meter

Surface color changes were also studied by the Gardner Meter which records an L value, a_L, and b_L which correspond to lightness, redness, and yellowness. Readings were taken at the same time intervals described for Munsell colorimetry. The cross sections of samples were placed on a glass plate (4 x 3 x 1/8 in.) which in turn was placed over an aperture of 15/16 inches with a "large" setting on the Gardner Meter. Before reading the samples, the machine was conditioned for at least one-half hour to the following reference plates. The machine was continuously standardized against the reference plate for each sample at each time interval.

Reference Plates for	Gardner Meter	
	Beef and Lamb	Pork
L	24.1	53.8
a_L	27.4	27.3
b_L	12.5	8.5

The differences of the color of each sample at each time interval from the above reference plate were recorded. The color changes in pork, beef, and lamb due to oxygenation were thus traced by the differences in the L, a_L, and b_L of the sample from the L, a_L , and b_L of the reference plate. The changes in color were appraised by a_L/b_L ratio, total color difference from the standard as expressed by $\sqrt{\Delta L^2 + \Delta a_L^2 + \Delta b_L^2}$, or by increases in a_L (redness).

3. Spectrophotometry

A third method employed only for lamb was the total myoglobin present according to a spectrophotometric procedure outlined by Ginger et al. (1954) and modified by Henry (1959). The procedure used was as follows. Duplicate 25 gram aliquots of ground sample were minced in a Waring blendor for two minutes with 100 ml of cold distilled water and centrifuged for 20 minutes at 2500 rpm at a temperature of 34°F. The supernatant was filtered through cotton, which retained much of the fat that had risen to the top of the solution, and adjusted to pH 7.0 with 1 N NaOH. Foreign proteins were precipitated by addition of 25 volumes

of saturated basic (pH 8) lead acetate based on volume after neutralization. This was added at room temperature since at lower temperatures the protein precipitation is incomplete while at high temperatures (38°C) the myoglobin will also precipitate (Schweigert, 1954). The precipitated solution was allowed to stand for twenty minutes and was then centrifuged for 20 minutes at 2500 rpm. The resulting supernatant was brought to pH 6.6 and the phosphate to 3 M by the addition of solid mono and dibasic potassium phosphate in the ratio of 2.32 moles to .68 moles, which precipitates hemoglobin and leaves myoglobin in solution. After the third centrifugation of twenty-minutes, the supernatant was filtered through Whatman number 41 H filter paper into a 50 ml volumetric flask. After removing two ml of the solution, potassium ferricyanide ($K_3Fe(CN)_6$) was added at .6 millimoles per liter followed by sodium cyanide at .8 m M/l. Care was taken to insure complete dispersal of each cyanide treatment because the potassium ferricyanide oxidizes all of the myoglobin into metmyoglobin and sodium cyanide reacts with metmyoglobin to form the cyanoderivative, cyanmetmyoglobin. This provided a relatively stable solution which was read at 540 millimicrons and slit width of .01-.02 millimeters on the Beckman DU spectrophotometer. The blank consisted of the same reagents and concentrations as the sample.

For the purpose of calculations, the extinction coefficient of 11.5 was considered equivalent to that of cyanmetmyoglobin (Drabkin, 1935). A molecular weight of 16,500 for myoglobin was also assumed (Ginger et al., 1954). The following expression was used to convert concentration of myoglobin to milligrams per gram of fresh tissue.

$$\frac{(A)}{(B)}\ \frac{16,500}{11,500} \times \frac{(C)}{(D)}\ \frac{125}{25} \times \frac{(E)}{(F)}\ \frac{100}{80} \times \frac{(G)}{(H)}\ \frac{50}{48} = 9.33\ K$$

(A) = Molecular weight of myoglobin

(B) = Extinction coefficient

(C) = Initial 100 ml. H_2O + 25 g. sample tissue

(D) = 25 grams of sample tissue

(E) = 80 ml. of supernatant + 20 ml. basic lead acetate

(F) = 80 ml. of supernatant

(G) = 48 ml. of supernatant + 2 ml. of cyanide solutions

(H) = 48 ml. of supernatant

(K) = constant

Using the above equation, the concentration of myoglobin in milligrams per gram of tissue can be expressed by the product of K and the optical density reading.

Statistical Analysis

The statistical analysis of data included means, simple correlation coefficients, and predicting formulae. The following formulae used in analyzing these data were obtained from Snedecor (1958).

Correlation coefficient

$$r = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{\left[N\Sigma X^2 - (\Sigma X)^2\right]\left[N\Sigma Y^2 - (\Sigma Y)^2\right]}}$$

Slope of regression line

$$B = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{N\Sigma X^2 - (\Sigma X)^2}$$

"Y" intercept

$$A = \bar{Y} - \beta \bar{X}$$

Predicting formula

$$\hat{Y} = A + \beta (X)$$

RESULTS AND DISCUSSION

The Effect of Oxygenation Measured by the Munsell Color System

Oxygenation appeared to exert two primary effects on the Munsell renotation. Hue progressed from the yellow-red region toward the red region as oxygenation increased. Chroma increased in magnitude with respect to oxygenation. Value, during a twenty-four hour period, remained relatively constant. For example, the following changes were observed in pork. Maximum hue changed 1.5 units from 7.1 YR to 5.6 YR in ninety minutes while maximum chroma increased 1.1 units from 2.5 to 3.6 in twenty-four hours. Thus, hue changed relatively rapidly in ninety minutes and then remained constant, while chroma increased more gradually and changed slightly less than hue. Value remained constant at 5.6. Data for beef indicated similar trends. Hue increased in redness by changing 1.7 units from 2.1 YR to .4 YR while chroma increased 2.6 units from 3.4 to 6.0 in twenty-four hours. Both hue and chroma changed gradually with respect to increasing time of air exposure but chroma changes were far greater than hue. Value remained constant at 3.9. In lamb, hue changed 1.3 units from 2.3 YR to 1.0 YR while chroma increased 2.1 units from 3.4 to 5.5 in twenty-four hours. As with beef, both hue and chroma changes were gradual but chroma was greater. Value remained constant at 3.9.

When the Munsell renotations were converted to Index of Fading by the Nickerson Formula (1946), oxygenation decreased the Index of Fading proportional to time of exposure to the air. Thus, as the Index of Fading decreased, the renotation of the sample more closely approximated the renotation of the

standard which had been oxygenated with pure oxygen as described in the procedure. In pork, the Index of Fading decreased 3.9 units from 18.7 initially to 14.8 in ninety minutes, which was the time required for maximum oxygenation. For beef there was a decrease of 7.0 units from 22.4 to 15.4. Lamb decreased 5.4 units from 16.3 to 10.9. Therefore, the order of extent of change in Munsell renotation based on Index of Fading due to oxygenation appeared to be beef, lamb, and pork.

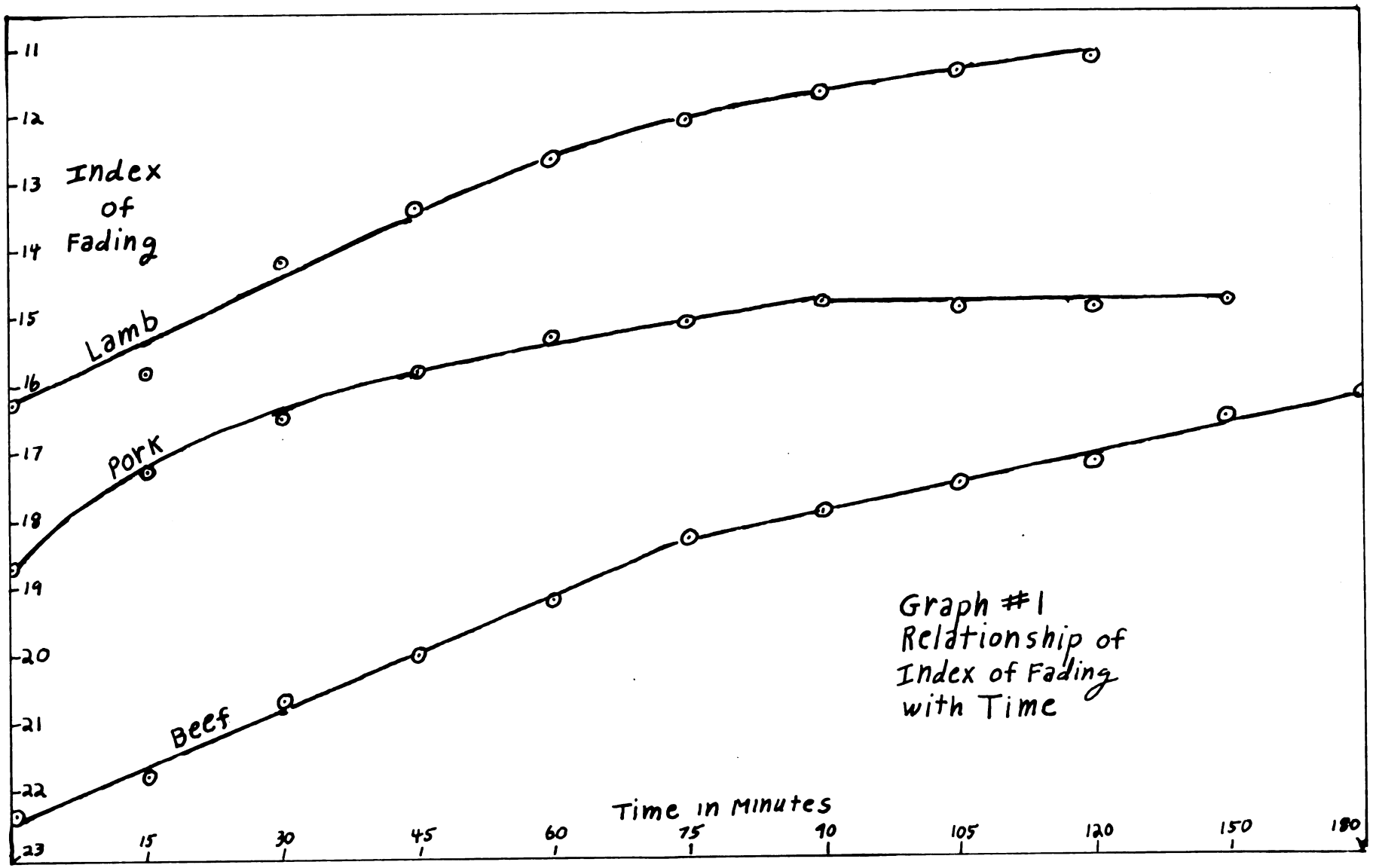
In Table 1 and Graph 1 the data obtained are summarized. Means of renotations are based on thirty samples for pork, twenty-five for beef, and fifteen for lamb.

The Effect of Oxygenation as Measured by Reflectance

The Gardner Color and Color Difference Meter was employed to determine change in surface color due to oxygenation using the L, a_L, and b_L scales. As with the Munsell system, oxygenation affected two criteria of color. As oxygenation increased, the a_L readings, corresponding to redness, increased extensively. The b_L readings, corresponding to yellowness, also increased but to a smaller extent. The L data, indicative of value, remained relatively constant. Most of the change in both a_L and b_L occurred in the first thirty minutes. Changes in color of a sample were determined by standardizing the color difference meter with standard plates and measuring the difference between the sample and the plate in terms of L, a_L, and b_L. The standard pork plate had the specifications of L = 68.5, a_L = 17.4, and b_L = 7.5, while beef and lamb were standardized to L = 24.1, a_L = 27.5, and b_L = 12.5.

Table 1. Summarized Munsell colorimetry data for pork, beef and lamb.

Time	Pork		Beef		Lamb	
	Renotation	Index of Fading	Renotation	Index of Fading	Renotation	Index of Fading
0	7.1 YR 5.7/2.5	18.7	2.1 YR 3.9/3.4	22.4	2.3 YR 3.9/3.4	16.3
15	6.5 YR 5.6/2.7	17.3	2.1 YR 3.9/4.0	21.8	2.5 YR 3.9/4.0	15.8
30	6.1 YR 5.6/2.9	16.5	1.7 YR 3.9/4.3	20.7	2.0 YR 3.9/4.5	14.2
45	5.9 YR 5.6/3.1	15.8	1.6 YR 3.9/4.6	20.0	1.8 YR 3.9/4.7	13.4
60	5.7 YR 5.6/3.3	15.3	1.3 YR 3.9/4.9	19.2	1.5 YR 3.9/4.9	12.7
75	5.7 YR 5.6/3.4	15.1	1.1 YR 3.9/5.2	18.3	1.3 YR 3.9/5.1	12.1
90	5.6 YR 5.6/3.5	14.8	1.0 YR 3.9/5.3	17.9	1.2 YR 3.9/5.2	11.7
105	5.7 YR 5.6/3.6	14.9	.9 YR 3.9/5.5	17.5	1.1 YR 3.9/5.3	12.4
120	5.7 YR 5.6/3.6	14.9	.8 YR 3.9/5.6	17.2	1.0 YR 3.9/5.4	11.2
150	5.7 YR 5.6/3.6	14.8	.7 YR 3.9/5.8	16.5	----	--
180	----	--	.6 YR 3.9/6.0	16.2	----	--
24 hrs.	5.7 YR 5.7/3.6	15.0	.4 YR 3.9/6.0	15.4	1.1 YR 3.9/5.5	10.9



Graph #1
Relationship of Index of Fading with Time

In pork an increase was observed on the a_L scale of 2.9 units from 5.9 to 8.8 while on the b_L scale there was only 2.1 units increase from 8.1 to 10.2 for twenty-four hours. In thirty minutes there was an increase of 1.3 units in a_L and 1.2 units in b_L. The L scale remained relatively constant with a slight downward trend from 42.4 to 40.5. The most extensive changes occurred in beef. The a_L increased 7.3 units from 14.1 to 21.4 while the b_L increased 1.8 units from 9.4 to 11.2. Of these changes, 4.3 units of a_L and 1.5 units of b_L resulted during the first thirty minutes. The L scale declined slightly from 25.2 to 24.8 in three hours. Similar but less extensive changes developed in lamb. The a_L scale increased 5.0 units from 14.2 to 19.2 while the b_L changed 2.1 units from 9.3 to 11.4. In thirty minutes there was an increase of 3.1 units in a_L and 1.6 units in b_L. The L scale remained constant at 25.0 to 25.5.

There are three methods for appraising rate of color change by the Color Difference Meter. These included tracing the change in a_L, total light difference expressed by the relationship $\Delta E^2 = \sqrt{\Delta L^2 + \Delta a_L^2 + \Delta b_L^2}$, and the a_L/b_L ratio. Changes in a_L were previously stated to increase with oxygenation. Total light difference decreased as oxygenation increased. It is also important to note that if the percent changes of a_L and $\sqrt{\Delta L^2 + \Delta a_L^2 + \Delta b_L^2}$ are compared, there will be an agreement within 5%. Changes in total light difference in pork were too small to be established. In beef there was a total change of 7.4 units from 13.7 down to 6.28 in twenty-four hours. In thirty minutes there was a change of 4.5 units. In lamb a similar decrease was observed. A drop of 5.1 units from 13.6 to

8.49 was noted in twenty-four hours with 3.3 units decrease resulting in thirty minutes.

A third technique used to evaluate color change is the a_L/b_L ratio which will increase with oxygenation because a_L or redness increased more rapidly than b_L, or yellowness. However, changes in a_L/b_L were small when compared to a_L and total light difference. In pork an increase of .155 units from .728 to .863 was observed in twenty-four hours. In thirty minutes there was .046 units increase. Beef indicated an increase of .41 units from 1.50 to 1.91 in twenty-four hours. In thirty minutes there was a .19 unit change. Lamb developed an increase of .15 units from 1.53 to 1.68 with .06 units change occurring in thirty minutes. Little correspondence was found in percent color change between a_L/b_L and total light difference or a_L. All information obtained from the Color Difference Meter is summarized in Tables 2 to 4 and Graph 2.

Percent Change in Color Due to Oxygenation

Two methods have been applied for the determination of rate of blooming or increasing redness of muscle pigment due to oxygenation. Although there is some lack of agreement between data obtained from Munsell Colorimetry and the Gardner Color and Color Difference Meter, it can generally be concluded that blooming is most extensive and rapid in the first hour for pork, beef, and lamb. In this study, maximum bloom was assumed to be the color specifications obtained by each method after twenty-four hours of exposure to the air in darkness and sealed in a plastic bag to limit moisture loss. The percentage color change was derived in the

Table 2. Summarized reflectance data for pork

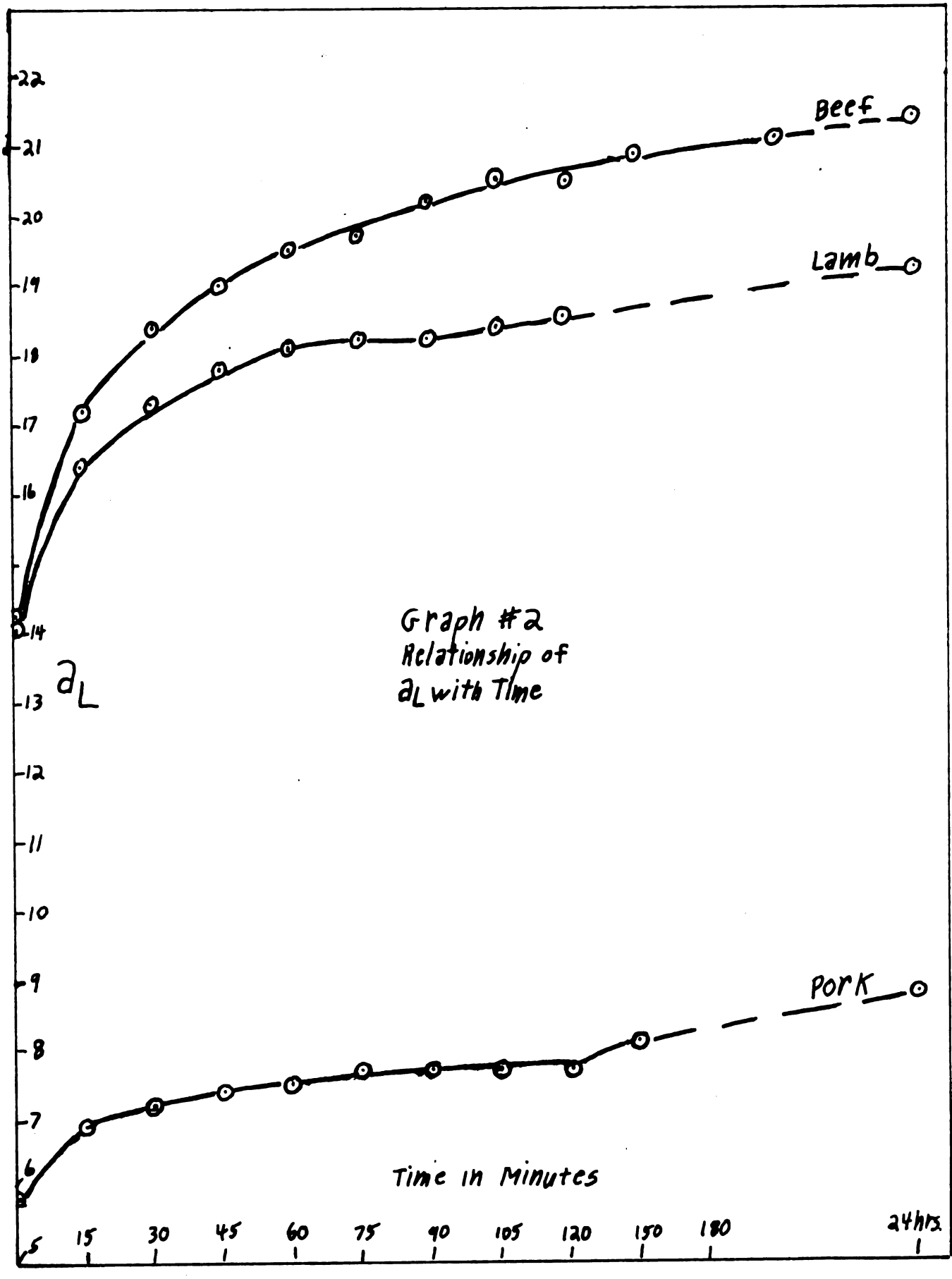
	Means of raw data					Percent changes		
Time	L	a_L	b_L	a_L/b_L	$\Delta E^2 = \sqrt{\Delta L^2 + \Delta a_L^2 + \Delta b_L^2}$	a_L %	ΔE^2 %	a_L/b_L %
0	42.4	5.9	8.1	.728	28.5	--	--	--
15	42.0	6.9	8.9	.775	28.5	34.5	0	34.8
30	41.8	7.2	9.3	.774	28.6	44.8	8.3	34.1
45	41.3	7.4	9.2	.804	29.0	51.7	41.7	56.3
60	41.3	7.5	9.4	.798	29.0	55.2	41.7	51.8
75	41.2	7.7	9.5	.810	29.0	62.1	41.7	60.7
90	40.6	7.7	9.5	.810	29.6	62.1	91.7	60.7
105	40.7	7.7	9.5	.810	29.5	62.1	83.3	60.7
120	40.5	7.7	9.5	.810	29.7	62.1	100	60.7
150	40.6	8.1	9.8	.826	29.5	75.9	83.3	72.6
24 hrs.	41.9	8.8	10.2	.863	28.1	--	--	--

Table 3. Summarized reflectance data for beef

	Means of raw data					Percent changes		
Time	L	a_L	b_L	a_L/b_L	$\Delta E^2 = \sqrt{\Delta L^2 + \Delta a_L^2 + \Delta b_L^2}$	a_L %	ΔE %	a_L/b_L %
0	25.2	14.1	9.4	1.50	13.7	--	--	--
15	25.1	17.2	10.4	1.65	10.5	42.5	44.3	36.6
30	25.3	18.4	10.9	1.69	9.22	58.9	60.4	46.3
45	25.2	19.0	10.9	1.74	8.63	67.1	68.3	58.5
60	25.2	19.5	11.0	1.77	8.12	74.0	75.2	65.9
75	25.1	19.7	11.0	1.79	7.91	76.7	78.0	70.7
90	25.1	20.2	11.0	1.89	7.42	83.6	84.6	82.9
105	25.0	20.5	11.0	1.86	7.11	87.7	88.8	87.8
120	24.9	20.5	11.0	1.86	7.10	87.7	88.9	87.8
150	24.8	20.9	11.0	1.90	6.71	93.1	94.2	97.6
180	24.8	21.1	11.0	1.92	6.51	95.9	96.9	102.4
24 hrs.	25.4	21.4	11.2	1.91	6.28	--	--	--

Table 4. Summarized reflectance data for lamb

Time	Means of raw data					Percent changes		
	L	a_L	b_L	a_L/b_L	$\Delta E^2 = \sqrt{\Delta L^2 + \Delta a_L^2 + \Delta b_L^2}$	a_L %	ΔE %	a_1/b_L %
0	25.3	14.2	9.3	1.53	13.6	--	--	--
15	25.5	16.4	10.4	1.58	11.3	40.0	45.0	33.3
30	25.4	17.3	10.9	1.59	10.3	62.0	64.6	40.0
45	25.5	17.8	11.1	1.60	9.81	72.0	74.2	46.7
60	25.4	18.1	11.0	1.64	9.51	78.0	80.0	73.3
75	25.4	18.2	10.9	1.66	9.43	80.0	81.6	86.7
90	25.3	18.2	10.9	1.66	9.41	80.0	82.0	86.7
105	25.1	18.4	11.0	1.67	9.18	84.0	86.5	93.3
120	25.0	18.5	11.0	1.68	9.07	86.0	88.6	100.0
24 hrs.	26.0	19.2	11.4	1.68	8.49	--	--	--


22
21
20
19
18
17
16
14
13
12
11
10
9
8
7
6
5
a_L
Beef
Lamb
Pork
Graph #2
Relationship of
a_L with Time
Time in Minutes
15
30
45
60
75
90
105
120
150
180
24hrs

Munsell system by calculating the Index of Fading from the Nickerson Formula and dividing the difference in index at each time interval from the initial index by the total change in index. Similarly, the percent change in theGardner system was determined by dividing the difference in a_L at each time interval from the initial a_L by the total change in a_L.

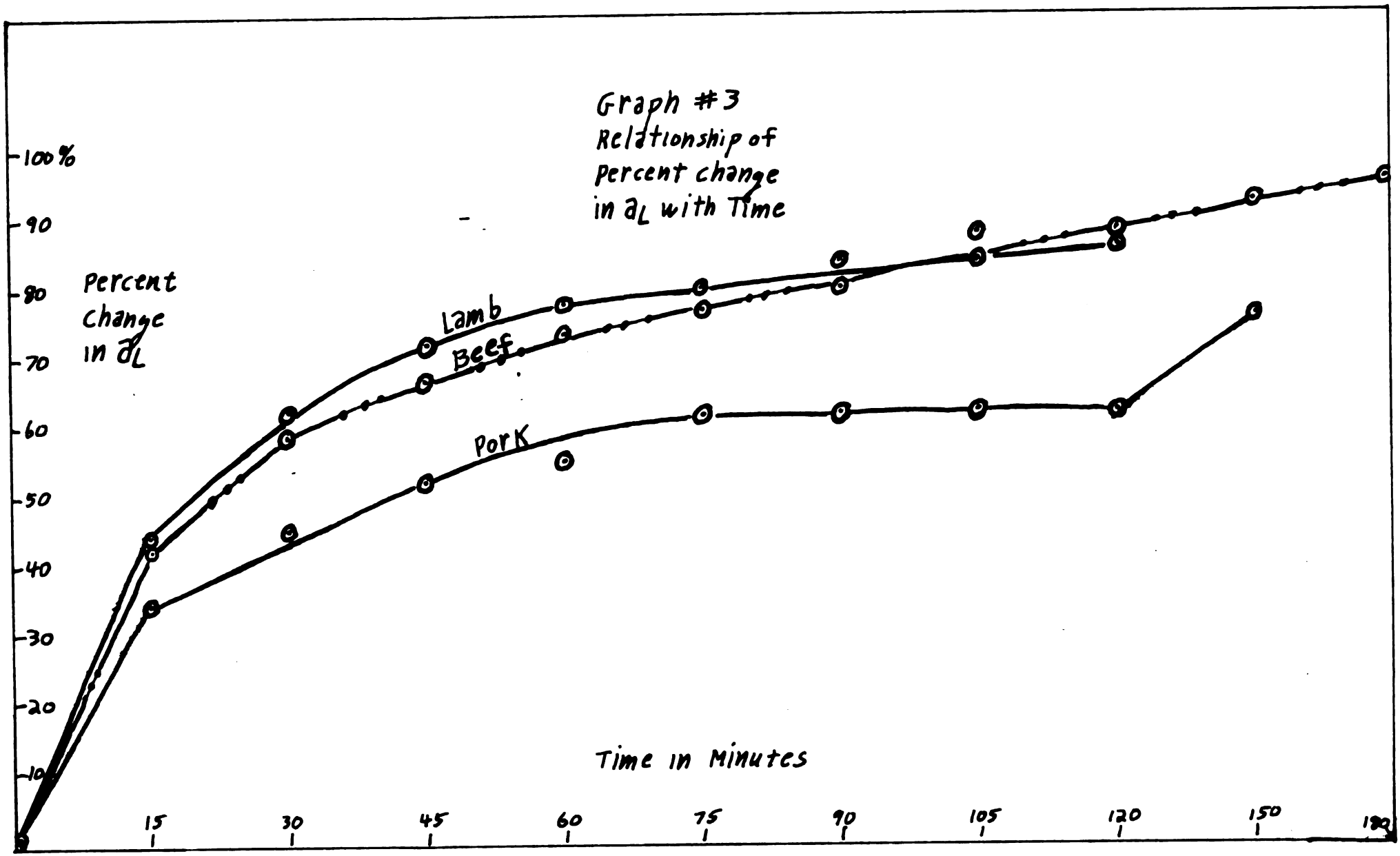
In pork there was a change of 87% by Index of Fading and 55% by a_L in one hour. Munsell colorimetry indicated that a 100% change due to blooming occurred in ninety minutes while reflectance inferred that blooming is much more gradual during a twenty-four hour period. Data from beef also demonstrated that blooming occurred most rapidly during the first hour as shown by 45% change in Index of Fading and 74% in a_L. Both methods agree that at least 90% of the change was produced in three hours. Reflectance data indicated the rate of change in color to be much more rapid than did Munsell colorimetry for beef. In pork Munsell colorimetry indicated a much more rapid change than reflectance. Trends in data for lamb were similar to that of beef. Reflectance measurements showed that there was a more rapid change than did Munsell colorimetry. The percent change in one hour was 78% by a_L as compared to 67% by Index of Fading. Both methods agree that over 85% of the total change resulted in two hours. A conclusion that may be determined from the obtained data is that muscle tissue containing small concentrations of myoglobin required less time to become fully oxygenated than did tissue having higher myoglobin content. Thus pork, lamb, and beef appeared to be the order of least time required to achieve maximum bloom. This is substantiated by Munsell

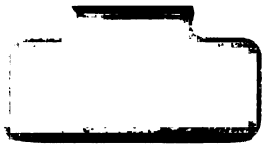
colorimetry as shown by respective changes of 87%, 67%, and 45% change in Index of Fading in one hour. Reflectance data showed less conclusive change in percent a_L. In Table 5 and Graphs 3 and 4 the percent color changes for pork, lamb, and beef are summarized using the same sampling as described in Munsell colorimetry.

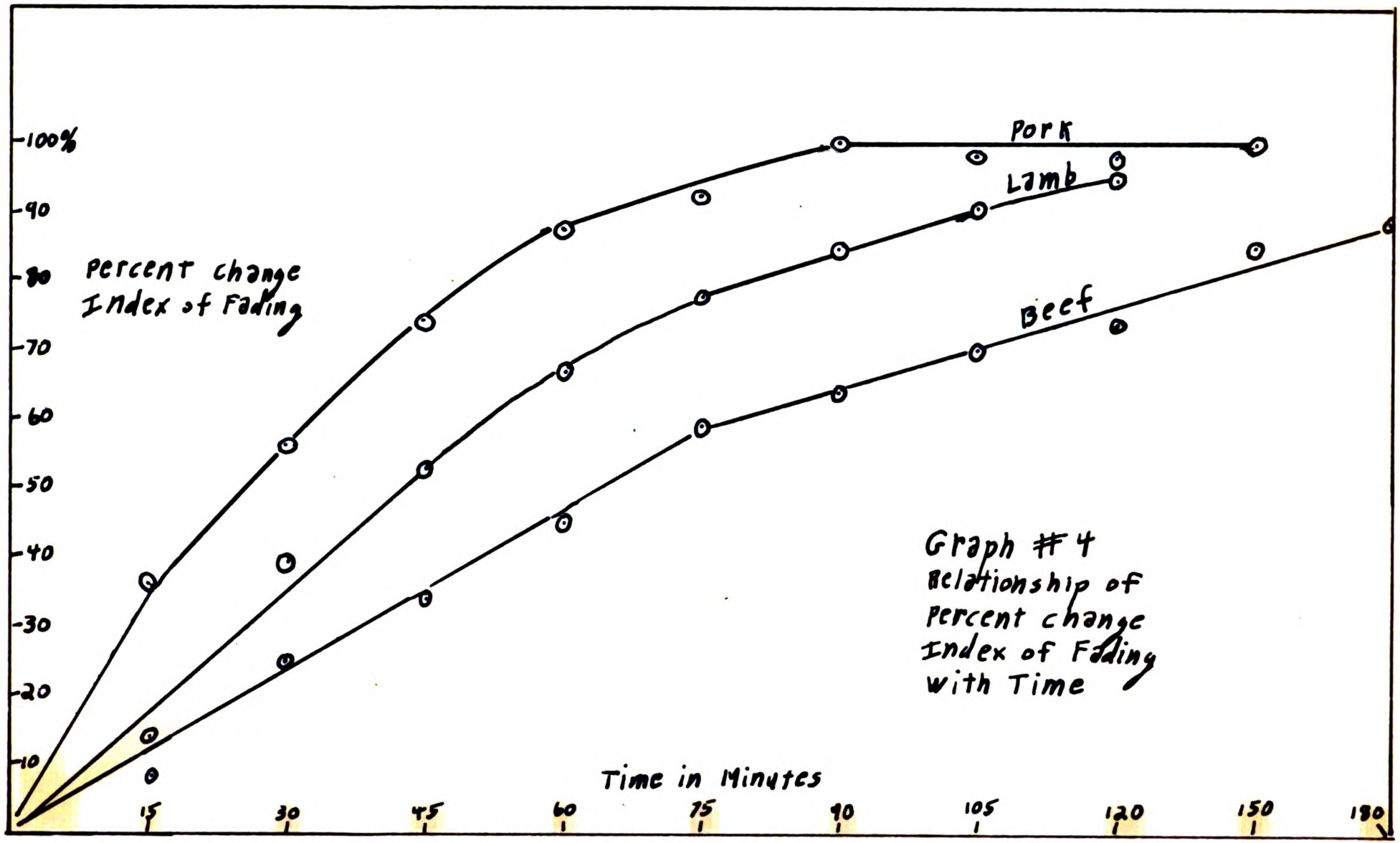
Table 5. Comparison of percent color change between Munsell and reflectance systems

	Index of Fading			a_L		
Time	Pork %	Lamb %	Beef %	Pork %	Lamb %	Beef %
0	--	--	--	--	--	--
15	36	9	9	34	44	42
30	56	39	24	45	62	59
45	74	53	34	52	72	67
60	87	67	45	55	78	74
75	92	78	59	62	80	77
90	100	85	64	62	80	84
105	98	91	70	62	84	88
120	98	95	74	62	86	88
150	100	--	85	76	--	93
180	--	--	90	--	--	96
24 hrs.	--	--	--	--	--	--

On the basis of the above data, recommendations can be made for optimal time to read color as a prediction of final color based on percent change in a reasonable time lapse. The following conclusions were drawn:


Graph #3
Relationship of
percent change
in a_L with Time
100%
90
80
70
60
50
40
30
20
10
Percent
Change
in a_L
Lamb
Beef
Pork
15
30
45
60
75
90
105
120
150
180
Time in Minutes





Graph #4
Relationship of
Percent change
Index of Fading
with Time

1. Pork can be read in thirty minutes by Munsell colorimetry which will produce a 56% change.
2. Pork can be read in forty-five minutes by reflectance which will produce a 52% change.
3. Beef can be read in seventy-five minutes by Munsell colorimetry which will produce a 59% change.
4. Beef can be read in thirty minutes by reflectance which will produce a 59% change.
5. Lamb can be read in forty-five minutes by Munsell colorimetry which will produce a 53% change.
6. Lamb can be read in thirty minutes by reflectance which will produce a 62% change.

Conversion of Reflectance Data to Munsell Renotations

The Munsell renotation may be determined indirectly by two different methods from data obtained from the Color Difference Meter. One method involves the conversion of Gardner L, a_L, and b_L into I.C.I. tristimulus values (X, Y, Z) by appropriate conversion calculations and using the same I.C.I. chromaticity diagrams employed for Munsell renotations (Davis and Gould, 1955). The second technique employs the conversion of Gardner L into Munsell value and uses diagrams which directly convert a_L and b_L into hue and chroma (Davis and Gould, 1955).

The first method requires the computation of the tristimulus values (X, Y, Z) from Gardner data L, a_L, and b_L by means of the following equations. Initially, Y is determined.

$$L = 100\ (Y^{1/2}) \text{ or } Y = (\frac{L}{100})^2$$

$$a_L = \frac{175\ (1.02\ X - Y)}{Y^{1/2}}$$

$$b_L = \frac{70\ (Y - .847\ Z)}{Y^{1/2}}$$

Knowing Y and a_L, X is calculated and knowing Y and b_L, Z is calculated. The chromaticity coordinates (x, y, z) are computed from the tristimulus values (X, Y, Z) as fractions of their totals as follows. The sum of x, y and z must equal one.

$$x = \frac{X}{X + Y + Z},\ y = \frac{Y}{X + Y + Z},\ z = \frac{Z}{X + Y + Z}$$

In order to determine Munsell value, the I.C.I. (Y) equivalents published by Nickerson (1948) must be consulted. Because data are presented in terms of Yw (%) relative to a standard white magnesium oxide, the Yw (%) must be divided by 100 to obtain Y from which any specified Munsell value can be determined. Knowing value, x, and y, the Munsell renotation for hue and chroma can be observed from the I.C.I. chromaticity diagrams in the usual manner. In cases where the sample value lies between two values, the usual interpolations must be performed.

The second method involves the direct conversion of Gardner L, a_L, and b_L readings into Munsell renotations. First, L readings are converted to Y by the Gardner equation $Y = (\frac{L}{100})^2$. The number obtained for Y is converted to Yw (%) by multiplying by 100. The correct Munsell value is then obtained from the Nickerson tables. After L is converted to value, the Munsell value is used to determine which chromaticity diagrams to use in order to obtain hue and chroma renotations from Gardner a_L and b_L readings. In order to facilitate conversion, the hue and chroma renotations of any point which

falls within the boundaries of an area established by two hue and two chroma loci are further geometrically subdivided into .5 hue units and .5 chroma units. The spacing of hue and chroma steps is less uniform in terms of a_L and b_L than in terms of the Munsell units because of the configuration of the color solid (Younkin, 1950). If the value obtained lies between two values, the hue and chroma renotations from the two appropriate diagrams must be interpolated as in the Munsell system. Detailed conversions and diagrams are presented by Davis and Gould (1955).

MacGillivray (1931) reported a comparison of data obtained by direct renotation of Munsell hue, value, and chroma with data derived from reflectance L, a_L, and b_L based on tomato color. His conclusions were:

1. Munsell hues obtained directly were considerably more red than hues calculated from Gardner readings.
2. Munsell chromas obtained directly were considerably higher than chromas calculated from Gardner readings.
3. Munsell values were approximately the same as values calculated from Gardner readings.

The above statements were based on nominal Munsell notations before the "study of spacing of the Munsell system was made by a subcommittee of the colorimetry committee of the Optical Society of America." (Davis and Gould, 1955). Now more precise charts and tables are available constituting the definition of the Munsell system in smoothed I.C.I. chromaticity diagrams. In addition to spacing of charts, Gould (1955) has reported several other factors which will effect renotation conversion. Instrumental illuminating conditions in the Color Difference Meter effect the L,

a_L, and b_L obtained, which effect the conversion. Also, different readings will result from small and large aperture size. Large area illumination spreads the light from the light source over the entire aperture in a relatively diffuse manner. Small area illumination concentrates the light in a small spot allowing greater possibility of light loss due to lateral dispersion. There is also the chance of obtaining readings in localized areas which are not representative of the whole by use of the small aperture.

According to data obtained on beef and lamb, results appeared to be directly opposite to MacGillivray (1931). The following trends were observed in data derived directly from renotation of Munsell hue, value, and chroma in comparison to conversion from reflectance L, a_L, and b_L using the large aperture and constant illumination.

1. Munsell hues were more yellow-red or less red than converted hues from Gardner readings.
2. Munsell chromas were lower than chromas obtained from conversion of Gardner readings.
3. Munsell value units were higher, or whiter, than value converted from Gradner readings.
4. Index of Fading approximately corresponded between the two methods when based on the same standard index of fading.

Since all samples were viewed by the photocell through a glass plate described in the procedure, an attempt was made to calibrate the error caused by the glass plate. This was done by standardizing the machine with the reference plate L = 24.1, a_L = 27.4, and b_L = 12.5. The glass plate was then placed over the aperture and the reference plate placed

on top of the glass. The mean of readings taken through the glass were L = 21.9, a_L = 21.9, and b_L = 11.1. The effect of the glass was to decrease L by 2.2 units which corresponds to a drop of .3 value units when converted to the Munsell system. There was also a drop of 5.5 a_L units and 1.4 b_L units due to the glass. This caused an approximate loss in redness of .4 R units hue, and a decrease of 1.6 units chroma when converted on a value diagram of 3. Thus the effect of the glass was to decrease L, a_L, and b_L readings which decreased value, redness, and chroma. Therefore, the glass accounted for much of the difference established in the data between the Munsell renotations derived directly by disk colorimetry and by conversion from reflectance.

An attempt was made to convert reflectance readings in pork to the Munsell system but changes were considered too small. In Tables 6 and 7 the results obtained for beef and lamb are summarized for the conversion of reflectance data to the Munsell Color System using the second method of conversion.

In Table 6 the changes in beef color due to oxygenation were recorded for both the original Munsell renotation obtained by disk colorimetry and converted Munsell renotation derived by the Color Difference Meter. Comparative Indexes of Fading and percent color changes based on Indexes of Fading are also presented. Initially the original Munsell renotation was 2.1 YR 3.9/3.4 as compared to 1.1 YR 5.0/4.7 for the converted renotation. Thus, the original renotation was found to be more yellow-red or less red in hue, higher in value, or whiter, and lower in chroma or less intense than the converted renotation. Both renotations were converted

Table 6. Summary of Munsell data obtained directly and by conversion from reflectance for beef

Time	Original Munsell data			Converted reflectance data			a_L %
	Munsell renotation	Index of Fading*	Percent change	Munsell renotation	Index of Fading*	Percent change	
0	2.1 YR 3.9/3.4	22.4	--	1.1 YR 3.0/4.7	23.6	--	--
30	1.7 YR 3.9/4.3	20.7	24	.5 YR 3.0/5.9	20.5	49	59
60	1.3 YR 3.9/4.9	19.2	45	.25 YR 3.0/6.2	19.3	68	74
90	1.0 YR 3.9/5.3	17.9	64	10 R 3.0/6.3	18.7	77	84
120	.8 YR 3.9/5.6	17.2	74	9.9 R 3.0/6.4	18.2	84	88
180	.6 YR 3.9/6.0	16.2	90	9.7 R 3.0/6.5	17.5	97	96
24 hrs.	.4 YR 3.9/6.0	15.4	--	9.7 R 3.0/6.6	17.3	--	--

*Index of Fading for beef based on 7.0 R 4.0/8.0

Table 7. Summary of Munsell data obtained directly and by conversion from reflectance for lamb

Time	Original Munsell data			Converted reflectance data			a_L %
	Munsell renotation	Index of Fading*	Percent change	Munsell renotation	Index of Fading*	Percent change	
0	2.3 YR 3.9/3.4	16.3	--	1.0 YR 3.0/4.7	15.1	--	--
30	2.0 YR 3.9/4.5	14.2	39	.9 YR 3.0/5.7	13.9	28	62
60	1.5 YR 3.9/4.9	12.7	67	.7 YR 3.0/5.9	12.0	74	78
90	1.2 YR 3.9/5.2	11.7	85	.6 YR 3.0/5.9	11.8	79	80
120	1.0 YR 3.9/5.4	11.2	95	.6 YR 3.0/6.0	11.6	83	86
24 hrs.	1.1 YR 3.9/5.5	10.9	--	.6 YR 3.0/6.3	10.9	--	

*Index of Fading for lamb based on 8.4 R 3.8/6.5

to Index of Fading using the same reference index which resulted in approximately the same index at each time interval for the two methods. For example, initially the original index was 22.4 while the converted index was 23.6. The percent color changes were also compared and indicated that from ninety minutes to three hours there was an agreement of within 13%. For example, in ninety minutes the original Munsell data indicated a 64% change while the converted L, a_L, and b_L data showed a 77% change based on percent change of Index of Fading. The percent change in a_L was 84%.

In Table 7 the results for lamb are summarized, which were found to closely parallel those for beef. Again, the original renotation for hue was more yellow-red, value was higher, and chroma was lower than the converted renotation. For example, the original initial renotation was 2.3 YR 3.9/3.4 while the converted renotation was 1.0 YR 3.0/4.7. As with beef, close correspondence was obtained between Indexes of Fading as shown by 16.3 for the original Munsell renotation as compared to 15.1 for the converted L, a_L, and b_L renotation based on the same standard Index of Fading. Close correspondence was also obtained within 12% for the percent change of color between the methods. For example, the original percent change in one hour was 67% as compared to 74% by the converted method. The corresponding percent change in a_L was 78%.

Correlation Between Methods of Color Analysis

1. Correlation between reflectance and Munsell systems.

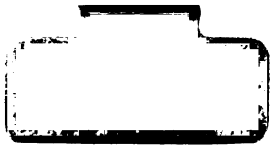
Rikert (1956) indicated that it is desirable to express color as a single number and conducted a survey to determine whether meat color

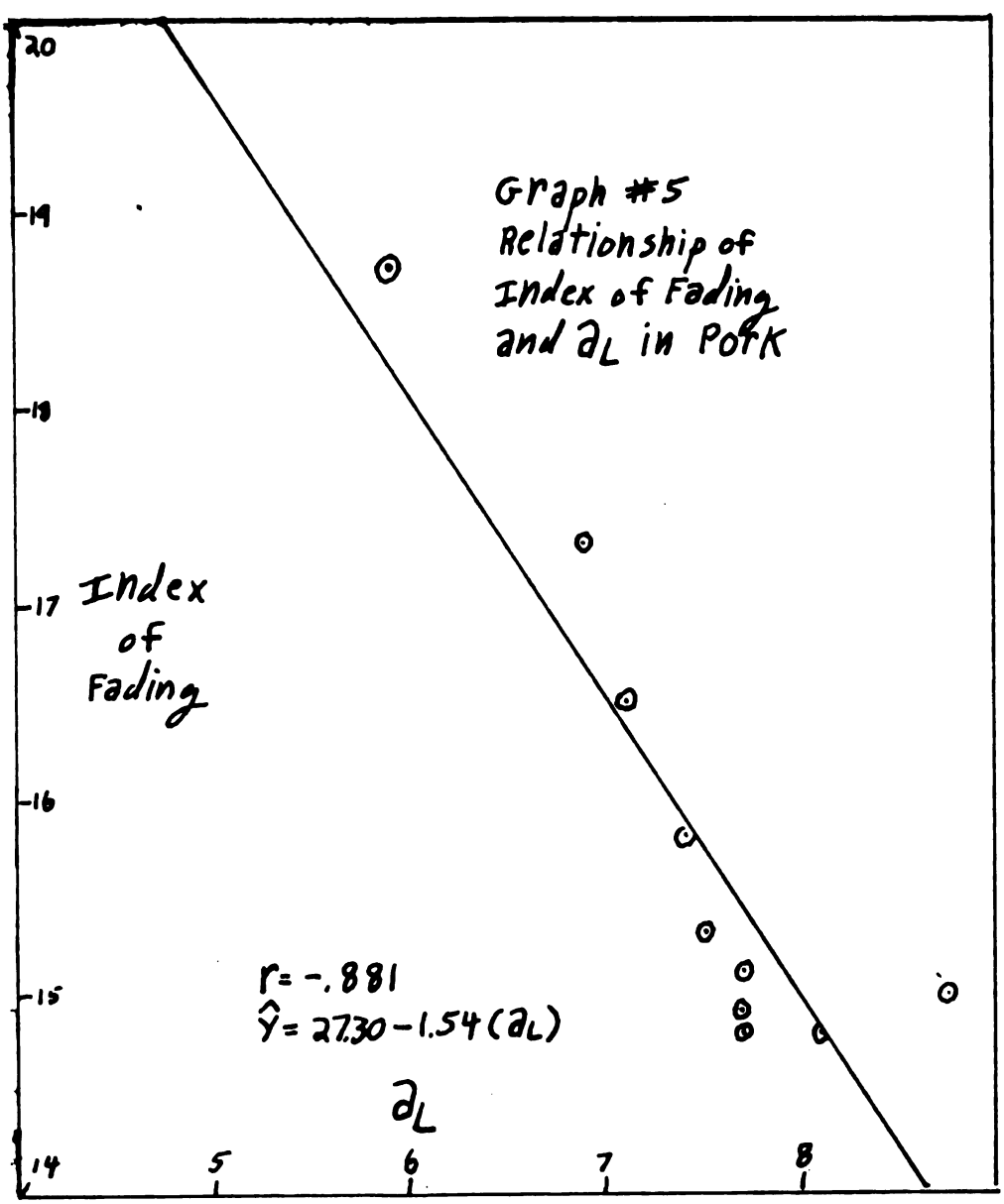
on the Gardner meter correlated significantly with Munsell renotation. Since value in the Munsell system is practically indentical to L in the Gardner system, he attempted no correlations on value. He found that a_L showed a highly significant correlation with both hue and chroma on fresh ground meat. Also, b_L showed a significant correlation only with chroma. Since a_L significantly correlated with hue and chroma, he stated that it seems to qualify as a satisfactory index of the color of fresh meat.

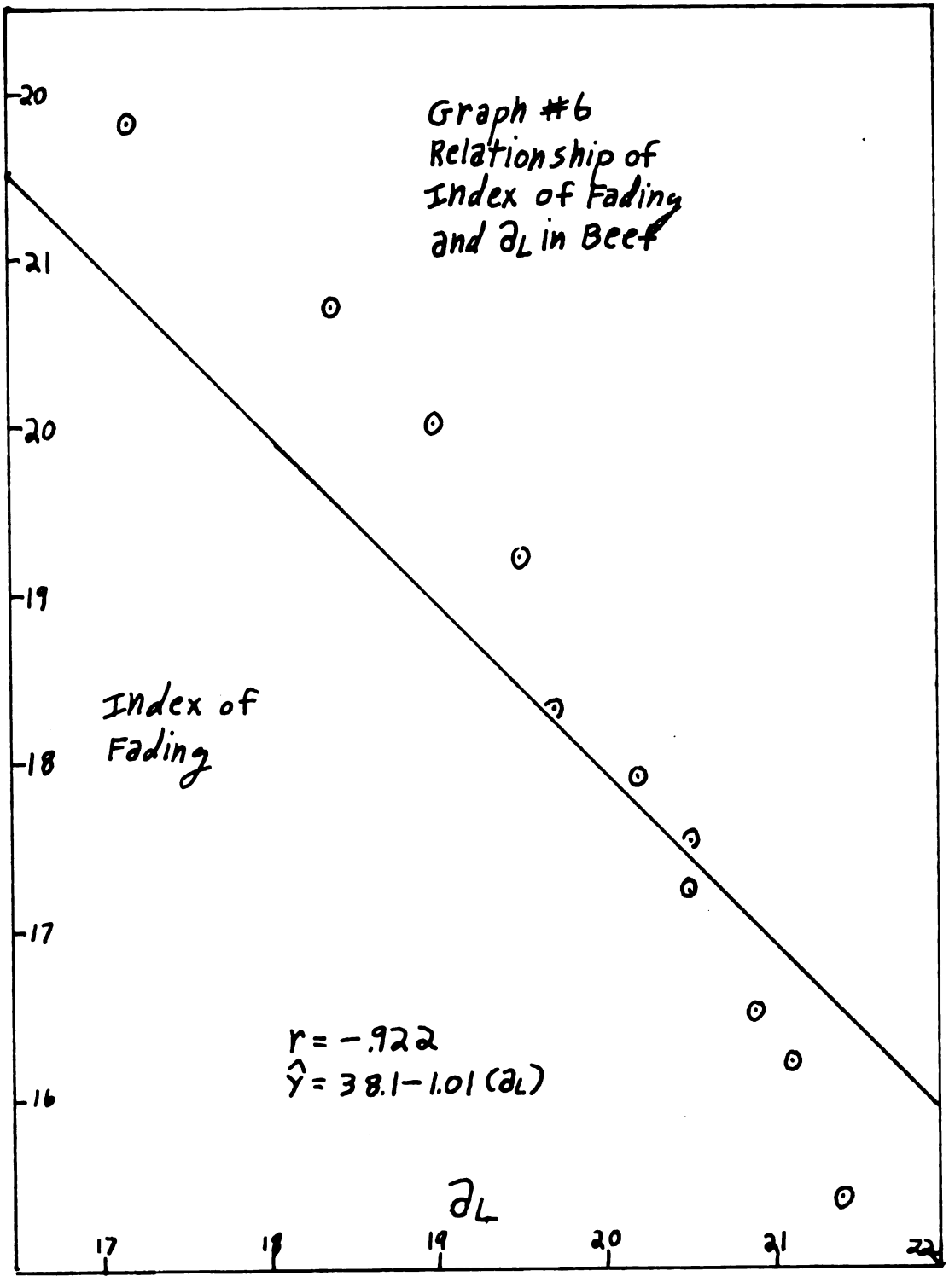
Using data obtained from the Munsell and Gardner systems, correlations were determined between Index of Fading and a_L in pork, beef, and lamb. Highly significant negative correlations were obtained by comparing the Index of Fading and a_L at each time interval during the oxygenation study. A correlation of -.881 was found for pork based on eleven time intervals. A correlation of -.922 was found for beef based on twelve time intervals. A correlation of -.922 was found for lamb based on ten time intervals. Thus, there is a highly significant negative correlation between Index of Fading of the Munsell system and a_L of the Gardner system. In Table 8 and Graphs 5 to 7, the information on correlation is summarized.

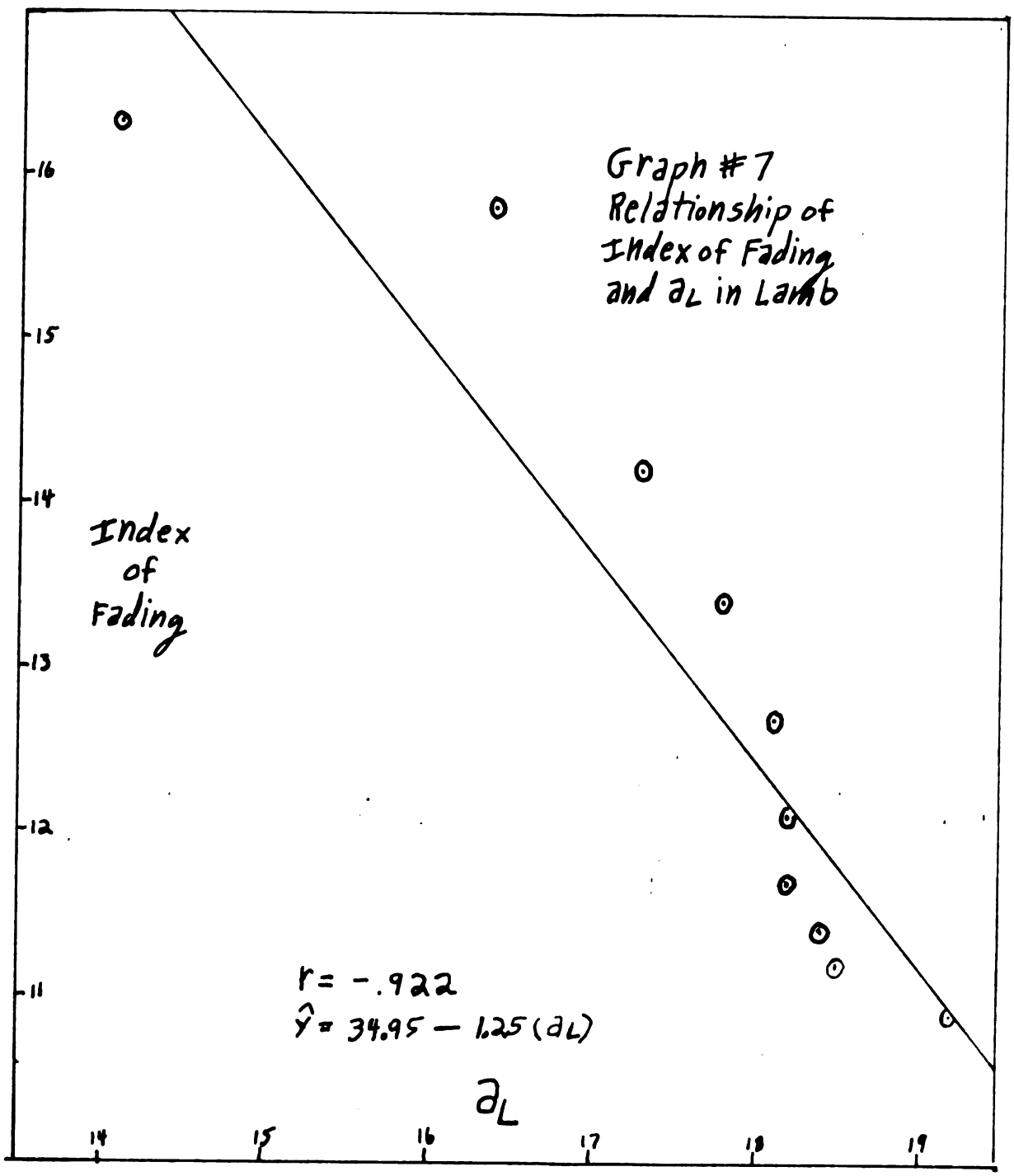
Table 8. Correlation of Munsell and reflectance data

	Pork	Beef	Lamb
Correlation coefficient	-.881	-.922	-.922
Slope (B)	-1.540	-1.009	-1.247
"Y" intercept (A)	27.30	38.13	34.95
Predicting formula	Y=27.3-1.54(X)	Y=38.1-1.01(X)	Y=34.9-1.25(X)
Level of significance	1%	1%	1%




20
19
18
17
16
15
14
5
6
7
8
Index of Fading
∂_L
Graph #5
Relationship of
Index of Fading
and ∂_L in Pork
$r = -.881$
$\hat{y} = 27.30 - 1.54(\partial_L)$


Graph #6
Relationship of
Index of Fading
and ∂_L in Beef
Index of
Fading
20
21
20
19
18
17
16
$r = -.922$
$\hat{y} = 38.1 - 1.01(\partial_L)$
∂_L
17
18
19
20
21
22


Graph #7
Relationship of
Index of Fading
and a_L in Lamb
Index
of
Fading
16
15
14
13
12
11
r = -.922
$\hat{y}$ = 34.95 − 1.25 (a_L)
a_L
14
15
16
17
18
19

2. Correlation between Munsell and spectrophotometric colorimetry

Some attempts have been made to correlate the Munsell and spectrophotometric methods of analysis. Butler (1953) studied relation between Index of Fading and percent metmyoglobin in fresh beef and found the correlation coefficients ranged from .830 to .882. Townsend (1958) found a correlation on frozen beef of .777 to .930 between Index of Fading and percent metmyoglobin. Henry (1959) found a correlation coefficient of .69 on pork between Index of Fading and total myoglobin. In limited research conducted on lamb, the results of the present study indicate a non significant correlation of .596 between Index of Fading and total myoglobin. This study was based on five trials comparing the total myoglobin by the Ginger (1954) procedure as modified by Henry (1959) with the Index of Fading obtained from different lamb samples at the initial reading. A correlation of .604 was obtained between initial a_L in reflectance and total myoglobin on lamb on the basis of five trials.

Advantages and Limitations to Methods of Color Analysis

There are many advantages and limitations in the Munsell system of colorimetry. Advantages include simplicity of apparatus, no effect from electrical power fluctuations, inexpensiveness of apparatus, no sample preparation, and the evaluation of surface color. Disadvantages include human judgment in matching the disks with the sample, disagreement between operators on what is a match, length of time required to match while sample color is changing, alteration of color on disks due to air exposure and use, inability to replace disks with exactly the same color specification, operator fatigue, operator training, and labor and time needed

to renotate.

The Gardner Color and Color Difference Meter also has many advantages and limitations. Advantages include quick and precise measurements, no operator fatigue, impartial objective basis for judgment in "borderline disputes", small sample preparation, and no operator training. Limitations involve increase in error as specification of color in sample differs from the reference plate, "Metameric colors" or the same color yielding different color data on the same instrument, some variance between instruments, electrical fluctuations in the power line serving the potentiometer, dependence on a complicated apparatus that may be difficult to service, and error due to the reflection of glass on top of which the sample is placed for readings. According to the Gardner Laboratory service bulletin (G6550), instrumental precision is comparable to the smallest perceptible color difference discernible by the trained eye of a human color matcher. This is usually considered to be about .2 - .3 NBS (National Bureau of Standards Units). This service bulletin also stated that the same reference plate will have a variance of .3 NBS units between instruments.

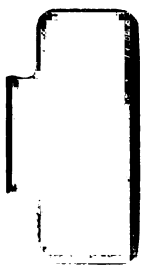
A third method of color analysis applied only to lamb was spectrophotometry. Advantages for spectrophotometry include the elimination of human judgment error, sample homogeneity, and an estimation of the relative percentages of reduced, oxy-, and metmyoglobin involved in meat color. Disadvantages are labor required for sample preparation, greater possibility for procedure variance, and incomplete fractionation of myoglobin during isolation.

SUMMARY AND CONCLUSIONS

A study was conducted to determine the oxygenation rates of pork, beef, and lamb by the Munsell Colorimetry and the Gardner Color and Color Difference Meter. On the basis of data obtained, recommendations can be made for the time required to read color after one half of the color change has occurred due to oxygenation. By Munsell Colorimetry, pork may be read in thirty minutes, beef in seventy-five minutes, and lamb in forty-five minutes. By reflectance, pork may be read in forty-five minutes, beef in thirty minutes, and lamb in thirty minutes.

The effect of oxygenation on the methods of color analysis was also reviewed. In the Munsell system, oxygenation appeared to increase the redness of hue and to increase chroma while value remained constant. In the Gardner system, oxygenation appeared to extensively increase a_L which corresponds to redness. Also, b_L, corresponding to yellowness, was increased to a lesser degree. The L readings indicative of value, remained constant. An attempt was also made to convert the Gardner system into the Munsell system. Original Munsell renotations appeared to be more yellow-red, or less red in hue, higher in value, or whiter, and lower in chroma than the converted Gardner renotations. Indexes of Fading between the two methods seemed to correspond very closely.

Several highly valuable relationships were found between Munsell and reflectance colorimetry. In reflectance, a_L was shown to compare closely with total light difference on a percent color change basis. Thus, the use of a_L as an indication of color change eliminates the labor involved



in calculating $\sqrt{\Delta L^2 + \Delta a_L^2 + \Delta b_L^2}$. Also, a highly significant negative correlation was found between Index of Fading in the Munsell system and a_L in the Gardner system. Therefore, a_L could be used as an indication of rate of oxygenation.

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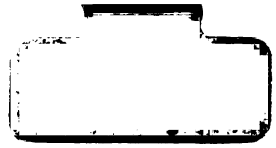

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APPENDIX

Appendix I. Pork data obtained by Munsell Colorimetry

Time	Loin H Sample 1 Renotation	Loin H Sample 1 Index of Fading	Loin H Sample 2 Renotation	Loin H Sample 2 Index of Fading	Loin H Sample 3 Renotation	Loin H Sample 3 Index of Fading
0	7.0 YR 6.2/2.5	21.4	7.3 YR 5.6/2.7	17.9	6.9 YR 5.2/2.4	15.4
15	6.5 YR 6.2/2.8	20.5	6.6 YR 5.6/2.9	16.9	6.8 YR 5.1/2.5	14.6
30	6.2 YR 6.2/3.0	19.9	6.5 YR 5.6/3.0	16.6	6.3 YR 5.1/3.0	13.4
45	5.6 YR 6.2/3.0	19.0	6.2 YR 5.6/3.2	16.0	6.3 YR 5.1/3.1	13.2
60	5.3 YR 6.2/3.3	18.2	6.1 YR 5.6/3.4	15.5	5.7 YR 5.1/3.5	11.8
75	5.3 YR 6.2/3.4	18.0	6.1 YR 5.6/3.7	15.1	5.7 YR 5.1/3.7	11.5
90	5.3 YR 6.2/3.5	17.9	5.5 YR 5.6/3.7	14.6	5.8 YR 5.2/3.8	12.1
105	5.3 YR 6.2/3.5	17.9	5.6 YR 5.6/3.9	14.0	6.3 YR 5.2/3.7	13.0
120	5.7 YR 6.2/3.3	19.7	6.1 YR 5.6/3.8	14.5	6.3 YR 5.2/3.7	13.0
150	5.6 YR 6.2/3.5	18.3	6.1 YR 5.6/3.8	14.5	6.2 YR 5.2/3.4	13.3
24 hrs.	5.8 YR 6.2/3.6	18.4	6.1 YR 5.6/3.8	14.5	5.0 YR 5.2/3.4	11.6

Appendix I. Pork data obtained by Munsell Colorimetry (continued)

	Loin I					
	Sample 1		Sample 2		Sample 3	
Time	Renotation	Index of Fading	Renotation	Index of Fading	Renotation	Index of Fading
0	7.6 YR 5.7/2.5	19.0	7.6 YR 5.5/2.4	17.9	7.4 YR 5.5/2.7	17.4
15	6.7 YR 5.7/2.6	18.0	6.5 YR 5.4/2.9	15.6	6.8 YR 5.5/2.9	16.5
30	6.4 YR 5.7/2.8	17.4	6.1 YR 5.3/3.1	14.2	6.2 YR 5.5/3.1	15.5
45	5.9 YR 5.7/3.1	16.3	5.8 YR 5.3/3.4	13.3	6.0 YR 5.5/3.3	14.9
60	5.7 YR 5.6/3.3	15.1	6.0 YR 5.3/3.6	13.3	6.0 YR 5.5/3.5	14.6
75	6.1 YR 5.6/3.5	15.4	6.0 YR 5.3/3.8	13.3	5.9 YR 5.5/3.8	14.0
90	6.4 YR 5.6/3.4	15.9	6.0 YR 5.3/3.8	13.0	5.9 YR 5.5/3.8	14.0
105	6.4 YR 5.6/3.4	15.9	6.0 YR 5.3/3.8	13.0	5.9 YR 5.5/3.8	13.4
120	6.4 YR 5.6/3.4	15.9	6.0 YR 5.3/3.8	13.4	5.8 YR 5.5/4.1	13.4
150	5.9 YR 5.6/3.3	15.4	6.0 YR 5.3/3.8	13.4	5.8 YR 5.5/4.1	13.4
24 hrs.	5.9 YR 5.6/3.3	15.1	5.7 YR 5.5/3.8	13.7	5.1 YR 5.6/4.2	12.7

Appendix I. Pork data obtained by Munsell Colorimetry (continued)

	Loin J					
	Sample 1		Sample 2		Sample 3	
Time	Renotation	Index of Fading	Renotation	Index of Fading	Renotation	Index of Fading
0	7.3 YR 6.2/3.0	21.2	7.4 YR 6.2/2.7	21.6	7.4 YR 6.6/2.6	24.1
15	7.0 YR 6.1/3.2	20.0	7.0 YR 6.1/2.7	20.6	7.0 YR 6.5/2.8	22.8
30	7.0 YR 6.1/3.6	19.5	7.0 YR 6.1/2.8	20.4	6.8 YR 6.5/3.0	22.4
45	6.7 YR 6.1/3.7	19.0	6.8 YR 6.1/3.2	19.4	6.7 YR 6.5/3.3	21.9
60	6.4 YR 6.1/3.9	18.2	6.3 YR 6.1/3.3	15.9	6.7 YR 6.5/3.3	21.9
75	6.2 YR 6.1/4.2	17.5	6.1 YR 6.1/3.6	18.2	6.7 YR 6.5/3.4	21.7
90	6.2 YR 6.1/4.2	17.5	6.1 YR 6.1/3.6	18.2	6.7 YR 6.5/3.4	21.7
105	6.8 YR 6.1/4.0	18.7	6.7 YR 6.2/3.5	19.8	6.8 YR 6.5/3.7	21.5
120	6.8 YR 6.1/4.0	18.7	6.7 YR 6.2/3.5	19.8	6.8 YR 6.5/3.7	21.7
150	6.8 YR 6.1/4.0	18.7	6.7 YR 6.2/3.5	19.8	6.8 YR 6.5/3.7	21.7
24 hrs.	6.8 YR 6.1/4.0	18.7	6.5 YR 6.3/3.3	17.4	7.2 YR 6.7/3.2	23.8

Appendix II. Pork data obtained by reflectance

Time	Sample 1			Sample 2			Sample 3		
	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L
				Loin H					
0	45.1	7.7	8.8	46.3	7.2	8.2	47.6	8.7	9.1
	45.3	7.9	9.1	45.7	6.7	8.3	47.8	8.0	10.0
15	44.4	9.6	10.4	44.7	9.2	9.9	47.3	9.8	10.2
	44.6	9.6	10.5	43.9	7.0	10.0	47.4	9.6	10.2
30	44.2	9.7	10.2	44.8	9.6	10.1	46.4	9.7	11.5
	44.1	9.8	10.4	44.1	9.5	10.2	47.0	9.6	11.6
45	44.2	9.9	10.4	43.6	9.3	10.2	46.4	10.1	11.4
	43.8	10.0	10.4	43.3	9.2	10.2	46.2	9.9	11.4
60	45.4	10.2	10.2	44.5	9.6	10.4	43.9	12.7	11.5
	44.4	10.1	10.2	43.9	10.5	10.6	45.5	11.2	11.6
75	45.4	10.3	10.7	43.8	10.3	10.3	43.5	12.8	11.5
	44.1	10.1	10.6	43.4	10.0	10.5	45.5	11.0	11.8
90	46.4	9.6	10.3	43.9	10.4	10.5	44.7	11.6	10.2
	44.2	9.8	10.8	43.8	10.5	10.6	45.0	11.6	11.6
105	45.3	9.6	10.2	42.9	9.8	10.6	44.9	12.0	11.8
	43.4	9.7	10.2	42.4	9.8	11.0	45.0	11.1	12.0
120	45.4	10.1	10.3	42.7	10.0	10.5	44.6	10.5	11.8
	44.9	9.6	10.4	42.4	9.8	10.4	41.5	11.7	12.0
150	45.1	11.1	10.7	44.2	11.5	10.5	44.9	11.2	11.8
	44.1	11.1	11.3	42.7	11.5	10.8	41.3	12.0	12.0
24 hrs.	46.5	11.2	11.1	45.7	12.3	11.1	42.2	11.1	11.0
	44.9	11.2	11.3	44.6	12.3	11.1	44.7	9.1	11.0

Appendix II. Pork data obtained by reflectance (continued)

Time	Sample 1			Sample 2			Sample 3		
	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L
				Loin I					
0	42.9	5.8	7.5	42.9	6.0	7.6	42.4	7.0	7.4
	42.3	5.7	7.5	41.9	6.0	8.0	42.5	7.0	7.3
15	42.4	7.0	9.0	41.5	7.0	8.2	41.4	8.3	9.3
	41.3	6.9	9.0	41.2	7.0	9.0	41.4	8.0	9.3
30	41.3	7.2	9.6	41.0	7.6	9.0	40.5	8.6	9.8
	41.2	7.2	9.7	40.2	7.6	9.0	40.5	8.5	10.0
45	40.3	7.4	9.0	42.3	7.8	9.0	40.5	8.9	9.6
	41.5	7.2	9.2	40.6	7.7	9.2	40.8	8.9	9.8
60	40.4	7.2	9.2	41.6	7.8	9.0	41.0	8.6	9.6
	40.9	6.9	9.8	40.5	7.7	9.2	40.8	8.6	10.0
75	40.6	7.8	9.3	41.3	8.0	10.0	40.4	8.3	10.0
	40.0	7.7	9.5	40.0	7.9	10.0	40.5	8.3	10.0
90	39.7	7.4	8.8	39.6	8.1	9.0	40.0	9.0	9.9
	39.3	7.4	9.0	39.4	8.0	9.1	39.9	8.8	10.0
105	39.4	7.8	9.6	40.2	8.0	9.9	40.0	8.8	10.0
	39.4	7.6	9.7	39.6	7.9	9.9	39.8	8.9	10.0
120	38.9	7.9	9.4	40.2	7.4	9.8	39.6	8.8	9.0
	39.0	7.8	9.9	39.8	7.4	9.8	39.6	8.7	10.0
150	39.6	7.8	9.3	40.7	8.1	10.3	39.6	8.3	10.0
	39.5	7.9	9.9	39.4	8.1	10.3	39.8	8.3	10.0
24 hrs.	40.2	9.8	10.1	41.4	8.9	10.4	40.3	9.8	10.2
	39.7	9.8	10.2	41.2	8.4	10.4	40.2	9.8	10.2

Appendix II. Pork data obtained by reflectance (continued)

Time	Sample 1			Sample 2			Sample 3		
	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L
				Loin J					
0	44.5	4.8	9.5	44.3	5.9	8.5	41.5	5.5	8.4
	41.9	4.8	10.0	41.6	5.9	9.7	41.6	5.1	8.4
15	43.9	5.3	9.7	40.3	6.8	9.2	40.9	6.7	9.2
	41.7	5.6	10.0	39.9	6.5	9.2	40.0	6.7	9.7
30	43.9	5.9	10.3	41.5	7.3	10.5	41.5	6.6	9.3
	43.9	5.9	10.2	39.9	7.0	10.5	40.4	6.8	9.8
45	43.5	6.0	10.1	40.9	6.9	9.5	40.0	7.1	9.8
	43.2	6.0	10.1	40.6	7.0	10.1	39.5	7.1	10.2
60	41.8	6.3	10.5	39.7	6.9	9.8	40.8	6.8	9.7
	41.3	6.2	10.5	41.8	7.2	10.3	40.2	6.9	10.0
75	43.5	6.3	10.4	41.0	6.6	10.1	40.4	6.8	9.8
	42.9	6.2	10.6	40.6	6.5	10.1	40.2	6.8	10.4
90	43.0	6.4	10.1	40.0	7.2	10.3	39.5	6.9	10.2
	41.2	6.4	10.3	41.0	7.3	11.3	39.0	6.9	10.2
105	43.2	6.8	10.1	41.2	9.9	10.0	40.0	6.9	9.6
	41.3	6.9	10.2	40.9	6.8	10.0	39.6	6.8	10.4
120	42.6	6.9	10.1	40.6	6.8	9.6	39.2	7.0	9.6
	41.8	6.9	10.1	39.5	6.9	9.5	39.0	6.9	9.5
150	41.8	7.6	11.6	40.3	7.0	10.4	39.2	7.6	10.0
	41.9	7.7	11.8	40.7	7.4	11.6	39.0	7.3	10.4
24 hrs.	42.0	8.0	11.8	42.8	8.8	11.6	40.8	9.0	10.8
	42.9	7.9	11.8	38.6	8.5	11.5	40.7	9.1	10.8

Appendix III. Beef data obtained by Munsell Colorimetry

Time	Sample 1 Renotation	Sample 1 Index of Fading	Sample 2 Renotation	Sample 2 Index of Fading	Sample 3 Renotation	Sample 3 Index of Fading	Sample 4 Renotation	Sample 4 Index of Fading	Sample 5 Renotation	Sample 5 Index of Fading
					Rib B					
0	1.6 YR 4.1/3.0	21.1	1.4 YR 3.4/3.1	23.7	2.9 YR 4.2/3.1	23.2	3.1 YR 3.9/3.1	22.9	.5 YR 3.6/3.2	21.3
15	1.8 YR 4.0/3.7	19.8	1.4 YR 3.4/3.8	22.9	2.6 YR 4.1/3.6	21.9	2.4 YR 3.8/3.5	22.7	.9 YR 3.6/3.9	20.8
30	1.4 YR 3.9/4.1	19.5	1.0 YR 3.5/4.1	21.3	2.3 YR 4.0/4.1	20.4	1.9 YR 3.8/3.8	21.2	.6 YR 3.6/4.2	19.8
45	.9 YR 3.9/4.4	18.3	.6 YR 3.5/4.5	20.0	1.9 YR 4.0/4.2	19.6	1.6 YR 3.8/4.2	20.3	.3 YR 3.7/4.4	18.4
60	.6 YR 4.0/4.6	16.8	.6 YR 3.4/5.0	19.8	1.7 YR 4.0/4.4	19.1	2.0 YR 3.9/4.5	20.1	9.8 R 3.7/4.5	17.3
75	.4 YR 4.0/4.7	16.3	.6 YR 3.4/5.0	19.8	1.3 YR 4.0/5.0	17.6	1.8 YR 3.9/4.5	19.7	9.8 R 3.7/4.7	17.0
90	.2 YR 4.0/4.8	16.0	.3 YR 3.4/5.0	19.2	1.3 YR 4.0/5.0	17.6	1.8 YR 3.9/4.7	19.5	10 R 3.7/5.2	16.4
105	.2 YR 4.0/4.8	16.0	.3 YR 3.5/5.1	18.6	1.1 YR 4.0/5.1	17.0	1.8 YR 3.9/4.7	19.5	10 R 3.7/5.2	16.4
120	.1 YR 4.0/4.8	15.8	.3 YR 3.5/5.1	18.6	1.1 YR 4.0/5.1	17.0	1.5 YR 3.8/5.1	19.1	9.6 R 3.7/5.3	15.4
150	.1 YR 4.0/5.2	15.0	.2 YR 3.4/5.9	17.4	1.1 YR 4.0/5.1	17.0	1.5 YR 3.8/5.0	19.2	9.5 R 3.7/5.9	14.4
180	.1 YR 4.0/5.2	15.0	.2 YR 3.4/5.9	17.4	1.1 YR 4.0/5.1	17.0	1.3 YR 3.8/5.3	18.4	9.5 R 3.7/5.9	14.4
24 hrs.	.1 YR 4.0/5.2	15.0	.2 YR 3.4/5.9	17.4	1.1 YR 4.0/5.1	17.0	1.3 YR 3.8/5.3	18.4	9.5 R 3.7/5.9	14.4

Appendix III. Beef data obtained by Munsell Colorimetry (continued)

Time	Sample 1 Renotation	Sample 1 Index of Fading	Sample 2 Renotation	Sample 2 Index of Fading	Sample 3 Renotation	Sample 3 Index of Fading	Sample 4 Renotation	Sample 4 Index of Fading	Sample 5 Renotation	Sample 5 Index of Fading
					Rib C					
0	2.2 YR 4.4/3.3	23.4	3.5 YR 4.1/3.7	23.1	2.8 YR 3.5/3.8	24.4	.9 YR 3.7/3.7	20.5	2.7 YR 3.7/3.5	23.3
15	2.0 YR 4.3/3.7	22.1	3.2 YR 4.1/3.8	22.6	3.0 YR 3.6/4.5	23.7	1.9 YR 3.7/4.2	21.4	3.0 YR 3.8/4.0	22.8
30	2.2 YR 4.2/4.3	20.5	2.8 YR 4.1/4.0	21.9	2.9 YR 3.5/4.9	23.9	1.4 YR 3.7/4.3	20.5	2.6 YR 3.8/4.2	22.0
45	2.1 YR 4.2/4.6	20.4	2.4 YR 4.1/4.1	21.2	2.4 YR 3.6/5.3	21.9	1.0 YR 3.7/4.8	19.1	2.3YR 3.7/4.6	21.1
60	1.7 YR 4.2/4.7	19.9	2.0 YR 4.1/4.4	20.2	2.0 YR 3.6/5.4	21.0	.7 YR 3.7/5.0	18.2	1.6 YR 3.8/4.4	19.5
75	1.7 YR 4.2/4.7	19.9	1.6 YR 4.1/4.8	19.0	1.6 YR 3.7/5.7	19.1	1.2 YR 3.7/5.5	18.5	1.5 YR 3.8/5.1	19.1
90	1.7 YR 4.2/4.8	19.8	1.6 YR 4.1/4.8	19.0	1.2 YR 3.7/5.9	18.0	1.1 YR 3.7/5.9	17.8	1.3 YR 3.8/4.8	19.0
105	1.7 YR 4.2/4.8	19.8	1.6 YR 4.1/4.8	19.0	1.3 YR 3.6/6.2	18.5	1.1 YR 3.7/5.9	17.8	1.2 YR 3.8/5.1	18.3
120	1.4 YR 4.2/5.2	18.7	1.6 YR 4.1/5.3	18.4	1.1 YR 3.6/6.1	18.1	1.0 YR 3.7/6.0	17.4	1.0 YR 3.8/5.4	17.6
150	1.2 YR 4.2/5.3	18.2	1.1 YR 4.1/5.4	17.2	.8 YR 3.7/6.5	16.2	.9 YR 3.7/6.1	17.0	.8 YR 3.8/5.9	16.5
180	1.2 YR 4.2/5.3	18.2	.7 YR 4.1/5.6	16.1	.7 YR 3.7/6.7	15.6	.8 YR 3.7/6.2	16.4	.8 YR 3.8/6.0	16.3
24 hrs.	1.2 YR 4.2/5.3	18.0	.7 YR 4.1/5.7	15.9	.7 YR 3.7/6.7	15.6	.6 YR 3.5/6.4	15.2	.8 YR 3.8/6.0	16.3

Appendix III. Beef data obtained by Munsell Colorimetry (continued)

Time	Sample 1 Renotation	Sample 1 Index of Fading	Sample 2 Renotation	Sample 2 Index of Fading	Sample 3 Renotation	Sample 3 Index of Fading	Sample 4 Renotation	Sample 4 Index of Fading	Sample 5 Renotation	Sample 5 Index of Fadin
					Rib D					
0	2.3 YR 4.6/3.2	24.8	3.6 YR 4.3/3.8	24.4	3.7 YR 4.1/3.6	25.4	3.2 YR 4.3/3.7	23.9	2.9 YR 4.0/3.7	21.6
15	2.5 YR 4.6/3.7	24.6	3.6 YR 4.3/3.9	24.4	3.7 YR 4.1/4.1	23.3	3.5 YR 4.3/4.3	24.1	3.1 YR 4.0/4.2	21.6
30	1.9 YR 4.6/4.1	23.3	3.3 YR 4.3/4.1	23.8	3.3 YR 4.1/4.5	22.4	2.9 YR 4.3/4.4	22.9	2.6 YR 4.0/4.6	20.5
45	2.1 YR 4.6/4.5	23.3	3.3 YR 4.3/4.5	23.6	2.9 YR 4.1/4.7	21.3	2.4 YR 4.3/4.6	21.9	2.5 YR 4.0/4.8	20.2
60	1.8 YR 4.6/4.8	22.4	2.5 YR 4.3/4.7	22.0	2.6 YR 4.1/5.2	20.7	2.4 YR 4.3/5.0	21.6	2.0 YR 4.0/5.3	18.7
75	1.3 YR 4.6/5.0	21.2	2.6 YR 4.3/5.0	22.0	3.0 YR 4.1/5.7	21.2	1.8 YR 4.3/5.4	19.9	1.7 YR 4.0/5.5	17.8
90	1.3 YR 4.6/5.1	21.1	2.5 YR 4.3/5.1	21.7	2.7 YR 4.1/5.7	20.5	1.5 YR 4.3/5.6	19.1	1.7 YR 4.0/5.5	17.8
105	1.2 YR 4.6/5.3	20.8	2.5 YR 4.3/5.4	21.5	2.4 YR 4.1/5.9	19.6	1.5 YR 4.3/6.0	18.6	1.7 YR 4.0/5.5	17.8
120	1.1 YR 4.6/5.4	20.2	2.5 YR 4.3/5.5	21.2	2.4 YR 4.1/6.0	19.5	1.5 YR 4.3/6.0	18.6	1.7 YR 4.0/5.6	17.7
s150	1.0 YR 4.6/5.5	19.9	2.2 YR 4.3/5.6	20.6	2.2 YR 4.1/6.0	19.1	1.4 YR 4.3/6.0	18.4	1.3 YR 4.0/5.6	16.8
180	.8 YR 4.6/5.6	19.3	2.4 YR 4.3/5.8	20.9	2.3 YR 4.1/6.5	19.9	1.3 YR 4.3/6.1	18.0	1.4 YR 4.0/6.1	16.3
24 hrs.	.6 YR 4.6/5.7	18.2	2.0 YR 4.3/6.1	19.7	1.4 YR 4.1/6.3	17.0	.3 YR 4,3/6.2	15.4	1.2 YR 4.0/6.1	15.9

Appendix IV. Beef data obtained by reflectance

Time	Sample 1			Sample 2			Sample 3			Sample 4			Sample 5		
	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L
							Rib B								
0	25.8	12.2	9.2	25.4	13.1	8.6	24.5	12.9	8.2	23.8	13.0	8.6	26.0	13.5	8.6
	24.2	13.0	9.5	24.1	13.4	9.2	24.0	13.3	9.2	24.2	12.9	8.6	26.0	14.8	9.3
15	25.5	15.7	9.7	24.8	16.0	10.2	24.2	15.8	10.0	24.1	15.2	9.0	25.7	16.2	9.5
	24.9	15.7	10.3	24.0	16.1	10.3	23.8	16.0	10.1	23.5	15.2	9.8	26.0	17.0	10.6
30	26.2	16.9	10.3	25.2	18.1	10.5	24.3	17.2	10.2	23.9	17.0	10.2	26.0	17.2	10.2
	24.9	17.4	10.8	24.8	19.0	11.0	24.1	16.8	10.3	23.8	16.0	10.0	26.0	17.2	10.3
45	25.1	17.8	10.1	24.4	18.5	10.0	24.1	17.4	10.4	24.8	16.5	10.0	26.0	17.5	10.5
	24.8	19.0	10.0	24.5	19.0	10.0	23.4	17.5	10.6	24.8	16.5	10.0	25.6	17.7	10.6
60	25.2	17.8	10.4	24.5	18.2	10.2	24.2	17.6	10.3	24.6	16.8	9.4	26.3	18.0	10.8
	23.8	18.5	10.8	24.6	19.2	10.0	24.4	18.3	10.7	24.0	16.9	10.0	25.5	18.2	10.8
75	26.1	18.6	10.4	25.2	18.3	10.2	24.4	18.2	10.7	24.3	17.5	10.2	26.2	18.5	10.6
	24.3	19.8	11.2	24.3	18.7	10.2	23.7	18.2	10.5	23.5	17.3	11.0	25.8	18.3	10.1
90	25.7	19.1	11.0	25.3	19.2	10.8	23.8	18.0	9.8	24.5	17.7	10.3	25.9	18.1	10.4
	24.8	20.3	11.2	24.1	18.8	10.7	23.9	18.0	10.3	23.5	17.4	10.2	26.0	19.5	11.0
105	25.8	18.8	10.8	24.4	19.6	10.7	23.7	18.3	10.2	25.4	17.2	9.8	26.0	18.0	10.3
	24.7	20.0	11.0	24.1	19.4	10.7	24.4	18.5	10.5	24.5	17.5	10.0	26.0	19.3	11.0
120	26.0	19.6	10.7	25.2	19.4	10.6	24.2	19.2	10.3	24.1	17.6	10.0	25.7	20.3	11.1
	23.9	19.6	10.8	24.5	19.0	10.6	23.5	18.7	10.5	23.4	17.2	10.0	25.4	19.3	10.8
150	24.6	19.8	10.5	25.3	19.8	10.2	24.1	18.7	10.2	24.5	18.2	10.1	25.7	19.0	10.4
	24.2	19.6	10.5	24.8	19.6	10.3	23.2	18.5	10.3	24.0	18.2	10.1	25.4	18.9	10.5
180	25.0	20.0	10.5	25.0	20.0	10.1	24.3	18.8	10.1	23.5	18.3	10.0	25.5	18.8	9.8
	24.3	20.5	11.0	24.6	20.5	10.2	23.8	18.6	10.2	22.8	18.5	10.1	25.2	19.2	10.8
24 hrs.	24.8	19.2	10.7	24.2	19.2	10.9	24.8	20.0	10.9	24.5	20.0	10.8	27.0	20.8	11.3
	24.5	19.2	10.5	24.8	19.2	10.2	24.6	19.6	10.2	23.9	19.7	10.5	26.0	21.5	11.3

Appendix IV. Beef data obtained by reflectance (continued)

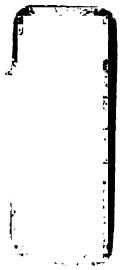
Time	Sample 1			Sample 2			Sample 3			Sample 4			Sample 5		
	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L
								Rib C							
0	24.6	14.2	9.2	23.8	13.9	9.5	24.1	13.9	8.8	25.2	14.4	10.0	24.6	14.6	9.5
	24.8	13.8	9.5	24.0	13.3	9.4	23.8	13.8	9.2	24.3	14.1	9.4	24.1	13.8	9.4
15	24.8	16.5	10.6	24.9	17.0	10.4	24.2	17.6	10.5	24.8	17.8	10.6	24.6	16.7	10.4
	24.7	17.0	10.5	24.5	16.7	10.2	24.5	18.2	10.7	24.7	17.7	10.7	24.2	16.3	10.2
30	25.1	17.9	11.0	24.8	17.5	10.4	24.4	18.2	10.2	24.8	18.8	10.9	24.5	17.8	10.9
	24.2	18.0	11.0	24.4	17.8	11.0	24.2	18.2	10.7	25.2	18.6	11.0	26.3	18.5	11.0
45	24.6	19.2	10.8	24.8	19.0	11.0	24.6	18.8	10.6	24.8	20.4	11.3	25.2	19.4	11.0
	24.6	19.0	11.0	24.6	19.4	10.8	24.2	19.2	11.0	24.8	19.5	11.0	24.0	18.7	10.8
60	25.3	19.4	11.0	25.5	19.3	10.5	24.2	19.2	10.5	25.6	20.6	11.6	24.9	19.0	10.5
	24.3	19.0	11.1	24.8	19.7	10.8	24.2	19.5	10.9	24.5	20.3	11.2	25.3	20.0	10.8
75	25.2	19.7	11.0	24.6	19.5	10.5	24.2	19.2	10.6	24.4	20.2	10.9	25.0	14.2	10.5
	24.2	19.7	11.0	24.3	19.5	10.5	24.0	19.3	10.1	24.6	20.8	11.0	24.1	19.2	10.8
90	25.0	19.8	10.5	24.5	20.4	10.5	24.0	20.8	11.0	24.6	20.8	11.1	24.8	19.5	10.5
	24.3	19.6	11.0	24.6	20.2	10.5	24.2	19.8	11.0	24.4	20.2	11.1	24.5	19.7	10.5
105	24.8	20.5	11.0	24.5	20.2	10.9	24.1	19.8	10.7	24.5	20.6	10.3	24.6	19.6	10.9
	24.1	19.8	11.0	24.7	21.0	10.3	23.9	19.2	10.6	24.8	20.5	10.8	23.9	19.3	10.3
120	24.3	20.2	11.0	24.7	19.8	10.8	23.9	19.7	10.6	24.8	20.5	10.8	24.7	19.5	10.8
	23.9	19.9	11.0	24.6	20.5	10.6	24.0	19.7	10.8	24.0	20.2	10.8	24.0	19.7	10.6
150	24.0	21.3	10.7	24.9	21.4	10.9	23.6	20.0	10.5	24.8	20.6	10.8	24.7	20.2	10.9
	23.9	21.0	11.0	24.0	21.0	10.8	23.9	20.1	10.5	24.3	20.8	10.6	24.5	20.5	10.8
180	24.2	21.7	11.0	24.3	21.5	10.9	23.7	20.5	10.3	24.9	21.5	11.0	24.6	20.3	10.9
	23.8	21.7	11.1	24.0	21.5	11.0	24.1	20.4	10.4	24.7	21.5	11.2	24.6	21.3	11.0
24 hrs.	25.8	21.3	10.6	25.2	21.1	11.2	25.4	19.9	11.3	24.2	20.3	10.9	25.0	20.0	10.9
	24.9	20.1	11.0	24.6	21.2	11.2	25.3	19.9	11.3	24.5	22.0	11.4	25.1	19.8	10.8

Appendix IV. Beef data obtained by reflectance (continued)

Time	Sample 1			Sample 2			Sample 3			Sample 4			Sample 5		
	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L
								Rib D							
0	27.3	14.8	10.0	26.2	14.9	10.0	26.0	15.0	9.6	27.3	15.2	9.4	27.0	15.2	10.5
	26.8	15.1	10.6	26.6	15.0	10.3	26.0	15.1	10.0	27.0	15.6	10.4	27.6	15.2	10.8
15	26.4	18.6	11.4	26.8	18.9	11.1	26.0	19.0	11.0	27.0	18.0	11,8	26.5	18.5	11.3
	26.3	18.5	11.4	26.7	18.5	11.7	25.7	18.3	10.5	28.9	17.5	10.8	27.5	18.8	11.5
30	27.7	19.7	11.2	27.5	19.9	12.0	25.9	19.5	11.3	27.0	20.3	11.8	27.3	20.5	12.0
	26.5	19.3	11.3	26.6	20.4	12.0	26.0	19.1	11.0	26.0	20.2	11.5	27.0	20.2	12.0
45	28.0	20.8	11.6	28.1	20.1	11.2	26.8	20.4	12.0	27.6	19.6	12.0	27.8	20.6	12.0
	26.7	20.7	12.0	25.6	20.9	12.1	26.0	20.8	11.8	26.2	19.5	11.5	26.4	20.8	11.8
60	27.3	20.4	10.9	26.8	21.2	12.2	25.5	21.0	12.0	26.7	20.0	11.0	28.2	21.8	12.3
	26.7	21.8	12.2	26.3	21.0	12.2	24.6	21.5	12.2	26.7	20.9	11.5	24.6	20.4	12.2
75	27.0	21.0	11.3	26.8	21.3	12.0	26.8	21.7	12.0	26.7	21.0	12.0	27.2	21.7	12.1
	27.6	22.2	11.3	27.3	21.1	11.5	25.9	21.6	11.8	26.3	20.7	11.6	26.3	22.0	12.5
90	27.0	21.8	12.0	27.8	21.8	12.5	26.2	22.0	11.7	26.6	22.0	12.0	27.1	22.0	12.1
	27.2	21.6	11.1	27.0	22.7	12.3	25.9	21.8	11.8	26.3	21.0	11.8	26.5	22.5	12.2
105	27.5	21.8	12.0	28.5	22.8	12.3	25.9	22.9	11.5	26.5	22.4	12.0	27.0	22.4	12.1
	26.2	22.0	12.0	26.8	22.3	12.3	25.9	21.6	11.9	26.3	21.6	12.0	26.6	22.9	12.1
120	26.7	22.7	12.2	27.8	23.0	12.2	26.8	22.5	11.5	26.5	22.6	12.1	27.1	24.4	12.5
	26.7	22.6	12.2	26.5	23.0	12.0	26.5	22.5	12.0	26.3	22.2	11.8	26.1	22.9	11.5
150	26.7	23.6	12.4	27.0	22.3	12.1	25.6	22.4	11.9	26.0	22.7	12.1	26.6	24.1	12.3
	25.9	22.8	12.1	26.8	22.2	12.2	25.5	22.7	11.8	26.0	22.8	12.2	26.8	22.8	12.2
180	26.8	23.6	12.2	26.0	23.6	12.2	26.0	23.2	12.0	25.8	22.7	12.0	25.8	23.8	12.2
	26.8	23.5	12.2	27.0	22.8	12.0	26.2	24.0	12.0	25.8	22.3	12.0	25.8	23.6	12.0
24 hrs.	26.8	23.2	11.8	27.6	23.3	12.4	26.5	23.4	12.2	26.3	23.0	12.2	26.3	23.5	12.2
	26.9	23.0	11.8	27.5	23.6	12.4	26.8	23.8	12.1	26.5	23.1	12.1	26.5	23.8	12.1

Appendix V. Lamb data obtained by Munsell Colorimetry

Time	Sample 1 Renotation	Sample 1 Index of Fading	Sample 2 Renotation	Sample 2 Index of Fading	Sample 3 Renotation	Sample 3 Index of Fading
			Rack D			
0	3.0 YR 4.1/3.0	17.8	2.6 YR 3.9/3.2	15.9	2.7 YR 4.0/3.2	16.6
15	2.4 YR 4.1/3.8	16.0	2.7 YR 4.o/3.8	15.8	2.7 YR 4.0/3.8	15.8
30	2.3 YR 4.0/4.0	14.9	2.3 YR 4.0/4.2	14.6	2.3 YR 4.0/4.2	14.6
45	1.9 YR 4.0/4.2	14.0	1.9 YR 4/4.4	13.7	1.9 YR 4.0/4.4	13.7
60	1.5 YR 4.0/4.5	12.8	1.7 YR 4/4.5	13.0	1.5 YR 4.0/4.9	12.1
75	1.5 YR 4.0/4.6	12.6	1.5 YR 4/4.9	12.1	1.3 YR 4.0/5.0	11.5
90	1.5 YR 4.0/4.6	12.6	1.3 YR 4/5.0	11.5	1.3 YR 4.0/5.0	11.5
105	1.3 YR 4.0/4.7	12.0	1.3 YR 4/5.0	11.5	1.3 YR 4.0/5.6	10.4
120	1.3 YR 4.0/5.1	11.3	1.3 YR 4/5.1	11.3	1.3 YR 4.0/5.6	10.4
24 hrs.	1.1 YR 4.0/5.5	10.1	1.3 YR 4/5.1	11.3	1.3 YR 4.0/5.6	10.4

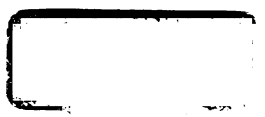


Appendix V. Lamb data obtained by Munsell Colorimetry (continued)

Time	Sample 1		Sample 2		Sample 3	
	Renotation	Index of Fading	Renotation	Index of Fading	Renotation	Index of Fading
			Rack E			
0	2.2 YR 4.3/2.4	18.9	1.4 YR 4.7/3.1	19.3	2.8 YR 4.0/3.1	16.8
15	2.5 YR 4.3/2.9	18.5	1.9 YR 4.7/3.4	19.5	2.7 YR 4.0/3.8	15.8
30	1.9 YR 4.3/3.2	17.4	1.1 YR 4.7/3.7	17.8	2.0 YR 3.9/4.7	12.6
45	1.4 YR 4.3/3.3	16.6	1.2 YR 4.7/4.0	17.4	1.7 YR 3.8/4.9	11.1
60	1.2 YR 4.3/3.6	15.7	.7 YR 4.7/4.2	16.2	1.6 YR 3.8/5.0	10.9
75	1.0 YR 4.3/3.9	14.9	.7 YR 4.7/4.2	16.2	1.5 YR 3.8/5.4	10.0
90	1.0 YR 4.3/3.9	14.9	.1 YR 4.7/4.5	14.5	1.3 YR 3.8/5.5	9.4
105	.7 YR 4.3/4.0	14.2	.1 YR 4.7/4.5	14.5	1.3 YR 3.8/5.7	9.0
120	.6 YR 4.3/4.1	13.8	.2 YR 4.7/4.7	14.2	1.1 YR 3.8/6.1	7.8
24 hrs.	1.2 YR 4.3/4.6	13.8	.7 YR 4.7/4.8	14.8	1.1 YR 3.8/6.1	7.8

Appendix V. Lamb data obtained by Munsell Colorimetry (continued)

Time	Sample 1		Sample 2		Sample 3	
	Renotation	Index of Fading	Renotation	Index of Fading	Renotation	Index of Fading
			Rack F			
0	2.6 YR 3.8/3.5	14.9	3.0 YR 3.6/3.6	16.5	2.9 YR 3.9/3.1	16.4
15	2.6 YR 3.8/4.2	14.0	3.0 YR 3.6/4.5	15.5	2.8 YR 3.9/3.9	15.3
30	2.2 YR 3.8/4.7	12.5	2.7 YR 3.6/5.1	14.2	2.2 YR 3.9/4.3	13.7
45	1.8 YR 3.8/4.9	11.5	2.3 YR 3.6/5.3	13.1	1.8 YR 3.9/4.6	12.6
60	1.5 YR 3.8/5.4	10.0	2.1 YR 3.6/5.4	12.5	1.6 YR 3.8/5.0	12.1
75	1.2 YR 3.8/5.6	8.9	2.2 YR 3.5/5.7	12.3	1.6 YR 3.8/5.1	11.9
90	1.2 YR 3.8/5.6	8.9	1.2 YR 3.5/5.7	12.3	1.4 YR 3.8/5.6	10.6
105	1.2 YR 3.8/5.7	8.8	1.9 YR 3.5/5.8	12.0	1.4 YR 3.8/5.6	10.6
120	1.2 YR 3.8/5.7	8.8	1.9 YR 3.5/5.8	12.0	1.4 YR 3.8/5.7	10.4
24 hrs.	1.1 YR 3.8/6.1	7.8	1.7 YR 3.5/5.8	11.3	1.0 YR 3.8/5.7	8.3



Appexdix VI. Lamb data obtained by reflectance

Time	Sample 1			Sample 2			Sample 3		
	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L
				Rack D					
0	25.2	13.9	9.0	26.1	13.9	10.0	26.4	14.3	10.1
	25.4	14.2	9.7	26.2	14.0	10.1	26.0	14.0	10.2
15	26.3	16.9	10.4	25.5	16.3	10.8	26.7	15.6	11.0
	25.7	16.4	10.8	25.4	16.5	11.0	26.6	15.9	11.0
30	25.3	17.3	11.0	25.9	17.6	11.2	25.8	17.0	11.3
	25.2	17.5	11.0	25.8	17.5	11.3	26.1	17.2	11.3
45	25.1	17.9	11.2	26.0	18.0	11.3	26.4	17.6	11.4
	25.2	17.8	11.2	25.6	17.8	11.3	26.2	17.5	11.2
60	25.8	18.7	11.5	25.8	18.3	11.3	26.6	17.4	11.2
	25.5	18.7	11.3	25.8	18.0	11.3	26.3	17.5	11.4
75	25.8	18.6	11.2	26.3	17.8	11.2	26.5	17.6	11.3
	25.8	18.7	11.3	26.0	17.9	11.1	25.5	18.0	11.2
90	25.4	19.0	10.8	25.8	17.9	11.4	26.0	17.9	11.3
	25.3	19.0	11.3	25.4	17.7	11.3	25.8	17.6	11.2
105	25.7	19.1	11.4	25.9	18.0	11.3	26.3	17.8	11.2
	25.0	19.0	11.3	25.3	17.5	11.3	25.5	17.7	11.4
120	25.3	19.3	11.4	25.8	18.1	11.4	26.4	17.9	11.3
	25.1	19.2	11.3	25.5	17.6	11.3	25.2	17.7	11.4
24 hrs.	25.9	18.9	11.2	25.8	18.0	11.3	26.2	18.2	11.4
	25.9	19.1	11.3	25.6	18.1	11.3	25.8	18.0	11.3

Appendix VI. Lamb data obtained by reflectance (continued)

Time	Sample 1			Sample 2			Sample 3		
	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L
				Rack E					
0	27.1	14.5	9.2	25.7	14.7	9.0	25.7	13.8	8.7
	24.2	13.8	8.4	23.6	13.5	9.0	25.2	14.1	8.8
15	26.8	17.8	11.4	26.2	17.2	11.0	25.5	16.9	10.6
	26.6	17.5	11.3	25.8	16.8	10.8	24.9	16.7	10.6
30	26.7	18.4	11.5	25.2	17.4	10.2	25.2	17.0	10.0
	26.5	18.3	11.5	25.0	17.6	10.2	25.3	17.4	10.2
45	27.0	18.6	11.6	25.7	18.4	11.2	24.9	17.8	11.0
	26.5	18.9	11.5	25.2	18.2	11.0	25.1	18.4	11.1
60	26.5	18.8	11.4	26.0	18.9	11.3	24.9	18.7	11.0
	26.0	18.7	11.4	24.8	18.0	10.7	24.8	18.3	11.0
75	26.3	19.1	10.8	25.2	18.9	11.3	24.7	18.9	11.3
	25.6	18.8	11.4	24.8	18.7	11.1	24.6	18.3	10.4
90	26.1	19.5	11.7	24.7	18.7	11.1	24.6	18.9	10.3
	25.7	19.7	11.8	25.6	18.7	11.3	24.8	18.7	11.2
105	24.5	18.7	10.3	25.2	19.0	11.1	24.5	18.3	10.9
	25.7	18.8	10.7	24.8	18.9	11.0	24.5	18.2	11.0
120	26.1	19.8	11.6	24.9	19.1	11.0	24.1	18.3	10.9
	25.6	19.7	11.4	25.8	18.9	11.2	24.0	18.1	10.7
24 hrs.	27.5	20.5	12.6	26.1	20.3	11.3	26.3	19.9	11.0
	26.7	19.5	11.5	25.8	20.2	11.4	26.2	20.0	10.4

Appendix VI. Lamb data obtained by reflectance (continued)

Time	Sample 1			Sample 2			Sample 3		
	L	a_L	b_L	L	a_L	b_L	L	a_L	b_L
				Rack F					
0	25.3	14.0	9.3	23.3	13.7	9.0	25.0	14.3	9.5
	23.9	13.9	9.2	23.3	14.1	8.8	24.3	14.1	9.3
15	24.3	15.4	9.6	24.2	15.7	10.0	24.8	16.8	10.4
	23.6	15.3	9.7	24.6	16.2	10.2	24.2	16.5	10.3
30	25.2	16.8	10.8	23.8	16.7	10.4	25.0	17.7	11.0
	24.6	16.6	10.5	24.5	17.0	10.6	24.8	17.7	11.0
45	25.5	17.5	11.2	24.3	17.5	10.8	24.7	18.3	11.0
	24.7	18.0	11.1	25.1	17.7	11.0	24.8	18.3	11.0
60	23.8	17.3	10.6	23.8	18.1	10.7	24.9	18.9	11.1
	24.8	18.4	11.1	23.6	17.4	10.4	24.5	18.9	11.0
75	24.2	17.7	10.0	25.6	18.4	10.6	23.9	17.4	10.5
	24.7	18.7	11.2	25.0	19.0	11.2	24.7	18.5	11.1
90	24.8	18.3	10.3	25.0	17.3	10.0	25.1	19.0	10.5
	23.8	17.4	10.4	23.9	18.0	11.0	24.3	19.1	11.0
105	23.9	17.5	9.8	25.2	19.7	11.4	24.8	19.4	10.5
	25.0	18.8	11.0	23.8	18.8	10.8	23.8	18.5	10.8
120	23.5	18.4	10.2	24.5	18.5	10.5	24.8	19.8	11.1
	23.5	17.9	10.2	24.3	18.4	10.4	23.7	19.0	10.8
24 hrs.	25.4	19.3	11.2	24.7	19.7	11.3	25.7	20.0	11.6
	25.6	19.1	11.3	25.5	19.8	11.5	25.8	19.8	11.6

Appendix VII. Correlation of myoglobin concentration and Index of Fading in lamb.

Rack No.	Index of Fading	Myoglobin (mg./g.)
2	14.7	1.66
3	15.8	2.67
4	16.8	2.55
5	18.3	3.29
6	15.9	3.20
$\lesssim X^2$	= 1335.67	$\lesssim Y^2$ = 37.45
$\lesssim X$	= 81.5	$\lesssim Y$ = 13.37
$(\lesssim X)^2$	= 6642.25	$(\lesssim Y)^2$ = 178.75
$\lesssim XY$	= 220.515	
$(\lesssim X)(\lesssim Y)$	= 1092.10	
N	= 5	

$N \lesssim X^2 - (\lesssim X)^2 = 6678.35 - 6642.25 = 36.10$

$N \lesssim Y^2 - (\lesssim Y)^2 = 187.25 - 178.75 = 8.50$

$N \lesssim XY = 1102.57$

$N \lesssim XY - (\lesssim X)(\lesssim Y) = 1102.57 - 1092.10 = 10.47$

$$r = \frac{N \lesssim XY - (\lesssim X)(\lesssim Y)}{\sqrt{\left[N \lesssim X^2 - (\lesssim X)^2\right]\left[N \lesssim Y^2 - (\lesssim Y)^2\right]}}$$

$$r = \frac{10.47}{(36.10)(8.50)} = .596$$

Appendix VIII. Correlation of myoglobin concentration and a_L in lamb.

Rack No.	a_L	Myoglobin (mg./g.)
2	14.0	1.66
3	14.7	2.67
4	14.1	2.55
5	14.1	3.29
6	14.0	3.20

$r = .604$