Sensory and Objective Evaluation of the Color of Pork Longissimus Dorsi Muscle Heated to 155° and 170°F

Winifred Ann Akin

University of Tennessee, Knoxville
To the Graduate Council:

I am submitting herewith a thesis written by Winifred Ann Akin entitled "Sensory and Objective Evaluation of the Color of Pork Longissimus Dorsi Muscle Heated to 155° and 170°F." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

Bernadine Meyer, Major Professor

We have read this thesis and recommend its acceptance:

Mary Rose Gram, Curtis C. Melton

Accepted for the Council:

Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)
To the Graduate Council:

I am submitting herewith a thesis written by Winifred Ann Akin entitled "Sensory and Objective Evaluation of the Color of Pork Longissimus Dorsi Muscle Heated to 155° and 170°F." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science.

We have read this thesis and recommend its acceptance:

[Signatures]

Major Professor

We have read this thesis and recommend its acceptance:

[Signatures]

Accepted for the Council:

[Signature]

Vice Chancellor for Graduate Studies and Research
SENSORY AND OBJECTIVE EVALUATION OF THE COLOR OF
PORK LONGISSIMUS DORSI MUSCLE
HEATED TO 155° AND 170°F

A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by

Winifred Ann Akin

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ABSTRACT

The color of longissimus dorsi muscle of 4-6 rib pork roasts was evaluated by sensory tests, by color reflectance, and by myoglobin content, after heating to 155° and 170°F. The color of the raw muscle of 8-9 rib area was evaluated by color reflectance and for myoglobin content. The roasts, procured from eighteen Duroc or Hampshire hogs, were classified subjectively into three color groups.

Color reflectance measurements on raw muscle indicated that as the subjective color classification increased from slightly pale (2) to slightly dark (4) the color was more dull and more purple. The color differences found by the Color Eye Colorimeter in the raw muscle were associated with the myoglobin content of the raw muscle ($r = 0.791, P < 0.01$).

Approximately 7 to 15 percent of the myoglobin remained after heating muscle to 155°F and essentially no myoglobin remained after heating muscle to 170°F. The sensory panel distinguished a difference in color between muscle heated to 155°F and 170°F as demonstrated by triangle tests. The panelists preferred the color of the muscle heated to 170°F. The color reflectance measurements did not distinguish a difference between muscle heated to 155°F and that heated to 170°F.
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CHAPTER I

INTRODUCTION

Myoglobin is a respiratory pigment primarily responsible for the red color of meat. It is a porphyrin-protein complex composed of the heme portion in which an iron atom is bound in a porphyrin ring, and to which a globin (protein) portion is complexed. During heating the globin is denatured, the iron oxidized, and the characteristic red color of meat is lost.

Although myoglobin is the predominant pigment in meat, much work has been reported on hemoglobin, possibly because myoglobin was more difficult to obtain in a sufficiently purified form than was hemoglobin. Reliable information concerning the properties of myoglobin was not available until its crystallization by Theorell (1932). Morgan (1936) in working with horse heart observed that the pigment was extremely soluble in phosphate buffers at pH 6.6 even at phosphate concentrations as high as 3 M. Since hemoglobin was not soluble under these conditions, this observation made possible the introduction of a method for an almost quantitative separation of myoglobin and hemoglobin.

The color reflectance from the surface of pork muscle has had limited evaluation. The most common instruments used for reflectance measurements are the reflectance attachments of spectrophotometers and various color difference meters. Each color difference meter has its own notation, however all can be converted to the CIE notation. The diversity of size, shape, distribution of pigmentation, and other physical characteristics of foods presents a major problem in obtaining
reliable physical measurements of surface reflectance characteristics. Optimum results are obtained with flat, opaque, uniformly colored surfaces where color measurements relate directly to visual appearance.

Little attention has been given to myoglobin content and color reflectance measurements of heated pork muscle, which is the major interest in the present investigation. Myoglobin content was measured chemically and color reflectance was measured physically with a Color Eye Colorimeter on raw pork longissimus dorsi muscle as well as muscle heated to 155° and 170°F. Currently, 170°F is the recommended endpoint for fresh pork (National Live Stock and Meat Board, 1965). The 155°F endpoint corresponds to the medium-rare stage of beef, is above the thermal death point of 140°F (Carlin et al., 1969) of Trichinella spiralis and has been shown to yield desirable products (Morris, 1967). A sensory panel was employed to determine if there was visual difference between the colors of the muscles heated to 155° and 170°F and to determine if the difference was associated with preference for one endpoint over the other.
CHAPTER II

REVIEW OF LITERATURE

I. MEAT PIGMENTATION

Materials contributing to the color of muscle tissue include myoglobin, hemoglobin, cytochromes, vitamin $\text{B}_{12}$, and the flavins. The heme pigments, myoglobin, hemoglobin, and cytochromes contain iron in a porphyrin-protein complexed structure. Vitamin $\text{B}_{12}$, a more complexed structure than the heme pigments though it contributes less to pigmentation, also contains the same porphyrin ring, but is coordinated to a cobalt atom instead of iron. The flavins, minor contributors to muscle color, are yellow coenzymes involved with cytochromes in electron transport in the cell (Giffee et al., 1960).

Myoglobin is generally the only pigment present in large enough quantities to color the tissue. In the live animal myoglobin accounts for about 10 percent of the total iron. During slaughter, the bleeding process removes most of the other iron in the form of hemoglobin. In well-bled skeletal muscle of beef as much as 95 percent or more of the iron present is in the form of myoglobin (Giffee et al., 1960).

**Myoglobin Structure and Function**

Myoglobin is a porphyrin-protein complex composed of the heme portion, an iron atom bound in a porphyrin ring, to which a globin portion is complexes. The porphyrin is made up of four pyrrole units, heterocyclic compounds linked by methene bridges. The side chains
attached to the porphyrin portion of the molecule are methyl, vinyl and propyl groups (Giffee et al., 1960).

Myoglobin is a complex protein, similar in function to the blood pigment hemoglobin in that they both serve to complex with the oxygen required for metabolic activity of the animal. Hemoglobin acts as an oxygen carrier in the blood stream whereas myoglobin provides essentially a storage mechanism for oxygen in the cells. Myoglobin reflects its storage role in the quantities of pigment found in various tissues. The quantity present is generally a function of the muscular activity of the tissue, the blood supply, the oxygen availability, and the age of the animal. Although myoglobin exists in small quantities in heart muscle, it is present in this organ in larger quantities than in any other tissue. The ability of whales to remain submerged for periods as long as an hour without breathing can be accounted for by their having the highest myoglobin content of all mammals. The relationship between age of the animal and the myoglobin content is directly proportional. As the animal becomes older, the myoglobin content increases (Giffee et al., 1960).

**Myoglobin Derivatives and Color**

Complexes of myoglobin with ligands are of two classes depending on whether the iron of myoglobin is in the ferrous or ferric state (Giffee et al., 1960). Myoglobin, with the iron in the reduced or ferrous state, has a purplish red color. In the presence of oxygen myoglobin is converted to oxymyoglobin and metmyoglobin, the oxygenated and oxidized forms, respectively. Oxymyoglobin, a bright red compound,
is an example of the ferrous covalent complex of myoglobin with oxygen. The oxidation of either myoglobin or oxymyoglobin produces metmyoglobin which has the iron in the oxidized or ferric state and is brown in color. In meat there is a constant conversion of myoglobin and oxymyoglobin to metmyoglobin. There is also a continuous supply of reducing coenzymes from the enzymatic oxidation of substrates such as glucose, which are capable of reducing metmyoglobin back to oxymyoglobin and myoglobin. As long as the supply of oxygen and reducing substances is plentiful on the surface of fresh meat, oxymyoglobin is evident by a bright red color. Myoglobin, with the iron in the reduced state, is evident in the reddish purple color of the interior of raw meat.

The brown color of cooked meat is due to a variety of pigments, among which is the principal heme pigment, a denatured globin compound (Giffee et al., 1960). Upon prolonged cooking at high temperatures the oxidation and polymerization of fats, sugars, and proteins contribute to the color. The heme pigment in cooked meat has been identified as a denatured globin nicotinamid hemichrome produced from myoglobin. There are probably a number of factors involved in this conversion. Among these are denaturation of globin, oxidation of iron in the heme, the acceleration of the oxidation of all other reducing substrates with the consequent inability of the tissue to further reduce ferric iron.

**Myoglobin Concentration in Muscle**

Some factors affecting myoglobin concentration in muscle include age, activity, and species. The effects of age and activity on myoglobin concentration in pork muscle were investigated by Lawrie (1950). Myoglobin
concentration increased as age increased \((P < 0.001)\). The rate of increase was rapid from birth up to one year in pigs. After this period of time, the myoglobin remained constant except in the longissimus dorsi muscle which had a significant rise throughout life. The effect of activity was indicated by a lower myoglobin concentration in longissimus dorsi muscle of immobile pigs (those confined in a pen just sufficiently large to accommodate them) than in normally active pigs of the same age.

A difference in myoglobin concentration dependent on species was found by Ginger et al. (1954) in quantitative determinations of myoglobin in beef and pork muscle. The ratio of the concentration in beef (3.7 mg/g of tissue) to that of pork averaged 4.7 to 1 for light colored pork (0.79 mg/g of tissue) and 2.6 to 1 for dark colored pork (1.44 mg/g of tissue). The average myoglobin concentrations for beef muscle of 2.43 mg/g wet tissue reported by Fleming et al. (1960) and 2.80 mg/g wet tissue reported by Rickansrud and Hendrickson (1967) were somewhat lower than the 3.7 mg/g wet tissue reported by Ginger et al. (1954). The average myoglobin concentrations for pork longissimus dorsi muscle of 0.86 mg/g wet tissue reported by Janicki et al. (1967), 0.79 mg/g wet tissue reported by Ginger et al. (1954), and 0.78 mg/g wet tissue reported by Lawrie (1950) are very similar. In four beef muscles studied by Rickansrud and Hendrickson (1967), myoglobin concentration was highest in the biceps femoris, followed by the longissimus dorsi and psoas major, and lowest in the semitendinosus. In four pork muscles studied by Lawrie (1950) myoglobin concentration was highest in the psoas major, followed by the diaphragm and the longissimus dorsi, and lowest in the heart.
Myoglobin concentrations in muscle have been found to be correlated with the fiber type (Briskey et al., 1970). Type I (red fibers) have a high myoglobin content and type II (white fibers), low myoglobin content. Varying gradations of intermediate fibers may also be present. Differences in total myoglobin content in different muscles may be determined by the proportion of type I and type II fibers and probably also by the absolute content of myoglobin per type I or other fiber, which may vary from one species to another. Porcine muscles show histochemical patterns whereby red fibers are found in groups of several fibers completely surrounded by white fibers.

Although myoglobin is the predominant pigment in meat, much more work has been reported on hemoglobin, possibly because myoglobin was more difficult to obtain in a sufficiently purified form than was hemoglobin. Myoglobin was first crystallized by Theorell (1932). In his work with horse heart muscle he found a protein resembling, but nevertheless distinct from, the blood pigment hemoglobin, a fact which prior to that time was in doubt. Theorell's procedure consisted of extraction of finely ground meat tissue with water, followed by precipitation with lead acetate. The filtrate then was repeatedly dialyzed against solutions of saturated ammonium sulfate until characteristic fan-shaped clusters of needle crystals appeared. Morgan (1936) observed that myoglobin appeared to be extremely soluble in phosphate concentrations as high as 3 M. As a result of this observation a simple method was available for the separation of hemoglobin and myoglobin, since hemoglobin was not soluble under these conditions.
Since these first workers elucidated the basic properties of myoglobin, other workers have used spectrophotometric studies to quantitatively determine myoglobin concentrations. Shenk et al. (1934), basing their calculations on oxygenated pigments, were the first to estimate the concentrations of hemoglobin and myoglobin in extracts containing both pigments. Drabkin and Austin (1935) determined total pigment from washed blood cells by measuring the absorbance of cyanmethemoglobin in solution to which potassium ferricyanide (final concentration of 0.6 mM per liter) and potassium cyanide (final concentration of 0.8 mM per liter) had been added. In the formula for conversion of optical density at 540 m\( \mu \) to mM per liter an extinction coefficient of 11,500 for cyanmethemoglobin was used. Crandall and Drabkin (1946) and Drabkin (1950) used an extinction coefficient of 11,300 at wavelength of 540 m\( \mu \) for cyanmethemoglobin determinations. DeDuve (1948) and Poel (1949) determined the concentration of hemoglobin and myoglobin in solution mixtures of the carbon monoxide derivatives. Ginger et al. (1954) used a modification of Morgan's (1936) and Drabkin and Austin's (1935) procedures for chemical studies on metmyoglobin from beef and pork muscle. Rickansrud and Hendrickson (1967) used modifications of Drabkin's (1950) and Ginger's et al. (1954) procedure for determinations of myoglobin in four bovine muscles. The extinction coefficient 11.3 mM per liter was used by Rickansrud and Hendrickson (1967). Fleming et al. (1960) compared methods in which myoglobin was converted to the cyanmet- (Ginger et al., 1954 and Drabkin, 1950), carbonyl- (DeDuve, 1948 and Poel, 1949), and oxy- (Shenk et al., 1934) myoglobin derivatives. The carbonylmyoglobin
method gave higher values than the cyanometmyoglobin method or the oxymyoglobin method, both of which gave values that were very close together.

II. COLOR MEASUREMENT

The concentration of heme pigments in fresh red meats, as determined by extraction methods, often does not yield results that can be closely correlated with color as evaluated by visual rating. This is due to the fact that the color measurements on meat extracts do not reflect the chemical states of the pigment (myoglobin, metmyoglobin), the distribution of the pigment, or the state of dehydration of the meat at the surface of the cut. These are all factors that influence visual color evaluation. Measurements of light reflected from the meat surface or comparison of the meat surface color to some known standard, usually yields results that are more closely related to visual observations than do measurements of total pigment content (Doty, 1960).

Color in substances is due to the selective absorption of part of the white light of the sun (or an artificial light) by molecules or atoms or ions. An object will appear to be red, for instance, if it absorbs sufficient visible wavelengths in the blue, green, yellow, and orange regions and reflects or transmits the radiation in the red region (Keenan and Wood, 1966).

When considering the color of meat, factors such as water holding capacity, moisture content, pH, total protein content and fat content along with total pigments and myoglobin should be taken into account.
Janicki et al. (1967) found little relationship between dominant wavelength of light reflected from raw, fresh pork, using the reflectance attachment of a Zeiss VSU-1 spectrophotometer, and properties such as total pigments, water holding capacity, moisture content and total protein content. The only factor affecting the light wavelength of the minced muscle color was pH. The pigment, myoglobin, was influenced by the pH of the muscle. Therefore, the pH of the muscle determined the hue of the muscle color. Lightness of color, which represents the total energy reflected from the surface of the sample, decreased with increase of pigment content, water holding capacity and pH. Hamm and Deatherage (1960) found that the pH of meat increased as it was heated above 104°F. In this way the change in pH during cooking may affect the color of the cooked meat. Janicki et al. (1967) concluded that the role of fat in influencing muscle color was highly dependent on the total muscle fat content and variability.

Many instruments and procedures have been used in determining the color of meat. One of the most common instruments is the spectrophotometer. Fresh, raw pork muscle has been evaluated with the Bausch and Lomb Spectronic 20 reflectance attachment by Ockerman and Cahill (1969) and Elliott (1969). Ockerman and Cahill (1969) plotted CIE chromaticity coordinates x and y from their data and used a series of pork quality color photographs for a panel to evaluate color. They found significant correlations between coordinate x, coordinate y, dominant wavelength, purity and the visual color scores assigned by the panel. Elliott (1969) found significant correlations between Munsell values and scores from ten trained panelists. Hegarty (1969) used a set of seven color discs (Lovibond) and had panelists match fresh, raw pork muscle with one disc. He found training necessary for duplication in scores.
Many factors affect the reflectance characteristics of surfaces, such as particle size, shape and orientation, granularity, texture, degree of packing, and state of hydration. These variables must be carefully controlled to insure reproducability of results (Mackinney and Little, 1962). In general, solid foods may be presented to the sample port of reflectance measuring instruments unaltered or slightly altered as by flattening with pressure, homogenizing, or otherwise controlling particle size. Methods of sample preparation and presentation have an important effect on the instrument readings. The diversity of size, shape, distribution of pigmentation, and other physical characteristics of food presents a major problem in obtaining reliable physical measurements of surface reflectance characteristics. Optimum results are obtained with flat, opaque, uniformly colored surfaces where color measurements relate directly to visual appearance. These criteria are seldom met in foods. Another problem is that any surface, whether glass, lucite, or other material, interposed between the sample and the viewing instrument will affect the reflectance readings.

Cooked pork color has had limited evaluation. Pengilly and Harrison (1966) used ground pork loin roasts cooked to endpoints of 149°, 167°, and 185°F for color measurements. The Gardner Color Difference Meter was used to obtain Rd (reflectance), a- (greenness–interpreted as loss of pinkness), and b+ (yellowness) values. Rd values were not significantly different between the three endpoints. The a- and b+ values increased significantly as the endpoint temperature increased. Morris (1967) found no difference in color acceptability of lean in pork loin roasts cooked to 170° and 185°F as judged by six panelists. Lower scores were given to pork cooked to 155°F when it did not have the characteristic gray white color of well done pork, but these scores were also in the very acceptable
Crowder (1965) found little difference in color scores among endpoints of 149°, 167°, and 185°F in pork roasts. There was a slight preference by the panel for the color of the roasts cooked to the two lower endpoints.

III. ROASTING PORK

The United States Department of Agriculture (1960) requires that all parts of pork muscle tissue must be heated to 137°F to destroy trichinae. Recommendations for endpoint temperatures for roasting fresh pork have been reduced from 185°F to 170°F (National Live Stock and Meat Board, 1965). Carlin et al. (1969) reported that all trichinae larvae were killed between 130° and 140°F internal temperature in fresh pork roasts. The final endpoint of 170°F was found to be well above the thermal death point of *Trichinella spiralis*. When comparing 185° and 170°F internal temperatures, Carlin et al. (1965) found the optimum quality of pork roasts were obtained with an internal temperature of 170°F. Roasts cooked to 170°F were comparable in flavor, tenderness, higher in juiciness, had lower cooking losses and required less cooking time than roasts cooked to 185°F. Oven temperatures of 325° to 350°F were recommended by Carlin et al. (1965). Pengilly and Harrison (1966) found no difference in overall acceptability of pork loin heated to 149°, 167°, and 185°F.
CHAPTER III

PROCEDURE

I. PLAN OF STUDY

Forty-five roasts were used in this study. Eighteen pairs of the roasts were 4-5-6 rib cuts from each of eighteen carcasses of hogs of Duroc or Hampshire breeds. In addition, nine roasts containing the 8-9 ribs were obtained from one half of these carcasses as indicated in Table I. All carcasses were procured from the Animal Husbandry-Veterinary Science Department of the University of Tennessee, Knoxville. The fresh raw longissimus dorsi muscle was subjectively scored by the staff of the Animal Husbandry-Veterinary Science Department according to color standards developed by Iowa State University (1969). The Iowa State Standards consisted of a color photograph of a fresh raw pork loin roast. This was compared to the fresh raw muscle used in the present study to determine the color classification. The color classifications for the fresh raw pork ranged from 2, which was described as slightly pale, soft, and watery, to 4, which was described as slightly dark and firm. The most frequent score of 3 indicated a normal greyish pink color. There were three carcasses in color classification 2, ten carcasses in color classification 3, and five carcasses in color classification 4 (Table I).

Each week of testing included sensory evaluation of two pairs of cooked roasts (randomly selected), Color Eye Measurements on heated and raw muscle and myoglobin determinations. Myoglobin determinations were done on raw and heated roasts from three carcasses of each of the three color classifications 2, 3, and 4.
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Roasts were frozen and stored at -20°F until tested. Prior to testing, roasts were thawed to 40° ± 2°F. Paired cuts were roasted at 350°F two pairs at a time in preheated ovens of two household electric ranges. Thermocouples were placed in the center of the roasts with the sensing element in the approximate center of the longissimus dorsi muscle. A multipoint temperature recorder was used to determine internal temperature of the roasts while cooking. One roast of each pair was heated to 155° ± 2°F and the other to 170° ± 2°F. The roasts were cooled to room temperature before evaluation.

II. METHODS OF EVALUATION

Sensory

After roasting and cooling, the longissimus dorsi muscle was separated from bone and fat tissue. Two uniform slices of the muscle, adjacent to the position where the thermocouple was located, were removed. Triangle and preference sensory tests on each pair of roasts were performed by seven panelists on each test day. In the triangle test, three coded samples were presented to the panelists. Two of the samples were identical, i.e., from the same endpoint roast, and one was different. The panelists were asked to select the odd sample. The panelists then indicated which sample or samples were preferred. For each day's tests, the 155°F roast was the odd sample in one of the triads, and the 170°F roast supplied the odd sample for the other triad. Thus the odd sample was represented by each endpoint the same number of times in the study. A sample score sheet may be found in the Appendix.
**Color Reflectance**

Color Eye readings of X, Y, Z, and X' were taken on the sliced and ground raw and heated longissimus dorsi muscle. The readings were a measure of the percent reflectance from the sample at wavelengths 610 µm (X), 550 µm (Y), 445 µm (Z), and 435 µm (X') in relation to a white vitrolite standard. The readings were converted to CIE chromaticity coordinates x and y and plotted on a chromaticity diagram to determine the dominant wavelength and purity of the color of the meat. A lightness index was also calculated to estimate the brightness or dullness of the color. The equations for these conversions may be found in the Appendix.

**Myoglobin Determination**

Myoglobin determinations were done following the procedures of Ginger et al. (1954) with only slight modifications. Duplicate 12-g samples of twice ground meat were extracted twice with distilled demineralized water. The first extraction was carried out for four hours with 7 ml of water. Samples were centrifuged at 2000 x G for 15 minutes at 42°F and the supernatant separated. The second extraction with 5 ml of water was then performed overnight. Samples were centrifuged again at 2000 x G for 15 minutes at 42°F and the supernatant combined with that from the first extraction. The pH of the extract was adjusted to 7.0 using 0.5 M phosphate buffer (pH 8.3). Saturated basic lead acetate equal to 0.25 the volume of the supernatant was added to precipitate protein other than myoglobin and hemoglobin. The precipitate was removed by centrifugation at 2000 x G for 15 minutes at room temperature. The total volume of supernatant above the
precipitate was recorded. A 10-ml aliquot of the supernatant was
removed. Mono- and di-basic potassium phosphate (2.04-g and 2.61-g,
respectively) were added to the aliquot to bring the pH to 6.6 and the
total phosphate concentration to 3 M. Samples were centrifuged at 2000
x G for 15 minutes at room temperature to precipitate the hemoglobin
which is not soluble under these conditions. The supernatant was
filtered through Whatman #2 filter paper. The myoglobin in the
filtrate was converted to cyanmetmyoglobin by the addition of 0.06
ml of 0.1 M potassium ferricyanide and 0.08 ml of 0.1 M sodium cyan­
ide. The optical density (O.D.) was measured on the Bausch and Lomb
Spectronic 20 at a wavelength of 540 mµ.

The equation for converting absorbance readings to milligrams of
myoglobin per gram of wet tissue was:

\[
\text{OD} \times \text{vol of extract (liters)} \times \text{mol wt of Mb} \times 1000 \text{ mg/g} \times \frac{\text{extinction coefficient}}{\text{x g of meat sample}}
\]

Total molar concentration of the pigment was determined by Drabkin's
(1950) molar extinction coefficient 11,300 for cyanmetmyoglobin at
wavelength 540 mµ. The molecular weight of myoglobin was assumed to
be 17,000 g/mole (Rickansrud and Hendrickson, 1967). Myoglobin values
were also calculated on a fat-free-dry basis since moisture and fat of
the meat varied with the heating conditions. The percent decrease in
myoglobin from the raw to the samples heated to 155° and 170°F was
then calculated on the fat-free-dry basis.

**Nonfat-Dry Weight Determinations**

Moisture and fat content were determined in duplicate for each raw and
cooked sample and the average percent fat-free-dry weight was calculated.
Approximately 5-g samples were weighed by difference to the nearest mg into Whatman 22 x 80 mm single thickness extraction thimbles. The samples were dried in a warm oven (150°F) prior to drying for 16 hours in a vacuum oven at 150°F. After cooling in a dessicator the samples were weighed and the percent dry weight determined. The dried samples then were extracted with petroleum ether for six hours on a Goldfisch apparatus. After cooling and evaporating the solvent, the samples were redried, reweighed, and the percent nonfat-dry weight was calculated.

**Statistical Analyses**

Significance of the triangle sensory test was based on the statistical table in Larmond (1967). Simple correlation coefficients were calculated between raw color classification and myoglobin content of raw meat; raw color classification and myoglobin content of meat heated to 155°F; raw color classification and CIE values for raw muscle; raw color classification and CIE values for muscle heated to 155° and 170°F; myoglobin content of raw meat and CIE values for raw meat; myoglobin content of muscle heated to 155°F and CIE values for muscle heated to 155°F; CIE values for sliced and ground muscle. Mean CIE values for sliced and ground muscle were compared with a paired "t." The effect of pork color on variation in myoglobin content was evaluated for both the raw and cooked meat utilizing a one way analysis of variance. Variation in CIE values was partitioned with a two way analysis of variance. The factors in the mathematical model were raw color classification, temperature and their respective interaction (Steel and Torrie, 1960). Where significance of means was obtained, Duncan's Multiple Range test was applied (Duncan, 1951).
CHAPTER IV
RESULTS AND DISCUSSION

I. SENSORY EVALUATION

The results of the triangle and preference sensory tests are shown in Table II. The percentage of correct responses indicated the probability was better than could be attributed to chance for the selection of the odd sample. Among those who were correct in identifying the odd sample, about 70 percent of the judgements indicated a preference for the pork heated to 170°F. Some judges indicated no preference between pork heated to 155°F and that heated to 170°F. While there were no consistent color differences noticed by panelists between pork heated to 155°F and 170°F, enough difference was present for the panelists to identify the odd sample. There was little difference in the ability of the panelists to identify the odd sample on the triangle test within the raw color classifications. A sample test form may be found in the Appendix.

Morris (1967) found that panelists scored color of pork loin heated to 155°F lower (P < 0.01) than that heated to 170° and 185°F. However, all color scores for heated pork loin were in the desirable category. Crowder (1965) found little difference in the color scores of panelists for pork heated to endpoints of 149°, 167°, and 185°F. There was a slight preference by the panelists for the color of the pork heated to the 167°F endpoint in the Crowder study.

II. MYOGLOBIN

The myoglobin content averaged 0.43 mg myoglobin per g wet tissue as shown in Table III. This value for myoglobin of raw pork longissimus...
TABLE II

RESULTS OF TRIANGLE AND PREFERENCE SENSORY TESTS FOR COLOR OF PORK LOIN HEATED TO 155°F and 170°F

<table>
<thead>
<tr>
<th>Raw Color Classa</th>
<th>Number of Judgements</th>
<th>Percent Correct</th>
<th>Preference of Correct Respondees Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>No Preference</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>60.0*</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>67</td>
<td>65.5**</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>62.9**</td>
<td>1</td>
</tr>
</tbody>
</table>

*aAssigned according to the standards for pork color, firmness and marbling. Pub. Pm-452. Iowa State University.

*Significant at the .05 level.

**Significant at the .01 level.
<table>
<thead>
<tr>
<th>Raw Color Classification</th>
<th>Hog No.</th>
<th>Myoglobin (mg/g wet tissue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>9-1</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>14-5</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>21-7</td>
<td>0.45</td>
</tr>
<tr>
<td>3</td>
<td>17-8</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>7-1</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>10-12</td>
<td>0.55</td>
</tr>
<tr>
<td>4</td>
<td>7-2</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>21-9</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>19-1</td>
<td>0.40</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>0.43</td>
</tr>
</tbody>
</table>
(Table III) is lower than the average values of 0.79 mg per g wet tissue reported by Ginger et al. (1954), 0.86 mg per g wet tissue reported by Janicki et al. (1967), and 0.78 mg per g wet tissue reported by Lawrie (1950). The myoglobin content of the raw muscle of one carcass in the present study was comparable to the values reported by other workers. Ginger et al. (1954) measured cyanmethemoglobin while Janicki et al. (1967) and Lawrie (1950) measured carbonylmyoglobin and oxymyoglobin respectively. All these workers used meat that had not been frozen. The meat used in the present study had considerable loss of red juice upon thawing prior to analysis. Myoglobin could have been lost in this thaw drip. Ginger et al. (1954) assumed fifty percent partition between meat and extract, when one extraction was used. Other workers' values were obtained by double extraction as was done in the present study.

The average myoglobin contents on a fat-free-dry basis of raw pork longissimus dorsi muscle and that heated to 155°F and 170°F for the three color classifications of raw meat are shown in Table IV. Approximately 7 to 15 percent of the original myoglobin remained after the meat was heated to 155°F. In only one roast heated to 170°F was there any measurable myoglobin remaining. Bernofsky et al. (1959) found that about 40 percent of the myoglobin remained after holding ground pork muscle at 149°F for 20 minutes and only 5 percent of the myoglobin remained after holding ground pork muscle at 176°F for 20 minutes.

The mean squares from the analyses of variance for the myoglobin content of the raw muscle and muscle heated to 155°F are shown in Table V. These data indicated no significant difference in myoglobin content
### TABLE IV

**AVERAGE MYOGLOBIN CONTENT\(^a\) OF PORK LONGISSIMUS DORSI MUSCLE**

<table>
<thead>
<tr>
<th>Raw Color Classification</th>
<th>Raw 155°F (mg/g fat-free-dry tissue)</th>
<th>170°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.26 ± 0.54</td>
<td>0.20 ± 0.16</td>
</tr>
<tr>
<td>3</td>
<td>2.51 ± 0.96</td>
<td>0.31 ± 0.16</td>
</tr>
<tr>
<td>4</td>
<td>1.81 ± 0.04</td>
<td>0.13 ± 0.04</td>
</tr>
</tbody>
</table>

\(^a\)Mean and standard error of three determinations.

### TABLE V

**MEAN SQUARES FROM ANALYSIS OF VARIANCE FOR MYOGLOBIN CONTENT OF RAW AND HEATED PORK**

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of Freedom</th>
<th>Myoglobin Content of Raw</th>
<th>Myoglobin Content of Heated to 155°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Color Class</td>
<td>2</td>
<td>0.484</td>
<td>0.026</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td>0.636</td>
<td>0.018</td>
</tr>
</tbody>
</table>
of the raw muscle of pork of the three raw color classifications or of muscles heated to 155°F.

III. COLOR REFLECTANCE

Color reflectance values obtained with the Color Eye Colorimeter were converted to CIE values. As CIE values for coordinate x increase redness of color increases. Greeness of color increases as values for coordinate y increase. The lightness index is a measure of intensity, brightness or dullness, of color. As the lightness index (L) value increases the brightness of color increases.

Raw Muscle

The mean squares from the one way analysis of variance utilized on CIE values for raw pork loin are shown in Table VI. Significant differences were indicated among the raw color classifications within coordinate y and the lightness index (L).

The mean CIE values for raw pork loin are shown in Table VII. Since the analysis of variance indicated no significant differences within coordinate x, the Duncan's Multiple Range test was not applied. The CIE values of raw meat for coordinate y were higher in color classification 2 than in color classification 3 and 4 indicating a decreasing amount of greeness with an increase in raw color classification. The CIE values of raw muscle for the lightness index (L) were higher in color classification 2 than in color classification 3 indicating muscle of color classification 2 was brighter in color than muscle of color classification 3.
### TABLE VI

**MEAN SQUARES FOR CIE COLOR VALUES OF RAW PORK LOIN**

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of Freedom</th>
<th>CIE Values</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>x</td>
<td>y</td>
<td>L</td>
</tr>
<tr>
<td>Raw Color Class 2</td>
<td>2</td>
<td>0.577</td>
<td>1.178*</td>
<td>2.439***</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td>0.434</td>
<td>0.262</td>
<td>0.223</td>
</tr>
</tbody>
</table>

*Significant at the .05 level.

***Significant at the .005 level.

### TABLE VII

**MEAN CIE VALUES FOR RAW PORK LOIN**

<table>
<thead>
<tr>
<th>Raw Color Classification</th>
<th>CIE Values</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x</td>
<td>y</td>
<td>L</td>
</tr>
<tr>
<td>2</td>
<td>0.347</td>
<td>0.336a</td>
<td>5.990a</td>
</tr>
<tr>
<td>3</td>
<td>0.347</td>
<td>0.328b</td>
<td>4.776b</td>
</tr>
<tr>
<td>4</td>
<td>0.340</td>
<td>0.328b</td>
<td>5.047ab</td>
</tr>
</tbody>
</table>

abValues in the same column with the same superscript do not differ.
Muscle Heated to 155° and 170°F

Mean squares from the two-way analysis of variance utilized for CIE values for pork loin heated to 155° and 170°F are shown in Table VIII. A significant interaction between temperature and raw color classification was found within CIE coordinate x. The interaction in CIE coordinate y was approaching significance.

The mean CIE values for pork loin heated to 155° and 170°F are shown in Table IX. Duncan's Multiple Range test indicated that the 170°F endpoint roasts of raw color classification 2 had significantly lower CIE x values than those of the 155°F endpoint of raw color classification 2 and 3 and the 170°F endpoint of raw color classification 4. This could be interpreted as indicating that the roasts heated to 170°F of raw color classification 2 had less redness than the roasts heated to 155°F of raw color classification 2 and 3 and roasts heated to 170°F of raw color classification 4. No differences were indicated within coordinate y or the lightness index.

Pengilly and Harrison (1966) found no difference in Rd (lightness) values using a Gardner Color Difference Meter between endpoints of 149° and 167°F of ground pork loin. Pork heated to 149°F had a higher a- (greenness, interpreted as loss of pinkness) and b+ (yellowness) values than pork which was heated to 167°F. The Gardner a- value would correspond to the CIE y coordinate and the Gardner b+ value would correspond to the CIE x coordinate.

Sliced Versus Ground Muscle

Mean CIE values and "t" values for sliced and ground pork loin are shown in Table X. Ground muscle had significantly higher CIE
TABLE VIII
MEAN SQUARES OF CIE VALUES FOR PORK MUSCLE HEATED TO 155°F AND 170°F

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of Freedom</th>
<th>CIE Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Raw Color Class</td>
<td>2</td>
<td>0.204</td>
</tr>
<tr>
<td>Temperature</td>
<td>1</td>
<td>0.836</td>
</tr>
<tr>
<td>Temp x Raw Color Class</td>
<td>2</td>
<td>1.356*</td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>0.354</td>
</tr>
</tbody>
</table>

*Significant at the .05 level.
TABLE IX
MEAN CIE VALUES FOR PORK HEATED TO 155°F and 170°F

<table>
<thead>
<tr>
<th>Final Temperature and Raw Color Class</th>
<th>CIE Values</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x</td>
<td>y</td>
<td>L</td>
</tr>
<tr>
<td>Heated to 155°F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.3484&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.3414</td>
<td>7.026</td>
</tr>
<tr>
<td>3</td>
<td>0.3497&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.3423</td>
<td>7.042</td>
</tr>
<tr>
<td>4</td>
<td>0.3480&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.3404</td>
<td>7.010</td>
</tr>
<tr>
<td>Heated to 170°F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.3439&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.3409</td>
<td>7.008</td>
</tr>
<tr>
<td>3</td>
<td>0.3461&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.3418</td>
<td>7.122</td>
</tr>
<tr>
<td>4</td>
<td>0.3501&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.3438</td>
<td>6.978</td>
</tr>
</tbody>
</table>

<sup>ab</sup>Values in the same column with the same superscript do not differ. Others differ (F < .05).
### TABLE X

Mean CIE values and "t" value for sliced and ground pork loin

<table>
<thead>
<tr>
<th>CIE Values</th>
<th>Sliced</th>
<th>Ground</th>
<th>&quot;t&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>0.346</td>
<td>0.363</td>
<td>-8.506***</td>
</tr>
<tr>
<td>y</td>
<td>0.330</td>
<td>0.337</td>
<td>-6.683***</td>
</tr>
<tr>
<td>L</td>
<td>5.248</td>
<td>5.791</td>
<td>-4.310***</td>
</tr>
<tr>
<td>Heated to 155°F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>0.350</td>
<td>0.344</td>
<td>3.802***</td>
</tr>
<tr>
<td>y</td>
<td>0.342</td>
<td>0.341</td>
<td>0.156</td>
</tr>
<tr>
<td>L</td>
<td>7.029</td>
<td>7.381</td>
<td>-3.596**</td>
</tr>
<tr>
<td>Heated to 170°F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>0.346</td>
<td>0.342</td>
<td>2.795**</td>
</tr>
<tr>
<td>y</td>
<td>0.342</td>
<td>0.343</td>
<td>-0.469</td>
</tr>
<tr>
<td>L</td>
<td>7.083</td>
<td>7.450</td>
<td>-4.147***</td>
</tr>
</tbody>
</table>

**Significant at .01 level.**

***Significant at .001 level.
values of raw meat than did sliced muscle. There was a significant
difference between sliced and ground muscle for CIE values x and L for
the muscle heated to 155° and 170°F. Since a difference was found
between sliced and ground meat CIE values, any research done on meat
using CIE values should specify whether sliced or ground product was
evaluated.

Correlation coefficients were also calculated on CIE values of
sliced versus ground muscle. Significant correlation between sliced
and ground values would indicate that they are varying together and
therefore only a constant factor distinguished one from another. Since
significance was found only with raw meat for CIE y (r = 0.521,
P < .05) and CIEL (r = 0.722, P < .01) values, the preceding state­
ment was applicable to raw meat but not for that which has been heated.
From these data it is difficult to predict whether sliced or ground
meat would give the most valid results with the Color Eye Colorimeter.

IV. INTERRELATIONSHIPS OF COLOR CLASSIFICATION AND
MYOGLOBIN CONTENT WITH CIE MEASURES

Correlation coefficients for raw pork muscle and muscle heated
to 155°F are shown in Table XI. The significant negative correlation
for CIE y and L values of raw meat with the raw color classifications
reflect decreasing CIE y and L values as the raw color classification
increased. The interpretation of this would be that as the raw color
classification increased from 2 to 4 the color of the raw meat was
more dull and more purple. Ockerman and Cahill (1969) found a signifi­
cant correlation between subjective color evaluation using color
TABLE XI
CORRELATION COEFFICIENTS FOR RAW PORK MUSCLE AND MUSCLE HEATED TO 155°F

<table>
<thead>
<tr>
<th>Variate</th>
<th>Degrees of Freedom</th>
<th>Raw Color Classification</th>
<th>Myoglobin Content</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIE x</td>
<td>7</td>
<td>-0.380</td>
<td>0.316</td>
</tr>
<tr>
<td>CIE y</td>
<td>7</td>
<td>-0.508*</td>
<td>-0.566*</td>
</tr>
<tr>
<td>CIE L</td>
<td>7</td>
<td>-0.595**</td>
<td>-0.631**</td>
</tr>
<tr>
<td>Dominant Wavelength</td>
<td>1</td>
<td>-0.500</td>
<td>0.998*</td>
</tr>
<tr>
<td>Purity</td>
<td>1</td>
<td>0.789</td>
<td>0.999*</td>
</tr>
<tr>
<td>Raw Color Class</td>
<td>- -</td>
<td>- -</td>
<td>0.305</td>
</tr>
<tr>
<td>Myoglobin Content</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heated to 155°F</td>
<td>7</td>
<td>0.237</td>
<td>0.794**</td>
</tr>
<tr>
<td><strong>Heated to 155°F</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIE x</td>
<td>16</td>
<td>0.045</td>
<td>0.037</td>
</tr>
<tr>
<td>CIE y</td>
<td>16</td>
<td>-0.165</td>
<td>-0.116</td>
</tr>
<tr>
<td>CIE L</td>
<td>16</td>
<td>-0.284</td>
<td>0.240</td>
</tr>
<tr>
<td>Dominant Wavelength</td>
<td>1</td>
<td>-0.386</td>
<td>0.586</td>
</tr>
<tr>
<td>Purity</td>
<td>1</td>
<td>0.268</td>
<td>-0.410</td>
</tr>
<tr>
<td>Raw Color Class</td>
<td>7</td>
<td>- -</td>
<td>0.237</td>
</tr>
</tbody>
</table>

*Significant at .05 level.

**Significant at .01 level.
photographs similar to the ones used by the Animal Husbandry-Veterinary Science Department for the present study, and the CIE x, y, dominant wavelength, and purity. There was no correlation between raw color classification and any of the parameters of muscle heated to 155°F.

Significant correlations between myoglobin content of raw muscle and all the CIE parameters except the chromaticity coordinate x were found. This indicated that color differences in raw muscle as measured by the Color Eye Colorimeter were associated with myoglobin of raw muscle. Janicki et al. (1967) reported a significant correlation between lightness and myoglobin content of raw muscle but not between dominant wavelength and myoglobin content of raw muscle. The lightness decreased with increased pigment content, as would be expected. The nonsignificant correlation of myoglobin content with raw color classification could indicate that the subjective color classifications were based on other parameters besides but not necessarily excluding myoglobin.

There were no significant correlations between myoglobin of heated muscle (155°F) and any of the CIE parameters. The Color Eye seems to be measuring parameters not associated with the myoglobin content of heated muscle or probably there was too little myoglobin remaining to affect the color of the heated muscle.

V. DISCUSSION

Differences in color of pork longissimus dorsi muscle heated to 155° and 170°F are apparent in sensory panel evaluations. Since chemical analysis indicated that there was some residual myoglobin in the
meat heated to 155°F but essentially none in meat heated to 170°F, it seems possible that residual myoglobin in the heated muscle may have been a factor in the sensory panel's evaluations. From data obtained with the Color Eye Colorimeter, no general statement could be made as to the color difference in pork muscle heated to 155°F and 170°F.

The subjective color classifications assigned by the Animal Husbandry-Veterinary Science Department to fresh raw muscle did not seem to reflect myoglobin content. The reflectance differences found by the Color Eye Colorimeter in the raw muscle seem to be associated with myoglobin content of raw muscle.

While panelists could successfully distinguish a color difference between the 155°F and the 170°F endpoints, the magnitude of the difference was slight as indicated by instrumental color measurements. It is not clear why myoglobin content could have affected the sensory results of the heated meat but was not related to the subjective color classification of the raw meat, while reflectance measurements seemed to reflect myoglobin concentration in the raw but not the heated muscle.

VI. RECOMMENDATIONS

Further research on meat color could be improved by obtaining a pure myoglobin standard to test the reliability of the chemical method used. A sensory evaluation in which heated meat was assigned a score that could be analyzed in relation to the Color Eye measurements and myoglobin content would be of great value. More extensive research is needed in the area of cooked pork especially in the reflectance measurement of color.
CHAPTER V

SUMMARY

I. SCOPE OF STUDY

The purpose of this study was to investigate myoglobin concentration in pork heated to two endpoints and to determine whether differences between the two endpoints could be detected by sensory panel and reflectance measurements. Thirty-six paired 4-6 rib roasts and nine single 8-9 rib roasts were obtained from Hampshire and durochogs on which subjective color classifications had been made by the Animal Husbandry-Veterinary Science Department. One roast from each pair was cooked to 155°F and the pairmate to 170°F. Heat treatments were replicated eighteen times, using paired roasts from eighteen carcasses.

Myoglobin was measured chemically on the heated pairs and the raw single roasts from nine of the carcasses. Color differences in heated muscle were measured by a sensory panel. The sensory panel also chose the sample they preferred based on color. Color reflectances were measured spectrophotometrically using the Color Eye Colorimeter. Reflectance was also measured on the unheated muscle of the nine carcasses.

II. PRINCIPAL FINDINGS

The sensory panel could distinguish a difference between muscle heated to 155°F and 170°F as demonstrated by triangle tests. About 70 percent of the correct respondees preferred roasts heated to the 170°F endpoint.

No difference in color of muscle heated to 155°F and that heated to 170°F was detected by the Color Eye Colorimeter reflectance measurements.
Color reflectance measurements on raw muscle indicated that as the subjective raw color classification increased from slightly pale (2) to slightly dark (4) the color was more dull and more purple. The color differences determined by the Color Eye Colorimeter in the raw muscle were associated with the myoglobin content of the raw muscle (r = 0.791, P < 0.01).

There was no difference in the myoglobin content of the raw muscle from the nine carcasses tested in this study. The average value was 0.43 mg/g of thawed frozen tissue. There was no relationship between the raw color classifications and the myoglobin content of the raw muscle. Approximately 7 to 15 percent of the myoglobin remained after heating muscle to 155°F and essentially no myoglobin remained after heating muscle to 170°F.
LIST OF REFERENCES
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Drabkin, D. L. 1950. The distribution of the chromoproteins, hemoglobin, myoglobin, and cytochrome c in the tissues of different species, and relationship of the total content of each to body mass. J. Biol. Chem. 182, 317-333.


TRIANGLE PREFERENCE TEST I

Name ___________________________ Date _______________________

Instructions: You will have three samples, two of which are alike and one is different. You are to select the one which is different based on color of the lean muscle.

Which is the odd sample? ______________________________

Briefly describe the difference you observe. ______________________________

__________________________________________________________

Which sample do you prefer? ______________________________

TRIANGLE PREFERENCE TEST II

Which is the odd sample? ______________________________

Briefly describe the difference you observe. ______________________________

__________________________________________________________

Which sample do you prefer? ______________________________
CALCULATIONS FOR CIE VALUES

\[ X_{cie} = X_{ce} (0.6633) + X'_{ce} (0.1711) \]
\[ Y_{cie} = Y_{ce} (0.8560) \]
\[ Z_{cie} = Z_{ce} (1.0109) \]

Coordinate \( x = \frac{X_{cie}}{X_{cie} + Y_{cie} + Z_{cie}} \)

Coordinate \( y = \frac{Y_{cie}}{X_{cie} + Y_{cie} + Z_{cie}} \)

Lightness \( L = \sqrt{Y_{ce}} \)

Dominant wavelength is the wavelength where the \( x \) and \( y \) coordinates converge on a chromaticity diagram.

Purity is the percentage of the distance from the dominant wavelength to the true white center of the chromaticity diagram.

cie = CIE notation

ce = reading from Color Eye colorimeter
VITA

Winifred Ann Akin was born in Cleveland, Ohio on April 15, 1948. She attended elementary school in Nashville, Tennessee and graduated from Hillsboro High School in Nashville June, 1966. That summer she entered Middle Tennessee State University at Murfreesboro, Tennessee and began work on a Bachelor of Science degree in Vocational Home Economics, which was completed in May, 1969.

She entered Graduate School at the University of Tennessee, Knoxville, Tennessee in September, 1969 as a research assistant and began work on the Master of Science degree with a major in Food Science. Degree requirements were completed August, 1971. She is a member of Kappa Omicron Phi and Omicron Nu Home Economics Honor Societies, Alpha Gamma Delta Social Fraternity, American Home Economics Association, and Institute of Food Technologists.