Guidelines for Meat Color Evaluation

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Table of Contents

I. INTRODUCTION ................................................................. 3

II. VISUAL APPRAISAL ............................................................. 3
A. Sample Preparation ........................................................... 3
B. Visual Appraisal Guidelines ................................................ 4

III. INSTRUMENTAL COLOR METHODOLOGY .................................. 4
A. Sample Preparation ........................................................... 4
B. Instrumental Methods ....................................................... 4
C. Pigment Extraction and Quantitation Guidelines ....................... 5
D. Fresh Meat Color Measurement .......................................... 5
E. Cured Meat Color Measurement ........................................... 6
F. Cooked Meat Color Measurement ........................................ 6
G. Instrumental Measurement Guidelines .................................. 7

IV. BACKGROUND INFORMATION ON COLOR .................................. 8

V. INSTRUMENTAL COLOR EVALUATION SYSTEMS .......................... 9
A. Munsell Color Solid ......................................................... 9
B. CIE Color Solid ............................................................... 9
C. Reflectance Spectrophotometry ........................................... 10
D. Tristimulus Colorimetry ................................................... 10
E. Hunter Color Solid .......................................................... 10

REFERENCES ................................................................. 11
PICTORIAL COLOR STANDARDS ............................................ 12
GLOSSARY OF COLOR TERMS ................................................ 12
EXAMPLE COLOR SCALES ..................................................... 14

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I. Introduction

The color of muscle foods is critically appraised by consumers and often is their basis for product selection or rejection. Color measurements, whether for fundamental research or product development, description or specification, must be done as carefully as other measures of chemical and physical traits. Unfortunately, the science of color measurement described by Francis and Clydesdale (1975), Little (1976), Kropf et al. (1976), Hunt (1980) and Setser (1984) is complex and subject to misuse in routine work. The purpose of these guidelines is to provide suggestions for researchers needing to measure color of muscle foods. In some instances, these guidelines can be used as a "cookbook" to appraise color measurement; but for most projects, these guidelines will only help investigators adapt color measurement methodology appropriate to the unique goals of their experiments. In addition, the booklet by Minolta (1988) contains many diagrams and charts in color that aid understanding of color measurement.

Color of uncooked meat and meat products is usually described as pink or red, but colors range from nearly white to dark red. Discoloration of these products often involves tan, brown, gray, green or yellow colors. Unfortunately, brown colors are difficult to measure instrumentally, and for meat, it is often easier to measure a lack of redness or other normal color. Cooking, smoking, curing and other processing not only present opportunities to enhance product appearance and color stability but often create colors that vary from the exterior to the interior of the product. Even within a slice of product, lack of color uniformity, due to either inherent muscle properties or processing techniques, creates color measurement problems (Hunt and Kropf, 1985). If products are packaged and displayed, lighting systems can have a major effect on their appearance and create special considerations for color measurement. This infinite number of combinations of colors and factors affecting them makes it difficult to accurately describe and follow meat color changes. Simply, complete color evaluations usually cannot be done with only one scale, sampling technique or instrumental measurement.

Sections II and III of these guidelines contain specific suggestions for visual and instrumental measurements, respectively. For those needing additional background information, sections IV and V provide more detail on color and color systems. The glossary should be especially useful for those using color as a research technique. Lastly, the color scales listed were selected for three reasons: 1) they may be the scale of choice for many projects, 2) they will serve as references for development of scales for specific needs, and 3) they show differences in scales used for describing meat color vs scales needed for following color changes over time.

II. Visual Appraisal

Visual appraisals of color are closely related to consumer evaluations and set the benchmark for instrumental measurement comparison. They are not easy to conduct with either trained or consumer panels, since human judgements may not be repeatable from day to day and are influenced by personal preference, lighting, visual deficiencies of the eye and appearance factors other than color. Various scoring scales have been utilized for panel evaluations. Many of these are descriptive and imply averaging the color over the entire meat surface area. Others utilize a "worst-point" color score for a single or cumulative discolored area of at least 2 cm in diameter, whereas still other systems are various combinations of these two methods. Some scales with hedonic terms have been misused with descriptive panels. Correctly structured scoring scales and appropriate pictorial standards substantially improve panel consistency and validity.

Pictorial color standards have been developed and are useful to support specific color scales. Appropriate scales and standards for specific experiments are dependent upon project objectives, as is the decision of whether trained (descriptive) panels, consumer (acceptance) panels or both are required. The most suitable scales usually are best constructed through preliminary studies in which the product is treated in a similar manner, because scales reflecting the type of color changes unique to specific experiments are essential. Scales developed in this way will encompass the spectrum of sample colors most likely to appear and can be used for panel training and as reference standards during visual appraisals conducted during the experiment.

A. Sample Preparation

Color measurement, as do many analytical techniques, has the fundamental problem of obtaining a representative sample. Care must be taken in sample selection regardless of the means to be used for examining and evaluating the sample. Sample preparation for color measurement requires standardized procedures that are both repeatable (by the same person in the same laboratory) and reproducible (by different people in different laboratories at different times). All samples must be handled in exactly the same manner to prevent artifacts. This is of particular importance when live animal treatments are being evaluated for their effects on meat color. Muscle foods are generally opaque and will absorb, reflect or scatter incident light but generally do not transmit much light. Factors for which standardization is especially important include (unless the factor is an experimental variable): animal nutritional regimen, carcass chill rate, muscle, sample location within a muscle, fiber orienta-
tion, muscle pH, time and temperature of postmortem storage, muscle exposure time to oxygen, marbling content and distribution, surface wetness and gloss, myoglobin concentration, packaging and display conditions. These factors must be considered when preparing samples for color evaluation.

B. Visual Appraisal Guidelines

1. Select panelists with normal color vision and screen and train them using statistical techniques described in AMSA (1978).
2. Standardize as many sample variables as possible (see part II-A on sampling).
3. Conduct pretrials to determine the spectrum of colors and discoloration patterns unique to the study; this is often overlooked but is extremely useful.
4. Conscientiously match scoring scale descriptions (see section on example scales) to the objectives of the study and color variations anticipated. Use hedonic scales (e.g. desirability, acceptability) only with large consumer color panels, not with small descriptive panels.
5. Conduct acceptance appraisals under conditions (i.e. retail cases, lighting, temperature, defrost cycling, packaging) that simulate the conditions under which consumers make their selections.
6. Use samples at least 12 to 15 mm thick; stack wafer-type samples and evaluate against a white background. Most backing boards or plastic foam trays meet this requirement.
7. Overwrap with the type of film most commonly used in merchandising the specific product.
8. Keep panelist viewing angle constant relative to the light source, about 45° to view mainly diffuse reflectance.
9. Whenever possible, use colored pictures tiles or three-dimensional aids for panel training; and to minimize variation due to day or replication, provide color standards for panel reference. (Refer to later section for list of standards currently available. Store pictorial color standards in the dark, because most are subject to light-induced color changes).
10. Evaluate areas of normal color and discoloration color separately, using an averaging approach for areas of normal color and a “worst-point” approach for discoloration. If percentage discoloration is scored by panelists, be sure the percentage breaks in the scale are realistic and reflect consumer discrimination.
11. Rotate packages from front to back and side to side to help minimize variations in temperature and air movement in display cases.
12. Utilize objective visual methods, such as measuring the proportion of the surface area that is discolored with a grid or planimeter.
13. Standardize case display temperature. If cases have a defrost cycle, these also must be controlled. Be aware that case temperature usually is not the same as product temperature. The latter can be determined by placing a thermocouple 1 mm below the surface of the meat.
14. Standardize the type of lighting used for color evaluations and display studies. If fluorescent, state the specific lamp used. Recommended fluorescent lamps for meat (fresh or cured; oxygen permeable or impermeable films) display studies include: SPX-30 (a high efficiency lamp, General Electric Co.), Color-Gard 32 (Duro-Test Co.), Deluxe Cool White, Deluxe Warm White, Soft White, Natural White or Natural (all available from General Electric, Philips and Sylvania). Do NOT use Cool White, Daylight, or Standard Grolux lamps because their color balance of wavelengths do not complement meat color and appearance.
15. Standardize lighting intensity from 807 to 1614 lux (75 to 150 foot-candles) continuously, 24 hours/day. Light meters are available from scientific and photographic companies.

III. Instrumental Color Methodology

A. Sample Preparation

Sample preparation is critical for instrumental color measurement regardless of whether one is using extraction or reflectance techniques. The same sample restraints and considerations given for visual color (section II-A) also apply to instrumental evaluations.

One of the greatest problems in sample presentation involves uneven color or variable discoloration. Areas within a given muscle can vary in color and specific areas can be severely discolored, whereas other areas are normal in color. When such a problem occurs, it is prudent to determine the proportion of the surface each section represents and to measure them separately.

Samples should be thick enough to be opaque. If an opaque backing must be used, this backing should be white rather than black. Orientation of muscle fibers within the sample may also influence the readings. For samples in which this is a problem, one reading should be taken, and then the sample should be rotated 90° and another reading should be taken; some instruments are now capable of averaging multiple readings. The type of film used to overwrap the sample influences readings, which makes it necessary to standardize the instrument for specific film types. Pressure applied to the sample on the aperture can affect readings, thus the sample should be flat and not “pillow” into the port.

B. Instrumental Methods

Three major considerations are: what instrumental methodology to use (pigment extraction or reflectance), how to express the data and how to use the data. For example, Hunter Lab-values or CIE Lab-values (also known as L*a*b*), tristimulus values, Munsell and reflectance at specific wavelengths have all been used to express color data. Munsell data are not used frequently. Tristimulus values (X,Y,Z), tristimulus coordinates (x,y,z), and mathematical expressions of these units are useful to describe accurately a particular meat color, but they have not been used much for following color change during display or for quality control measures. Numerous researchers have used L* a* b*-values to document treatment effects on color. Ratios of a/b, hue angle and saturation index have been used for discoloration studies (MacDougall, 1982). Various reflectance values have been used often to measure meat color, to follow color changes and to quantitate myoglobin forms (see sections III-D,E,F, and G).

The overriding issues in selection of methodology (Kroftp et al., 1984) are project objectives and the anticipated use for
the color data. With these in mind, the basic decision regarding methodology concerns whether to extract pigments and measure transmission or absorbance or to determine the reflectance of the intact sample. A major advantage of reflectance is that repeated measurements can be made on individual packaged samples. Extraction procedures give sharper peaks and better separation than reflectance measurements, but they overestimate oxymyoglobin and metmyoglobin and underestimate deoxymyoglobin because of changes occurring during extraction and measurement. Obtaining representative samples is a problem with extraction procedures, because surface color is the important part of the samples. Grinding of the entire sample will not give an accurate evaluation of the color on the surface, which makes it necessary to remove a thin layer from the surface during sampling. In addition, sampling and extraction terminate the usefulness of the sample, because oxymyoglobin and metmyoglobin differ in solubility. Usefulness of extraction procedures is largely confined to the determination of total heme or total myoglobin pigment.

C. Pigment Extraction and Quantitation Guidelines

Pigment extraction and transmission or absorption spectrophotometry are the methods of choice for total myoglobin and hemoglobin quantification. Extraction techniques do not prevent the conversion of one myoglobin form to another and provide no reliable information on pigment forms. Jeremiah et al. (1972), Kropf et al. (1976), and Hunt and Kropf (1988). Table 1 shows that the percentage of oxymyoglobin directly is preferable because oxymyoglobin content is highly related to consumer preference. This is possible by using 610 nm, which is isobestic for both deoxymyoglobin and metmyoglobin (Hunt and Kropf, 1988).

Many experiments require only the detection of product color differences rather than the more tedious quantitation of myoglobin forms. Jeremiah et al. (1972), Kropf et al. (1976),

Figure 1

Reflectance spectra of deoxy-(DMb), oxy-(OMb) and metmyoglobin (MMb). Note isobestic wavelengths at 474, 525, 572 and 610. Ratios of 630/580 nm approach 1.0 for metmyoglobin and >4.0 for oxymyoglobin. (Modified from Snyder, 1965).
Harrison et al. (1980), Hunt (1980) and Setser (1984) reported correlations (r=.1 to over .9) between numerous instrumental color measurements and visual scores. There are valid reasons why instrumental and visual measures are not always highly correlated, yet these objective measurements are useful in detecting relative color differences. Numerous researchers have successfully used Lab-values or ratios of these values for detection of fresh meat color differences. Reflectance differences between wavelengths (630 minus 580 nm) or the ratio of 630/580 nm (Strange et al., 1974) have been useful in experiments where redness differences exist, develop or decline. Coefficients of variation were lower when actual reflectance values were analyzed than when reflectance values were converted to K/S values (Setser, 1984). This also was true for values at individual wavelengths, reflectance ratios and differences in reflectance between two wavelengths. Another type of data alteration that seems to help correct for muscle pH, structure and pigment differences between samples is adjusting for reflectance of pigment-free meat at 730 nm (Krzywicki, 1979). Unfortunately, many instruments do not measure reflectance at 730 nm.

E. Cured Meat Color Measurement

Erdman and Watts (1957) provided an effective method for following changes in cured meat color. A reflectance ratio of wavelengths 650/570 (Figure 2) is particularly sensitive to the intensity of cured color development and also can be indicative of leaky vacuum packages or other conditions that promote color fading. Reference values for the 650/570 nm ratio and cured color intensity are: no cured color=1.1; moderate fade=1.6; less intense but noticeable cured color 1.7 to 2.0; and excellent cured color 2.2 to 2.6 (Hunt and Kropf, 1988). Measurements using this reflectance ratio must be done immediately after cutting the cured product because color may change rapidly if the product is not vacuum packaged. This reflectance ratio minimizes effects due to pigment concentration and is highly correlated with visual appraisals. Barton (1967 a,b) also reported successful use of two ratios involving wavelengths 570 and 650 and 540 and 560 in following changes in the color of cooked cured meats.

When a cured meat product is in lighted display, a tan or brownish color may develop. Discoloration (fading) decreases a-values and increases b-values (with or without a change in L). For this reason, another function, the a/b ratio, is useful and more sensitive in detecting shifts from pink to tan or from red to maroon to brown. Similar sensitivity (Setser, 1984) is obtained by reduction of the a- and b-values to either hue angle = tan⁻¹ b/a or saturation index = (a² + b²)¹/².

Hunter Lab-values and CIE notations also have been used for following cured color changes, but they do not seem as sensitive to color changes as the 650/570 nm ratio, are more difficult to interpret, and are more variable if pigment concentration differences occur.

Hornsey (1956) reported a method that is widely used to determine total heme pigment and the percentage conversion to nitrosohemochrome. This is applicable for studies of the efficiency of curing as well as for following the fading of cured color. Generally, good cured color development will have greater than 90% pigment conversion to nitrosohemochrome, intermediate color development will have greater than 80% conversion and leaky packages of cured meat will have values of 45% to 60% nitrosohemochrome. This method takes about 90 minutes to run and is sensitive to light.

F. Cooked Meat Color Measurement

Spectral scans of several muscle foods cooked to various degrees of doneness (Tappel, 1957; Ledward, 1971) showed significant changes in reflectance at wavelengths 545, 580 and 630. Correlations of reflectance ratios and differences of these wavelengths and others in the red portion of the spectrum were highly correlated to doneness scores (Flores et al., 1985). The change from red to brown in ground beef due to five endpoint temperatures (65 to 77°C) was detected using wavelengths 630 and 580 nm, CIE Lab-values, a/b ratio, hue angle and saturation index (Marksberry and Kropf, 1990).

Howe et al. (1982) reported that hue angle (tan⁻¹ b/a) was the most useful in monitoring color changes in cooked pork. Hue angle had the lowest coefficient of variation (C.V. = 5.4) and was more precise than either the sensory panel (C.V. = 13.1) and/or Hunter a-values (C.V. = 22.3). Flores et al. (1985) found that measures of redness (a- and CIE a'-values) were more highly correlated (0.88) to visual scores in cooked, restructured beef roasts than either L*- and b*-values or tristimulus notations. Because brown color is difficult to measure directly compared to the loss of redness in cooked samples, the determination of percentage denatured pigment may be useful in color evaluations of cooked meat (Tappel 1957; Bernofsky et al., 1959; Howe et al., 1982; Lyon et al., 1986; Trout 1989).
G. Instrumental Measurement Guidelines

1. Standardize as many sample variables as possible (see parts II-A and III-A on sampling).
2. Because pH can have a major effect on color dynamics, the pH of the color sample should be known and reported.
3. Use samples at least 12 to 15 mm thick. If wafer-thin slices are being measured, stack them to a similar thickness. For translucent samples, a standardized white tile background is recommended.
4. To prevent pillowing of unfrozen samples into the sample port, cover the instrument’s port with spectrally pure glass. Frozen sample surfaces must be as flat as possible. A black rubber “gasket” slightly larger than the aperture helps level uneven frozen surfaces and block stray light.
5. Generally meat will be packaged and scanned through the packaging film. However, depending upon the studies’ objectives, samples may be evaluated unpackaged and thus eliminate package film effects. A spectrally pure glass over the aperture will guard against meat pieces and juice entering the reflectance port. This glass must be kept clean.
6. Use the instrument manufacturer’s advice regarding standard tile color. Some may suggest a color standard that “matches” the samples being measured. However, data based on a white standard facilitate comparisons between laboratories.
7. Carefully prepare the standardizing tile, ceramic plate or magnesium oxide block for instrument standardization. Standards may be packaged in the packaging film to prevent the film from affecting reflectance at specific wavelengths.
8. Know the aperture size and the area of illumination that is being scanned by the instrument. For some studies, measuring the same sample area or areas is critical. Some instruments have multiple viewing port sizes; select the largest port when “average” surface color determination is most important and use the smaller port when trying to measure color of small, localized areas. Some HunterLab instruments may be less sensitive when using a 10 mm rather than 55 mm aperture for measurements from 580-700 nm (Sterrenberg, 1989).
9. Some instruments are capable of averaging values for several sample areas. The number of scans needed per sample to get a representative color evaluation is dependent upon the variation between and within treatments. Often meat samples vary within treatments, thus increasing number of observations is more beneficial than making several scans of each sample.
10. Preventing frost of haze from accumulating on both the sample and aperture glass cover is critical. Wipe them off, and minimize the time the sample is at room temperature.
11. Minimize scanning time of the sample (less than 10 seconds for many spectrophotometers).
12. Use standard notations for reporting results. Notations based on CIE (1976) L*a*b* formulas are recommended over the older Hunter Lab-value formulas as they put more emphasis on the red part of the spectrum. To differentiate between the two types of Lab values, refer to CIE (1976) notations as L*a* and b* or CIE Lab values and use only “Lab” when the older formulas are used.
13. Some instruments will calculate reflectance data based on different illuminants. Illuminant A is recommended (Illuminant C or D-65 is second choice), because it places more emphasis on color in the red portion of the spectrum and correlates better with visual scores than other illuminants.
14. Express reflectance data as ratios or differences between wavelengths rather than reflectance at individual wavelengths. Ratios or differences help eliminate color measurement variation due to differences in pigment concentration, marbling, fiber orientation, etc (see I-A).
15. For many studies, the following measurements will be useful:

\[-L^*a^*b^*\text{-values, (CIE, 1976 notations)}
-\text{a/b ratios, hue angle, saturation index (Little, 1975)}
-\text{Reflectance ratios:}
\begin{align*}
&630i 580 \text{ nm for fresh meat color and color change} \\
&630i 580 \text{ nm for cured meat color and fading} \\
&630i 580 \text{ nm for cooked meat color changing from red to brown}
\end{align*}
K/S474 : K/S525 for deoxymyoglobin estimation
K/S572 : K/S525 for metmyoglobin estimation
K/S610 : K/S525 for oxymyoglobin estimation
16. If the instrument measures 730 nm and if samples have large differences in texture, pigment or quality, consider using the pigment-free meat adjustment described by Krzywicki (1979).
17. K/S conversions are not necessary for monitoring color changes using reflectance ratios or differences; but when estimating percentage of myoglobin forms, conversion of reflectance to K/S values is necessary (see III-G-19d for formula).
18. The following formula gives an example for oxymyoglobin estimation (see #15 for other ratios of other pigment forms).

\[
\frac{K/S 610 \text{ for 100% deoxy or } K/S 610 \text{ for sample}}{K/S 525 \text{ metmyoglobin or } K/S 525} \times 100
\]
\[
\text{Oxymyoglobin} = \frac{K/S 610 \text{ for 100% deoxy or } K/S 610 \text{ for sample}}{K/S 525 \text{ metmyoglobin or } K/S 525 \text{ oxymyoglobin}}
\]
19. Conversion of fresh meat sample myoglobin to “100%” deoxy-, oxy-, or metmyoglobin requires special consideration because they interconvert rapidly.

a. Metmyoglobin: Place samples in 1.0% potassium ferrocyanide for one minute, drain, blot surface, package in oxygen permeable film and oxidize at 2°C for 12 hours, then scan.
b. Deoxymyoglobin: The most difficult to form and to retain at 100%. Place samples in 10% dithionite, drain, blot surface, vacuum package to reduce for 1 to 2 hours at room temperature, (repackage in oxygen permeable film to keep film type same as in a) and c) and scan immediately.)
c. Oxymyoglobin: Place samples at 0°C to 2°C in a high-oxygen atmosphere, such as a bomb calorimeter, and flush with 100% oxygen for 10 minutes, package in oxygen permeable film and scan immediately.
d. Once the myoglobin is converted to 100% of each pigment form, record the reflectance at 474, 525, 572, and 610 nm for each form and then convert reflectance percentages to K/S val-
ues using the following equation: \( K/S = (1-R)^2 \times 2R \) (\( R \) should be expressed as a decimal, i.e., 0.30, rather than 30%). These values can then be substituted into the appropriate equation (see 15 and 18) to calculate the percentage of deoxy-, oxy-, or metmyoglobin.

20. Few instrumental color evaluations and spectral reflectance curves of fat color are reported; however, \( L^*a^*b^* \)-values and their various notations are suggested.

IV. Background Information on Color

Physical production of color requires: 1) a source of light, 2) an illuminated sample, and 3) a detector, usually the eye and brain or some instrument. The light source is described by its spectral energy distribution curve, the sample by its spectral reflectance curve and the detector by its spectral response curve. The combination of these factors provides the stimulus that the brain converts into our perception of color.

Color has three quantitatively definable dimensions. Hue is the name of the color and is that quality by which we distinguish color families (red, green, blue, etc.). It is the result of differences in length of wave impulses on the retina producing the sensation of color. Value is the lightness of color and is that quality by which we distinguish lighter and darker colors. Chroma is the strength of a color and is that quality by which we distinguish strong and weak colors, also known as the color intensity or the degree of color saturation.

Although color is a physical property of muscle foods, it also belongs in the realm of sensory perception and can be measured in psychological terms. Physical measurements can provide data to serve as a basis for establishing psychophysical scales useful for evaluating visual appearance. Three quantities (color coordinates) must be specified to describe color; however, other qualities such as size, shape, gloss, surface texture, colors of surrounding objects and especially marbling also affect the appearance of an object.

The loose terms applied to color create problems in its measurement and visual assessment. The notion of a typical red may vary with each individual, and attempts to define a specific color without using all three dimensions are futile. Objects may have the same color coordinates and match under a given illuminant but have different spectral reflectance curves and not match under other illuminants, because different spectral reflectance curves have the same set of color coordinates. Such objects are said to exhibit metamerism, whereas two objects with the same spectral reflectance curves and, thus the same set of color coordinates, are non-metameric. When two objects appear to match one observer but not another, this is referred to as observer metamerism and results from minor differences in the spectral response curves of the observers (humans or instruments).

Assigning numbers to color responses is useful. Color measurement is associated with the use of instruments, but this is only one way to measure color. Visual assessment of color, with comparison to color standards, is as much a measurement of color as assessments involving elaborate and complex instruments. Replacing the human eye with an instrument removes a detector that is sensitive to qualitative differences (and one that can think) and replaces it with one that lacks this remarkable ability but instead has superior ability to measure and remember quantitative differences. To obtain numbers and repeatability, we sacrifice the abilities of the human observer.

The nature and amount of information a color measuring instrument is capable of providing are dependent upon the manner and extent to which light is varied in viewing the sample. Instrumental color measurement techniques can be classified by the way in which the light is treated in the measurement process. The three classifications are: 1) unaltered light, 2) three or four colored lights, and 3) monochromatic light. Instruments using three (or four) colored lights are called colorimeters, whereas instruments using monochromatic light (light of only one color) are called spectrophotometers and are capable of measuring the spectral reflectance (or transmittance) curve of a sample.

Instrumental metamerism is a common and serious defect of colorimeters, which results in variation in readings obtained with different instruments, even of the same make and model, for the same sample. Such metamerism results from the fact that with existing light sources, filters and detectors, it is difficult to make the spectral response curves of colorimeters exactly alike. Differences are of greater magnitude on darker samples and those more highly saturated with color. Colorimeter readings should never be considered to have any "absolute" significance but should rather be used for detecting and measuring small color differences between samples that are nearly alike in color. The key to obtaining good reproducibility of results from colorimeters lies in the principle of "local" calibration. A standard must be provided that has nearly the same color and spectral reflectance curve shape as the samples to be measured. This implies that the standard and samples are not metameric.

Spectrophotometric reflectance techniques are especially suitable for following either muscle color changes or for estimation of myoglobin forms. The samples are not destroyed and the package environment is maintained, so individual samples can be measured over time. The same location on the cut surface may be measured repeatedly. Some spectrophotometers permit readings to be made using illuminant A (2854 K, tungsten light), B (4800 K, noon sunlight), C (6770 K, daylight), D-65 (6500 K), and F (3400 K). Evidence exists that higher correlations are obtained between objective values and visual scores when illuminant A is used for instrumental measurements, because it has a higher proportion of red wavelengths than other illuminants.

In contrast to colorimeters, which are properly used only for measuring small color differences between pairs of samples, spectrophotometers can be used to obtain "absolute" values of the color coordinates for a single sample, as well as for measuring color differences between samples.

Objective color measurements may be used for various reasons: 1) to support descriptive visual appraisals, 2) as a basis for product acceptance or rejection, 3) to document the deterioration in color over time, and 4) to estimate the proportion of the various chemical states of myoglobin. However, the most important reasons for making objective color measurements are to support visual observations and to provide unbiased evidence of treatment effects that can be statistically analyzed. For these purposes, expression of data
as color coordinates (e.g., L a b-values) is probably sufficient, but it is essential that such data be used only to represent relative color differences, not “absolute” descriptions of color.

Regardless of methods utilized, color measurement consists of two major steps: examination and assessment. Examination involves: 1) a source of light to illuminate the sample and standard, 2) a sample that is evaluated against a standard, and 3) some means of detecting the light coming from the material being examined. Assessment also can be divided into three operations: 1) a decision regarding the difference between sample and standard based upon either instrumental or visual measurements, 2) expression of the difference in terms with a common meaning to all people involved (these terms may be standardized verbal descriptions, simple statements of instrumental readings or sets of color coordinates of a point in an acceptable color order system), and 3) evaluation of acceptability of the sample.

V. Instrumental Color Evaluation Systems

A. Munsell Color Solid

Tristimulus colorimeters yield a three-dimensional specification of color location (a point) within a three-dimensional color solid. A.H. Munsell, a Massachusetts art teacher, was one of the first (1905) to describe color in terms of a 3-D color solid (Figure 3).

Color is described in terms of three attributes; hue = H, value = V, and chroma = C. There are five principal hues (red, yellow, green, blue and purple) equally spaced around the circle at the base of the color solid (Anon, 1988). The value notation in the vertical axis indicates the degree of lightness or darkness of a color. Zero is absolute black and 10 is absolute white. Chroma is the term describing color intensity compared to a neutral gray of the same value. Minolta (1988) has excellent pictorial explanations of these color systems.

Disc colorimetry was one of the first instrumental methods to quantitate color of an unknown sample. Paper discs of known hue, value and chroma are overlapped a known amount on a motorized shaft; when discs are rapidly rotated, individual colors blend. The resultant color is dependent upon the relative exposed areas of the individual discs. The exposed areas are manually adjusted until the blended color (during rotation) matches the color of the sample. Color may be expressed in Munsell notation or converted to CIE (Commission Internationale de l’Eclairage, or International Commission on Light) tristimulus values. Because of the unavailability of instruments that directly read out sample tristimulus values, disc colorimetry has not been used widely in recent studies on meat color. Nevertheless, understanding the Munsell system is of value to meat color measurement, because it was the basis for later color measurement systems.

B. CIE Color Solid

Most colors can be matched by the appropriate mixture of the light-primary colors, green, red, and blue. A given color may be plotted on a Maxwell triangle (i.e., chromaticity diagram), where each corner of the triangle represents 100% green, red, or blue. However, not all colors may be matched by the addition of light-primary colors. If color matching is done by overlapping light beams from colored lamps, some blue-green colors can be matched only if red light is subtracted from the blue/green mix by adding red light to the sample (i.e., red light is beamed onto the sample). In effect, these colors can be plotted only on a chromaticity diagram by using negative values for red light.

To avoid the computation problems associated with negative numbers, the CIE in 1931 developed the XYZ primary system to describe color in numerical terms without use of negative numbers. XYZ can be calculated from the experimental tristimulus primaries (RGB) needed to match a given color. Figure 4 shows the XYZ triangle of the CIE system, and its relation to the RGB system. The shaded area along the B-G axis represents negative values of R needed to match certain bright blue-green and yellow colors. In the larger XYZ triangle, however, all spectral colors can be plotted using positive values of XYZ.

![Figure 3](image_url)
The Munsell Color Solid. (HunterLab, 1983).

![Figure 4](image_url)
The Complete XYZ Triangle of the CIE System. (Francis and Clydesdale, 1975).
To match a given color, lightness (brightness or luminosity) also must be considered. Sample lightness is the sum of luminosity of the matching red, green and blue colors. Figure 5 shows the CIE horseshoe-shaped spectrum locus in two dimensions, x and y. All real spectral colors can be plotted within this locus. At a given luminosity, hue and chroma in the CIE system are specified by the x, y and z coordinates in the chromaticity diagram. The z coordinate need not be specified, because \( x + y + z = 1.0 \). Note that \( x = X/(X + Y + Z) \), \( y = Y/(X + Y + Z) \), and \( z = Z/(X + Y + Z) \) and that X, Y and Z can be derived from experimentally determined R, G and B. The \%Y axis in CIE notation corresponds to lightness (value) in Munsell notation.

The cones of the human eye are more sensitive to green light than to red or blue. Brightness or luminosity of colored objects is dependent upon the amount of green light reaching the eye. The CIE system was designed so that luminosity (Y) is calculated from the amount of green light reflected from the sample.

**C. Reflectance Spectroscopy**

CIE X Y Z values may be obtained using a spectrophotometer equipped with a reflectance attachment (Francis and Clydesdale, 1975). However, the calculations by their “Weighted or Selected Ordinate Integration Method” are time-consuming. Reflectance values at each wavelength (400-700 nm) must be multiplied by the total energy available from the light source at each wavelength to obtain a relative reflectance curve for the sample. These values then must be multiplied by \( \tilde{x} \), \( \tilde{y} \), and \( \tilde{z} \) standard observer curves, to account for sensitivity of the human eye to red, green and blue light at each wavelength. Finally, the corrected or “weighted” reflectance values are summed (400-700 nm) to obtain X, Y and Z values. Reflectance spectrophotometry is not used commonly by the food industry for color measurements but is used often in research.

**D. Tristimulus Colorimetry**

Tristimulus colorimeters employ filters to simulate the response to the human eye. White light from a standard CIE source is shone on the sample. Light reflected at 45° is measured by a photo cell after it passes through an X, Y or Z filter. For example, at 650-700 nm in the red region of the visible spectrum, the human eye is not sensitive to blue or green light. The perceived red color is due entirely to the quantity of red primary color reaching the eye. For a colorimeter to simulate the human eye, the X filter must filter out all blue or green light reaching the detector.

The filters are designed so the energy output of the light source, as modified by the filter, creates a response in the photo detector equal to that seen by the human eye (standard observer) viewing the same sample illuminated by a standard source of known spectral energy (Francis and Clydesdale, 1975).

**E. Hunter Color Solid**

An early successful colorimeter made by the Henry A. Gardner Co. used amber, blue and green filters to obtain A, B and G readings of a sample relative to a white magnesium oxide-coated plate. R. S. Hunter, while employed by the Gardner Company in 1948, developed an improved colorimeter with a response in a different color solid with axes of Rd, a, b. Hunter subsequently left Gardner laboratory to form HunterLab, Inc. The L a b color space used in Hunter colorimeters is shown in Figure 6. The solid has a uniform surface color scale. The lightness axis, in the center of the solid, is calibrated from 0-100, where 100 is absolute white. Positive a-values are red, and negative a-values are green. Positive b-values are yellow, and negative b-values are blue. The a- and b-values are obtained electronically as the X-Y

![Figure 6](image)
and Y-Z difference signals, respectively. CIE X, Y and Z may be converted to L, a and b as follows:

\[
L = 10 \left( \frac{Y}{Y_0} \right)^{1/3}
\]

\[
a = 17.5 \left( \frac{X}{X_0} - \frac{Y}{Y_0} \right) \left( \frac{Y}{Y_0} \right)^{1/3}
\]

\[
b = 7.0 \left( \frac{Y-0.847}{Y_0} \right) \left( \frac{Y}{Y_0} \right)^{1/3}
\]

An advantage of the L a b color system over the CIE %Y, x, y system is that the L a b system is uniform. On the CIE x, y plot (chromaticity diagram), two samples with the same visual difference in one part of the solid and another pair in a different part of the solid will not have the same difference between them. Because of the uniformity of the L a b color solid and the ease of use of the Hunter colorimeters, the HunterLab system is the most widely used in the measurement of meat color.

Although Hunter L a b values only locate a single point within the color solid, the L-value has been useful to determine the extent of product lightening (increase of L) or darkening (decrease of L), and the a-value has been useful to determine the change in pink-to-red hue characteristic. When using a tristimulus colorimeter, data should be reported in two ways to allow other researchers to determine color location. Report L a b values for product comparisons and report a/b ratio, hue angle, or saturation index (refer to Little, 1975) to indicate change of color due to treatment (time, display effects, storage effects, etc.). The latter three functions, independently or in combination, provide greater sensitivity than a-values alone.

**References**


List of Pictorial Color Standards

BEEF

Color and Discoloration Standards for Retail Beef and Veal – Publ. No. 1734, Agr. Canada Res. Station, Lacombe, Alberta TOC 1SO, Canada.
Beef Color – Circular 398, Dept. of Animal Sciences and Industry, Weber Hall, Kansas State University, Manhattan, KS 66506.
Ground Beef Patty Cooked Color Guide – Dept. of Animal Sciences and Industry, Weber Hall, Kansas State University, Manhattan, KS 66506

PORK

Pork Quality Standards – Wisconsin Agr. Exp. Station Special Bulletin 9, 1805 Linden Drive, University of Wisconsin, Madison, WI 53706.

LAMB


Glossary of Color Terms

Absolute Black: A color of the lowest value possessing neither hue nor chroma, closely approximated by looking through a small aperture into a velvet-lined box.
Absolute White: A color of the highest value possessing neither hue nor chroma, closely approximated by viewing a piece of freshly cleaned magnesia.
Achromatic Colors: See Neutral Colors
Chroma: The strength or weakness of a chromatic color, expressed as weak, moderate or strong.
Chromatic Colors: All colors possessing both hue and chroma.
CIE Coordinate System: A three-dimensional color description system developed by the Commission Internationale d'Éclairage.
CIE Tristimulus Values: The standard color coordinates of the color measuring system developed by the Commission International d’Eclairage.

Color: A phenomenon of light and visual perception that enables one to differentiate otherwise identical objects.

Color Assessment: The process, following color examination, of making a decision regarding the difference between the sample and standard based upon either instrumental readings or thoughts, expressing the difference in terms with a common meaning to all people involved, and evaluating the expressed difference to arrive at a decision regarding the acceptability of the samples.

Color Attributes: See Color Dimensions

Color Balance: An aesthetic term referring to the feeling of balance, continuity and fitness found in beautiful color schemes; the physical balance of a color scheme in gray, detected solely by the eye, using disk colorimetry.

Color Blindness: The inability to distinguish colors properly, associated with an abnormal perception of hue and chroma because of congenital defects or to injury of the eye.

Color Chart: A series of color scales arranged so any two dimensions of color may vary while the third dimension remains constant.

Color Coordinates: See Color Dimensions

Color Description: The delineation of color by hue, chroma and value.

Color Dimensions: The attributes of hue, value and chroma used to describe color.

Color Dominance: The predominance of one hue in a color scheme.

Color Examination: Use of a source of light to illuminate a sample to be evaluated against a standard and some means of detecting the light coming from the material being examined.

Colorimeter: An instrument in which the sample is viewed in three kinds of light selected so the readings are in the form of three numbers, which, with suitable standards, are either directly equal to the three CIE tristimulus values, or are converted to them by simple calculations.

Color Intensity: See Chroma

Color Notation: An exact description of color using symbols and numerals. For example, a typical maroon is noted as: SR 3:4.

Color Order System: A system for orderly describing and specifying a given color in a universally accepted language.

Color Saturation: See Chroma

Color Scale: A series of colors exhibiting a regular gradation in one dimension, while the other two dimensions remain constant.

Color Standard: An object bearing a specific color against which samples are compared. Such standards may be color photographs or the three-dimensional lower third of the value scale.

Dark Color: A color that has a low value and is found in or adjacent to the lower third of the value scale.

Deoxyhemoglobin: One of the reduced forms of hemoglobin, purple-red in color.

Diffuse Reflectance: Light reflected at various angles from the incident light, primarily responsible for the object’s color.

Disk Colorimetry: A system for matching specific colors utilizing rapidly spinning disks comprised of different colors.

Foot-candles: English system unit of illumination; 1 foot-candle: 10.76 lux.

Gray: A neutral color that possesses neither hue nor chroma.

Home Value Level: The value level at which maximum chroma is reached in some particular hue.

Hue: The distinctive characteristic of any chromatic color distinguishing it from other hues found between the ends of the spectrum, i.e., red, yellow, green, blue or purple.

Hue Circle: A color circle that exhibits a progressively graded series of hues.

Hue Angle: The angle, \( \theta \), created by the slope of line \( b/a \) in a Hunter color space. \( H = \tan^{-1} b/a \), see Little (1975).

Illuminant: A source of light used to illuminate samples or standards.

Instrumental Metamerism: A phenomenon that occurs when similar instruments give different readings for exactly the same color because of differences in their spectral response curves.

Intermediate Hues: Hues located at visually determined midpoints between the five principal hues, i.e., yellow-red, green-yellow, blue-green, purple-blue and red-purple.

K/S Values: K is the absorption coefficient and S is the scattering coefficient. K/S values are useful for quantifying the proportion of the three chemical states of myoglobin present and are calculated from the reflectance \( R \), expressed as a decimal, not as a percentage) at selected wavelengths using the following equation: \( K/S = (1 - R)^2/2R \).

Light: The luminous energy that gives rise to color through stimulation of the retina, which produces nerve currents in the optic nerve and brain.

Light Color: A color of high value found in or adjacent to the upper third of the value scale.

Light Primaries: Three spectrally pure beams of light, which, when blended, allow a large number of colors to be seen.

Local Calibration: Calibration of a colorimeter using a standard having nearly the same color and spectral reflectance curve shape as the samples to be measured, thereby preventing the standard and samples from being metameric.

Lux: Metric system unit of illumination equal to 1 lumen/square meter; 10.76 lux/foot-candle.

Lumen: Unit of measure for the flow of light through a unit solid angle from a point source of one international candle.

Major Hues: The five principal hues and the five intermediate hues representing mutually equivalent hue-points to the eye.

Maximum Color: A color of strong chroma, on a value level characteristic of the hue in question. See Home Value Level.

Medium Color: A color of medium value located in or adjacent to the middle of the value scale.

Metameric Objects: Objects that have the same color coordinates and match under a given illuminant but have different spectral reflectance curves and do not match under other illuminants.

Metamerism: The phenomenon of two colors matching under a given illuminant but not matching under other illuminants, due to differences in their spectral reflectance curve or matching for one observer but not another, due to differences in their spectral response curves.
Metmyoglobin: An oxidized form of myoglobin, brown in color.

Moderate Color: A color of moderate chroma located between the fourth and sixth steps of chroma on Munsell Color Charts.

Monochromatic Light: Light of only one color.

Myoglobin: A sarcoplasmic protein of muscle; the basic pigment in muscle.

Neutral Colors: Colors characterized by a complete absence of hue and chroma, i.e., pure black, pure white and pure grays.

Null Detector: An observer used to tell when colors do not differ or match. Human observers are particularly adept as null detectors.

Observer: A human or instrument used to detect color differences.

Optical Properties: Properties involved in the relationship between light and vision, i.e., visual properties.

Oxymyoglobin: The oxygenated form of myoglobin, in which iron is reduced; color is bright red.

Pigment: Colored matter in an object.

Pigment Concentration: The quantity of pigment, usually in mg/g of wet tissue.

Primary Colors: Three colors from which all other colors can be derived, i.e., red, yellow and blue.

Principal Hues: Five hues that are visually equivalent to each other, i.e., red, yellow, green, blue and purple.

Psychometric Scales: Visual scales for the measurement of color developed through the mental acuity of trained descriptive panels.

Reflection Factor: The percentage of incident light reflected from a sample.

Saturation Index: Length of a radial vector from point of origin to the sample point in a Hunter color space. For meat, the greater the value, the greater the saturation of red. St = (a² + b²)¹/², see Little (1975).

Secondary Intermediate Hues: Hues located at the visually determined midpoints between each of the 10 major hues.

Shade: The color evoked by the mixture of a chromatic pigment with a black pigment or the appearance of that portion of a surface located in a shadow.

Special Intermediate Hues: All hues not classified as principal, intermediate or secondary intermediate hues.

Special Characteristics: Characteristics of an object related to its light reflectance properties within the visual spectrum.

Spectral Energy Distribution Curve: The curve created by plotting the energy emitted from a given light source against wavelength.

Spectrally Pure Color: The sensation evoked by spectrally pure light.

Spectral Reflectance Curve: The curve created by plotting the light reflected by an object against wavelength.

Spectral Response Curve: The curve created by plotting the response given by an observer against wavelength.

Spectrophotometer: An instrument used to determine light reflectance or transmission at different wavelengths across the spectrum.

Specular Reflectance: Light reflected at an angle (about 90° from the incident light) that gives a mirror-like appearance, mainly responsible for the gloss of an object.

Strong Color: A color of pronounced chroma found between the seventh and tenth steps of chroma on the Munsell Color Chart.

Tint: The color evoked when a chromatic pigment is mixed with a white pigment or when a small amount of chromatic pigment overlays a white background.

Value: The lightness or darkness of any color, i.e., dark, medium or light.

Value Level: The level at which all colors have the same value.

Value Scale: A series of visually equivalent neutral colors lying between absolute black and absolute white.

Visible Spectrum: The result of a passing beam of light through a glass prism. By this means, the beam of light is broken into an invariable sequence of increasing wavelengths, evident to the eye as a sequence of colors of subtly varying hues of strong chroma.

Visual Assessment: Assessment of color utilizing the visual acuity of sensory panels.

Weak Color: A color of reduced chroma located between the second and third steps of chroma on the Munsell Color Chart.

Worst-Point Color Score: A color score derived from the area most severely discolored on a meat surface (single or cumulative area at least 2 cm in diameter).

Example Color Scales

Characterization of Oxygenated Pigment Lean Color

<table>
<thead>
<tr>
<th>Beef</th>
<th>Lamb</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 = Extremely bright cherry-red</td>
<td>8 = Extremely bright red</td>
</tr>
<tr>
<td>7 = Bright cherry-red</td>
<td>7 = Bright red</td>
</tr>
<tr>
<td>6 = Moderately bright cherry-red</td>
<td>6 = Moderately bright red</td>
</tr>
<tr>
<td>5 = Slightly bright cherry-red</td>
<td>5 = Slightly bright red</td>
</tr>
<tr>
<td>4 = Slightly dark cherry-red</td>
<td>4 = Slightly dark red</td>
</tr>
<tr>
<td>3 = Moderately dark red</td>
<td>3 = Moderately dark red</td>
</tr>
<tr>
<td>2 = Dark red</td>
<td>2 = Dark red</td>
</tr>
<tr>
<td>1 = Extremely dark red</td>
<td>1 = Extremely dark red</td>
</tr>
</tbody>
</table>
Pork
8 = Extremely bright grayish-pink
7 = Bright grayish-pink
6 = Moderately bright grayish-pink
5 = Slightly bright grayish-pink
4 = Slightly dark grayish-pink
3 = Moderately dark grayish-pink
2 = Dark grayish-pink
1 = Extremely dark grayish-pink

Pork Color
5 = Dark purplish red
4 = Purplish red
3 = Reddish pink
2 = Grayish pink
1 = Pale purplish gray

Unstructured
1 = Pre-rigor, dark purple-red

Worst-Point Color
Single or combined area of at least 2 cm². Score using the same scale used to evaluate "average" lean color.

Unstructured
15 cm line anchored with appropriate descriptive terms.

Characterization of Deoxygenated Pigment Lean Color

Beef or Lamb or Pork
8 = Extremely bright purple-red or purplish-pink
7 = Bright purple-red or purplish-pink
6 = Moderately bright purple-red or purplish-pink
5 = Slightly purple-red or purplish-pink
4 = Slightly dark purple or purplish-pink
3 = Moderately dark purple or purplish-pink
2 = Dark purple or purplish-pink
1 = Extremely dark purple or purplish-pink

Beef or Pork or Lamb
5 = Bright purple-red or pink
4 = Dull purple-red or pink
3 = Slightly brownish-red or pink
2 = Moderately brownish-red or pink
1 = Brown

(purple-red = beef or lamb, purplish-pink = pork)

Lean Discoloration and Uniformity of Lean Color

Amount of Browning
6 = Dark brown
5 = Brown
4 = Brownish-gray
3 = Grayish
2 = Dull
1 = No evidence of browning

Discoloration
5 = Extreme
4 = Moderate
3 = Small
2 = Slight
1 = None

Surface Discoloration
7 = Total discoloration (100%)
6 = Extensive discoloration (80-99%)
5 = Moderate discoloration (60-79%)
4 = Modest discoloration (40-59%)
3 = Small discoloration (20-39%)
2 = Slight discoloration (1-19%)
1 = No discoloration (0%)

Color Uniformity
5 = Extremely two-toning
4 = Moderately two-toning
3 = Small amount two-toning
2 = Slightly two-toning
1 = Uniform

Worst-Point Color
Single or combined area of at least 2 cm². Score using same scale used to evaluate discoloration.

Surface Discoloration
5 = Severe 61-100%
4 = Moderate 21-60%
3 = Small 11-20%
2 = Slight 1-10%
1 = No discoloration
Meat Display Color Stability

Non-Vacuum
5 = Dark red or pink or brown
4 = Moderately dark red or pink or brown
3 = Slightly dark red or pink or brown
2 = Bright red or pink
1 = Extremely bright red or pink
(red = beef or lamb, pink = pork)

Vacuum
5 = Brown
4 = Moderately brownish-red or brownish-pink
3 = Slightly brownish-red or brownish-pink
2 = Dull purplish-red or pink
1 = Bright purplish-red or pink
(red = beef or lamb, pink = pork)

Worst-Point Color
Single or combined area of at least 2 cm². Score using the same scale used to evaluate display color.

Ground Meat Color

Ground Meat of Similar Fat Level
8 = Light grayish-red or pale-pink
7 = Very light cherry-red or grayish-pink
6 = Moderately light cherry-red or grayish-pink
5 = Cherry-red or grayish-pink
4 = Slightly dark red or grayish-pink
3 = Moderately dark red or grayish-pink
2 = Dark red or grayish-pink
1 = Very dark red or grayish-pink

Ground Meat of Differing Fat Levels
8 = Very light red or grayish-pink
7 = Moderately light red or grayish-pink
6 = Light red or grayish-pink
5 = Slightly light red or grayish-pink
4 = Slightly dark red or grayish-pink
3 = Dark red or grayish-pink
2 = Moderately dark red or grayish-pink
1 = Very dark red or grayish-pink

Ground Meat Display Discoloration
5 = Very dark red or grayish-pink or brown
4 = Moderately dark red or grayish-pink or brown
3 = Slightly dark red or grayish-pink or brown
2 = Bright red or grayish-pink
1 = Very bright red or grayish-pink

Cooked Meat Color

Surface and Internal Cooked Color
(beef, pork, lamb, or ground beef)
13 = Extremely brown
12 = Brown
11 = Moderately brown
10 = Slightly brown
9 = Gray or tan
8 = Moderately gray or tan
7 = Slightly gray or tan
6 = Slightly pink
5 = Moderately pink
4 = Pink
3 = Slightly red
2 = Moderately red
1 = Red

Cooked Surface Color:
Differences
3 = Moderately lighter
2 = Slightly lighter
1 = Very slightly lighter
0 = Not different from control
-1 = Very slightly darker
-2 = Slightly darker
-3 = Moderately darker

Cooked Surface Color:
Uniformity
5 = Extreme amount of variation
4 = Moderate amount of variation
3 = Small amount of variation
2 = Slight amount of variation
1 = No variation

Internal Cooked Color
7 = Brown
6 = Gray brown
5 = Pinkish-grey
4 = Slightly pink
3 = Pink
2 = Medium red
1 = Very red

Internal Doneness
6 = Very well
5 = Well
4 = Medium well
3 = Medium
2 = Medium rare
1 = Rare
### Other Scales Associated with Meat Color Evaluation

**Heat Ring**
- 5 = Severe
- 4 = Moderate
- 3 = Small
- 2 = Slight
- 1 = None

**Fat Color**
- 5 = Yellow
- 4 = Moderately yellow
- 3 = Slightly yellow
- 2 = Creamy white
- 1 = White

**Iridescence Intensity**
- 5 = Very strong iridescence
- 4 = Strong iridescence
- 3 = Moderate iridescence
- 2 = Slight iridescence
- 1 = Very slight iridescence
- 0 = No iridescence

**Pork Quality Structure**
- 5 = Extremely soft, exudative
- 4 = Soft, exudative
- 3 = Normal
- 2 = Firm, dry
- 1 = Extremely firm, dry

**Fat Discoloration**
- 4 = Extremely discolored
- 3 = Moderately discolored
- 2 = Slightly discolored
- 1 = No discoloration

**Percentage Iridescence**
- 5 = 81-100% of area
- 4 = 61-80% of area
- 3 = 41-60% of area
- 2 = 21-40% of area
- 1 = 1-20% of area
- 0 = No iridescence

**Purge Characterization**
- 6 = Dark red or purple
- 5 = Light red
- 4 = Clear
- 3 = Opaque
- 2 = Milky white
- 1 = Other (list on scoring sheet)

**Off-Odor: Immediate & 30-Minute**
- 5 = No off-odor
- 4 = Slight off-odor
- 3 = Small off-odor
- 2 = Moderate off-odor
- 1 = Extreme off-odor

**Off-Odor Characterization**
- 6 = Putrid
- 5 = Acid
- 4 = Sour
- 3 = Sweet
- 2 = Arid
- 1 = Other (list on scoring sheet)

### Hedonic Scales for Consumer Panels

**Color of This Package**
- 7 = Like very much
- 6 = Like moderately
- 5 = Like slightly
- 4 = Neither like nor dislike
- 3 = Dislike slightly
- 2 = Dislike moderately
- 1 = Dislike very much

**Based on Color**
- 7 = Very definitely would purchase
- 6 = Definitely would purchase
- 5 = Probably would purchase
- 4 = May or may not purchase
- 3 = Probably would not purchase
- 2 = Definitely would not purchase
- 1 = Very definitely would not purchase

**Meat Has Good Color**
- 7 = Very strongly agree
- 6 = Strongly agree
- 5 = Slightly agree
- 4 = No opinion
- 3 = Slightly disagree
- 2 = Strongly disagree
- 1 = Very strongly disagree

**Overall Color**
- 8 = Extremely desirable or acceptable color
- 7 = Very desirable or acceptable color
- 6 = Moderately desirable or acceptable color
- 5 = Slightly desirable or acceptable color
- 4 = Slightly undesirable or unacceptable color
- 3 = Moderately undesirable or unacceptable color
- 2 = Very undesirable or unacceptable color
- 1 = Extremely undesirable or unacceptable color