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COLOR STABILITY OF FROZEN BEEF STEAKS AS AFFECTED BY VARIOUS COMMERCIAL DISPLAY LIGHTING SOURCES

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Chapter 1

INTRODUCTION

In recent years the meat industry has been moving toward centralized processing of meat. Centralized processing is deemed feasible because of increased efficiency of larger plants, ease of transportation from a centralized location and more economical distribution of retail cuts based on geographic demand. Centralized retail processing lends itself to what many in the meats industry indicate is the coming method of meat retailing, namely, frozen meat processing.

Frozen meat, from central processing to the retail counter, has many advantages over fresh meat processing and is likely to claim a large share of the market as improvements in processing techniques are mastered. One of the inherent problems with frozen retail meat cuts is consumer resistance. Therefore, from the outset an attractive high quality product must be presented.

Color is one of the prime determinants of meat quality to the consumer. Frozen meat color should approach the acceptable cherry red oxymyoglobin color of fresh meat if it is to become a major factor in the retail market.

The production and maintenance of acceptable color

is somewhat more difficult in frozen as opposed to fresh meat. Variation from the cherry red oxygenated state may occur as a result of temperature fluctuations, display lighting (source and intensity), freezing system, package material, packaging method and the intrinsic color properties of the muscle.

One of the most important factors affecting the maintenance of acceptable color of frozen meat is the type of light under which the meat is displayed.

Measurement of meat color has long been an area of debate among meat researchers. Interpretation of results of various methods of color determinations has always been difficult and in many cases has been poorly related to actual visual appearance of the product. Recently, reflectance spectrophotometry has become a popular non-destructive method of color measurement of meat. Advances in the area of integration of tristimulus data are especially promising.

The purpose of this study was to determine the effect of various commercial light sources on the color stability of frozen beef.

Chapter 2

REVIEW OF LITERATURE

Color of meat is of major importance in the consumer acceptance and therefore, the salability of this product. The consumer relates bright red oxymyoglobin color directly to fresh and acceptable quality in meat. Pangborn (1967) states that "to a large extent, man recognizes, discriminates and selects nutrients with the eye. Through conditioning and association he expects an item of certain shape and color to have a specific odor, taste and texture." Thus the meat industry should be cognizant of the consumers' preference for a certain color in meat products.

Judd and Wyszecki (1963) and Francis (1963) agree that consumer preference for food stuffs is based largely on color.

Because of this strong consumer desire for a certain specific color in meat, providing conditions for maintaining acceptable color should be foremost in the minds of meat retailers.

As the meat industry has considered ways of improving the production and processing efficiency, quality and stability of meat and meat products, several new processing methods have been attempted.

Recently considerable work has been performed on the process of cryogenic processing of meat. Kropf et al. (1971)

have shown a system of freezing-packaging meat with excellent results as far as color and color stability are concerned. This method has much promise as a means of increasing efficiency of meat retailing in the future.

Factors Affecting Meat Color Deterioration

Three meat pigments of major concern in the fresh and frozen meat industry are myoglobin, oxymyoglobin, and metmyoglobin. Each represents a different color due to its characteristic spectral energy distribution and thus varies in appeal to the consumer. The specific color of fresh and frozen meat is largely determined by the relative proportions and distribution of purple reduced myoglobin, red oxymyoglobin and brown metmyoglobin (Watts et al., 1966). Metmyoglobin is the most commonly occurring undesirable pigment on meat surfaces; its brown color is noticable when 60 percent of the myoglobin exists in this form (Brooks, 1938).

Pirko and Ayres (1957) found that the reducing potential of muscle tissue has a direct effect on spectral changes in intact beef muscles. The hydrogen ion concentration (pH) of the muscle appears to relate to muscle color. Pirko and Ayres (1956) found that muscle with a pH greater than 5.7 was generally darker in color than a muscle with a pH of 5.7 or less. Other workers (Cutaia and Ordal,

1964) and (Elliot, 1967) agree that pH has an effect on meat color.

Aside from pH, other muscle characteristics may be responsible for pigment changes in meat. The mitochondria and enzyme systems are still functional. Fox (1968) states that oxygen is carried by hemoglobin in the blood to the mitochondria in the muscle cells. Even after death, the oxygen present in these still functioning mitochondria and in the air surrounding the meat surface is used to oxygenate metabolic intermediates. During this process, a certain amount of myoglobin is oxidized to metmyoglobin. Pirko and Ayres (1957) found a continuous consumption of oxygen in postmortem intact muscle samples. They concluded that an insufficient migration of oxygen resulted in darkening of the muscle explained in the following manner. They noted that oxymyoglobin increased and decreased inversely with reduced myoglobin and formation of metmyoglobin influenced the equilibria between reduced myoglobin and oxymyoglobin. They concluded that before metmyoglobin can be formed, oxymyoglobin must dissociate into oxygen and reduced myoglobin. In other words, a muscle without sufficient oxygen pressure will darken first by the formation of the dark purple reduced myoglobin pigment and second by formation of metmyoglobin. The response of muscle pigments to a limitation of oxygen

is of special interest in selecting the oxygen permeability of packaging materials. Medium permeability (209.3 cc/24 hrs. @ 37°C) film was more beneficial for frozen meat color than low (4.65 cc) or high permeability (465.0 cc) film (Sandberg, 1970).

Other extrinsic factors have a great effect on the color of meat. Many studies have established the effects of accelerated microorganism growth in reducing the color stability of meat. Kraft and Ayres (1954) found that surface growth bacteria on meat caused discoloration. Cutaia and Ordal (1964) found similar results.

Storage or display temperature has been found to have a profound effect on the stability of meat color. Rickert et al. (1957) discovered the stability of fresh meat color could be drastically affected by storage temperature. At 85°F a very rapid loss of red color was noted. At 54°F a color loss was observed, however at a significantly slower rate than the 85°F temperature. A temperature of 34°F was found to be satisfactory, and in fact, acceptable color was maintained for up to 20 days at this temperature. Cutaia and Ordal (1964) concur with these results and state that storage temperature affected the rate of metmyoglobin formation and its conversion to reduced myoglobin. Fellers et al. (1963) also found that at 32°F, color was maintained on packaged beef cuts better than at 42°F.

Sandberg (1970) found that decreasing display case temperature resulted in increased visual brightness in frozen beef steaks. He found that steaks displayed at -28.9°C showed acceptable color through 21 days of display, while steaks displayed at -12.2°C and -20.6°C temperatures lost much of their brightness between day 7 and day 21.

Effect of Lighting on Meat Color

Light source can drastically affect meat color as it appears to the human eye. This variation in color stems from the different spectral energy distribution of each light source (Elseuier, 1968). For example, cool white fluorescent light has emission peaks at 440, 530 and 580 nanometers (nm) (Mpelkas, 1967). These emission peaks will effect the light reflected from the meat surface, thereby changing the apparent color of the meat. Fluorescent light sources appear to have more and stronger emission peaks than incandescent sources. Kraft (1954) reported that ultraviolet light caused a rapid discoloration in fresh beef. Townsend and Bratzler (1958) used various colored filters to test the effect of different wavelengths on frozen beef color stability. They subjected this meat to several modifications of incandescent light; namely no filter, green filter, yellow filter, orange filter, red filter and total darkness. Steaks subjected to no filter,

red filter or orange filter showed the largest amount of metmyoglobin formation while steaks stored in darkness showed little change in color. Townsend and Bratzler did further work employing colored fluorescent light sources. Steaks stored in darkenss showed little change in color, while those stored under yellow fluorescent and white fluorescent lighting showed the greatest color deterioration. Red and green fluorescent light sources showed an intermediate change in color. They concluded from this study that light energy at 500 nm is absorbed by myoglobin and results in a photo-chemical reaction changing myoglobin or oxymyoglobin to metmyoglobin. In other words, the yellow portion of the spectrum caused the most color degradation in packaged frozen meat.

Solberg and Franke (1970) also investigated the photosensitivity of fresh meat color for a two and five day exposure period. They used six different wavelengths; 420 nm, 510 nm, 550 nm, 570 nm, 590 nm, or 632.8 nm each at an intensity at 0.5 milliwatts/cm^2 at both 34^{o}F and 41^{o}F. These workers found that none of these specific wavelengths enhanced formation of metmyoglobin more than any other wavelength studied. However, illuminated samples contained an average of 5.5 percent more oxidized heme pigment than did controls kept in total darkness. Metmyoglobin content increased with lengthened storage time

and increased temperature. Solberg and Franke suggest that enhancement of metmyoglobin formation as a result of illumination may be due to photo-chemical activation of a compound such as riboflavin to a form which may cause oxymyoglobin to oxidize to metmyoglobin. Haurowitz (1950) also found that incandescent, tungsten-filament and unspecified fluorescent lighting all cause the same degree of fading of color on both fresh and cured meat surfaces for a given time of exposure and light intensity. Freezing affords no protection against discoloration by light (Lawrie, 1966).

Rickert et al. (1957) working with pork, both fresh and cured, noted that fresh pork appears to increase in visual redness upon exposure to light, but cured ham color rapidly deteriorates under the same conditions. The authors speculate that light of any type catalyzes the oxidation of nitric oxide hemoglobin and nitric oxide hemochromagen in the presence of oxygen. Further, in the absence of oxygen, light did not cause discoloration.

Hansen and Sereika (1969) contend that illumination of prepackaged frozen meat accelerates deterioration of color but this rate of deterioration is essentially the same no matter what type of light source is used and the spectral energy distribution of the source is not a factor in color degradation. This tends to agree with the work of Rickert et al. (1957) who found no meat surface color

difference due to varying light sources.

Disagreement exists regarding the direct effect of various types of light on the color of both fresh and frozen meat.

Another factor involved in lighting is intensity of light sources. Hansen and Sereika (1969) studied the effect of display light intensity on the color stability of frozen beef. Four intensities of cool white fluorescent lighting were investigated; 50 foot candles, 100 foot candles, 200 foot candles and 400 foot candles. They found that "any intensity over 200 feet candles was very deleterious to color stability." These workers stated that light intensity was one of the most significant variables affecting meat color stability.

Santamaria (1970) performed a similar study on frozen beef using light intensities of 807, 1076, 1614 and 3228 lm/m^2 with the control kept in the dark. He concluded that the most satisfactory and practical light intensity was 1076 lm/m^2. At this intensity, the color stability was acceptable and the light was sufficient for illuminating product. Saccharow (1971) states that controlling light intensity and "permeation" into the package is a prime factor in protecting color retention of food products.

Earlier, yet somewhat less conclusive work, was performed by Vorgille (1952) who observed meat under 215

foot candles and found incandescent light was responsible for rapid fresh meat discoloration due to increased surface temperature from heat generated by display lights. Hansen and Sereika (1969) in a discussion of their previous findings disclosed that no variation, regardless of light source or intensity, in surface temperature of frozen beef was observed by thermocouples placed at the meat surface. These findings are contrary to the observations of Gould (1963) who stated that increasing intensities of illumination from incandescent lights contributed to increased surface heating and more rapid discoloration of fresh pork chops. Gould also reported that light intensities that did not increase surface temperature had no effect on discoloration of fresh pork chops.

Systems of Color Measurement

One problem plaguing the meat industry is that of precise measurement of meat color. Use of visual color score is very subjective and, in many cases, unreliable, especially for color research, where small color differences may be measureable only by a more consistent and objective means than the human eye.

Several color matching methods attempt to incorporate greater objectivity into visual evaluation. Mackintosh (1932) described a method of applying the Munsell spinning disk

technique to meat color. Hiner (1954) noted the application of color paddles to meat color measurement. These methods have never been used widely due to a lack of color stability and uniformity. The spinning disk method is also quite time-consuming. Photographic standards are often used in evaluating meat color. The University of Wisconsin Pork Standards (1963) and the recently published Kansas State University Frozen Beef Color Standards (1971) are examples. Both are useful for rapid color comparisons especially when used by a trained observer, but are not suitable for following more subtle color changes in meat. Actually, the eye is unsurpassed when used to decide whether the color of two samples held side by side is identical or not (Billmeyer and Saltzman, 1966). However, since it is impractical to reproduce and match every shade of color that may be encountered in meat, visual scores are still quite subjective. Also, differences among observers can lead to variation in judgments in color matching and limits comparison of this type of visual data (Brown, 1957; Smith, 1963).

Several instruments designed for color measurement rely on the eye as a detector. The afore mentioned disk colorimeter is an example of this method. Other instruments that necessitate using the eye as a detector are the Koenig-Martens spectrometer (McNicholas, 1928) and the Donaldson

colorimeter (Donaldson, 1947). These instruments are less used today because of advances in development of more sophisticated color measuring instruments.

Two color measurement devices of a more advanced design are the Hunter Color and Color Difference Meter, and the Gardner Color Difference Meter. These colorimeters are similar in nature in that the sample is compared to various colored standardized filters or plates and a null meter arrangement is employed to determine differences between the sample and standards. Dean and Ball (1958) successfully used the Hunter device as did Rickert et al. (1957) and Fellers et al. (1963) to determine color changes in packaged beef. The readings obtained were convertible to ICI tristimulus values and to Munsell values.

Spectrophotometry involves the defraction of a white light source into spectral components by use of a prism or defraction grating. This spectrum then is used either one wavelength at a time, or the whole spectrum may be passed across the sample to be studied as in a Scanning spectrophotometer (Billmeyer and Saltzman, 1966).

Two applications of spectrophotometry have been thoroughly investigated as a means of determining pigment concentrations and pigment states on meat surfaces. These methods are absorbancy of pigment extracts and surface reflectance. Austin and Drabkin (1935) described a method of using absorbancy to determine methemoglobin

content in *in vitro* systems. This method was further developed by Broumand, Ball and Stier (1958) to determine the percentage of reduced, oxy and metmyoglobin. This method was dependent on pigment extraction which has several intrinsic faults (Schweigert, 1954). With the use of cyanide derivatives, Dean and Ball (1960a) demonstrated extraction procedures that allowed myoglobin conversion from one form to another. This method proved especially useful for total pigment determination. Naughton, Frodyma and Zeitlin (1957) used absorbancy ratios as a means of expressing the color of tuna meat. They established that a ratio of absorbance at 540 nm to absorbance at 640 nm was useful in establishing green discoloration. They determined that ratios of these absorbancies should be widest for normal color and narrowest for green discoloration. Difficulties in obtaining clear solutions, sample destruction or chemical alteration and standardization of depth to which the meat should be sampled are problems inherent to extraction methods.

Reflectance methods appear to be a promising means of spectrophotometric evaluation of meat pigments. Ockerman and Cahill (1969) observed that reflectance is a rapid, objective method of measuring muscle color and results in good agreement with visual panel scores. Reflectance percentages depend on several factors, including concentration and chemical state of the meat pigment but are

affected by intramuscular fat, water on the cut surface and surface texture (Snyder, 1965).

Kraft and Ayres (1954) used spectrophotometric measurements of packaged fresh beef expressed as percent mean reflectance at eight wavelengths selected in the region from 540 to 800 nm. Tappel and Maier (1957) observed that reflectance spectra of hematin compounds possess enough maxima and minima throughout the visible part of the spectrum to allow differentiation between chemical states of heme pigments. Pirko and Ayres (1956) used reflectance as a measure of pigment changes of beef during storage. Reflectance readings were taken at 5 to 10 nm intervals from 400 to 650 nm. These reflectance percentages were then plotted against wavelength and it was determined that those at 500, 545, 555, 580 and 635 nm were useful in observing color changes in beef with peaks attributed to metmyoglobin at 500 and 635 nm, peaks attributed to oxymyoglobin at 545 and 580 nm, and a peak attributed to reduced myoglobin at 555. A method using the log of the reciprocal of reflectance, absorbance, rather than raw reflectance was described by Naughton, Frodyma and Zeitlin (1957). Wavelengths of absorption maxima from reflectance corresponded to those of transmission; therefore, an interchange of data is possible.

The K/S value which is the ratio of absorption

coefficient (K) to the scattering coefficient (S) per unit of sample thickness has received much use in the last decade (Tolansky, 1965). Dean and Ball (1960a) observed reflectance of beef at 473, 507, 573, and 597 nm. They used ratios of K/S values of 507/573 and 473/597 to estimate quantitative proportions of the myoglobin forms, but this data was poorly related to the loss of redness of vacuum packed beef. Stewart, Zipser and Watts (1965) contend that data obtained at these wavelengths would not be expected to produce a linear relationship between K/S ratios and proportion of pigment present. They suggest the use of a 572/525 K/S ratio as a means of predicting the metmyoglobin present in a sample. They also observed that K/S ratios from reflectance data were quite different from ratios of absorbancy coefficients at the same wavelengths calculated from transmission data. Another important observation made by Stewart and co-workers was that reflectance measured on an absorbance scale at 525 nm, an isobestic point of all three states of myoglobin, had a non-linear relationship to total pigment. However, when expressed as K/S at 525 nm the relationship to total pigment was linear. Ledward (1970) also used the K/S ratio of 572/525 nm with excellent results.

The use of another isobestic point, that of 474 nm, was discussed by Snyder (1965). His results showed that

474 nm was indicative of a change of myoglobin to oxy-myoglobin. He also used 571 nm as an indicator of change from myoglobin to metmyoglobin. The spectra obtained were adjusted so that the reflectance measured on the absorbancy scale R_A was 1.0 at 525 nm to correct for light scatter caused by factors other than myoglobin. He contended that reflectance at 474 and 571 nm wavelengths was less variable than others used previously, thereby resulting in less error. Pierson et al. (1970) used these suggested K/S ratios of 474/525 to calculate percent myoglobin and 571/525 to calculate percent metmyoglobin. These same ratios were successfully used by Seward (1970) to detect pigments change in beef stored in an oxygen depleted atmosphere.

Decreasing reflectance values at 474 nm appeared to closely follow color deterioration occurring in prepacked steaks after 96 hours of time after packaging. This was observed by Allen et al. (1969) when studying color changes in prepackaged beef over a period from 0 to 240 hours after cutting and packaging. They also found reflectance values at 525, 538, 568 and 571 nm to be generally insensitive to color deterioration while a gradual decrease in reflectance at 600, 610, 620 and 630 nm did not indicate discoloration. Allen and his co-workers observed that a ratio of 474/525 nm was observed to decrease as color brightened and increase as color deteriorated. Fellers et al. (1964) suggest the

use of reflectance values in meat because of a condition they choose to call dynamic color changes.

Ockerman and Cahill (1969) used percent reflectance in conjunction with prediction equations. These equations were obtained by combining data from 150 observations and two visual scoring panels. The equations thus derived are as follows:

Visual pork color = -1.96 + 10.48 (reflectance @ 685 nm) - .17 (visual marbling)

Visual beef color = -1.86 + 12.34 (reflectance @ 685 nm)

Franke and Solberg (1971) used varying known amounts of metmyoglobin and oxymyoglobin to establish known concentration curves. The height of the absorption peak at 632 nm was directly related to the amount of metmyoglobin. For 100 percent oxymyoglobin R_A632 was at a minimum and equal to R_A750. For 100 percent metmyoglobin R_A632 was at a maximum and the height of the response was dependent on the total pigment present. A linear relation was obtained when R_A632 was plotted against percent metmyoglobin or total pigment as shown by Hornsby (1956). This method requires making two readings of the meat samples at a single wavelength, namely one reading of the sample followed by one reading of the same sample after oxidation with potassium ferrocyanide. This provides a quantitative evaluation of the metmyoglobin concentration and the total heme pigment concentration and appears to have strong possibilities for

future use in following meat discoloration.

Little (1969) observed the following in regard to reflectance of canned tuna samples: magnitude and direction of the chromaticity shift of tristimulus values is related inversely to the level of luminous reflectance of the sample and to the visual scores as evaluated by expert panels and is directly related to the concentration of hemochrome pigment.

Most work described above was performed on spectrophotometers with recording attachments that present the data as percent reflectance. However, systems are available that will transform spectrophotometric reflectance data directly into the tristimulus system, such as the Davidson Hemmindinger tristimulus integrator (Hemmendinger and Davidson, 1966). In the minds of many workers in the area of color research, this should be an excellent tool and will be in much wider use as its advantages become more widely known (Pitt et al., 1967). According to Hemmendinger and Davidson, a spectrophotometer so equipped can be maintained in sufficiently good calibration so that a single measurement of one of the National Bureau of Standards calorimetric standards normally agrees with the tristimulus values ascribed to that filter. They further state that this accuracy is such that the uncertainty of absolute color determinations of most reflecting samples

is less than one-half MacAdam unit. Thus it appears that the tristimulus integrator may be a color measuring device of great impact in the future. At present the cost of the device is prohibitive for all except the largest institutions and manufacturers (Pitt, 1967).

Histochemical Muscle Differences and Their Effect on Meat Color

Certain individual muscles have been classified as white or red (Beecher et al., 1965). Muscles with greater than forty percent red fibers were designated as red muscle and those with less than thirty percent red fibers were arbitrarily termed white muscles.

Examples of white muscle found in most mammals were the light area of semitendinosis; outside (superficial) biceps femoris; longissimus dorsi; and gluteus medius. Examples of red muscles were serratus ventralis; rectus femoris; inside (deep) biceps femoris; and trapezius (Beecher et al., 1965).

Dawson and Romanul (1964) and Romanul (1964) have indicated a close relationship between the red fiber content of a muscle and the visual muscle color which agreed with the earlier work of Ogata (1958). The difference in red and white fibers appears to be a large difference in the presence of the muscle pigment myoglobin. Lawrie (1966) showed that in porcine muscle, the psoas major

contained about twice as much myoglobin as *longissimus dorsi*. Briskey *et al.* (1960) and Cassens *et al.* (1963) have reported similar findings.

Longissimus dorsi muscle has less pigmentation than *psoas major* resulting in different degrees of biochemical activities, which may be largely responsible for varying rates of meat surface discoloration.

As histochemical and biochemical activities of red and white fibers were investigated, another fiber was reported by Edstrom and Kugeberg (1968). This third fiber type was frequently referred to as intermediate fibers, but Edstrom and Kugeberg chose to introduce new nomenclature at this point by designating white fibers as Type A fibers, red fibers as Type C fibers and the newly discovered intermediate fibers as Type B fibers owing to their generally intermediate sizes and intensities of activity.

Lawrie (1953) has shown a statistically significant direct correlation in muscle between the percentage of myoglobin and the activity of the succinic dehydrogenase-cytochrome system. The succinic dehydrogenase-cytochrome system catalyzes intracellular uptake for energy production by the oxidation of metabolites (Conn and Strumph, 1967). It is the post mortem continuation of these systems that causes discoloration in meat (Stewart *et al.*, 1965).

Typically, psoas major muscle in the adult horse contains almost twice as much cytochrome oxidase activity as the longissimus dorsi. Similar results are shown for both succinic oxidase and succinic dehydrogenase activities. Thus, oxidative enzymic activity is significantly greater in psoas major than longissimus dorsi (Lawrie, 1953).

Since this enzymatic activity is greater in red muscles, oxygen will be used at a greater rate and will change the oxygen tension at the meat surface at a greater rate than in a white muscle. This factor will effect the relative amounts of various chemical forms of myoglobin on the meat surface.

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Chapter 3

COLOR STABILITY OF FROZEN BEEF STEAKS AS AFFECTED BY VARIOUS COMMERCIAL DISPLAY LIGHTING SOURCES

Centralized cutting of meat lends itself to frozen processing of retail cuts. Frozen meat, from the central cutting operation to the retail meat counter, has many advantages over fresh meat and is likely to have a large impact on the meat industry in the near future.

One of the primary criteria of fresh meat quality is color. A bright cherry red color is necessary for consumer acceptance of fresh meat. It is therefore essential that frozen meat in the retail counter maintain this acceptable color.

Variations in color of frozen meat may occur as a result of display light conditions. Both the type of lighting and intensity of lighting have profound effects on the color stability of frozen meat. Other factors influencing the color of frozen meat are temperature fluctuation, muscle differences, packaging material and the freezing system employed.

The purpose of this study was to determine the effect of various commercial light sources on the color stability of frozen beef.

Experimental Procedure

Steaks in this study were displayed under ten light sources at intensities of 1076 lm/m^2 (Table 1), five in each of two Hussman self-defrosting (twice each 24 hours) display cases. In the first study, the cases were held at -20.6°C at the meat surface and in the second the temperature was held at -26.1°C.

Ten wholesale loins from animals slaughtered the same day were used for each of two replications. The loins were choice grade, weighed approximately 25 kg per loin, had from 0.7 to 1.3 cm of fat cover and had small to moderate marbling in the longissimus dorsi surface between the twelfth and thirteenth rib. Ten steaks were cut from each loin. While cutting steaks from the loins, care was taken to assure that there was sufficient area on each of the two muscles studied (longissimus dorsi and psoas major) to cover the aperture on the reflectance attachment of the spectrophotometer used for color measurement. Of special concern at this point was the area of the anterior portion of the psoas major. At times up to 10 cm from the anterior portion of the loin had to be sacrificed to ensure a large enough area of psoas major. When it was ascertained that the psoas major area was sufficient, a measurement was taken from the anterior loin surface to the posterior edge of the fifth lumbar vertebra. This measurement varied from 22.0 to 28.0 cm,

TABLE 1. Ten commercial display lighting sources

Delux Warm White
Grolux Wide Spectrum
Incandescent Fluorescent
Standard Grolux
Delux Cool White
Verda Ray
Cool White
Soft White
Incandescent
Cool Beam

and the distance for each loin was divided by 10 to determine the steak thickness for each loin. This resulted in a steak thickness variation of from 2.2 to 2.8 cm. The steaks were cut on a Toledo band saw, laid out in order from anterior to posterior, trimmed and scraped clean of all bone dust. Steaks were then identified as to position and loin number. The position numbers ranged from 1 through 10 with 1 being the most anterior and 10 the most posterior. The loin numbers were assigned randomly to each of the ten loins involved in each replication.

Steaks were allotted to treatments so that each treatment had a steak from each of the 10 loins and each of the 10 anterior-posterior positions.

After steaks were cut, trimmed and labeled they were allowed to bloom for thirty minutes. After this blooming time, steaks were placed in a NCG-Ultra-Freeze Simulator Freezer which is a liquid nitrogen vapor freezing system. The steaks were subjected to the following schedule:

½ minute @ -17.8°C
½ minute @ -46.6°C
1 minute @ -73.2°C
1 minute @ -101.2°C
1 minute @ -129.7°C
1 minute - temper

Counting time required to lower temperature to the next

step, a total freezing time of about 8 to 9 minutes resulted and steaks were crust frozen. After this freezing cycle the steaks were removed from the freezer and prepared for packaging by directing a hot air flow from a heat gun over the surface to remove the frost that developed in the freezing process. The steaks were then placed in a DuPont MSG I packaging machine and packaged in Iolon, a clear, medium permeability film.

After packaging the steaks were kept in dark conditions at display temperature until the preliminary spectrophometric and visual evaluation. Each muscle of each steak was placed on a Bausch and Lomb spectronic 600 (scan speed of 250 nm/min) with reflectance attachment, using magnesium carbonate blocks to standardize 100% reflectance. Each muscle (longissimus dorsi and psoas major) was scanned for reflectance through the entire visible spectrum, 400 - 700 nm, and percent reflectance was recorded. Percent reflectance at eight wavelengths and three areas under various portions of the reflectance curves were evaluated to determine color change. The wavelengths used were: 474, 525, 572, 582, 600, 630, 650 and 685 nm. The areas used were: 450 - 474 nm, 630 - 700 nm and total area. Percent reflectance at 630 nm is indicative of meat color deterioration. As percent reflectance at 630 nm decreases metmyoglobin increases. Two sources in this study (Incandescent and Cool Beam) proved quite inconsistent in

light intensity and care was taken to assure that steaks were displayed only in areas of 100 foot candles of light intensity. Spectrophotometric and visual appraisal were also conducted on day 1, day 3, day 7, day 21 and on day 35.

Steaks were visually evaluated under each of three lights: Delux Cool White, Incandescent and the display lighting for that particular steak. The steaks were scored by each of two scorers to the nearest 0.5 point on a five point scale as follows:

1 = Very bright
2 = Bright
3 = Slightly dark
4 = Moderately dark
5 = Extremely dark

Results and Discussion

Type of Light - Day 0. When the steaks were scored at day 0 under display lighting by scorer K, (Table 3) (see pages 45-51) those under Standard Grolux lighting followed by Incandescent lighting, were significantly brighter (lower score) than any of the other sources, while Delux Cool White, Cool White and Soft White steaks were scored darkest. Scorer F (Table 4) at day 0 found the Incandescent and Cool Beam sources to be the most desirable, and Cool White and Soft White to be least desirable.

No color deterioration was expected at 0 time, therefore any difference in visual appearance under the ten display lights should be attributable to differences in

relative spectral energy distribution (color balance or rendition). Therefore all steaks, regardless of display lighting, were also subjectively scored under Delux Cool White and Incandescent lighting.

Visual scores (scorer K) (Table 5) under Delux Cool White showed steaks under Grolux Wide Spectrum and Delux Cool White to have significantly darker scores, although differences are very small. Scorer F (Table 6) scoring under Delux Cool White found no significant differences.

Visual scores (scorer K) (Table 7) under Incandescent lighting (a well balanced light) showed no significant differences. Scorer F (Table 8) found steaks under Cool Beam to have lower scores (brighter color) than those under Incandescent Fluorescent, Soft White, Delux Cool White, Cool White and Grolux Wide Spectrum. However, reflectance at 630 nm (Table 2) showed no significant differences between any of the steaks studied, supporting the idea that no color deterioration had taken place.

Day 1. Scorer K at day 1, under Display lighting, found little difference from day 0 in ranking of steaks. Similarly, scorer F at day 1 found little change in ranking of light sources from day 0.

At 630 nm, percent reflectance showed no significant differences, raising the question as to whether differences in real deterioration existed.

Scores under Delux Cool White lighting (Scorer K)

found steaks displayed under Delux Warm White, Grolux Wide Spectrum, Incandescent Fluorescent, and Cool White to be superior to other sources with Cool Beam, Incandescent, and Delux Cool White the poorest. Scorer F found no significant differences at day 1 under Delux Cool White lighting.

Scores under Incandescent lighting (Scorer K), found Incandescent Fluorescent, Grolux Wide Spectrum, Delux Warm White, and Delux Cool White sources to be significantly better and Cool Beam, Soft White, and Incandescent to be significantly poorer. Scorer F, under Incandescent lighting, found Verda Ray, Cool White, Standard Grolux, Grolux Wide Spectrum, Incandescent Fluorescent, and Incandescent sources to be better with Cool Beam scoring the poorest.

Day 3. Scorer K, under display lighting, found Standard Grolux to be a significantly better source than all others, but this may be due to overly red color balance which may misrepresent the steaks by masking color deterioration. Cool White, Soft White, and Cool Beam were found to be poorest sources. Scorer F found Incandescent lighting to be the best while Delux Cool White, Soft White, Cool White and Delux Warm White were the poorest, as represented by higher (darker) color scores.

Reflectance at 630 nm showed no significant differences,

again raising the question as to whether metmyoglobin discoloration had occurred.

Scorer K, scoring under Delux Cool White, found steaks stored under Incandescent Fluorescent, Grolux Wide Spectrum, Standard Grolux, and Cool White to be more desirable in color while Incandescent and Soft White were the poorest. Scorer F, under Delux Cool White lighting for evaluation found steaks displayed under Grolux Wide Spectrum, Standard Grolux, Incandescent, Cool White, and Soft White to be significantly more desirable than those displayed under Verda Ray and Cool Beam.

Scorer K, scoring under Incandescent lighting, found Incandescent, Standard Grolux, Grolux Wide Spectrum, Delux Warm White, and Cool White to be significantly better than Cool Beam, Soft White, Verda Ray and Delux Cool White. Scorer F found similar results.

Day 7. When color was visually evaluated under display lighting, scorer K found steaks displayed under Standard Grolux lighting to be significantly more desirable in color, whereas those under Cool White were deemed the darkest. Scorer F found Incandescent and Grolux Wide Spectrum sources to be more desirable while Cool White, Verda Ray, Delux Warm White, and Soft White were found significantly poorer.

At 630 nm, the muscles from steaks displayed under the Standard Grolux source had a higher percent reflectance

(indicative of less metmyoglobin) than those under Verda Ray, Delux Cool White, Soft White, Cool White and Incandescent Fluorescent.

Scorer K, scoring under Delux Cool White found that use of Delux Warm White, Grolux Wide Spectrum, Incandescent Fluorescent and Standard Grolux caused significantly brighter scores than all other light sources. Scorer F found similar results with Cool White, Verda Ray, and Soft White sources having the poorest scores. Scoring under Incandescent lighting, scorer K found steaks stored under Delux Warm White, Incandescent Fluorescent, and Grolux Wide Spectrum to have significantly higher scores. Scorer F found Grolux Wide Spectrum, Standard Grolux and Incandescent Fluorescent to result in significantly better scores. Both scorers found Verda Ray, Cool White, Soft White, Incandescent and Cool Beam to have significantly lower scores.

Day 21. Scoring under display lighting, scorer K found Standard Grolux and Delux Warm White to be more desirable in terms of effect on muscle color stability, while Cool White was least desirable. Scorer F found Incandescent lighting and Grolux Wide Spectrum lighting to be more desirable while Delux Cool White, Cool White and Soft White were least desirable.

No reflectance data was available for day 21.

Scoring under Delux Cool White lighting for evaluation

scorer K found steaks stored under Delux Warm White, Incandescent Fluorescent, and Grolux Wide Spectrum sources to be the most desirable. Steaks stored under Verda Ray, Cool White, Soft White and Incandescent sources were darkest after 21 days of display. Scorer F favored Standard Grolux and Incandescent Fluorescent, and found darkest muscle color those displayed under Cool Beam lighting.

Scorer K, scoring under Incandescent lighting, found steaks displayed under Incandescent Fluorescent and Delux Warm White lighting to be significantly more acceptable. Delux Cool White and Cool White were least desirable but were not significantly different from Incandescent, Cool White and Verda Ray. Scorer F found Grolux Wide Spectrum, Incandescent Fluorescent and Standard Grolux to cause less muscle darkening while Cool Beam, Soft White and Incandescent sources caused more color deterioration.

Day 35. Scoring under display lighting, scorer K found Standard Grolux and Delux Warm White to be the most desirable sources while Cool White, Soft White and Delux Cool White were the poorest. Scorer F found Incandescent and Cool Beam to be the most desirable, and Cool White to be least desirable.

No significant differences were found in percent reflectance at 630 nm, although the variance ratio closely approached significance. A trend was found toward lower

reflectance of muscles displayed under Cool White, Soft White and Delux Cool White lighting, suggesting more metmyoglobin discoloration under these lighting systems.

Scoring under Delux Cool White lighting, scorer K found steaks stored under Delux Warm White and Incandescent Fluorescent lighting to be more desirable. Scorer F found similar results except that steaks stored under Grolux Wide Spectrum, Standard Grolux and Incandescent were found to be equally desirable. Both scorers rated steaks that had been displayed under Soft White and Cool White to be the lowest.

Scoring under Incandescent lighting scorer K found steaks stored under Incandescent Fluorescent lighting to be the most desirable. Delux Warm White and Grolux Wide Spectrum, although they were less desirable than Incandescent Fluorescent, were significantly better than the remaining sources. Scorer F found Delux Warm White, Grolux Wide Spectrum and Incandescent Fluorescent to be significantly better than the other sources.

Lighting Summary. Over the 35 day display periods for both temperatures investigated, significant differences in light sources were evident. Under display lighting, scorer K favored Standard Grolux and Delux Warm White. Scorer F favored Incandescent, Cool Beam and Grolux Wide Spectrum sources throughout the study. Soft White, Cool White and

Delux Cool White were deemed the poorest sources.

Scoring under Delux Cool White lighting, after 7 days of display both scorers found steaks scored under Delux Warm White, Grolux Wide Spectrum, Incandescent Fluorescent and Standard Grolux to be significantly more desirable while those scored under Cool White, Soft White and Verda Ray had the darkest color. Similar results were found scoring under Incandescent lighting.

Percent reflectance at 630 nm showed significant differences at day 7 only. Standard Grolux had a higher percent reflectance than Verda Ray, Delux Cool White, Soft White, Cool White and Incandescent Fluorescent.

These findings disagree with the results of Hansen and Sereika (1969) who contend that illumination of pre-packaged frozen meat accelerates the deterioration of color, but the rate of deterioration is essentially the same no matter what type of light source is used.

Longissimus Dorsi vs. Psoas Major. Since beef T-bone and Porterhouse steaks were utilized in this study, two muscles were observed; the longissimus dorsi and the psoas major.

At day 0, both scorer K and scorer F, under display lighting found the longissimus dorsi muscle to be brighter in color than the psoas major.

At 630 nm, reflectance studies showed the longissimus

dorsi to be of higher reflectance, indicating a redder color.

At day 0, when scoring steaks under Delux Cool White and Incandescent sources, both scorers found the longissimus dorsi to be significantly more desirable in color. This trend of superior color in the longissimus dorsi was observed throughout the entire study and indicates that maintaining saleable color is a greater problem with the psoas major. This darker color of the psoas major agrees with the findings of Beecher et al. (1965).

Temperature. At day 1, both scorers found that steaks stored under the lower temperature of -26.1°C had significantly better color scores than those stored at -20.6°C. This was true for both muscles.

Higher reflectance at 630 nm at day 1 for muscles displayed at -26.1°C indicated a brighter, redder color than for those maintained at -20.6°C.

It was noted throughout the study that steaks displayed at the lower temperature of -26.1°C were often significantly superior to those stored at -20.6°C. This agrees with the earlier work of Rickert et al. (1956), Fellers et al. (1963) and the more recent work of Sandberg (1970).

SUMMARY

Color stability of frozen beef loin steaks (long-

issimus dorsi and *psoas major* muscles) as affected by 10 commercial display lighting sources was investigated. Two replications were involved; the first with display cases held at -20.6°C and the second at -26.1°C. Visual and spectrophotometric evaluations were done after freezing and after 1, 3, 7, 21 and 35 days of display.

At 0 time, no color deterioration was expected, and any difference in visual appraisal under various display lighting systems was due to differences in spectral energy distribution of the light sources.

Day 1 observations showed no significant differences in reflectance at 630 nm. Evaluation under display lighting favored cuts kept under Standard Grolux and Incandescent with least desirable results under Cool White and Delux Cool White lighting. Delux Warm White, Grolux Wide Spectrum, Incandescent Fluorescent and Cool White were considered superior while Cool Beam was found to be the poorest source when all steaks were evaluated under identical light sources.

In general, day 3 scores for Standard Grolux, Incandescent, Incandescent Fluorescent, Grolux Wide Spectrum and Standard Grolux were superior, while Delux Cool White, Verda Ray, Soft White and Cool White were poorer light sources. The remainder of the evaluation at days 7, 21 and 35 all showed similar results. Under display lighting scorer K favored Standard Grolux and Delux Warm White

while scorer F favored Incandescent and Cool Beam. Both scorers agreed that Cool White, Soft White and Delux Cool White were the poorer sources. When scoring under Delux Cool White and Incandescent, both scorers found steaks stored under Grolux Wide Spectrum sources to be generally superior while steaks displayed under Cool White, Soft White, Verda Ray and Incandescent sources showed more color deterioration.

Several light sources appear to be superior in both color stability and display appearance, namely, Delux Warm White and Grolux Wide Spectrum and both are recommended for frozen beef display. Incandescent Fluorescent is also excellent, but the slight yellowish tint to this source may affect the overall appeal. Standard Grolux use results in excellent muscle color stability, but this source has too much red and may be misleading.

Throughout the entire period the psoas major was darker than the longissimus dorsi, both in visual evaluation and in lowered reflectance at 630 nm. Thus, color of the psoas major muscle will deteriorate more quickly in retail display, suggesting separate packaging or a very high packaging film oxygen permeability, or some processing alteration.

The steaks displayed at -26.1°C showed better color stability than those at -20.6°C

Table 2. The effect of type of lighting, muscle and display temperature on percent reflectance @ 630 nm

Lighting Type[e]	Time (Days) 0	1	3	7	35
Delux Warm White	30.4	29.9	26.8	26.6^{bc}	26.1
Grolux Wide Spectrum	31.9	30.8	26.9	26.3^{abc}	24.8
Incandescent Flourescent	30.1	30.7	26.6	25.0^{ab}	25.5
Standard Grolux	32.2	32.3	28.8	27.7^{c}	26.0
Delux Cool White	31.5	29.3	26.5	24.1^{ab}	23.5
Verda Ray	30.7	29.8	26.6	23.8^{a}	24.8
Cool White	31.7	30.9	26.2	24.9^{ab}	22.8
Soft White	32.8	31.5	26.9	24.7^{ab}	23.4
Incandescent	31.7	29.4	26.7	26.2^{abc}	24.5
Cool Beam	30.9	28.4	25.5	26.6^{bc}	24.0
F Value	0.96	1.48	1.21	1.91*	1.75
LSD	2.30	2.60	2.12	2.52	2.37
Muscle - Temperature °C					
LD -26.1	36.4^{c}	35.4^{d}	29.1^{b}	27.4^{c}	26.8^{c}
LD -20.6	35.8^{c}	33.2^{c}	30.1^{b}	29.3^{c}	25.1^{b}
PM -26.1	24.8^{a}	27.2^{b}	23.3^{a}	22.4^{a}	25.1^{b}
PM -20.6	28.5^{b}	25.4^{a}	24.4^{a}	23.3^{a}	21.1^{a}
F Value***	109.97	64.08	48.70	33.30	19.77
LSD	1.50	1.60	1.34	1.59	1.50

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

*= ($P<.05$) ***= All ($P<.001$) LSD = Least significant difference

[e] = Means represent pooled data for muscle and temperature

Table 3. The effect of type of lighting, muscle and display temperature on subjective color scores (Display Lighting) by scorer K

Lighting Type[h]	Time (Days) 0	1	3	7	21	35
Delux Warm White	1.96^{cd}	2.26^{bc}	2.55^{bc}	2.95^{b}	3.40^{ab}	3.69^{ab}
Grolux Wide Spectrum	2.08^{d}	2.29^{cd}	2.43^{b}	2.96^{b}	3.51^{bc}	3.86^{cd}
Incandescent Flourescent	2.04^{cd}	2.35^{cde}	2.48^{bc}	3.04^{bc}	3.52^{bc}	3.75^{bc}
Standard Grolux	1.80^{a}	1.93^{a}	2.19^{a}	2.68^{a}	3.30^{a}	3.55^{a}
Delux Cool White	2.25^{e}	2.53^{f}	2.86^{d}	3.40^{f}	3.98^{e}	4.28^{f}
Verda Ray	1.99^{cd}	2.38^{de}	2.55^{bc}	3.35^{f}	3.80^{d}	4.06^{e}
Cool White	2.36^{e}	2.76^{g}	3.14^{e}	3.75^{g}	4.36^{f}	4.76^{g}
Soft White	2.26^{e}	2.43^{ef}	2.88^{d}	3.31^{ef}	3.90^{de}	4.41^{f}
Incandescent	1.94^{b}	2.15^{b}	2.46^{bc}	3.13^{cd}	3.51^{bc}	3.99^{de}
Cool Beam	1.98^{cd}	2.30^{cd}	2.59^{c}	3.19^{de}	3.61^{e}	3.92^{de}
F value**	14.66	25.50	28.99	32.34	43.99	49.50
LSD	0.13	0.12	0.14	0.14	0.13	0.14
Muscle - Temperature °C						
LD -26.1	1.47^{b}	1.50^{a}	1.87^{a}	2.79^{a}	3.36^{a}	3.70^{a}
LD -20.6	1.29^{a}	1.80^{b}	2.38^{b}	2.88^{a}	3.40^{a}	3.76^{a}
PM -26.1	2.64^{c}	2.80^{c}	3.00^{c}	3.40^{b}	3.99^{b}	4.31^{b}
PM -20.6	2.87^{d}	3.10^{d}	3.21^{d}	3.65^{c}	4.03^{b}	4.34^{b}
F value***	776.78	708.13	360.84	155.46	142.58	109.24
LSD	0.08	0.08	0.09	0.09	0.08	0.09

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

= All ($P<.01$) *=All ($P<.001$) LSD = Least significant difference

[h] = Means represent pooled data for muscle and temperature

Table 4. The effect of type of lighting, muscle and display temperature on subjective color scores (Display Lighting) by scorer F

Lighting Type[g]	Time (Days) 0	1	3	7	21	35
Delux Warm White	2.62^{de}	2.84^{cd}	3.24^{c}	3.51^{def}	3.56^{e}	3.51^{bc}
Grolux Wide Spectrum	2.53^{cd}	2.84^{cd}	2.93^{b}	3.15^{ab}	3.08^{ab}	3.41^{b}
Incandescent Flourescent	2.69^{de}	2.74^{bc}	2.98^{b}	3.38^{cd}	3.28^{cd}	3.50^{bc}
Standard Grolux	2.40^{bc}	2.59^{b}	2.91^{b}	3.20^{bc}	3.25^{bcd}	3.40^{b}
Delux Cool White	2.59^{d}	3.04^{e}	3.31^{c}	3.45^{de}	3.41^{de}	3.55^{bc}
Verda Ray	2.66^{de}	2.74^{bc}	2.90^{b}	3.59^{ef}	3.26^{bcd}	3.48^{bc}
Cool White	2.72^{e}	2.94^{de}	3.24^{c}	3.66^{f}	3.42^{de}	3.86^{d}
Soft White	2.70^{e}	2.90^{cde}	3.25^{c}	3.48^{def}	3.41^{de}	3.65^{cd}
Incandescent	2.16^{a}	2.31^{a}	2.54^{a}	2.98^{a}	2.96^{a}	3.04^{a}
Cool Beam	2.25^{ab}	2.61^{b}	2.91^{b}	3.19^{bc}	3.19^{bc}	3.23^{a}
F value**	9.55	12.92	13.22	9.68	7.02	8.62
LSD	0.17	0.16	0.18	0.19	0.18	0.21
Muscle - Temperature ^{o}C						
LD -26.1	1.45^{a}	1.50^{a}	1.69^{a}	2.45^{a}	2.18^{a}	2.48^{a}
LD -20.6	1.95^{b}	2.23^{b}	2.80^{b}	2.88^{b}	2.80^{b}	2.92^{b}
PM -26.1	2.74^{c}	2.97^{c}	3.03^{c}	3.63^{c}	3.69^{c}	3.96^{c}
PM -20.6	4.00^{d}	4.33^{d}	4.57^{d}	4.47^{d}	4.47^{d}	4.50^{d}
F value***	796.65	1076.67	810.92	393.98	550.72	370.02
LSD	0.11	0.10	0.12	0.12	0.12	0.13

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

= All ($P<.01$) *= All ($P<.001$) LSD = Least significant difference

[g] = Means represent pooled data for muscle and temperature

Table 5. The effect of type of lighting, muscle and display temperature on subjective color scores (Delux Cool White Lighting) by scorer K

Lighting Type[f]	Time (Days) 0	1	3	7	21	35
Delux Warm White	2.10^{a}	2.27^{a}	2.70^{ab}	3.04^{a}	3.53^{a}	3.89^{a}
Grolux Wide Spectrum	2.25^{b}	2.31^{ab}	2.61^{a}	3.09^{a}	3.66^{a}	4.05^{b}
Incandescent Flourescent	2.19^{ab}	2.34^{abc}	2.58^{a}	3.15^{a}	3.53^{a}	3.81^{a}
Standard Grolux	2.15^{ab}	2.39^{bc}	2.65^{a}	3.11^{a}	3.83^{bc}	4.08^{b}
Delux Cool White	2.25^{b}	2.53^{de}	2.86^{cd}	3.40^{b}	3.98^{d}	4.36^{d}
Verda Ray	2.09^{a}	2.46^{cd}	2.79^{bc}	3.31^{b}	3.88^{bcd}	4.16^{bc}
Cool White	2.08^{a}	2.35^{abc}	2.70^{ab}	3.36^{b}	3.96^{bcd}	4.51^{e}
Soft White	2.20^{ab}	2.45^{cd}	2.94^{d}	3.41^{d}	4.05^{d}	4.51^{e}
Incandescent	2.10^{a}	2.54^{de}	2.84^{cd}	3.36^{b}	3.86^{bcd}	4.26^{c}
Cool Beam	2.14^{ab}	2.60^{e}	2.95^{d}	3.45^{b}	3.80^{b}	4.11^{b}
F value	2.21*	6.76**	7.95**	13.07**	15.40**	25.49**
LSD	0.12	0.12	0.13	0.15	0.13	0.13
Muscle - Temperature °C						
LD -26.1	1.63^{b}	1.68^{a}	2.00^{a}	2.89^{a}	3.49^{a}	3.89^{a}
LD -20.6	1.43^{a}	2.02^{b}	2.57^{b}	2.98^{a}	3.50^{a}	3.86^{a}
PM -26.1	2.70^{c}	2.88^{c}	3.17^{c}	3.53^{b}	3.15^{b}	4.56^{c}
PM -20.6	2.80^{d}	3.12^{d}	3.31^{d}	3.67^{c}	4.10^{b}	4.39^{b}
F value***	689.90	655.49	404.67	129.51	154.62	139.34
LSD	0.07	0.07	0.08	0.09	0.08	0.08

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

*= ($P<.05$) **= ($P<.01$) ***= All ($P<.001$) LSD = Least significant difference

[f] = Means represent pooled data for muscle and temperature

Table 6. The effect of type of lighting, muscle and display temperature on subjective color scores (Delux Cool White Lighting) by scorer F

Lighting Type[f]	Time (Days) 0	1	3	7	21	35
Delux Warm White	2.62	2.83	3.18^{abcd}	3.44^{abc}	3.51^{de}	3.34^{a}
Grolux Wide Spectrum	2.66	2.90	3.04^{a}	3.24^{a}	3.06^{a}	3.34^{a}
Incandescent Flourescent	2.70	2.93	3.15^{abc}	3.35^{ab}	3.26^{b}	3.33^{a}
Standard Grolux	2.65	2.78	3.09^{ab}	3.33^{ab}	3.29^{bc}	3.41^{ab}
Delux Cool White	2.56	3.04	3.13^{cd}	3.44^{abc}	3.41^{bcd}	3.55^{bc}
Verda Ray	2.55	2.95	3.35^{d}	3.60^{cd}	3.33^{bcd}	3.56^{bc}
Cool White	2.69	2.93	3.10^{ab}	3.66^{d}	3.34^{bcd}	3.58^{bc}
Soft White	2.69	2.80	3.11^{ab}	4.59^{cd}	3.43^{bcd}	3.70^{c}
Incandescent	2.69	2.95	3.09^{ab}	3.51^{bcd}	3.45^{cde}	3.44^{ab}
Cool Beam	2.59	2.95	3.23^{bcd}	3.45^{bc}	3.63^{e}	3.56^{bc}
F value	0.83	1.85	2.41*	3.22**	5.26**	2.99**
LSD	0.17	0.16	0.18	0.21	0.18	0.19
Muscle - Temperature °C						
LD -26.1	1.72^{a}	1.68^{a}	1.83^{a}	2.45^{a}	2.26^{a}	2.36^{a}
LD -20.6	1.95^{b}	2.29^{b}	2.84^{b}	2.99^{b}	2.88^{b}	2.99^{b}
PM -26.1	2.92^{c}	3.23^{c}	3.35^{c}	3.73^{c}	3.84^{c}	3.95^{c}
PM -20.6	3.99^{d}	4.42^{d}	4.64^{d}	4.68^{d}	4.50^{d}	4.65^{d}
F value***	727.96	1067.02	781.66	419.30	50.74	504.73
LSD	0.11	0.10	0.12	0.13	0.12	0.12

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

*= ($P<.05$) **= ($P<.01$) ***= All ($P<.001$) LSD = Least significant difference

f = Means represent pooled data for muscle and temperature

Table 7. The effect of type of lighting, muscle and display temperature on subjective color scores (Incandescent Lighting) by scorer K

Lighting Type[g]	Time (Days) 0	1	3	7	21	35
Delux Warm White	1.85	2.00^{abc}	2.30^{a}	2.66^{a}	3.25^{ab}	3.63^{b}
Grolux Wide Spectrum	1.94	1.96^{ab}	2.29^{a}	2.75^{ab}	3.38^{bc}	3.76^{bc}
Incandescent Flourescent	1.91	1.91^{a}	2.25^{a}	2.71^{a}	3.15^{a}	3.46^{a}
Standard Grolux	1.88	2.05^{bcd}	2.28^{a}	2.86^{bc}	3.43^{c}	3.83^{cd}
Delux Cool White	2.01	2.00^{abc}	2.44^{bc}	2.98^{c}	3.60^{e}	3.96^{de}
Verda Ray	1.91	2.09^{cde}	2.45^{bc}	3.06^{d}	3.51^{cde}	3.81^{c}
Cool White	1.89	2.05^{bcd}	2.34^{ab}	3.06^{d}	3.58^{de}	4.11^{e}
Soft White	1.98	2.18^{ef}	2.55^{c}	3.13^{d}	3.60^{e}	4.26^{f}
Incandescent	1.94	2.15^{de}	2.46^{bc}	3.13^{d}	3.51^{cde}	3.99^{e}
Cool Beam	1.96	2.28^{f}	2.55^{c}	3.06^{d}	3.45^{cd}	3.81^{c}
F value	1.20	6.60**	5.84**	14.33**	9.69**	22.61**
LSD	0.12	0.12	0.13	0.13	0.14	0.13
Muscle - Temperature ^{o}C						
LD -26.1	1.49^{b}	1.43^{a}	1.73^{a}	2.54^{a}	3.14^{a}	3.59^{a}
LD -20.6	1.11^{a}	1.51^{b}	2.17^{b}	2.69^{b}	3.18^{a}	3.58^{a}
PM -26.1	2.46^{c}	2.59^{c}	2.80^{c}	3.22^{c}	3.78^{b}	4.30^{c}
PM -20.6	2.67^{d}	2.75^{d}	2.90^{d}	3.31^{d}	3.70^{b}	3.98^{b}
F value***	697.40	680.05	335.84	165.86	117.28	126.66
LSD	0.07	0.07	0.08	0.08	0.08	0.08

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

= ($P<.01$) *= All ($P<.001$) LSD = Least significant difference
g = Means represent pooled data for muscle and temperature

Table 8. The effect of type of lighting, muscle and display temperature on subjective color scores (Incandescent Lighting) by scorer F

Lighting Type[g]	Time (Days) 0	1	3	7	21	35
Delux Warm White	2.15^{abc}	2.33^{b}	2.53^{abcd}	2.83^{bcd}	2.90^{cde}	2.75^{a}
Grolux Wide Spectrum	2.19^{bc}	2.28^{ab}	2.40^{ab}	2.60^{a}	2.58^{a}	2.75^{a}
Incandescent Flourescent	2.28^{c}	2.30^{ab}	2.38^{ab}	2.80^{abc}	2.65^{ab}	2.80^{a}
Standard Grolux	2.16^{abc}	2.20^{ab}	2.41^{abc}	2.70^{ab}	2.76^{abc}	3.04^{b}
Delux Cool White	2.20^{bc}	2.33^{b}	2.63^{de}	2.86^{bcde}	2.93^{cde}	3.09^{b}
Verda Ray	2.08^{ab}	2.18^{a}	2.56^{bcde}	3.04^{ef}	2.81^{bcd}	3.09^{b}
Cool White	2.20^{bc}	2.18^{a}	2.42^{abc}	2.96^{cdef}	2.80^{bcd}	3.04^{c}
Soft White	2.26^{c}	2.44^{bc}	2.68^{de}	3.01^{def}	3.01^{ef}	3.20^{bc}
Incandescent	2.18^{abc}	2.31^{ab}	2.58^{cde}	2.98^{cdef}	2.96^{def}	3.04^{b}
Cool Beam	2.01^{a}	2.49^{c}	2.71^{e}	3.13^{f}	3.13^{c}	3.04^{b}
F value	1.66	4.44**	4.04**	4.88**	6.28**	7.91**
LSD	0.17	0.14	0.16	0.20	0.18	0.19
Muscle - Temperature °C						
LD -26.1	1.23^{a}	1.17^{a}	1.26^{a}	1.88^{a}	1.74^{a}	1.88^{a}
LD -20.6	1.53^{b}	1.63^{b}	2.18^{b}	2.37^{b}	2.33^{b}	2.50^{b}
PM -26.1	2.18^{c}	2.41^{c}	2.56^{c}	3.22^{c}	3.29^{c}	3.47^{c}
PM -20.6	3.74^{d}	3.99^{d}	4.13^{d}	4.10^{d}	4.05^{d}	4.18^{d}
F value***	833.63	1571.60	969.68	441.05	590.67	574.19
LSD	0.11	0.08	0.11	0.13	0.12	0.12

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

= ($P<.01$) *= All ($P<.001$) LSD = Least significant difference

g = Means represent pooled data for muscle and temperature

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APPENDICES

Appendix A

The effect of type of lighting, muscle and display temperature on percent reflectance @ 474 nm

Lighting Type[d]	Time (Days) 0	1	3	7	35
Delux Warm White	10.0	11.2	11.0	11.9	14.4^{bc}
Grolux Wide Spectrum	10.2	11.3	11.2	11.9	13.8^{abc}
Incandescent Flourescent	9.7	11.2	10.7	11.2	13.3^{ab}
Standard Grolux	10.6	12.0	11.9	12.5	14.9^{c}
Delux Cool White	10.2	10.8	11.1	11.0	12.9^{ab}
Verda Ray	9.8	11.9	10.9	10.5	13.1^{ab}
Cool White	10.4	11.8	11.1	11.7	13.5^{abc}
Soft White	10.7	11.7	11.4	11.4	13.3^{ab}
Incandescent	10.5	10.6	10.8	11.2	12.8^{a}
Cool Beam	9.7	10.7	11.2	12.3	12.5^{a}
F value	0.75	1.20	0.73	1.78	2.08*
LSD	1.13	1.31	1.09	1.31	1.43
Muscle - Temperature °C					
LD -26.1	9.8^{b}	10.9^{ab}	10.8^{b}	11.8^{b}	14.0^{b}
LD -20.6	11.6^{c}	12.9^{c}	12.9^{c}	13.3^{c}	13.9^{b}
PM -26.1	7.7^{a}	10.1^{a}	9.4^{a}	9.9^{a}	13.7^{b}
PM -20.6	11.7^{c}	11.4^{b}	11.3^{b}	11.1^{b}	11.9^{a}
F value***	54.17	16.35	33.28	22.36	9.15
LSD	0.71	0.83	0.69	0.83	0.90

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

*= ($P<.05$) ***= All ($P<.001$) LSD = Least significant difference

[d] = Means represent pooled data for muscle and temperature

Appendix B

The effect of type of lighting, muscle and display temperature on percent reflectance @ 525 nm

Lighting Type[d]	Time (Days) 0	1	3	7	35
Delux Warm White	10.8	11.8^{bc}	11.5	13.0^{bc}	15.1^{bc}
Grolux Wide Spectrum	10.7	11.9^{bc}	11.7	12.7^{bc}	14.7^{abc}
Incandescent Flourescent	10.4	11.6^{bc}	11.3	12.0^{ab}	14.3^{ab}
Standard Grolux	11.5	12.8^{c}	12.1	13.5^{c}	15.8^{c}
Delux Cool White	10.8	10.8^{ab}	11.2	11.7^{ab}	13.4^{a}
Verda Ray	10.5	10.1^{a}	11.1	11.2^{a}	14.0^{ab}
Cool White	11.2	11.3^{ab}	11.3	12.2^{abc}	14.0^{ab}
Soft White	11.7	11.3^{ab}	11.6	11.9^{ab}	14.0^{ab}
Incandescent	11.1	10.9^{ab}	11.2	11.7^{ab}	13.7^{ab}
Cool Beam	10.7	11.2^{ab}	11.7	12.8^{bc}	13.3^{a}
F value	0.86	2.29*	0.62	1.95*	2.02*
LSD	1.25	1.34	1.13	1.36	1.49
Muscle - Temperature ^{o}C					
LD -26.1	9.1^{b}	10.2^{a}	9.9^{b}	11.7^{b}	15.0^{b}
LD -20.6	13.6^{c}	13.8^{c}	14.7^{d}	15.1^{c}	14.6^{b}
PM -26.1	7.8^{a}	9.6^{a}	8.6^{a}	10.2^{a}	14.7^{b}
PM -20.6	13.0^{c}	12.1^{b}	12.7^{c}	12.2^{b}	12.6^{a}
F value***	101.68	37.94	113.28	43.39	10.07
LSD	0.79	0.84	0.72	0.86	0.95

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

*= ($P<.05$) ***= All ($P<.001$) LSD = Least significant difference

[d] = Means represent pooled data for muscle and temperature

Appendix C

The effect of type of lighting, muscle and display temperature on percent reflectance @ 572 nm

Lighting Type[e]	Time (Days) 0	1	3	7	35
Delux Warm White	9.1	10.4	10.5	11.9^{cd}	15.4^{bc}
Grolux Wide Spectrum	9.1	10.5	10.5	11.7^{bcd}	14.7^{abc}
Incandescent Flourescent	8.8	10.3	9.8	10.9^{abc}	14.0^{ab}
Standard Grolux	9.5	11.2	10.9	12.5^{d}	15.9^{c}
Delux Cool White	9.2	9.5	10.1	11.0^{abc}	13.7^{a}
Verda Ray	8.8	9.4	10.2	10.4^{a}	14.0^{ab}
Cool White	9.3	10.1	10.2	11.3^{abcd}	14.6^{abc}
Soft White	9.8	10.1	10.4	11.0^{abc}	14.4^{abc}
Incandescent	9.3	9.6	9.9	10.6^{ab}	13.6^{a}
Cool Beam	8.8	9.8	10.6	11.8^{bcd}	13.5^{a}
F value	0.78	1.56	0.73	2.19*	1.97*
LSD	1.03	1.18	1.00	0.12	1.56
Muscle - Temperature °C					
LD -26.1	7.6^{b}	8.9^{a}	8.9^{b}	10.9^{b}	15.0^{b}
LD -20.6	11.2^{c}	12.1^{c}	13.2^{d}	14.1^{c}	15.4^{b}
PM -26.1	6.7^{a}	8.6^{a}	7.9^{a}	9.4^{a}	14.6^{b}
PM -20.6	11.2^{c}	10.9^{b}	11.2^{c}	11.0^{b}	12.5^{a}
F value***	99.99	38.04	107.87	48.91	13.00
LSD	0.65	0.75	0.64	0.79	0.99

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

*= ($P<.05$) ***= All ($P<.001$) LSD = Least significant difference

[e] = Means represent pooled data for muscle and temperature

Appendix D

The effect of type of lighting, muscle and display temperature on percent reflectance @ 582 nm

Lighting Type[e]	Time (Days) 0	1	3	7	35
Delux Warm White	8.0	9.3	9.3	10.3	13.8^{cd}
Grolux Wide Spectrum	8.3	9.5	9.6	10.8	13.4^{abcd}
Incandescent Flourescent	8.0	9.1	8.9	9.6	12.3^{ab}
Standard Grolux	8.5	9.8	10.1	10.8	14.3^{d}
Delux Cool White	8.2	9.0	9.6	10.1	12.5^{abc}
Verda Ray	8.2	8.9	9.4	9.4	12.5^{abc}
Cool White	8.3	9.3	9.4	10.9	13.7^{bcd}
Soft White	8.7	9.3	10.0	10.0	13.4^{abcd}
Incandescent	8.4	8.8	9.2	9.5	12.2^{a}
Cool Beam	7.8	8.7	9.5	10.9	12.1^{a}
F value	0.61	0.82	1.02	1.51	2.39*
LSD	0.92	1.07	0.99	1.32	0.14
Muscle - Temperature °C					
LD -26.1	7.3^{b}	8.2^{a}	8.5^{b}	10.3^{b}	13.3^{b}
LD -20.6	9.7^{c}	10.6^{c}	11.4^{d}	12.0^{c}	14.1^{c}
PM -26.1	5.9^{a}	8.0^{a}	7.8^{a}	8.5^{a}	13.1^{b}
PM -20.6	10.1^{c}	9.9^{b}	10.1^{c}	10.0^{b}	11.6^{a}
F value***	89.43	26.75	50.27	22.51	9.79
LSD	0.58	0.68	0.63	0.83	0.89

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

*= ($P<.05$) ***= All ($P<.001$) LSD = Least significant difference

[e] = Means represent pooled data for muscle and temperature

Appendix E

The effect of type of lighting, muscle and display temperature on percent reflectance @ 600 nm

Lighting Type[e]	Time (Days) 0	1	3	7	35
Delux Warm White	15.8	17.8	17.5	18.0	20.2
Grolux Wide Spectrum	17.1	18.2	17.8	18.1	19.1
Incandescent Flourescent	16.3	18.3	17.6	18.0	18.7
Standard Grolux	16.9	18.8	19.5	18.6	20.1
Delux Cool White	16.7	18.5	18.1	17.0	17.7
Verda Ray	16.3	19.7	18.0	16.7	18.1
Cool White	16.9	19.5	17.8	18.2	17.7
Soft White	16.9	20.8	18.6	17.9	19.0
Incandescent	16.6	18.8	17.7	18.1	17.9
Cool Beam	15.6	17.9	17.6	19.7	17.9
F value	0.46	1.21	0.86	1.05	1.75
LSD	2.00	2.48	1.85	2.20	2.02
Muscle - Temperature °C					
LD -26.1	21.2[d]	22.8[d]	21.4[d]	21.6[d]	21.8[c]
LD -20.6	16.5[c]	19.8[c]	19.2[c]	19.7[c]	19.1[b]
PM -26.1	13.2[a]	17.6[b]	16.6[b]	16.2[b]	19.4[b]
PM -20.6	15.0[b]	15.1[a]	14.9[a]	14.5[a]	14.9[a]
F value***	53.81	37.20	46.49	41.23	30.04
LSD	1.30	1.58	1.17	1.39	1.30

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

***= All ($P<.001$) LSD = Least significant difference

[e] = Means represent pooled data for muscle and temperature

Appendix F

The effect of type of lighting, muscle and display temperature on percent reflectance @ 650 nm

Lighting Type[e]	Time (Days) 0	1	3	7	35
Delux Warm White	34.6	34.4	29.9	28.7	27.9^{c}
Grolux Wide Spectrum	36.2	35.3	29.9	29.0	26.4^{abc}
Incandescent Flourescent	34.6	34.6	29.9	28.3	27.5^{bc}
Standard Grolux	36.4	36.4	32.2	30.1	27.8^{c}
Delux Cool White	35.7	33.0	29.8	26.9	25.1^{ab}
Verda Ray	34.9	34.3	29.7	26.5	25.9^{abc}
Cool White	35.9	34.6	29.5	27.9	24.3^{a}
Soft White	37.1	35.3	30.3	27.3	24.7^{a}
Incandescent	35.7	34.1	29.7	29.6	25.9^{abc}
Cool Beam	35.0	31.9	28.2	29.3	25.2^{ab}
F value	0.94	1.79	1.54	1.46	2.16*
LSD	2.40	2.60	2.23	2.75	0.25
Muscle - Temperature ^{o}C					
LD -26.1	40.9^{c}	40.2^{d}	33.5^{b}	31.2^{b}	28.4^{c}
LD -20.6	41.1^{c}	38.2^{c}	32.6^{b}	31.2^{b}	26.3^{b}
PM -26.1	28.3^{a}	30.6^{b}	26.6^{a}	25.7^{a}	27.1^{bc}
PM -20.6	32.2^{b}	28.6^{a}	26.8^{a}	25.3^{a}	22.4^{a}
F value***	132.10	90.37	52.41	27.54	20.99
LSD	1.50	1.70	1.41	1.74	1.60

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

*= ($P<.05$) ***= All ($P<.001$) LSD = Least significant difference

[e] = Means represent pooled data for muscle and temperature

Appendix G

The effect of type of lighting, muscle and display temperature on percent reflectance @ 685 nm

Lighting Type[e]	Time (Days) 0	1	3	7	35
Delux Warm White	40.2	42.0	41.4	42.7	44.9
Grolux Wide Spectrum	42.0	43.0	41.2	42.8	42.4
Incandescent Flourescent	40.2	42.2	41.2	42.2	42.8
Standard Grolux	42.3	44.5	43.7	44.6	44.7
Delux Cool White	41.2	41.8	41.4	42.2	41.4
Verda Ray	40.6	40.9	41.2	40.8	42.3
Cool White	41.7	42.9	41.1	42.3	40.4
Soft White	43.0	44.1	42.2	41.7	41.5
Incandescent	41.7	42.3	41.4	42.4	42.1
Cool Beam	40.9	41.3	41.1	43.7	42.2
F value	1.02	1.35	0.98	1.02	1.72
LSD	2.50	2.80	2.28	2.84	2.91
Muscle - Temperature °C					
LD -26.1	46.6[c]	47.1[b]	46.0[b]	47.7[b]	47.2[d]
LD -20.6	47.2[c]	49.2[b]	48.5[c]	48.8[b]	44.8[c]
PM -26.1	34.0[a]	37.2[a]	35.4[a]	37.2[a]	42.1[b]
PM -20.6	37.8[b]	36.0[a]	36.4[a]	36.5[a]	35.7[a]
F value***	126.50	118.33	161.95	103.28	55.88
LSD	1.60	1.80	1.44	1.80	1.80

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

***= All ($P<.001$) LSD = Least significant difference

[e] = Means represent pooled data for muscle and temperature

Appendix H

The effect of type of lighting, muscle and display temperature on percent blue reflectance[d]

	Time (Days)				
Lighting Type[e]	0	1	3	7	35
Delux Warm White	1.92	2.30	2.18	2.11^{b}	2.96^{a}
Grolux Wide Spectrum	2.00	2.40	2.28	2.06^{b}	2.88^{a}
Incandescent Flourescent	2.04	2.20	2.16	1.96^{ab}	3.12^{a}
Standard Grolux	2.16	2.20	2.33	2.11^{b}	4.82^{b}
Delux Cool White	2.08	2.20	2.11	2.03^{b}	2.86^{a}
Verda Ray	1.96	2.50	2.19	1.76^{a}	2.39^{a}
Cool White	1.99	2.40	2.18	2.14^{b}	2.60^{a}
Soft White	2.09	2.10	2.26	2.13^{b}	2.29^{a}
Incandescent	2.07	2.10	2.16	2.03^{b}	2.22^{a}
Cool Beam	1.98	2.30	2.36	2.40^{c}	2.49^{a}
F value	0.92	1.47	0.54	3.11**	2.35*
LSD	0.21	0.29	0.13	0.25	1.36
Muscle - Temperature ^{o}C					
LD -26.1	1.96^{b}	2.30	2.28^{b}	1.90^{a}	3.50^{b}
LD -20.6	2.23^{c}	2.30	2.42^{b}	2.40^{c}	2.70^{a}
PM -26.1	1.60^{a}	2.20	1.95^{a}	1.80^{a}	2.90^{ab}
PM -20.6	2.30^{c}	2.30	2.23^{b}	2.21^{b}	2.31^{a}
F value	44.66***	1.27	7.90**	24.08***	2.63*
LSD	0.13	0.18	0.20	0.16	0.86

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

*= ($P<.05$) **= ($P<.01$) ***= ($P<.001$) LSD = Least significant difference

[d] = Area under reflectance curve 450 - 474 nm

[e] = Means represent pooled data for muscle and temperature

Appendix I

The effect of type of lighting, muscle and display temperature on percent red reflectance[e]

Lighting Type[f]	Time (Days) 0	1	3	7	35
Delux Warm White	25.9	26.9^{b}	25.2	25.9	26.6^{d}
Grolux Wide Spectrum	27.1	27.1^{b}	25.4	25.8	25.8^{d}
Incandescent Flourescent	25.4	27.7^{bc}	25.2	25.6	24.0^{bc}
Standard Grolux	26.7	29.4^{c}	26.8	27.2	25.1^{cd}
Delux Cool White	26.6	27.1^{b}	25.8	25.3	22.8^{ab}
Verda Ray	26.1	26.4^{ab}	25.7	23.8	23.4^{bc}
Cool White	26.2	27.1^{b}	25.7	25.0	21.3^{a}
Soft White	27.8	25.6^{ab}	25.5	25.4	21.1^{a}
Incandescent	26.6	24.7^{a}	24.8	25.2	22.7^{ab}
Cool Beam	26.4	25.9^{ab}	24.1	26.9	22.8^{ab}
F value	0.93	3.10**	1.40	1.83	7.97**
LSD	1.90	2.00	1.68	1.98	1.81
Muscle - Temperature ^{o}C					
LD -26.1	28.9^{c}	30.1^{c}	27.3^{c}	28.5^{b}	26.2^{c}
LD -20.6	31.5^{d}	30.7^{c}	29.4^{d}	28.7^{b}	24.1^{b}
PM -26.1	20.5^{a}	23.3^{b}	21.6^{a}	22.8^{a}	23.9^{b}
PM -20.6	25.1^{b}	23.0^{a}	23.2^{b}	22.4^{a}	19.9^{a}
F value***	121.09	84.07	89.04	57.34	41.00
LSD	1.20	1.30	1.06	1.26	1.14

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

= ($P<.01$) *= All ($P<.001$) LSD = Least significant difference

e = Area under reflectance curve 630 - 700 nm

f = Means represent pooled data for muscle and temperature

Appendix J

The effect of type of lighting, muscle and display temperature on percent total reflectance[d]

Lighting Type[e]	Time (Days) 0	1	3	7	35
Delux Warm White	50.1	51.3	49.0	48.4	54.5[ab]
Grolux Wide Spectrum	50.6	53.1	49.5	49.3	51.8[a]
Incandescent Flourescent	48.9	52.3	48.4	47.2	66.4[b]
Standard Grolux	51.8	53.8	51.6	51.9	56.2[ab]
Delux Cool White	50.6	49.5	48.4	46.4	48.0[a]
Verda Ray	49.1	51.5	48.5	46.1	45.1[a]
Cool White	51.0	53.4	48.9	49.5	43.2[a]
Soft White	51.5	54.2	49.7	48.3	43.4[a]
Incandescent	50.3	51.6	62.7	47.1	43.9[a]
Cool Beam	49.1	50.3	47.1	51.8	43.9[a]
F value	0.57	0.89	0.83	1.70	2.38*
LSD	4.00	4.40	13.60	4.37	13.60
Muscle - Temperature °C					
LD -26.1	50.3[b]	56.4[b]	57.5[b]	51.0[b]	56.2[b]
LD -20.6	55.6[c]	58.4[b]	56.1[b]	55.7[c]	45.6[a]
PM -26.1	56.5[c]	46.1[a]	42.1[a]	43.4[a]	59.2[b]
PM -20.6	40.0[a]	47.5[a]	45.9[a]	44.3[a]	37.4[a]
F value***	81.43	36.84	5.94	33.85	10.30
LSD	2.30	2.80	8.60	2.76	8.66

Main effect means within time periods with same or no superscript letters not significantly different ($P<.05$)

*= ($P<.05$) ***= All ($P<.001$) LSD = Least significant difference

[d] = Area under reflectance curve 400 - 700 nm

[e] = Means represent pooled data for muscle and temperature

COLOR STABILITY OF FROZEN BEEF STEAKS AS AFFECTED BY VARIOUS COMMERCIAL DISPLAY LIGHTING SOURCES

by

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The effect of ten commercial display light sources each at a lighting intensity of 1076 lumens/meter^2 on frozen beef loin steaks (longissimus dorsi and psoas major muscles) was investigated. Steaks (2.2 - 2.8 cm thick) were cut from USDA Choice beef loins. Loins were randomly numbered and steaks allotted to treatments so each treatment had a steak from each of 10 loins and each of 10 anterior-posterior positions.

Steaks were cut and trimmed and allowed to bloom thirty minutes, prior to crust freezing in liquid nitrogen vapor (stepwise -17.8°C to -129.7°C in about 9 minutes) and skintight packaging in a medium permeability Iolon film. Muscles were evaluated visually under each of three light sources, namely, the display lighting for that particular steak, Delux Cool White and Incandescent lighting. Each muscle was then placed on a Bausch and Lomb Spectronic 600 (scan speed of 250 nm/min) with reflectance attachment. Reflectance and percentages at 474, 525, 572, 580, 600, 630, 650 and 686 nm and three areas under the reflectance curves, namely, 400 - 700 nm, 630 - 700 nm, and 440 - 474 nm (total, red and blue reflectance, respectively) were measured. Visual and reflectance evaluations were done after freezing and packaging and after 1, 3, 7, 21 and 35 days of display.

The study involved two replications; the first with

display cases held at -20.6°C and the second at -26.1°C, with twice daily defrost cycles in each study.

Pooled data for both temperatures (-20.6°C and -26.1°C) showed significant differences in percent reflectance at 630 nm at day 7 indicating that light effects were present after this time. Verda Ray, Delux Cool White, Soft White, Cool White and Incandescent Fluorescent all showed significantly higher percent reflectance than the remaining sources. Scorer K, scoring under display lighting, found steaks displayed under Standard Grolux to be significantly more desirable and those under Cool White to be the darkest. Scorer F found Incandescent and Grolux Wide Spectrum lighting to be most desirable while Cool White, Verda Ray, Delux Warm White and Soft White were significantly poorer. Scorer K and Scorer F, scoring under Delux Cool White, both found that use of Delux Warm White, Grolux Wide Spectrum, Incandescent Fluorescent and Standard Grolux caused significantly brighter color scores than all other light sources. Cool White, Verda Ray and Soft White were deemed to cause poorer scores. Similar results were noted for both scorers under Incandescent lighting. Similar results were found after day 21 and day 35. Delux Warm White and Grolux Wide Spectrum were found to be superior light sources for both color stability and

color rendition of steaks. Standard Grolux and Incandescent Fluorescent were both deemed superior, however, Incandescent Fluorescent had a yellowish tint and Standard Grolux had a misleading too-red color.

Soft White, Cool White and Verda Ray were found to have a significantly more deleterious effect on both color stability and display appearance of frozen beef steaks and are not recommended for display purposes. Delux Cool White, Incandescent and Cool Beam sources were found to be intermediate in effect.

Longissimus dorsi muscles were found to be brighter in color and remained acceptable in color for a longer period than the psoas major muscle.

Steaks stored at -26.1°C were found to be significantly superior to steaks stored at -20.6°C.