Current Advances in Meat and Poultry Color

Thermography Profiles of Cooked Beef Patties

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Premature brown color can occur at <60°C and persistent pink color can be present at >80°C in cooked beef patties. Variation in internal temperature can also exist within patties during cooking. The objective of this study was to document the variation in internal temperature of cooked beef patties using infrared thermography. In one study, different formulations of all-beef patties known to have persistent pink color were cooked to 71°C and to 81-85°C. In a second study, patties differing in fat content, and non-meat ingredients (iota carrageenan, oat fiber and bran, soy) were cooked from either the frozen or thawed state to 71°C. Cuts perpendicular to the flat surface were made just in front of thermocouples within five sec of cooking and infrared images were taken (AGEMA Thermovision 550) within one sec. Visual subjective color, L*, a*, b*, chroma and hue angle were determined. Imagery temperatures were less than inserted thermocouple temperatures due to the evaporative cooling that occurred in less than one sec. Patties cooked from the frozen state and to 71°C had considerable pink color, while patties cooked from the thawed state and to 81-85°C had brown internal color. Thermography revealed temperature ranges greater than 22°C for many patties. For all-beef patties cooked to 71°C, 48.6 % of the cut surfaces were between 57.2 and 62.8°C, while 61.0% of the cut surfaces were between 68.3 and 73.9°C for patties cooked to 81-85°C. Temperature profiles were similar between patties cooked thawed and those cooked frozen, although patties cooked frozen had more pink color and underwent more weight and configurational shrinkage ($P<0.05$). Added ingredients and fat content exerted minimal influence on thermal profiles. Use of infrared thermal imagery has revealed the occurrence of considerable temperature variability in cooked beef patties.

Visual and Instrumental Evaluations of Color in Beef Patties Obtained Nationwide and Cooked to Four Internal Temperatures

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Premature brown color in cooked beef patties at less than safe endpoint temperatures presents a potential food safety risk. To determine the prevalence of this situation, a nationwide study was conducted by two ARS-USDA and three FSIS-USDA laboratories. Ground beef (476 samples) was selected daily from retail stores over a four-week period in the cities where laboratories were located (local) and in five other cities (distance). Ground beef was processed into 112-116g patties and either cooked immediately or frozen and thawed by microwave, room temperature (two hr) or at 5°C (four hr) before cooking. Additional packages were frozen as bulk product and stored for 7 or 28 days before thawing at 5°C for 18 hr and processing into patties. Patties were cooked on electric griddles to either 57.2, 65.6, 71.1 or 79.4°C before visual and instrumental color evaluations. Using a criterion of complete absence of pink color to be assessed brown, 3.2% of the patties cooked to 57.2°C and 13.9% of the patties cooked to 65.6°C were assessed as brown. Permitting a slight area of pink in patties to also be included as brown resulted in 8.5% and 15.7% of the patties to be classified as brown when cooked to 57.2 and 65.6°C, respectively. Correspondingly, 47.4% and 15.8% of the evaluations were pink or red for patties cooked to 71.1 and 79.4°C, respectively. Thawed bulk ground beef produced more brown color when cooked than patties cooked fresh or rapidly thawed ($P<0.01$). Location of purchase (local, distance) did not influence cooked color ($P>0.01$). Correlations of external and internal ground beef a* values with cooked patty a* values were low due to the mixing of external and internal portions prior to making patties. Cooked a*, juice and texture values paralleled results for visual color scores. This study provides evidence that cooked beef patty color is not a good indicator of internal patty temperature.

Effects of Bloom Time, Muscle Location and pH on Pork Color

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The degree to which myoglobin "blooms" depends on muscle location, history (postmortem pH decline rate) and air exposure time. The objective of this study was to evaluate factors affecting instrumental and visual measures of pork color including muscle condition (pH), location and bloom time. Muscles including the *gluteus medius* (GM), *longissimus lumborum* (LL), *semimembranosus* (SM), *biceps femoris* (BF), and *triceps brachii* (TRI), from PSE, DFD and normal pork carcasses, were sliced and allowed to bloom for 0, 5, 10, 20 and 30 min. L*, a*, and b* values, hue angle ($\tan^{-1}$ b*/a*), and chroma ($(a^2 + b^2)^{1/2}$) were calculated from a spectral curve (400-700 nm) derived using a Hunter Lab spectrocolorimeter (illuminant C). Visual color scores were assigned by an eight-member panel using the Japanese Color Standards as anchors every 2.5 cm on a 15-cm line scale. Muscle location affected all color characteristics. LL had the highest L* value and hue angle, and the lowest a* and b* values, and chroma of the five muscles. TRI had the lowest L* and b* values, and hue angle, and the highest a* value. Bloom time had no effect on L* value; hue angle stabilized after 5 min, a* and b* values after 10 min and chroma after 20 min. pH was most highly correlated with L* and a* values, hue angle and chroma of LL muscle (r = -0.82, 0.51, -0.77 and -0.40, respectively); it was most poorly correlated with L* and a* values, and hue angle of TRI (r = -0.67, -0.01, and -0.51, respectively). When all muscles were pooled, pH was a good indicator of sensory redness (r = 0.84). In LL, pH (linear) could be used to predict L* value and hue angle (r^2 = 0.68 and 0.60, respectively). In addition, L* value (cubic) was a good predictor of sensory redness of LL (r^2 = 0.66) and SM (r^2 = 0.60).

Instrumental Operating Parameters for Measuring Pork Color

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The meat industry has been using instrumental color measurement systems to predict meat quality characteristics. At the 1996 National Pork Producer's Council Color Vision Training Session wide variation which was not uniform across the range of (pork) colors evaluated indicated that information derived with one instrument/condition may not be comparable to that of another. The objective of this study was to compare effects of instruments, illuminants and muscle locations on instrumental color characteristics. PSE and DFD conditions were created to provide a range of pork colors to evaluate. The *gluteus medius* (GM), *longissimus lumborum* (LL), *semimembranosus* (SM), *biceps femoris* (BF), and *triceps brachii* (TRI) were allowed to bloom 30 min. Spectral reflectance was determined (range = 400-700 nm) using a HunterLab Miniscan Spectrocolorimeter under illuminants C and F, and using a Minolta CR300 under illuminants C and D65. Eight judges evaluated color under fluorescent light using the Japanese Color Standards as anchor points every 2.5 cm on a 15-cm line scale. Significant differences occurred due to muscle location, instrument, and illuminant for most instrumental color measures and for sensory score. Using the Minolta with D65, sensory score best correlated with b* and L* values (r = -0.94 and -0.89) of LL. Using the Minolta with C, score was best correlated with L* value of all muscles except TRI (r range = -0.79 to -0.84). Using the Hunter with F, sensory score was well correlated with L* value and hue angle of all muscles except TRI (L* , r = -0.85 to -0.91; hue angle, r = -0.77 to -0.89). Using the Hunter with C, sensory score was well correlated with L* value of LL, GM, BF and SM (r > -0.47 for each muscle) and hue angle of LL, GM and SM (r = -0.67, -0.57 and -0.59). Regression equations are reported for converting instrumental measures determined using one instrument/illuminant to the same measure using any of the other instrument/illuminant combinations evaluated.

Rebloom and Display Color Stability of Beef Packaged in an Ultra-low Oxygen Modified Atmosphere System

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Effects of storage time on reblooming ability and display color stability of ground beef and three beef muscles packaged in an ultra-low oxygen active packaging system (APS) were determined. APS consisted of overwrapped retail cuts sealed inside a barrier pouch with an atmosphere of 30% carbon dioxide and <10 ppm oxygen. Ground beef and steaks from strip loins, tenderloins, and top rounds were individually packaged in APS or vacuum and stored for 7, 14, 21, or 35 d. After 60 min of bloom at each storage time, all cuts in APS, except for the outer portion (OP) of top round steaks, had slightly lower a* values and saturation indices ($P<0.05$) than vacuum controls. Top round steaks (OP) had no bloom differences ($P>0.05$) between packaging systems. After 7 d of storage and 1 d of display, visual scores and instrumental color values for ground beef were not different ($P>0.05$) between package type. APS extended color life of ground beef by 1-2 d after 14 and 21 d storage. Loin eye steaks in APS were more red ($P<0.05$) than vacuum after 3 d of display, and had extended color life by 1 d. Tenderloin steaks in APS initially had lower a* values and saturation indices ($P<0.05$), but by day 1 of

display, these traits did not differ for package types (P>0.05). Packaging systems did not affect color stability (P>0.05) of top round steaks (OP) after 14 and 21 d of storage; but after 35 d storage, those steaks in APS had more desirable color stability. Inner portions of top round steaks in APS had higher a* values and saturation indices (P<0.05) than vacuum for days 1 and 2 of display. Packaging ground beef and steaks from three beef muscles in APS for up to 35 d will rebloom and have display color stability equal to or exceeding that provided by vacuum packaging.

Effect of Storage Time, Storage Temperature, Cooking Temperature, and Holding Time After Cooking on Pigment Levels in Beef Patties.

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Beef patties (113 g) were commercially prepared, rapidly frozen, and stored at -29°C. Four separate experiments were conducted. In study 1, meat pigment levels were determined after 1 to 90 days frozen storage. Metmyoglobin (MetMb) levels increased from 3% initially to 17%, but retained acceptable appearance even after 90 days. Pigment levels were determined after clamshell grilling of frozen patties (Study 2) to 63, 68, 74, or 79°C internal temperature, measured 1 minute after removal from the grill. Thin (2 to 3 mm) samples (Study 4) were heated to the same temperatures in a water bath. Patties and thin samples were both thoroughly browned at 74 to 79°C, with <1 mg myoglobin/g meat, vs 4.4 mg myoglobin/g raw meat (> 75% Mb denaturation during cooking). Meat pH increased with cooking, from pH 5.75 for raw patties to pH 6.06 for patties cooked to 79°C. When heated to 63 or 68 C, thin samples had more Mb and red color than patties, probably since thin samples reached target temperatures faster. However, at 74 or 79°C, undenatured myoglobin levels were low (< 1 mg/g), and not affected by sample thickness. In study 3, patties were cooked to 71°C, held 0 to 120 sec after removal from the grill, then frozen in liquid nitrogen and stored at -29°C. Patties at 0 sec had slightly red internal color, with 1.6 mg Mb/g cooked pattie. Patties at 30 to 120 sec had less undenatured myoglogin (0.9 to 1.1 mg Mb/g), and brown internal appearance. Thus, significant myoglobin denaturation occurred within 30 sec after removal of patties from the grill. Finally, in study 4, some samples were abused at 5°C for 72 hr before cooking. MetMb levels increased to 39%, vs 16% in samples held 24 hr at 2°C. Abused patties browned faster, with higher percent MetMb and percent denatured myoglobin after cooking.

Effects of Electron Beam Irradiation on Color of Ground Beef Patties

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The objective was to determine the effects of packaging atmosphere and three levels of irradiation dose of Repetitive High Energy Pulsed Power on display color attributes of ground beef patties. Beef knuckles and beef fat were coarse ground, sampled, and analyzed by CEM to achieve 20% fat, ground through 0.32 cm plate, processed into approximately 10.2 cm^2, 115 g patties which were sealed either aerobically or nitrogen-flushed. Patties were exposed to either 0.0, 1.5, or 3.0. kGy at Sandia National Laboratories, transported to Kansas State University, and displayed at 3 +/- 2°C for 6 days under 1614 lux Deluxe Warm White fluorescent lighting in an open-top display case defrosted at twelve hour intervals. Hunterlab Instrumental color (Illuminant A) was measured daily. Because differences in myoglobin concentration cause color measurement variations, % reflectance (R) 610nm/R580nm and R630nm/R580nm were evaluated. The experiment was replicated three times, and data analyzed using SAS Proc Univariate and Proc Mixed. Aerobically packaged patties had higher (P<0.05) L*, b*, and hue-angle values compared to nitrogen packaged patties. Nitrogen packaged patties had higher (P<0.05) a*, saturation index values, R610nm/R580nm, and R630nm/R580nm values compared to aerobically packaged patties over the 6 day display. Patties irradiated at 3.0 kGy dose had higher (P<0.05) R610nm/R580nm and saturation index values than control patties. a* values of nitrogen packaged patties irradiated at 0.0 and 1.5 kGy and b* values of aerobically packaged patties irradiated at 3.0 kGy were not different (P>0.05) for any display days. For all display days, saturation index and hue angle values for nitrogen packaged patties irradiated at 3.0 kGy were similar (P>0.05). For all display days, R610nm/R580nm and R630nm/R580nm values of nitrogen flushed patties within each dose level were similar (P>0.05). Irradiation combined with nitrogen-flushing resulted in more stable, intense red colored patties compared to aerobic packaging and irradiation.

Prolonging Oxymyoglobin on Pork Surfaces in Vacuum

Packages Using Leghemoglobin

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Fresh pork loins (3 days post-slaughter) were cut into chops and randomly assigned to one of seven treatments: 1) polyvinyl-chloride (PVC) packaged, 2) vacuum packaged, 3) 0.2 mL of Tris-Buffer, 4) 0.2 mL of high leghemoglobin (HLb=0.52 g lypholized leghemoglobin/3 ml buffer) at high pH (7), 5) 0.2 mL of high Lb at low pH (5.6), 6) 0.2 mL of low Lb (LLb=0.15 g/3 ml buffer) at high pH (7), and 7) 0.2 mL of low Lb at low pH (5.6). Chops in treatments 3 through 7 had 0.1 ml of solution spread on each side and also were vacuum packaged. Leghemoglobin treated chops maintained higher ($P<0.05$) panel color scores at the point of purchase display (5-6 C) than vacuum packaged pork throughout 21 days of storage. The High Lb at low pH treatment had higher ($P<0.05$) CIE L* values than the vacuum packaged control treatments on days 3, 4, and 5 but the other Lb treatments did not affect ($P>0.05$) lightness. High Lb treatments had higher ($P<0.05$) CIE a* values on the day of manufacture than low Lb treatments. The CIE b* values of the high Lb at low pH treatment were higher ($P<0.05$) than vacuum packaged and buffer controls on day 0 through day 5. On the day of processing, the estimated oxymyoglobin of the High Lb treatments were higher ($P<0.05$) than the Low Lb treatments. The estimated metmyoglobin of the High Lb treatments was less ($P<0.05$) than the vacuum packaged and the buffer treatments on the day of manufacture. The pH of leghemoglobin did not affect ($P>0.05$) sensory or objective color, pigment state, purge or total psychrotrophic aerobic bacterial counts (TPC) throughout the study. The TPC of the Lb treatments were lower ($P<0.01$) than non-treated samples at all assessment times.

Incidence of Premature Browning in Ground Beef Purchased Retail

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To estimate the incidence of premature browning in ground beef purchased at retail and prepared using common household procedures, ground beef was purchased in the morning and afternoon from two stores. Patties made from packages purchased in the morning were cooked within two hours of purchase, whereas patties made from packages purchased in the afternoon were refrigerated overnight before cooking. Patties were formed from the outer 2 cm of tissue and from the inner core of each package and their color was evaluated. Patties were cooked at 177 C to 55°C, and the interior color was evaluated visually and instrumentally. Raw patty color had a store by purchase time interaction ($P<0.05$). Product purchased in the morning from store B was more red, yellow and saturated in color than product from store A. Product purchased in the afternoon from store A had the lowest a* values (least red). Visual score, a*, saturation index and hue angle of uncooked patties had a significant purchase time by location interaction. Product purchased in the afternoon and stored overnight became more ($P<0.05$) purple in the interior than on the outer surfaces or in the inner portion of morning product. The interior cooked color of patties from the outer portion of the packages were more ($P<0.05$) brown than patties formed from the inner portions. Patties made from the inner portion of packages purchased in the afternoon and held overnight were more red (a*), saturated and lower in hue angle indicating less premature browning than patties from other treatment combinations. These data suggest that both oxymyoglobin and metmyoglobin predispose patties to premature browning. Incidence of premature browning from 8 replications over 2 weeks averaged 47%. Consumers should use patty temperature, not color, as a guide for doneness.

New Color Standards for the U.S. Pork Industry

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Color of pork affects consumer-purchasing decisions. Previous studies highlighted the importance of industrial color classification as a major factor of quality assessment. Computer classifiers allow automation of color segregation using human color perception as a reference. NPPC color standards and Japanese Color Standards were created by subjective color definition and are currently used as visual references in color grading and segregation. Although current color standards are good for visual reference, they are not adequate for training a Color Machine Vision System to classify pork. The objective of this study is to create a set of color standards as industrial references for U.S. pork, which is representative of the pork color range and can be used for automated computer classification. To create new pork color standards, a series of images of pork chops from 29 pigs were captured in five repetitions. Dark meat color was created in selected pigs that were treated with epinephrine 12 hours prior to slaughter. To create pale meat color, selected carcasses were kept in a warm environment after slaughter. Images of *Longissimus, Gluteus medius, Triceps brachii, Semimembranosus* and *Biceps femoris* muscles were captured using the Color Machine Vision System. Color information from chops was compiled into a database for creating a color range for pork. A three-dimensional, RGB color space description of pork color was defined. This pork color space was divided into

six equally spaced segments. New color coordinates were defined for the six color classes. Based on these class descriptions, a set of color standards was created in cooperation with Color Curve Inc. in Fort Wayne, Indiana. The sample pork color standards were compared using RGB color coordinates and spectrophotometer data obtained at Purdue University. The spectrophotometric reflectance curves and RGB coordinates of the final standards will have to match that of the real meat.

Image Analysis to Measure Color Changes Over Time on Fresh Retail Beef

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Image analysis was used to determine color characteristics and especially discoloration of fresh retail beef. Vitamin E fed beef and control beef are merchandised by a local supermarket chain. Thick (5 cm) loin strip steaks (n=16) from the anterior end (13th rib section) were purchased at these supermarkets in the Reno, Nevada area. The steaks were bisected into 32 thinner steaks using a sterilized butcher knife. The resulting 2.5-cm thick steaks were repackaged supermarket style in Styrofoam trays with an oxygen permeable film over wrap so that the original displayed store surface could be compared to the fresh cut. The steaks were photographed at 0, 1, 2, 3, 4, and 6 d with 160T Kodak slide film under 3400K lighting conditions on a copy stand using an 18% gray card to adjust the F-stop. An HP ScanJet 3c was used to produce TIF images which were stored on a Zip disk. The color images were displayed on a computer screen. The images were converted from a RGB format to the CMY format. A segmentation procedure was used to map discolored areas in the cyan split image on a Macintosh IPLab software package. After comparison with the actual image, it was found that segmentation of the cyan image could very closely approximate the lean and discolored areas by adjusting the gate width by using the histogram function. This was converted to percent discolored pixels in the lean area. Experienced meat market managers scored the steaks as to probable and definite pull dates. These ratios of discolored to lean pixels were compared to meat managers color evaluations to fine tune the system. Image analysis shows promise to quantify discoloration by mapping the ratio of discolored to lean pixels.

Display Color Stability of Steaks and Ground Beef from Carcasses Cardiovascularly Infused Immediately After Exsanguination

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Steers (n=36) were stunned, exsanguinated, and subjected to a cardiovascular infusion treatment: 1) non-infused; 2) infused with a solution containing dextrose, sodium chloride, glycerin, sodium tripolyphosphate, and maltose, (MPSC solution); and 3) infused with 0.3 M $CaCl_2$. The pH declined more rapidly ($P<0.05$) in the *longissimus thoracis* and deep *semimembranosus* muscles of infused than non-infused carcasses; no differences occurred for temperature decline in these muscles. At 48 h postmortem the *longissimus lumborum* (LL), *semimembranosus* (SM), and *psoas major* (PM) were removed from each carcass and vacuum packaged for 14 d at 2^{o}C. At 14 d postmortem one steak was sliced from each muscle, bloomed at 2^{o}C for 1 h, and over wrapped in PVC for visual and instrumental color evaluations during display (1614 lux Deluxe Warm White lighting). The inside (ISM) and outside (OSM) portions of the SM were evaluated separately. LL and OSM steaks from MPSC-infused carcasses had a lighter-red *($P<0.05$)* initial appearance than steaks from the other treatments. LL steaks from non-infused carcasses had the most *($P<0.05$)* uniform color, the MPSC treatment was intermediate, and the $CaCl_2$ treatment was the most two-toned. Steaks from both infusion treatments had greater CIE L* values *($P<0.05$)* in the LL, ISM, and OSM muscles. Color traits of ground beef and the PM muscle did not differ ($P>0.05$) due to infusion. The LL muscle had more color traits that differed significantly than any other muscle. In general, the LL from $CaCl_2$-infused carcasses had lower values for CIE a*, saturation index, and 630nm–580nm and had larger hue angles. MPSC infusion also increased hue angles in the LL and OSM. Display color stability was lowest *($P<0.05$)* for LL steaks from $CaCl_2$-infused carcasses whereas steaks with MPSC infusion were lighter red in initial color but otherwise had display color stability similar to the non-infused treatment.

The Effect of pH, Myoglobin Form and Endpoint Temperature on Cooked Ground Beef Color

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Persistent red color of cooked ground beef is a costly problem to the beef industry. The objective of this study was to determine the effects of pH, pigment form, endpoint temperature on normal and persistent red color development in ground beef. Beef muscles from nine pH groups (5.5, 5.6, 5.7, 5.8, 5.9, 6.1, 6.2, 6.3, 6.4) were mixed with fat trim to 20% fat, ground (0.32-cm plate), formed into either oxymyoglobin or deoxymyoglobin patties and

cooked to four endpoint temperatures (66, 71, 77, 82°C). Each patty was cut in the center longitudinally and the center location was evaluated visually and instrumentally. Acid phosphatase (ACP) activity and percent myoglobin denaturation were determined on samples from center (lowest temperature) locations. Deoxymyoglobin patties pH with 6.2 and higher cooked to 66 C and 71°C were redder visually, supported by a higher 630nm/580nm reflectance ratio and by higher Hunter a* values. Similar trends were not as pronounced with oxygenated patties, but still observed. Percent myoglobin denaturation in patties cooked to 66, 71, 77 and 82°C were 73.5, 78.9, 80.1 and 84.8, respectively for oxygenated patties and 62.5, 67.1, 75.3 and 82.6, respectively for deoxygenated patties. ACP activity for oxygenated patties were 13.3, 7.5, 1.0 and 0.3, respectively for the increasing temperatures and 27.7, 13.9, 1.4, and 0.6, respectively for deoxygenated patties. The correlations of pH to Hunter L*, a*, hue angle, saturation index and 630nm/580nm reflectance ratio values for oxygenated patties were at least -0.87 (77°C), 0.83 (66°C), -0.85 (66°C), 0.56 (66°C), and 0.82 (66°C), respectively and -0.40 (82°C), 0.87 (77°C), -0.91 (71°C and up), 0.76 (66°C and 71°C) and 0.85 (71°C and 82°C), respectively for deoxygenated patties. Patties containing oxymyoglobin became distinctly more resistant to thermal denaturation at pH 6.2 and higher while deoxymyoglobin patties had a more linear decrease as pH increased. Deoxymyoglobin patties were more susceptible to persistent red color.

Determination of Nitrite and Nicotinamide Hemochrome Complexes by Reflectance Spectrophotometry in Cooked Ground Turkey

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A sporadic pink color generation in cooked, uncured turkey breast and other poultry products remains a problem within the meat industry. Reflectance spectroscopy has been used to measure certain pigments responsible for this pink color development. Two reflectance ratios were re-evaluated for their ability to predict nicotinamide-denatured globin hemochrome complexes (NICHEME; %R537nm/%R553nm) and nitrosylhemochrome (%R650nm/%R570nm) in samples prepared to contain a greater number of pigment levels than previously tested. Varying levels of nicotinamide from 0.10% to 2.00% and sodium nitrite from 1.5 ppm to 100 ppm were added to ground turkey before cooking. Reflectance values from 400 to 700 nm and CIE L*, a*, and b* values were measured on cooked turkey samples (80°C, internal temperature) immediately after cutting and after exposing the sample to light and air (2-min, 1076 lux). Measurements were repeated on samples treated to result in pigments that were oxidized (0.1% potassium ferricyanide), reduced (0.1M sodium dithionite), and samples that had the heme-ring destroyed (0.05% hydrogen peroxide). To model simulated levels of nitrite that could be associated with contamination and cause a pink color defect, a cubic polynomial regression was fit to the nitrite data containing samples of 20 ppm and less. All nicotinamide levels were used to determine fit to the cubic model. The reflectance ratio of %R650nm/%R570nm and CIE a* values increased up to approximately 10 ppm to 20 ppm added sodium nitrite but displayed a leveling-off at higher levels in contrast to nicotinamide which increased over the entire range tested. The reflectance ratio of %R537nm/%R553nm was a good predictor for NICHEME (r^2=0.99) while being a poor predictor of nitrosylhemochrome (r^2=0.68) in untreated samples. As expected, the ratio of %R650nm/%R570nm was a good estimator of nitrosylhemochrome (r^2=0.97), but may also predict NICHEME (r^2=0.87). The reflectance ratio of %R537nm/%R553nm can be used to estimate NICHEME with minimal interference from nitrosylhemochrome. However, the reflectance ratio of %R650nm/%R570nm may not be a viable predictor of nitrosylhemochrome when nicotinamide-denatured globin hemochrome is present.

Color Stabilization of Pork Chops Packaged With a Low Level of Carbon Monoxide

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Carbon monoxide (CO) binds strongly to myoglobin and forms carboxymyoglobin with a very stable cherry red color. A gas mixture containing 0.3 to 0.5 % CO is used commercially for packaging of retail red meats in Norway. The aim of this experiment was to compare the color stability of pork chops in modified atmospheres of 0.4% CO/ 60% CO_2/ 40% N_2 (CMON), 70% O_2/ 30% CO_2 (OXY) and 60% CO_2/ 40% N_2 with O_2 absorbers (ABS) during dark storage at 4 and 8°C for up to 21 days. Five chops per gas mixture and temperature were sampled every 3 to 4 days of storage, evaluated for visual color by a six-member trained panel, and measured for CIE L*a*b* values (lightness, redness, yellowness) with a Minolta Chroma Meter CR-300. The CMON produced meat with a bright, light red color, which was stable at both 4 and 8°C during the whole storage. This meat had higher a* values than the OXY and ABS meat and lower b* values than the OXY meat ($P<0.05$). L* values did not differ between the CMON, OXY and ABS meat ($P>0.05$). The OXY meat was light red at day 3 of storage, but discolored between days 3 and 14, faster at 8 than 4°C. The color stability of the OXY meat was poor compared to the CMON meat. The ABS meat was gray/green from day 3 throughout storage. CO is pres-

ently not approved as a packaging gas for meat in the USA and EU. However, meat packaged in modified atmospheres with < 0.5 % CO does not present any toxic threat to the consumer. Such meat has an extended microbiological shelf life compared to meat in high O_2 atmospheres, because of higher concentrations of CO_2 and absence of O_2. As the high color stability of meat packaged in CO containing atmospheres exceeds the microbiological shelf life, the consumer must detect spoilage by off-odor.

Measuring Muscle Color on Beef Carcasses Using the CIELAB Color Space

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Because beef muscle color affects consumers' purchasing decisions, is a factor in determining USDA grades, and has been shown to be useful in sorting carcasses according to palatability, this study was conducted to determine the effects of measurement conditions on CIE L*, a* and b* values, to determine the relationships among USDA quality grading factors, muscle pH, electrical impedance and colorimeter readings, and to develop a classification system which could be used to sort beef carcasses with respect to muscle color. Data were collected over two days on 145 beef carcasses in a commercial packing plant. The exposed *M. longissimus* at the 12th/13th rib was used for all muscle pH, electrical impedance and colorimeter measurements. Bloom time, from 0 to 93 min, had a greater effect on a* and b* readings than on L* readings. L* values stabilized after approximately 30 min bloom time, and a* and b* values stabilized after 78 min bloom time, but relative differences among carcasses in L*, a*, and b* values did not change after 3 to 12 min bloom time. Days postmortem, cut surface (anterior versus posterior), and within-muscle location (medial versus lateral) did not affect L*, a* and b* readings ($P > 0.05$). Blotting the surface moisture from the *M. longissimus* resulted in lower a* readings ($P < 0.05$), but did not affect L* and b* readings ($P > 0.05$). L*, a* and b* values were correlated with lean maturity scores (-0.67, -0.30 and -0.40, respectively), dark cutter discount (-0.60, -0.76 and -0.73, respectively), muscle pH (-0.57, -0.79 and -0.78, respectively), and electrical impedance (-0.27, -0.21 and -0.25, respectively). Two muscle color classification systems, nine classes each, are proposed, one system based on L* and one system based on b*. The main advantage of the L* categorization system over the b* system is that the L* value is less sensitive to bloom time, and the main advantage of the b* categorization system over the L* system is that the b* system is slightly more precise at segregating carcasses with respect to muscle pH.

Metmyoglobin Reducing Capacity of Fresh Normal, PSE, and DFD Pork During Retail Display

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The purpose of this study was to evaluate the relationship between muscle condition (PSE, normal, DFD), storage time and light exposure, on metmyoglobin reductase activity (MRA), oxygen consumption rate (OCR) and color of pork. Fresh pale, soft, exudative (PSE; pH=5.44), dark, firm, dry (DFD; pH=6.16), and normal (pH=5.52) pork were stored under fluorescent light or dark conditions at 4°C for 7 days. DFD pork had the highest MRA and OCR. Overall degree of MRA decline during storage was similar among the three muscle conditions (~50%). The reduction in MRA occurring in the early post-slaughter period in PSE pork was continuous during storage. Enzyme activity of PSE pork was lower than that of normal pork (until the 5th day of display), but no difference existed in OCR between PSE and normal samples. This activity in DFD pork appeared to enhance reduction and retard metmyoglobin accumulation resulting in slow discoloration; light appeared to accelerate loss of the reducing activity. MRA dropped slowly during storage; OCR decreased sharply during the first day of storage. The OCRs of normal and PSE muscles decreased up to 95% in the first day of storage while OCR decline rate of DFD samples was much lower. OCR declined in DFD pork stored in the dark more than in the light; light had no effect on OCR decline rates of PSE and normal samples. The rapid decrease in OCR and the slow loss of MRA suggested that reducing capacity controlled the metmyoglobin accumulation rate, and ultimately, meat discoloration. These findings have implications for the food industry relative to packaging materials selection (oxygen permeable vs vacuum) and retail meat display conditions for optimum product color. DFD pork is relatively tolerant of display lighting.

Relationship Between Instrumental and Sensory Color Evaluation in a Meat Model System

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To determine the magnitude of change required in instrumental color measurements which corresponded to a significant change in sensory score (redness), a range of meat redness was created by mixing ground chicken breast and very lean ground beef in predetermined ratios. Sensory redness under incandescent and fluorescent light, instrumental color (L*, a*, and b* values, hue angle, chroma) and red color contributed by oxymyoglobin (percent reflectance at 630nm-580nm) were determined under illuminants A and F. Correlation coefficients were determined between sensory and instrumental evaluations. One way ANOVA was used to test differences in visual scores and instrumental data due to meat ratio changes (within light source). Visual scores and instrumental data were regressed on meat ratio; linear, quadratic, and cubic effects

were tested and the best fitting model was chosen for further evaluation. To predict sensory score from instrumental data, the linear region of each significant model (linear, quadradic or cubic) was chosen and the linear model was determined for that region. The applied least significant differences (aLSDs) for instrumental color characteristics were then calculated from these models using sensory redness LSDs for required incremental changes. In addition to L* value and hue angle which are known to be highly correlated to sensory redness, a* and b* values, and R630nm-R580nm were highly correlated to sensory score (incandescent light: r = 0.99, -0.99, and 0.96; fluorescent light: 0.98, -0.98, and 0.96). While overall regression curves were cubic, in the 20% to 85% beef range, regression curves were linear. Hue angle, a* value and R630nm-R580nm could be used to predict sensory meat redness. Under illuminant A, an a* value change of 0.589 was required before a sensory panel perceived a significant difference under incandescent light. Under illuminant F, an a* value change of 0.386 was required for a sensory panel difference under fluorescent light.