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Color changes in the surface of fresh cut meat: A fractal kinetic application

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ABSTRACT

Color stability of fresh meat gives an idea about possible consumer preferences based on the appearance of the product, and it is an important property that influences its market value and the consumer's purchase decision. Color changes on the surface of fresh cut meat were evaluated applying fractal kinetic analysis based on the redness color value (a^* value from CIELab and R value from RGB) as an alternative to the traditional method where an average of the color intensity is used; in addition the thiobarbituric acid and metmyoglobin content in the meat samples were measured. The kinetic rate and the shape factor (empirical order) values were calculated from data fitted to the power law model. In the experiments, freshly cut samples of meat were placed on a styrofoam tray and the fresh cut surface was evaluated for color and color stability using a computer vision system. The styrofoam tray with the samples was placed inside an environmental test chamber at 5 °C (± 1 °C) and at 85% relative humidity for 2.2 days. The results showed that it is possible to model changes in the intensity of the redness color in meat using fractal kinetic analysis, and that fractal dimension can be used as an indicator of changes in the non-homogenous distribution of the colors associated with redness intensity.

1. Introduction

The color of fresh meat is an important property, influencing its market value and the consumer's purchase decision. Data on the color stability of fresh meat give an idea about possible consumer preferences based on the appearance of the product. The appearance of meat and meat products is a complex topic involving animal genetics, ante- and postmortem conditions, fundamental muscle chemistry, and many factors related to meat processing, packaging, distribution, storage, display, and final preparation for consumption (Goñi, Beriain, Indurain, & Insausti, 2007; Mancini & Hunt, 2005).

Meat color is due to the concentration of pigments (myoglobin, hemoglobin), their chemical states and the light-scattering properties of the meat. In living animals, equilibrium exists between the purplish-red myoglobin form (deoxymyoglobin) and the cherry-red oxymioglobin form. During meat storage, these two reduced myoglobin forms readily become oxidized to the brownish-red metmyoglobin (MetMb) (Dosi et al., 2006; Lawrie, 2002). Myoglobin is a metalloprotein composed of globin and an iron-containing heme prosthetic group. The oxidation of the central iron atom within the heme group is responsible for discoloration, a change from red oxymioglobin to brownish metmyoglobin. When ferrous heme iron oxidizes to its ferric form, oxygen is released and replaced by a water molecule (Faustman, Sun, Mancini, & Suman, 2010).

Measurement and subsequent evaluation of color in beef can be measured with a chemical indicator (metmyoglobin) or by physical evaluation using color spaces, i.e. CIELab which has three chromatic parameters: the L^* value is the luminance or lightness component; the a^* value measures redness and the b^* value measures yellowness. However, in the case of red meat, the RGB color space model can also be used because it has a parameter associated with redness (the R value) (Chen, Sun, Qin, & Tang, 2010; O'Sullivana et al., 2003).

Computer vision is a promising method for predicting visual color in beef (Chen et al., 2010; Gerrard, Gao, & Tan, 1996; Goñi et al., 2007; Gwartney, Gao, Tan, & Gerrard, 1996; Jackman, Sun, Allen, Brandon, & White, 2010; Larraín, Schaefer, & Reed, 2008; Zheng, Sun, & Zheng, 2006a). Computer imaging has been used to analyze the correlations between color parameters, determined by computer vision, and physicochemical methods (Zheng, Sun, & Zheng, 2006b). Vision analysis allows investigators to map the areas on the surface of a slice of meat where the color has changed, and to estimate the area covered by metmyoglobin (Mancini & Hunt, 2005).

A common practice in colorimetric methods based on computer vision is to quantify the color in meat using an average of the color intensity in the region of interest (Chmiel, Słowiński, & Dasiewicz, 2011). However, meat surfaces are not homogenous in color due to the presence of beef fat (yellow and white fat) or due to heterogeneous

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myoglobin concentrations in the muscle, among other factors, which can affect the evaluation of the overall color (Chen et al., 2010; Sawyer et al., 2007). A promising method recently used to quantify non-homogenous color surfaces in food is the application of the fractal method (Quevedo, Jaramillo, Díaz, Pedreschi, & Aguilera, 2009; Quevedo, Valencia, Alvarado, Ronceros, & Bastias, 2011). The method uses an indicator called fractal dimension (FD) which permits quantifying the color distribution on a surface instead of calculating the mean color value.

The aim of this study was to determine whether fractal texture, based on CIELab color space or on RGB color space, can be used to record changes in the intensity of the redness color in meat exposed to oxidation, stored at 5 °C.

2. Materials and methods

2.1. Samples

Twelve selected beef samples obtained from a large commercial slaughter facility (vacuum-sealed bags of round steaks) were transported to the laboratory. Muscles were then removed from the vacuum-sealed bags and they were trimmed of external fat. In the experiments, and for each beef sample, twelve small portions of 3 cm × 3 cm × 1 cm were placed on a styrofoam tray so that the fresh cut surface could be used to evaluate color and color stability using a computer vision system. Another twenty-five samples were placed around the styrofoam tray to be used for chemical analysis. All samples (12 for image capture and 25 for chemical analysis) were placed inside an environmental test chamber at 5 °C (± 1 °C), at 85% relative humidity, during 2.2 days. In total, three different experiments were carried out, one for each beef sample. After this time, a strong brown color was observed in the samples. The chamber enables users to simulate environmental conditions and to provide precise temperature and humidity control. A computer vision system was placed in the chamber. The experiment was replicated three times.

2.2. Image texture analysis

A computer vision system described by Quevedo, Díaz, Ronceros, Pedreschi, and Aguilera (2009) was used to capture the images (2800 × 2100 RGB color). Images were captured in quintuplicate at 0, 0.23, 0.59, 0.97, 1.23, 1.68, 1.98 and 2.2 days, respectively; and a total of 40 images were processed for each beef during storage. Color images were used in RGB color space and were transformed to L*a*b* color space using the quadratic model function proposed by Leon, Mery, Pedreschi, and Leon (2006); this transformation considers the influence of the square of the variables (R,G,B) on the estimate of the values of L*a*b*. From the RGB colors, a redness parameter (R) was used directly in order to register changes in redness intensity; from the L*a*b* color space, a* redness parameter was used. Surface intensities were generated (one corresponding to R values and a second to a* values) and were used to describe changes in the redness intensity, using the fractal Fourier method (Chan, 1995; Quevedo, Mendoza, Aguilera, Chanona, & Gutierrez-Lopez, 2008; Russ, 1994). Surface intensity (SI) of an image was obtained by plotting coordinates of pixels (x, y) against their intensity level values in the z-axis. It can be defined as a color intensity map showing the distribution of the intensity color on the image.

An algorithm written in Matlab® R2010a (The MathWorks Company) was used to compute the FD. It uses the fractal Fourier method which consists in applying the Fast Fourier Transform (in 2D) to the image in order to obtain the power spectrum of the selected area (corresponding to 2 cm × 2 cm of the meat surface) from the image data (the spatial resolution was 1 cm of beef = 110 pixels). The 2D power spectrum (D(f)) of the surface image is obtained and D(f) values are then arbitrarily grouped into 12 directions on the image (π/12). For each direction, D(f) is plotted as a function of the frequency, according to the following equation (Gonzales-Barron & Butler, 2008):

$$\mathrm{D(f)}\alpha\ \mathrm{f}^{-2\cdot(3-\mathrm{FD})} \tag{1}$$

If a linear variation is established from the log (D(f)) vs. log (f), we can use the slope to calculate an FD value. Finally, an average of the FD values on the image can be calculated.

In order to ascertain whether other image texture indicators (not based on fractal analysis) can be used to describe the color changes; the well-known textural parameter called the Gray-Level Co-Occurrence Matrix (GLCM function) was applied to the images. They characterize the texture of an image by calculating how often pairs of pixels with specific values and in a specified spatial relationship occur in an image. The GLCM function from Matlab® R2010a (The MathWorks company) was used to compute some textural images: Contrast (*con*), which measures the local variations in the red-level co-occurrence matrix. *P* is the number of co-appearances of red levels i and j (i and j are two different red levels of the image). *D* is the maximum number of pixels at distance and *n* is the next pixel. According to Tan (2004), only the direction of zero degrees (horizontal) and a distance of D = 3 were used:

$$con = \sum_{n=0}^{D} n^2 \left(\sum_{i} \sum_{\substack{j \\ |i-j| = n}} P(i,j) \right) \tag{2}$$

Correlation (*CR*) measures the joint probability occurrence of the specified pixel pairs. μ is the mean and σ is the variance; according to:

$$CR = \frac{\sum_i \sum_j (ij)P(i,j) - \mu^2}{\sigma^2} \tag{3}$$

Additionally, the classic image texture based on the standard deviation of the data on the images (sdtfilt function in Matlab® R2010a) was applied. Statistical parameters can characterize the texture of an image because they provide information about the local variability of the intensity values of pixels in an image. It is recognized that an increment in the FD value of a surface is indicative of an increment in its complexity or roughness (Russ, 1994).

2.3. Metmyoglobin content

Three meat samples were removed, from the 25 placed samples in the environmental test chamber, at each moment in the image analysis. The samples were minced together. Five grams of minced meat was placed into 50 mL polypropylene tubes, and 25 mL of an ice-cold phosphate buffer solution (pH 6.8) was added. The mixtures were homogenized using a Virtis homogenizer (Cyclone IQ2) for 10 s at 13500 rpm. The homogenized samples were placed in the refrigerator for 1 h at 48 °C and centrifuged at 5000 rpm for 30 min at 48 °C. For each sample, the supernatant was filtered through Whatman No. 1 filter paper, and the absorption rate (A) was read at 700, 572, and 525 nm using a spectrophotometer (Shimadzu1 Model UV-2401 PC). The percent of MetMb (%) was determined using the equation:

$$\mathrm{MetMb} = \left\{ 1.395 - \left[\frac{(A_{572} - A_{700})}{(A_{525} - A_{700})} \right] \right\} \cdot 100 \tag{4}$$

2.4. Thiobarbituric acid reactive substances (TBARS)

A TBARS assay was performed as described by Buege and Aust (1978). Minced meat samples prepared in the Section 2.3 were used for this analysis. Samples (0.5 g) were mixed with 2.5 mL of 0.375 %