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DETERMINATION OF INTERNAL COLOR OF BEEF RIBEYE STEAKS USING DIGITAL IMAGE ANALYSIS

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Abstract

Objective measurements of beef ribeye steaks were made to determine the color distribution throughout their interior after heat processing. Steaks from eight animals were grilled to five degrees of doneness according to traditional internal temperature specifications. Images of the interior of these steaks, as seen by a digital image processing system through red, green, and blue filters were analyzed. The mean, standard deviation, skewness, and kurtosis of the histograms of light intensity at all points throughout the surface were determined. The steaks were also analyzed raw and it was determined that little variation in the color of muscle tissue occurred among steaks from the different animals used. The statistics computed were analyzed to determine which could be used to classify steak doneness. It was found that the mean and standard deviation values for each of the three colors are sufficient to differentiate between eight of the ten pairs of steak doneness classes.

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Introduction

The increased use of sophisticated heat processing equipment in the food industry has made the need for further quantification of food quality increasingly important. The control of this equipment requires that standardized, accurate, reliable measurements can be made of the product quality. Consumers rely heavily on their vision to determine the quality of foods. More specifically, the perceived color of a food is an important indicator of food quality. This fact is fundamental to the use of food dyes and controlled lighting in food display cases. In order for the characteristics of food which are determined by consumers through vision to be controlled, they must be quantifiable using measurements which are indicative of the information perceived by the human eye.

During heat processing of beef steaks, consumer preference is associated with five doneness categories. These categories are traditionally defined by the temperature attained at the geometric center of the steak during heat processing. Between 60°C and 71°C, temperature disturbs the structure of myoglobin, changing its color from deep red to light shades of pink. At 79°C, enough hemichrome has accumulated to produce a light brown color. In actual practice, temperature measurements are not used to determine steak doneness. On the other hand, consumers judge the degree of doneness of steaks visually at the time of consumption. Therefore, to reliably control steak processing equipment so that steaks are prepared according to consumer preference, either a standard for doneness must be established which is based upon measurements of visible properties or a strong correlation must be established between non-visible properties and the doneness discerned visibly.

Measurements of the color of foods using a colorimeter produce average values over the field of view of the instrument. This type of measurement is insufficient to specify doneness because a range of colors can exist and doneness is indicated not only by the different colors present but the extent to which the surface is covered by these colors. It has been found that for roast beef the quantitative measurements from a colorimeter were not highly correlated with the internal temperature. On the other hand, sensory color and sensory doneness were found to be more highly correlated to internal temperature (Lyon et al., 1986). This indicates that the colorimetric information is not indicative of the information processed by the human vision system.

To differentiate steak doneness visually, it is at least necessary to be able to both discriminate colors over small areas, and assess the extent to which colors cover a larger surface. Efforts have been made to determine the color of a small area of food by using fiber optics. (Swatland, 1985; Fyhn and Slinde, 1985). Although this method gives accurate measurements of small areas, it did not give the extent to which the colors are present throughout the food product.

The use of digital image analysis allows the light received from a surface to be measured rapidly at points over the entire surface. These capabilities have made digital image processing able to emulate and surpass various aspects of human vision. Image analysis has been applied to foods to perform tasks normally performed by human vision. Methods have been developed allowing image processing to be used to sort stemmed blueberries and cherry peppers from those without stems (Wolfe and Sandler, 1985). Fresh tomatoes have been classified based on size, shape, color, and surface defects using image processing techniques (Sarkar and Wolfe, 1985).

Because of the quantitative capabilities of image processing systems which the human eye does not have, image analysis is useful in providing measurements which actually surpass human vision. Quantitative measurements of raw and gelatinized collagen, elastin, and bone particles in meat and meat products have been made in this manner (Hildebrandt and Hirst, 1985). The determination of protein quality in pizza crusts as indicated by surface browning is another example of the application of image processing (Heyne et al. 1985).

The purpose of the research described here was to quantify the color distribution throughout the interior of beef ribeye steaks of different doneness prepared according to the traditional definition.

Materials and Methods

Steak Preparation

The longissimus dorsi muscle was removed from eight sides of beef, choice quality grade, yield grade 2; wrapped in moisture-barrier protective paper and stored at -24° C for 2-3 weeks. Five ribeye steaks (IMPS No. 1103A) were prepared from the anterior end of each muscle. The thickness was 2.54 cm. Steaks were wrapped individually and stored at 4° C for 24 hours for tempering.

A Krups electric double contact grill (Model 2002) was preheated to position 2 for both upper and lower surfaces. Three Type K thermocouple wires, 24 gauge, Kaplon coated, were inserted near the middle of each steak, positioned away from connective tissue and visible intramuscular fat deposits. They were located about 2 cm from each other midway between the upper and lower surface and attached to a digital thermometer, Omega Model 2068A.

Steaks were heat processed in groups containing five steaks all from the same muscle. Each steak was heat processed individually to one of the five degrees of doneness. Steaks were placed on the middle of the grill surface and the lid was closed. They were heat processed until the average of the three thermocouples reached the desired temperature: rare: 57° C, medium rare: 62° C, medium: 68° C, medium well: 71° C, well: 74° C.

Using a Hobart meat slicer, steaks were horizontally sliced along their center plane. One side from each steak was selected at random for imaging. These half-steaks were positioned on a surface with their inner portion exposed to an ambient temperature for 20 minutes. This interval enabled surface evaporation to occur before image analysis was performed. This was necessary to reduce the specular reflection from the steak surface.

Image Acquisition

For each group of steaks, images of each heat processed steak and the image of one steak in the raw state were acquired using an image processing system composed of a Perkin-Elmer 3220 computer system; Lexidata 3400 color graphics display system; Spatial Data Systems, Model 108, image digitizer; and an Eyecom vidicon scanning camera with a Canon TV-16, 25 mm, 1:1.4 lens. To discern the color content of the reflected light from the steaks, images were acquired through three Wratten filters: #29 (Red), #62 (Green) and #47B (Blue). The steaks were illuminated by four 60 watt tungsten incandescent lamps located at the corners of a 25 cm square. The square was located symmetrically about the axis of the camera lens. The distance from the steak surface to each lamp was 34 cm. This arrangement of lights provided an illumination level of 170 foot-candles uniformly across the field of view. All images were acquired with no other source of light than the lamps discussed.

The distance from the bottom of the camera lens to the object plane was 40 cm. The lens was set to an f-stop of 4. This produced a field of view of 17.5 cm and 15.3 cm in the horizontal and vertical directions, respectively. The filters were located as close as possible to the camera lens and were shielded from the side. Thus, the camera could only receive light through the filters; no reflected light from the upper surface of the filters was received.

The image acquisition system was adjusted so that its sensitivity matched the total range of light levels received through all three filters, while scanning a diffuse black and a diffuse white surface. Because the response of the system drifted slightly, the system was readjusted before each steak was processed. Calibration data were collected before processing each steak to also account for the variations in spectral transmission among the filters. This process entailed digitizing portions of the black and white test surfaces. The average intensities seen through each filter were stored for later use.

Each steak was then digitized as seen through each filter at a spatial resolution of

256 x 256 pixels and an intensity quantization of 256 levels. Each pixel represented 0.068 cm in the horizontal direction and 0.064 cm in the vertical direction. Each of these images was stored for further processing.

Image Processing

The calibration data were first incorporated into the image data by scaling the image so that the average value obtained from the black surface was assigned to the minimum intensity value, zero, and the average value obtained from the white surface was assigned to the maximum intensity value, 255. This method insures that measurements made at various times are comparable. Since the transmission of the filters vary, thereby altering the scaling process, the values obtained for different colors cannot be compared to one another. Values of the same color from sample to sample are comparable.

The scaled images were then processed to extract the background. All steaks were digitized against a diffuse black background giving a distinct transition between the background and the steak. A value of intensity greater than the black background, but less than any value occurring within the steak was selected. Using this value, an outline was automatically generated around each steak. Histograms were generated giving the number of pixels at each intensity level occurring within the outlines for each of the three colors. For each histogram, the mean value, standard derivation, skewness, and kurtosis were computed.

For the raw steaks, in addition to the process described, three rectangular areas containing no fat or connective tissue were chosen. Each of these areas was processed in the same manner as each steak image. The measurements from these three areas were averaged to give an indication of only the red portion of the raw meat. The image analysis procedures were repeated eight times. Mean values were statistically analyzed using the general linear model for complete block randomized designs (SAS, 1982). Significant differences were analyzed using least significant difference procedures (Snedecor and Cochran, 1980).

Results and Discussion

The raw steak images were processed in the two ways described in order to determine variations from one animal to another. As shown in Table 1, the results of this analysis for the whole steak and for the rectangular muscle areas. This information showed that there was little difference in the color of the lean muscle tissue from one animal to another. This is evident from the relatively low standard deviations of both the mean and standard deviation of the three color histograms. There was more variation in the colors present in whole raw steaks than in the muscle tissue areas. This occurred because the visible surfaces of five adjacent steaks from the same animal differed as the proportions of muscle, connective tissue, and intramuscular fat varied. In addition to different sized muscles, these variations also occurred among the eight

Table 1. Mean Parameters (N=8) for Raw Ribeye Steaks

Sample Description	Parameters	Filters Red	Green	Blue
Whole steak	Mean value of histogram means	110	41	46
	S.D.[1] of histogram means	7.9	3.5	3.7
	Mean of histogram S.D.	27.7	24.8	20.9
	S.D. of histogram standard deviations	3.5	3.0	2.0
Muscle tissue	Mean value of histogram means	109	37	43
	S.D. of histogram means	8.3	2.5	3.6
	Mean of histogram S.D.	7.9	6.8	7.2
	S.D. of histogram standard deviations	1.1	0.7	0.6

[1]S.D. = standard deviation

animals. Because these variations were reduced when only muscle tissue was analyzed (Table 1), measuring the muscle tissue gives a better assessment of the similarities of color among raw steaks.

As shown in Table 2, the mean values of light intensity received for each of the three filters from each level of steak doneness. The

Table 2. Mean Intensity of Light from Ribeye Steaks of Various Doneness

Doneness	Filters Red	Green	Blue
Rare	144^{a}	70^{abc}	73^{ab}
Medium Rare	151^{b}	78	78
Medium	140^{c}	84^{a}	81^{a}
Medium Well	139^{b}	84^{b}	80^{b}
Well	127^{abc}	82^{c}	77

Entries in the same column with the same superscript letter differ significantly for $p \leq .05$.

rare steak, while still substantially red, has a lighter red color than raw steak as evidenced by an increase in all three color components. This lightening of red continued in the medium rare steak. The red intensity then dropped in the medium, medium well, and well steaks due to the darkening of the increasingly brown surface. The green intensity continued to increase as the color shifts from red to pink and then to brown. As seen on a CIE chromaticity diagram, the green component increased substantially as the color changed from red to pink but only slightly from pink to brown. The blue component increased somewhat in the transition from red to pink but decreased slightly from pink to brown. This trend is seen in the data for blue light.

The values of standard deviation for the light received through the three filters from the various steaks is shown in Table 3. These values

Table 3. Standard Deviation of Light Intensity for Ribeye Steaks of Various Doneness

	Filters		
Doneness	Red	Green	Blue
Rare	31^{a}	19^{abc}	19^{abc}
Medium Rare	37^{ab}	21	21
Medium	35^{c}	24^{a}	23^{a}
Medium Well	34^{d}	23^{b}	22^{b}
Well	30^{bcd}	23^{c}	22^{c}

Entries in the same column with the same superscript letter differ significantly for $p \leq .05$.

indicate the extent to which the color varies across the steak surface. The standard deviation was low for the predominantly uniform color of rare steaks. As the meat was heated, the standard deviation increased, denoting changes in color. Values of standard deviation were highest in the midranges of doneness where the widest range of color was present. The values dropped again as the steak became well done and had a more uniform brown color.

The values of skewness are shown in Table 4.

Table 4. Skewness of Light Intensity for Ribeye Steaks of Various Doneness

	Filters		
Doneness	Red	Green	Blue
Rare	-1.3	-0.8	-1.2
Medium Rare	-1.4	-1.2	-1.6
Medium	-1.2	-1.1	-1.4
Medium Well	-1.2	-1.0	-1.4
Well	-1.2	-0.8	-1.2

While the values of skewness do not differ significantly ($p<.01$), they are all less than zero. This indicates that the mean is to the left of the peak of the histogram. Since lower values of intensity lie on the left side of the histogram, this indicates that in all cases there were areas of dark color present. This dark color stemmed from the charred material around the periphery of the steak. This occurred when the surface reached high temperatures, increasing the rate of the complex browning reactions and the development of color. In addition, the connective tissue had been converted into soluble gelatin, reducing the initial white color. With image analysis, this conversion was seen visibly as a darker color. Because no significant differences were found among kurtosis values, they were excluded from further discussion.

In order for these measurements to be used in classifying doneness as determined by the internal temperature, significant differences must exist between measurements for different doneness classes. The statistics which differ significantly at a level, $p \leq 0.05$, between all pairs of doneness classes are shown in Table 5. Mean and standard deviation values can be used to determine variation in doneness in most cases. The three major classes, rare, medium and well, are separable from one another by at least two statistical parameters. Rare steaks can be separated from both medium and well done steaks by using four parameters. The distinction between medium and well done steaks is given by two parameters. Rare steaks can be separated from medium well and medium rare by the use of four parameters and one parameter, respectively. Well done steaks can be differentiated from both medium rare and medium well steaks by two statistics. In addition, medium rare and medium well steaks can be distinguished from each other by one parameter. The only difficulties in separation arose between the two sets of classes, medium rare to medium, and medium to medium well. In these cases, none of the statistics computed differed significantly.

As expected, the statistics generated from the red portion of the spectrum provided the highest amount of discriminatory power. However, these results, Table 5, prove that measurements of green and blue light are essential to the determination of doneness of steaks.

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Table 5. Statistics which Discriminate Between Classes of Doneness

Doneness	Rare	Medium Rare	Medium	Medium Well	Well
Rare		S.D.[1] Red	Mean Green Mean Blue S.D. Green S.D. Blue	Mean Green Mean Blue S.D. Green S.D. Blue	Mean Red Mean Green S.D. Green S.D. Blue
Medium Rare			None	Mean Red	Mean Red S.D. Red
Medium				None	Mean Red S.D. Red
Medium Well					Mean Red S.D. Red

[1]S.D. = standard deviation.

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Discussion with Reviewers

H. J. Swatland: What is the potential interaction between the residual temperature (heat capacity of meat) and the aerobic exposure and pigment stability? Was it not possible to find a better way of reducing specular reflection?

J. D. Fairing: Was any visual change in the steak color observed during the 20 minute exposure at ambient temperature?

Authors: The specular reflection from the moist meat surface caused large errors in the measurement of surface color. Because the surface was irregular, it was not possible to eliminate specular reflection by adjusting the angles of the incident and measured light. Removal of the surface moisture was the only method found which would eliminate specular reflection. Blotting of the water was not successful because colored material was removed along with the water. The method finally chosen was to allow the moisture to evaporate. The disadvantage of this method was that the aerobic exposure of the warm meat surface caused some change in its color. This change was primarily an increase in the intensity of the red regions. Since the aerobic exposure was consistently applied to all steaks, it does not affect the classification process. On the other hand, a better way to remove specular reflection is being sought.

J. D. Fairing: Was any attempt made to assess the taste of the steaks and to correlate this with the temperature and color measurements?

Authors: Sensory analysis is an important component of consumer acceptance of beef. However, such analysis was not included in this work. The authors intend to explore the correlation between sensory measurement and objective measurement of steak doneness in the future.