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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.

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...
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, f/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 deviation, 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 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

<table>
<thead>
<tr>
<th>Sample Description</th>
<th>Parameters</th>
<th>Filters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole steak</td>
<td>Mean value of histogram means</td>
<td>Red 41 Green 46 Blue 46</td>
</tr>
<tr>
<td></td>
<td>S.D.¹ of histogram means</td>
<td>7 3 3.7</td>
</tr>
<tr>
<td></td>
<td>Mean of histogram S.D.</td>
<td>7.9 24.8 20.9</td>
</tr>
<tr>
<td></td>
<td>S.D. of histogram standard deviations</td>
<td>3.5 3.0 2.0</td>
</tr>
<tr>
<td>Muscle tissue</td>
<td>Mean value of histogram means</td>
<td>109 37 43</td>
</tr>
<tr>
<td></td>
<td>S.D. of histogram means</td>
<td>8.3 2.5 3.6</td>
</tr>
<tr>
<td></td>
<td>Mean of histogram S.D.</td>
<td>7.9 6.8 7.2</td>
</tr>
<tr>
<td></td>
<td>S.D. of histogram standard deviations</td>
<td>1.1 0.7 0.6</td>
</tr>
</tbody>
</table>

¹S.D. = standard deviation

As shown in Table 2, the mean values of light intensity received for each of the three filters from each level of steak doneness are presented. Significant differences were analyzed using least significant difference procedures (Snedenard and Cochran, 1980).

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

<table>
<thead>
<tr>
<th>Doneness</th>
<th>Red</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rare</td>
<td>144a</td>
<td>70abc</td>
<td>73ab</td>
</tr>
<tr>
<td>Medium Rare</td>
<td>151b</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Medium</td>
<td>140c</td>
<td>84a</td>
<td>81a</td>
</tr>
<tr>
<td>Medium Well</td>
<td>139b</td>
<td>84b</td>
<td>80b</td>
</tr>
<tr>
<td>Well</td>
<td>127abc</td>
<td>82c</td>
<td>77</td>
</tr>
</tbody>
</table>

Entries in the same column with the same superscript letter differ significantly for p ≤ .05.

As the steaks were cooked, the color of the meat changed. The rare steak, while still substantially red, has a lighter red color than raw steak as evidenced by an increase in the red intensity. 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 shifted 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

<table>
<thead>
<tr>
<th>Doneness</th>
<th>Red</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rare</td>
<td>31\textsuperscript{a}</td>
<td>1g\textsuperscript{abc}</td>
<td>1g\textsuperscript{abc}</td>
</tr>
<tr>
<td>Medium Rare</td>
<td>37\textsuperscript{ab}</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Medium</td>
<td>35\textsuperscript{c}</td>
<td>24\textsuperscript{a}</td>
<td>23\textsuperscript{a}</td>
</tr>
<tr>
<td>Medium Well</td>
<td>34\textsuperscript{d}</td>
<td>23\textsuperscript{b}</td>
<td>22\textsuperscript{b}</td>
</tr>
<tr>
<td>Well</td>
<td>30\textsuperscript{bcd}</td>
<td>23\textsuperscript{c}</td>
<td>22\textsuperscript{c}</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Doneness</th>
<th>Red</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rare</td>
<td>-1.3</td>
<td>-0.8</td>
<td>-1.2</td>
</tr>
<tr>
<td>Medium Rare</td>
<td>-1.4</td>
<td>-1.2</td>
<td>-1.6</td>
</tr>
<tr>
<td>Medium</td>
<td>-1.2</td>
<td>-1.1</td>
<td>-1.4</td>
</tr>
<tr>
<td>Medium Well</td>
<td>-1.2</td>
<td>-1.0</td>
<td>-1.4</td>
</tr>
<tr>
<td>Well</td>
<td>-1.2</td>
<td>-0.8</td>
<td>-1.2</td>
</tr>
</tbody>
</table>

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 .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 separa­
tion arose between the two sets of classes,
medium rare to medium, and medium to medium.
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

<table>
<thead>
<tr>
<th>Doneness</th>
<th>Rare</th>
<th>Medium Rare</th>
<th>Medium</th>
<th>Medium Well</th>
<th>Well</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rare</td>
<td>S.D.²  Red</td>
<td>Mean Green</td>
<td>Mean Green</td>
<td>Mean Red</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean Blue</td>
<td>Mean Blue</td>
<td>Mean Green</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S.D. Green</td>
<td>S.D. Green</td>
<td>S.D. Green</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S.D. Blue</td>
<td>S.D. Blue</td>
<td>S.D. Blue</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>Rare</td>
<td>None</td>
<td>Mean Red</td>
<td>Mean Red</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean Red</td>
<td>S.D. Red</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
<td>None</td>
<td>Mean Red</td>
<td>Mean Red</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean Red</td>
<td>S.D. Red</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>Well</td>
<td></td>
<td>Mean Red</td>
<td></td>
<td>S.D. Red</td>
</tr>
</tbody>
</table>