An Analysis of Color Characteristics as Related to the Heme Pigment in Processed Meat

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Abstract The visual color characteristics of processed meats, namely, cooked meat and cooked nitrite-cured meat, are greatly influenced by heme pigment content and its different forms. They are indicated by the three parameters of lightness, saturation and hue angle. The complicated interrelationships between the sensory color values and the heme pigment were systematized numerically according to the CIE 1976 color scale. The CIE tristimulus values were obtained as functions of heme pigment content and the functions were applied to meat color analysis. When change in pigment content occurred, variation of meat color essentially depended on the lightness, while color difference between the heme forms depended on the difference in chromaticity. The characteristic curves of lightness decreased with increasing pigment content of logarithmic scale and were sigmoid in shape and also, similar between heme forms. In the range of pigment content for actual meat, the lightness curves were indicated as straight lines, thus the variation of lightness with pigment content was suggested to be in inverse proportion to pigment content. Chromaticity on a^* , b^* -plane was characterized as a parabolic locus, and the positions and the curvatures were different between the heme forms. decreases in lightness were accompanied by a rise in saturation and redness of hue angle from yellow to orange angle for cooked meat and yellow to red angle for cooked nitrite-cured meat. Further decreases in lightness were accompanied by a decline in saturation; however, hue angle hardly varied. The color difference between heme forms increased in proportion to logarithmic pigment content in the range of actual meat and indicated a maximum value at 150 ppm of hematin content.

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The color of a cut of meat contributes much to its appearance. The appearance of intact or processed meat is a first criterion in a consumer's choice, thus the color of meat is the major factor in the quality of the appearance, which principally depends on the spectral reflectance at the surface due to heme pigment.

It is well known that the pigment of processed meat consists primarily of the two forms, i. e. hemichrome in cooked meat and nitrocyl-hemochrome in cooked nitrite-cured meat. Along with the pigment content, each heme pigment form has different spectral characteristics, resulting in the variety of color. Fox¹⁾ stated that the chemistry of the color of meat was the chemistry of the heme pigment. However, pigment is material and color is sensory response and the corresponding variation in color value affected by heme pigment was not constant with solid meat²⁾ nor with myoglobin solution³⁾. It is difficult to directly relate the quantity of each.

Meat color has been examined individually by colorimetry⁴⁻⁹⁾ and chemical analy-

sis of heme pigment¹⁰⁻¹²⁾. For the assay of heme pigment using reflectance spectrophotometry, STEWORT *et al.*¹³⁾ used Kubelka-Munk K/S value derived from reflectance value, a light scattering coefficient S and an absorption coefficient K , to give total heme pigment content and its forms in raw meat. Snyder and Armstrong¹⁴⁾ found that with suspensions of myoglobin in non fat milk, the K/S value was sufficient for accurate measurement of metmyoglobin.

An improved direct method¹⁵⁾ was devised for the assay of heme pigment by a combination of K/S values at different wavelengths. Recently, it was demonstrated that the K/S function contains the property of reciprocal reflectance, and the linear relationship of the reciprocal values of integrated reflectance spectra vs. heme pigment content in processed meat was proved statistically¹⁶⁾. Consequently it was assumed that CIE (Commission Internationale de l'Eclairage: International Commission on Illumination) tristimulus color values should be characterized by the parameter of heme pigment content.

The objectives of this research on processed meat are to confirm the quantitative relationship of CIE tristimulus color values vs. heme pigment content of each heme form and to characterize numerically the tricoordinate uniform color behavior.

Materials and Methods

Processed meat preparation

Intact porcine meat after chilling at 3°C for 2 or 3 days post-slaughter was purchased from a commercial market. To obtain widely different pigment contents, the desired muscles were selected from loin and ham portions of commercial type swine and ham portions of an adult swine. Each muscle was ground twice using a meat grinder after trimming off visible fatty and connective tissues as much as possible.

Eight meat samples, including 3 mixtures of ground muscles, were prepared with curing ingredients per weight of 3% salt, 1% sugar, 0.05% L-sodium ascorbate and 0.02% sodium nitrite to produce products of cooked cured meat color (CCMC). Sodium nitrite was omitted for the products of cooked meat color (CMC). These were stuffed into PVC film bag and kept in a refrigerator at 5°C for 30 hr. The cured meat was water-cooked first at 45°C for 25 min and at 70°C for 20 min and then chilled immediately in ice water. Fifty CCMC and 43 CMC samples were used for the experiments.

Reflectance spectrophotometry

Visible reflectance spectra of processed meat samples were measured under reflectivity conditions¹⁷⁾ from 380 to 700 nm as described in the previous paper¹⁸⁾.

Determination of total heme pigment

Total heme pigment content was determined as hematin by a slight modification¹⁵⁾ of Hornsey's method¹¹⁾.

Treatment of data

CIE tristimulus values X, Y, Z from reflectance data were calculated using the weighted ordinate method¹⁹⁾ for standard C illuminant. The quantitative relationship

between CIE tristimulus values and total heme pigment contents were analysed statistically.

Objective color values were converted from the tristimulus values according to CIE 1976²⁰⁾.

$$L^* = 116 (Y/Y_n)^{1/3} - 16$$

$$a^* = 500 [(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$

$$b^* = 200 [(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$

In these equations, X_n , Y_n and Z_n are the tristimulus values of the chosen illuminant. The other procedures of calculation and the specification of color difference followed JIS²⁰⁾ (Japanese Industrial Standard) Z 8730. The chromaticity parameters of hue angle and saturation were calculated from L^* , a^* and b^* values.

Results and Discussion

Regression analysis

The statistical results of linear regression analysis are summarized in Table 1. The shape and the maximum absorption wavelengths of reflectance spectrum agreed well with the results of Tappel²¹⁾ on CCMC and those of Ledward²²⁾ on CMC. Range of hematin content was from minimum 22 ppm for *M. longissimus thoracis* of commercial type swine to maximum 114 ppm for *M. semitendinosus* of adult swine.

Extremely high correlation coefficients ($P < 0.01$) for reciprocal CIE tristimulus

Table 1. Linear regression analysis of reciprocal CIE tristimulus values on ppm hematin contents

Dependent Variable	Sample ¹⁾	Regression equation ²⁾		SE ³⁾			r ⁴⁾
		a	b	SE _y	SE _a × 10 ³	SE _b	
[I]							
1/X	CCMC	.0269	1.672	.158	.878	.051	.975
	CMC	.0319	1.456	.158	.971	.060	.982
1/Y	CCMC	.0350	1.591	.181	1.001	.059	.981
	CMC	.0354	1.404	.169	1.042	.064	.983
1/Z	CCMC	.0378	1.512	.154	.851	.050	.988
	CMC	.0438	1.367	.207	1.271	.079	.983
			Common ⁵⁾				
			Av. (M. D.)				
1/X	CCMC	.0286	1.564(.108)	.164			
	CMC	.0304		.162			
1/Y	CCMC	.0365	1.498(.093)	.184			
	CMC	.0341		.171			
1/Z	CCMC	.0389	1.440(.073)	.155			
	CMC	.0428		.206			

1) CCMC: Cooked nitrite-cured meat color, CMC: Cooked meat color. 2) a: Slope, b: Intercept. 3) SE: Standard error, SE_y: SE of dependent variable from regression line, SE_a: SE of slope, SE_b: SE of intercept. 4) r: Relationship coefficient, $P < .01$. 5) Intercept as a common, Av.: Average, M. D.: Mean deviation.

values as dependent variables vs. the amount of hematin were obtained in procedure I. Therefore, the variance values of dependent variables were very small, as had been expected by the results of a previous investigation¹⁶⁾ using the same reflectance data as this regression analysis.

The dependent variables give intercept values when there is no hematin, i.e. pigment-free meat, so that the intercept within the same dependent variable is independent of pigment and theoretically common between pigment forms. Therefore, the linear regression equation results from the common intercept as the average of two forms obtained as shown in procedure II by the least square method.

In comparing experimental regression equations in procedure I with calculated equations through the common intercept in procedure II, there were no significant differences between corresponding equations within the same dependent variable in slope ($P > 0.05$), intercept ($P > 0.05$) or standard error of dependent variable from regression line ($P > 0.25$). Consequently the experimental results were considered to express the changes in each tristimulus value as a function of reciprocal linear equation with parameter of hematin content through a common intercept.

The functions obtained were applied to the following color analysis of CCMC and CMC ranging from ideal pigment-free meat to pigment alone. To demonstrate actual meat color, the range of hematin content is regarded to be from 20 to 200 ppm, for convenience.

Lightness

Lightness L^* depends only upon Y in tristimulus values as shown in the described definite formula. Positive relationships were obtained between reciprocal Y and hematin contents as shown in Table 1, so that L^* decreases with increasing hematin content. The characteristic curves of L^* associated with hematin contents are as shown in Fig. 1. The horizontal axis was taken on a logarithmic scale because the lower hematin content resulted in a greater color variation, and in order to obtain a wide range of hematin content. These curves were nearly identical and sigmoid in shape. Experimental values of L^* for samples agreed well with the calculated values by equation and the standard errors from the calculated values of CCMC and CMC were 1.14 and 1.33, respectively.

The relation between L^* and hematin content is very complicated as L^* is related to the cubic root of Y and reciprocal Y is related to hematin content. However, the curves were approximately straight lines within the range of hematin content for actual meat. The equation was derived by the use of the pooled data of CCMC and CMC as follows:

$$L^* = -14.0 (1/n \text{ Ch}) + 116.5 \quad (r: -0.978, \text{SE: } 1.41)$$

where Ch is ppm hematin in processed meat. Hence,

$$dL^*/dCh = -14.0/Ch$$

This equation means that the variation of L^* with hematin content is in inverse proportion to hematin content.

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Fig. 1. Characteristics of lightness plotted against logarithms of heme pigment content as hematin. Closed and open circles are CMC and CCMC, respectively.

Chromaticity

Close agreement of lightness between the two pigment forms was obtained as described above, thus the difference of visual color between forms was considered to depend on the difference in chromaticity.

The chromaticity loci on a^* , b^* -diagram are as shown in Fig. 2. The curves were characterized as parabolic loci and the positions and the curvatures were different from each other. The loci of CCMC and CMC in L^* , a^* , b^* -color solid described parabolic lines from the common color point of pigment-free meat ($L^*=85.3$, $a^*=-3.5$, $b^*=7.3$) to the origin of the L^* , a^* , b^* coordinates as hematin content

Fig. 2. Comparison of chromaticity loci on the a^* , b^* -chromaticity plane. Numbers in graph are ppm hematin shown by points. Symbols used are the same as in Fig. 1.

varied. It was found that the chromaticity variation with pigment content decreased in geometric progression with increasing pigment content. In the range of actual meat, it was noted that a^* values of CCMC were higher than CMC, and b^* values were lower. Close agreement was found between the experimental values and the calculated locus, the differences represented by standard error for CCMC and CMC were 1.15 and 0.78, respectively.

Saturation

Saturation of chromaticity, Sat^* , is defined as the radial distance from the origin of a^* , b^* -plane which had the following equation:

$$Sat^* = [(a^*)^2 + (b^*)^2]^{1/2}$$

Higher Sat^* value means higher saturation and/or purity of chromaticity. Changes in Sat^* with hematin content are as shown in Fig. 3. Sat^* of CCMC was higher than that of CMC when hematin was above ca. 20 ppm. The maxima for both forms and the maximum difference between heme forms were found ca. 150 ppm of hematin. Therefore, it can be assumed that the sensory difference of chromaticity saturation in actual meat increases with increasing pigment content, and decreases slightly after reaching ca. 150 ppm of hematin. These characteristics become evident by the combination of chromaticity diagram shown in Fig. 2, where each maximum Sat^* corresponds to the turning locus of chromaticity.

Hue angle

Hue angle, Hue^* , is represented as a radian from a^* to b^* axis in the following equation:

$$Hue^* = \tan^{-1} (b^*/a^*)$$

where Hue^* of 0, $\pi/4$ and $\pi/2$ mean red, orange and yellow, respectively.

Changes in Hue^* with hematin content are shown in Fig. 4. CCMC varied from

Fig. 3. Characteristics of saturation plotted against logarithms of heme pigment content as hematin. Symbols used are the same as in Fig. 1.

Fig. 4. Characteristics of hue angle plotted against logarithms of heme pigment content as hematin. Symbols used are the same as in Fig. 1.

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yellow in pigment free meat to near red, while CMC varied from yellow to orange. Hue* decreased with increasing hematin content until ca. 100 ppm, then remained constant even if hematin increased. In summary, the variation of Hue* decreased as pigment increased and the difference between heme forms was basically constant at hematin content above ca. 20 ppm. Therefore, the difference for actual processed meat is considered to be constant.

Color difference

Color difference, ΔE^* , means a perceptually uniform color difference in the L^* , a^* , b^* -color solid. ΔE^* between a pair of heme forms is shown in Fig. 5.

Fig. 5. Characteristics of color difference between heme pigment forms plotted against logarithms of heme pigment content as hematin.

The maximum ΔE^* value reached approximately 10, and was observed in the 100 to 200 ppm range of hematin content. It was found that ΔE^* increased in proportion to the logarithmic hematin content up to approximately 150 ppm after which it decreased. In the range of hematin content in actual meat, it should be emphasized that the more pigment content, the greater the color difference between heme forms, but the lower the variation of the color difference when pigment content changes. The color difference in a dark processed meat containing 100 ppm of hematin was considered to be 1.7 times more than a pale processed meat containing 20 ppm of hematin.

Interrelationships between color variables

The color values were graphically compared and a number of interrelationships between color variables with respect to pigment content and the heme forms became immediately apparent. In the L^* , a^* , b^* -space, the experimental values of samples agreed well with the calculated results of the derived loci and the standard errors of the cubic difference for CCMC and CMC were, 1.63 and 1.55, respectively.

When the color loci for heme forms were compared, the graphs demonstrated that

the loci of lightness were nearly identical, but the loci of chromaticity resulted in different parabolic curves. Therefore, the color difference due to heme forms was caused primarily by the variation of chromaticity. The decreases in lightness were accompanied by a marked rise in saturation and redness. Further decreases in lightness were accompanied by a decline in saturation.

When the color were compared between samples of different pigment content, the variation of lightness was greater than that of chromaticity and the color difference essentially depended on the change in lightness more than any other color variable. As pigment content in actual meat increased, the dependence of color difference (ΔE^*) upon lightness difference (ΔL^*) increased and upon chromaticity difference decreased. In contrast, when changes in heme form occurred, color difference depended on chromaticity difference. In order to obtain quantitative and detailed information on color characteristics, the dependence of chromaticity upon hue and saturation should be further investigated.

The overall tendency of color behavior was essentially found to be similar to that of intact pork²³⁾, intact beef⁸⁾ and tomato²⁴⁾ shown in Hunter's color scale. Whereas Hunter's color values have been used by many investigators to describe the uniform color space, recently CIE 1976 uniform color space was recommended for use²⁵⁾, and Hunter's color has gradually been superseded by CIE 1976 color. In order to compare the present data with the earlier Hunter's color data, it will be necessary to calculate the difference between CIE 1976 color and Hunter's color values.

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加工肉のヘム色素に関する色調特性

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豚肉を原料とする加工肉の異なるヘム色素誘導形態について、その色調特性の解析を試みた。色調特性は CIE 1976 L*, a*, b* 等歩度色調空間によって表現された。ヘム色素含量による色調変化は明度が支配的であり、ヘム色素誘導形態による色調変化は色度が支配的であった。色素含量（対数値）に対する明度特性は誘導形態間でほとんど一致し、シグモイド曲線となり減少した。この明度特性は実在の肉のヘム色素含量に限定された範囲において直線性が認められたので、色素含量の変化による明度変化は色素含量に反比例することが示唆された。

a*, b* 平面上の色度特性は放物線状となり、誘導形態間で放物線の位置と形状が異なった。彩度はヘマチン 150 ppm 付近で最大値を示し、実在の肉のヘム色素含量の範囲では加熱塩漬肉が加熱肉より高い値を示し、色素含量の増加につれてその差が大きくなった。色相角度は色素含量の増加につれて加熱塩漬肉では黄色系から赤色系に、加熱肉では黄色系から橙色系に変化し、高色素含量では一定になった。誘導形態間の色素はヘマチン 150 ppm 付近で最大値を示した。

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