27
chapter

CIE Color Specifications Calculated from Reflectance or Transmittance Spectra

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27.1 Introduction
- 27.1.1 Background
- 27.1.2 Reading Assignment
- 27.1.3 Objectives
- 27.1.4 Materials
- 27.1.5 Optional

27.2 Procedure
- 27.2.1 Weighted Ordinate Method
- 27.2.2 Expression in Other Color Specification Systems

27.3 Questions

27.1 INTRODUCTION

27.1.1 Background

Food color is arguably one of the most important determinants of acceptability and is, therefore, an important specification for many food products. The development of compact and easy to use colorimeters and spectrometers has made the quantitative measurement of color a routine part of product development and quality assurance.

There are several widely employed systems of color specification: notably Munsell, Commission Internationale de l'Eclairage (CIE) tristimulus, and the more recent CIEL*a*b* system. The Munsell system relies on matching with standard color chips. Value, hue, and chroma are employed to express lightness, "color," and saturation, respectively. The CIE tristimulus system uses mathematical coordinates (X, Y, and Z) to represent the amount of red, green, and blue primaries required by a "standard observer" to give a color match. These coordinates can be combined to yield a two-dimensional representation (chromaticity coordinates x and y) of color. The CIEL*a*b* system employs L^* (lightness), a^* (red-green axis), and b^* (yellow-blue axis) to provide a visually linear color specification.

Available software, often incorporated into modern instruments, enables the investigator to report data in any of the above notations. Understanding the different color specification systems, and the means of interconversion, aids the food scientist in selecting an appropriate means of reporting and comparing color measurements.

27.1.2 Reading Assignment

Wrolstad, R.E., and Smith, D.E. 2017. Color analysis. Ch. 31, in *Food Analysis*, 5th ed. S.S. Nielsen (Ed.), Springer, New York.

27.1.3 Objectives

1. Learn how to calculate the following CIE color specifications from reflectance and transmission spectra:
   (a) Tristimulus values X, Y, and Z
   (b) Chromaticity coordinates x and y and luminosity, Y
   (c) Dominant wavelength (λ_d) and % purity (using the chromaticity diagram)
2. Using readily available software, interconvert between the CIE Y and chromaticity coordinates and other color specification systems including Munsell and CIEL*a*b*.

27.1.4 Materials

1. % transmittance (%T) spectrum (A spectrum of syrup from Maraschino cherries colored with radish extract is provided, Table 27.1.)

Table 27.1 % Transmittance[a] and reflectance[b] data for Maraschino cherry

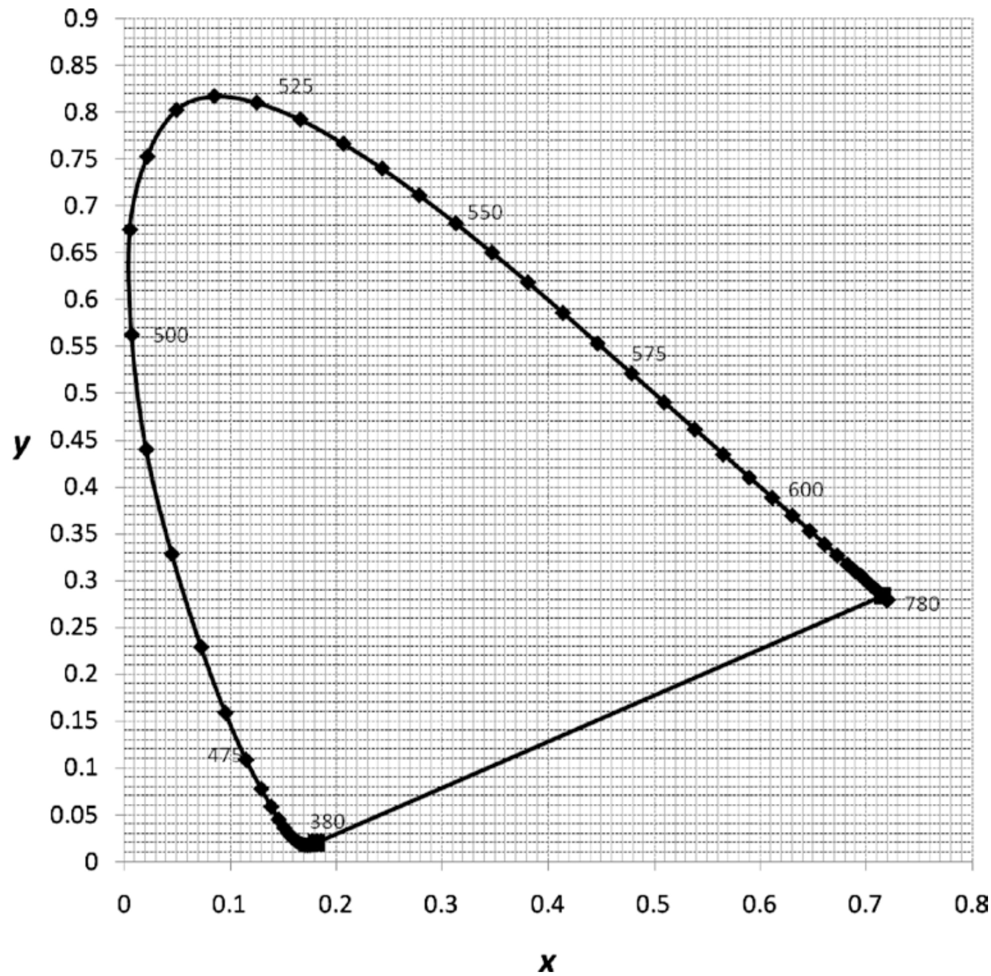
λ_{nm}	%T Maraschino cherry syrup	%R Maraschino cherries
400	1.00	0.34
410	2.00	0.34
420	2.70	1.08
430	3.40	0.89
440	3.80	1.14
450	3.50	1.06
460	2.40	0.85
470	1.30	0.83
480	0.60	0.7
490	0.30	0.77
500	0.30	0.75
510	0.30	0.8
520	0.30	0.85
530	0.30	0.77
540	0.40	0.86
550	1.30	0.82
560	6.60	0.99
570	7.60	1.42
580	13.6	2.19
590	22.4	4.29
600	33.9	7.47
610	46.8	11.2
620	59.0	15.0
630	68.6	17.8
640	74.9	20.2
650	78.8	21.8
660	81.1	23.2
670	82.7	25.1
680	84.2	26.3
690	84.8	27.8
700	85.7	28.4

[a]1 cm pathlength; Shimadzu Model UV160A Spectrophoto meter
[b]Hunter ColorQuest 45/0 Colorimeter, illuminant D_{65}, reflectance mode, specular included, 10° observer angle

2. % reflectance spectrum (%R) (A spectrum of Maraschino cherries colored with radish extract is provided, Table 27.1.)
3. CIE chromaticity diagram (Fig. 27.1), Munsell conversion charts, or appropriate interconversion software

Examples:

(a) An online applet http://www.colorpro.com/info/tools/labcalc.htm is a graphical tool that permits the user to adjust tristimulus values by means of slider bars. Corresponding values of CIE $L^*a^*b^*$ and Lch equivalents and a visual representation of the associated color are displayed.
(b) A second application, http://www.colorpro.com/info/tools/rgbcalc.htm, provides the same



27.1 figure 1964 Chromaticity diagram (10 supplemental standard observer)

slider adjustment of RGB values with conversion to equivalent values in other systems.

(c) Convert L^*, a^*, and b^* values to other notations: http://www.colorpro.com/info/tools/convert.htm#TOP.

(d) A free evaluation copy of software that permits entry of numeric values for any of tristimulus, Munsell, CIE $L^*a^*b^*$, and chromaticity (x, y) coordinates, with conversion to the other systems can be obtained from http://www.xrite.com/. An annual license for this program (CMC) is available for purchase from http://wallkillcolor.com.

27.1.5 Optional

Spectra of other samples can be acquired using the following instruments:

1. Visible spectrophotometer (transmittance spectrum)
2. Spectrophotometers for color analyses (commonly called colorimeter) operated in transmittance or reflectance mode

27.2 PROCEDURE

27.2.1 Weighted Ordinate Method

1. Determine percent transmittance (%T) or percent reflectance (%R) at the specified wavelengths (e.g., every 10 nm between 400 and 700 nm). [*Note*: Example data for transmittance and reflectance (Table 27.1) are provided and can be used for these calculations.]
2. Multiply %T (or %R) by $E\bar{x}$, $E\bar{y}$, and $E\bar{z}$ (see Tables 27.2 or 27.3, respectively, for %T or %R). These factors incorporate both the CIE spectral distribution for illuminant D_{65} and the 1964 CIE standard supplemental observer curves for x, y, and z.
3. Sum the values $\%T(\text{or}\%R)E\bar{x}$, $\%T(\text{or}\%R)E\bar{y}$, and $\%T(\text{or}\%R)E\bar{z}$ to give X, Y, and Z, respectively (Table 27.4). The sums of each are divided by the sum of $E\bar{y}$ (760.7). (By doing this, the three values are normalized to $Y=100$, which is "perfect" white; objects are specified relative to

27.2 table

Calculation of CIE specifications by the weighted ordinate method: % transmittance

λ_{nm}	$\%T$	$E\bar{x}$	$E\bar{x} \bullet \%T$	$E\bar{y}$	$E\bar{y} \bullet \%T$	$E\bar{z}$	$E\bar{z} \bullet \%T$
400		0.60		0.10		2.50	
410		3.20		0.30		14.90	
420		8.80		0.90		41.80	
430		13.00		1.60		64.20	
440		19.10		3.10		98.00	
450		20.40		4.90		109.70	
460		16.50		7.00		95.00	
470		10.20		9.70		68.90	
480		4.20		13.30		40.60	
490		0.80		16.90		20.70	
500		0.20		24.10		11.40	
510		2.10		33.80		6.20	
520		7.00		45.00		3.60	
530		15.70		58.10		2.00	
540		26.10		66.60		0.90	
550		38.10		71.40		0.30	
560		48.70		68.90		0.00	
570		57.50		62.60		0.00	
580		67.30		57.70		0.00	
590		73.50		51.10		0.00	
600		79.90		46.80		0.00	
610		76.30		39.10		0.00	
620		63.50		29.50		0.00	
630		46.00		20.10		0.00	
640		30.20		12.60		0.00	
650		18.30		7.30		0.00	
660		10.70		4.20		0.00	
670		5.70		2.20		0.00	
680		2.70		1.10		0.00	
690		1.20		0.50		0.00	
700		0.6		0.2		0.00	
SUM				*760.7*			

1964 CIE color matching functions for 10° standard supplemental observer, illuminant D_{65}:

$X = E\bar{x} \bullet \%T / E\bar{y} =$

$Y = E\bar{y} \bullet \%T / E\,\bar{y} =$

$Z = E\bar{z} \bullet \%T / E\,\bar{y} =$

27.3 table

Calculation of CIE specifications by the weighted ordinate method: % reflectance

λ_{nm}	$\%R$	$E\bar{x}$	$E\bar{x} \bullet \%R$	$E\bar{y}$	$E\bar{y} \bullet \%R$	$E\bar{z}$	$E\bar{z} \bullet \%R$
400		0.60		0.10		2.50	
410		3.20		0.30		14.90	
420		8.80		0.90		41.80	
430		13.00		1.60		64.20	
440		19.10		3.10		98.00	
450		20.40		4.90		109.70	
460		16.50		7.00		95.00	
470		10.20		9.70		68.90	
480		4.20		13.30		40.60	
490		0.80		16.90		20.70	
500		0.20		24.10		11.40	
510		2.10		33.80		6.20	
520		7.00		45.00		3.60	
530		15.70		58.10		2.00	
540		26.10		66.60		0.90	
550		38.10		71.40		0.30	
560		48.70		68.90		0.00	
570		57.50		62.60		0.00	
580		67.30		57.70		0.00	
590		73.50		51.10		0.00	
600		79.90		46.80		0.00	
610		76.30		39.10		0.00	
620		63.50		29.50		0.00	
630		46.00		20.10		0.00	
640		30.20		12.60		0.00	
650		18.30		7.30		0.00	
660		10.70		4.20		0.00	
670		5.70		2.20		0.00	
680		2.70		1.10		0.00	
690		1.20		0.50		0.00	
700		0.6		0.2		0.00	
SUM				*760.7*			

1964 CIE color matching functions for 10° standard supplemental observer, illuminant D_{65}:

$X = E\bar{x} \bullet \%R / E\bar{y} =$

$Y = E\bar{y} \bullet \%R / E\bar{y} =$

$Z = E\bar{z} \bullet \%R / E\bar{y} =$

27.4 table CIE color specifications worksheet for Maraschino cherry sample

	%T	%R
X		
Y (luminosity)		
Z		
X + Y + Z		
x		
y		
λ_d		
% Purity		
Munsell notation		
CIE L^*		
a^*		
b^*		
Hue angle, arctanb/a		
Chroma, $(a^{*2}+b^{*2})^{1/2}$		

luminosity of perfect white rather than the absolute level of light.)

4. Determine chromaticity coordinates x and y as follows:

$x=(X)/(X+Y+Z)$	$y=(Y)/(X+Y+Z)$

5. *Luminosity* is the value of Y following the normalization described above.

27.2.2 Expression in Other Color Specification Systems

Plot the x and y coordinates on the CIE chromaticity diagram (Fig. 27.1) and determine dominant wavelength and % purity:

Dominant wavelength = λ_d = wavelength of spectrally pure light that if mixed with white light will match a color; analogous to hue.

On the CIE chromaticity diagram (Fig. 27.1), draw a straight line from illuminant D_{65}, extending through the sample point to the perimeter of the diagram. The point on the perimeter will be the dominant wavelength.

Coordinates for illuminant D_{65}: $x=0.314$
$y=0.331$

% purity = ratio of distance (a) from the illuminant to the sample over the distance ($a+b$) from the illuminant to the spectrum locus. Analogous to *chroma*.

Determine Munsell *value*, *hue*, and *chroma* with chromaticity coordinates x and y. Also convert these data to their $L^*a^*b^*$ equivalents. Calculate chroma and hue as indicated.

Chroma = $(a^{*2}+b^{*2})^{1/2}$
Hue angle = arctanb^*/a^*

27.3 QUESTIONS

Assume D_{65} illuminant and 10° supplemental standard observer for all measurements in the questions below.

1. What is the analogous term in the Munsell system to luminosity in the CIE system?
2. What are the dominant wavelength and % purity of a food with chromaticity coordinates $x=0.450$ and $y=0.350$?
3. A lemon is found to have values of $L^*=75.34$, $a^*=4.11$, and $b^*=68.54$. Convert to corresponding chromaticity coordinates x and y and plot on the 1964 chromaticity diagram.
4. Which has the greater hue angle, an apple with coordinates $L^*=44.31$, $a^*=47.63$, and $b^*=14.12$ or $L^*=47.34$, $a^*=44.5$, and $b^*=15.16$? Which apple has the greater value of chroma?

RESOURCE MATERIALS

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