Color Determination in Olive Oils

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Color characterization of olive oil may be of great importance to the industry. To determine the color of a solution, it is necessary to accurately measure a series of tristimulus coordinates for which several methods exist. This study analyzes the errors in the calculation of tristimulus values of olive oil color based on methods, by using several selected ordinates and an increasing number of weighted ordinates, and how these errors affect the values of the chromatic parameters defined in the various chromatic systems. The above analysis shows that the use of a large number of ordinates will lead to better results in the color definition of oils. For its determination, we have used the CIE 1931, CIELUV 1976 and CIELAB 1976 spaces; the latter yields the best results.

KEY WORDS: Color characterization, chromatic coordinates, edible oil, oil color, olive oil.

The organoleptic characteristics that describe an oil (aroma, color, taste, etc.) provide necessary qualitative subjective information, but instrumental methods are needed to objectively measure and control quality. Color is an important quality factor, and many instrumental methods are used for its determination. Nevertheless, little importance has been given to the color characterization of olive oils as an indication of quality. As a result, there are no olive oil color standards available (1). Recently, olive oil color characterization was reported by comparing it with standard solutions (2), and a numerical characterization (3–5) was used by adapting methods that were developed for palm oils (6–10) and seed oils (8–14). Spectral measurements, taken at four wavelengths, have been combined into a mathematical expression to yield an index that correlates with the Wesson color values (15). Color characterization with these methods or with the AOCS spectrometric method for the determination of oil color (1,13,14) depends on (i) the number of transmittance values used: 3, 4 or 5, measured at different wavelengths; and (ii) on the coefficient values by which the transmittance values are multiplied—these being different for each method.

In the color characterization of various foodstuffs, smaller wavelength intervals are increasingly used (16). Thus, to determine the color of wines, the International Office for Wine has recommended taking forty measurements, 10 nm apart, at the interval of 380–770 nm, although its official method uses only four transmittance values (17).

The objective of this study was to examine the relationship between the number of transmission values measured and the color characterization of olive oil by various methods.

MATERIALS AND METHODS

Materials. All olive oil samples were obtained from various distributors throughout the Andulusian region. The samples included extra virgin olive oil, refined olive oil and refined husk olive oil (18).

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A Perkin-Elmer Lambda 5 UV/V spectrometer (Palo Alto, CA) with an appropriate PC-type computer interface was used. Samples were examined without dilution to avoid color variation. Cyclohexane [for ultraviolet (UV) spectroscopy] was used in the reference beam (3–5). No differences were observed in the spectra when the reference cell was empty or contained water instead of cyclohexane. Suprasil quartz cells with pathlengths of 1, 5 and 10 mm were used, whose visible spectral transmittance was maintained between 20–80%. The absorbance values were converted to the values that would have been obtained if the entire spectrum had been recorded with 1-cm cells. To represent the spectrum, the experimental absorbance values were converted into transmittance percentages (%T) which were subsequently divided by 100, to calculate the tristimulus values.

Methods. To calculate the tristimulus coordinates X,Y,Z, ten methods with different numbers of transmittance values were selected and divided into two groups. The first four are older methods, developed for other types of oil but which have later been applied for olive oil samples (4) and which use simple equations. These are compared to six methods that use a larger number of transmittance values and that have been developed to show the influence of the number of data employed on the tristimulus values and, hence, on the results of the chromatic parameters.

Selected ordinates methods. The tristimulus coordinates of the sample are calculated after measuring 3, 4, or 5 transmittance values at certain wavelengths (T_λ). (i) The Presnell Method (6) uses:

$$X = 0.20\ T_{445} + 0.15\ T_{555} + 0.65\ T_{600} \quad [1]$$

$$Y = 0.10\ T_{445} + 0.70\ T_{555} + 0.20\ T_{600} \quad [2]$$

$$Z = 1.20\ T_{445} + 0.06\ T_{555} \quad [3]$$

(ii) The Sambuc-Naudet Method (7–10) uses:

$$X = 0.19\ T_{444.4} + 0.33\ T_{551.8} + 0.46\ T_{624.2} \quad [4]$$

$$Y = 0.17\ T_{495.2} + 0.63\ T_{551.8} + 0.20\ T_{624.2} \quad [5]$$

$$Z = 0.94\ T_{444.4} + 0.24\ T_{495.2} \quad [6]$$

(iii) The Bigoni Method (11) uses:

$$X = 0.19\ T_{445} + 0.37 T_{550} + 0.40\ T_{625} + 0.04\ T_{660} \quad [7]$$

$$Y = 0.17\ T_{495} + 0.64\ T_{555} + 0.19\ T_{625} \quad [8]$$

$$Z = 0.82\ T_{445} + 0.18\ T_{495} \quad [9]$$

(iv) The Stella-Bigoni Method (12) uses:

$$X = 0.18\ T_{445} + 0.36\ T_{550} + 0.39\ T_{625} + 0.04\ T_{660} \quad [10]$$

$$Y = 0.17\ T_{495} + 0.64\ T_{555} + 0.19\ T_{625} \quad [11]$$

$$Z = 0.97\ T_{445} + 0.21\ T_{495} \quad [12]$$

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Note that, if in any of the abovementioned methods $T = 1$ for all of the selected wavelengths, some of the tristimulus values would be different from those corresponding to an illuminant C.

Weighted ordinates methods. The tristimulus coordinates are obtained by adding up the transmittance readings multiplied by suitable coefficients. The methods were: (v) 13 readings between 400–700 nm each 25 nm; (vi) 16 readings between 400–700 nm each 20 nm; (vii) 21 readings between 400–700 nm each 15 nm; (viii) 40 readings between 380–770 nm each 10 nm; (ix) 79 readings between 380–770 nm each 5 nm; (x) 391 readings between 380–770 nm each 1 nm.

The first three methods cover a more reduced spectral interval, but similar to the preceding methods that use selected ordinates. The last three methods cover the entire color-sensitive interval of the human eye, this being the interval that should be used to characterize the color of olive oil, without neglecting the zone close to the UV, because its absorption spectrum usually shows a broad absorption zone between 375 and 525 nm. The method with 40 readings has been employed to measure the color of other foodstuffs (16). To be able to use 391 readings (i.e., transmittance values), it was necessary to calculate beforehand the appropiate coefficients. This was done by means of a linear interpolation with data from a table with an interval of 5 nm, assimilating the experimental system to an illuminant C with a foveal angle less than 4° (19). In Figure 1, the calculated coefficients are represented at intervals of 1 nm. Curves $\bar{x}$ and $\bar{y}$ do not vary linearly with the wavelength but are of a gaussian type with $\bar{x}_{max}$ = 450 and 600 nm and $\bar{y}_{max}$ = 550 nm. The other curve has its maximum at $\bar{z}_{max}$ = 450 nm.

Each of the abovementioned methods has been applied to the spectral data for each type of oil, resulting in their tristimulus values X, Y and Z, which were used to calculate the respective parameters of each of the chromatic spaces: CIE 1931, CIELUV and CIELAB 1976 (16, 19–21). Due to the color of the studied oils, the calculation of the dominant wavelength of the CIE 31 space was performed with the equation proposed by Piracci (22). The results of the method with 391 ordinates were used to check the results of the other methods. Using 391 transmittance values implies taking readings at each nm in the spectrum and is a reasonable value, because it is less than the normal resolution of UV/V spectrometers and close to the discrimination threshold of the human eye.

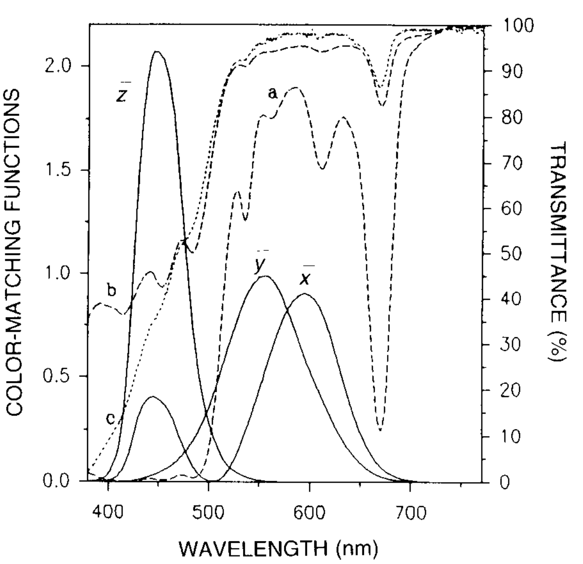

FIG. 1. Solid lines: Plots of the color-matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ weighted by relative spectral radiant power distributions of CIE standard illuminant C, from λ = 380 to 770 nm at wavelength intervals $\Delta\lambda$ = 1 nm. Dashed lines: Spectra of a) extra virgin olive oil, b) olive oil, c) husk olive oil.

RESULTS AND DISCUSSION

In Figure 1 are represented the spectra of three types of oil: extra virgin olive oil, refined olive oil and refined husk olive oil. The spectra show a broad band with three well-defined maxima at 410, 450 and 525 nm that correspond to the carotenoid fraction, and an intense band at 670 nm due to absorption by the chlorophyllic fraction. The average width of this latter band is around 10 nm, thus the color definition is improved when transmittance measurements are performed at intervals less than the average width. Only in methods viii–x are readings with $\Delta\lambda \leqslant 10$ nm performed.

The joint representative in Figure 1 of the olive oil spectra and the color matching function to calculate the tristimulus gives us some indications of how each transmittance value contributes to the results of the tristimulus and certain chromatic parameters. Thus, the band at 670 nm will affect only the tristimulus X and Y, but not Z. Because the coefficient curve used to obtain Y covers a wide wavelength interval, any of the ten calculation methods will yield acceptable results. The weighted-ordinates methods use many transmittance values of the interval covered by Y, and many of them will be multiplied by a coefficient with significant value. However, the value of Y will be small when the spectrum has bands between 500 and 600 nm.

Likewise, it is the profile of the spectral zone of between approximately 400 and 500 nm that affects the value of tristimulus Z. In this zone appear the carotenoid bands whose content is considerably higher for the extra virgin olive oils than in the refined oils (i.e., olive oil and husk olive oil), which will have much higher Z values. As to the tristimulus X value, this one will be affected by the transmittance of the chlorophyllic fraction and the carotenoid fraction. Because the extra virgin olive has a higher content in both fractions than the other types of oil, it has a correspondingly smaller tristimulus X value. Examining the wavelengths used by each selected ordinates method and studying the color-matching function graphic in Figure 1, one can conjecture about which method yields the best values for each tristimulus.

The above reasoning is confirmed when examining the results gathered in Tables 1–3, corresponding to each type of oil, which include the tristimulus coordinates and the chromatic parameters calculated by means of each of the ten methods described above. The value in parentheses, shown next to each datum, is the relative error, estimated as: [(tabulated value − value with 391 ordinates)/(value with 391 ordinates)]%. When this error was less than 1, it is indicated by <1.

Tristimulus. Tables 1–3 show that, as the number of weighted ordinates increases, the values converge toward the results obtained with 391 ordinates. With 40 ordinates, good results can already be obtained. For olive oil, good results are obtained with any of the methods that use weighted ordinates, even with those that only read data of the interval 400–700 nm; this is a consequence of the spectral profile because, above 700 nm, its transmittance is close to 100%, and below 400 nm, the multiplying coefficients used to calculate Z have small values, as shown in Figure 1. This tristimulus shows the major errors, mainly in those methods with selected ordinates and even with some of the methods that use weighted ordinates.

Table 1 shows that, with the selected-ordinates methods, somewhat higher values can be obtained when calculating tristimulus X and tristimulus Y; however, all the results are found within an acceptable variation interval, except those that are obtained by the Presnell Method (6). For tristimulus Z, the Sambuc-Naudet, Bigoni and Stella-Bigoni methods (7–12) yield values that are almost half those obtained through weighted ordinates, whereas the Presnell Method (6) yields double these values. This inaccuracy in the Z value results from those methods that use equations with few terms, some of which remain outside the color-matching function interval to calculate Z, as occurs with the measurement at 555 nm in the Presnell Method (6). The other methods, although they include more ordinates, likewise use empirical coefficients obtained from oils other than olive oils; and hence, they do not necessarily lead to good results. The Bigoni and Stella-Bigoni equations differ only slightly in the multiplying coefficients, yet they lead to significant differences in X and Z when applied to olive oil.

In Table 2, olive oil shows higher tristimulus values than extra virgin olive oil, which agrees with its higher transmittance. The tristimulus methods for refined olive oil show smaller errors when calculated with any selected-ordinates methods because its spectral profile is somewhat

TABLE 1

Tristimulus Coordinates and Chromatic Parameters for Various Colorimetric Systems for an Extra Virgin Olive Oil as a Function of the Number of Transmittance Values Used (relative errors in % in parentheses)

	Selected-ordinates methods				Weighted-ordinates methods					
Magnitude[a]	Presnell[b]	Sambuc[c]	Bigoni[d]	Stella[e]	13 Ordinate	16 Ordinate	21 Ordinate	40 Ordinate	79 Ordinate	391 Ordinate
X	0.627(5)	0.620(4)	0.620(4)	0.605(1)	0.610(2)	0.595(<1)	0.596(<1)	0.597(<1)	0.597(<1)	0.597
Y	0.716(11)	0.664(3)	0.663(3)	0.663(3)	0.667(3)	0.634(2)	0.641(<1)	0.647(<1)	0.647(<1)	0.646
Z	0.056(143)	0.013(42)	0.011(55)	0.012(47)	0.022(4)	0.021(8)	0.022(5)	0.023(<1)	0.023(<1)	0.023
CIE 31										
L	71.62(11)	66.41(3)	66.33(3)	66.33(3)	66.67(3)	63.41(2)	64.12(<1)	64.68(<1)	64.67(<1)	64.64
λ_d	573.0(<1)	575.8(<1)	575.8(<1)	574.8(<1)	574.9(<1)	575.9(<1)	575.6(<1)	575.3(<1)	575.3(<1)	575.3
S	89.33(6)	97.24(2)	97.82(3)	97.43(2)	95.43(<1)	95.46(<1)	95.34(<1)	95.17(<1)	95.16(<1)	95.13
CIELUV										
L^*	87.78(4)	85.20(1)	85.17(1)	85.17(1)	85.34(1)	83.66(<1)	84.03(<1)	84.32(<1)	84.31(<1)	84.30
u^*	18.88(41)	36.06(12)	36.72(14)	30.36(6)	30.48(5)	35.97(12)	34.09(6)	32.23(<1)	32.24(<1)	32.23
v^*	111.51(1)	112.72(2)	113.10(3)	113.71(3)	112.11(2)	108.97(1)	109.66(<1)	110.20(<1)	110.18(<1)	110.14
C^{uv}	113.10(1)	118.35(3)	118.91(4)	117.70(3)	116.18(1)	114.75(<1)	114.82(<1)	114.82(<1)	114.80(<1)	114.76
CIELAB										
L^*	87.78(4)	85.20(1)	85.17(1)	85.17(1)	85.34(1)	83.66(<1)	84.03(<1)	84.32(<1)	84.31(<1)	84.30
a^*	−16.47(92)	−7.02(18)	−6.75(21)	−10.42(22)	−9.99(17)	−6.21(27)	−7.42(10)	−8.58(<1)	−8.56(<1)	−8.56
b^*	106.67(11)	129.77(9)	133.19(12)	130.91(10)	121.69(2)	119.57(<1)	119.60(<1)	119.37(<1)	119.33(<1)	119.21
C^*	107.93(10)	129.97(9)	133.36(12)	131.33(10)	122.10(2)	119.73(<1)	119.83(<1)	119.68(<1)	119.63(<1)	119.52
H*	98.73(5)	93.05(1)	92.86(1)	94.51(<1)	94.65(<1)	92.93(1)	93.50(<1)	94.07(<1)	94.06(<1)	94.06

[a]L = luminosity, γ_d = dominant wavelength, S = saturation, L^* = lightness, C^* = chroma, H^* = hue; X,Y,Z = tristimulus coordinates.
[b]Reference 6; [c]References 7–10; [d]Reference 11; [e]Reference 12.

TABLE 2

Tristimulus Coordinates and Chromatic Parameters for Various Colorimetric Systems for an Olive Oil as a Function of the Number of Transmittance Values Used (relative errors in % in parentheses)

	Selected-ordinates methods				Weighted-ordinates methods					
Magnitude[a]	Presnell[b]	Sambuc[c]	Bigoni[d]	Stella[e]	13 Ordinate	16 Ordinate	21 Ordinate	40 Ordinate	79 Ordinate	391 Ordinate
X	0.848(3)	0.834(<1)	0.849(3)	0.826(<1)	0.828(<1)	0.827(<1)	0.827(<1)	0.827(<1)	0.827(<1)	0.827
Y	0.893(<1)	0.883(<1)	0.882(1)	0.882(1)	0.893(<1)	0.889(<1)	0.889(<1)	0.891(<1)	0.891(<1)	0.891
Z	0.597(7)	0.570(2)	0.477(14)	0.562(<1)	0.553(<1)	0.552(1)	0.555(<1)	0.557(<1)	0.557(<1)	0.557
CIE 31										
L	89.31(<1)	88.36(<1)	88.25(1)	88.25(1)	89.27(<1)	88.90(<1)	88.93(<1)	89.14(<1)	89.15(<1)	89.14
λ_d	574.8(<1)	574.4(<1)	576.3(<1)	573.7(<1)	573.1(<1)	573.3(<1)	573.2(<1)	573.1(<1)	573.1(<1)	573.1
S	31.63(<1)	33.32(3)	42.19(22)	33.70(2)	34.90(1)	34.88(1)	34.60(<1)	34.49(<1)	34.47(<1)	34.47
CIELUV										
L^*	95.71(<1)	95.31(<1)	95.26(<1)	95.26(<1)	95.69(<1)	95.54(<1)	95.55(<1)	95.64(<1)	95.64(<1)	95.64
u^*	13.15(38)	12.68(33)	22.29(134)	10.92(15)	9.56(<1)	10.30(8)	9.88(4)	9.49(<1)	9.48(<1)	9.51
v^*	50.11(9)	52.58(5)	62.99(13)	53.61(3)	56.05(1)	55.71(<1)	55.42(<1)	55.42(<1)	55.40(<1)	55.39
C^{uv}	51.81(8)	54.08(4)	66.82(19)	54.71(3)	56.86(1)	56.65(1)	56.29(<1)	56.23(<1)	56.21(<1)	56.20
CIELAB										
L^*	95.71(<1)	95.31(<1)	95.26(<1)	95.26(<1)	95.69(<1)	95.54(<1)	95.55(<1)	95.64(<1)	95.64(<1)	95.64
a^*	−5.09(41)	−6.00(31)	−2.91(66)	−7.33(15)	−8.76(1)	−8.24(5)	−8.42(3)	−8.65(<1)	−8.65(<1)	−8.64
b^*	33.23(10)	35.02(5)	43.97(20)	35.61(3)	37.23(1)	37.08(<1)	36.82(<1)	36.77(<1)	36.75(<1)	36.75
C^*	33.61(11)	35.53(6)	44.06(17)	36.36(4)	38.25(1)	37.98(<1)	37.77(<1)	37.77(<1)	37.76(<1)	37.75
H*	98.67(4)	99.69(3)	93.74(9)	101.59(2)	103.20(<1)	102.48(<1)	102.84(<1)	103.20(<1)	103.2(<1)	103.18

[a–e]See footnotes to Table 1.

planer. The Stella–Bigoni (12) equation could be used as an abbreviated method to calculate the tristimulus for this oil. Likewise, on increasing the number of weighted ordinates, a better fit for the tristimulus coordinate values is obtained and consequently for the analyzed chromatic parameters.

Similar comments can be made about the magnitude of the results for refined husk olive oil. Likewise, minor errors are committed when applying any of the methods except for the calculation of Z with the Bigoni Method, as shown in Table 3.

Chromatic parameters. Previously, we reasoned that any type of oil would have a different tristimulus Y value because its transmittance in the 500–600 nm zone was different. A similar reasoning can be made for the luminosity (L or L^*) because of its direct relation with any of the three chromatic systems, and likewise, it can be concluded that extra virgin olive oil will show less luminosity due to its higher transmittance in this zone. This can be observed in Tables 1–3. Figure 1 alone would not allow us to draw conclusions about the relative values of any of the other chromatic parameters of the other types of oil because its relations with the tristimulus are not straightforward.

Tables 1–3 show that the errors in the tristimulus calculation are not transferred to an equal degree to the chromatic parameters, except for the dominant wavelength. Some chromatic parameter errors affect, in turn, other chromatic parameters. Thus, the error in chroma, C^* of the CIELAB system, is a consequence of parameters a^* and b^*, more so of the latter because its value is higher, even though the error in a^* is larger. The error in b^* is less when the spectrum has fewer bands as shown by the spectra in Figure 1 and the data in Tables 1–3.

In general, the chromatic parameters of the refined olive oils and husk olive oil (Tables 2 and 3) have smaller errors than the extra virgin olive oils (Table 1) because the latter's tristimulus has larger errors. The values of the saturation parameter calculated with the Bigoni Method (11) are an exception because this method shows much larger errors for the refined olive oils and the refined husk olive oils.

With only forty ordinates in the spectrum of any of the three types of olive oil, good chromatic parameters can already be obtained. On the other hand, of the methods with weighted ordinates that do not use the entire spectral interval, only the one with 21 ordinates would be acceptable, although some parameters show significant errors, especially those that are affected by the error in the tristimulus Z. Of the selected-ordinates methods, the Stella–Bigoni Method (12) results in the smallest errors when calculating the chromatic parameters of any of the olive oil types. The errors are more serious for the coordinate u^* of the CIELUV system, for the coordinates a^* and b^* and for the chroma C^* values of the CIELAB system, especially for extra virgin olive oil. This method, and perhaps the Sambuc–Naudet Method (7–10), could be used to quickly estimate a large number of chromatic parameters of refined olive oils and refined husk olive oil. Of the other selected-ordinates methods, the Presnell Method (6) yields the least reliable results, especially when calculating the chromatic parameters of extra virgin olive oil in the CIE 31 and CIELAB systems. This is a consequence of the bad fit of the tristimulus Z, which affects to a lesser degree the parameters of the CIELUV system.

Thus, some of the selected-ordinates methods can be employed to calculate chromatic parameters for certain types of olive oils, such as the husk oil, but the rest of the methods do no yield an acceptable color characterization. Thus, it is necessary to use a method with weighted ordinates and transmittance data of the entire visible spectral interval, as shown in Figure 2, which represents the color difference, defined as:

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \qquad [13]$$

where Δ = a method's chromatic parameter value subtracted from the same value but from the method that uses 391 ordinates. Note that the larger values of ΔE occur with the extra-virgin olive oil, being $\Delta E > 10$ CIELAB

TABLE 3
Tristimulus Coordinates and Chromatic Parameters for Various Colorimetric Systems for a Husk Type of Olive Oil as a Function of the Number of Transmittance Values Used (relative errors in % in parentheses)

	Selected-ordinates methods				Weighted-ordinates methods					
Magnitude[a]	Presnell[b]	Sambuc[c]	Bigoni[d]	Stella[e]	13 Ordinate	16 Ordinate	21 Ordinate	40 Ordinate	79 Ordinate	391 Ordinate
X	0.847(2)	0.834(<1)	0.851(2)	0.828(<1)	0.831(<1)	0.831(<1)	0.829(<1)	0.831(<1)	0.831(<1)	0.831
Y	0.901(1)	0.913(<1)	0.913(<1)	0.913(<1)	0.915(<1)	0.912(<1)	0.912(<1)	0.915(<1)	0.914(<1)	0.914
Z	0.475(<1)	0.483(1)	0.404(15)	0.476(<1)	0.466(3)	0.469(2)	0.470(2)	0.478(<1)	0.478(<1)	0.478
CIE 31										
L	90.12(1)	91.26(<1)	91.28(<1)	91.28(<1)	91.53(<1)	91.25(<1)	91.19(<1)	91.48(<1)	91.44(<1)	91.44
λ_d	574.7(<1)	572.7(<1)	574.5(<1)	572.2(<1)	572.4(<1)	572.5(<1)	572.4(<1)	572.3(<1)	572.3(<1)	572.3
S	42.84(<1)	42.01(1)	50.06(18)	42.47(<1)	43.61(3)	43.22(2)	43.07(1)	42.49(<1)	42.44(<1)	42.44
CIELUV										
L^*	96.05(<1)	96.52(<1)	96.52(<1)	96.52(<1)	96.63(<1)	96.51(1)	96.49(<1)	96.61(<1)	96.59(<1)	96.59
u^*	17.10(93)	9.97(13)	18.97(114)	8.48(4)	9.31(5)	9.73(10)	9.42(6)	8.87(<1)	8.87(<1)	8.86
v^*	65.84(3)	66.84(1)	75.81(12)	67.88(<1)	69.34(2)	68.62(1)	68.45(1)	67.87(<1)	67.78(<1)	67.79
C^{uv}	68.03(1)	67.58(1)	78.15(14)	68.41(<1)	69.97(2)	69.30(1)	69.10(1)	68.44(<1)	68.36(<1)	68.37
CIELAB										
L^*	96.05(<1)	96.52(<1)	96.52(<1)	96.52(<1)	96.63(<1)	96.51(1)	96.49(<1)	96.61(<1)	96.59(<1)	96.59
a^*	−6.68(45)	−11.18(8)	−8.02(34)	−12.34(2)	−12.19(<1)	−11.76(3)	−11.91(2)	−12.10(<1)	−12.07(<1)	−12.09
b^*	45.56(1)	45.50(<1)	54.04(17)	46.18(<1)	47.44(3)	46.92(2)	46.75(1)	46.20(<1)	46.13(<1)	46.14
C^*	46.05(4)	46.86(2)	54.63(15)	47.80(<1)	48.98(3)	48.37(1)	48.24(1)	47.76(<1)	47.69(<1)	47.70
H*	98.30(6)	103.77(<1)	98.40(6)	104.92(<1)	104.37(<1)	104.03(<1)	104.25(<1)	104.64(<1)	104.63(<1)	104.64

[a–e]See footnotes to Table 1.

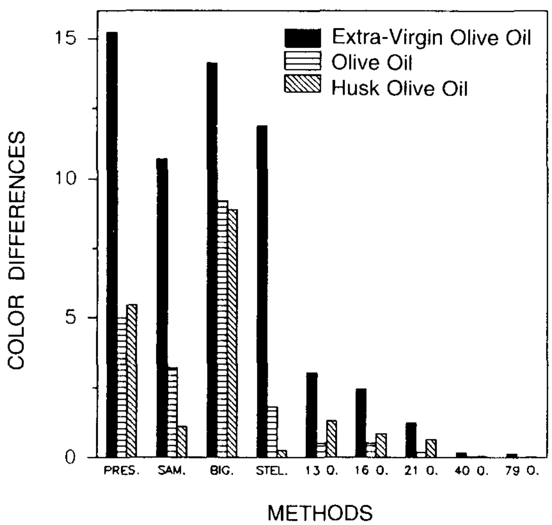

FIG. 2. Color differences ΔE in units of the CIELAB system depend on the method used. PRES., SAM., BIG. and STEL. are Methods described in references (6–12).

units with any of the selected-ordinates methods. Even with the weighted-ordinates methods, $\Delta E > 1$ CIELAB units when $\Delta\lambda > 10$ nm. For refined olive oil, the result $\Delta E = 1.8$. CIELAB units of the Bigoni–Stella Method is acceptable. With any of the weighted-ordinates methods, $\Delta E < 1$ for this oil. Something similar occurs with refined husk olive oil.

It can be concluded that, unlike for other foodstuffs, it is necessary to use the entire interval 380–770 to calculate the tristimulus coordinates and the chromatic parameters of an olive oil. Given the processing speed of present day computers, it is preferable to define the color from the largest number of spectral measurements instead of using a simplified equation. It appears sufficient to measure each 10 nm, although it may be preferable to take measurements each 1 nm.

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REFERENCES

1. *Official Methods of Analysis*, edited by D. Firestone, Association of Official Analytical Chemists, Washington, D.C., 1990, Chapter 41.
2. Gutiérrez-G., R. Quijano and F. Gutiérrez Rosales, *Grasas y Aceites 37*:282 (1986).
3. Minguez-Mosquera, M.I., L. Rejano-Navarro, B. Gandul-Rojas, A.H. Sánchez-Gómez and J. Garrido-Fernández, *J. Am. Oil Chem. Soc. 68*:332 (1991).
4. Guillén, R., F. Yépez, F. Heredia and M. Guzmán, *J. Sci. Food Agric. 54*:619 (1991).
5. Snyder, J.M., T.L. Mounts and R.K. Holloway, *J. Am. Oil Chem. Soc. 68*:285 (1991).
6. Presnell, A.K., *Ibid. 26*:13 (1949).
7. Naudet, M., and E. Sambuc, *Rev. Fr. des Corps Gras. 12*:851 (1955).
8. Naudet, M., E. Sambuc and P. Desnuelle, *Ibid. 6*:425 (1956).
9. Sambuc, E., and M. Naudet, *Ibid. 3*:838 (1956).
10. Sambuc, E., and M. Naudet, *Ibid. 1*:21 (1960).
11. Bigoni, G., *Riv. Ital. Sost. Grasse 40*:116 (1963).
12. Stella, C., *Olearia 5*:111 (1966).
13. *Official Methods and Recommended Practices of the American Oil Chemists' Society*, Vol. 27, American Oil Chemists' Society, Champaign, 1977, reapproved 1989, Method Cc 13 C-50.
14. *Ibid.*, Vol. 62, 1988, Method Cc 13d-55.
15. Ong, J.T.L., in *Proceedings of 2nd ASA Symposium on Soybean Processing: Refining of Soy Oil Caustic or Physical?*, Antwerp, Belgium, 1981, pp. 1–6.
16. Escolar, D., Mª.R. Haro, A. Saucedo, J. Ayuso, J. Gómez and J.A. Alvarez, *Feuillet Vert de l'O.I.V. 927*:1 (1992).
17. International Office for Wine, *Recueil des Méthodes internationales d'analyse des Vins et des moûts*, Paris, 1990, p. 28.
18. *Official Diary of the European Union*, Brussels, Dec. 18, 1991, No. L 349, p. 36.
19. Wyszecki, G., and W.S. Stiles, *Color Science. Concepts and Methods, Quantitative, Data and Formulae*, 2nd edn. Wiley, New York, 1982.
20. Wright, W.D., *The Measurement of Color*, 4th edn., Hilger & Wats, London, 1969.
21. Escolar, D., Mª.R. Haro, A. Saucedo, J. Ayuso, A. Jiménez and J.A. Alvarez, *Appl. Spectr.*, in press (1995).
22. Piracci, A., *Rev. Vit. e di Enol. 4*:28 (1984).

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