J Am Oil Chem Soc (2009) 86:627–636
DOI 10.1007/s11746-009-1387-2

ORIGINAL PAPER

Color Measurements in Blue-Tinted Cups for Virgin-Olive-Oil Tasting

M. Melgosa · L. Gómez-Robledo · R. Huertas · L. F. Capitán-Vallvey · M. J. Moyano · F. J. Heredia

Received: 14 January 2009 / Revised: 25 March 2009 / Accepted: 7 April 2009 / Published online: 28 April 2009

Abstract Color measurements have been performed using eighteen virgin-olive-oil tasting cups with ten different commercial virgin olive oils, positioned in a color cabinet with a D65 source. Three geometries (spectroradiometer tilted 0°, 30°, and 60°) were employed, simulating different positions of the taster's eye. Our main goal was to test whether traditional blue-tinted cups effectively conceal the color of virgin olive oils, as desired in sensorial analyses. None of the cups employed had all their geometrical dimensions within the standardized values, despite being cups used in official sensorial analyses. Measuring a magnitude similar to the spectral transmittance, we found substantial differences among the glasses of the eighteen tasting cups. Comparing color variability for one virgin olive oil in different tasting cups, and one tasting cup with different virgin olive oils, we discovered that: (1) variability was higher in the case of one virgin olive oil in different cups; (2) in both cases the variability increased with the tilt of the spectroradiometer; (3) even when the variability was lowest (i.e., 0° measurements for two oils in the same cup), the average color difference was above typical visual thresholds in simultaneous comparison experiments. In the most usual case of a successive comparison between two oils in the same tasting cup, it is expected that in most cases tasters will perceive color differences between the oils when their eyes are tilted 60° with respect to the horizontal, but not when they observe the cup in the horizontal direction. In summary, blue-tinted olive-oil-tasting cups reduce, but do not completely conceal, oil color. The use of opaque tasting cups with black walls is suggested.

Keywords Virgin olive oil · Oil tasting · Color measurement · Color differences · Standard oil-tasting cups

M. Melgosa (✉) · L. Gómez-Robledo · R. Huertas
Departamento de Óptica, Facultad de Ciencias,
Universidad de Granada, 18071 Granada, Spain
e-mail: mmelgosa@ugr.es

L. F. Capitán-Vallvey
Solid Phase Spectrometry Research Group,
Departamento de Química Analítica,
Facultad de Ciencias, Universidad de Granada,
18071 Granada, Spain

M. J. Moyano
Almazara Experimental del Instituto de la Grasa,
CSIC, 41012 Sevilla, Spain

F. J. Heredia
Grupo de Color y Calidad de Alimentos,
Facultad de Farmacia, Universidad de Sevilla,
41012 Sevilla, Spain

Introduction

The International Oil Council classifies virgin olive oils in different commercial categories on the basis of results obtained from specific chemical and sensorial analyses [1]. This classification is important because it is directly related to the possibilities of marketing olive oils: for example, in the European Union, only virgin olive oils in the categories "extra" and "fino" can currently be bottled for direct human consumption [2]. As a sign of quality and distinction, most appreciated and expensive virgin olive oils in the category "extra" also require accurate specifications of their properties determined through chemical and sensorial analyses. For example, this is true of virgin olive oils with "Denomination of Origin", those derived from ecological agriculture, or those produced from only one olive variety [3]. It is remarkable that today olive-oil production and marketing continues to seek improved quality, in a similar way as has happened with wine production. Chemical and sensorial analyses of virgin olive oils can be considered complementary, although it has been stated that from the consumer's standpoint the most important quality attributes are the sensorial ones [4].

In general, sensorial analysis is evaluation of the organoleptic properties of a product (smell, flavor, texture, etc.) using the human senses. With regard to virgin olive oils, the sensorial analysis is currently a rigorous, well-established procedure, which focuses on the measurement of positive and negative attributes of olive-oil samples by a group of expert tasters appropriately selected and trained for this task [2]. The tasters work with suitable materials, under well-defined environmental conditions, using precise scientific methodology [5]. A taster is a keen-sighted and sensitive person who estimates through his/her senses the organoleptic properties of a food [6].

Commercially, color is, perhaps, the most important characteristic of many foods, because it is usually the only one easily considered by the customer, influencing buying decisions. Although color may be the most important characteristic of foods, in particular when it is related to other aspects of quality [7, 8], in sensorial analyses of virgin olive oils, color is not considered, for two main reasons [4]:

1. it is a way to avoid a psychological bias of the taster, who may, for example, prefer a green color to a yellow one, and therefore would have an unconscious tendency to give higher scores to the green oils; and
2. oils produced from green olives have different sensorial characteristics from yellow oils made from riper olives; consequently, on seeing a green oil, a taster might describe it with the specific characteristics of green oils, without further careful consideration.

As a means of circumventing these biases, virgin olive oils are tasted from cups with tinted glass, meant to prevent the visual perception of any color in the oil samples.

Cups used in sensorial evaluation of virgin olive oils (Fig. 1) have been standardized by the International Oil Council [9]. Specifically, it is stated that the standard cups for oil taste must have:

1. maximum stability to avoid tipping and spilling of the oil;
2. easy heater-adaptable bases, enabling homogeneous warming of the base of the cup;
3. narrow rims to concentrate odor and aid identification by the taster;
4. dark glass to prevent any oil-color perception by the taster;
5. homogeneous glass, without bubbles or scratches, which should also be resistant to temperature changes;
6. specific geometric dimensions; and
7. a transparent watch glass acting as the lid for each cup, to avoid oil oxidation, prevent dust contamination of the oil, and bouquet losses.

It is also recommended [10] that the tasting room where the sensorial analyses are performed be free of noises and smells, have walls with a homogeneous light color, allow for individual cabinets with uniform diffuse illumination, including a comfortable seat with adaptable heights for each taster, etc.

Color is not considered in virgin-olive-oil sensorial analyses, although it is recognized as an important organoleptic property influencing consumer's preferences and subsequent choices. Therefore different color-specification techniques for virgin olive oils have been reported in the literature. Thus, a visual comparison between the color of a given oil sample and a two-dimensional scale with 60 fixed solutions, called bromthymol blue (BTB) scale, has been suggested [11]. The BTB standards were correlated with CIELAB color coordinates [12], which is interesting because currently CIELAB is one of the two internationally proposed spaces for color specification [13]. The limited precision and accuracy achievable from the BTB standards [14] led to the proposal of an alternative theoretical scale, named Uniform Oil Color Scale (UOCS), with improved performance upon BTB method [15]. Color specification of virgin olive oils from spectrophotometric and spectroradiometric measurements have also been proposed, showing the lack of good correlation between these two techniques [16]. Following our previous research on the color of virgin olive oils, this paper focuses on the color of blue-tinted virgin-olive-oil tasting cups, analyzing whether they really conceal the color of commercial virgin-olive-oil samples. From the results, we provide information on the cups currently employed in official virgin-olive-oil tasting [9], seeking to improve virgin-olive-oil sensorial analyses.

Materials and Methods

For consistent results, the use of standard cups is essential in sensorial (subjective) assessments of virgin olive oils performed by panels of expert tasters. We have collected a set of eighteen blue-tinted cups for virgin olive oils, which were previously employed by experts at different laboratories of the "Instituto de la Grasa" (National Research Council, Seville, Spain). These eighteen blue-tinted cups can be regarded as a representative selection of the cups used by official tasting panels. Colors in glass are mainly obtained by addition of metallic salts homogeneously distributed, or by precipitation of dispersed particles. Different metal ions have been used for blue color glass. The

Fig. 1 Photograph of three cups for virgin-olive-oil tasting used in the current work, illuminated by a D65 source. Color reproduction is only approximate, but it can be noted that the glass colors of the three cups differ visibly

most usual blue glass, especially historical blue glass, contains cobalt (0.025–0.1%), that today is very commonly employed in mixtures with different metallic salts to adjust the desired color. In the case of blue color, mixtures can be cobalt and iron(II) [17], cobalt, iron(II), and nickel [18], or cobalt, iron(II), and chromium(III) [19]. Figure 1 shows three of these cups, with noticeable color differences among them. A vernier caliper, with sensitivity ±0.05 mm, was used to measure the different dimensions of each cup, and a glass-graduated cylinder, with a sensitivity of ±2 ml, to measure their capacity.

Seeking colors as varied as possible, we chose ten commercial extra-virgin olive oils produced in Spain, which might be considered representative of the extra-virgin olive oils found by consumers in the marketplace. The spectral transmittances of samples of these ten oils were measured with a Jasco V650 spectrophotometer (Jasco Europe, Cremella, Italy), using a 5.0 mm path-length cell, and their corresponding CIELAB color coordinates were computed, assuming the D65 illuminant and CIE 1964 Supplementary Standard Observer (see results in Ref. [16], Fig. 1, and Table 1).

Color specifications in this study used the CIELAB color space, currently recommended by the International Commission on Illumination (CIE) [13], and color difference computations were also performed using CIELAB. In the past few years, many CIELAB-based color difference formulas have been proposed [20], the last one recommended by the CIE being the CIEDE2000 color difference formula [21], which particularly improves the CIELAB predictions of visually perceived color differences [22]. Because the CIEDE2000 formula was recommended for color differences lower than 5.0 CIELAB units, whereas this work often deals with far greater color differences, we report only color differences in CIELAB units. The size of a just-noticeable or threshold color difference depends on experimental conditions: in some simultaneous comparison experiments [23] threshold differences of around 0.4 CIELAB units have been reported whereas for a broad set of surface colors [24] the average difference was 1.1 CIELAB units. In general, color differences below 1.0 CIELAB units are hard to perceive under normal visual conditions, in simultaneous comparison experiments [25]. Successive (memory) comparison experiments consistently report higher color differences than those found in simultaneous comparison experiments, but the magnitude of this change varies from experiment to experiment, probably as a consequence of the different methodologies and visual observation conditions employed in each experiment. Thus, an average sixfold increase in the size of CIE 1931 x, y discrimination ellipses has been reported [26] whereas in another experiment [27] this average increase was only a factor of 2.4. In another experiment [28] a two-fold wavelength threshold increase was reported, which would imply an approximately fourfold increase of the size of the CIE x, y ellipses [27]. More recently, for a bluish-green color center assessed by a group of old observers using delay times of 15 s, 15 min, and 24 h, the CIELAB color difference was approximately twofold greater than in the simultaneous color-matching experiment [29].

Color variability for a set of N points in CIELAB space (e.g., the ten virgin olive oils in one of our tasting cups) has been quantified using the average color difference of all potential pairs (that is, 45 pairs for ten oil samples) $\overline{(\Delta E^*_{ab})_{i,j}}$, and the mean color difference from the mean MCDM, proposed by Berns [30]:

$$\mathrm{MCDM} = \frac{\sum_{i=1}^{N}\left[\left(L_i^* - \overline{L^*}\right)^2 + \left(a_i^* - \overline{a^*}\right)^2 + \left(b_i^* - \overline{b^*}\right)^2\right]^{1/2}}{N} \quad (1)$$

where each *i-th* measured color is compared with the average, $\overline{L^*}$, $\overline{a^*}$, $\overline{b^*}$, and the arithmetic mean of the N color differences is finally computed. Comparison between $\overline{(\Delta E^*_{ab})_{i,j}}$ and MCDM is not the objective of this paper, but a high correlation may be expected between these two measurements of color variability. The standard deviation (SD) of the set of N CIELAB color differences involved in the computation of the MCDM was also computed, because it can provide additional information about the dispersion of the data (e.g. presence of outliers).

Table 1 Geometrical characteristics of the eighteen olive-oil tasting cups employed in this work

Cup number	Capacity (ml)	Height (mm)	Rim diameter (mm)	Maximum diameter (mm)	Diameter at the bottom (mm)	Thickness at the bottom (mm)
1	128	61.00	45.82*	68.24*	40.00*	6.70*
2	136	61.18*	50.00	71.06*	24.00*	6.24*
3	142	63.54*	51.00	68.74*	25.14*	6.54*
4	142	59.82	50.28	70.88	25.06*	6.12*
5	140	61.20*	45.90*	68.76*	40.58*	5.40
6	144*	60.50	46.10*	69.20	34.00	4.38
7	160*	60.40	49.28	71.10	21.68*	3.82*
8	140	61.82*	45.20*	68.84*	31.58*	6.22*
9	138	59.72	49.60	70.40	27.66*	5.72
10	144*	59.74	49.82	71.08*	26.70*	7.36*
11	148*	59.44	49.74	70.92	27.66*	6.54*
12	156*	61.08*	49.40	70.74	28.22*	7.38*
13	148*	60.50	49.96	71.16*	26.48*	7.36*
14	150*	60.38	48.04*	71.04	28.00*	6.30*
15	154*	59.32	49.42	70.50	30.78*	4.70
16	142	60.10	49.68	70.90	25.80*	7.16*
17	132	60.98	43.10*	70.50	23.25*	8.58*
18	154*	63.14*	47.10*	70.90	30.20*	7.84*
Mean	144.33*	60.77	48.30*	70.28	28.71*	6.35*
Standard Deviation	8.44	1.16	2.21	1.01	5.20	1.23
Standard cup	130 ± 10	60 ± 1	50 ± 1	70 ± 1	35 ± 1	5 ± 1

The last row shows the characteristics of the standard cup [9], except the thickness of the lateral walls of the cup. The uncertainties of our measurements of capacity and length were ±2 ml and ±0.05 mm, respectively. Values outside the limits fixed for the standard tasting cups [9] are indicated by asterisks

We poured 200 ml oil into each cup, and located the cup in a fixed position on the floor of a GretagMacbeth Spectralight III color cabinet equipped with a daylight source which simulates the CIE D65 illuminant quite well [31]. Spectral radiant powers were measured using a SpectraScan PR704 (Photoresearch, Chatsworth, CA, USA) spectroradiometer. The spectroradiometer was positioned in front of the color cabinet on a sturdy tripod that allowed both vertical movements and three different tilts of the optical axis of the spectroradiometer: 0°, 30°, and 60° (Fig. 2). These different positions of the spectroradiometer may be regarded as representative of those of the taster's eyes performing sensorial analyses in a cabinet. The spectroradiometer performed spectral power measurements in the range 380–780 nm in 2-nm steps, using a measurement field of 1°. Using 1° measurement field and the spectroradiometer positioned horizontally (0° tilt), for some cups with a thick bottom glass, we needed a little more than the 150 ml oil officially recommended [32], this being the reason we used 200 ml in each cup. Because both the glasses of the cups and the virgin olive oils are partly transparent, we put a white paper (Canson Extra Quality Paper Print-on, 130 g, dpi 360–660) with CIELAB coordinates $L^*_{ab,10} = 95.17$, $a^*_{10} = 0.78$, and $b^*_{10} = -6.59$ just under the cups and also behind the cups as a background. This white paper was used instead of the gray color of the cabinet, in order to follow the conditions recommended for sensorial evaluation of virgin olive oils. From Fig. 2, note that when the spectroradiometer was tilted 60°, its optical axis crossed a thickness of oil, the bottom glass of the cup, and the white paper under the cup. However when the tilt of the spectroradiometer was 30°, its optical axis crossed a greater thickness of oil, the two walls of the cup, and the white paper under the cup. Finally, with the spectroradiometer axis at 0°, the optical axis crossed the greatest thickness of oil, the two walls of the cup, and the white paper positioned behind the cup. As mentioned before, these three different positions of the spectroradiometer measure approximately what the taster's eye would see in a standard cabinet for sensorial analyses of virgin-olive oils [9, 10]. The CIE 1964 Supplementary Standard Observer [13] was assumed in all our color measurements, because the samples measured subtended an angle higher than 4° in all cases. Specifically, for the cup with smallest maximum diameter (6.824 cm) employed in this work, the visual angle subtended by an observer placed 50 cm from this cup should be 7.8°.

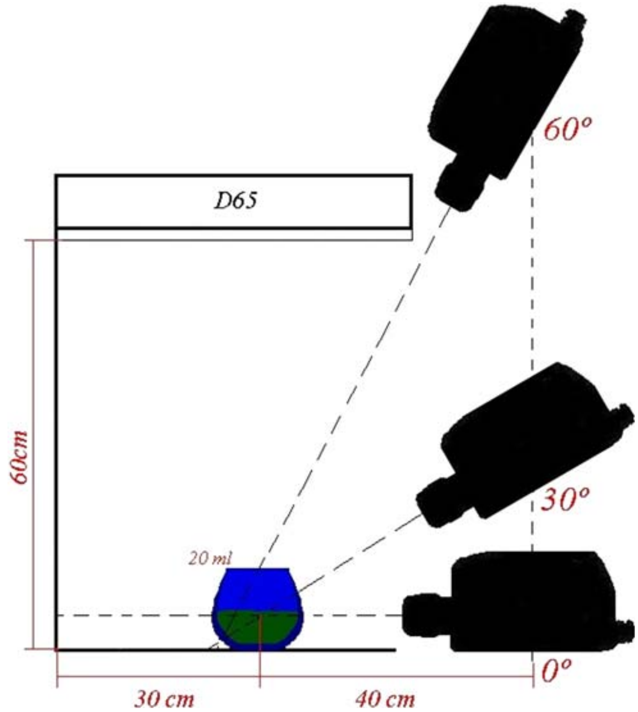

Fig. 2 Schematic diagram of the setup for spectroradiometric measurements. The main dimensions of the color cabinet with a D65 source, and the position of the cup and spectroradiometer are indicated. Three different positions for the spectroradiometer are considered (optical axis at 0°, 30°, and 60°), simulating some of the potential positions of a taster's eye

Because CIELAB computations of color coordinates require a reference white [13], we used a standard PTFE surface, provided by the manufacturer of our spectroradiometer, which was positioned in the cabinet at the place of the white background when the spectroradiometer was tilted 0° (no tilt), and on the floor of the cabinet, just at the position occupied by the cup, when the spectroradiometer was tilted 30° or 60°.

A total of 540 instrumental color measurements were performed (18 cups × 10 oils × 3 tilts of the spectroradiometer), plus the corresponding measurements of the reference white. The spectroradiometer was operated with the available three-cycle option, providing the average results of three consecutive measurements. After each of the 540 color measurements, the corresponding cup was cleaned with *n*-hexane and dried. No visual assessments were made in this work: it was assumed that our computed color differences in CIELAB are representative of the visually perceived differences by normal observers.

Results and Discussion

In practice, the main objective of the blue-tinted glasses of the cups used in virgin-olive-oil sensorial assessments is to conceal the color of any oil sample, so that the important organoleptic attribute of color does not influence or bias the tasters' judgments on oil samples. In this section, we consider four subsections: first we analyze some physical properties of the cups, and then we focus on color changes of various oils in different cups.

Some Characteristics of Oil-Tasting Cups

For each cup (Fig. 3), we measured six magnitudes (capacity and five lengths), obtaining the results shown in Table 1. The last row in Table 1 shows the standardized values of these magnitudes with their corresponding tolerances [9]. We did not measure the "glass thickness in the lateral walls of the cup", which was assigned a standard value 1.5 ± 0.2 mm, because this thickness is difficult to measure, changes along the walls (Fig. 3), and the exact position where this thickness must be measured is not specified by the International Oil Council [9]. Given the uncertainties associated with our measurements and the tolerances of the standard values, Table 1 indicates that no cup in our study had all dimensions within the standardized values; the cup with the "best" dimensions was number 9, with only one of their six measured values out of range. More specifically, we note that 60/108 (55.6%) of the measured dimensions are outside the standardized ranges, "diameter at the bottom" and "glass thickness at the bottom" being the magnitudes accounting most of the failures (17/18 and 14/18, respectively). It can be concluded that standard dimensions of tasting cups for virgin-olive oils have not been carefully followed by the manufacturers.

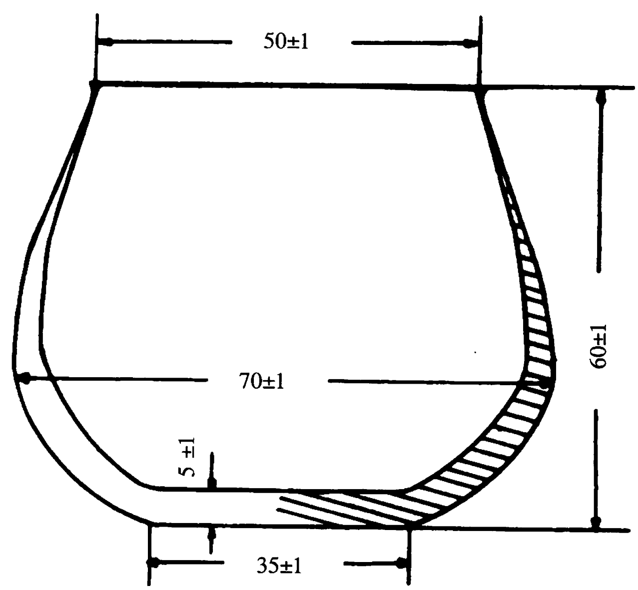

Fig. 3 The main geometrical dimensions of the standard cups employed for virgin-olive-oil taste [9]

With respect to the glasses of the tasting cups, they used to be dark blue, whereas the current regulation [9] states only that they must be dark to prevent the taster from perceiving the oil color. Using the PR-704 spectroradiometer at 0° (Fig. 2), for each of our eighteen cups, we measured the ratio of the spectral power distribution (SPD) of the empty cup to the SPD of its fixed white background. These SPD ratios (Fig. 4) might be regarded as similar to the spectral transmittances (or trans-reflectances) of the glasses of our cups, and they will be designated here as "transmittances". Figure 4 shows large differences between the glass of our tasting cups, although following similar patterns: strong increase of the "transmittances" for wavelengths outside the interval 500–700 nm, which are nearly constant (but not always close to zero) inside this wavelength interval. These spectral "transmittances" are consistent with the dark-blue color (very slightly purplish) we can perceive on the cups. Ideally, to conceal the color of the oil poured into a tasting cup (i.e. to see an overall black color) it would be necessary for the product of the spectral transmittances of the oil and the cup to be constant at all wavelengths, and close to zero. From the spectral "transmittances" in Fig. 4 and the typical spectral transmittances of virgin-olive-oil samples [33], it can be ascertained that in most cases we will not perceive a black color. Figure 5 shows an example of the measured spectral "transmittance" for a given cup and oil, using the 0°, 30°, and 60° tilts of our spectrophotometer (Fig. 2). A low (but non null) constant "transmittance" can be seen in the approximate range 420–680 nm, followed by a substantial increase in the large-wavelength region, where the sensitivity of the human eye is poor. Therefore, a very dark grey-reddish color might be expected when this cup and oil are observed illuminated by a non-selective light source.

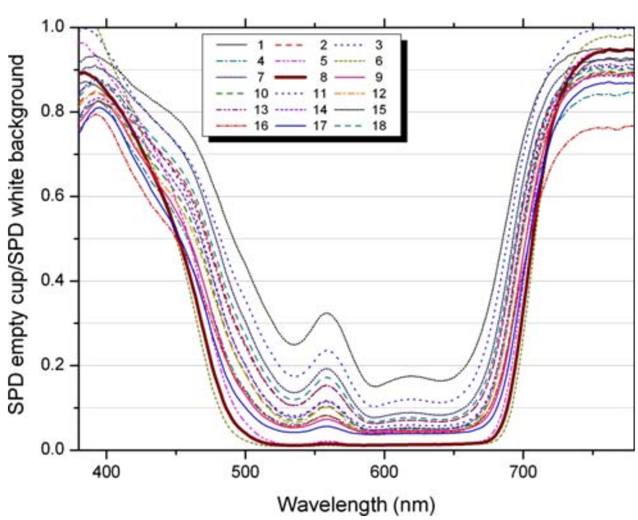

Fig. 4 Spectral characteristics of the glasses of the eighteen virgin-olive-oil-tasting cups. *SPD*, spectral power distribution

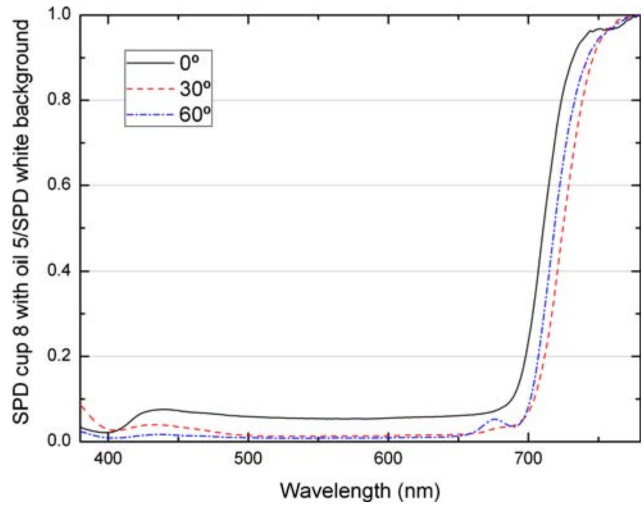

Fig. 5 Ratio of the SPD measured with cup number 8 plus oil number 5 to the SPD of the white background, for different tilts of the spectroradiometer

The slightly smaller "transmittances" shown in Fig. 5 for the 30° and 60° tilts with regard to the 0° tilt may be attributed to the shadow projected by the cup on the floor of the cabinet. In any case, the key question is not the perceived color, but the color changes arising when the cups/oils change, as discussed in the following subsections.

One Virgin Olive Oil in Different Tasting Cups

Because we have eighteen tasting cups, for each olive oil it is possible to have 153 comparisons (pairs of cups). Considering all oils, we found that the average color differences for these 153 pairs were 2.85, 5.13, and 6.15 CIELAB units, for the 0°, 30°, and 60° geometries of measurement, respectively (Table 2). These average color differences are greater than threshold values reported in simultaneous comparison experiments [25], and maybe also in successive comparison experiments [26–29], signifying that, on average, two tasting cups with the same oil will be perceived as having different colors, in particular when compared simultaneously. This is particularly true for the 60° geometry, a measurement angle at which the light crosses only one of the two walls of the cup. It can be concluded that the walls of the tasting cups contribute to masking or concealing oil color because average color differences of the 153 pairs increases with tilt. The maximum color differences of the 153 color pairs were very high: 10.94, 13.73, and 19.07 CIELAB units, for the 0°, 30°, and 60° measurement geometries, respectively.

Table 2 also shows the MCDM for each of the ten oil samples, considering the eighteen CIELAB color differences relative to the average color. The average MCDMs were 1.93, 3.49, and 4.30 CIELAB units for the geometries

Table 2 Color variability (CIELAB units) for each oil in the eighteen tasting cups

Oils	0°			30°			60°		
	$\overline{(\Delta E^*_{ab})_{i,j}}$	MCDM	SD	$\overline{(\Delta E^*_{ab})_{i,j}}$	MCDM	SD	$\overline{(\Delta E^*_{ab})_{i,j}}$	MCDM	SD
1	2.96	1.96	1.60	5.46	3.72	2.52	6.95	4.80	3.36
2	2.79	1.83	1.56	4.70	3.07	2.23	5.83	4.25	3.15
3	3.12	2.12	2.73	4.54	3.05	2.04	5.23	3.70	2.49
4	1.81	1.18	1.07	4.76	3.25	2.12	5.59	3.93	3.29
5	3.06	2.03	1.86	5.08	3.50	1.87	6.14	4.35	3.85
6	2.48	1.73	1.84	5.10	3.44	2.04	6.89	4.67	3.79
7	3.79	2.67	3.09	4.75	3.12	2.75	4.94	3.44	2.86
8	3.08	2.08	2.10	5.70	3.90	2.19	6.17	4.27	2.81
9	2.03	1.38	1.09	5.42	3.78	2.26	7.29	5.15	3.18
10	3.36	2.28	2.23	5.76	4.07	1.92	6.43	4.41	2.84
Average	2.85	1.93	1.92	5.13	3.49	2.19	6.15	4.30	3.16

For each spectroradiometric geometry (0°, 30°, 60°), we show the average CIELAB color difference for the 153 pairs of tasting cups for each oil $\overline{(\Delta E^*_{ab})_{i,j}}$ (where i, j denote any two tasting cups), the mean CIELAB color difference from the mean MCDM [30], and the standard deviation SD of the eighteen CIELAB color differences relative to the average color

0°, 30°, and 60°, respectively, again indicating that the color variability increases with the tilt of the spectroradiometer; that is, the walls of the tasting cups are useful to conceal oil color, as mentioned above. The correlation coefficients R^2 between $\overline{(\Delta E^*_{ab})_{i,j}}$ and MCDM values in Table 2 were very high, as expected: specifically, 0.989, 0.976, and 0.973 for the 0°, 30°, and 60° geometries, respectively. The average standard deviation, SD, of the CIELAB color differences relative to the average color also increases with tilt (Table 2), and the values found are rather high (e.g. 1.92 CIELAB units for the 0° tilt, the lowest one), suggesting that there are large differences between the eighteen tasting cups used in this work. A more detailed assessment of our results reveals that, irrespective of the oil considered, tasting cups numbers 15 and 7 had considerably higher differences from the average color than did other cups. This fact is consistent with the high and distinctive "transmittance" values shown in Fig. 4 for these three cups.

It can be argued that observation of the same oil in two different tasting cups is not usual in sensorial analyses performed by expert tasters, and therefore the results reported in this subsection have limited usefulness. This may be true, and leads us to the next subsection where we will study the color changes found when different oils are poured in a given tasting cup.

One Tasting Cup with Different Virgin Olive Oils

For each tasting cup, it is possible to consider 45 pairs of oils, because we have ten virgin-olive-oil samples. The average color differences for these 45 pairs were 2.03, 2.51, and 4.07 CIELAB units, for the 0°, 30°, and 60° geometries of measurement, respectively (Table 3). These average color differences are smaller than those found in the previous subsection. For the 60° geometry, a measuring angle such that only one of the two walls of the cup contributes to the result, it can be said that, on average, two virgin olive oils in the same tasting cup will be perceived as having different colors, both in simultaneous and successive comparisons [25–29]. Average color differences of the 45 pairs increases with the tilt of the spectroradiometer. Therefore, bearing in mind Fig. 2, we can again conclude that the walls of the tasting cups contribute to masking or concealing oil color, but not sufficiently. The maximum color differences of the 45 color pairs were also quite high: 5.31, 6.14, and 9.82 CIELAB units, for the 0°, 30°, and 60° measurement geometries, respectively. These maximum color differences are approximately 0.5 times those found in the previous subsection. The good performance of tasting cups numbers 1 and 8 for the 0° geometry is noticeable in Table 3; average CIELAB color differences were below 1.0 CIELAB units (approximately the visual threshold in simultaneous comparisons) and standard deviations were very small. We think that for the 0° geometry, in most tasting cups two different virgin olive oils will have undiscernible colors in a successive comparison experiment, as desired in professional sensorial analyses.

Table 3 also shows the MCDM for each of the eighteen tasting cups, considering the ten CIELAB color differences relative to the average color. The average MCDMs were 1.38, 1.71, and 2.76 CIELAB units, for the geometries 0°, 30°, and 60°, respectively, which indicates that the color variability increases with the tilt of the spectroradiometer; that is, the walls of the tasting cups are useful for concealing oil color. Now the correlation coefficients R^2

Table 3 Color variability (CIELAB units) for each tasting cup, considering the ten virgin olive oils

Tasting cup	0°			30°			60°		
	$\overline{(\Delta E^*_{ab})_{i,j}}$	MCDM	SD	$\overline{(\Delta E^*_{ab})_{i,j}}$	MCDM	SD	$\overline{(\Delta E^*_{ab})_{i,j}}$	MCDM	SD
1	0.59	0.39	0.18	1.80	1.17	0.79	3.38	2.27	1.73
2	2.08	1.41	0.89	2.66	1.78	0.94	5.07	3.36	1.82
3	1.55	1.03	0.53	2.01	1.36	0.71	4.37	3.02	1.18
4	1.54	1.02	0.73	3.35	2.28	1.28	4.66	2.95	2.42
5	1.28	0.89	0.42	2.88	1.97	1.08	2.81	1.86	1.21
6	1.74	1.15	0.70	2.59	1.85	0.77	2.68	1.74	1.31
7	5.65	3.66	4.56	4.47	3.00	1.92	8.63	6.66	1.50
8	0.99	0.66	0.43	1.84	1.19	0.90	3.77	2.62	1.61
9	2.10	1.48	1.01	1.83	1.18	0.84	3.77	2.56	1.47
10	1.94	1.34	0.87	1.91	1.26	0.93	3.43	2.26	1.31
11	1.69	1.02	1.01	1.92	1.23	0.91	3.51	2.29	1.42
12	1.78	1.25	0.53	3.27	2.42	0.85	4.37	2.93	1.93
13	2.04	1.37	0.76	2.04	1.42	0.61	3.97	2.71	0.94
14	1.24	0.82	0.46	3.50	2.40	1.51	4.44	3.02	1.31
15	5.47	3.79	1.63	2.65	1.84	0.83	4.33	3.01	1.50
16	2.34	1.63	0.85	2.74	1.78	1.16	3.00	1.97	1.37
17	1.43	1.04	0.39	1.51	1.08	0.49	3.30	2.01	1.92
18	1.15	0.82	0.54	2.29	1.53	0.90	3.73	2.40	1.91
Average	2.03	1.38	0.92	2.51	1.71	0.97	4.07	2.76	1.55

For each spectroradiometric geometry (0°, 30°, 60°), we show the average CIELAB color difference for the 45 pairs for each cup $\overline{(\Delta E^*_{ab})_{i,j}}$ (where i, j denote any two virgin olive oils), the mean CIELAB color difference from the mean MCDM [30], and the standard deviation SD of the ten CIELAB color differences relative to the average color

between $\overline{(\Delta E^*_{ab})_{i,j}}$ and MCDM values were also very high (even slightly greater than those found from Table 2): 0.995, 0.985, and 0.987 for the 0°, 30°, and 60° geometries, respectively. The average standard deviation SD of the CIELAB color differences with respect to the average color also increases with tilt (Table 3), and are moderate (e.g., 0.92 CIELAB units for the 0° tilt), suggesting that there are no major differences between the ten oils used in this work.

A comparison of color variability considering one virgin olive oil in different tasting cups (Table 2), and one tasting cup with different virgin olive oils (Table 3), enables us to conclude that in general:

1. variability is higher for one virgin olive oil in different tasting cups;
2. in both cases, variability increases with spectroradiometer tilt; and
3. even when the variability is lowest (that is, measurement at 0° tilt for two oils in the same cup), the average color differences are above the average visual threshold for normal observers in simultaneous comparison experiments, but maybe not in a successive comparison experiments (except perhaps for the 60° tilt).

In other words, in the most usual case of successive comparison of two oils using the same tasting cup (Table 3), an expert taster or tasters' panel, will perceive color differences between these oils, mainly when the taster's eyes are tilted 60° at to the horizontal, i.e. when the cup is far below the taster's eyes, as usually happens. In any case, it should also be mentioned that these noticeable color differences are lower than those perceivable using transparent glasses, as will be illustrated in the next subsection.

Different Virgin Olive Oils and Different Tasting Cups

In this last subsection, we computed for each measurement geometry (0°, 30°, and 60°) a total of 13,770 CIELAB color differences, which is the result of considering all the combinations by pairs of the eighteen available tasting cups (153 pairs) and the ten virgin olive oils (45 pairs), multiplied by 2 because we must distinguish, for example, the case of oil 1 in cup 1 versus oil 2 in cup 2, from the case of oil 1 in cup 2 versus oil 2 in cup 1.

Figure 6 shows the percentage of color pairs with CIELAB color differences in different intervals, distinguishing the measurement geometries of 0°, 30°, and 60°. It can be seen that for the 0° geometry the percentage of color pairs with CIELAB color differences in the interval 0-2 CIELAB units is close to 50%, whereas this percentage is

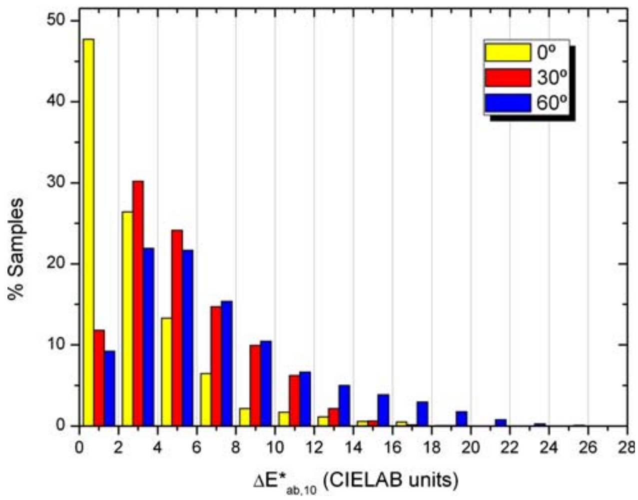

Fig. 6 Histogram of CIELAB color differences measured by a combination of all potential color pairs from eighteen tasting cups and ten virgin olive oils, distinguishing the three measurement geometries (0°, 30°, and 60° tilt of the spectroradiometer)

much lower (approx. 10%) for the 30° and 60° geometries. This means that a large percentage of small color differences (<2 CIELAB units) can be found for two tasting cups with different oils when the visual observation is made in a horizontal direction (0° tilt). However, if the observations are made at 30° or 60°, this percentage of small color differences is approximately a factor of five times lower than for 0° visualization. In addition, Fig. 6 also shows a very large number of pairs with clearly perceptible color differences (>2.0 CIELAB units) in simultaneous comparisons: specifically, more than 50% of the total pairs for the 0° geometry, and more than 85% of the total pairs for the 30° and 60° geometries. In addition, for the 60° geometry, there are pairs with very large color differences (>15 CIELAB units). These results are consistent with those reported in the two previous subsections.

For each one of our three measurements geometries, Table 4 shows the average CIELAB color difference $\overline{(\Delta E^*_{ab})_{i,j}}$ and standard deviation (SD) found with the 13,770 color pairs possible from our eighteen oil-tasting cups and ten virgin olive oils. In agreement with previous results,

Table 4 Average CIELAB color difference $\overline{(\Delta E^*_{ab})_{i,j}}$ and standard deviation (SD) computed from the 13,770 color pairs obtainable from our eighteen olive-oil tasting cups and ten virgin-olive oils, considering each of the three measurement geometries

Measurement geometry (°)	$\overline{(\Delta E^*_{ab})_{i,j}}$	SD of values leading to $\overline{(\Delta E^*_{ab})_{i,j}}$
0	3.07	2.87
30	5.25	3.07
60	6.89	4.59

Table 4 shows that the lowest average color differences and standard deviations correspond to the 0° geometry, with values clearly greater than the human visual threshold in simultaneous comparison experiments [25]. In any case, it must be said that, as expected, use of blue-tinted glass for oil-tasting cups reduces the perceived color differences between different olive oils: for example, in previous work [16] we found that when transparent Pyrex glass in cells with 46.4 mm thickness were used, the average color differences from the ten oils considered here was 10.96 CIELAB units, with a standard deviation of 7.23 CIELAB units (clearly higher than those shown in Table 4).

Conclusion

Although available oil-tasting cups usefully reduce color perception of different oils, as desired in rigorous virgin-olive-oil sensorial analyses, instrumentally measured color differences in this work are often greater than typical human visual thresholds. Therefore it would be reasonable in virgin-olive-oil sensorial analyses to propose the use of opaque tasting cups made from black material (not necessarily glass). In this way it would be possible to completely avoid the influence of color on the tasters' assessments, even when the taster observes oil from tilted perspectives. These opaque tasting cups may have the same geometrical dimensions as the current ones, but with more precise recommendation of "glass thickness in the lateral walls of the cup". Manufacturers must carefully control production in such a way that all geometrical dimensions of the cups are within the established tolerance limits, including a fixed color-tolerance and appearance (e.g. a defined low gloss and texture) for the black material to be used for the official virgin-olive-oil tasting cups in the future. Although oil color is disregarded in official sensorial analyses, it must be considered that virgin-olive-oil color is an independent important property, with direct influence on commercial consumption. In commercial sales, therefore, precise specification of oil color is also recommended [16], as a representative and distinctive property of highest-quality oils, as done with other oil properties, for example acidity, variety, etc., and also with other foods (e.g. wine, honey, etc.).

Acknowledgments Research Project P06-AGR-01744, Consejería de Innovación, Ciencia y Empresa, Junta de Andalucía (Spain), with European Regional Development Fund (ERDF) support.

References

1. COI (1999) Norma comercial aplicable al aceite de oliva y al aceite de orujo de oliva. Consejo Oleícola Internacional, COI/

T.15/NC n°2/Rev.9; 10 de Julio 1999. Also published in: Madrid, A., Cenzano, J.M. 2002. Legislación y normas sobre el aceite de oliva y las aceitunas de mesa. Ediciones Mundi-Prensa, Madrid, pp 92–103
2. Romero A, Tous J (2003) Análisis sensorial de aceite virgen de oliva, http://www.percepnet.com/cien12_03.htm. Last Accessed 20 Nov 2008
3. Romero A, Tous J (2005) Copas normalizadas de cata de aceites de oliva virgen. http://www.percepnet.com/perc09_05.htm. Last Accessed 20 Nov 2008
4. Izquierdo JR (1997) Parámetros físico-químicos que definen la calidad del aceite de oliva virgen. In: Alba J, Izquierdo JR, Gutiérrez F (eds) Aceite de oliva virgen. Análisis sensorial. Editorial Agrícola Española, S.A., Madrid, pp 21–34
5. Gutiérrez F (1997) Análisis sensorial. In: Alba J, Izquierdo JR, Gutiérrez F (eds) Aceite de oliva virgen. Análisis sensorial. Editorial Agrícola Española, S.A., Madrid, pp 47–81
6. COI (1987) Análisis sensorial: vocabulario general básico. Consejo Oleícola Internacional, COI/T.20/DOC. n°4; 18 de Junio 1987. Also published in: Madrid A, Cenzano JM. 2002. Legislación y normas sobre el aceite de oliva y las aceitunas de mesa. Ediciones Mundi-Prensa, Madrid, pp 75–82
7. Angerosa F (2003) Calidad sensorial de los aceites de oliva. In: Aparicio R, Harwood J (eds) Manual del aceite de oliva. Ediciones Mundi-Prensa, Madrid, pp 345–380
8. Hutchings JB (1999) Food color and appearance, 2nd edn. Aspen Publishers, Maryland
9. COI (1987) Copa para la degustación de aceites. Consejo Oleícola Internacional, COI/T.20/DOC. n°5; 18 de Junio 1987. Also published in: Madrid A, Cenzano JM. 2002. Legislación y normas sobre el aceite de oliva y las aceitunas de mesa. Ediciones Mundi-Prensa, Madrid, pp 82–85
10. COI (1987) Guía para la instalación de una sala de cata. Consejo Oleícola Internacional, COI/T.20/DOC. n°6; 18 de Junio 1987. Also published in: Madrid A, Cenzano JM. 2002. Legislación y normas sobre el aceite de oliva y las aceitunas de mesa. Ediciones Mundi-Prensa, Madrid, pp 85–91
11. Gutiérrez R, Gutiérrez F (1986) Método rápido para definir el color de los aceites de oliva vírgenes. Grasas y Aceites 37:282–284
12. Moyano MJ, Melgosa M, Alba J, Hita E, Heredia FJ (1999) Reliability of the bromthymol blue method for color in virgin olive oils. J Am Oil Chem Soc 76:687–692
13. CIE Publication 15 (2004) Colorimetry (Technical Report), 3rd edn. International Commission on Illumination (CIE). CIE Central Bureau
14. Melgosa M, Perez MM, Hita E, Heredia FJ, Alba J, Moyano MJ (2000) Precision and accuracy in the color specification of virgin olive oils from the bromthymol blue method. J Am Oil Chem Soc 77:1093–1099
15. Melgosa M, Huertas R, Hita E, Roa JM, Heredia FJ, Alba J, Moyano MJ (2004) Proposal of a uniform color scale for virgin olive oils. J Am Oil Chem Soc 81:323–329
16. Gómez-Robledo L, Melgosa M, Huertas R, Roa R, Moyano MJ, Heredia FJ (2008) Virgin-olive-oil color in relation to sample thickness and the measurement method. J Am Oil Chem Soc 85:1063–1071
17. Morimoto S, Noguchi T, Taniguchi M, Taguchi Y (1994) Blue-colored infrared and ultraviolet radiation absorbing glass and method of producing. US patent 5,344,798
18. Boulos EN, Best MF, Surowiec R (1991) Blue glass compositions. US patent 5,070,048
19. Shelestak LJ, Haskins DR (2002) Composición de vidrio de color azul que absorbe las radiaciones infrarrojas y ultravioletas. Spanish patent 2,171,777
20. Melgosa M (2000) Testing CIELAB-based color-difference formulas. Color Res Appl 25:49–55
21. CIE Publication 142 (2001) Improvement to industrial colour-difference evaluation (Technical Report). International Commission on Illumination (CIE). CIE Central Bureau
22. Melgosa M, Huertas R, Berns RS (2008) Performance of recent advanced color-difference formulas using the standardized residual sum of squares. J Opt Soc Am A 25:1828–1834
23. Witt K (1990) Parametric effects on surface color-difference evaluation at threshold. Color Res Appl 15:189–199
24. Luo MR, Rigg B (1986) Chromaticity-discrimination ellipses for surface colours. Color Res Appl 11:25–42
25. Melgosa M, Hita E, Romero J, Jiménez del Barco L (1992) Some classical color differences calculated with new formulas. J Opt Soc Am A 9:1247–1254
26. Newhall SM, Burnhman RW, Clark JR (1957) Comparison of successive with simultaneous color matching. J Opt Soc Am 47:43–56
27. Romero J, Hita E, Jiménez del Barco L (1986) A comparative study of successive and simultaneous method in colour discrimination. Vis Res 26:471–476
28. Uchikawa K, Ikeda M (1981) Temporal deterioration of wavelength discrimination with successive comparison method. Vis Res 21:591–595
29. Pérez-Carpinell J, Camps VJ, Trottini M, Pérez-Baylach CM (2006) Color memory in elderly adults. Color Res Appl 31:458–467
30. Berns RS (2000) Billmeyer and Saltzman's principles of color technology, 3rd edn. Wiley, New York, pp 75–105
31. Roa R, Huertas R, López-Álvarez MA, Gómez-Robledo L, Melgosa M (2008) A comparison between illuminants and light-source simulators. Opt Pur Apl 41:291–300
32. COI (1996) Metodología general para la valoración organoléptica del aceite de oliva virgen. Consejo Oleícola Internacional, COI/T.20/Doc. n° 13/Rev.1; 20 de Noviembre 1996. Also published in: Madrid A, Cenzano JM, 2002. Legislación y normas sobre el aceite de oliva y las aceitunas de mesa. Ediciones Mundi-Prensa, Madrid. pp 61–64
33. Moyano MJ (2002) Estudio del color de aceites de oliva vírgenes de Andalucía, Ph.D. Dissertation. Facultad de Farmacia (Universidad de Sevilla), Instituto de la Grasa (CSIC), Sevilla, Spain