One Wine Many Colors

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Abstract

The color measurement and color appearance of wine under various illumination types was examined to assess the importance of illumination in the sensory evaluation of wine. Six wines were measured in eight different spectrophotometric and spectroradiometric geometries, both in analytical cuvettes and ISO tasting glasses. The resulting spectral transmittance data were analyzed colorimetrically using two color spaces (CIELAB and CIECAM02) to examine the effects of both measurement geometry and viewing condition on the appearance of wines. The results indicate that the lighting used to view wines, as well as the lighting levels, can have significant impact on the perceived colors of wines and ultimate quality judgements.

Introduction

It's a hard grape to grow, as you know. It's thin-skinned, temperamental. It's not a survivor like Cabernet that can grow anywhere and thrive even when neglected. Pinot needs constant care and attention, you know? And, in fact, it can only grow in these really specific, little, tucked away corners of the world. And, and only the most patient and nurturing of growers can do it, really. Only somebody who really takes the time… to understand Pinot's potential… can then coax it into its fullest expression.

-Miles Raymond, from the movie *Sideways*

Red, white, pink, yellow, or orange, color is one of the most fundamental descriptors of wine despite often being neglected as reflected in the above ode to Pinot Noir (even though color is literally half the grape's name). It is one of the attributes of wine to which viticulturists and winemakers dedicate their constant care, attention, patience, and nurturing. Even after harvest, much is done to coax colors from the grapes into their full potential and expression in the wine. Aging also has its clear, and often desirable, impacts on color such that the consumer taps into the haunting, brilliant, thrilling, subtle, and ancient history of the beverage. But how is color evaluated, controlled, assessed, and ultimately experienced? This paper looks at some of the variables of color, most critically the illumination, and explores their potential impact on wine appearance.

While the vast majority of wine volume is made up of water and alcohol, the remaining fractional percentage provides each wine with unique colors, aromas, and flavors (neglecting any residual sugar). Most of that fractional percentage is made up of phenolic compounds. Kennedy *et al*.[1] provide an historical review of the importance of phenolics. With respect to color appearance in wine, two types of phenolics are dominant. These are the anthocyanins that provide much of the pH-sensitive (higher pH is more purple) color of red wines and the flavenols that largely control the color of white wines. Much research has been done on anthocyanins in grapes and wine due to their unique properties and relatively high concentrations.[1] Concentrations of phenolics in grape juice or wine can be determined using traditional techniques of analytical spectroscopy. When color is the main interest, this entails visible-light spectrophotometry in which the percentage of light transmitted straight through a liquid sample in a cuvette (or measurement cell) of specified thickness is measured across the visible spectrum. These measurements can then be used as the basis of colorimetric analyses. This paper focusses mainly on the illumination under which the wine color is evaluated and its effect on both instrumental and sensory, or visual, analysis and then ultimately the sensory evaluation and consumer experience of the wine itself.

The spectrophotometric measurements completed in this work were further analyzed using colorimetric parameters in CIELAB and CIECAM02.[2] CIELAB is by far the most commonly used color space across all industries. The CIELAB space, published in 1976, accounts for the sample, the illumination, and the observer to predict values that correlate with perceived lightness (L*), chroma (C*), hue (h_{ab}), and redness-greenness (a*) and yellowness-blueness (b*), which directly define chroma and hue. CIELAB is most commonly used to measure color differences and define tolerances for color accuracy. CIECAM02, published in 2002, is a more modern color appearance model. It also accounts for additional viewing conditions such as the level of illumination and degree of chromatic adaptation. This allows one to use CIECAM02 for predictions of brightness (Q) and colorfulness (M) in addition to lightness (J), chroma (C) and hue (h).

Recently, Hernández *et al*.[3] measured the color of a variety of red wines in a geometry intended to simulate "a taster's eye". They measured red wine samples in standard wine samplers with simulated daylight illumination from above and the glasses tilted 45° away from the observation angle, which was normal to the front of the wine glass (45° from the table surface) as those performing wine sensory evaluation might do. Hernández *et al*.[3] found that computed CIELAB coordinates were useful in classifying the wine and that hue (h_{ab}) was most important. It is likely that other dimensions would have been more important had a greater variety of wines been assessed. They were able to show a clear correlation between hue at the rim (shortest path length) and age as well as to classify the wine types by hue at the rim. Their work shows, as expected, that careful colorimetry can perform as well as human visual assessment.

All analyses in this research were completed using the CIE 1964 Standard Colorimetric Observer, also known as the 10-degree observer. To evaluate the effects of lighting on wine perception, several illuminants and sources were evaluated. These included CIE Standard Illuminants A, D65, and F11 (representing incandescent light, average daylight, and tri-band fluorescent "office/retail lighting") and two 4000K LED sources typical of those that might be used in modern commercial or residential applications.

Sensory evaluation of wine has assumed a key and critical role in the world of viticulture, enology, and wine appreciation. Entire books have been written on the subject.[4,5] The typical normal sequence in wine tasting is to view, smell, and taste with various levels of detail and objectives for each of the senses. It is well known that visual appearance, and color in particular, can have a strong influence on smell, which in turn has a defining impact on taste and flavor.[6]

In a well-known, but sometimes misinterpreted, study, Morrot *et al.*[7] examined the impact of wine color on the sensory evaluation of odors. They had a panel of 54 tasters, undergraduate enology students from the University of Bordeaux, describe the odors perceived in two pairs of wine samples. In the first session a white (W) and a red (R) were evaluated. In the second session, the same white wine (W) was evaluated with a sample of that very white wine dyed red (RW) with a dye shown to be neutral. Being a linguistic study of odor perception, the experimenters recorded the words used to describe odors. Wine (W) was described with typical terms for yellow/light objects while typical terms for red/dark objects were used for wine (R). This is to be expected. In the second session, however, the white wine (W) was again using yellow/light object terms while the white wine dyed red (RW) was described using typical red wine descriptors (red/dark objects). The direct conclusion is that the color of the wine plays a greater role in defining perceived odor than the chemical constitution of the wine. Since taste is largely defined by odor, it is likely that this effect would have carried over into tasting the wine, but that was not tested. This study illustrates that color can have a profound impact on the sensory evaluation of wine and should be treated carefully, including thoughtful definition of viewing conditions.

Given the importance of color appearance on smell and taste, one would expect that the illumination and viewing conditions for wine sensory analysis would be well defined and standardized. Unfortunately, this is far from the case. Normally, the entire mention of lighting and viewing is limited to something along the lines of "it's best to have ample natural light and a white paper to view against". Then authors normally go on to say that when natural light is not available, make do with what is available. This is equivalent to saying that color is irrelevant, which is not the case.

Experimental

Six wines from the 2013 and 2014 vintages were selected as representative samples of three white and three red wines from around the world. The specific wines are labelled with the letters A through F to simplify designation throughout the results and discussion. Wines A-C are white wines while wines D-F are red wines. The varietals included are: A-Riesling (Finger Lakes), B-Grechetto (Umbria), C-Chardonnay (Pouilly-Fuissé), D-Pinot Noir (Oregon), E-Zinfandel (California), and F-Shiraz (Barossa). Wines were measured at room temperature (approximately 68°F/ 20°C). The particular wines selected for this work are not critical as it is just a comparative colorimetric analysis.

The first set of measurements can be characterized as traditional visible transmittance spectrophotometry using a Macbeth ColorEye 7000 spectrophotometer in transmittance mode. Measurements were made from 360nm to 750nm nm in 10nm increments and reported as percent transmittance relative to air. These were external regular transmittance measurements including the path length of wine sample and the liquid cells (cuvettes). The cell walls were retained in the measurements to avoid difficulties of index matching at the wine-cell interfaces and to most closely resemble measurements of wine in a glass. The cuvettes used included wine transmittance path lengths of 5mm, 10mm, 20mm, and 40mm. The cuvettes were 25mm square (normal to the light path) and designated as Optical Crystal Cell Type 60 "G".

The second set of measurements, referred to as *in situ* measurements, were a set of four different spectroradiometric measurements made of wine samples in ISO taster glasses under simulated daylight illumination in a standard viewing booth. Each sample was 60ml placed in a clean ISO taster glass. The viewing booth was a GTI CMB-3064 viewing booth with fluorescent daylight (D65) simulators as the selected illumination. A rig was constructed to securely hold the glass at an angle of 45°. A white standard reference plaque (near perfect white) was placed directly under the bowl of the glass to allow the wine to be viewed from above with a white background. A mirror was placed directly above the wine sample (also at 45°) to allow a spot spectroradiometer (Photo Research PR655) in the laboratory to effectively view the wine sample from above. The light source directly above the glass was blocked to avoid measurement of reflections of the diffuse white in the wine glass itself. Figure 1 is a photograph of the experimental setup with a sample glass and the spectroradiometer in place. Percent spectral transmittance of the wine (and the glass) was computed by dividing the measurements of the wine sample by the measurements of the white reference (and multiplying by 100).

FIGURE 1. The experimental setup for in situ (ISO tasting glass) wine transmittance measurements.

Finally, the glass was placed normally in the bottom of the viewing booth and measurements made from the side of the glass in the center of the sample. These measurements are referred to as "Straight" to suggest viewing the glass straight on and would be similar to the center measurements made by Huertas *et al.*[8] However, the background in these measurements was the gray booth wall, perhaps a good simulation of a real viewing environment, and transmittance was computed relative to the white reference measurement described above. It is therefore likely that the present measurements suggest the wine to be slightly darker than the prior measurements.[8]

Five illuminants were used to explore the effects of various types of illumination on apparent wine color. These are listed in Table 1 along with some descriptive data. The first represents a standardized incandescent lamp, CIE Illuminant A, with a correlated color temperature (CCT) of 2856K, a CIE color rendering index (CRI) of 100 as one of the reference points for that metric, and IES TM-30 color fidelity index of (R_f) of 100 and color gamut index (R_g) of 100. Metrics for the other illuminants can be found in Table 1. The illuminants also include CIE illuminant D65 (representing an average overcast daylight), CIE illuminant F11 (representing typical tri-band office/commercial fluorescent lighting), and two modern LED illumination systems both with 4000K correlated color temperatures (like F11) but with very different spectral characteristics. One is a common blue-pumped LED (blue LED pumping a yellow phosphor to produce white) and the second is a high-color-quality RGBA LED made up of red, green, blue, and amber LEDs to produce white. The first three illuminants allow the exploration of different types and colors of illumination while the last three allow the examination of lighting with different properties (such as color rendering) while all being nearly the same color (a slightly warm, or yellowish, white).

TABLE 1. Colorimetric Illuminants Investigated

Designation	CCT, Description	CIE CRI	TM-30 R_f, R_g
CIE Illuminant A	2856K, Incandescent Illumination	100	100,100
CIE Illuminant D65	6503K, Average Daylight	100	100,100
CIE Illuminant F11	3999K, Tri-Band Fluorescent	83	78,101
LED4K (BP)	3889K, Blue-Pumped LED, TM-30 #101	75	66, 84
LED4K (RGBA)	3993K, RGBA LED, TM-30 #155	98	94,102

Evaluation of the data was performed using both CIELAB and CIECAM02. CIELAB is a color space recommended by the CIE in 1976 for the evaluation of color tolerances and small color differences. As input, it takes the CIE tristimulus values for the sample and for the light source (to account for our adaptation to the lighting) and computes parameters that describe the lightness (L*), hue (h_{ab}), chroma (C*), redness-greenness (a*), and yellowness-blueness (b*). Relative color appearance can be described using two sets of parameters that can be derived from one another, either $L^*h_{ab}C^*$ or L*a*b*. In this paper a derivative metric, which correlates with perceived saturation is used. This saturation metric (S) is simply the chroma divided by lightness (C*/L*).[2] Thus, the lightness-hue-saturation of the wines samples ($L^*h_{ab}S$) are the CIELAB parameters of interest.

CIECAM02 was established by the CIE in 2002 as a more sophisticated space for the description of color appearance.[2] In addition to the tristimulus information for the sample and illuminant required by CIELAB, CIECAM02 also requires the absolute luminance of the lighting and parameters about the background, surround, and degree of adaptation. CIECAM02 is used in this paper to explore the effects of amount of light (luminance) and color rendering on wine appearance. Output appearance correlates from CIECAM02 include lightness (J), brightness (Q), hue (h), hue quadrature (H), chroma (C), colorfulness (M), and saturation (s). In this paper, the focus is on lightness, hue, saturation and hue quadrature (JhsH) with their importance described more fully in the results in discussion below. All CIECAM02 computations in this research were done assuming an average gray background/surround such that the only variables considered were the illumination color and level.

All of the spectral transmittance data and colorimetric parameters described above for each wine have been compiled into a single spreadsheet file that is publicly available for further analyses. It is posted on the author's website at www.rit-mcsl.org/fairchild/files/MDF_WineData.xlsx>.

Results and Discussion

Brief analysis of geometry (CIELAB)

Figure 2 shows the CIELAB lightness (L*) for illuminant D65 and the 10° observer for each of the six wines and eight measurement geometries. The four data points to the left are from cuvette measurements of different path lengths while the four data points to the right are for the various ISO taster glass measurements in the viewing booth. The three white wines (tan lines) have virtually the same lightness and show similar changes with geometry (darkening with path length and most dark in the straight side measurement). The red wines (burgundy lines) show similar trends except with more variation due to their greater density. All get darker with path length for the cuvette measurements with Wine D – Pinot Noir having the highest lightness and Wine F - Shiraz the lowest. The in-glass measurements show little effect of path length since glass reflection is controlling the lightness and the straight to the side measurements are all similar since they have very high path length (these are essentially measurements of the glass with black liquid in them). One can also observe that the in-glass edge measurements align, in lightness, with the cuvette measurements for path lengths between 20mm and 40mm.

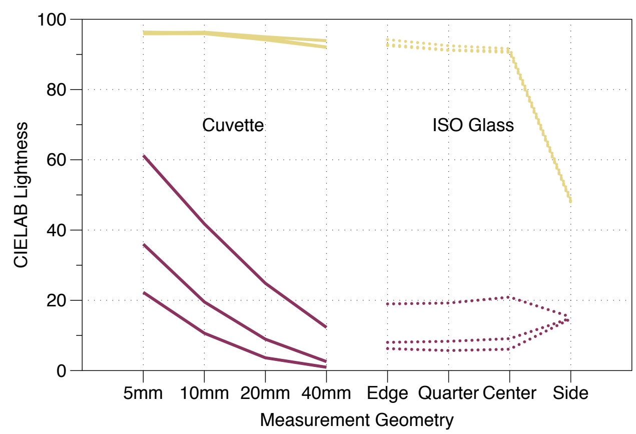

FIGURE 2. CIELAB lightness (L) for six wines and eight measurement geometries.*

Effects of luminance on color appearance

Looking in detail at Wine A - Riesling and Wine D – Pinot Noir, one can use CIECAM02 to examine the effects of luminance level on the color appearance attributes of wine. In this case, only the 20mm path length is examined and only CIE illuminant D65 is used in the computation. Three luminance levels are examined, 10 cd/m^2, 100 cd/m^2, and 1000 cd/m^2. Approximately, these can be considered to represent a dim restaurant or seminar room, a typical office or retail store, and outside under indirect illumination or light overcast, respectively.

Figures 3 and 4 show the appearance correlates for Wine A – Riesling and Wine D – Pinot Noir, respectively. For Wine A –

Riesling, the lightness (J) is relatively constant across the change in luminance levels. This wine looks light and pale regardless of amount of light. The hue (h) changes rather substantially from a slightly greenish yellow to more nearly a unique yellow at higher luminance levels. It is not clear what causes this shift, but it could be due somewhat to changes in the degree of adaptation to this lighting where the perceived hue is a "more pure" assessment of the appearance. Lastly, saturation (s) decreases with increased luminance level. While normally, saturation is thought to increase with luminance, the opposite effect is seen for very pale colors such as this wine. Essentially the observer adapts more to the wine itself (becoming less sensitive to its saturation) as luminance increases. This point illustrates that more light is not always better and that there is almost certainly an optimum middle level of illumination for wine sensory evaluation.

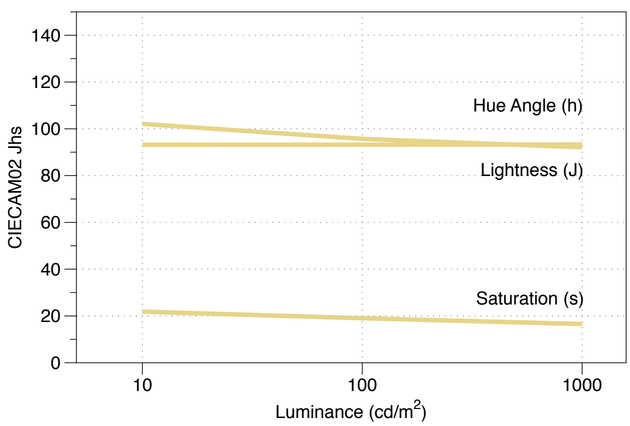

Figure 3. CIECAM02 color appearance correlates of lightness (J), hue angle (h), and saturation (s) for Wine A – Riesling across three different luminance levels with a 20mm cuvette path length. Values reported are for CIE illuminant D65.

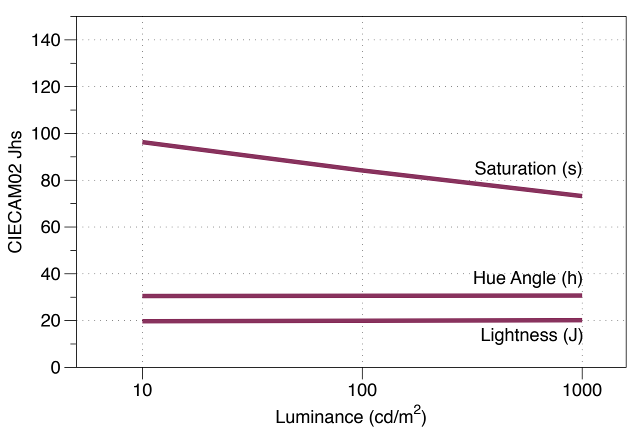

Figure 4. CIECAM02 color appearance correlates of lightness (J), hue angle (h), and saturation (s) for Wine D – Pinot Noir across three different luminance levels with a 20mm cuvette path length. Values reported are for CIE illuminant D65.

Figure 4 shows the same results for Wine D – Pinot Noir. Lightness (J) and hue (h) are almost perfectly constant for these changes in luminance level. This is a surprising result and is probably largely due to the specific hue and lightness of the wine more than anything. It is interesting that a drink that holds such a unique place in human society also happens to occupy a unique spot in color appearance space. Saturation (s), however shows a more unusual variation with luminance. Traditional color science would expect increases in both chroma and lightness with luminance level to offset and create approximately constant saturation (this is why saturation was used in this study). Instead, there is a constant lightness, along with a decrease in chroma that results in the decrease in saturation. Regardless, this does illustrate that Wine D – Pinot Noir is indeed changing appearance with luminance level and becoming less saturated, essentially less "radiant" relative to the background, at higher luminance levels and that critical sensory evaluation should pay attention to the luminance level.

Effects of lighting type on color appearance

Is wine color appearance sensitive to the color/type of illumination? Figure 5 show the CIECAM02 saturation (s) for all six wines. All computations are for the 20mm cuvette at 100 cd/m^2. It has been asserted that "any bright, white light source is probably acceptable".[9] If that were the case, then Fig. 5 would have nothing but straight lines horizontal to the x-axis for each of the six wines and all appearance dimensions. As is easily seen, that is not the case. Saturation, as well as lightness and hue, has significant dependency on the illuminant. The fluorescent (sometimes recommended) and blue-pumped LED significantly desaturate the red wines (they look less red) compared with the standard incandescent (A), daylight (D65), or the high-quality RGBA LED. The white wines are less impacted, due to their paleness, but they are also significantly influenced by lighting type.

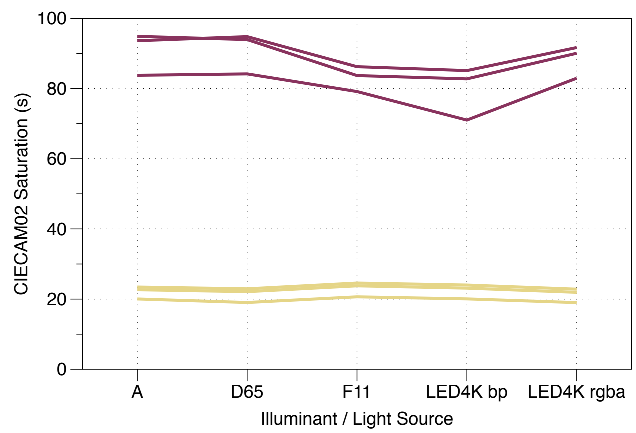

Figure 5. CIECAM02 saturation (s) for all six wines at 100 cd/m^2 with a 20mm path length and all 5 illuminants.

Hue is critically important in considering wine since it is the dimension that leads to names like purple (bluish-red), ruby (red), and garnet (yellowish-red). Thus, the hue composition bar charts for Wine A – Riesling under each of the five tested illuminants are given in Fig. 6. These are from the same computations discussed above. The hue changes from a significantly reddish-yellow to a greenish-yellow of nearly equal significance depending on the illuminant. It appears that this pale wine has a slight tendency to take on the hue of the light source. Other whites show similar results. The red wines all appear slightly-yellowish red in these conditions with Wine F – Shiraz showing the lowest yellow content. It never crossed over into purplish in these viewing conditions, but it appears it would in a low luminance incandescent (or candelight) situation. What is important for the red wines is to see how the percentage of yellow content changes significantly with the changing light source types. These range from what would be called a nice “ruby” to a strong “garnet”. Another way to think about it is that changing from daylight to fluorescent F11 or the blue-pumped LED would be a way to simulate the appearance of the wine being nicely aged.

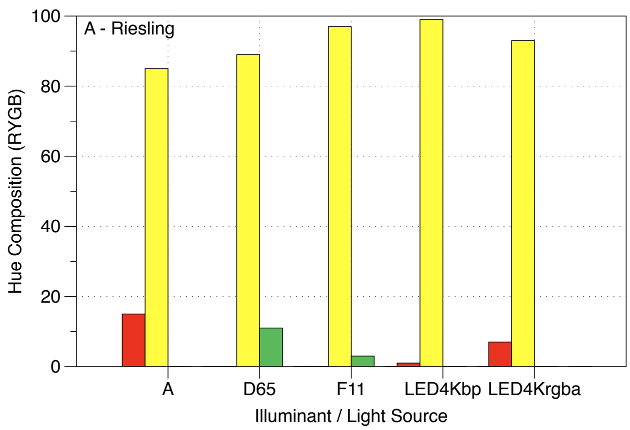

Figure 6. CIECAM02 hue composition bar charts for Wine A – Riesling for all five illuminants. In this case hue composition is dominated with the high yellow percentage and small percentages of either green or red depending on the illuminant. All computations for the 20mm path length and 100 cd/m^2.

Color rendering indices

One more detailed question to examine regarding light sources is the effect of color rendering index (CRI). To examine this, the two LED illuminants were selected both because they represent modern lighting (residential and commercial) and because they have the same color (~4000K correlated color temperature) but different color rendering indices (see Table 1). The LED4K (BP) is a blue-pumped LED in which a blue LED is used to pump a yellow phosphor to create white light. It has a CRI of 75, which is quite poor, and suggests that it will render the colors of objects under it incorrectly. The LED4K (RGBA) is a RGBA LED that produces white light with a combination of red, green, blue, and amber LEDs and has a CRI of 98, which is good enough to be used in critical color assessment applications. The changes in color witnessed here are not due to changes in the color of the illumination, but are due only to differences in the spectral power distributions of the lighting. The whites are relatively constant in lightness while all the reds increase in lightness for the RGBA lamp. Hue angle changes with lamp for most of the wines. The whites shift toward a reddish hue while the reds shift in both directions or stay roughly constant. Finally, the reds are all more saturated with the RGBA lamp due to its increased red content. The whites, on the other hand show a slight decrease in saturation.

Lastly, Figures 7-8 show hue composition bar charts for two wines and this change in color rendering index (CRI) for 4000K CCT LED lamps. Wine A – Riesling becomes significantly more reddish (still mainly yellow, of course) under the RGBA lamp. Wine D – Pinot Noir loses a significant amount of yellowness under the RGBA lamp. Each wine interacts with each illumination type in its own unique way and it should be clear that the color, the illumination level, and the spectral content (CRI) can all impact wine sensory evaluation in sometimes unexpected ways. Significant precision and accuracy improvements could be made in wine color assessment if the illumination was specified, standardized, and controlled as is done in most colorimetric applications.

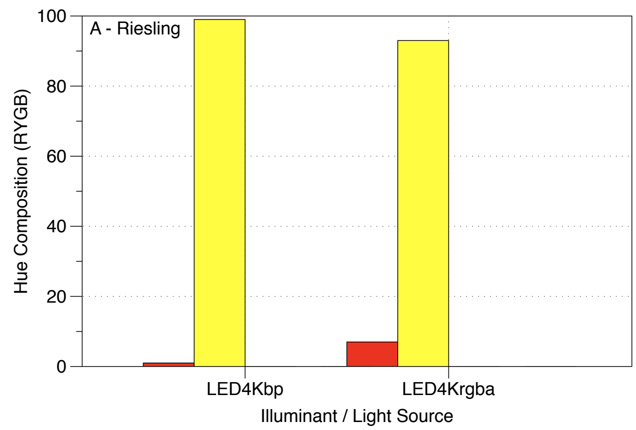

Figure 7. CIECAM02 apparent hue quadrature for Wine A – Riesling under the two LED illuminants with the same color, but different spectral properties.

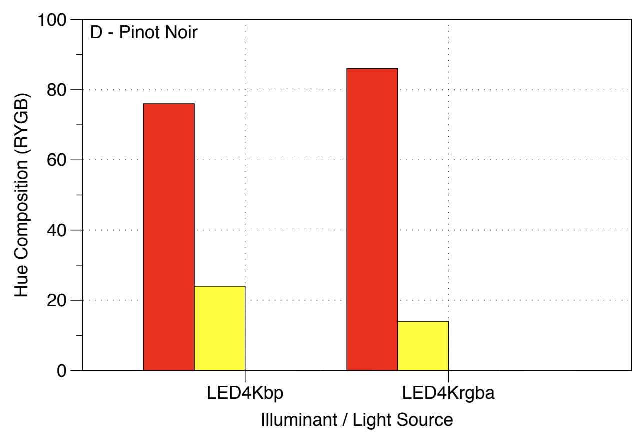

Figure 8. As in Fig. 7, but for Wine D – Pinot Noir.

Conclusion

If there is to be one conclusion drawn from the measurements and analyses, it should be that a wine has more than one color. This was illustrated through examination of two types of spectrophotometric measurement techniques with eight different illumination and viewing geometries. No two of these situations produced the same measured color. This clearly illustrates the need for standardized and controlled measurement conditions if wine color is ever to be systematically evaluated on a widespread basis.

The point was further illustrated by examining the effects on color appearance of changes in the color, type, and level of illumination. Without doubt, the variation in these results shows that standard illumination type, level, spectra, and environmental geometry are needed for meaningful sensory evaluation and inter-comparison of results across laboratories or venues. The results of this study show that typical recommendations are far too loose in lighting control for critical color evaluations.

More details on this work, including full spectral and CIELAB/CIECAM02 analyses and examination of the effects of measurement geometries, has been recently published in a comprehensive journal paper.[10]

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