Is there a need to re-define the methods to evaluate wine color

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Abstract. Both the Glories method and the CIE L*a*b*/L*C*h^0 system are used in analytical protocols to expredd the chromatic characteristics of wine [1-4]. Both emthodes allow for the interpretation of color intensity, color hue, and other chromatic characteristics. They are utilized in scientific studies to compare experimental treatments and many innovations have been assessed on whether they could retain a higher color intensity or yield ore color brilliance. The validity of the two methods and the explanatory power of the respective color parameters were investigated by comparing the two methods with data from a sensory study. Data intervals from 0.5 to 5 nm and different scan speeds were tested as spectrophotometer settings. A trained panel evaluated 112 dark red, light red and white wines from different grape varieties, origins, and vintages. The correlation between Glories system and the CIE color space was found to be strong for dark red wines ($r > -0.9$). Lighter red wines and white wines ($L^* > 20$) do not correlate with the same quality, except for the correlation between CI and L^* ($r > -0.9$). In comparison with the human perception, the red and white wines could not be distinguished well with the Glories' system. The CIE color space was found to be more suited to depict the perceived color for red and white wines. In recent years, the CIE re-defined the color distance calculation within the CIE L*a*b* color space due to non-uniformities. The CIEDE2000 color distance ΔE_{00} was proposed [4–6] for a better approximation of the erceived color than the Euclidean color distance ΔE^*_{ab}. A just noticeable distance (JND) test was carried out using triangle testing for the wines segmented into three wine color area: dark red, light red, and light yellow. For dark red wines, the JND was $\Delta E_{00} = 1.4$ or $\Delta E^*_{ab} = 3.1$, respectively. For light yellow wines, the JND was found to be much lower values at $\Delta E_{00} = 0.64$ and $\Delta E^*_{ab} = 0.60$. And for light red wines, the JND was found to be very high at $\Delta E_{00} = 3.4$ or $\Delta E^*_{ab} = 8.1$, respectively. The CIEDE2000 formula resulted in lower JND values than the Euclidean color distance. Although still not uniform for the huge diversity of wine colors, the ΔE_{00} provides better comparability and is suggested for future studies.

1 Introduction

The color of wine is known to alter sensorial impression like aroma and mouthfeel. The relationship between aroma and color was established by Morrot et al., where panelists described a red colored white wine with typical aroma descriptors for red wine, while the native uncolored wine was described with typical white wine aroma descriptors [7]. A recent study by Nguyen et al., was conducted to measure the impact of the knowledge of the wine color on the aromatic profiles of white and red wines. The intensity of the odors freen fruit, citrus fruit, and stone fruit increased in coherence with the knowledge of the color in white wine. The odors of red fuit, and oak increased in coherence with the color in red wine [8]. Apart from the correlation between color and aroma profiles, the color of wine is also important for consumer preference, perceived typicality, and regulations [9-11]. The results of these findings and regulations suggest the importance of an objective, generally applicable, and reproducible method. The wine color can be evaluated sensorially. The advantages of this method are the general applicability and the independence from mathematical approximations. A panel can be used for every purpose, research question, and wine type. However, this approach requires enough trained panelists to maintain objectivity as prior studies demonstrated the subjectivity of a sensory evaluation [8]. Furthermore, it is very time consuming and requires a vast amount of organization. Other methods like the Glories color measurement ant the CIE color space use photometry to evaluate wine color [1,12]. The advantage of the photometric methods lie in their objectivity, their simplicity, and the required time. The disadvantages of photometric methods differ depending on the method. Glories color measurement comprising the absorbance values at 420 nm, 520 nm, and 620 nm is used to calculate the Color Intensity (CI), the hue (T), and the Brillance (dA(%)), has a disadvantage regarding the general applicability. The Glories method was designed with and for dark red wines [12]. There, the use of Glories color measurement for every other wine type or style has t o be called into question. It is worth noting that the Glories color measurement is recommended by the International Organization for Wine and Vine (OIV) [3]. Besides the use of Glories measurement, the CIE L*a*b*/L*C*h^0 color space is also widely used and recommended by the OIV for the measurement of wine color [3]. Here, the complete transmission spectrum, the relative sensitivity of the human eye known as the color matching function, as well as the emitted light of the standard illuminant D65 is used to calculate the Cartesian coordinated L*, a*, and b*. The Cartesian coordinates can also be transformed to polar coordinated C* and h^0. In both coordinate systems represents the L*coordinate the lightness of an object, whereas a* the redness if positive, or the greenness if negative of an object represents. The b* coordinate describes either the yellowness if positive or the blueness if negative of an object. The C* coordinate, also known as the color vector, describes the saturation of an object. Another CIE L*a*b*/L*C*h^0 parameter h^0, also known as the hue angle, starts at 0° (360°) with the redness. At 90° the yellow hue is noted and 180° represent the greenness, whereas 270° stands for blue [2,4,13]. In general, the CIE L*a*b*/L*C*h^0 color space is considered more accurate, since it uses the relative sensitivity of the human eye to mimic the color response of the human eye, whereas Glories color measurement is easier to understand [12]. For the transmission spectrum measurement, the OIV recommends a data interval of 5 nm. However, no recommendations are given for any other photometer parameter [3]. The crucial difference between Glories' color measurement and the CIE L*a*b*/L*C*h^0 is the ability to calculate the distance between two color points. For wine color the OIV recommends the CIE76 Euclidean color distance. However, the CIE recommends the CIEDE2000 color distance formula [4-6]. It has yet to be established how the CIEDE2000 color distance formula impacts the JND in wine. The objective of the presented study is to contribute to a better understanding of color measurement of wine. It needs to be established how and if the parameter settings on the photometer and differenct photometers affects the CIE L*a*b*/L*C*h^0 color space [14]. Since both, Glories' color measurement and CIE L*a*b*/L*C*h^0, are recommended for the use in wine, it needs to be evaluated if the methods can be used interchangeably and which of the methods depict the human color perception better [14,15]. Previous studies indicate that this is not the case for light red colored wine. With a sample size of 56 red wines a correlation was performed for dark red wine with $L^* \leq 20$ ($n = 34$) and light red wine with $L^* > 20$ ($n = 22$) [14]. These results must be validated with a bigger sample size. The last part is to re-evaluate the JND with the CIEDE2000 color distance formula and compare the results to the Euclidean color difference.

2 Materials and methods

2.1 Evaluating the impact of the photometric parameters

2.1.1 Samples

Seven Merlot wines as an example for red wines were used in this study to measure the effect of the photometric parameters. Seven Chardonnay wines were used as an example for white wines. The red wines originated from France, Italy, United Stated of America, and New Zealand. The vintages ranges from 2016-2019 [14].

2.1.2 Photometric measurement

Complete transmission spectra from 200-900 nm were recorded on a JASCO double-beam photometer. The CIE L*a*b*/L*C*h^0 calculations were performed between 360 nm and 830 nm using a flow-through quarz-cuvette with a pathlength of 1 mm for red wine, whereas for white wines the 10 mm polystyrene cuvettes were used. The experiments were done in triplicates and validated on a Varian cary 100. The 14 wines were measured with data intervals ranging from 0.5 nm, 1 nm, 5 nm measured with a scan speed of 100 nm/min and 1000 nm/min (Table 1)[14]. The JASCO V-730 is equipped with a Silicon photodiode, which generates a current based on the irradiation of the n-p junction of a semiconductor [16]. The Varian Cary 100 uses a photomultiplier tube, which can generate a current when the incident light is low. This is possible due to the amplification of the incident light [17].

Table 1. Photometer comparison regarding data intervals and scan speeds used with the two different.

Data interval [nm]	Scan speed [nm/min] (V-730)	Scan speed [nm/min] (Cary 100)
0.5	100	100
0.5	1000	1000
1	100	100
1	1000	1000
5	100	-
5	1000	n.a.

2.2 Comparing different color measurements

*2.2.1 Comparing CIE L*a*b*/L*C*h^0 and Glories*

For the comparison of CIE L*a*b*/L*C*h0 and Glories color measurement 925 red wines were examined. Following the previous published classification, the data set was furthermore divided into dark red wines with an $L^* \leq 20$ and light red wines with $L^* > 20$. The dateset of the dark red wines consisted of 617 wines and the light red wines consisted of 306 wines. For white wine the sample set consisted of 56 white. The sample set is smaller, due to the lower variance of white wine color. The red wine samples were obtained during the Mundus Vini summer tasting 2022 and the color was measured immediately after opening the bottle. For the measurements a StellarRad™ (StellarNet Inc. FA, USA) handheld colorimeter in combination with a dip probe was used to record transmission spectra. The dip probe was equipped with a tip containing a 2 mm pathlength. The transmission spectra were recorded between 200 and 1100 nm. The transmission spectra were referred to a 10 mm pathlength and the CIE L*a*b*/L*C*h0 coordinates were calculated between 360 and 830 nm. Also, the color vector and the hue angle were calculated. The primary Glories parameters were extracted from the transmission spectra. After calculation of the secondary Glories parameters a Spearman correlation was performed between the Glories and CIE L*a*b*/L*C*h0 parameters. The White wines consisted of 7 wines per grape variety. The five grape varieties were used two of whom were evaluated in the two wine styles dry and sweet. The wines originated from the Germany, France, Italy, Spain, United States of America, New-Zealand, and Australia as the red wines except for Austria and the vintages ranged from 2013 to 2020 were measured as described in the previous section.

2.2.2 Comparing the human perception with analytical methods

For the comparison of the human perception and the photometric methods a total of 112 wines were used, 56 of whom were red wines and the 56 white wines described in Sect. 2.2.1. Seven red wines each from eight different grape varieties were used and the wines originated from Germany, France, Italy, Spain, United States of America, New Zealand, Australia, and Austria. The vintages ranged from 2012 to 2020. The wines were examined in a specialized sensory box that reduces as much interfering stimuli as possible. The evaluation was performed with the help of two linear line scales. The first liner line scale evaluated the darkness, respectively the lightness of a wine. The second linear line scale evaluated the perceived hue and ranged from violet to red to orange in red wine and from green to yellow to orange in white wine. The CIE L*a*b*/L*C*h0 and Glories parameters were calculated as stated in literature. The sensory panel consisted of 23 trained individuals, 11 of whom were male and 12 of whom were female. The panel was chosen demographically between 18 and 60 years. The panel had to proof their color vision and were trained with different hues of wine color [15]. 2.2.3 Re-evaluating the just noticeable difference to evaluate the JND the triangle test according to DIN EN ISO 4210:2021 was performed. For this, different blends of Cabernet Sauvignon wine and one Riesling wines were created to manipulate the hue in the dark red, light red, and light yellow color area. Undiluted Cabernet Sauvignon was used to as base wine for the dark red wine, an 8-fold dilution of Cabernet Sauvignon and Riesling was used to create the base wine of the light red color area. For the light yellow color area, the undiluted Riesling was used as base wine. The same panel as described in Sect. 2.2.2 was used [15].

2.3 Statistical analysis

For the evaluation of the impact of photometer settings on the calculation of the CIE L*a*b*/L*C*h 0 coordinates normality testing, as well as ANOVA, and Tukey Honest significant difference post hoc test, as well as the linear and nonlinear regressions were performed in Origin(Pro) (2020b, OriginLab, USA). XLSTAT (2020, ADDINSOFT, France) was used to calculate Bartlett's test to evaluate homoscedasticity. Correlation between Glories and CIE L*a*b*/L*C*h0 were calculated and visualized in Python using the pandas [18], NumPy [19], matplotlib [20], and seaborn [21] libraries.

3 Results

In Fig. 1 the impact of the data interval and scan speed is depicted for two different photometers. The bars are the averaged sum of squares deviation (SSD) and therefore show the distinguishability between the wines of the photometer settings. The error bars are the standard deviations and show the reproducibility of the measurement for each photometer setting [14]. In general, the ability to distinguish between the wines was not affected significantly. However, the reproducibility was affected by the data interval and scan speed. A higher data interval of 5 nm resulted in the lowest reproducibility. In Fig. 1 it was possible to reproduce most of these findings disregardful of the detector system. A lower data interval could minimize the error and yield a higher reproducibility. Furthermore, the results show that the data interval should not be too small. The reproducibility of the photometer with the Silicon photodiode decreased when a data interval of 0.5 nm was used. This is not the case for the photometer using a photomultiplier tube. The photomultiplier tube amplifies the signal while this is not the case for the Silicon photodiode. Therefore, it is possible that the noise of the detector has different impacts on the spectra measurement. A data interval of 1 nm in combination with 1000 nm/min yielded the highest reproducibility in both photometers.

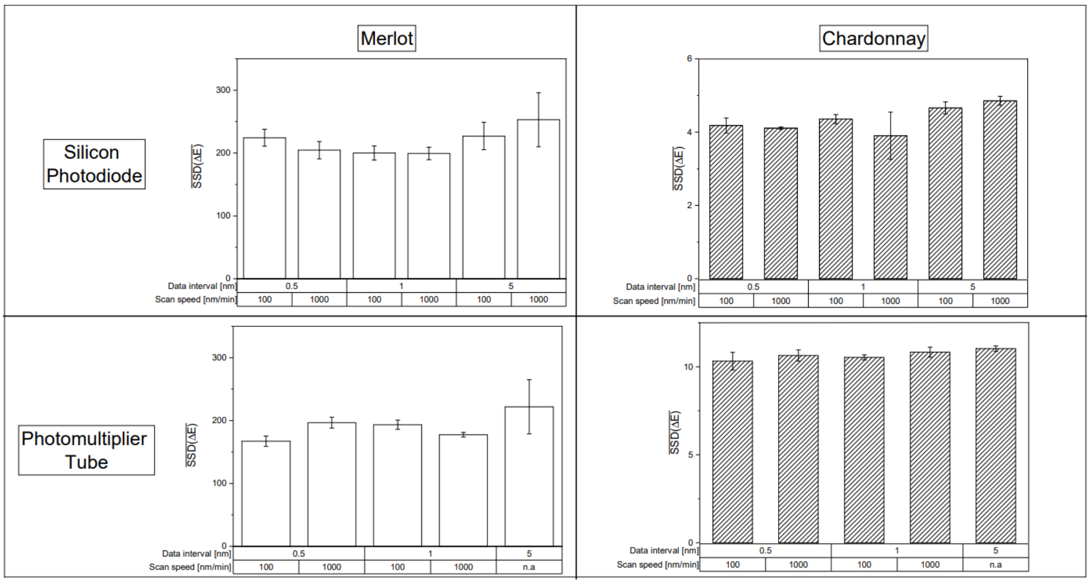

Figure 1. Influence of the photometer settings data interval and scan speed on the CIE *L**a*b*/*L**C*h^0 coordinates on using a Silicon photodiode and a photomultiplier tube as detector systems. The mean sum of squared deviations is shown with error bars (SD; *n* = 3; α = 0.05).

3.1 Correlation between CIE *L**a*b*/*L**C*h^0 and Glories

The correlation of 617 dark red wines and 306 light red wines as well as 56 white wines are displayed in Fig. 2. In Fig. 2A the examination of the dark red wines revealed a strong correlation between the optical density of the Glories parameters and the CIE color space. This is not the case for the secondary Glories parameters T and dA(%). Here, the correlation with the optical density of the primary Glories parameters and the CIE color space is very weak. However, the correlation between the *L**, a*, and b* coordinates as well as the correlation between the absorbance values of absorbance values of the Glories parameters is strong. In Fig. 2B the same correlation is depicted for the light red wines. In contrast to the correlation of the dark red wines, the correlation between the Glories color measurement and the CIE color space is in general weak. The only exception of this is the *L** coordinates that shows a strong correlation with CI of the Glories parameters. These results extend the findings of previous studies that the CIE color space and Glories' color measurement are not interchangeably usable. Prior studies hereby focused on the absorbance values of the Glories method. It is now evident that the other parameters also do not correlate with the CIE *L**a*b*/*L**C*h0 color space. To evaluate which of the methods should be used, the alignment with the human perception.

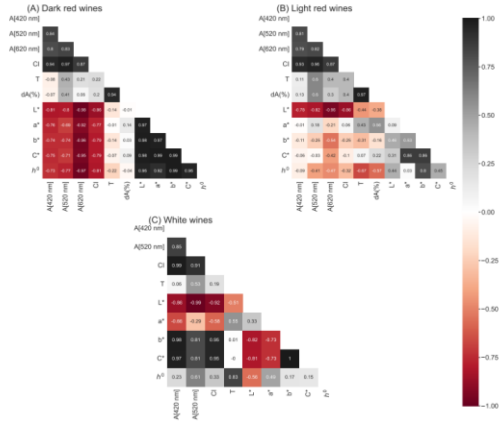

Figure 2. Spearman correlation for dark red wines (*n*=617), light red wines (*n*=308), and white wines (*n*= 56).

3.2 Comparing the human perception with the analytical methods

To evaluate which of the analytical methods depicts the human perception better, the red and white wines were evaluated by a panel and compared to the analytical methods of Glories' color measurement and CIE color space. The correlation between the primary absorbance values of Glories color measurement correlates very good with the perceived lightness (Fig. 3A). The correlation of the *L** coordinate with the perceived lightness yielded similar results for red wine (Fig. 3B).

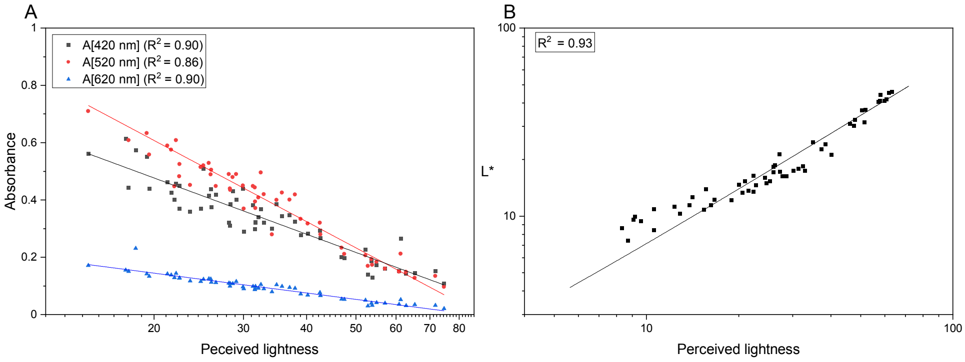

Figure 3. Regression of Glories absorbance values on the perceived lightness (A) and the *L** coordinate of the CIE color space on the perceived lightness (B) in red wine.

Figure 4A shows the regression of perceived hue and perceived lightness compared to the regression of the *L**a* projection in red wine. Figure 4B shows the regression of perceived hue and perceived lightness compared to the regression of the *L**b* projection. The correlation between the perceived color and the color obtained from the CIE *L**a*b*/*L**C*h^0 coordinates starts to deviate from each other with an increasing lightness. Regarding the perceived color, the relationship between the perceived lightness and the perceived hue is linear, whereas the relationship between the *L** coordinate and the a*, and b* coordinate respectively is non-linear. The coefficient of determination in both cases is R2 ≥ 0.9. However, this is not the case for the comparison between the perceived color and the Glories color measurement. Glories' secondary parameters dA (%) (Fig. 4C) and T (Fig. 4D) are not suited to depict the human perception of red wine color.

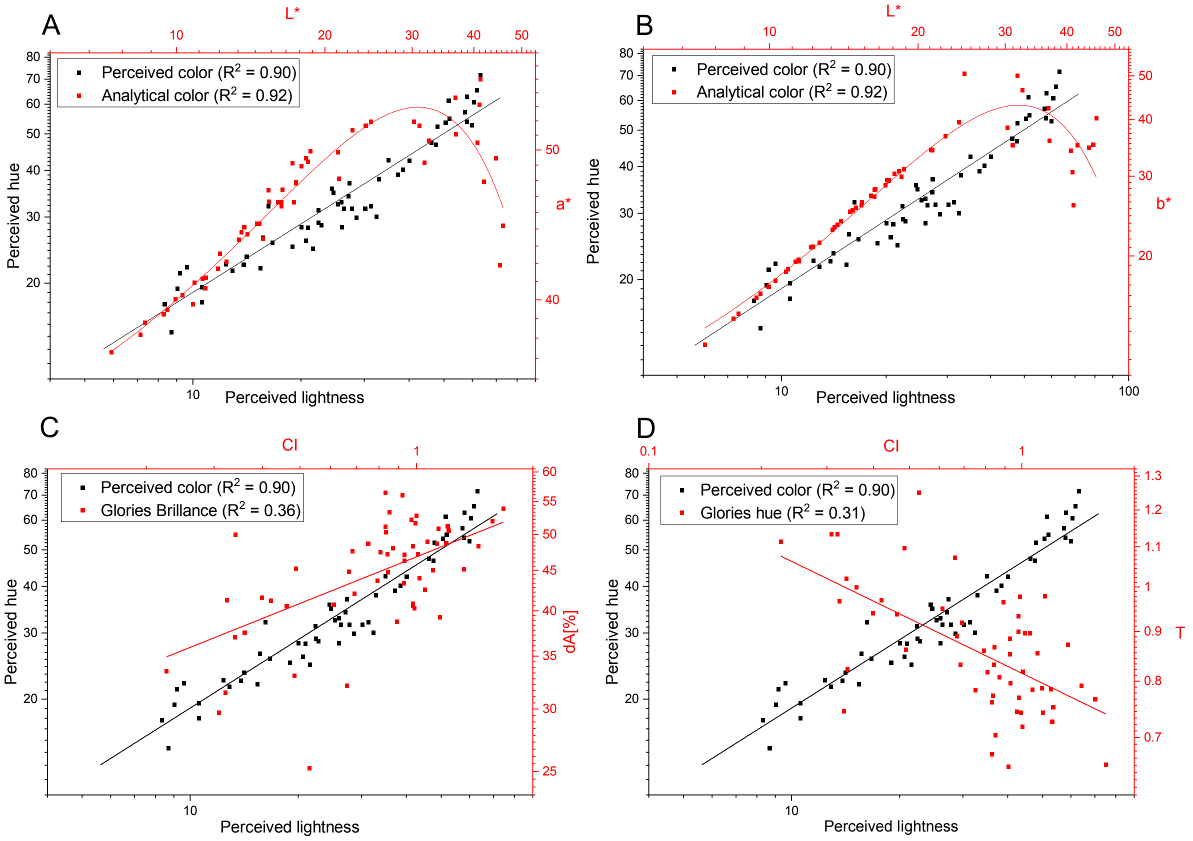

Figure 4. Regressions of perceived hue and perceived lightness compared to the regressions of the *L**a* projection (A), *L**b* projection (B), Glories' CI and T (C), as well as Glories CI and dA(%) (D) in red wine.

In Fig. 5A, the relation between the perceived lightness and the absorbance values of the Glories measurement system for white wine is shown. The same relation between the perceived lightness and the *L** coordinate is shown in Fig. 5B. Due to the low absorbance values at 620 nm only the absorbance values at 420 nm and 520 nm were used. Regarding white wines, the findings were similar to the findings in red wine. Both, the Glories color measurement, and *L** coordinate have a similar capacity to depict human perception. In Fig. 5C the perceived color is compared with Glories' hue and according to the coefficient of determination Glories hue parameter is also not suited to depict the perceived color of white wine in coherence with the findings in red wine. In Fig. 5D the comparison between the perceived color and the CIE $L^*a^*b^*/L^*C^*h^0$ color space is shown revealing a better suitability to depict the human perception. However, the regressions of white wine are not as good as the regressions for red wine.

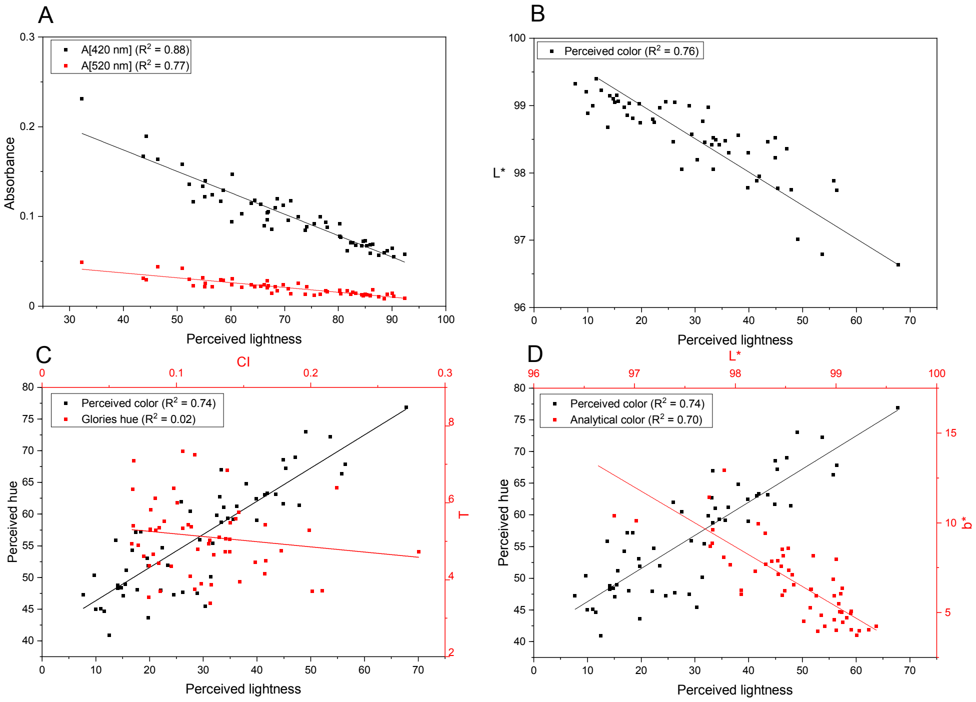

Figure 5. Regressions of Glories absorbance values and perceived lightness (A), as well as the Regression of the *L** coordinate and the perceived lightness (B). Also, the regressions of the perceived hue and perceived lightness compared to the regression of CI and T (C), and the *L**b* projection (D) in white wine.

3.3 Re-evaluating the just noticeable difference

For the JND the color difference was calculated with the Euclidean color difference (ΔE_{ab}) and the color distance according to CIEDE2000 (ΔE_{00}). The color differences are shown in Table 2. It is visible that the prior used $\Delta E_{ab} = 3$ established by Martinez et al. could be replicated [22]. However, the visible color threshold changes throughout the color areas, yielding a higher visible color threshold in the light red color area and a lower visible color threshold in the light yellow color area. Melgosa et al. established the Standardized Residual Sum of Squares (STRESS) to measure the uniformity of color spaces [5,6,23]. According to these findings and the findings of Luo et al., where the results showed tolerance ellipses in the CIE color space, the Euclidean color distance yields lower equidistance than the modernized CIEDE2000 color distance formula. However, this color distance formula is also not completely uniform, which explains why the visible color threshold is not the same disregardful of the color area. However, the range between the lowest visible color threshold and the highest visible color threshold decreases 2.7-fold, resulting in a higher degree of uniformity. Therefore, the CIEDE2000 color distance should be used instead of the Euclidean color difference with the evaluated color thresholds as a reference point.

Table 2. The JND expressed as the Euclidean color difference and the CIEDE2000 color distance [15].

Color area	ΔE^*_{ab}	ΔE_{00}
Dark red	3.1	1.4
Light red	8.1	3.4
Light yellow	0.6	0.64
$\Delta E_{Max} - \Delta E_{Min}$	7.5	2.8

4 Conclusion

In the presented work new insights on how color measurement is affected by photometers, how different photometric color measurements are correlated, and how this is in coherence with the results of the sensory evaluation were gained. For the CIE color space, the currently recommended data interval of 5 nm yielded the lowest reproducibility. A higher reproducibility was achieved by using a lower data interval of 1 nm. Furthermore, the presented work validates our understanding about the correlation between Glories' color measurement and the CIE color space. And since this section indicates that Glories and CIE L*a*b*/L*C*h0 cannot be used interchangeably the comparison showed which method better aligns with the perception of the human eye the CIE color space is recommended before Glories color system. Additionally, due to better understandings about the uniformity or lack thereof it was possible to redefine new JND's that differs in dependence of the color area. The JND expressed as the updated CIEDE2000 color distance formula is advised to use.

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