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Chemical and Sensory Effects of Storing Sauvignon Blanc Wine in Colored Bottles under Artificial Light

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ABSTRACT: The chemical and sensory effects of storing Sauvignon Blanc in colored bottles and exposing them to artificial light were examined. The colors of the bottles chosen were Dead Leaf Green, Antique Green, Amber, and Flint. The light was provided by fluorescent tubes with a regime of 16 h of exposure during 8 months of storage. The results indicated that the wine's chemical composition was affected by the type of bottle used. The Flint bottle presented the lowest concentration of total phenols. Yellow coloration was not dependent on the bottle color, as the wine in darker bottles (Amber, Antique Green, and Dead Leaf Green) had considerably more yellow color development than the wine in clear bottles. With regard to the sensory analyses performed, a trend showing an increase in color intensity and a decrease in overall aromas depending on the bottle color was observed. The wine's aromatic description changed significantly during its storage under artificial light conditions, demonstrating a decrease in vegetal aromas and an increase in citrus and tropical flavors that was dependent on the bottle color.

KEYWORDS: *bottle color, wine storage, fluorescent light, phenolic compounds, Sauvignon Blanc*

INTRODUCTION

Wine bottles in wine shops are exposed to different sources of light. To date, fluorescent lamps are one of the most widely used lighting alternatives for supermarket and shops, among others. On the other hand, a selection of colored bottles aims to produce a product that is more attractive to the consumer; however, a proper bottle color may improve the expected shelf life of the wine by diminishing the negative influence of light on the quality of the final product. Anecdotal evidence suggests that darker colored bottles tend to give more protection against the influence of light exposure, as they reduce the transmission of UV radiation.[1] This claim has been supported by evidence showing that radiation in the UV and blue regions of the visible spectrum (350−500 nm) affects the chemical composition and sensorial attributes of wine and other products, such as beer and milk.[2]

Previous work on this subject has shown that a Sauvignon Blanc wine, stored in different colored bottles and exposed to sunlight for 70 days, developed more of a yellow color in darker colored bottles (Antique Green, Classic Green) than in Flint or French Green colored bottles.[1] In this study, the wines were subjected to a wide variation in both maximum and minimum values of temperature. In a more recent study, a Chardonnay wine was exposed to radiation below 400 nm using an array of glass bottles at a constant storage temperature of 45 °C.[3] The results of that study indicated that the wine's yellow color enhancement was dependent on the color of the bottles used, with more color being generated in the wines in Flint bottles. This order is the reverse of that observed by Maury et al.[1] Furthermore, the exposure of a Chardonnay wine to a mercury vapor lamp under controlled temperature conditions (30 ± 2 °C) stimulated the following increases in wine coloration, depending on the type of bottle used, as follows: Antique Green < French Green < Arctic Blue < Flint. When the same trial was performed without controlling for temperature, the wine color development was still highest in the wine bottled in Antique Green bottles and lowest in the Flint ones.[4] This alternate order reflects the ability of darker bottles to retain heat longer than lighter colored bottles.

Previous studies have observed the effects of bottle color on the chemical composition of wine. Most of these studies used light sources that emitted large amounts of heat, leading to considerable increases in the temperature of the wine. Furthermore, the use of uncontrolled temperature conditions and the addition of (+)-catechin allowed researchers to observe changes in the chemical composition of wine over a short period of time. The Sauvignon Blanc in Chile is the first white variety to be exported[5] and is esteemed for its pale color in the international market. Although the majority of Chilean Sauvignon Blanc wines preserve their pale color during commercialization, some of them are affected by commercial storage conditions (light exposure). For this reason, it is important to understand the effects of light on chemical, physical, and sensory conditions.

The effects of the commonly used fluorescent lighting and of bottle colors typically used in the Chilean wine industry were investigated in this study by storing the wines at a constant

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temperature and assessing any sensory changes that developed after this storage. The primary aim of this study was to examine the relationship between bottle color and the development of a yellow-golden color, phenolic composition, and sensory characteristics in a Sauvignon Blanc wine after 8 months of storage.

MATERIALS AND METHODS

Reagents and Chemicals. Gallic acid (≥99%), caffeic acid (≥98%), *p*-coumaric acid (≥98%), caftaric acid (≥97%), quercetin (≥98%), and (+)-catechin (≥99%) standards were purchased from Sigma Chemical Co. (St. Louis, MO). Polyethylene membranes of a 0.22 μm pore size were acquired from EMD Millipore (Billerica, MA). Ethyl acetate (≥99.8%), diethyl ether (≥99.7%), anhydrous sodium sulfate (≥98%), glacial acetic acid (100%), ethanol (≥99.9%), hydrochloric acid (37%), and acetonitrile (HPLC-grade) (≥99.9%) were purchased from Merck (Darmstadt, Germany). All reagents were of analytical grade or higher. Ultrapure water was obtained from a Purelab Ultra MK2 purification system (Elga, St Albans, UK).

Wine Bottles. The bottles used (Bordeaux Punted model, 750 mL capacity) were provided by Cristalchile (Santiago, Chile). The bottles used in this study were designated by their trade names (Dead Leaf Green, Antique Green, Amber, and Flint) to describe their color. Groups of 25 bottles were used for each bottle color, for a total of 100 bottles. These colors were chosen because they represent the most commonly used bottles in the wine industry.

White Wine. A commercial Sauvignon Blanc wine (100 L) was provided from "Viña Veramonte" (Casablanca Valley [33°22′14″ S, 71°17′41″ W], Chile). The bottles were filled and capped with roll-on tamper-evident screw caps (Saran Tin liner) (Amcor, Hawthorn, Australia) at "Viña Veramonte". The basic chemical parameters for the wine were as follows: pH, 3.1; titratable acidity, 6.4 g/L (tartaric acid); free sulfur dioxide, 33 mg/L; total sulfur dioxide, 98.1 mg/L, reducing sugars, 1.2 g/L; ethanol, 13.9% (v/v).

Artificial Light Exposure Experiment. During the trial period (8 months), the bottles were stored in a dark room in which small temperature variations were observed (16.8 °C ± 2.9 °C) with a relative humidity of 40−50%, as registered using a VWR-4184 temperature/humidity meter (VMR International, Radnor, PA). Further details regarding the storage temperature will be given later. The bottles only received the light provided by the fluorescent tubes. The wine bottles were placed vertically inside three open cabinets, as shown in Figure 1 (height, 213 cm; width, 110 cm; depth, 52 cm). Each cabinet had four shelves, spaced at 40 cm, with two fluorescent tubes each (T10 40 W 54, standard daylight 6500 K, General Electric, Fairfield, CO), which were located 16 cm from the base of the shelf. The light emitted from the fluorescent tubes was measured using a HD9021 radiometer (Delta OHM, Padua, Italy), placing the radiometer's sensor at a distance of 20 cm from the fluorescent tubes. The incidental radiation at 20 cm from the fluorescent tubes was 68.0 ± 0.1 μmol/m^2·s. These measurements were used to delimit an area of the shelves in which radiation was uniform, to place all of the bottles within that area. The bottles were distributed at a distance of 20 cm from the light source and at a distance of 20 cm from each other. Subsequently, the light exposure regime was adjusted with a Tactic 111.0 timer (Grässlin, St. Georgen, Germany) to 16 h per day (from 8:00 to 24:00 h), with 8 h without light to simulate night-time conditions during the 8-month period of exposure. Furthermore, to assess the ability of each bottle type to limit the light radiation reaching the wine within the bottle, the radiometer recorded the incident radiation in the test room and the transmission inside the bottle. To measure the incident radiation and the transmission of light through the glass, a sensor was placed inside an empty bottle in the medium section, with the bottle located at 20 cm from the light source provided by the fluorescent tubes. All of the bottles were stored for 2 weeks to equilibrate them in the same dark room before the assay was initiated.

Figure 1. Photograph showing the open cabinets with the arrangement of the fluorescent tubes and bottles during the 8 months of storage.

Wine Chemical Analyses. The analyses were performed every month, but considering that the results did not vary much, only the results obtained every 2 months are presented. The chemical analyses at time zero (month 0) were performed after 2 weeks of storage without artificial light exposure. The wine's pH, titratable acidity (g tartaric acid/L), reduced sugar content (g glucose/L), ethanol content (% v/v), and free sulfur dioxide (mg/L) were measured according to OIV methods.[6] The total phenol content was determined by UV absorption at 280 nm using gallic acid as a standard and expressed as mg GAE (gallic acid equivalent)/L.[7] The total tannin content was measured using the method of Ribéreau-Gayon and Stonestreet.[8] Color intensity (CI) was estimated using the method described by Glories.[7] The color coordinates, lightness (L^*), chroma (C^*), hue (h^*), a^* (red-greenness), and b^* (yellow-blueness) were determined according to Ayala et al.[9] All absorbance measurements were taken with a UV−vis spectrophotometer, model UV/vis 1700 Pharmaspec (Shimadzu, Kyoto, Japan).

HPLC-DAD Analyses of Low Molecular Weight Phenolic Compounds. A 50 mL aliquot of white wine was extracted with diethyl ether (3 × 20 mL) and ethyl acetate (3 × 20 mL) to concentrate the phenolic compounds. The organics fractions were combined, dehydrated with 2.5 g of anhydrous sodium sulfate, and evaporated to dryness under a vacuum at 30 °C. The solid residue was dissolved in 2 mL of a methanol/water (1:1, v/v) solution and filtered through a 0.22 μm pore size membrane. A chromatographic system used for identification of individual phenolic compounds consisted of an Agilent Technologies 1100 series (Agilent Technologies, Santa Clara, U.S.) equipped with a diode-array detector (DAD) model G1315B, a quaternary pump model QuatPump G1311A, a degasser model G1379A, and an autosampler model G1329A. Aliquots (25 μL) of the final solution were subjected to reverse-phase chromatographic separation at 20 °C on a reverse-phase Nova Pack C_{18} column (4 μm, 3.9 mm i.d. × 300 mm; Waters Corp.). A photodiode array detector was set from 210 to 360 nm. Two mobile phases were used as follows: A, water/acetic acid (98:2 v/v); and B, water/acetonitrile/acetic acid (78:20:2 v/v/v). A gradient was applied at a flow rate of 1.0 mL/min from 0 to 55 min and 1.2 mL/min from 55 to 90 min as follows: 100−20% A, 20−10% A from 55 to 57 min, 10−0% A from 57 to 90 min. Each major peak in the HPLC chromatograms of the extracts was characterized by both the retention time and the absorption spectrum (from 210 to 360 nm), according to Peña-Neira et al.[10] Quantitative determinations were performed using the external standard method on commercial standards. The calibration curves were produced by injecting the standard solutions before an extraction, under the same conditions as for the samples analyzed, over the range of concentrations observed ($r^2 \geq 0.93$). Quercetin glycosides, for which no standards were available, were quantified using standard curves for quercetin. All of the qualitative and quantitative analyses of phenolic

composition (including their extraction step) were performed in triplicate.[11]

Sensory Evaluation. The sensory panel consisted of personnel (five females and seven males) from the Department of Agro-industry and Enology, ranging in age from 24 to 53 years. All of the judges had previous experience with sensory analysis in white wines. An initial training session was conducted for the recognition of aromatic references. The training consisted of a familiarization exercise with aromatic descriptors by using fresh and processed fruits and vegetables to exemplify the most common aromatic descriptors founded in Sauvignon Blanc wines. The evaluation sessions were performed in individual tasting booths, in a temperature-controlled room set at 20 °C. A total of 20 mL of wine was served at 10−11 °C in wine-tasting glasses (Arcoroc, Arques, France) after being labeled with a three-digit code using a completely randomized order. Each wine was evaluated with regard to two sensory attributes, color intensity, and aromatic intensity, on a 15 cm unstructured linear scale, anchored from "low" to "high" intensity. Furthermore, the judges analyzed the aromatic descriptors of each wine. The flavor descriptors appropriate for discriminating among wines are provided in Table 1. The judges chose a series of flavor descriptors, and the descriptors with the highest scores were chosen after the evaluation and expressed as a percentage. These terms were derived from previous studies of aromatic properties in Sauvignon Blanc wines.[12,13] All judges rated each wine in duplicate. The data were collected using the Fizz software (ver. 2.47b, Biosystemes, Couternon, France). The evaluation sessions lasted approximately 3 h each and were performed every 2 months.

Table 1. Flavor Descriptors and Reference Materials Used in Association with Each Descriptor

typicity	groups	aromas	reference material
vegetal	fresh vegetables	leaves/stems	green leaves
		grass	freshly cut grass
		green capsicum	green capsicum slice
		green pepper	green pepper slice
		tomato stalk	tomato stalks
		boxwood/cat urine	boxwood leaves
	canned/cooked	green beans	fresh green beans
		asparagus	canned asparagus
		green olives	canned green olives
		artichoke	canned artichoke
citric	citrus fruits	grapefruit	grapefruit slices
		lemon	lemon slices
		orange	orange slices
		lemon peel	lemon peel
tropical	tropical fruits	pineapple	pineapple slice
		melon	melon piece
		banana	banana piece
		cherimoya	cherimoya piece
others	stone fruits	apricot	fresh apricot slice
		peach	fresh peach slice
	pome fruits	green apple	fresh green apple slice

Statistical Analyses. Analysis of variance (ANOVA) and the Tukey's Honestly Significant Difference (HSD) test were used to separate the means at a significance level of 95% ($p < 0.05$). All of the chemical and physical analyses were performed in triplicate. The sensory data were analyzed by ANOVA and Least Significance Difference (LSD) test ($p < 0.05$). All statistical analyses were conducted using Statgraphics Centurion (ver. 15.2, Statpoint Technologies, Warranton, VA) and Excel 2007 version 12.0 (Microsoft Corp., Redmond, WA).

RESULTS AND DISCUSSION

Characterization of Bottle Type. To assess the ability of each bottle type to limit the light radiation reaching the wine within the bottle, a radiometer was used to record the incident radiation and the transmission inside the bottle. Table 2 compares the light transmission for the four types of bottles. The Flint bottles had the highest incident radiation with a value of 56.2 μmol/m^2·s. The colored bottles showed a range of incident radiation from 20.3 to 21.5 μmol/m^2·s with slight differences among them. The Flint bottles also had the highest value of transmittance. These results are corroborated by those in the study of Maury et al.,[1] who showed that the highest percentage of transmittance corresponded to the Flint bottles and that the lowest corresponded to the colored bottles. These authors showed that the Flint bottle is capable of transmitting all visible and some UV light; however, darker bottles reduce the amount of visible light reaching the sample and allow only a small amount of UV light to be transmitted.

Table 2. Radiation and Transmittance Percentages in Bottles[a]

bottles	incident radiation (μmol/m^2·s)	transmittance (%)
Dead Leaf Green	20.3 ± 0.2 c	29.9 ± 0.2 c
Antique Green	20.2 ± 0.1 c	29.8 ± 0.2 c
Amber	21.5 ± 0.2 b	31.7 ± 0.2 b
Flint	56.2 ± 0.3 a	82.7 ± 0.4 a

[a]All data are expressed as the mean ± standard deviation ($n = 3$). Different letters among bottle color indicate significant differences ($p < 0.05$) according to Tukey's HSD test.

Chemical Composition of the Wines. Table 3 shows the values of titratable acidity, pH, free sulfur dioxide, and phenolic composition of wine samples. The pH varied from 3.05 to 3.25. With regard to titratable acidity, the values varied from 6.1 to 6.6 g tartaric acid/L. The free SO_2 varied from 27.3 to 33.7 mg/L. These results were in agreement with data from white wines in previous studies.[14,15] No differences were observed in the concentration of total phenols at time 0.

From the second month onward, a slight increase in total phenol concentration was observed in all colored bottles as compared to the Flint ones. The increase in the content of total phenols in the first months could be due to a hydrolysis reaction and complex formation.[16,17] Moreover, the study of Maury et al.[1] on different colors of wine bottles showed a decrease in absorbance at 280 nm in Flint and Green bottles, coinciding with the lowest concentration of total phenols in the Flint bottle.

Regarding the analysis of the total tannins, there was an increase in the concentration across all treatments during wine storage, although an initial decrease was observed in the first month in the dark bottles; however, it is possible that this variation was due to experimental error. The Bate−Smith assay was utilized for the quantification of the total tannins and can be influenced by several variables that might affect the kinetics of color formation. For example, the incomplete transformation of proanthocyanidins into anthocyanidins has reaction yields that depend on both the structure and the polymerization degree of the proanthocyanidins.[18] The medium conditions and the presence of light may also have caused a depolymerization of the more polymerized tannins, leading to the consequent release of less polymerized tannins, procyanidins, and monomers, causing a greater reactivity of these compounds, specifically polymerized tannins and procyanidins in the acid-catalyzed oxidative depolymerization of these compounds.[19]

Table 3. Phenolic Composition and Chemical Parameters in Sauvignon Blanc Wines in Different Bottle Colors under Artificial Light Conditions during the 8 Months of Storage[a]

time (months)	bottles	total phenols (mg GAE/L)	total tannins (mg CE/L)	pH	titratable acidity (g tartaric acid/L)	free SO_2 (mg/L)
0	Dead Leaf Green	199.7 ± 5.2 Ba	60.3 ± 5.4 ABCa	3.21 ± 0.0 Ba	6.4 ± 0.0 Aa	32.0 ± 1.3 Aa
	Antique Green	196.4 ± 2.1 Ba	45.1 ± 4.5 Cb	3.20 ± 0.0 Ba	6.4 ± 0.0 Aa	31.2 ± 0.7 Ba
	Amber	197.5 ± 3.5 ABa	55.9 ± 1.9 ABab	3.22 ± 0.0 Ba	6.4 ± 0.0 Aa	33.3 ± 1.3 Aa
	Flint	191.9 ± 1.8 Ca	55.7 ± 5.4 ABab	3.21 ± 0.0 Ba	6.4 ± 0.0 Aa	33.0 ± 0.7 Aa
2	Dead Leaf Green	210.5 ± 3.8 Aa	49.5 ± 4.7 Cab	3.06 ± 0.0 Da	6.6 ± 0.2 Aa	29.0 ± 0.7 Bab
	Antique Green	205.2 ± 0.3 Ab	62.1 ± 6.0 Aa	3.05 ± 0.0 Da	6.4 ± 0.2 Aa	29.0 ± 0.7 Cab
	Amber	201.0 ± 0.3 Ab	48.9 ± 4.5 Bb	3.05 ± 0.0 Da	6.4 ± 0.0 Aa	30.0 ± 0.7 Ba
	Flint	201.7 ± 0.4 Ab	44.9 ± 4.1 Bb	3.06 ± 0.0 Da	6.4 ± 0.0 Aa	27.3 ± 0.7 Bb
4	Dead Leaf Green	196.3 ± 0.2 Bab	53.4 ± 5.1 BCab	3.17 ± 0.0 Ca	6.6 ± 0.2 Aa	29.0 ± 0.7 Bab
	Antique Green	196.8 ± 0.2 Ba	51.0 ± 2.0 BCb	3.17 ± 0.0 Ca	6.6 ± 0.2 Aa	28.2 ± 0.0 Ca
	Amber	194.3 ± 0.6 Bc	64.4 ± 6.4 Aa	3.16 ± 0.0 Ca	6.6 ± 0.2 Aa	30.0 ± 0.7 Bb
	Flint	195.4 ± 0.6 Bbc	59.0 ± 4.5 Aab	3.16 ± 0.0 Ca	6.4 ± 0.2 Aa	27.3 ± 0.7 Ba
6	Dead Leaf Green	196.3 ± 0.1 Bb	65.9 ± 5.0 ABa	3.24 ± 0.0 Aa	6.4 ± 0.0 Aa	33.3 ± 0.0 Aa
	Antique Green	198.6 ± 0.2 Ba	60.8 ± 2.9 ABa	3.25 ± 0.0 Aa	6.4 ± 0.0 Aa	32.0 ± 1.3 ABa
	Amber	199.9 ± 1.0 Aa	64.2 ± 1.5 Aa	3.25 ± 0.0 Aa	6.4 ± 0.0 Aa	33.3 ± 0.0 Aa
	Flint	192.4 ± 0.2 BCc	58.3 ± 4.9 ABa	3.25 ± 0.0 Aa	6.4 ± 0.0 Aa	29.0 ± 0.7 Bb
8	Dead Leaf Green	198.6 ± 1.3 Ba	70.9 ± 7.0 Aa	3.18 ± 0.0 Ca	6.1 ± 0.0 Ba	27.0 ± 1.3 Bc
	Antique Green	198.4 ± 0.3 Ba	62.1 ± 2.4 Aa	3.17 ± 0.0 Cab	6.1 ± 0.0 Ba	34.0 ± 0.7 Aa
	Amber	199.0 ± 0.3 Aa	62.9 ± 3.2 Aa	3.16 ± 0.0 Cb	6.1 ± 0.0 Ba	31.2 ± 0.7 ABab
	Flint	194.5 ± 0.2 ABb	67.8 ± 6.7 Aa	3.16 ± 0.0 Cb	6.1 ± 0.0 Ba	29.0 ± 1.5 Bbc

[a]All data are expressed as the mean ± standard deviation ($n = 3$). Different lowercase letters indicate significant differences ($p < 0.05$) between bottle colors in each month according to Tukey's HSD test. Different uppercase letters indicate significant difference ($p < 0.05$) for each bottle color during time storage according to Tukey's HSD test. GAE, gallic acid equivalent; CE, (+)-catechin equivalent.

These effects could have resulted in an increase in the value of total tannins quantified by this method.

Table 4 shows the content of some of the major low-molecular-weight phenols in Sauvignon Blanc white wines. The hydroxybenzoic acid quantified was gallic acid, and the hydroxycinnamic acids quantified were caftaric, *cis*-caffeic, *trans*-caffeic, and *p*-coumaric acids. The flavanol quantified was (+)-catechin, and the flavonols quantified were quercetin-3-glucoside, quercetin-3-galactoside, and quercetin. All of these compounds were detected in all of the wines used in this study.

The compounds exhibiting higher concentrations were *trans*-caffeic, caftaric, and *p*-coumaric acids. At time zero (month 0), the greatest differences in concentration were observed, with the highest concentrations of gallic acid, (+)-catechin, caftaric acid, *p*-coumaric acid, and quercetin-3-galactoside being noted in colored bottles, especially in Dead Leaf Green bottles. By contrast, Flint bottles presented a lower content of these compounds.

During storage under artificial light conditions, there was varying behavior in some of the phenolic compounds analyzed. With regards to phenolic acids, *cis*-caffeic acid, a slight increase in concentration during storage was observed, while instead caftaric acid showed a decrease in their concentration. On the other hand, gallic and *trans*-caffeic acids showed a more erratic behavior. The concentration of *p*-coumaric acid decreased substantially in Flint bottles, especially toward the end of the assay. During wine aging, both depolymerization and condensation occur. The storage conditions are expected to strongly affect the content of phenols, because they can undergo modifications during storage, mainly due to hydrolysis (enzymatic or not), oxidations, and complexations that are mainly responsible for the increase of simpler compounds, such as free phenolic acids, especially in colored bottles[16,17] that could support the behavior of some compounds in this assay. Cleavage of interflavan bonds of proanthocyanidins could happen at the pH of wine.[20] According to Schofield et al.,[19] the interflavan links in most condensed tannins may be broken under acid condition. In general, an increase in (+)-catechin concentration during wine storage was observed. This pattern may be due to the medium conditions, in which the combination of low pH (3.05−3.25) and the presence of light were able to cause a depolymerization of the higher molecular mass flavanols (i.e., condensed tannins) and the concomitant release of (+)-catechin monomers.[21] This hypothesis can be supported by the analysis of total tannins, wherein the presence of light and medium conditions could cause the depolymerization of more polymerized condensed tannins and consequent (+)-catechin release (Table 3).

Concerning the flavonols identified, there were different behaviors among them during storage under artificial light conditions. With respect to quercetin-3-glucoside, there were no differences between bottle colors and only minor, erratic differences throughout the time of storage. In contrast, quercetin-3-galactoside showed a clear decrease in concentration during storage that resulted in nondetectable values from the sixth month of storage onward; only in month 0 were differences among bottle color found to occur at a higher concentration in colored bottles. Moreover, quercetin was the predominant flavonol quantified in all samples, demonstrating an increased concentration throughout the wine storage period with no differences among bottle colors. This increase could be due to the hydrolysis reaction (enzymatic or not) that was mainly responsible for the increase in the number of simpler compounds,[16,17] such as quercetin, and was supported by the observed decrease in quercetin-3-galactoside throughout storage. These reactions may be accelerated by the presence of light.

Table 4. Mean and Standard Deviations Values (mg/L) for Wine Phenolic Compounds As a Result of the Exposition of Sauvignon Blanc Wines in Different Bottle Colors under Artificial Light Condition during 8 Months of Storage[a]

compounds	months	Dead Leaf Green	Antique Green	Amber	Flint
gallic acid	0	0.37 ± 0.03 Aa	0.32 ± 0.03 BCab	0.32 ± 0.02 Bab	0.28 ± 0.03 Cb
	2	0.41 ± 0.02 Aa	0.40 ± 0.05 ABa	0.42 ± 0.01 Aa	0.43 ± 0.03 ABa
	4	0.48 ± 0.04 Aa	0.43 ± 0.04 Aa	0.44 ± 0.01 Aa	0.51 ± 0.06 Aa
	6	0.32 ± 0.03 Aab	0.31 ± 0.01 Cb	0.34 ± 0.00 Bab	0.36 ± 0.01 BCa
	8	0.42 ± 0.03 Aa	0.43 ± 0.01 Aa	0.43 ± 0.02 Aa	0.45 ± 0.02 ABa
(+)-catechin	0	0.55 ± 0.12 Aa	0.34 ± 0.01 Cb	0.39 ± 0.03 Bab	0.23 ± 0.02 Db
	2	0.37 ± 0.10 Aa	0.50 ± 0.06 BCa	0.39 ± 0.01 Ba	0.43 ± 0.05 CDa
	4	0.36 ± 0.08 Aa	0.40 ± 0.11 BCa	0.34 ± 0.04 Ba	0.53 ± 0.19 BCa
	6	0.62 ± 0.08 Aa	0.67 ± 0.22 ABa	0.69 ± 0.09 Aa	0.82 ± 0.09 Aa
	8	0.71 ± 0.11 Aa	0.84 ± 0.09 Aa	0.68 ± 0.08 Aa	0.80 ± 0.06 ABa
caftaric acid	0	1.81 ± 0.13 Aa	1.59 ± 0.14 Aab	1.53 ± 0.16 BCab	1.30 ± 0.15 BCb
	2	1.70 ± 0.14 ABa	1.62 ± 0.21 Aa	1.81 ± 0.05 Aa	1.70 ± 0.15 Aa
	4	1.59 ± 0.18 ABa	1.17 ± 0.12 Ba	1.33 ± 0.07 CDa	1.40 ± 0.13 ABCa
	6	1.37 ± 0.16 Ba	1.28 ± 0.08 ABa	1.23 ± 0.06 Da	1.15 ± 0.07 Ca
	8	1.50 ± 0.10 ABa	1.56 ± 0.09 Aa	1.68 ± 0.05 ABa	1.52 ± 0.08 ABa
cis-caffeic acid	0	0.34 ± 0.02 Aa	0.31 ± 0.03 Ba	0.32 ± 0.04 Ba	0.28 ± 0.03 Ba
	2	0.41 ± 0.03 Aa	0.38 ± 0.05 ABa	0.43 ± 0.01 Aa	0.40 ± 0.03 ABa
	4	0.42 ± 0.05 Aa	0.38 ± 0.06 Ba	0.39 ± 0.01 Aa	0.48 ± 0.09 Aa
	6	0.44 ± 0.06 Aa	0.33 ± 0.03 Ba	0.37 ± 0.02 ABa	0.35 ± 0.02 ABa
	8	0.44 ± 0.02 Aa	0.48 ± 0.03 Aa	0.41 ± 0.03 Aa	0.39 ± 0.10 ABa
trans-caffeic acid	0	2.10 ± 0.11 Aa	1.97 ± 0.20 ABa	1.88 ± 0.08 Ba	1.70 ± 0.14 Ba
	2	2.06 ± 0.14 ABa	2.12 ± 0.28 Aa	2.19 ± 0.01 Aa	2.07 ± 0.06 Aa
	4	2.10 ± 0.11 Aa	1.66 ± 0.09 Bb	1.80 ± 0.08 Bab	1.88 ± 0.16 ABab
	6	1.69 ± 0.12 Ca	1.59 ± 0.09 Ba	1.48 ± 0.08 Cab	1.34 ± 0.06 Cb
	8	1.77 ± 0.12 BCa	1.85 ± 0.03 ABa	1.94 ± 0.11 Ba	1.81 ± 0.03 ABa
p-coumaric acid	0	1.40 ± 0.04 Aa	1.32 ± 0.12 ABab	1.30 ± 0.07 Cab	1.16 ± 0.09 Bb
	2	1.36 ± 0.06 ABa	1.40 ± 0.19 Aa	1.50 ± 0.00 ABa	1.37 ± 0.02 Aa
	4	1.06 ± 0.06 Ca	1.04 ± 0.05 Ba	1.51 ± 0.02 ABa	1.02 ± 0.01 Ca
	6	1.18 ± 0.08 Ca	1.17 ± 0.07 ABa	1.44 ± 0.03 Ba	1.10 ± 0.03 BCa
	8	1.19 ± 0.07 BCa	1.31 ± 0.02 ABa	1.57 ± 0.05 Aa	1.21 ± 0.04 Ba
quercetin-3-glucoside	0	0.28 ± 0.03 Aa	0.28 ± 0.03 Ba	0.27 ± 0.03 Ba	0.22 ± 0.02 Ca
	2	0.42 ± 0.09 Aa	0.39 ± 0.07 Aa	0.48 ± 0.02 Aa	0.41 ± 0.03 ABa
	4	0.36 ± 0.02 Aa	0.34 ± 0.04 ABa	0.34 ± 0.05 ABa	0.45 ± 0.10 Aa
	6	0.44 ± 0.11 Aa	0.25 ± 0.02 Ba	0.23 ± 0.07 Ba	0.28 ± 0.02 BCa
	8	0.29 ± 0.06 Aa	0.30 ± 0.02 ABa	0.28 ± 0.09 Ba	0.29 ± 0.04 BCa
quercetin-3-galactoside	0	0.51 ± 0.05 Aa	0.45 ± 0.05 Aab	0.46 ± 0.04 Aab	0.36 ± 0.03 Ab
	2	0.40 ± 0.15 ABa	0.35 ± 0.08 ABa	0.42 ± 0.02 Aa	0.34 ± 0.04 Aa
	4	0.29 ± 0.03 Ba	0.24 ± 0.01 Ba	0.26 ± 0.01 Ba	0.35 ± 0.11 Aa
	6	nd	nd	nd	nd
	8	nd	nd	nd	nd
quercetin	0	0.47 ± 0.06 Ba	0.47 ± 0.07 Ba	0.41 ± 0.03 Ca	0.35 ± 0.05 Ba
	2	0.72 ± 0.06 Aa	0.70 ± 0.06 Aa	0.74 ± 0.00 Ba	0.75 ± 0.13 Aa
	4	0.89 ± 0.16 Aa	0.75 ± 0.04 Aa	0.77 ± 0.02 Ba	0.79 ± 0.02 Aa
	6	0.93 ± 0.31 Aa	0.78 ± 0.04 Aa	0.82 ± 0.05 ABa	0.70 ± 0.06 Aa
	8	0.81 ± 0.15 Aa	0.80 ± 0.05 Aa	0.91 ± 0.05 Aa	0.74 ± 0.03 Aa

[a]All data are expressed as mean ± standard deviation ($n = 3$). Different lowercase letters in a row indicate significant differences ($p < 0.05$) between bottle colors in each month according to Tukey's HSD test. Different uppercase letters in a column indicate significant difference ($p < 0.05$) for each bottle color during time storage according to Tukey's HSD test. nd: not detected.

Regarding wine color, storage under artificial light conditions produced differences in the L^* parameter, which was significantly affected only in the treatments with a lower transmittance percentage, such as Antique Green and Dead Leaf Green bottles (Table 5). The Flint bottle showed a lower value of the parameter C^* throughout the 8 months of storage. This suggests that the higher value of C^* occurring in dark bottles may be linked to the production of pigments that contribute a higher color intensity and browning. The relationship between the loss of luminance (L^*) and the increase of chroma (C^*) is a characteristic of white wines stored for a certain time.[22] The hue values (h^*) differed among all bottle colors in their amounts, suggesting that most of the wines presented a medium yellow color, with a slight tendency toward green.[17,22] Regarding the color coordinates a^* and b^*, the Flint bottle presented the lowest values. The colored bottles showed a greater tendency toward red-greenness or yellow-blueness, especially the Amber bottle, which presented the highest value in coordinate b^*.

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Table 5. Color Coordinates in Sauvignon Blanc Wines in Different Bottle Colors under Artificial Light Conditions during the 8 Months of Storage[a]

time (months)	bottle types	L^*	C^*	h^*	a^*	b^*
0	Dead Leaf Green	99.37 ± 0.06 Ca	3.47 ± 0.03 ABa	95.88 ± 0.07 Ca	−0.35 ± 0.01 Bd	3.45 ± 0.03 Ab
	Antique Green	99.30 ± 0.00 Ca	3.46 ± 0.00 Ba	94.84 ± 0.16 Cb	−0.29 ± 0.01 Bb	3.45 ± 0.01 Bb
	Amber	99.30 ± 0.00 Ca	3.58 ± 0.01 Bb	95.34 ± 0.08 Ec	−0.33 ± 0.01 Ac	3.56 ± 0.01 Ba
	Flint	99.37 ± 0.06 Ca	2.84 ± 0.01 Ab	94.30 ± 0.09 Dd	−0.21 ± 0.01 Aa	2.84 ± 0.01 Ac
2	Dead Leaf Green	99.70 ± 0.00 Ab	3.26 ± 0.04 Dc	102.73 ± 0.55 Ab	−0.72 ± 0.03 Da	3.19 ± 0.05 Cc
	Antique Green	99.70 ± 0.00 Ab	3.41 ± 0.02 BCb	103.43 ± 0.12 Aab	−0.79 ± 0.01 Db	3.32 ± 0.02 Cb
	Amber	99.70 ± 0.00 Ab	3.58 ± 0.01 Ba	103.40 ± 0.53 Aab	−0.83 ± 0.03 Eb	3.49 ± 0.01 Ca
	Flint	99.80 ± 0.00 Aa	2.74 ± 0.05 Bd	104.07 ± 0.57 Aa	−0.66 ± 0.02 Da	2.65 ± 0.06 Bd
4	Dead Leaf Green	99.53 ± 0.06 Bb	3.29 ± 0.06 CDb	101.47 ± 0.29 Ba	−0.65 ± 0.03 Cb	3.23 ± 0.06 BCb
	Antique Green	99.70 ± 0.00 Aa	3.36 ± 0.02 Cb	102.93 ± 0.12 Aa	−0.75 ± 0.01 Dc	3.28 ± 0.03
	Amber	99.67 ± 0.06 Aa	3.59 ± 0.01 Ba	102.10 ± 0.44 Ba	−0.75 ± 0.03 Dc	3.50 ± 0.01 Ca
	Flint	99.73 ± 0.06 Aa	2.40 ± 0.05 Dc	101.33 ± 1.25 Ba	−0.47 ± 0.05 Ca	2.35 ± 0.06 Dc
6	Dead Leaf Green	99.60 ± 0.00 ABa	3.38 ± 0.03 BCb	100.7 ± 0.44 Ba	−0.63 ± 0.03 Cc	3.32 ± 0.02 Bc
	Antique Green	99.40 ± 0.00 Bb	3.42 ± 0.03 BCb	97.91 ± 0.70 Bb	−0.47 ± 0.03 Cb	3.40 ± 0.03 Bb
	Amber	99.53 ± 0.06 Ba	3.71 ± 0.01 Aa	100.53 ± 0.51 Ca	−0.68 ± 0.03 Cc	3.65 ± 0.02 Aa
	Flint	99.60 ± 0.00 Ba	2.51 ± 0.02 Cc	98.05 ± 0.47 Cb	−0.35 ± 0.03 Ba	2.48 ± 0.02 Cd
8	Dead Leaf Green	99.03 ± 0.06 Db	3.49 ± 0.02 Ac	89.18 ± 0.33 Dd	0.047 ± 0.01 Aa	3.49 ± 0.02 Ac
	Antique Green	99.10 ± 0.00 Db	3.61 ± 0.04 Aa	91.77 ± 0.20 Dc	−0.11 ± 0.01 Ab	3.61 ± 0.04 Ab
	Amber	99.37 ± 0.06 Ca	3.76 ± 0.04 Ab	99.08 ± 0.29 Da	−0.59 ± 0.02 Bd	3.71 ± 0.04 Aa
	Flint	99.47 ± 0.06 Ca	2.70 ± 0.02 Bd	97.79 ± 0.25 Cb	−0.37 ± 0.01 Bc	2.68 ± 0.01 Bd

[a]All data are expressed as the mean ± standard deviation ($n = 3$). Different lowercase letters indicate significant differences ($p < 0.05$) between bottle colors in each month according to Tukey's HSD test. Different uppercase letters indicate significant difference ($p < 0.05$) for each bottle color during time storage according to Tukey's HSD test.

Surprisingly, the color intensity of the Flint bottles presented values significantly lower ($p < 0.05$) than those of the colored bottles during the 8 months of storage (Figure 2), which is in agreement with the lowest value of C^* in Flint bottles (Table 5). Maury et al.[1] proposed that dark colored glass absorbs and retains more heat, driving pigmentation development in these bottles. Moreover, the higher retention of heat possibly occurring in dark bottle and the high composition of iron oxide[23,24] could result in a higher absorption of UV, visible, and infrared light and a higher production of pigments that increase the color intensity in dark bottles. In our study, the temperature of the dark room was registered at three points at 12:00 pm during the assay, as follows: March, min 17.0 °C, max 20.7 °C; July, min 12.6 °C, max 15.5 °C; October, min 16.0 °C, max 19.2 °C. At the same time, the thermometer probe was placed near of the surface of the bottles to register the temperature. Temperature recording near the bottles (5 cm) showed an average of 18 °C, which was quite variable depending on the temperature of the dark room. Because this experiment was performed with fluorescent tubes, the heat emission was predictably fairly low. In the study of Dias et al.,[4] the use of a mercury vapor lamp under controlled temperature conditions (38 ± 3 °C) produced increased coloration in Flint bottles, although uncontrolled temperature conditions led to the highest development of wine color in Antique Green bottles but the lowest development of wine color in Flint bottles. Moreover, in the study of Maury et al.,[1] a Sauvignon Blanc stored in bottles of different colors exposed to sunlight, with measurement of temperatures between 12.5 and 17.5 °C in the months of May, June, and July at the southeast of Australia, showed greater color development in darker bottles that are in agreement with the results of this work. In that case, the temperatures recorded outside of the bottles in this assay are similar to that exposed by Maury et al.[1] By observing the results of the low molecular weight phenolic compounds (Table 4), in some of them (e.g., caftaric, *p*-coumaric acids) there were a higher concentration in the wines bottled in darker color, especially during the first months of the assay. This slightly significant difference combined with the long storage of these bottles to artificial light conditions may explain the increase in yellow coloration found in the wines from colored bottles. Furthermore, another possibility is that the type of light transmitted by fluorescent tubes (e.g., small quantities of UV light) through the glass in the Flint bottles can degrade the pigments responsible for yellow coloration in white wines, as exposed by other authors.[1,4,25]

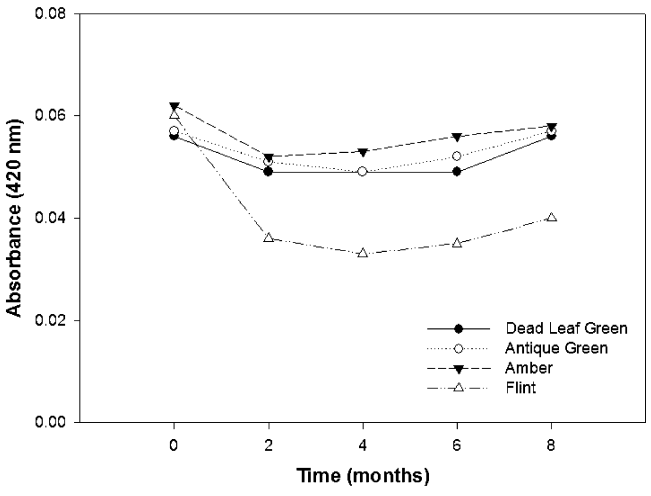

Figure 2. Comparison of color intensity measured at 420 nm for Sauvignon Blanc wines in different bottle colors under artificial light condition over 8 months of storage ($n = 3$).

Sensory Evaluation of Wines. Although within the sensory evaluation, the judges were asked about certain

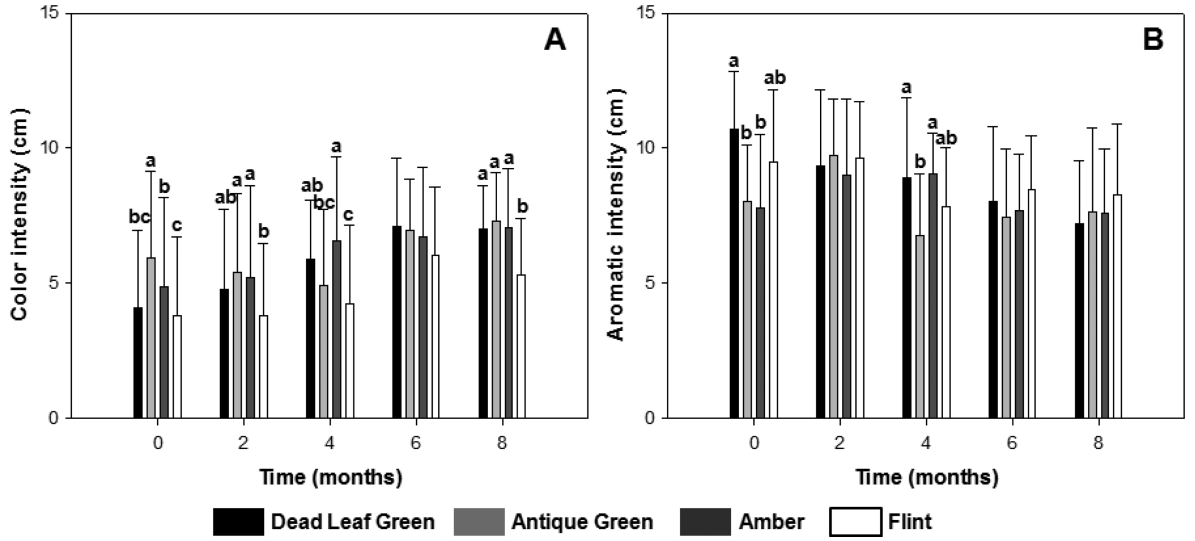

Figure 3. Sensory evaluation of the color intensity (cm) (A) and aromatic intensity (cm) (B) in Sauvignon Blanc wine in different bottle colors under artificial light conditions over 8 months of storage (n = 12). Different letters denote significant differences among bottle colors (p < 0.05, LSD test).

gustatory characteristics, such as bitterness, acidity, and taste intensity, these parameters did not show significant changes throughout the experiment; no differences were found among the treatments. Figure 3 shows the results of color and aromatic intensity. With regards to the perception of color, significant differences were observed among the treatments. The Flint bottles always had the lowest average values of color intensity, with varying differences across the sampling points. Still, only a trend reflecting an increasing color intensity during storage under artificial light conditions was observed. Furthermore, the color intensity by absorbance at 420 nm (Figure 1) and color coordinates (Table 5) correlated well with the sensory data. With regards to the aromatic intensity, only a trend of decreasing intensity was observed during the assay.

With regards to the aromatic descriptors analyzed, clear differences were observed among the treatments. The Sauvignon Blanc grapes are often described as producing wines that have a very distinctive varietal aroma, characterized by descriptors of fruity and vegetable flavors, including passion fruit, green capsicum, and boxwood.[12] In this study, the wines were grouped into four categories that represented the main aromatic characteristics of the Chilean Sauvignon Blanc, as follows: vegetal (e.g., grass, green capsicum, boxwood, asparagus), citric (e.g., lemon, orange), tropical (e.g., pineapple, cherimoya), and others aromas (e.g., apricot, peach, green apple) (Table 1). In general, the wines were described as having an important vegetal and citrus character, with lower notes of tropical fruits and other fruit aromas, specifically, peach and green apple. The analyses of the aromatic descriptors showed that there was a decrease in vegetal aromas in the darker bottles, especially in Antique Green bottles. In general, the storage time and exposure to artificial light produced an increase in citrus and tropical flavors. Clearly, storage under exposure to an artificial light produced significant changes in the aromatic descriptors that depended on the color of bottle used (Figure 4).

Although the principal aromatic descriptor of this cultivar is mainly due to the presence of volatile thiols, esters, and methoxypirazines,[2] further studies are needed to observe whether the use of different conditions of light and temperature

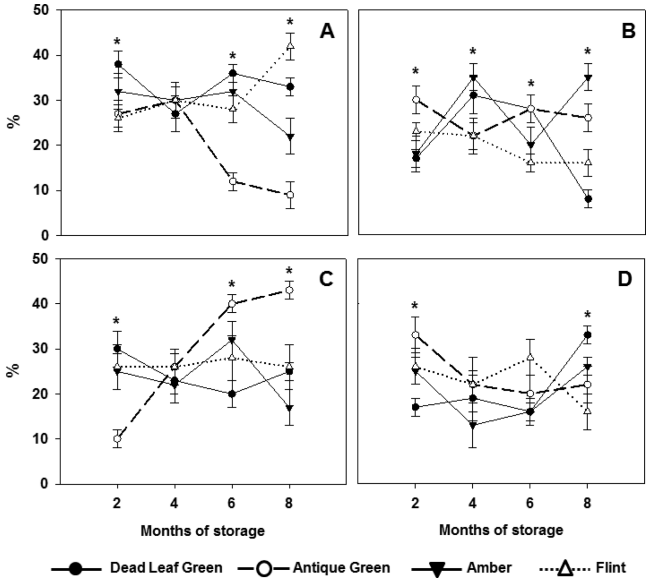

Figure 4. Evolution of the most important aromatic descriptors, such as vegetal (A), citric (B), tropical (C), and others (D), of Sauvignon Blanc wines in different bottle colors under artificial light conditions (n = 12). "*" denotes significant differences among bottle colors in each month (p < 0.05, LSD test).

can affect the concentrations of these compounds during wine storage.

In brief, this artificial light exposure experiment provided important data on the use of Flint and colored bottles and their effects on certain chemical and sensory features of wines. The implications of the results of this study are important to achieve a better comprehension of the principal factors affecting the chemical composition of the wines during storage. The color of the bottles, along with the light used, may affect the chemical composition of the wines. Furthermore, the exposure of the wines under artificial light after a long storage period may produce significant changes in the sensory properties of white wines, especially in the aromatic descriptors. This characteristic and the increase in the yellow coloration of the wines in darker

bottles should be taken into account by wineries and retail shops so that they may improve the safety of their wine storage.

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