THE EFFECT OF TREATMENT OF A RED WINE WITH TWO COMMERCIAL AERATION DEVICES

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ABSTRACT

Aeration devices available to the retail wine consumer promise to improve the flavor of wine. Several oxygen-derived flavor compounds, principally esters and aldehydes, contribute favorably and unfavorably to wine flavor. Studies have shown that wine poured from bottle to glass quickly exhibit reduced concentrations of fruity flavor compounds, while wines subjected to longer periods of oxygenation develop flavor compounds typical of oxidized wines. In this study, red wine poured through two commercial aeration devices was analyzed to determine the extent to which certain chemical parameters and sensory perception of the aerated wine differed from each non-aerated control sample.

BIOGRAPHICAL SKETCH

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CHAPTER 1: INTRODUCTION

Adding oxygen to wine. *"C'est l'oxygène qui fait le vin,"* wrote Louis Pasteur near the time of his discovery of the fermentative activity of yeast cells (Pasteur 1866). Reactions in which oxygen compounds are either oxidized or reduced cause many changes (both positive and negative) critical to the development of must and wine (Balboa-Lagunero et al. 2011). These changes commence during de-stemming and crushing, proceed through fermentation, continue in the fermented wine in tank and barrel and further develop while in the bottle. As addition of oxygen to wine is seen to produce notable aroma and flavor benefits, several techniques have been developed to oxygenate wines during fermentation and thereafter. Air introduced to fermenting wines during punch-down and pump-over can help remove undesirable reduced sulfur aromas. Controlled micro-oxygenation may be practiced on wines in tank to attempt to mirror the improvements to wine quality caused by oxygen diffusing through the barrel (Oliveira et al. 2011, Schmidtke et al. 2011). Further along in the process, winemakers use a variety of closure methods to control the amount of oxygen contained in the wine during bottling. Wine consumers often decant wine to add oxygen, a technique believed to bring out favored aromas while suppressing off aromas (The Science Behind Decanting Wine, 2018). Different wine aerating devices, each promising to improve the quality of the poured wine by incorporating oxygen, are available to the wine consumer. In this study, a young California Cabernet Sauvignon was treated by two wine aerating devices and subjected to quantitative and sensorial analysis.

Commercial aeration devices. The Aervana Luxury Wine Aerator (the "Aervana") and the Vintorio Omni wine aerator (the "Vintorio") are two of many wine aerating devices produced for sale to the retail wine drinker. While employing different aerating techniques, each promise that oxygen imparted to wine by use of the aerating device will improve the aroma and taste of wines by "freshening up" and helping to reveal the "true character" of the wine. Advertising materials claim that, among other things, the aerators will reduce alcohol and sulfites, release unnamed volatile compounds, intensify aromas and flavors and permit (unidentified) unpleasant aromas to "blow off" (Aervana 2018, Vintorio 2018).

Oxidation in wine. Oxygen reacts with juice and wine either enzymatically or non-enzymatically (Oliveira et al. 2011). The oxidation of a wine product is a redox reaction, resulting in an increase in the number of covalent bonds of that product with oxygen or a reduction of the number of covalent bonds of that product to hydrogen (Waterhouse et al. 2016). Prior to and during fermentation, juice and fermenting wine is subject to enzymatic oxidation, which is dependent on the level of hydroxycinnamate concentrations (including flavan-3-ols). Non-enzymatic wine oxidation, also known as chemical oxidation, occurs in fermented wine and often begins with oxidation of polyphenols containing a catechol (Oliveira et al. 2011). Oxidation radical compounds formed by sequential reduction of molecular oxygen in its ground, triplet state[1] react with catechols to form quinones and

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[1] Oxygen is generally unable to participate in wine oxidation reactions in its ground, triplet state. Instead, oxygen must first be reduced by transition metals (principally copper) to permit it to participate in oxidation reactions. After a series of electron additions, the resultant hydroxyl radical

hydrogen peroxide. Hydrogen peroxide then reacts with ethanol (after water, the compound highest in concentration in wine) to produce acetaldehyde, the major oxidation product of wine, and quinones can react with different wine nucleophiles to produce further oxidized products (Oliveira et al. 2011, Waterhouse et al. 2016). While acetaldehyde enhances wine fruitiness at low concentrations, it has been described as contributing nutty notes at higher concentrations and, at still higher concentrations, adds bruised/rotted apple characteristics.

Besides acetaldehyde, other aldehydes affecting wine quality are produced by Strecker reactions. A Strecker aldehyde is formed either by degradation of the precursor amino acid or by peroxidation of the related alcohol (Bueno et al. 2018, Ferreira et al. 2014) Methional and phenylacetaldehyde, both Strecker aldehydes, are recognized as off aromas in red wine, and methional has been identified as the most important aroma compound present in white wine (Culleré et al. 2007, Silva Ferreira et al. 2003, Ugliano 2013). Methional is described (perhaps with respect to white, not red, wines) as contributing cereal, dirty grass, unpleasant, dung and rotten aromas, and has been found to transform fresh fruit notes to dried fruit notes in red wines (Pons et al. 2013). Other compounds noted to contribute to wine flavor include the hydroxycarboxylic acid soloton (4,5-dimethyl-3-hydroxyl-2(SH)-furanone), the (E)-2-alkenals 2-methylpropanal and 2- and 3- methylbutanals, and 3-methyl-2,4-nonanedione. The (E)-2-alkenals identified above are also known as Strecker aldehydes (Bueno et al. 2018). Regardless of chemical composition and means of formation, if sufficient antioxidants are not present, quinones and aldehydes increase in concentration, creating an oxidized product (Ugliano 2013, Waterhouse et al. 2016) characterized by reduction of phenolic concentration, loss of fruity and floral aromas and the development of oxidized and other off aromas (Balboa-Lagunero et al. 2011).

While most research appears to have focused on oxidation of white wines (perhaps because white wine is described as being more prone to oxidation than is red wine) (Balboa-Lagunero et al. 2011), other studies, many recent, have reported on the effects of controlled oxidation of red wines[2]. In these studies, red wines were subjected to different levels of controlled oxygenation for short periods and the chemical and sensory effects analyzed and discussed. Oxidation of red wines is reported to evolve from (1) loss of fresh fruit flavor to (2) development of prune and fig notes to (3) development of rancio (a pungency associated with wine oxidation) to (4) turpentine aroma characteristics While the experimental conditions of the studies are different from conditions under which the aerator devices would be operated, the study results nevertheless offer a worthwhile basis of comparison for the chemical and sensory results of this study.

In one work, bottled red wines, including some of relatively recent vintages, were subjected to varying degrees (1.1, 3.1, 10.6 and 30.4 mg/L) of oxygen dosage and then stored at 25°C for six months. Sensory results showed slight increases in black fruit, dried fruit, woody and lactic acid characteristics and a more pronounced increase in cooked vegetable and spicy notes (Sáenz-Navajas et al. 2014). While the different oxygen doses were expected to have a greater impact on the quality of the wines, it

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(•OH) is capable of oxidizing nearly every compound found in wine, generally reacting with the first available species (Waterhouse et al. 2016).

[2] The same study noted the relative absence of research regarding the oxidation of red wines (Balboa-Lagunero et al. 2011).

instead appeared that the length of storage time had a greater influence. Under somewhat similar conditions, young red wines showed increased concentrations in Strecker aldehyde concentrations closely corresponding to the amount of the oxygen dose. Young red wines, including young wines, poured from the bottle and exposed to air for either four days or 30 days exhibited increased concentrations of Strecker aldehydes methional (increased from 2.14 µg/L in the control sample to 10.9 µg/L in the oxidized sample) and phenylacetaldehyde (from 11 µg/L in the control sample to 69.2 µg/L in the oxidized sample)(Culleré et al. 2007)[3].

In another study, young red wines were dosed with oxygen until dissolved oxygen concentrations reached 100%, after which the wines were stored at 60°C for 10 days. Increased concentrations of methional (2.24 µg/L to 83.56 µg/), phenylacetaldehyde (8.74 µg/L to 90.18 µg/L) and several other odor compounds (including the Strecker (E)-2-alkenals) was noted (Balboa-Lagunero et al. 2011). Sensory analysis reported decreases in perceived herbal (35% decrease), flowery (13%), fruity (7%) and lactic/yeasty (8%) aroma characteristics and increased intensity of phenolic (31% increase) and oxidative (139%) notes. Also noted was a 114% increase in recognized off odors, including those falling within general descriptor categories of varnish/paint/glue/resin/rubber/solvent and very ripe fruit/raisin/overripe fruit. Aldehydes were cited as possibly responsible for these undesirable odors. While Strecker aldehydes may reach significant concentrations only at high oxygen dose levels, they were shown to increase in concentration more quickly than did acetaldehyde concentration, which increases quite slowly (Bueno et al. 2018).

Compounds other than aldehydes contribute to wine oxidation. In young Bordeaux red wines oxidized to six mg/L and opened sequentially over eight days, increased concentrations of a particular ketone (3-methyl-2,4-nonadenione) that can produce prune, fig, mint, fruit pit, anise and dried parsley flavors was found (Pons et al. 2013). Increased concentrations of the ketone ranged from a multiple of one to a multiple of 25 of the compound's perception threshold and correlated with the sensory perception of prune notes and with the degree of oxidation (but only after two days had passed following oxidation).

The studies summarized above support the view that subjecting young red wines to different degrees of controlled oxidation for different periods (none shorter than one day) and at different temperatures can change the concentrations of different chemical compounds (principally aldehydes) known to affect wine aroma. While concentrations of some of those compounds may improve wine quality (e.g. low acetaldehyde concentrations levels enhancing fruitiness), other resulting increases in concentration are seen to create notes characteristic of oxidized compounds, including nutty, bruised/rotten apple, black fruit, dried fruit, woody, lactic acid, cooked vegetable, spicy, prune, fig, mint, fruit pits, rancio, varnish/paint/glue/resin/rubber/solvent, very ripe fruit/raisin/overripe fruit, turpentine, anise and dried parsley. These aromas define oxidative spoilage (Silva Ferreira et al. 2003, Waterhouse et al. 2016).

The adverse effect of controlled oxygenation over the time periods described above are not contradicted by chemical and sensory analysis of red wines poured from bottle to glasses of different shapes and sizes and analyzed after a short period. Concentrations of several volatile compounds (principally ethyl esters and various acetates) in a young Cabernet Sauvignon decreased, most by a

[3] The odor threshold of methional and phenylacetaldehyde has been reported at 0.5 µg/L and 1.0 µg/L, respectively.

statistically significant amount, within two hours of pour (Wollan et al. 2016)[4]. An affective test of an Italian Chianti Classico (age not provided) poured from bottle to glasses of different shapes and sizes and tasted at pour and after 40 and 120 minutes showed decreased scores for intensity of color, intensity of odor, harmony of odors, persistency of taste and overall appreciation (Venturi et al. 2014). While samples tasted from the different glasses produced different scores, nearly each score[5] for each glass fell at the different tasting times.

The summary above supports the position that exposure of red wine to oxygen (whether pursuant to controlled oxygen dosing or pour into the glass) should not be expected to improve the aroma and flavor of the wine. The makers of the Aervana and Vintorio wine aerators claim that the aroma and flavor of wine aerated by the devices will perceptibly improve. In this study, a young California Cabernet Sauvignon poured through the two aerator devices was analyzed to determine differences from the untreated control.

[4] The study reports that thirteen of eighteen discrimination test panelists were able to identify the odd sample. While this result is statistically significant, the small number of panelists should be considered when evaluating the materiality of the test.

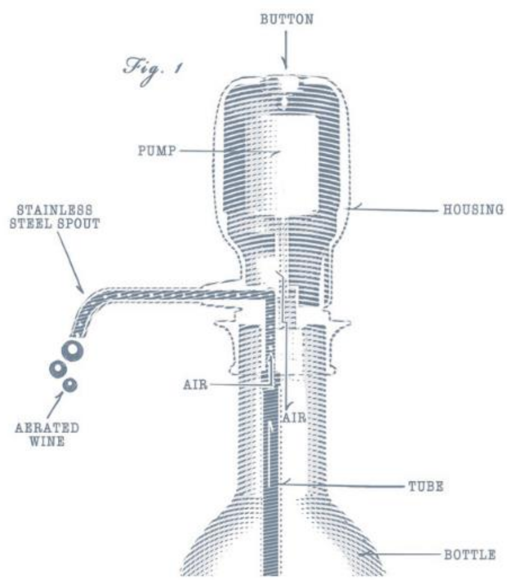
[5] Of 48 different odor-related comparisons, all but three decreased in concentration.

CHAPTER 2: MATERIALS AND METHODS

Aeration devices*:* A brief description of the Aervana and Vintorio devices is set out below[6]:

Aervana. The Aervana device contains a battery-powered pump, activation of which is controlled by a push-button at the top of the device. The pump draws wine up a plastic tube connected to the device and inserted into the bottle, then through an aeration chamber contained in the device housing and finally through a spout to the glass (Figure 1). The amount of air drawn into the device cannot be controlled.

Figure 1. Aervana Luxury Wine Aerator.



Aervana product claims. The Aervana website makes several product claims[7], both with respect to device speed and quality of the treated wine. Included in those claims are the following: "Wine changes as it's exposed to air. For many wines—whether it be from being cooped-up in the bottle or being heavy in alcohol or sulfites— a freshening-up through rapid exposure to air can help reveal the true character of the wine… The Aervana's patented pneumatic process provides high-speed aeration with the ideal mix of air and wine, with a push of a button. Aervana instantly opens the full flavor profile of wine…Air is injected under pressure into a narrow flow of wine through the tube to maximize and focus the exposure of the wine to bubble surface. The air exposure is 6 times greater than gravity fed funnel style aerators."

Vintorio: The Vintorio device is a gravity fed funnel style device. Wine poured into the top "cradle" of the device exits through several openings located approximately in the middle of the device. Wine sprays through the openings, having the effect similar to some decanter funnels (Figure 2).

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[6] Product claims and images in this section are taken from the Aervana and Vintorio websites as found at https://aervana.com/ and https://www.vintorio.com/, respectively.

[7] Neither the Aervana nor the Vintorio websites provide any qualitative data supporting their product claims.

Figure 2. Vintorio Omni Wine Aerator (upper chamber view).

The Vintorio treatment is patterned after a "time tested spray aeration technique, commonly implemented in traditional decanter funnels, and considered to be one of the oldest and most reliable methods of aeration".

After passing through the top cradle openings, the wine then flows through a widening aperture at the bottom of the device (Figure 3) before exiting. The wine is there subjected to a more modern aeration process, "as the wine is then injected with even more air…via the Bernoulli Effect."[8].

[8] The Bernoulli Effect (more commonly known as the Bernoulli Principle) is a conservation of energy principle which explains the lift achieved by an airplane wing and the ability of a sailboat to sail upwind. The increase in kinetic energy achieved by liquid passing through a point in a flow stream must be accompanied by a corresponding decrease in pressure energy. If the velocity of the liquid is increased to a point at which the pressure falls below atmospheric pressure, air will be forced into the liquid stream through an available opening. Jackson, M.L. (1964). Aeration in Bernoulli Types of Devices. A. I. Ch. E. Journal 10: 836-842.

Figure 3. Vintorio Omni Wine Aerator (lower chamber view).

Vintorio product claims. The Vintorio website sets out many product claims, principally with respect to improving favorable aromas and reducing unpleasant aromas. Some of those claims are briefly summarized below. "[W]ine is art made by science! And by making a few adjustments to the science, it is possible improve the aromas, taste, and mouthfeel of your favorite wine… Oxygen reacts with the volatile compounds present in the wine and releases and intensifies the aromas and flavors in it. Let's say you have a young wine you've been dying to try. You open it up and take a sip but can instantly tell it's not showing to its full potential… what you'll need to do is add oxygen to your wine. Two things take place when wine is aerated: evaporation and oxidation. By introducing a controlled amount of oxygen, you give all the lovely volatile compounds in your wine the opportunity to unfold almost instantly. You also allow the wine's less attractive aromas, which are often present when you first uncork a bottle, to blow off. These unsavory aromas tend to react and evaporate off the wine faster than the appealing ones."

Continuing, "[F]or that bold, young, tannic red, an aerator is your best bet…As the wine passes through the aerating chamber, it is injected with air bubbles which immediately react with the wine's volatile compounds to unlock aromas and flavors and instantly open up your wine. [N]ever again will you ... drink a wine that is anything less than excellent…"

Concluding the Vintorio product claims: "Have you ever opened up a bottle of wine and been hit by waves of alcohol fumes or found it smells like matchsticks? Your wine isn't off, it just needs to be aerated…Once allowing these undesirable aromas to blow off, you can get to the heart of the wine and experience the finer nuances it has to offer…Aerating doesn't just release aromas in a wine; it's a gentle way to smooth out rough tannins and create an overall more pleasing wine drinking experience.."

Wine: 2016 Robert Mondavi Private Selection Central Coast Cabernet Sauvignon, packaged in standard 750mL glass bottles with natural cork closures, was purchased commercially for $10.99/bottle. Wines were stored in their original bottle at ambient temperature until opened for experimental or analytical use

Quantitative analysis*:* Dissolved oxygen (DO), pH, titratable acidity (TA), free SO_2, total SO_2, ethanol concentration and glucose and fructose concentrations of the control and the two treated samples were measured in duplicate pursuant to the procedures described below.

Approximately 50 mL of the control sample was poured into a 100 mL beaker. Approximately 30 mL of each treated sample was poured through the respective aeration device into 100 mL beakers. DO concentrations were measured using a Hach HQ30D portable multi-meter device with an attached Luminescent/Optical DO sensor (Hach Company, Loveland, CO.). Free and total SO^2 concentrations were measured using a FOSS FiaStar device (FOSS, Edina, MN.). TA, % ethanol v/v and glucose and fructose concentrations were measured with an EnoFOSS FTIR device (FOSS, Edina, MN.). Wine pH was measured using a Fisher Scientific Accumet Excel XL25 Dual Channel pH/Ion meter. Dissolved oxygen, TA, % ethanol and glucose and fructose measurements were taken immediately following pour. Free and total SO_2 measurements and pH were taken not more than two hours following pour.

Discriminatory sensory analysis*:* The null hypothesis for the two triangle tests states that, in the long run, across all possible replications and groupings of people, if there is indeed no perceptible difference between the products, the underlying population will pick each of the three samples one time out of three (Lawless and Heymann 2010). A triangle test was performed on a control sample (the Robert Mondavi Cabernet Sauvignon poured untreated from the bottle) and the respective aerated sample (the same wine poured through the Aervana and Vintorio devices, respectively) to determine whether the null hypothesis (that the Robert Mondavi wine poured from the bottle could not be distinguished from the sample poured through the aerator) should be rejected.

Wine samples. To prepare sensory samples, all wines were first transferred from their commercial bottles into standard empty, clean, 750mL glass wine bottles in an effort to decrease variations in air exposure other than those created by the treatment devices. The control wine was poured directly from the commercial bottle to the second bottle through a plastic funnel. The Aervana treatment was prepared by attaching the device to a bottle of the sample wine and activating it, causing the wine to travel through the device into the second bottle. Vintoro samples were prepared by placing the funnel on a clean bottle and pouring the sample wine through. From these secondary bottles, 30mL of each wine was poured into matching 150mL ISO tasting glasses, which were capped with plastic lids to prevent ethanol evaporation. Each sample was assigned a three-digit code, and samples were presented to each panelist in a balanced, randomized order. Samples were presented to the panelists between one minute and 20 minutes following pour.

Sensory panel. A panel of 69 members of the Alcohol Beverage Consumer Panel, each of whom reported drinking red wine at least once a week, were assembled at the Cornell Sensory Evaluation Center. Panelists were seated in separate sensory booths, were presented with two successive triangle tests, and were instructed to taste each sample (expectorating after each tasting) and identify the sample that was perceived as different than the other two. Each panelist was further instructed to cleanse his or her palate with a cracker and water between the two tests. Panelist responses were collected digitally using RedJade software (RedJade Software Solutions, LLC, Boulder, CO).

Panelist responses were analyzed via the RedJade triangle test statistical method of analysis to determine whether the null hypothesis should be accepted or rejected. Results were evaluated at the 5% probability level.

CHAPTER 3: RESULTS AND DISCUSSION

Quantitative analysis. DO, pH, TA, free and total SO_2, ethanol concentration and glucose and fructose concentrations of the control and the two treated samples were analyzed in duplicate (Table 1).[9]

Table 1. Chemical parameters of control and treatment wines.

Sample	DO (mg/L)	pH	TA g/L	Free SO_2	Total SO_2	Ethanol vol. %	G/F g/L
Control	0.22	3.58	6.1	24	63	13.3	3.2
Aervana	4.59	3.58	6.1	23	60	13.2	3.2
Vintorio	2.25	3.61	6.1	24	61	13.6	3.2

The results shown above indicate that notable differences were not found in the measured parameters, save for dissolved oxygen concentrations. DO concentration in the control sample was quite low. Aervana DO concentration was approximately 55% of the maximum oxygen concentration for wine at 20°C[10] (8.4 mg/L), while Vintorio DO concentration was approximately 27% of that amount.

Discriminatory sensory analysis.

Table 2. Consumer triangle tests for sensory differences in control and treatment wines.

Device	Total responses	Total correct	% Correct	Confidence level (%)	P-value
Aervana	69	19	28	12.4	0.876
Vintorio	67	24	36	62.4	0.376

Statistical analysis of the triangle test results produced p-values well above the 0.05 critical threshold. Thus, the null hypothesis should not be rejected. This result, together with the results of the quantitative analysis summarized above, can fairly lead to the conclusion that the wine treated by the two aeration devices are not significantly different from the untreated control sample.

Previous studies analyzed the effect of aeration of red wines in two different circumstances – forced aeration and pour into glass. The forced aeration studies generally report a material increase in oxidized compounds and corresponding change in flavor profile, but only after a period ranging from four days to six months had elapsed after pour. The studies analyzing wines poured into glasses show marked decreases in the concentrations of different fruity flavor compounds over the time periods analyzed after pour (40 minutes to two hours). In this work, the treated wines showed a 10 times (Vintorio) and nearly 20 times (Aervana) increase in DO, and both Aervana and Vintorio claim that oxygenation of wines poured through the devices will improve wine flavor. While neither Aervana nor Vintorio

[9] Results of the first test are reported. Results of the second test were either identical to, or not notably different from, those reported above with respect to the first.
[10] The measured temperature of the control sample was 28°C.

publicized the DO of wine aerated by their respective devices, there is no reason to believe that the increased DO levels noted above would be notably different from those achieved generally by use of the devices. Thus, it is fair to conclude that the qualitative and quantitative tests conducted in this study subjected wine to aeration under conditions that were substantially identical to those that would be expected to be experienced generally by consumers using the devices.

Consequently, one could have reasonably anticipated that the Aervana and Vintorio devices would produce flavor changes of some sort, either the generally negative changes noted by the summarized studies or, alternatively, the favorable changes promised by the Aervana and Vintorio product claims. However, the triangle test instead indicated that there was not a significant difference between the aerated samples and the control. There are several reasons why the results of the triangle test might not support the results of those earlier studies. Most of the sensory testing conducted in those studies were descriptive tests, not discrimination tests such as the triangle test conducted here. Discriminatory analysis and descriptive analysis attempt to answer different questions. Panelists participating in discriminatory analysis are asked only to pick the sample that differs from the others. Conversely, panelists in a descriptive analysis are asked to determine the intensity of different attributes, usually on a scale. Accordingly, it is possible that a descriptive panel would notice differences with respect to individual flavor attributes, while a discriminatory panel would not be able to distinguish between the two samples considered as a whole. Further, it may be true that, to exhibit the degree of flavor profile change shown by the referenced studies, the treated wine must be oxygenated (whether through an aeration device, by pour into the glass, by forced aeration or by some other method, such as decanting) for more time than the short period tested in this study. In addition, the method used to preserve the treated wine from the time of pour to the time of panelist testing might also have caused the treated wines not to exhibit the type of flavor changes seen in the summarized studies. Perhaps a greater change in sensory profile would have been perceptible had the treated samples not been covered with plastic lids from the time of pour to the time of tasting (Wollan et al. 2016).

Notwithstanding these qualifications, the results of this study fairly lead to the conclusion that wine treated by the two aeration devices is not significantly different than the untreated control sample. Accordingly, the product claims summarized above, generally promising that use of the aerating devices will improve the aroma and flavor of wine, are not supported by this study. Thus, the wine drinker should not expect to notice a difference between the aerated wine and the control wine.

BIBLIOGRAPHY

Balboa-Lagunero T, Arroyo T, Cabellos JM, Aznar M. 2011. Sensory and Olfactometric Profiles of Red Wines after Natural and Forced Oxidation Processes. Am J Enol Vitic 62:527–535.

Bueno M, Marrufo-Curtido A, Carrascon V, Fernandez-Zurbano P, Escudero A, Ferreira V. 2018. Formation and Accumulation of Acetaldehyde and Strecker Aldehydes during Red Wine Oxidation. Front Chem.

Culleré Laura, Cacho J, Ferreira V. 2007. An Assessment of the Role Played by Some Oxidation-Related Aldehydes in Wine Aroma. J Agric Food Chem 55:876–881.

Ferreira V, Bueno M, Franco-Luesma E, Culleré L, Fernández-Zurbano P. 2014. Key Changes in Wine Aroma Active Compounds during Bottle Storage of Spanish Red Wines under Different Oxygen Levels. J Agric Food Chem 62:10015–10027.

Lawless HT, Heymann H. 2010. Discrimination Testing. *In* Sensory Evaluation of Food: Principles and Practices. HT Lawless and H Heymann (eds.), pp. 79–100. Springer New York, New York, NY.

Oliveira CM, Ferreira ACS, De Freitas V, Silva AMS. 2011. Oxidation mechanisms occurring in wines. Food Res Int 44:1115–1126.

Pasteur L. 1866. Études sur le vin, ses maladies, causes qui les provoquent, procédés nouveaux pour le conserver et pour le vieillir /. Paris :

Pons A, Lavigne V, Darriet P, Dubourdieu D. 2013. Role of 3-Methyl-2,4-nonanedione in the Flavor of Aged Red Wines. J Agric Food Chem 61:7373–7380.

Sáenz-Navajas M-P, Avizcuri J-M, Ferreira V, Fernández-Zurbano P. 2014. Sensory changes during bottle storage of Spanish red wines under different initial oxygen doses. Food Res Int 66:235–246.

Schmidtke LM, Clark AC, Scollary GR. 2011. Micro-oxygenation of red wine: techniques, applications, and outcomes. Crit Rev Food Sci Nutr 51:115–131.

Silva Ferreira AC, Hogg T, Guedes de Pinho P. 2003. Identification of Key Odorants Related to the Typical Aroma of Oxidation-Spoiled White Wines. J Agric Food Chem 51:1377–1381.

The Science Behind Decanting Wine. 2018. SevenFifty Dly. as found on the website (https://daily.sevenfifty.com/the-science-behind-decanting-wine/).

Ugliano M. 2013. Oxygen Contribution to Wine Aroma Evolution during Bottle Aging. J Agric Food Chem 61:6125–6136.

Venturi F, Andrich G, Sanmartin C, Scalabrelli G, Ferroni G, Zinnai A. 2014. The expression of a full-bodied red wine as a function of the characteristics of the glass utilized for the tasting. CyTA - J Food 12:291–297.

Vintorio. 2018. Vintorio. Vintorio. as found on the website (https://www.vintorio.com/).

Waterhouse AL, Sacks GL, Jeffery DW. 2016. Understanding Wine Chemistry. John Wiley & Sons, Ltd, Chichester, UK.

Wollan D, Pham D-T, Wilkinson KL. 2016. Changes in Wine Ethanol Content Due to Evaporation from Wine Glasses and Implications for Sensory Analysis. J Agric Food Chem 64:7569–7575.