Best Practice for Wine by the Glass Programs: An Investigation of the Interaction Between Storage Methods and Temperature

A Thesis Presented to the
Faculty of the
Conrad N. Hilton College of Hotel and Restaurant Management
University of Houston

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

Derek Reihl
May 2017

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Abstract

Wine by the glass programs are strong sources of income for restaurants and bars, and are also enjoyed by customers as it allows for the tasting of many wines over the course of a meal. Once a wine has been opened though, oxidation begins to occur which causes the deterioration of the aromas and flavors of the wine. Oxidation can cause a wine to become unfit for sale to a customer within days of opening the bottle. By storing the wine at cool temperatures or reducing the amount of oxygen that can interact with the wine, the process of oxidation can be diminished.

In this study, the effectiveness of temperature control and bottle closure to diminish oxidation in an opened bottle of wine was observed. The storage temperatures of 72°F, 60°F, and 50°F were paired with the bottle closure methods of recorking, vacuum sealing, and inert gas preservation. This led to nine combinations of storage temperature and bottle closure which were used to preserve wine for sixteen days. In order to measure the effectiveness of the preservation methods at slowing oxidation, sensory analysis was performed. The preserved wines were compared to fresh wine in duo-trio testing, and results of the testing were analyzed using ANCOVA methods with a covariate of the taster's years of wine industry experience. The effects of storage temperature and closure method were both found to be significant with no interaction effect between the two. The combination of storage temperature and closure method that was found to be the most effective at reducing the discernable signs of oxidation was vacuum closure at 50°F storage temperature.

CHAPTER I

Introduction

By implementing a wine by the glass sales systems in restaurants and bars, customers are able to consume a variety of different wines during a meal rather than just one full bottle. By being able to have multiple wines over the course of a meal, a new wine can be paired with each course being served which can create a better dining experience for the customer. Being able to order wine by the glass also allows the customer to also try wines without the financial burden of purchasing a full bottle without knowing beforehand if they will enjoy the wine or not. In the current restaurant and bar environment, many establishments rely on the method of recorking and refrigeration for storing wine after it has been opened. With the use of different storage methods the integrity of wine can be maintained for longer periods of time compared to if the wine was left open at room temperature (Lee, Kang, Park, 2011).

The integrity of wine is compromised when the volatile organic compounds (VOCs) in the wine begin to oxidize. As described in research by Waterhouse and Laurie (2006), oxidation in wine is a chemical change that occurs as oxygen reacts with the phenols in wine. When the oxygen reacts with the phenols, a chain reaction occurs that results in the production of acetaldehyde. The oxidation of wine results in the loss of flavors and aroma. Producers of the vacuum and inert gas preservation methods have both claimed to further the shelf life of wine that has been previous opened (referred to as secondary storage), but there is very little formal research on their effectiveness at reducing the rate of oxidation. Additionally, most previous research concerning the oxidation of wine has been done using headspace gas chromatography to analyze the dissolved VOCs in the headspace of the wine.

Preservation Methods

Inert Gas. An inert gas is a gas that will not react with volatiles surrounding it and cannot be absorbed by the surrounding elements (McQuarrie, Rock, Gallogly, 2011). The inert gases that can possibly be used for storing wine are nitrogen, argon, and carbon dioxide. Inert gases are meant to prevent oxidation by creating a layer over the surface of the wine. Since argon is heavier than oxygen, the argon will sit directly on top of the wine's surface and oxygen will be prevented from reaching the VOCs in the wine. To further clarify, there will still be oxygen inside the headspace of the bottle, but this oxygen will not be able to reach the wine due to the layer of inert gas acting as a barrier between the oxygen in the headspace and the wine.

Vacuum. Vacuum pumps work by removing a large portion of the oxygen from the headspace of the wine bottle, and by doing this oxidation cannot occur since there is no oxygen present for the VOCs to react with. Manually operated vacuum pumps have recently risen in popularity for at-home use since they are relatively inexpensive, but these inexpensive vacuum pumps can be inconsistent if not the user does not spend the time to pump out as much air as possible, which is not an issue that occurs with the electric vacuum pumps available for restaurant use. An example of an electric vacuum pump that is used in restaurants would be Vinfinity. Another benefit of the use of an electric pump is that it is able to remove the oxygen from the headspace of a bottle more rapidly than a traditional hand-pump is able to. Despite these benefits, there is worry that as the pump draws out the oxygen from the bottle, the VOCs are being drawn out of the wine as well. This process of removing VOCs through vacuum pumps is called vacuum distillation. If this were to occur, the integrity of the wine would be negatively affected.

Recorking. Recorking is simply reinserting the cork that came with the wine bottle, back in to the wine bottle after the wine has been served as needed. In some cases the original cork may not fit back in the bottle, so in this case another cork can be used as long as it provides a tight seal. Recorking is the least expensive out of the preservation methods as it rarely requires anything outside of what is provided with the bottle of wine. By recorking the wine, oxygen is not able to enter or leave the bottle of wine. Therefore, any oxygen in the headspace of the bottle will remain in the bottle and will be allowed to oxidize with the wine. While this method is seems better than leaving the bottle uncorked at letting oxygen freely flow in and out of the bottle's headspace, when using the recorking method there will always be a small amount of oxidation that does occur. Despite the drawbacks, this is the most convenient method so it is the method most often practiced.

Temperature. Three common storage temperatures for wine are room temperature (72°F), 60°F, and 50°F. Room temperature storage occurs when a restaurant leaves the wine behind the bar after the preservation method had been used, which happens frequently in bars and restaurants. As for 60°F and 50°F, there are many debates over what the ideal cellar temperature is for wine storage, and these two temperatures are both within the range of industry-perceived ideal temperatures. 60°F is representative of a slightly warm wine cellar, and 50°F is representative of a slightly cold wine cellar. By reducing the temperature of the wine, the VOCs in the wine should become less volatile, thus decreasing the rate of oxidation (Dominé, 2004). Morozova, Schmidt, Schwack (2015) have shown that a sensory panel can detect differences in oxidation when wine is stored at 41°F and 68°, but 41°F is far cooler than most cellars. Drawing from this study though, it can be seen that differences in storage temperature can lead to large enough changes in VOCs that the changes are detectable through sensory analysis.

By pairing the three preservation methods with the three common storage temperatures, there are nine total variables to be tested. This is the standard three-by-three experimental design consisting of two factors with three levels in each. For further understanding, the variables are as follows:

- Variable 1: Room temperature (72°F) and Recork
- Variable 2: Room temperature (72°F) and Inert Gas
- Variable 3: Room temperature (72°F) and Vacuum
- Variable 4: Cellar temperature (60°F) and Recork
- Variable 5: Cellar temperature (60°F) and Inert Gas
- Variable 6: Cellar temperature (60°F) and Vacuum
- Variable 7: Cool cellar temperature (50°F) and Recork
- Variable 8: Cool cellar temperature (50°F) and Inert Gas
- Variable 9: Cool cellar temperature (50°F) and Vacuum

In order to find which combination of preservation method and storage temperature is most effective at reducing the rate of oxidation during secondary storage, sensory analysis was used. The sensory panels were composed of people with at least two years of wine sales experience, and average consumers that have no formal wine training.

The panel members performed an organoleptic analysis where the wines that have went through secondary storage were compared against freshly opened wine.

Problem Statement

In the beverage industry, there is no clear answer as to what the best way to slow the oxidation of wine during secondary storage is. Previous studies that attempted to find the answer have used chemical analysis to measure rates of oxidation between preservation methods. This study will use only sensory analysis to measure the effectiveness of preservation methods, since the occurrence of oxidation is only relevant if a consumer can sense that oxidation has occurred.

Research Questions

Question 1: Does the storage temperature of wine during secondary storage significantly affect the rate of oxidation of the wine?

Question 2: Does the closure method of wine during secondary storage significantly affect the rate of oxidation of the wine?

Question 3: Is there an interaction effect between storage temperature and closure method?

Question 4: What is the best combination of closure method and storage temperature for delivering maximum quality to customers by slowing the oxidation rate of wine during secondary storage of wine?

By answering question 4, industry standards will be proven as to which combination of closure methods and storage temperatures is most effective. This information is key to the success of wine-by-the-glass programs; if a way to preserve wine during secondary storage for extended periods of time is found, then restaurants will be able to expand their wine-by-the-glass lists extensively which will lead to more options available for the customers and potentially a large increase in revenue.

Delimitations

The most notable delimitations for this study are the variables that we have chosen. There are other preservation methods that could be tested such as a hand-pump vacuum or the Coravin system. We have chosen the three preservation methods for this study after considering which preservation methods have the lowest barriers to entry and what methods are already in place in the industry. The next delimitation is the temperature conditions for the wine. Not all wine is stored at the conditions that we are testing; some restaurants may use temperatures above, in between, or below the conditions that we are testing. The last delimitation is the number of days that we are allowing the wine to undergo the preservation treatments. If we were able to perform this analysis while comparing wines that have been preserved for eight days, sixteen days, and twenty-four days against fresh wine, then further analysis allowing for the decay rate of VOCs to be identified may have been possible. This analysis may be approached in further research if the results if this study are substantive.

Hypothesis

Hypothesis 1: The predominant spoilage process during secondary storage of wine is caused by the oxidation of the VOCs in wine. By limiting the wine's exposure to oxygen through different closure methods oxidation can be slowed.

Hypothesis 2: Lower storage temperatures slow the oxidation rate of VOCs.

Hypothesis 3: Lower storage temperatures will enhance the preservation effect of inert gas more than it will enhance the preservation effect of the other two preservation methods.

CHAPTER II

Review of Literature

There is very little research comparing the effectiveness of preservation of wine during secondary storage, as opposed to the amount of research done on the proper conditions for wine during the initial storage. The most similar research to this paper comes from Lee, Kang, and Park (2011) in which they studied how four different oxidation rates effected cabernet sauvignon during secondary storage. The four different oxidation rates tested with the use of natural cork, natural cork with an oxygen scavenger of low capacity, natural cork with an oxygen scavenger of high capacity, and a vacuum stopper. While the vacuum system they used is not the exact same as the one in this study, the concept is still the same. In their study a mass spectrometer was used to measure the VOCs in the headspace of the wine and the level of oxidation that had occurred after one week of storage. This procedure allowed eight volatiles to be identified that are directly associated with the oxidation of wine. Along with the mass spectrometer, sensory analysis was performed by a trained panel to attempt to detect differences in the wine. Since the study wanted to determine differences in both taste and flavor, the panel was trained for three 1-hour sessions. During the training sessions the panelists learned how to differentiate aromas and use basic taste terms, which would allow them to accurately describe the attributes of each sample of wine. Through sensory analysis of the four different storage conditions, the wine that was stored with the oxygen scavenger of high capacity was found to be different than the three other wines in both taste and flavor.

Polyphenols in red wine can be found at a concentration of 1 to 5 grams per liter, while polyphenol concentration in white wine is typically 0.2 to 0.5 grams per liter (Oliveira, Ferreira, Freitas, Silva, 2012). Due to the higher polyphenol count, red wines are often more fragrant than red wine. A higher polyphenol count will also allow for oxidation to become more apparent if it does occur during the secondary storage.

Sensory

The basic methodology of using a panel for sensory evaluation is explained in works by Wierenga and Wageningen (2007) and Angerosa (2002). Guidelines for the analysis of the data from the sensory panel are provided by Zeng, Ruan, and Koehl (2007); this article also presents methods for analyzing non-numerical data, which opens the possibility for having a panelist be able to describe why they believe a wine is the odd-one-out. Following this path would make the data more difficult to analyze, and for the current scope of this research, numerical information will suffice. Models for using sensory panels to test for wine oxidation can be found in literature by Hopfer, Ebeler, and Heymann (2012) and Gambuti, Rinaldi, Ugliano, and Moio (2013). These models produced significant results when it comes to panelists being able to identify oxidized wine, but both studies have critical flaws in that the panelists have been trained to identify specifically signs of oxidation. After panelists have been gained knowledge about how to detect oxidation, and are aware that some of the wine will be oxidized, the panelists will be more likely to notice the oxidized wine than they were before the training.

The use of sensory analysis to detect oxidation has been used in other foods as well. In a study performed by Morales, Rios, and Aparicio (1997) sensory analysis was used alongside chemical analysis to detect oxidation in virgin olive oil, since the taste of olive oil changes as oxidation occurs in the oil. In this study, the results of the sensory analysis were in line with results of the chemical analysis.

When wine is stored using the recorking method, oxidative processes can occur in the wine for up to 60 days after the opening of the wine (Castellari, Matricardi, Arfelli, Galassi, Amati, 2000). However, most restaurants using a wine-by-the-glass system will not be keeping their wines in secondary storage for periods of time that long, so it is not necessary for the testing of preservation methods to preserve the wine for 60 days or longer.

Lastly, there has been research done Jacob and Neal (2011) where wines were preserved using recorking, vacuum, and inert gas for the storage periods of twenty-four hours, forty-eight hours, and seventy-two hours. Restaurants that offer wine by the glass programs and also have an extensive selection of wine will often need to store their opened wine for extended periods of time, since some wines may not be in frequent demand. Because of this, for a preservation method to be of most use to the restaurant industry, the preservation method will need to effectively preserve the wine for a period of time longer than seventy-two hours.

CHAPTER III

Methodology

Rather than following the common methods of analyzing oxidation through chemical analysis, this study has taken a different approach through sensory analysis to find out if consumers can discern the differences in VOCs that occurred as the wines under went the preservation process. The sensory analysis was performed by two groups of volunteers. One group of volunteers was composed of tasters that have previous job experience and training related to selling wine. The other group of tasters was composed of naïve consumers, naïve meaning that they have not had any training related to wine. The wine being used for the primary testing was the 2012 Kendall-Jackson Vintner's Reserve Summation Red Blend, which is composed mostly of Zinfandel, Syrah, and Merlot. A red wine was chosen for this study since, as mentioned, red wines typically have a higher polyphenol count than white or rose wines. Due to this higher amount of polyphenols, the occurrence of oxidation will be more apparent in red wines.

Choice of Closure Methods

The most commonly used inert gas for wine preservation systems is argon. Due to this, food-grade argon was also used as the inert gas in this study.

Since there are multiple vacuum closure options, a vacuum widely-used in the restaurant industry was chosen. Vinfinity was chosen due to its use in many restaurants including high-end restaurants with extensive wine programs such as Flemings, Treo, and Cut by Wolfgang Puck.

Tasting Panel Selection.

Tasters in this study did not receive training on how to differentiate wines during the course of the experimentation, so only tasters that were currently employed in the beverage industry could serve as part of the professionally trained taster group. Sales representatives from beverage distribution companies served as the professional tasters needed for the study. By using sales representatives it is guaranteed that the tasters frequently describe and taste wine, which should fully prepare them to differentiate between oxidized wine and fresh wine. The naïve tasters were composed of college students that ranged in age from 21 to 39, and lacked any standardized beverage-related training. If the effects of oxidation during the secondary storage are very minor then only the professionally trained panelists should detect it, if they do detect it at all. However, if the general consumer panelists are able to consistently identify the wine that had gone through secondary storage, then that preservation method will have failed.

Variables.

Independent variable. The independent variable is wine that will undergo a combination of one of three preservation methods and one of three temperature conditions for a sixteen day period.

Dependent variables. The dependent variable will be the tasters' organoleptic abilities that are used to differentiate the stored wine from the fresh wine.

Applying the variable conditions. The wines were stored under these conditions for sixteen days prior to the sensory analysis, which should be ample time for oxidation to occur. Additionally, most restaurants with extensive wine by the glass programs may need to hold wine in secondary storage for up to two weeks, so the sixteen day storage time is also relevant due to this. In order for the conditions to affect the wine, headspace must be created in the wine bottle to allow for oxygen to enter. Headspace was created by pouring 90mL of wine out of each bottle before applying the preservation method and entering the temperature controlled storage. Recorking was performed by simply reinserting the original cork back in to the bottle. The inert gas preservation method was performed by filling the headspace of the wine bottle with food-grade argon gas for four seconds at 1.5bar. The vacuum preservation method was performed by using the Vinfinity preservation system following the manufacture's recommend procedures. Vinfinity uses a specialized rubber cork that allows for air to be drawn out of the bottle, but does not allow for air to re-enter the bottle until the rubber cork has been removed by hand.

For the temperature conditions, a pair of adjustable True commercial refrigerators were used along with probe thermometers to monitor the temperature of the fridges over the sixteen-day period. All wine was allowed substantial time to reach room temperature just before the tasting occurred. This was necessary since fresh wine is stored at room temperature and may release VOCs more easily than one of the variable wines that may still be at a lower temperature due to previous storage, therefore will have less VOCs being released for the taster to sense.

Sensory Analysis Procedures.

Pilot testing. A pilot study was conducted to evaluate the procedures of the sensory analysis. The pilot testing also tested for proof of concept for this study. The goal of this pilot study was to get a general idea as to how well naïve consumers could differentiate between a fresh wine and a wine that was heavily oxidized, and how frequently consumers believed there was a difference between two samples of the exact same wine. In the pilot study, three different situations were tested for consumer preference through sensory analysis procedures. The participants were all naïve consumers in this scenario. There was a fresh red wine, which served as the control sample and one variable sample, and a sample of red wine that had been allowed to oxidize for over a week (the same red wine was used for both conditions). Oxidation of the variable sample occurred by pouring the wine in to a large container that allowed for the wine to exposed to a large amount of oxygen. Both the control and variable wines were held at room temperature during the storage period prior to the tasting. Three groups of naïve consumers were tested, with each group composed of approximately twenty consumers. Each participant was presented with two samples of wine, and asked which of the two samples they preferred, or if they had no preference. Group 1 was presented two samples of fresh red wine, Group 2 was presented two samples of oxidized red wine, and Group 3 was presented with one sample of fresh red wine and one sample of oxidized red wine.

Primary testing. For this sensory analysis, duo-trio testing was used; in this method the participants were presented with three samples of wine, two of the samples were the same and one sample was different. The participant were aware that one sample was different, and they were asked to identify which sample was the different one. Each sample of wine was one ounce, measured by using a one ounce bottle pourer. Each participant was given two sets of four trios of wine, for a total of eight trios. The two sets of trios were identical which allowed for the testing of inter-taster reliability in a post-hoc analysis. An example of the eight trios that a participant could receive is below:

- Trio 1: Fresh wine sample, Variable 1 sample, Fresh wine sample
- Trio 2: Variable 5 sample, Fresh wine sample, Fresh wine sample
- Trio 3: Variable 2 sample, Variable 2 sample, Fresh wine sample
- Trio 4: Variable 6 sample, Fresh wine sample, Variable 6 sample
- Trio 5: Variable 5 sample, Fresh wine sample, Fresh wine sample
- Trio 6: Variable 6 sample, Fresh wine sample, Variable 6 sample
- Trio 7: Fresh wine sample, Variable 1 sample, Fresh wine sample
- Trio 8: Variable 2 sample, Variable 2 sample, Fresh wine sample

As seen above, trios 5-8 are the same trios as 1-4, but in a different order. Each panelist indicated which wine of the trios that they believed to be the different one. Each survey also included questions relating demographics and wine related training that they have received. The demographic data and similar questions were answered after tasting trio 4. The time spent answering these questions allowed for the participants to recover from any palette fatigue that may have occurred after sampling the first four trios. The survey that was used for the primary testing can be found in Appendix A.

Data analysis procedures.

Statistical analysis of the data was performed with the use of an analysis of the covariance (ANCOVA) using IMB SPSS. For the test, the three temperature conditions and the three closure methods were treated as the two independent variables. The tasters' percentage correct in identifying the odd wine out in the duo-trio test served as the dependent variable. Years of beverage industry experience of each taster, which was gathered during the demographic questions in the tasters' surveys, served as the covariate.

Chapter IV

Results

Pilot Testing Results

For Group 1, participants were served two fresh samples of the same wine, and only 20% of the tasters had no preference between the samples. For Group 2, participants were served two samples of oxidized wine, and only 14% of the tasters had no preference between the samples. For Group 3, participants were served one fresh sample of wine and one oxidized sample. From this group, 33% preferred the fresh wine, 41% preferred the oxidized wine, and 26% had no preference. It was from these results that it was determined that asking for preference was incorrect for testing if consumers could tell the difference. While a consumer expressing a preference between two things is inherently the same as recognizing the two things are different, our goal of this study could be more easily reached by instead asking the tasters, “Is there a difference between the two samples?”

Preliminary Analysis

When the responses from the naïve tasters and the professional tasters were both evaluated, there was a striking difference in the performance between the two groups. The professional tasters were expected to perform somewhat better than the naïve tasters, but it turned out that the naïve tasters’ responses were seemingly random. The naïve tasters frequently failed when inter-rater reliability was checked, further influencing the theory that the naïve tasters may have been too inexperienced to have the ability to consistently differentiate between the samples of wine at all. When the amateurs were presented with the same two trios of wine, the amateur tasters were only able to identify the fresh wine in both trios 17.51% of the time. After considering the low inter-rater reliability score of the amateurs, we felt that more accurate results from our analysis could be drawn by only using the responses from the professionally trained tasters. The remainder of the analysis will only include data that was generated using the responses from the professionally trained tasters.

Analysis

The overall performance of each of the preservation methods can be observed without adjusting for the covariate (Table 1). From this broad view of the results, it can be seen that the variable 1 combination of recorking and storage at room temperature was the least effective method of secondary storage. While also looking at the performance of the recorking closure method, the strong effects of temperature on effectiveness of preservation can be seen as recorking performs much better at 50°F compared to room temperature. The variable 6 combination of vacuum and storage at 50°F was the most effective overall.

Table 1

Descriptive Statistics

Treatment	Temp	Mean	Std. Deviation	N
Recork	RT	0.729	0.449	48
	60	0.638	0.485	58
	50	0.471	0.503	70
	Total	0.597	0.492	176
Vacuum	RT	0.600	0.494	55
	60	0.483	0.504	58
	50	0.441	0.500	68
	Total	0.503	0.501	181
Gas	RT	0.660	0.479	50
	60	0.660	0.478	53
	50	0.557	0.500	70
	Total	0.619	0.487	173
Total	RT	0.660	0.475	153
	60	0.592	0.493	169
	50	0.490	0.501	208
	Total	0.572	0.495	530

Note. Dependent variable: score (1= able to identify fresh wine in duo-trio, 0= unable to identify the fresh wine in duo-trio).

Moving forward with the results of the ANCOVA, both temperature and closure method had significant effects on the effectiveness of secondary storage. Along with this, there was no significant interaction effect between closure method and storage temperature (Table 2). The lack of a significant interaction effect is important for the usefulness of this research to application in the industry, since it shows that both temperature control and proper closure methods can independently effect the effectiveness of secondary storage. This is necessary because the use of both temperature control and various closure methods are not always available for secondary storage of wine.

Table 2

Test of Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5.341	9.000	0.593	2.480	0.009
Intercept	69.365	1.000	69.365	289.871	0.000
Years	0.710	1.000	0.710	2.965	0.086
Treatment	1.505	2.000	0.753	3.145	0.044
Temp	3.007	2.000	1.504	6.283	0.002
Treatment * Temp	0.527	4.000	0.132	0.551	0.698
Error	124.435	520.0	0.239		
Total	303.000	530.0			
Corrected Total	129.775	529.0			

Following this, the effectiveness of each closure method can be independently analyzed (Table 3). The closure method of recorking only performs slightly better than the gas closure method, with a mean score of 0.015 less than recorking which is smaller than the standard error for both methods. The performance of the vacuum method is notably better than both of the other two methods though. This is not surprising though based on the previous results as the combination of vacuum closure and 50°F was seen to be the most effective overall. This suggests that if a restaurant does not have the option of temperature-controlled storage for their open wines, but does have the ability to provide a closure method besides recorking, then vacuum closure is the most effective option of the three compared here.

Table 3

Treatment

Treatment	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Recork	0.613	0.037	0.539	0.686
Vacuum	0.508	0.037	0.436	0.580
Gas	0.628	0.038	0.554	0.702

Note. Dependent variable: score (1=able to identify fresh wine in duo-trio, 0=unable to identify the fresh wine in duo-trio).

Next, the effectiveness of each storage temperature can be compared to see which of the three tested temperatures was most effective at preserving wine during secondary storage (Table 4). For the three tested temperatures, room temperature (72°F) was the least effective. Fifty degrees Fahrenheit was the most effective temperature for the preservation of the wine, and the performance of 60°F storage fell between room temperature and 50°F. This suggest that as temperature decreases from 72°F to 50°F, the effectiveness of preserving wine during secondary storage increases. An initial glance at the data may lead one to draw the general conclusion that as temperature decreases, effectiveness of preservation increases, but there may be limit as to how low storage temperature can be before the temperature has adverse effects on the wine. Due to limitations of size of this study, this general conclusion cannot be drawn, but does show room for future studies to be performed.

Table 4

Temperature

Temperature	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
RT	0.666	0.040	0.588	0.744
60	0.598	0.038	0.523	0.672
50	0.485	0.034	0.418	0.552

Note. Dependent variable: score (1=able to identify fresh wine in duo-trio, 0=unable to identify the fresh wine in duo-trio).

Lastly, the overall performance of each combination of closure method and storage temperature can be observed with the adjustment for the covariate of years of experience of each taster (Table 5). When controlling for the covariate, the results are very similar to the means previously estimated in Table 1, but overall the means are slightly lower and within the standard error for each variable. Once again, the combination of the vacuum closure method along with storage at 50°F resulted in the lowest scores in the duo-trio tests performed by the tasters.

Table 5

*Temperature*Treatment*

Treatment	Temp	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Recork	RT	0.734	0.071	0.595	0.873
	60	0.639	0.064	0.513	0.765
	50	0.466	0.059	0.351	0.581
Vacuum	RT	0.598	0.066	0.469	0.728
	60	0.487	0.064	0.361	0.614
	50	0.438	0.059	0.321	0.554
Gas	RT	0.666	0.069	0.530	0.802
	60	0.666	0.067	0.534	0.799
	50	0.551	0.059	0.436	0.666

Note. Dependent variable: score (1= able to identify fresh wine in duo-trio, 0= unable to identify the fresh wine in duo-trio).

With the results of the ANCOVA, the research questions can be answered and the hypothesis can be evaluated. The use of temperature control during the secondary storage of wine was found to have a significant effect on the rate of oxidation. With all three of the tested closure methods, as the storage temperature decreased, the tasters in the sensory analysis were less frequently able to discern the stored wine from fresh wine. This suggests that as long as a restaurant is using recorking, vacuum, or inert gas as their method of treating and closing the wine for secondary storage, the wine should be stored in an environment below room temperature.

The use of a closure method to preserve the wine also significantly reduced the rate of oxidation. Out of the three closure methods, the vacuum closure method was the most effective at reducing the rate of oxidation based on the results of the sensory analysis. The ANCOVA results showed that when temperature is not considered, recorking was slightly more effective at slowing oxidation than inert gas preservation. When temperature is considered, inert gas is more effective at preserving the wine than recorking at room temperature; at 60°F and 50°F recorking was more effective at preserving the wine than inert gas was. These results were surprising since using inert gas should slow oxidation from occurring by separating the oxygen in the headspace of the bottle from the surface of the wine, while only recorking freely allows for oxidation to occur in the headspace of the bottle. These results suggest that either the procedures used for applying the inert gas preservation method in the testing were flawed, or that another undiscovered factor reduced the effectiveness of the inert gas preservation. Despite this issue, since the vacuum closure method was more effective than both recorking and inert gas, this is the best closure method for wine during secondary storage at all three of the tested storage temperatures.

The lack of an interaction effect between storage temperature and closure method supports the independency of the two methods of reducing the rate of oxidation during secondary storage. If there was a significant interaction effect, a conclusion could still be drawn as to which combination of the variables was most effective. This would not be as convenient for industry application though as not all establishments that serve wine and wish to preserve it after opening it have a variety of closure methods and temperature-controlled storage methods at their disposal.

With the results of the study, two of the proposed hypothesis were supported, and one hypothesis failed to be supported. Hypothesis 1 claimed that by using a variety of closure methods to preserve the wine during secondary storage oxidation could be slowed. This was supported as the effect of the closure methods was found to be significant.

Hypothesis 2 claimed that at lower temperatures, the rate of oxidation would decrease. This was also supported as the effect of temperature was found to be significant. The last hypothesis, was not supported by the testing though. Hypothesis 3 proposed that the inert gas closure method would benefit the most from the decrease in temperature. The idea behind this hypothesis was that as temperature decreased, the volatility of the VOCs would decrease thus making it easier for the inert gas to maintain the barrier between the oxygen and the surface of the wine and prevent oxidation. As previously mentioned (Table 4), the recorking closure method's effectiveness benefitted the most from the decrease in storage temperature between 72°F and 50°F.

Chapter V

Discussion

In the restaurant, bar, and beverage industry as a whole, there has never been a unanimously agreed upon best practice for storing wine during secondary storage. Through the combination of the three storage temperatures of 72°F, 60°F, and 50°F, and the three most common closure methods of recorking, vacuum sealing, and inert gas, the goal was to identify which combination was the most effective. The broader goals were also to see if by manipulating the storage temperature or closure methods during secondary storage, the effectiveness of wine preservation during secondary storage could be significantly affected.

The flavors and aromatics in wine become less potent as the VOCs in wine are oxidized, and research in the field of organic chemistry can explain how this process occurs. There has also been chemical tests performed to measure the rates at which VOCs become oxidized, and some of the ways to control the rate of oxidation through temperature control and oxygen deprivation. While it is very useful to know exactly how this process occurs, the usefulness of this information significantly decreases if the knowledge gained cannot be effectively applied in industry practices. Rather than continuing with the existing approach of chemical analysis of the effectiveness of preservation methods, the approach of using sensory analysis to measure the effectiveness of preservation methods allows for straightforward use of the information in industry practices.

It was found that the combination of 50°F storage temperature and vacuum closure was the best way, out of the nine combinations tested, to preserve wine during secondary storage over a sixteen day storage period. The combination of 50°F storage temperature and recork closure was the second best way to preserve the wine, which is very notable due to this combination's ease of implementation in the industry. These results are similar to the study by Jacob et al. (2011) where the most effective preservation conditions were tested after forty-eight hours of storage with the recork closure method and storage at 45°F. Recorking as a closure method does not require the additional tools that the vacuum closure method does, which makes recorking the simpler closure method to perform. The slight drop in preservation performance between vacuum at 50°F and recorking at 50°F may be acceptable for some beverage establishments that do not have any funds to invest in their wine programs.

Use of Professional Sensory Panel

Research in to the difference in performance between naïve and professional tasters in other sensory analysis literature led us to believe that the responses of the naïve tasters may dilute the significance of the responses provided by the professional tasters. One similar study performed by Smythe and Bamforth in 2002 involved sensory analysis of beer with the use of both naïve and professional tasters. In their study, the tasters were given two beers and told that the two beers had differing sugar sources, while in reality the two beers were identical. Their results showed that there were "clear indications that naïve judges will be likely to report a preference, while more highly trained judges will be more prone to express no preference." Another sensory analysis focusing on beer conducted by Giacalone, Ribeiro, and Frost in 2016 reached similar conclusions. Their findings included that “the level of expertise was associated with a better use of sensory attributes.” After considering the results from these two studies based on a beverage similar to wine due to their shared alcoholic content and the inter-rater reliability of the naïve tasters in this study, we felt that more accurate results from our analysis could be drawn by only using the responses from the professionally trained tasters.

Limitations

The variety of storage temperatures that could be used in this study was limited by the amount of temperature controlled storage space that was available. Commercial refrigerators were used to store the wines at 60°F and 50°F. These two temperatures were chosen as they are the most commonly used temperatures for wine cellars in the restaurant industry. Ideally, additional storage temperatures would have been used such as 40°F, 30°F, and 20°F. Due to the various alcohol content levels in wine, most wine will not freeze at 30°F but will freeze at temperatures near 20°F. To reach temperatures this low, additional storage options, such as commercial freezers, would be needed for preserving the wine. By having additional temperatures below 50°F, the theory that as the secondary storage temperature decreases the rate of oxidation also decreases may have gained substantial evidence.

Since there was not a large group of professionally trained tasters that could be pulled for the experimentation, the demographics of tasters were not considered. Due to this, the demographics of the tasters may not match the demographics of wine consumers as a whole.

Conclusion

The goal of this study was to solve the beverage industry debate as to what is the best way to preserve wine during secondary storage. The results of this clearly showed which closure method out of three of the most commonly used was most effective at preserving wine, and which temperature was most effective at preserving wine. With these results, the goal of the study was achieved.

There are many different methods proposed by industry experts most of which involve storage of the wine at a cool temperature, and also often involve a unique closure method. For opened wine to remain as similar to a fresh bottle, the main process that needs to be slowed down is the oxidation of the VOCs in the opened wine. Previous research on VOCs through headspace gas chromatography has shown that temperature control slows oxidation as does the process of preventing oxygen from reaching the surface of the wine. And while it is valuable to know how this process works, it is only valuable to the beverage industry if the oxidation can be slowed to the point at which a consumer cannot consistently distinguish a fresh bottle of wine from a bottle of wine that has previously been opened and served from.

Wine by the glass programs in restaurants can lead to substantial profits for the restaurant, but they are often plagued with issues of wines spoiling before the full bottle of wine can be sold to customers. A preservation method that can be applied during secondary storage and increase the lifetime of an opened bottle of wine would substantially reduce the issues with wine spoilage. Based on our data analysis, significant statistical results show that using recorking, vacuum, and inert gas closure methods to preserve wine during secondary storage can reduce traits of oxidation that are discernable through sensory analysis. Our analysis also showed that temperature controlled storage can significantly reduce the traits of oxidation that are discernable through sensory analysis. Combinations of temperature controlled storage and closure methods can lead to very effective ways to preserve wine during secondary storage. The most effective combination was vacuum closure and 50°F storage temperature. Using this combination for the preservation method, many trained wine professionals were unable to differentiate wine that was opened and preserved for sixteen day from a fresh bottle of wine that was opened within an hour of them tasting the wine.

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Appendix A

Record the code on each of the glasses onto the form. Three samples are presented in front of you, two of the samples are identical, the other sample is different. Please evaluate all three samples in order from left to right.

Please select the sample that is different.

- ❍ ____________________
- ❍ ____________________
- ❍ ____________________

Please select the sample that is different.

- ❍ ____________________
- ❍ ____________________
- ❍ ____________________

Please select the sample that is different.

- ❍ ____________________
- ❍ ____________________
- ❍ ____________________

Please select the sample that is different.

- ❍ ____________________
- ❍ ____________________
- ❍ ____________________

Please answer the following questions to the best of your ability.

What is your gender?
❍ Male
❍ Female

What year were you born? Please answer in YYYY format.
___ ___ ___ ___

How many years of education did you complete?
❍ 12
❍ 13
❍ 14
❍ 15
❍ 16
❍ 17 or more

How many total years of experience in selling wine in retail, on premise or wholesale do you have? _______________

Please think of the past week, the last 7 days, and answer the following questions as precisely as you can recall… Thinking of the past week (7 days), how many days did you consumed wine? Spirits or spirit based cocktails?

Freq.	Wine	Spirits	Beer
0	❍	❍	❍
1	❍	❍	❍
2	❍	❍	❍
3	❍	❍	❍
4	❍	❍	❍
5	❍	❍	❍
6	❍	❍	❍
7	❍	❍	❍

Please indicate what levels of WSET® certification you have achieved.

- ❑ Level 1 Award in Wines
- ❑ Level 1 Award in Wine Service
- ❑ Level 1 Award in Spirits
- ❑ Level 2 Award in Wines and Spirits
- ❑ Level 2 Award in Spirits
- ❑ Level 3 Award in Wines and Spirits
- ❑ Level 3 Award in Sake
- ❑ International Higher Certificate in Wines and Spirits
- ❑ Level 4 Diploma in Wines and Spirits
- ❑ I have not passed in any WSET® programs.

Please indicate the highest level of the Court of Master Sommeliers certification that you have achieved.

- ❍ Level I
- ❍ Level II
- ❍ Level III
- ❍ Level IV
- ❍ I have not passed in any Sommelier certification programs.

Please indicate the type of the Society of Wine Educators certification that you have achieved.

- ❑ Certified Specialist of Wine
- ❑ Certified Wine Educator
- ❑ Certified Specialist of Spirits
- ❑ Certified Spirits Educator
- ❑ Hospitality/Beverage Specialist
- ❑ I have not passed in any Society of Wine Educators programs.

Record the code on each of the glasses onto the form. Three samples are presented in front of you, two of the samples are identical, the other sample is different. Please evaluate all three samples in order from left to right.

Please select the sample that is different.

- ❍ ___________________
- ❍ ___________________
- ❍ ___________________

Please select the sample that is different.

- ❍ ___________________
- ❍ ___________________
- ❍ ___________________

Please select the sample that is different.

- ❍ ___________________
- ❍ ___________________
- ❍ ___________________

Please select the sample that is different.

- ❍ ___________________
- ❍ ___________________
- ❍ ___________________