

Article

Analysis of Retronasal Flavor Alterations in Smoke-Affected Wines and the Efficacy of Various Inter-Stimulus Rinse Protocols in Clearing Smoke-Related Attributes

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Abstract: Wildfires produce smoke, which can then encounter wine grapes, causing the fruit to absorb smoke-related volatile organic compounds. These compounds impact the sensorial profiles of the resulting wines, introducing an uncharacteristic smokey flavor and ashy finish. Since these off-flavor attributes are observed to have longer-lasting perception, a proper inter-stimulus protocol is necessary to ensure an accurate sensory analysis. Previous work has indicated that a 1 g/L pectin rinse with 120 s of separation is effective for clearing the smoke flavor to mitigate potential carryover effects. The purpose of this work was to determine if there was a more efficient rinsing protocol to lessen the time taken between samples. By using wines with various levels of smoke exposure (high, moderate, and none), the efficacy of four different rinse systems were evaluated with a fixed-time-point evaluation system. These results indicate that a 4 g/L glucose solution is more efficient than pectin, requiring only 90 s of separation to clear smoke flavor perception. Additionally, this work identified appropriate references for the retronasal attributes associated with smoke taint in wine. These results can be used to guide a sensory analysis of wildfire-affected wines to ensure effective and accurate results.



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Keywords: smoke taint; wine; wildfires; sensory analysis

1. Introduction

With the ability to carry over 500 volatile organic compounds, smoke can impart distinct aromas and flavors in food and beverages [1]. When purposely incorporated in processing, such as in meats and cheese, smoke can produce positive sensory experiences [2]. However, when not purposefully introduced, negative qualities may ensue. Wildfires produce smoke that can impact wine grapes, which leads to defects in wine, known as smoke taint and first noted as an issue in 2003 [3]. The compounds contained within smoke are absorbed by the grapes and then remain present in the resulting wine. Smoke-affected wines are described as having smokey, burnt, and medicinal aromas, with a lasting ashy flavor on the finish, along with excessive drying [3]. These descriptors are considered to be detractors of wine quality, and these descriptors have also been found to pose issues for evaluating the sensory qualities of smoke-affected wines in both research and production settings.

The volatile compounds attributed to smoke taint in wine have predominantly been identified as various phenols that are produced from lignin pyrolysis during burning [4]. The accumulation of these compounds in grapes, and therefore the finished wine, are dependent on many factors, such as varietals, growth stage during smoke exposure, duration of smoke exposure, and other environmental conditions [5]. The phenols found in the largest concentrations are guaiacol, 4-methylguaiacol, and syringol; however, combinations of solely these phenols are unable to recreate the smoke flavor experience [6,7]. As determined by Parker (2013), the currently identified indicators for smoke taint in wine are guaiacol, 4-methylsyringol, syringol, *o*-cresol, *m*-cresol, and *p*-cresol due to both their abundance

and low sensorial thresholds. Using these compounds as quality markers is problematic, since they can be found naturally in certain grape varieties and in oak-aged wines [8]. When present in oak-aged wines, these phenols are described as having pleasant oak and vanilla notes, indicating that there are other components of smoke taint that influence strong negative descriptors [5]. Along with the introduction of unpleasant smoke flavors, a masking of more typical, pleasant wine descriptors has been observed [8,9].

Not only are there volatile compounds present in smoke-affected wines but also phenolic glycosides. Once incorporated into grapes some of the volatiles bind with the prevalent sugars to form these non-volatile, and therefore non-perceptible, glycosides [10]. During fermentation, there is some release of the volatile from the glycoside due to yeast and other enzymatic actions [5]. A large portion of glycosides remain in the resulting wine, which can then potentially be released during aging and storage [11]. Another place of volatile release is within the mouth. It has been observed that there is additional release caused by the actions of microorganisms and other enzymes within the oral cavity [12,13]. Since these phenols become perceptible when unbound from the sugar, this action within the mouth is presumed to be the leading cause of the lasting nature of smoke-related flavor attributes.

Sensorial carryover is a bias that occurs during sensory evaluation due to residual sensations from one sample influencing the following ones [14]. In the realm of attribute intensity, this influence causes panelists to inflate or deflate ratings from the true values determined when a sample is evaluated alone [15]. In wine, this is a major concern when studying astringency. Due to the lasting nature of the astringent sensation, there is an increase in astringency intensity as you move through samples, as it has not been properly cleared from the mouth from the previous sample [16]. Smoke-related flavor attributes have also been found to have this lingering effect, which can lead to biases and the inaccurate analysis of these wines. To mitigate carryover, there are many practices that can be employed. One is using a sample presentation design that is balanced for these effects, such as randomized complete block or split-plot designs [17]. Inter-stimulus protocols are an additional method used to mitigate carryover bias. This can be in the form of mandatory time separation between samples and palate-cleansing procedures. Palate cleansers can come in many forms, depending on the product and attributes being evaluated, but are always meant to return the mouth to baseline conditions to mitigate the influence of residual sensations [18].

With an estimated 70% increase in the number of fire danger days by 2050 and the increasingly frequent wildfire seasons, the impact of smoke on the flavor perception of wines is greatly significant [5]. The lasting nature of these flavors requires a careful consideration of interstimulus rinsing to ensure the mouth is returned to baseline conditions for an effective and accurate sensory analysis. From previous work, different interstimulus rinse protocols had varying effects on the length of time that smoke flavor was perceived. It was determined that pectin was the most effective rinse; however, a 2 min separation was required between samples to ensure a full clearing of lingering smoke-related flavors [19]. This lengthy separation is not optimal for an efficient analysis nor for industry production tastings. The objective of this work is to determine if there may be a more optimal rinse than pectin for clearing the mouth of these smoke flavor attributes to lessen the amount of time needed between tasting samples. It is hypothesized that the use of rinses when taking into consideration the solubility of the phenols and the glycosides present in smoke-tainted wines will be more efficient than the currently recommended pectin rinse.

2. Materials and Methods

2.1. Panelists

Initially, 89 panelists (30-M/58-F/1-gender nonconforming) for the just-about-right (JAR) test and 49 panelists (16-M/33-F) for the fixed-time-point evaluation, selected from 78 panelists (26-M/52-F) from panel screening (ages 21 to 60+) were recruited from the Oregon Wine Research Institute wine consumer database. Panelists were screened to

determine red wine consumers who had a minimum of 1 serving of red wine per week. Those who smoked, had taste deficits or other oral disorders, oral lesions, canker sores, or oral piercings; women who were pregnant; and individuals with wine allergies were excluded from recruitment. Approval for this study was granted by the Oregon State University Institutional Review Board (IRB-8781).

2.2. Reference Just-About-Right (JAR)

Three differentiable concentrations (Table 1) of each of the reference standards were determined during a preliminary panel (data not shown). Panelists picked all samples from Weigand Hall on Oregon State University's campus (Corvallis, OR, USA) to be evaluated over the course of the 3 days in their homes. Approximately 20 mL of each sample was provided in blindly coded 2 oz black sample cups (Pactiv LLC, Lake Forest, IL, USA). Samples were split between 3 bags, corresponding to each day of evaluation, with 4 samples for each day. Sample presentation order was randomized for each panelist.

Table 1. Attributes analyzed across all studies with definitions provided during JAR evaluation and concentrations (%v/v or w/v) of all samples evaluated.

Attribute	Definition	Samples
Ashy	Dry, dusty, dirty aroma associated with the residual of burnt products, e.g., a day-old campfire ^a	20% v/v ash solution in water 15% v/v ash solution in water * 10% v/v ash solution in water
Floral	Sweet, light, slightly perfumy impression associated with all flowers ^b	0.06% v/v violet extract ^c in floral solution 0.03% v/v violet extract ^c in floral solution Floral solution *
Mixed Berry	Sweet, sour, sometimes dark aromas associated with a variety of berries, such as blackberries, strawberries, raspberries, currants, etc. ^b	35% w/v mixed berry preserves in water 30% w/v mixed berry preserves in water * 25% w/v mixed berry preserves in water
Smokey	Sweet, brown, pungent, acrid, slightly charred/burnt aroma associated with woodfire smoke ^a	7% v/v whiskey in water 6% v/v whiskey in water 5% v/v whiskey in water *

* Sample identified as optimal for training, ^a [20], ^b [21], ^c (All Star Extracts, Inverness, FL, USA).

Panelists were instructed to sip and spit each sample and wait 5 s before evaluating. They were asked if when thinking about the specified attribute, if the sample was much too weak, too weak, just-about-right, too strong, or much too strong. Attribute definitions were supplied when being evaluated (Table 1). Between each sample, there was a mandatory 2 min rest to cleanse the mouth with water.

The ash solution was prepared using a charred leek ash solution. Leek tops were burnt in a 500 °F oven for 1 h. The burnt tops were then crumbled and mixed with distilled water for a 10% weight by volume solution. The mixture was left overnight to soak and then solids were filtered out using two coffee filters (Kroger, Cincinnati, OH, USA) nested in a fine mesh strainer. This 10% w/v solution was then diluted with distilled water to the concentrations used in this study (Table 1). The floral solution was prepared by mixing 2% v/v lavender syrup (Monin, Bourges, France), 2% v/v rose syrup (Monin, Bourges, France), and 0.005% w/v citric acid (Crush2Cellar, Newburg, OR, USA) with distilled water. The mixed berry solution was prepared by blending mixed berry preserves (Trailblazer Foods, Portland, OR, USA) blended with distilled water at the concentrations indicated in Table 1. Solids were strained out using a fine mesh sieve and 0.03% v/v blackberry extract (All Star Extracts, Inverness, FL, USA) was added to the filtered solution. The whiskey solution was prepared by diluting Islay 10-year single-malt Scotch whiskey (Ardbeg Distillery Limited, Argyll, Scotland) with distilled water to the concentrations indicated in Table 1.

2.3. Standard In-Person Panel Procedures

All in-person evaluation sessions were completed in the Arbuthnot Dairy Lab on the Oregon State University campus (Corvallis, OR, USA). All tests were completed using Compusense Cloud Software[®] (Version 27.0.773.192939). For each wine sample, 20 mL was served in blindly coded black INAO wine glasses (Lehmann glass, Kiyasa Group, New York, NY, USA). At each session, panelists were provided with spit cups, distilled water, and a 1 g/L pectin rinse (Modernist Pantry, Vernon Hills, IL, USA). To comply with university COVID-19 guidelines, custom tabletop booths were used for evaluation, and two air purifiers (Winix, Vernon Hills, IL, USA) were run continuously to maintain air quality. All booths were more than 7 feet apart, and the temperature of the testing room was maintained at a constant 20–22 °C.

2.4. Panel Screening

Panelists were served a standard red wine (NV Merlot from California), a low-smoke-exposure wine (2020 Petit Verdot from Washington), and a high-smoke-exposure wine (2020 Petit Verdot from Washington). The smoke-exposed wines were made following standard winemaking procedures, as described in Section 4.1 of Fryer et al. (2021). They were instructed to sip and spit the wine, wait approximately 5 s, and then rate the intensity of the attributes (Table 1) on unstructured lines scales with high and low anchors at 10% and 90%, respectively. There was then a mandatory 2 min rest between the samples, so that participants could rinse with the provided 1 g/L pectin rinse solution, followed by distilled water. Wine presentation order was randomized for each panelist and attribute order was randomized for each sample. Panelists who could clearly distinguish smoke attributes in the samples were invited to participate in the fixed-time point evaluation.

2.5. Panel Training

Panelists selected from the screening participated in a training session to be able to recognize the four flavor attributes along with the system that would be used in the four formal evaluation sessions. Week 1 was a training session, and then panelists were retrained in week 3 due to a holiday break in the middle of the study. For each attribute, panelists were instructed to sip and expectorate a reference standard, wait 5 s, then select which attribute from the list best described the in-mouth flavor of the sample (Table 1). After selection, they were informed of the identity of the standard and asked to retry the sample while thinking of that attribute. All references were evaluated in duplicate. Reference order was randomized for each panelist and the order of multiple-choice flavor options were randomized for each sample. Between each sample there was a mandatory 2 min rest where panelists were instructed to rinse with the pectin rinse solution, followed by water.

For training in the fixed-time point evaluation system, panelists were instructed on the use of line scales and were then taken through the evaluation procedure with a red wine (NV Merlot from California) and a smoke-affected sample (2020 Petit Verdot from Washington), each paired with the 1 g/L pectin rinse solution in accordance with the procedure described below.

2.6. Fixed Time-Point Evaluation

Three wines made at Washington State University were used during the formal evaluation. Each wine was produced from grapes with varying levels of smoke exposure (high, moderate, and none). Wines were produced as described in Section 4.1 of Fryer et al. (2021) [19].

The evaluation procedure followed is described in Section 4.5.3 of Fryer et al. (2021) with some modifications [19]. Panelists were instructed to sip and then spit out a blind-coded sample of wine. After expectoration, panelists were instructed to start the evaluation system and immediately rate the intensity of all attributes on the unstructured line scales with “low” and “high” anchors. After deciding on the initial ratings, they rinsed with the paired rinse solution (Table 2) followed by water. Every 30 s, the responses on the line scale

faded and panelists were prompted to rerate all of the attributes (Figure S1). The evaluation was performed over 120 s for a total of 5 evaluation points (0 s, 30 s, 60 s, 90 s, 120 s). Each week, prior to beginning the formal evaluation, panelists completed a warm-up evaluation with a standard red wine (NV Merlot from California).

Table 2. Rinses evaluated during the fixed-time point evaluation.

Rinse	Preparation
Pectin solution	Powdered pectin (Modernist Pantry, Eliot, ME, USA) suspended in distilled water using an immersion blender (Mueller Austria Ultra-Stock, City of Industry, CA, USA) at a concentration of 1 g/L.
Ethanol solution	Dilution of 95% grain alcohol (Luxco, St. Louis, MO, USA) in distilled water to a 7% <i>v/v</i> concentration.
Lipid solution	Dilution of liquid medium-chain triglycerides (Stepan Specialty Products LLC, Maywood, NJ, USA) suspended in a 10% ethanol solution ^a using an immersion blender (Mueller Austria Ultra-Stock, City of Industry, CA, USA) at a concentration of 10 g/L.
Glucose solution	Dextrose (NOW Foods, Bloomingdale, IL, USA) fully dissolved in distilled water at a concentration of 4 g/L.

^a Prepared using same method as 002.

Each wine–rinse pair was presented on a tray and was repeated for a total of 3 replicates. After each set, there was an extended break of 1 min until the next set of 3 wine–rinse pairs were presented. During this time, panelists were asked to cleanse their palate with a pectin rinse solution (1 g/L; Modernist Pantry, Eliot, ME, USA) followed by water. Attribute line-scale order was randomized for each wine and wine order was randomized within each set. For each session, panelists saw only one rinse solution, completing a total of 4 evaluation sessions. Rinse order was randomized for each panelist.

2.7. Data Analysis

For the JAR test, a 2-sample proportion test was run between all combinations of ratings (above JAR, JAR, below JAR) for each sample using R package stats version 4.0.5 (R-Studio, Boston, MA, USA).

For the fixed-time-point evaluation, all data analyses were performed using XLSTAT (XL Stat 2020.3.1 Sensory Package, Addinsoft, Paris, France). For this data set, 2 panelists showed lower intensity ratings for the high-smoke wine and were removed due to a lack of smoke sensitivity. The discriminant analysis function was used, using the grouping factor of smoke level at each time point, broken down by each rinse to analyze differences between the wines over time at a 95% confidence level.

A three-way ANOVA using type III sum of squares analysis was performed for each attribute and Tukey HSD post hoc comparison of the means at a 95% confidence interval. All interactions for rinse system, wine, and time were analyzed according to the equation below:

$$y_{\text{attribute}} = \text{Rinse} + \text{Wine} + \text{Time} + \text{Rinse} * \text{Wine} + \text{Rinse} * \text{Time} + \text{Wine} * \text{Time} + \text{Rinse} * \text{Wine} * \text{Time}$$

An additional two-way ANOVA, using type III sum of squares, was used to determine the effect of wine smoke level and position of the sample in the set. An ANOVA was run for each rinse based on the initial intensity ratings ($T = 0$) for the ashy and smokey attributes according to the equation below:

$$y_{\text{attribute}} = \text{Wine} + \text{Position} + \text{Wine} * \text{Position}$$

To determine if there were any modifications to the initial flavor profile ($T = 0$ s) of the wines based on the rinse system, a MANOVA was run on each wine for the rinse system across all attributes at a 95% confidence level.

3. Results

3.1. Reference JAR

The results of the JAR analysis were evaluated based on the proportion of panelists who rated a sample as just-about-right, as opposed to being too strong (above JAR) or too weak (below JAR) (Figure 1). The optimal reference sample for each attribute was selected based on a significant ($\alpha = 0.05$) difference in the proportion between the JAR ratings and the other two categories. With the floral solution, more than two samples met this criterion. The optimal floral sample was then chosen based on the sample that showed the most equal split between the above and below JAR ratings, indicated by the statistical similarity between the percentage of panelists who rated a sample as below and above JAR. For the mixed berry solution, two samples met the original and expanded criteria; therefore, the sample with the highest proportion of JAR ratings was chosen. With the smokey solution, no sample met these criteria, so the lowest concentration was selected.

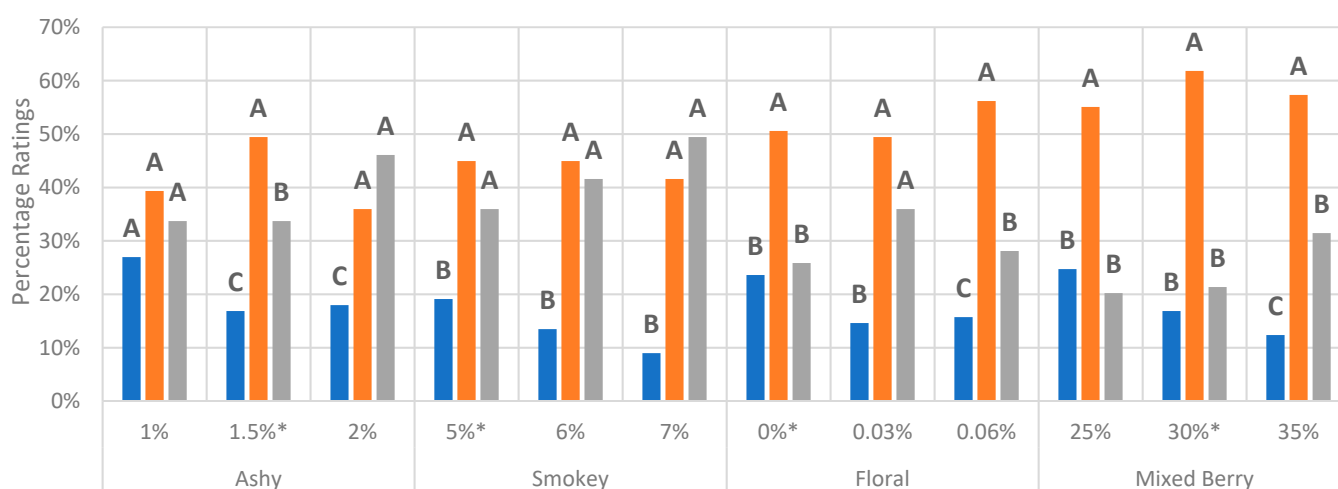


Figure 1. Percentage of ratings above (grey), below (blue), and at JAR (orange). The same letter above bars indicates statistical similarity between groups within each sample ($\alpha = 0.05$), as determined by a two-sample proportion test. * indicates optimal % for reference; see Table 1 for % information.

3.2. Fixed Time Point (FTP) Evaluation

Discriminant analysis (DA) plots were used to show how the flavor profiles of each wine changed over time when the pectin and glucose rinse (Figure 2) and ethanol and lipid rinse (Figure S2) were employed. Across all plots, F1 is strongly related to the time point, explaining 74.26–86.53% of the variability. F2 showed a strong relationship with the smoke level of the wine, explaining 13.17–24.69% of the variability. In these plots, quadrant I correlated to the typical wine attributes (floral and mixed berry) while quadrant IV correlated to the smoke attributes (ashy and smokey).

With the pectin rinse, the high-smoke wine took 120 s to reach statistical similarity compared to the low- and moderate-smoke wines (Figure 2A). The low- and moderate-smoked wines were not statistically different at any time points. With the glucose rinse, the high-smoke wine reached a statistical similarity to the low- and moderate-smoke wines at 90 s (Figure 2B). The low- and moderate-smoke wines were statistically similar from 30 s to the end of the evaluation.

With the ethanol rinse, the high-smoke wine reached a statistical similarity with the low- and moderate-smoke wines at 90 s, similar to the glucose rinse (Figure S2A). However, with the use of the ethanol rinse, the 95% confidence intervals of the high-smoke wine and the no-smoke wine barely overlapped, while with the glucose rinse, it was clear that these wines were no longer perceptibly different. With the lipid rinse, the high-smoke wine again required the full 120 s to reach a statistical similarity to the moderate- and low-smoke

wines (Figure S2B). The low- and moderate-smoke wines with both rinses were statistically similar from 30 s to the end of evaluation.

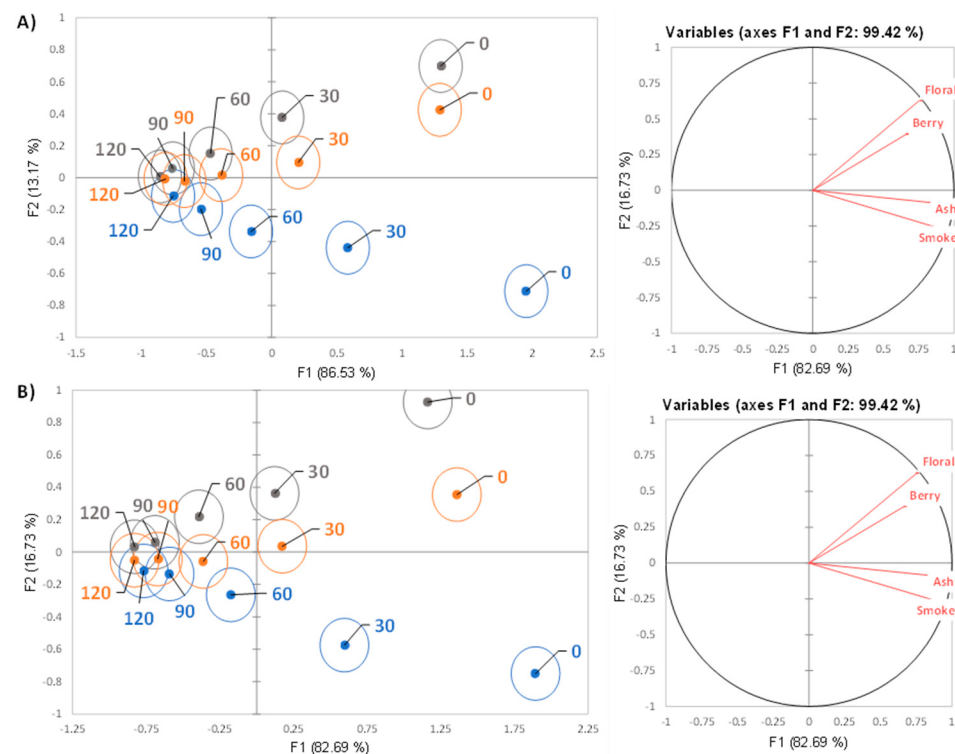


Figure 2. Separation of high-smoke-exposure (blue), moderate-smoke-exposure (orange), and no-smoke-exposure (grey) wines at 30 s intervals, based on DA for the pectin (A) and glucose (B) rinse systems. Ellipses represent a 95% confidence interval around the means.

To ensure that there were no alterations to the initial perception based on rinses, a MANOVA was run for rinses across all attributes at a time of 0 s. For each wine, the rinse system had no significant effects (Table S2).

To further understand the impact of smoke level, time, and rinse system, a three-way ANOVA was run (Table 3). The ANOVA indicated that the wines were all perceptually different across all attributes and that the time point was also significant across all attributes. The rinse system used showed varying levels of significance based on the attribute, having the largest impact on the ashy and floral attributes. The interaction of rinse and time was significant only for the smokey attribute. The wine and time interactions were significant across all attributes. The rinse and wine interaction and rinse/wine/time interaction were non-significant for all attributes.

Table 3. Summary of the significance of random effects according to a three-way ANOVA from the intensity ratings at all time-points for all attributes.

	Smoke Attributes		Non-Smoke Attributes	
	Ashy	Smokey	Floral	Mixed Berry
Rinse	**	^	**	^
Time	***	***	***	***
Wine	***	***	***	***
Rinse*Time	NS	^	NS	NS
Wine*Time	***	***	***	*

(NS) no significance, (^) significance, 0.1, (*) significance, $p < 0.05$, (**) significance, $p < 0.01$, (***) significance, $p < 0.001$. Rinse*Wine and Rinse*Wine*Time not included as they were NS for all attributes.

To further understand the temporality of these attributes, the average intensity at each time point for all attributes was plotted (Figure 3). The average intensity at each time point across all wines and rinses indicated that, for the smoke attributes (ashy and smokey), the average intensities were significantly different at all time points. For the typical wine attributes (floral and mixed berry), the final two time points (90 s and 120 s) did not have significantly different intensity ratings.

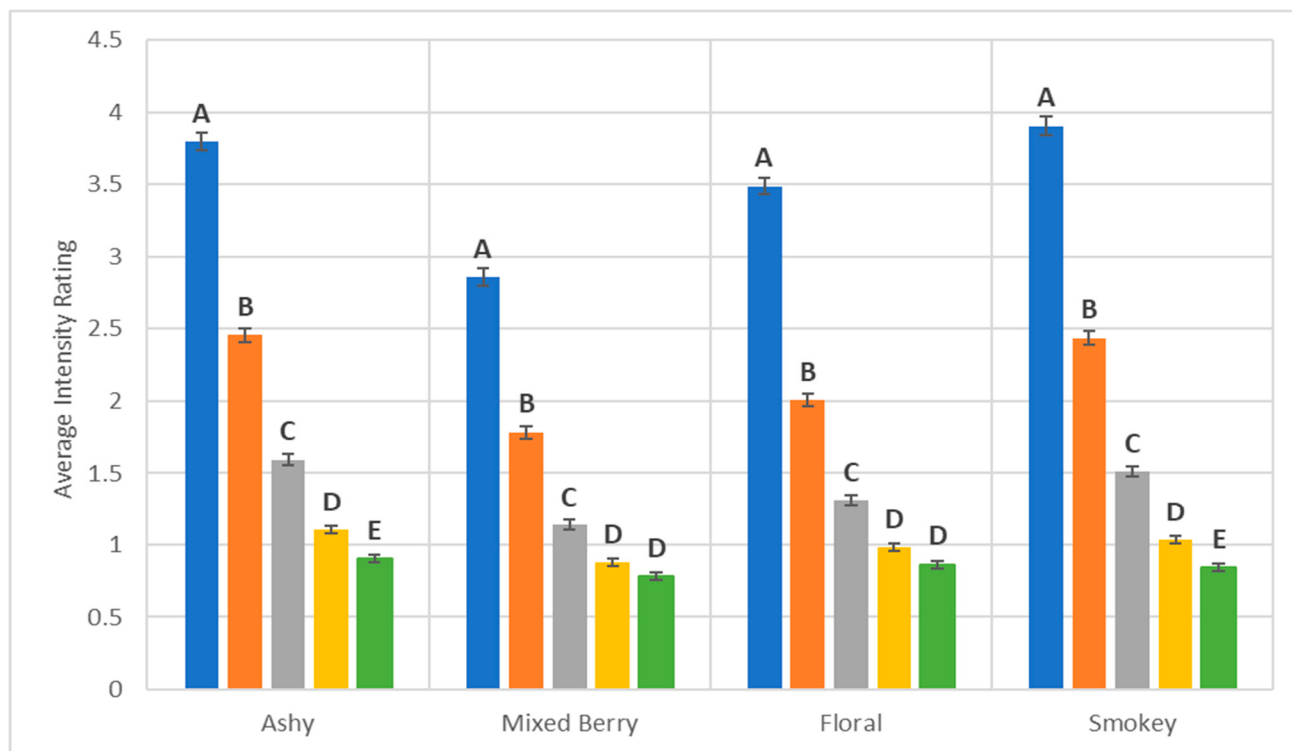


Figure 3. The average intensity of all wines and rinses at 0 s (blue), 30 s (orange), 60 s (grey), 90 s (yellow), and 120 s (green). The same letter above the bars indicates no statistical difference ($\alpha = 0.05$) between average intensity ratings at each time point within each attribute, as determined by Tukey HSD comparison of means. Error bars represent standard error of the means.

To evaluate the impact of carryover for the smoke-related attributes, a two-way ANOVA of the intensity ratings of these attributes at 0 s indicated that there was no impact of sample position within each set of three wines (Table S1).

4. Discussion

4.1. JAR and Reference Evaluation

The first part of this work aimed to better define in-mouth flavor references for the analysis of alterations to flavor perception caused by smoke. Most sensorial research prior to this study focused on orthonasal aromas only, as opposed to retronasal perception. Although both studies are a part of the olfactory system and trigger the same receptors in the olfactory epithelium, their perception is route-dependent [22]. This is found to be consistent in both typical food odors along with odors more associated with the external world, which include smoke [23]. Therefore, proper references needed to be found to better retronasally equilibrate the panelists with the descriptors, especially since these are more novel sensations. With concerns regarding carryover, panels with a greater level of training on and alignment to attributes are less subjected to biases [14].

The results of the JAR analysis were evaluated based on the proportion of panelists who rated a sample as just-about-right as opposed to being too strong or too weak, along with the distribution of the non-JAR ratings. Based on these criteria, the optimal references

were chosen as indicated in Table 1. For ashy, the 1.5% ash solution was selected as the optimal solution; however, the ideal concentration is most likely between 1% and 1.5%, as a significantly higher proportion of panelists rated the 1.5% as above JAR, rather than below JAR. For the smokey standard, all solutions were found to be too strong. The ideal concentration was most likely below 5%, but since these concentrations were not evaluated and there was still a majority of ratings on the JAR scale, the 5% solution was selected. Additionally, during preliminary tastings, it was found that below 5% the smokey flavor was too weak, and the flavor was described as more alcoholic, which was not the target attribute.

In general, consensus profiling is the method predominantly used to define attributes for training in a descriptive analysis. In regard to smoke sensory analysis, this method was used to generate terms and references for the aromas and flavors associated with smoke taint [12,13]. This method, however, has limitations that were desired to be overcome with this novel use of JAR scaling. Due to conditions surrounding the COVID-19 pandemic, we desired to ensure the safety of both panelists and staff by not requiring a large group of people to be in a common space with limited safety measure (i.e., masks). Allowing participants to pick up samples and evaluate them in the safety of their own space, and at a time that was most convenient to them, was a preferred option. Looking to the future, there are improvements to be made to this methodology. The inclusion of an option of “this sample does not represent this flavor” should be included to allow for panelists to indicate if a reference is not effective for defining an attribute.

4.2. Evaluation of Rinses

The results of this work further confirm the alterations to a wine's flavor profile introduced by wildfire-affected grapes. Wine with a high level of smoke exposure showed higher intensities of smoke-related flavors, ashy and smokey, than desirable wine attributes. Across all rinses, the initial ratings of the high-smoke-exposed wines tended toward the smoke-related attributes, while the moderate- and no-smoke-exposure samples tended towards mixed berry and floral aromas (Figures 2 and S2). This is consistent with the ANOVA results, with the wine being significant for the model of all attributes. For smoke-related attributes, the high-smoke-exposed wine showed significantly higher intensities. For the mixed berry and floral aromas, the high-smoke wine contained significantly lower intensities. This also indicated the masking ability of smoke attributes over typical wine attributes, such as fruity, floral, and confection [24,25].

Considering the main objective of this work—to find the optimal inter-stimulus protocol for the sensory analysis of wildfire-affected wines—it was found that glucose was the most efficient rinse for clearing the mouth of smoke flavor attributes. This was evaluated by looking at the time that the wines were no longer perceptibly different (Figures 2 and S2). The pectin rinse performed as well as previously observed, indicating that 120 s was required to cause all wines to taste similar [19]. This phenomenon is hypothesized to be due to pectin's ability to complex with phenolic compounds, which are then removed upon expectoration, and an additional rinse with water [16,26]. The lipid rinse was just as effective as pectin, with the wines no longer being perceptibly different at 120 s. Many of the phenols found in smoke show some level of solubility in lipid solutions [27]. Although this rinse did show some efficacy, there were other problems with its use. Due to the mouthcoating associated with lipids, there is the potential for other lingering tactile sensations to be caused by the rinse [28]. Since this study focused on flavor, there was no evidence that this impacted the flavor profile of the samples (Table S2); however, if other sensations need to be measured, such as astringency or bitterness, there may be alterations to the true profile if lipids are introduced [29].

Ethanol was studied for a similar reason to the lipid rinse. A majority of the phenols, and their glycosides, found in smoke show some level of solubility in ethanol [27]. Additionally, there has been work that has showed that ethanol has some inhibitory ability on the release of volatile phenols from their glycoside [13]. Ethanol showed to be more

effective than both the pectin and lipid solution, only requiring 90 s for all wines to be similar. However, the wines just reached statistical similarity at the 95% confidence level at 90 s. When looking at the glucose rinse, the wines are clearly the same at 90 s, indicating that it is more effective than the ethanol rinse. Similarly, glucose has been shown to limit the release of volatile phenols from their glycosides [13]. This is most likely due to the ability of glucose to compete with the effective binding of the glycoside to the enzyme for releasing the volatile [30]. With limiting the release of the phenols from the glycoside, this then reduces the lasting nature of these attributes upon expectoration.

Previous work has also investigated tackling this issue from controlling the enzymatic action within the mouth by using an antimicrobial mouthwash to reduce the viable bacteria within the oral cavity [19]. This study, however, showed that there were alterations to the initial sensory profiles of the wine and a reduction in the expression of smoke-related attributes that would not be optimal for the sensory analysis of these wines. In this study, neither the glucose nor the ethanol rinse demonstrated these similar effects on the initial sensory profiles of these wines (Table S2), therefore making them both effective rinsing strategies. Regarding carryover, with the 120 s of separation between samples within each of the sample sets, there was no evidence that position influenced the intensity rating of the smoke-related attributes (Table S1). Since this work indicates that 90 s of separation can be used with the glucose rinse, this should be validated through further experimentation.

A final aspect that this work indicates as a direction for further research is the evaluation of an individual's sensitivity to smoke-related compounds. It has been observed in various studies that there is a wide variation in people's perceptions and sensitivity to smoke-related attributes [12,13,19,26]. To combat this, a panel screening was conducted prior to beginning evaluation to ensure that all panelists were able to perceive the smoke-related attributes. Even with this procedure, there were still two individuals who were found to not be sensitive to these attributes in the formal evaluation, so they were removed from the experiment. This shows that there needs to be a more robust method to determine a panelist's sensitivity to ensure an accurate analysis and that data are not skewed due to lack of perception.

5. Conclusions

Based on this experimentation, a glucose solution was found to be the most effective and efficient rinse to clear the mouth of smoke-related flavors, as indicated by the statistical similarity of all wines at 90 s from a fixed-time-point evaluation. At 90 s, the lasting, potent flavors associated with smoke taint are no longer perceptible, which ensures that bias does not augment the intensity ratings of subsequent samples from additive carryover effects. This mitigation of carryover should be validated through future works to determine that a 90 s separation between samples with the glucose rinse does not lead to carryover and to calculate the number of samples evaluated in the sequence that this is effective for. Additionally, this study determined retronasal flavor references for the unique flavors associated with smoke taint to ensure panelist alignment on the less familiar attributes. Looking to the future of understanding the extent of smoke taint in wines, proper panelist screening procedures need to be evaluated along with further investigations into the in-mouth breakdown of glycosides. Based on this study, it is recommended that a 4 g/L glucose rinse solution, followed by water, is used for the sensory analysis of smoke-affected wines with a minimal of 90 s separation between the samples evaluated.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/beverages8020023/s1>, Figure S1: Flowchart of fixed-time-point evaluation procedure, as seen in Fryer (2021). Figure S2: Separation of high-smoke phenol (blue), moderate-smoke phenol (orange), and low-smoke phenol (grey) wines in 30 s intervals based on DA for the ethanol (A) and lipid (B) rinse systems. Ellipses represent a 95% confidence interval around the means; Table S1: Summary of significance of wine and position within set (1, 2, or 3) according to a two-way ANOVA from the intensity ratings at T = 0 s for smoke-related attributes (smokey and

ashy); Table S2: Summary of significance of rinse according to a MANOVA from the intensity ratings of at T = 0 s for all attributes at an $\alpha = 0.05$.

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