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The Effect of Carbonation Level on the Acceptability and Purchase Intent of Muscadine and Fruit Wines

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Abstract: Carbonation is a value-added process that can affect the mouthfeel, perception of volatile compounds, perception of sweetness, and ultimately if a consumer likes a wine. While much work has been completed on traditional varieties of sparkling wine, little research has been completed on niche market wines such as muscadine and fruit wines, which make up a large percentage of wines produced in the Southeastern USA. The objective of this research was to create and evaluate force-carbonated sparkling wine at five carbonation levels. Five finished wines from Florida wineries were obtained, then assessed for the sugar and alcohol content. Each wine was carbonated and then presented to consumers for sensory evaluation (n = 68–89 per evaluation). The questionnaire assessed the perceived sweetness, preference, liking, purchase intent, and comments of each sample. The data illustrated participants consistently preferred the carbonated samples over the noncarbonated sample. The data indicates a roughly even distribution of preference between the four carbonation levels. The data also showed statistically significant differences between the original wine and the carbonated varieties with respect to liking, preference, and purchase intent, which was supported by the consumer's comments for the most preferred and least preferred samples. Overall, this research serves to impact the wine industry by identifying how carbonation levels affect the acceptability of niche wine varieties, and allows winemakers to successfully expand, diversify, and increase the product portfolio for wineries.

Keywords: carbonation; sensory; muscadine wine; fruit wine; CO_2 level

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1. Introduction

For winemakers, the rising popularity of carbonated wine is an opportunity to diversify their product offerings without needing to invest years into novel grape plantings. According to the International Wines and Spirits Record (IWSR), the sparkling wine category posted a 5.2% annual compounded growth rate from 2014 to 2019 [1]. Muscadine grapes (*Vitis rotundifolia*) are commonly grown in the Southeast United States as the variety is more suitable than traditional grapes. Specifically, Muscadine grapes are more tolerant of disease and insects compared to traditional European grapes (*Vitis vinifera*) [2]. The climate of Florida is conducive to growing many fruits besides grapes, such as blueberries. As a result, many wineries in Florida produce muscadine and fruit wines to diversify their product portfolio and compete with other regions. However, minimal research on carbonated versions of these wines has been published. This presents an opportunity to assess both how carbonation affects these products and the production of carbonated muscadine and fruit wines as a viable product. This study investigated how the level of carbonation of Florida wines influenced consumer acceptability through sensory panel evaluation, defined as the effect of carbonation on perceived sweetness, preference rank, liking, and intent to purchase.

Carbonation levels of wine can range from virtually absent, to extremely high, causing overstimulation (bite) on the palate. Still wines may contain some CO_2 due to residual fermentation byproduct, but this is limited to sub sparkling levels. For carbonation in wine

to be detected, a concentration greater than 1.2 g/L must be present [3]. A carbonation level of 3.92 g/L is the minimum amount of carbonation necessary for a product to be considered a carbonated beverage by the Alcohol and Tobacco Tax and Trade Bureau (TTB) (27 CFR 4.21). A carbonation level of approximately 5.9 g/L is often used for fruit sodas such as lemon, lime, or grapefruit soda, while a carbonation level near 7.8 g/L is common for colas and tonics. A carbonation level around 9.8 g/L is common for wines made using the traditional method [4]; however, this varies by style and region.

The concentration of carbonation at equilibrium within a wine is related to the partial pressure of CO_2 gas in contact with the wine and a solubility coefficient termed Henry's Constant (H_C). This relationship is referred to as Henry's law, as shown in Equation (1). Hc is highly dependent upon many factors, of which temperature, sugar, and ethanol are particularly important for wine. These components change how much CO_2 will be dissolved into the wine at a given pressure. The paper by Lonvaud-Funel and Matsumoto [5], assessed the effects of these parameters within wine yielding Equation (2). At the sugar and ethanol levels found within Florida wines, a failure to account for ethanol and sugar within wine could offset the carbonation by levels as high as 30% at 5 °C when compared to water.

$$H_c = P/C \quad (1)$$

where H_c = Henry's constant in L*atm/mol, P is the partial pressure in atm, and C is the concentration in mol/L.

$$\ln pCO_2 = \left(7 * 10^5 * y - 0.02905\right)t - 0.0179y - 0.00111x + 0.51912 \quad (2)$$

where p is a dimensionless variation of Henry's constant in L/L, y is alcohol in volume/volume (vol/vol), t is the temperature in Celsius, and x is extract total in g/L [5].

When combined, these equations allow winemakers to set the carbonation level of wine by accurately incorporating both the ethanol and sugar content of wines. Furthermore, the addition of carbonation has been shown to affect sensory attributes such as the perception of sweetness, acidity, and mouthfeel [6]. In general, Kappes found that physical attributes such as carbonation influenced consumer acceptability and mouthfeel. However, as Florida wines are unique in the high sugar content typical of the style, it is unknown if this correlation is appropriate for Florida wines.

The objective of this research was to explore how carbonation level affects specific attributes of Florida wine (characterized by a high sugar content (~96 g/L) and average ethanol levels (~11% *v/v*)). Five wine samples were assessed at five carbonation levels (still, 3.92, 5.88, 7.84, 9.80 g/L, or nominally still (2, 3, 4, 5 vol/vol)) to determine how the CO_2 level affected: perceived sweetness, preference, liking, purchase intent, and comments. This study will help determine if carbonation is appropriate for these wines, and if so, at what specific carbonation level.

2. Materials and Methods

Five wines were collected from four participating wineries. Each wine was assessed at four forced-carbonation levels compared to the commercially available "still" versions of the wines (without added carbonation). Verification of carbonation equations ensured accurate CO_2 levels as determined to be critical for sensory evaluation. Each of the four wineries was chosen based on the available wineries at the Certified Florida Farm Wineries and Vineyard page on the Florida Department of Agricultural and Consumer Services (FDACS). All five Florida wines broadly fell into two categories: white Carlos muscadine and blueberry wines.

To determine the carbon dioxide (CO_2) solubility coefficient (Hc) to be used for the carbonating process, each wine was first assessed for sugar, alcohol, and density using an ALcohol and EXtract meter (ALEX) 500 (Anton Paar—Graz, Austria). This was necessary to calculate the pressure needed to accurately achieve the desired carbonation levels. The five carbonation levels (uncarbonated "still" wine, 3.92, 5.88, 7.84, 9.80 g/L, or nominally

still (2, 3, 4, 5 vol/vol)) were roughly modeled after common industry and regulatory carbonation levels. The noncarbonated "still" wine was the finished wine from each winery that served as the control without modifications. The "low" (3.92 g/L–2 vol/vol) level of carbonation is the minimum amount of CO_2 in wine to be considered sparkling wine from the TTB (27 CFR 4.21).

Each wine was carbonated in 6.5 L stainless steel kegs. The kegs were stored at 4 °C to increase the solubility of CO_2 and reduce the required headspace pressure. The wine was carbonated until the pressure came to equilibrium within the kegs according to Le Chatelier's principle. After carbonation, the wine was bottled into 187 mL clear glass bottles (rated to 6 vol/vol) with a liquid volume of 180 mL to leave space for the cork and a small amount of headspace. These bottles were chosen due to the high-pressure rating, and bottling was completed under CO_2 counter pressure dependent upon the carbonation level. Carbonation level was confirmed using a Zahm and Nagel 6000 CO_2 pierce device (Zahm and Nagel Co., Holland, NY, USA) to ensure proper levels were achieved.

During the sensory evaluation, all of the 180 mL wine bottles were kept at 0 °C in an ice water bath to ensure a consistent temperature until poured. The sample cups used had a small surface area to volume ratio to delay CO_2 loss during sampling. Only one researcher acted as the server for every panel to consistently pour the beverage to minimize the loss of CO_2. All carbonation levels and the original, noncarbonated still wine were blindly tasted with randomized 3-digit codes. The serving volume of each sample was 20 mL based on the approval by the University of Florida Institutional Review Board (IRB). A single bottle served 8–9 participants, ensuring consistent carbonation level between all participants served as all samples were poured and assessed at once. The five samples of each wine for each panel were presented to the participants in random order. The protocol implemented during the sensory evaluations was approved by the IRB. All participants signed a consent form that acknowledged the purpose, risks, and rewards of the study. The participants received compensation in the form of University of Florida dining vouchers. The questionnaire presented to participants first inquired about demographics, specifically age and gender, with screening questions including allergies and pregnancy status.

For every wine panel, each of the five carbonation levels were assessed individually for perceived sweetness, preference, liking, and purchase intent, with the option to assign comments to the most and least preferred carbonation levels. Perceived sweetness was assessed on a 5-point Just About Right (JAR) scale with the following terminology:

1. Not at all sweet enough
2. Somewhat not sweet enough
3. Just about right
4. Somewhat too sweet
5. Much too sweet

To assess the CO_2 level preference, all the samples were ranked from the most preferred (1) to least preferred (5) sample; this resulted in the most preferred CO_2 level receiving the lowest preference rank value.

The liking for every carbonation level was assessed using a 9-point hedonic scale with the following terminology:

1. Dislike extremely
2. Dislike very much
3. Dislike moderately
4. Dislike slightly
5. Neither like nor dislike
6. Like slightly
7. Like moderately
8. Like very much
9. Like extremely

The purchase intent of each carbonation level was assessed using a 5-point hedonic scale with the following terminology.

1. Definitely will not buy
2. Probably will not buy
3. Might or might not buy
4. Probably will buy
5. Definitely will buy

Finally, the participants selected from a list of attributes that the researchers created to identify the qualities determining why the participants chose their most and least preferred sample.

Each panel was individually analyzed using the same statistical methods. The perceived sweetness, liking, and purchase intent data used a two-way ANOVA analysis and a Tukey's HSD to determine the statistical significance and *p*-values. The preference data was assessed using the Friedman Analysis of rank and Tukey's HSD to determine statistical significance and *p*-values. These tests were performed using "Compusence cloud" statistical software (Compusence Inc., West Guelph, ON, Canada). The level of significance used for all statistical tests was $\alpha = 0.05$.

3. Results and Discussion

3.1. Analysis of Raw Material

The results of sugar, ethanol, density, and pH analysis for every wine sample prior to carbonation is shown in Table 1. Triplicate trials were performed for each of the five wines. These values were used to determine the pressure level required to carbonate the wine as per Equations (1) and (2). The recorded analysis provided a foundation to base the determined carbonation levels by considering the amount of ethanol and sugar in solution as previously discussed. All wines were carbonated using the pressure/temperature combination that corresponded to the aforementioned calculated levels.

Table 1. Physical characteristics (sugar content, alcohol level, and density) of five Florida white muscadine and blueberry wines as determined using an Anton Paar ALEX 500 with mean ± standard deviation from triplicate trials. The pH was assessed using a Fisher scientific AB15 pH meter.

	White Muscadine 1	White Muscadine 2	White Muscadine 3	Blueberry Blend 1	Blueberry Blend 2
Apparent Brix° (%*w*/*w*)	3.63 ± 0.055	4.63 ± 0.015	5.63 ± 0.010	6.38 ± 0.012	8.07 ± 0.023
Extract Total (g/L)	74.53 ± 0.462	85.17 ± 0.208	97.03 ± 1.266	105.80 ± 0.265	114.97 ± 0.115
Alcohol (%*w*/*w*)	8.46 ± 0.036	8.50 ± 0.017	8.84 ± 0.297	9.06 ± 0.059	6.62 ± 0.017
Alcohol (%*v*/*v*)	10.85 ± 0.042	10.95 ± 0.023	11.43 ± 0.386	11.75 ± 0.076	8.91 ± 0.023
Density $(g/cm)^3$	1.0124 ± 0.0002	1.0164 ± 0.0001	1.0203 ± 0.0001	1.0233 ± 0.0001	1.0302 ± 0.0001
pH	3.15	3.13	2.84	3.50	3.61

3.2. Demographics of Participants

For all panels, a total of 373 participants were recruited, resulting in an average of 74.6 ± 6.8 consumers per panel. The cumulative samples poured by the researchers totaled 1865 samples. Among those participants, 207 participants were female (55.5%), and 166 participants were male (44.5%). All participants also indicated that they did not have a sulfite allergy or a fruit allergy and were not pregnant.

3.3. Perceived Sweetness

Although the amount of sugar in the wines did not change with carbonation level, the perceived sweetness has been shown to be affected in previous studies [7]. The average amount of sugar in the five wines tested was 5.66 apparent Brix°, and the extract total was 95.5 g/L of sugar, or 9.6 actual Brix° when corrected for the density of alcohol. For all panels, a 5-point JAR scale was used to assess the perceived sweetness for each carbonation level. There was not a statistical significance in any of the five panels, and the conclusion was that carbonation did not affect the perceived sweetness of the wines assessed.

3.4. Preference of Carbonation Level

The preference ranking data showed that the consumer had a clear preference for carbonated wine. Figure 1 shows the rank sum for all five carbonation levels for each wine. The original still variety of Florida wine was consistently ranked as less preferred compared to all carbonation levels, as indicated by the higher total.

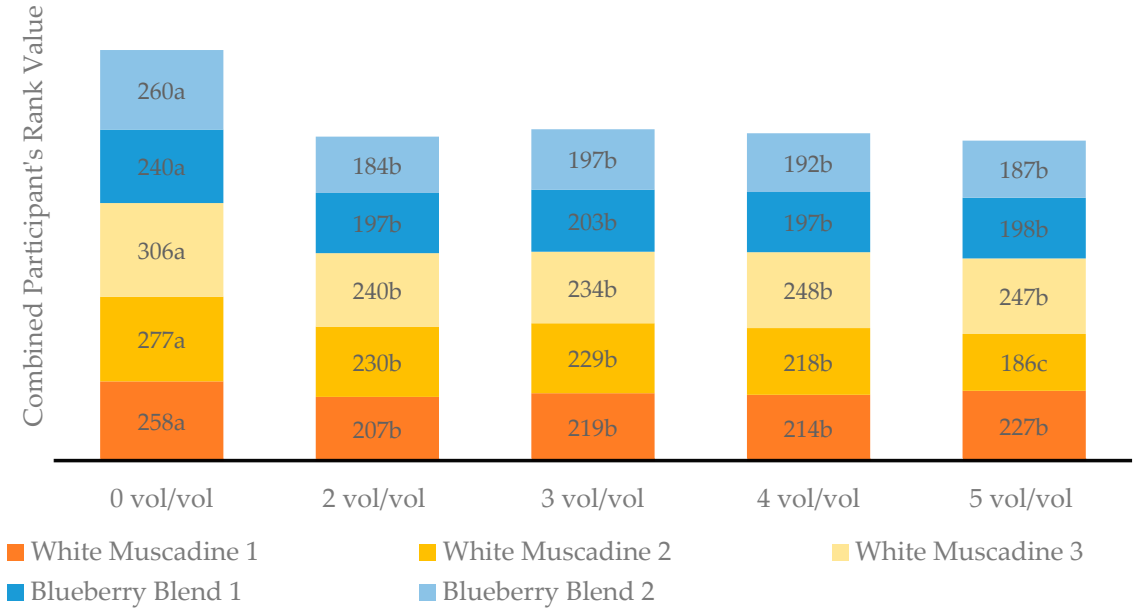

Figure 1. The preference rank sums for all five carbonation levels for all five Florida wines. Letter (a, b, c) denotes statistical significance ($p < 0.05$) between wine carbonation levels using Friedman analysis of rank and Tukey's HSD statistical tests.

These results highlight that the addition of carbonation may help Florida wine companies diversify their products. These findings may be partly due to the carbonation enhancing the perception of desired volatiles from wine. As the CO_2 leaves the solution, a higher concentration of volatiles may be perceived by the orthonasal olfaction system [8]. Alternatively, the effect of CO_2 on the mouthfeel may also play a significant role as the effervescence is increased (as described by Vlădescu et al. [9]). As the wine is ingested, supplemental aroma compounds will appeal to the enjoyment of the wine through the retronasal olfaction system [8].

A common trend between all the panels was the statistical difference between the still and the carbonated wine, but rarely was there any significance between carbonated levels. While carbonation was clearly preferred, the ideal level of carbonation depended heavily on participant's own opinions. For winemakers, these results allow flexibility in creating a sparkling wine product that suits their needs. The amount of carbonation to add to each wine produced can be tailored based on what the winemaker views as ideal, or to adhere to tax and safety regulations.

3.5. Wine Evaluation

The mean evaluation scores are shown in Figure 2, with the exception of the data from the Blueberry Blend 1 panel. The wording of the questionnaire used during the initial sensory panel (Blueberry Blend 1) was determined in retrospect to be ambiguous. Every other wine panel used an improved questionnaire (as described in the methods section), thus the results from Blueberry Blend 1 were not included in Figure 2 or Figure 3. There was a statistically significant ($p < 0.05$) difference between the still and the most preferred wine samples. The liking of the carbonation levels indicates a remarkably similar trend to the previous section where the carbonated samples were more preferred. The addition of carbonation resulted in statistical significance both in the individual panels and in the cumulative data.

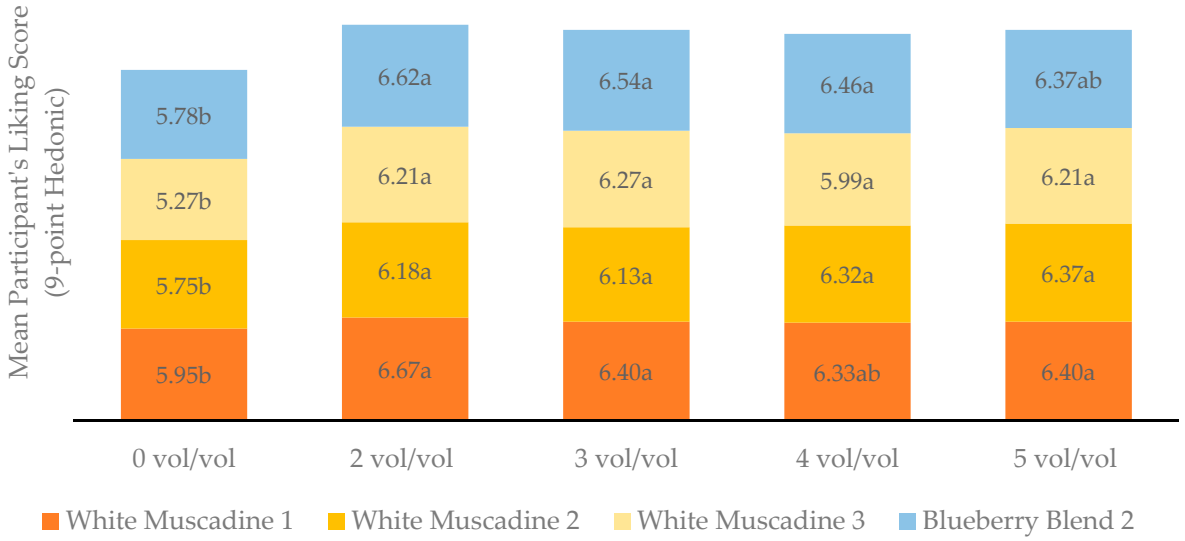

Figure 2. The mean liking using 9-point hedonic scale for each of the four Florida wines. a, b denotes statistical significance ($p < 0.05$) for each individual wine between carbonation levels using Two-way ANOVA and Tukey's HSD statistical tests.

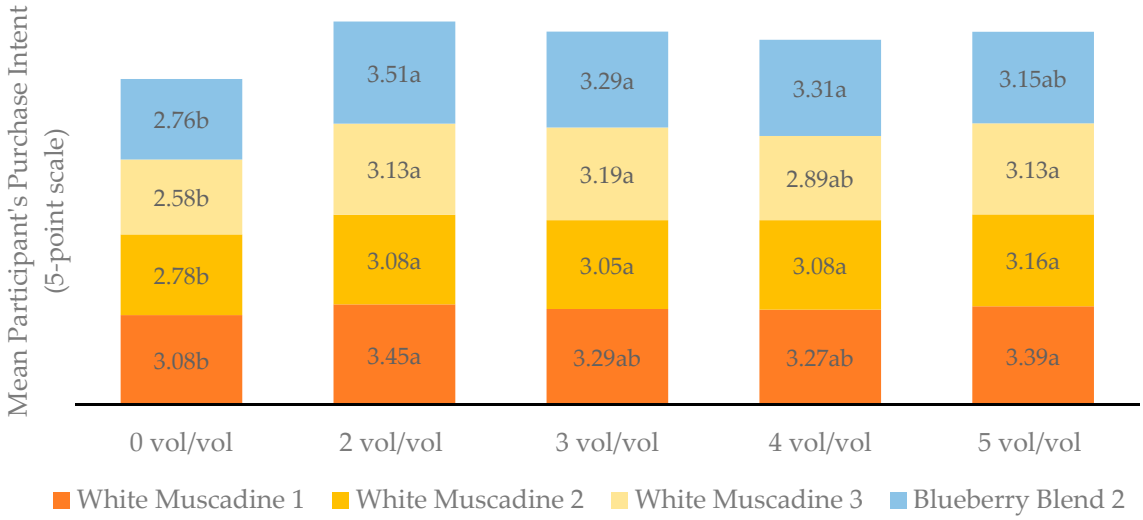

Figure 3. The average purchase intent using a 5-point hedonic scale from each panel for four Florida wines. a, b denotes statistical significance ($p < 0.05$) for each individual carbonation level for each wine.

3.6. Purchase Intent

The questionnaire asked about the purchase intent for each wine sample. The purchase intent portion of the data follows a similar trend as previous sections, with the most preferred carbonated varieties having a higher preference ranking than the noncarbonated variety (as shown in Figure 3). The purchase intent data from the last four panels align with the previous data that carbonated Florida wine was favored over "still" Florida wine. The average hedonic score for still wine was 2.8, which is between "Probably will not buy" and "Might or might not buy.", whereas the most preferred carbonated sample had an average of 3.3, which is between "Might or might not buy" and "Probably will buy".

3.7. Comments

The final question in the panel allowed participants to select comments to describe the most and least preferred carbonation levels for each wine. The attributes that the participants selected were chosen from a list, and participants could choose as many of the comments that correlated with their choice as desired. The total represents what all

participants valued in their most preferred and least preferred samples across five Florida wines. The summarized information is compiled in Table 2.

Table 2. Comments indicating attributes for the most preferred and least preferred sample from five Florida fruit and muscadine wines. A green–red heat map is used to indicate the highest number of participants selecting a comment (green) to the lowest (red).

Most Preferred Attributes	White Muscadine 1	White Muscadine 2	White Muscadine 3	Blueberry Blend 1	Blueberry Blend 2	Total
Balanced Taste	60	53	71	49	58	291
Adequate Sweetness	55	56	59	41	52	263
Adequate Carbonation	54	46	57	50	51	258
Enjoyable Mouthfeel	44	41	56	40	46	227
Smooth	31	34	47	33	43	188
No Unpleasant Aftertaste	27	34	32	31	28	152
Pleasant Aftertaste	31	21	24	24	31	131
Least Preferred Attributes						
Unpleasant Aftertaste	35	33	57	31	39	195
Bitter	28	24	38	30	27	147
Not Carbonated Enough	21	30	27	27	35	140
Not Sweet Enough	20	25	25	15	21	106
Too Sour/Tart	14	15	35	12	20	96
Too Dry	22	15	25	12	18	92
Too Carbonated	20	19	22	16	11	88
Too Sweet	14	20	15	16	19	84

Analyzing the comments for the most preferred samples shows that over half of the participants picked “adequate sweetness”, “balanced taste”, “adequate carbonation”, and “enjoyable mouthfeel”. This indicates that these characteristics factored into choosing their most preferred sample or were noticeably different from the other samples. The data illustrated that 77% and 70% of participants chose “balanced taste” and “adequate sweetness”, respectively. Also, 68% and 60% of the participants selected “adequate carbonation” and “enjoyable mouthfeel”, respectively.

With respect to the least preferred sample, an unpleasant aftertaste was chosen to be a significant determinant for Florida wine samples, with 52% of participants selecting this attribute. The second most attributed comment was “bitter”, with 39% of participants choosing this as a reason for their least preferred sample. The following reason why participants chose their least preferred was “not enough carbonation”, with 37% of participants choosing this trait.

Due to the subjective nature of comments and preference, it is possible that participant’s evaluations were influenced by their cultural background [10,11]. This may have contributed to the broad acceptance across all carbonation levels as observed in Figures 1 and 2. Torrico et al. [10] observed cultural differences when asking about acceptability, and as the University of Florida has a diverse population of students and staff, the influence of cultural differences was likely a factor that may have affected the acceptability and comments. As winemakers will want to tailor products to target specific customers, additional research into this topic will likely be beneficial to the industry.

4. Conclusions

Florida wines showed statistically significant differences between the commercial available “still” wine and any level of carbonation. While carbonation was consistently preferred, there was not a particular carbonation level that had a clear statistically significant preference during any panel. Overall, carbonation was shown to enhance the liking and purchase intent of the wines assessed, which were characterized by high sugar and average alcohol levels. While these wines were characteristic of Florida white and berry styles, the results will not apply to all wines produced in Florida. Additionally, the preferences of different demographic or cultural groups will likely vary. Therefore, in the case of muscadine and blueberry wines, the choice to carbonate, and to what level, will ultimately depend on the preference of the winemaker and winery. This study may help winemakers

determine if carbonated products are appropriate for their businesses and to help identify the various types of carbonated wines that can appeal to consumers. This knowledge can contribute and add value to businesses, allowing winemakers to successfully expand and diversify their portfolio with a range of carbonated offerings.

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