Assessing the Sensory Profiles of Sparkling Wine over Time

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Abstract: Sparkling wine sensory properties are driven by many factors, including the amount of CO_2 and pressure in the bottle. We were interested in characterizing the sensory attributes of California blanc de blanc sparkling wine and the sensory impact of various effervescence conditions, such as artificial nucleation points, on the aroma and flavor. Beginning with the effect of effervescence conditions on the aroma and flavor intensity, three different nucleation treatments (air-dried glasses, paper towel-dried glasses, and glasses with an etched nucleation point) were compared. Thirty-three panelists assessed overall aroma and flavor intensity for each treatment in triplicate. No statistically significant differences in aroma and flavor intensity were found. Following this, the sensory profiles of eight Californian blanc de blanc sparkling wines were determined using a generic descriptive analysis. Eleven trained judges used visual, aroma, taste, mouthfeel, and bubble descriptors to characterize the sensory differences among the sparkling wines. The characterization was done at both 1 and 5 min after pouring, using the same descriptors, to assess temporal variation. In addition, the atmospheric pressure of each wine bottle was measured to determine the influence of pressure on taste and aroma over time. Sparkling wines assessed at 1 and 5 min showed a significant difference in all wines. This difference was characterized by a decrease in bubble size and concentration and allowed for greater differences within the sample set; thus, at 5 min there was a greater differentiation among the wines. No correlations between bottle pressure and sensory attributes were found.

Key words: sensory evaluation, sparkling wine, temporal aspects

According to the Wine Institute (http://www.wineinstitute.org/resources/statistics/article121), the 2012 US consumption of sparkling wine (SW) and Champagne was 17.7 million nine-liter cases. Generally, SWs are made by one of three methods – traditional method, transfer method, and the Charmat method. Champagne is always made by the traditional method, in which the second fermentation occurs in individual bottles that are then riddled and disgorged to remove the yeast sediment. This method is regarded as producing the best quality sparkling wines and is commonly used by many SW producers. Each second fermentation is a small in-bottle fermentation which could lead to bottle-to-bottle variation (Mortimer 2000). Such variation reduces the style consistency, but also creates a selling point.

Sparkling wine contains dissolved carbon dioxide (CO_2) from the second fermentation and the CO_2 is held under pressure when the SW is bottled. When the bottle is opened, the pressure is released, forcing the CO_2 out of solution, thereby forming bubbles on small nucleation points. When the wine is poured, the CO_2 is released from the solution by diffusion through the liquid, and bubbles are formed (Liger-Belair et al. 2002). Thus, SW is effervescent in a glass due to small imperfections or debris on the glass surface, which act as nucleation points for bubble formation. A typical SW glass may consist of a flute with a small, textured etching or engraved mark at the base, acting as a nucleation site. The etchings produce a steady, uniform, stream of bubbles (Liger-Belair 2012) which may be considered aesthetically pleasing, with greater bubble evolution and the perception of more effervescence (Liger-Belair et al. 2009). Glassware without applied nucleation points may nevertheless contain nucleation sites consisting of natural fibers, such as cellulose, which may be deposited on the interior of the glass by various drying regimens, such as paper towels. These cellulose fibers are cylindrical in shape with a hollow center, with capillary-like properties. Once the wine comes in contact with the fiber, it fills the space within the fiber, via capillarity action. When filled, a gas-space may be left inside the fiber, and coupled with the CO_2 dissolved in the wine, the gas-space increases in the fiber until it reaches the end of it, subsequently releasing a bubble (Liger-Belair 2012). Recently, it was found that in the first three to four minutes after pouring, the wines with more intense effervescence lose the most CO_2, but after about three minutes, the rate of CO_2 loss in wines with the most effervescence is not sustained (Liger-Belair et al. 2013).

It has been implied, and anecdotally stated, that wine in glassware with etched nucleation points at the base will be perceived differently than in glassware with cellulose fibers acting as nucleation points (Liger-Belair 2012, Polidori et al. 2009). It is stated that etched glassware can produce a more vigorous bubble evolution, thereby irritating the consumer's nose and possibly altering the perceived aroma. However, while sensorial claims about the effects of nucleation points on glassware were made in these studies, no sensory analyses were conducted to provide evidence for these hypotheses.

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Additionally, there are few publications on the sensory evaluation of SWs. In some cases, the authors only evaluated the base wine prior to the second fermentation, and thus without the CO_2 that iconically makes an SW effervescent (Torrens et al. 2008). In sensory studies where SWs were used, attempts to control for the CO_2 release were not mentioned; examples are Martínez-Rodríguez et al. (2001) and Pozo-Bayón et al. (2004). This is potentially important, as slight variations in pouring could lead to differences in foaming which would lead to possible sensory differences due to aerosol and volatile compound formation. Additionally, the CO_2 may dissipate over time, leading to evaluations of the SWs that differ because panelists evaluated the samples at slightly different time intervals.

Some authors evaluated both base wine and SWs using the same protocol without addressing the issues related to the presence of the CO_2 in the SWs (Dozon and Noble 1989, Torrens et al. 2010). Dozon and Noble (1989) do mention a time element—the SWs were poured 15 min prior to placing a plastic petri dish lid on the wine glass and were served 5 to 30 min later. Their assumption was that the initial 15 min period would lead to total decarbonation of the sparkling wine. A different study also mentioned that the glasses were covered after a 5 min CO_2 equilibration period but did not indicate how long after this the panelists evaluated the wines (de la Presa-Owens et al. 1998). Vannier et al. (1999) controlled the time from pouring to serving but only to ensure that all sparkling wines were served at the same temperature. Hidalgo et al. (2004) also does not address the timing between pouring and visual assessment in their study of the foaming characteristics. Gallart et al. (2004) were the only authors to explain their glass washing and pouring protocols and also to ensure that the judges evaluated the wines within 5 min. However, they only did visual evaluations of the foam characteristics, which they then compared to the data obtained by gas-sparging the SWs.

In our study, we sought to develop a protocol that accounted for and/or standardized for variability in pouring. We also wanted to determine if adding nucleation points (by etching or cellulose fiber addition) lead to differences in the perceived aroma of the wine in the headspace. Additionally, we wanted to determine if there were sensory differences in an SW 1 min after pouring versus 5 min after pouring, as this would indicate whether standardizing the time of assessment after pouring is important. We chose these time intervals because we felt that they would be representative of early interaction with a poured glass of SW by a consumer.

Materials and Methods

Eight California traditional method blanc de blanc wines, each containing at least 75% Chardonnay were used (Table 1).

Chemical analysis. Wines were analyzed for pH, titratable acidity (TA), free and total sulfur dioxide (SO_2), residual sugar (RS), and ethanol (EtOH). Three measurements were taken from each bottle, and three bottles of each wine were measured, totaling nine measurements for each wine. Wines were decarbonated by centrifugation prior to all measurements. TA, pH, and free and total SO_2 were measured via a Mettler Toledo DL50 autotitrator (Columbus, OH). RS was measured via enzymatic reaction with glucose reagent and D-fructose, using a kit from ThermoFisher (Waltham, MA). EtOH was measured via Anton Paar Alcolyzer (Gerlingen, Germany).

Pressure. Bottle pressure information for each wine was collected in triplicate, using a Series 1100 Zahm Modified Piercing Device (Zahm and Nagel, Holland, NY). All measurements were taken at an ambient temperature of 21°C. The standard gasket on this equipment was too short to pierce an SW cork and a new gasket of appropriate length was constructed at the UC Davis Pilot Winery. All foil was removed from bottlenecks and bottles were drilled, using a standard drill press, through the wire cage, three quarters into the cork. The needle on the piercing device was then manually forced the rest of the way through the cork, thus displaying the internal bottle pressure on the face of the pressure gauge.

Effervescence conditions and bubble nucleation. The glasses used in this study were clear glass with a flute shape and a volume of 170 mL (model: Nuance flute; Luminarc, Arques, France). One set of glasses were etched on the bottom of the bowl using a Dremel rotary tool with a Flex-Shaft attachment (model 4000-6/50; Robert Bosch Tool Corporation, Racine, WI) and Dremel diamond bit (model 7105; Robert Bosch Tool Corporation). Each glass was etched until a mark approximately one-third the diameter of the drill bit was made. The second set of glasses was dried with a paper towel (Bounty Select-A-Size paper towels; Proctor and Gamble, Cincinnati, OH). One perforated towel was used to dry the inside of each of the damp glasses. Glasses were wiped until no water remained. Following this treatment, small residual cellulose fibers on the glass surface were visible to the naked eye when viewed in white light. The control glasses, with no artificial etching, were allowed to air dry after washing with 65°C water. No detergent was used with any of the glasses.

For the sensory evaluation, a commercially available wine produced via the traditional method was used. Wine for each panelist set was required to be poured from the same bottle (i.e., panelists only received wine from one bottle; multiple

Table 1 Sparkling wines, retail price, vintage, and mean carbon dioxide pressure in the bottle.

Wine	Price US$[a]	Vintage	Pressure (atmospheres)
Piper Sonoma (W1)	17.99	NV[b]	4.93 e[c]
Gloria Ferrer (W2)	32.00	2007	6.27 a
Mumm Napa (W3)	38.00	2007	5.76 cd
Schramsberg (W4)	37.00	2009	6.17 ab
Korbel (W5)	10.99	NV	5.69 d
Frank Family (W6)	45.00	2008	6.0 bc
Iron Horse (W7)	40.00	2007	5.80 cd
Chandon Napa (W8)	30.00	NV	6.40 a
LSD[d]			0.259

[a]Per 750 mL bottle.
[b]Nonvintage.
[c]Wines with the same letter do not differ significantly ($p < 0.05$).
[d]Least significant difference.

bottles were never used for individual panelists). All wines were served at room temperature and were poured with the glass held at a 45º angle, with the wine poured down the side.

The panel was comprised of 33 panelists (18 females). Panelists were given nine samples (each treatment and the control in triplicate) in one sitting, which enabled us to evaluate panelist variation within a bottle, but not bottle-to-bottle variation across panelists. They were instructed not to swirl the glass during assessment, were required to expectorate all samples, and were given unsalted saltine crackers and water as palate cleaners. Formal evaluations took place under red light to mask visual bubble characteristics. Panelists were asked to assess overall aroma intensity and overall flavor intensity (by mouth) for each sample. All scoring was recorded via FIZZ (Version 2.47B; Biosystèmes, Couternon, France).

Sensory descriptive analysis. Panelists were trained over six 1-hour training sessions. SW bottles were opened once all panelists arrived to the given session. During training, each wine was assessed by the panelists at least once. However, due to limited availability of samples used in this study, an additional wine (at least 75% Chardonnay, traditional method, Colombia Valley, WA, nonvintage) was used just for training purposes. An experienced tasting group assessed this wine prior to the study and deemed it appropriate for training due to its similar attributes to the wines in the study. No members

Table 2 Sensory attributes and their reference standards used in the descriptive analysis.

Attribute[a]	Reference Standard[b]
Overall Aroma (A)	No reference standard. Defined as the total intensity of the perceived aroma.
Apple (A)	12 g green apple chopped, 15 mL water, 1/4 t ascorbic acid (King Arthur Flour, Norwich, VT).
Citrus (A)	3 g orange peel, 1 g lemon peel, 2.5 g grapefruit peel, 15 mL wine.
Tropical (A)	10 mL pineapple juice (Dole, Thousand Oaks, CA), 5 drops guava juice (Kern's Beverages, Santa Ana, CA), 1 drop passion fruit juice (Kern's Beverages).
Stone Fruit (A)	10 mL peach juice (Kern's Beverages), 4 drops apricot juice from canned apricots (Del Monte Foods, San Francisco, CA).
Artificial Fruit (A)	1 watermelon Jolly Rancher (The Hershey Company, Hershey, PA), 1 drop banana extract (McCormick and Company, Baltimore, MA), 30 mL wine.
Confectionary (A)	1/4 t honey (Honey Bear; Dutch Gold Honey, Lancaster, PA), 15 mL wine.
Floral (A)	15 mL wine, 3 drops rose extract (Star Key White In, Congers, NY), 4 drops orange blossom extract (Eden Botanicals, Petaluma, CA), 4 drops violet essence (Uncle Roy's Comestible Concoctions, Moffat, Scotland), 5 drops linalool essence (Eden Botanicals).
Yeasty/Bready (A)	Standard 1: Two 1 cm cubes toasted brioche (Nugget Brioche Rolls, Nugget Markets, Woodland, CA). Standard 2: 0.25 g Fleischman's bakers yeast (ACH Foods, Oakbrook, IL), 15 mL water.
Nutty/Oxidized (A)	Standard 1: Four roasted almonds (Nugget Mixed Roasted, No Peanuts, Nugget Markets), 30 drops Pedro Ximenez sherry (Hidalgo, Spain). Standard 2: 15 mL sherry (Tio Pepe, Spain).
Cooked Apple (A)	1 T unsweetened apple sauce (Motts, Dr. Pepper-Snapple, Plano, TX), 6 g dried cut red apples (Trader Joe's, Monrovia, CA).
Woody/Toasty (A)	0.5 g ēVoak French oak small chips, HT (Oak Solutions Group, Napa, CA), toasted further using a blow torch until evenly browned in 15 mL water.
Herbal (A)	0.15 g "Five Herb Seasonings Blend" (Davis Co-Op, Davis, CA). Contains: basil, chervil, tarragon, marjoram, chives.
Canned Veg (A)	25 mL artichoke juice (Reese Specialty Foods, Nashville, TN), 10 mL canned green bean juice (Jolly Green Giant, General Mills, Minneapolis, MN), 20 drops fresh onion juice.
Chemical (A)	Standard 1: 30 drops ethyl acetate (Sigma Aldrich, St Louis, MO), 15 mL wine. Standard 2: Standard 1 + 1/2 t white vinegar (HJ Heinz Co., Pittsburgh, PA), 30 mL water.
Sulfur (A)	Standard 1: 20 drops SO_2, 15 mL wine. Standard 2: Four cut rubber bands (Amazon, Seattle, WA), 30 mL wine.
Sour (T)	1.5 g/L citric acid (Sigma Aldrich).
Sweet (T)	Standard 1: 10 g sucrose(C&H Sugar, Crockett, CA / 1 L water. Standard 2: 15 g/L sucrose. Standard 3: 20 g/L sucrose.
Viscous (T)	High concentration: 3 g carboxymethyl cellulose (CMC, Sigma Aldrich) / 1 L water; Low concentration: 1.5 g CMC in 1 L water.
Bitter (T)	800 mg/L caffeine (Sigma Aldrich).
Bubble Size (V)	Low: 'Gently' sparkling mineral water (Hildon Estate, Test Valley, Hampshire, England). Low/Med: San Pellegrino mineral water (Lombardy, Italy).
Bubble Concentration (V)	Med/High: Perrier mineral water (Vergeze, France). High: Mountain Valley Spring Water (Hot Springs, AR).

[a](A): aroma attributes, (T): taste and mouthfeel attributes, (V): visual attributes.
[b]All "wine" listed refers to Franzia Vintner's Select Chardonnay (Ripon, CA).

of this group were panelists. Panelists generated all attributes and reference standards via consensus (Heymann et al. 2014) and chose to use 16 aroma, 4 taste, and 2 bubble attributes (Table 2).

Panelists were introduced to timed assessments starting during the second training session and by the last training session, were able to assess the aroma attributes in 1 min with the taste and bubble attributes taking another minute. A timer was provided on the screen with the attributes. Panelists were instructed not to swirl glasses during the assessment. Each panelist adjusted their seat to a height where their nose fit directly over the glass, requiring no movement or agitation of the glass during aroma assessment.

Formal evaluation sessions were held for six days, twice per day, three days a week, for ~2.5 weeks. Panelists were asked to attend one of two sessions (1000 hr or 1400 hr) offered on each day. All panelists were required to smell aroma reference standards prior to each session. Formal evaluations took place in a positive pressure environment and under red light to mask visual bubble characteristics. The bubble characteristics rated by the panelists (bubble size and concentration) were mouthfeel attributes. At the start of each session, panelists were asked to adjust their seats to accommodate the above mentioned aroma assessment technique. Panelists were required to expectorate all samples and were given unsalted saltine crackers and water as palate cleaners.

All wines, at both 1 and 5 min time points, were presented in a forced randomized order in triplicate, such that all paired combinations of wines were assessed. Each wine was opened immediately prior to pouring and only when panelists were already seated in the evaluation booths. Panelists were asked to assess aroma, taste, and bubble attributes. All scoring was recorded via FIZZ (Version 2.47B; Biosystèmes). There were no forced answers; panelists only rated attributes that they perceived. To accomplish this, FIZZ software was programmed to default to a zero rating for all attributes. Panelists were instructed to only adjust the cursor placement on the line scale for each attribute they would rate above zero, thereby eliminating the need for each panelist to adjust the cursor for each attribute, unless needed.

Due to the nature of this experiment, wines were unable to be assessed for individual bottle irregularities (e.g., corked bottles) by the panel leader prior to the panelists being presented with each sample. Thus, the panel leader and additional experienced tasters tasted each bottle after each formal session, noting any irregularities.

Serving. Panelists were asked to assess all eight wines in each formal session. All wines were presented at room temperature (21°C). No panelist assessed the same wine at two different time points in the same session, with the goal of randomizing order effects. Wines to be assessed at 5 min were poured immediately after the bottle was opened and timed. Wines to be assessed at 1 min were then poured and given to panelists. Wines were presented to the panelists monadically.

Pouring and weights. Due to the interference of CO_2, wine volumes could not be controlled while maintaining the integrity of the experimental design. To combat this, the weight of each sample was recorded and used in the data analysis. Each empty glass was tared, then weighed with wine. All wines were poured with the glass held at a 45° angle, with the wine poured down the side. Each weight was recorded and associated to the specific wine, at the given time point, for each panelist and replicate. For wines at 1 min, the time lapse between pouring and assessment was less than 10 sec.

Data analysis. One-way analysis of variance (ANOVA) (main effect: wine) was performed on chemical and pressure data. For the bubble nucleation data, each attribute, a three-way ANOVA with judge, wine, and replicate, and all two-way interactions was performed.

Two panelists each missed one formal session of the descriptive analysis (DA), resulting in imputation of 2.7% of the data. Imputations were conducted by averaging scores of missed samples with the two replications of each panelist that was present. To differentiate the two time points for one wine, each time point was treated as an independent product. Thus, Wine 1 at one min was analyzed as a different product than Wine 1 at five min.

Recorded wine weights were treated as covariates in the univariate three-way analyses of covariance (ANCOVA, main effects: judge, wine, and replication, and all two-way interactions) of all sensory attributes. A pseudo-mixed model was calculated for significant attributes with both a significant wine effect and significant wine interactions (judge by wine and wine by replicate) (Gay 1998). Fisher's least significant difference was calculated for all significant wine attributes. Canonical variate analysis (CVA) was performed to graphically display sample differences. Linear correlations between bottle pressure and the sensory attributes were calculated. A significance level of $\alpha = 0.05$ was used for all analyses and all analyses were performed using XLSTAT (Version 2012; Addinsoft, New York, NY).

Results

The wines all differed from each other for pH and nearly so for TA (Table 3). The RS concentrations varied from 2.0

Table 3 Basic mean wine chemical analyses: pH, residual sugar, titrable acidity, free and total sulfur dioxide, and ethanol concentration.

Wine	pH	Residual sugar (g/L)	Titratable acidity (g/L)	Free sulfur dioxide (mg/L)	Total sulfur dioxide (mg/L)	Ethanol (% v/v)
W1	3.14 d[a]	14.02 a	9.06 a	17 a	90 a	12.20 e
W2	3.22 c	13.34 b	7.92 d	4 cd	52 cd	13.34 a
W3	3.02 h	11.06 c	8.74 b	15 b	51 d	12.66 d
W4	3.09 e	14.07 a	8.34 c	4 d	30 f	12.87 c
W5	3.32 a	13.25 b	7.03 f	4 d	44 e	11.91 f
W6	3.23 b	10.66 d	7.71 e	5 c	64 b	12.86 c
W7	3.04 g	2.0 f	8.69 b	4 d	55 c	13.11 b
W8	3.06 f	9.96 e	6.70 a	3 d	52 cd	12.85 c
LSD[b]	0.009	0.278	0.057	0.977	2.816	0.029

[a]Wines within a column with the same letter do not differ significantly ($p < 0.05$).
[b]Least significant difference.

g/L to over 14 g/L; this was due to differing dosage additions after disgorging. Free SO_2 levels varied from 4 mg/L to 17 mg/L and total SO_2 from 30 mg/L to 90 mg/L. The EtOH concentration varied but only from 11.91% (v/v) to 13.34% (v/v). In-bottle pressures also varied significantly between 4.93 Atm to 6.40 Atm.

For the effervescence conditions study, the different glasses very clearly had visual differences in bubble entrainment (Figure 1), with even the unetched, air-dried glassware (control) showing effervescence, possibly due to glass impurities. However, the panelists could not see these differences under the red light. Therefore, they only made their assessments based on their perceived intensities in the nose and mouth. Neither overall aroma intensity nor overall flavor intensity were significantly different among the treatments (Table 4). These results indicate that the various treatments that impact the visual bubble flow patterns in sparkling wine seem not to impact the overall aroma and flavor of wine in the glass. However, this finding counters the speculation by Polidori et al. (2009) that the bubble stream may alter the perceived aroma of the sparkling wine. Additional work is needed in this area. Based on our results, we used glassware with no applied nucleation points, neither etching nor paper towel drying, for our further studies, thus the descriptive sensory analysis used unetched air-dried glassware.

Based on the ANCOVA, the only sensory attribute affected by the pouring weights was bubble concentration. Pours with larger weights were found to have a greater bubble concentration. All other attributes were unaffected by weight. The average pour weight for the study was 22.9 ± 3.7 g.

Based on the univariate ANCOVAs, six aroma, two taste, and two bubble attributes were significantly different across wines and times (Table 5). In general, at 1 min, all SWs were perceived to be relatively high in bubble concentration, bubble size, and sour taste, while lower in tropical, herbal, and floral aroma attributes. Wines varied moderately in sweet taste, and yeasty/bready and nutty/oxidized aroma attributes at 1 min. At 5 min, wines began to show a greater differentiation among each other. Numerous wines that were lower in individual attributes at 1 min showed an increase in that attribute after 5 min. For example, wine 1 increased in tropical fruit and confectionary aromas from 1 to 5 min. Wines 6, 7, and 8 also increased in confectionary aroma while wines 5 and 6 increased in sweet taste during that time. Wines 5 and 7 decreased in herbal aroma between 1 and 5 min. However, most wines decreased in bubble size (wines 2, 4, 5, 6, and 8) and in bubble concentration (wines 3, 4, 5, 6, 7, and 8) between 1 and 5 min. The range of observed bubble concentrations became greater after 5 min.

Figure 1 Picture of bubbles in sparkling wine glasses. Control: air dried, no etching; Etched: air dried, etched in base; Paper Towel: dried with paper towel, no etching.

The CVA scores are shown in Figure 2A and the CVA loadings are plotted in Figure 2B. The first three canonical variates (CVs) were significant and explained 62% of the variance ratio in the data set, however, the addition of CV3 did not materially change the interpretation of the space (data not shown). CV1 and CV2 indicate that the attributes herbal, bubble size, bubble concentration, and sour are positively correlated to each other, while being negatively correlated with sweet and tropical fruit (Figure 2B). Confectionary and yeasty/bready are negatively correlated with bubble concentration and nutty/oxidized is negatively correlated with floral.

In general, CV1 displays a separation of wines over time, with all 1 min wines situated on the right side of the biplot (Figure 2A) and all 5 min wines on the left of the biplot. Each wine after 5 min is significantly different from its 1 min counterpart. Additionally, wines at 5 min show more differentiation among the wines at that time point than the wines at 1 min, and are thus more dispersed within the CV1 and CV2 space.

Overall, wines at 1 min are driven by higher levels of herbal, sour, bubble size, and bubble concentration attributes; wines at 5 min are driven by higher levels of yeasty/bready, sweet, and confectionary attributes. A decrease in bubble size and bubble concentration is shown over time. Wines at 1 min show a greater association with both bubble attributes, while wines at 5 min are seen as being less associated with these attributes, thus indicating these wines over time are perceived to be decreasing in CO_2 content, which is responsible for the carbonation.

This apparent decrease in bubble attributes may also explain why sour is more closely associated with wines at 1 min compared to wines at 5 min. Yau and McDaniel (1992) found carbonation increased sourness perception. In this study, wines evaluated 5 min after pouring showed a decrease in carbonation, indicating that the perception of sour at 1 min may also be driven by CO_2 content. Thus, when CO_2 content is decreasing over time, perception of sour is also decreasing.

Table 4 Mean intensity scores for sparkling wines evaluated in glasses that had been air dried, dried with a paper towel, or etched to change the effervescence of the CO_2 bubbles.

Effervescence treatment	Overall Aroma Intensity	Overall Flavor Intensity
Air-dried glasses	4.9 a[a]	5.7 a
Paper towel-dried glasses	5.5 a	5.4 a
Etched and air-dried glasses	5.3 a	5.4 a

[a]Means within a column with the same letter do not differ significantly ($p < 0.05$).

At 1 min, wines 3, 4, and 8 show a greater association with the taste attribute sour (Figure 2A); these wines also have some of the lowest pH of the set (Table 3). At 5 min, wines 1, 2, 3, and 5 show a greater association with the taste attribute sweet; however, these wines had ranging amounts of residual sugar (Table 3). At 5 min, wines 4, 6, 7, and 8 were associated with the confectionary aroma attribute (Figure 2A). Herbal aroma was most associated with wines 3 and 4 at 1 min, while floral aroma was most associated with wines 1 and 2 at 1 min. Bubble concentration was most associated with wines 5 and 6 at 1 min.

As above stated, each wine was significantly different after 5 min, compared to the evaluation at 1 min. Wines 1 and 2 changed the least, while wines 3 and 6 changed the most. At 1 min, wines 1 and 2 were not significantly different from each other, but after 5 min, they became significantly different from each other. This is also the case for wines 5 and 6, and wines 8, 3, and 4 (Figure 2A). Conversely, wines 1 and 5 were significantly different at 1 min, but at 5 min, they were no longer significantly different (Figure 2). This is also the case for wines 2 and 5, and wines 6 and 8 (Figure 2A).

There were no significant linear correlations between the bottle pressures and any of the sensory attributes. The initial goal of assessing bottle pressure was to relate the pressure to a possible trajectory of a wine's movement over time within the CV-space. While no correlation was found in this data, perhaps the inclusion of additional time points (such as 10 min) at which the wine is evaluated may provide additional information regarding any effects bottle pressure has on the overall sensory profile of these wines.

Discussion

No difference in the etched, paper towel-dried, or air-dried treatments was found when assessing overall aroma and flavor of an SW in the absence of visual clues. This indicates that various treatments that impact bubble flow patterns in SW probably do not impact the overall aroma and flavor of SW in a glass. While a sensory study evaluating these treatments has not previously been conducted, assumptions have been made regarding the sensorial effect of these treatments on wine (Polidori et al. 2009). Our study was relatively brief, and looked for general differences; nevertheless, this panel was not able to detect differences in the treatments. It is assumed these results may have implications for future work and conjecture about the sensorial effect of glassware treatments in other research.

The SWs used in this study were quite different from one another (Table 1), and we expected to see differences among wines. However, the significant differences due to time were very surprising. The DA of wines at 1 and 5 min demonstrated a significant difference in each wine with respect to time. It is well known that CO_2 is released into the air from carbonated beverages. Thus, not unexpectedly, both bubble size and bubble concentration generally decreased after 5 min in this study. This apparent decrease in bubble attributes may also explain why the attribute sour is more closely associated with

Table 5 Mean values and Fisher's least significant difference values for significant sensory attributes, calculated for all wines at 1 and 5 min after pouring.

	One minute after pouring								
Attribute[a]	**W1**[b]	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**LSD**[c]
Tropical fruit (A)	0.9 bcdef	1.0 bcdef	0.7 def	0.9 bcdef	1.1 abcde	1.3 abcd	0.3 f	0.7 def	0.84
Confectionary (A)	1.2 ef	1.6 def	1.7 cdef	1.7 def	1.4 ef	0.9 f	1.7 cdef	2.1 bcde	0.98
Floral (A)	1.92 a	1.5 ab	0.8 cde	0.6 e	1.2 abcde	0.8 bcde	0.9 bcde	1.1 bcde	0.71
Yeasty (A)	1.2 cde	1.5 bcde	1.9 abcd	1.1 de	0.9 e	2.0 abc	1.8 abcd	1.5 bcde	0.84
Nutty (A)	1.2 bcde	1.5 bcde	1.4 bcde	1.6 bcd	0.9 e	1.8 abcd	2.2 ab	2.0 abcd	1.05
Herbal (A)	0.7 bcd	0.5 bcde	0.2 cde	0.8 abc	1.3 a	0.4 cde	1.0 ab	0.8 abcd	0.59
Sour (T)	4.2 abc	4.3 abc	4.9 a	4.0 bc	4.4 ab	4.1 bc	4.6 ab	4.4 ab	0.76
Sweet (T)	2.5 abcd	2.2 bcde	2.2 bcde	2.1 bcde	2.1 bcde	1.7 ef	1.2 f	1.9 cdef	0.75
Bubble Size (V)	3.3 bcde	3.8 ab	3.4 abcd	4.3 a	3.6 abc	3.8 ab	3.4 abcd	3.6 abc	0.92
Bubble Concn[d] (V)	4.7 ab	4.7 ab	4.9 a	4.9 a	5.0 a	5.0 a	4.9 a	4.7 ab	0.85
	Five minutes after pouring								
Attribute[a]	**W1**[b]	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**LSD**[c]
Tropical fruit (A)	1.9 a	0.8 cdef	0.9 bcdef	0.6 def	1.7 ab	1.5 abc	0.4 ef	0.5 ef	0.84
Confectionary (A)	2.5 abcd	2.5 abcd	2.5 abcd	2.4 abcd	1.7 cdef	2.7 abc	2.9 ab	3.1 a	0.98
Floral (A)	1.4 abc	1.0 bcde	1.0 bcde	0.6 de	1.3 abcd	0.8 bcde	0.6 e	0.7 cde	0.71
Yeasty (A)	1.2 cde	0.8 e	2.1 ab	1.4 bcde	1.1 de	2.5 a	1.4 bcde	1.5 bcde	0.84
Nutty (A)	1.0 de	1.2 bcde	1.0 de	2.1 abc	1.1 cde	2.7 a	2.6 a	2.7 a	1.05
Herbal (A)	0.2 de	0.1 e	0.1 e	0.2 cde	0.4 cde	0.3 cde	0.2 cde	0.2 de	0.59
Sour (T)	3.9 bc	4.3 abc	4.4 ab	4.4 ab	3.1 d	3.6 cd	4.5 ab	3.9 bc	0.76
Bubble Size (V)	2.4 ef	2.7 cdef	3.1 bcdef	2.9 bcdef	2.4 f	2.5 def	2.8 cdef	2.4 ef	0.92
Bubble Concn[d] (V)	4.4 abc	3.9 bcd	3.8 cd	3.8 cd	3.3 de	2.8 e	3.7 cde	2.8 e	0.85

[a](A): aroma attributes, (T): taste and mouthfeel attributes, (V): visual attributes.
[b]Wines within a row with the same letter do not differ significantly ($p < 0.05$).
[c]Least significant difference.
[d]Concentration.

wines at 1 min compared to wines at 5 min. Yau and McDaniel (1992) found carbonation increased sourness perception. In this study, wines evaluated 5 min after pouring showed a decrease in carbonation, indicating that the perception of sour at 1 min may also be driven by CO_2 content. Thus, when CO_2 content is decreasing over time, perception of sour is also decreasing.

Additionally, this change in the dynamic nature of the wines, with decreasing association to both bubble attributes, displays a potential interference of a variable not often accounted for in previous SW sensory studies. For example, in the study conducted by Vannier et al. (1999), details regarding panelist training, attribute generation, and storage and serving conditions are discussed, yet no mention of any potential CO_2 interference is made.

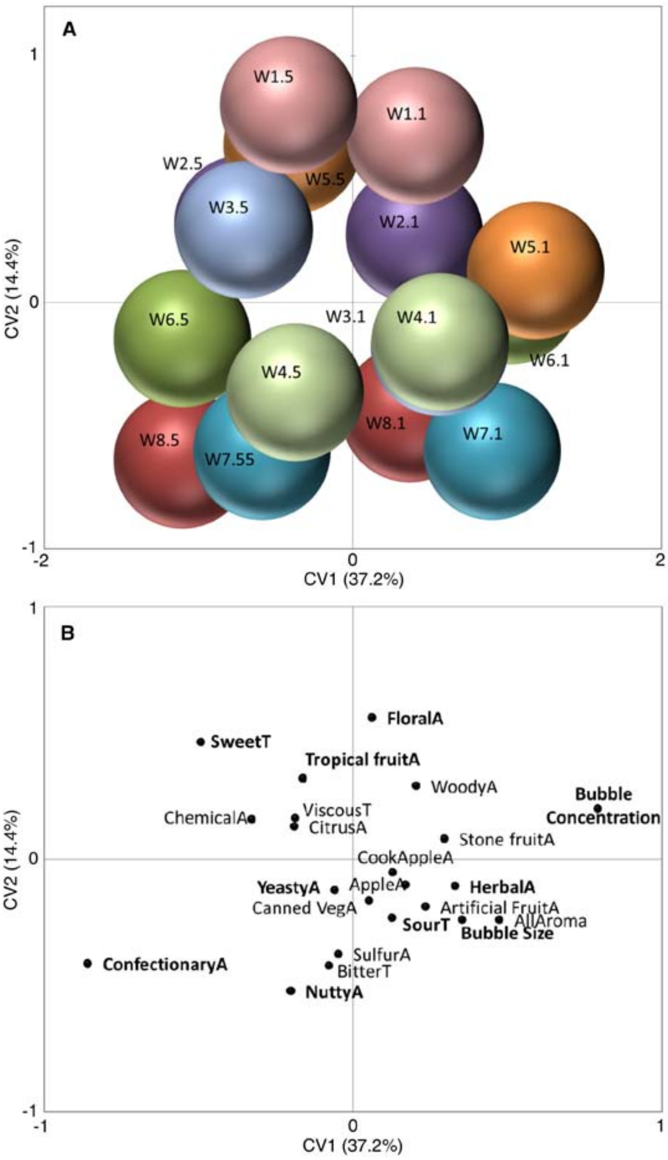

Figure 2 (**A**) Canonical variate analysis (CVA) score plot of eight California sparkling wines sensorially evaluated 1 and 5 min after pouring. Wines are coded X.1 and X.5 for 1 min after pouring and 5 min after pouring, respectively. When the 95% confidence circles intersect, the wines are not significantly different. (**B**) Canonical variate analysis (CVA) loadings plot for the eight California sparkling wines sensorially evaluated 1 and 5 min after pouring. Attributes that differed significantly are in bold type.

Similarly, the lack of controls for CO_2 is an apparent theme in SW sensory studies. Rarely do studies indicate any time between when wines are poured and presented to panelists and any time limitations for panelist assessment, although there are a small number of studies that do address a time element in serving (Vannier et al. 1999, Dozon and Noble 1989). Often these time constraints are not in place to account for CO_2, but rather to control other aspects of the wine, such as temperature (Vannier et al. 1999) or differences in still and SWs (Dozon and Noble 1989). Yet, with the results shown in this research, time can significantly impact the sensory profile of SW, thereby impacting the perceived attributes once the SW is in the glass.

Most notably, this study demonstrates how over a relatively brief time of 5 min, the sensory attributes of these wines become significantly ($\alpha = 0.05$) different from the initial assessment. These findings suggest that many of the methods previously used in SW sensory studies do not adequately control for the changes SWs can exhibit over time.

The results in this study do raise several questions. As the difference in wines at 1 and 5 min was assessed, questions arose as to the effect additional time may have on the wines. Similarly, will wines at a further time point continue to change at the same rate? Or will some equilibration occur?

While these results provide information regarding the profiles of these SWs at two time points, they may also suggest that if a consumer enjoys a newly poured glass of SW, it should be consumed quickly.

Conclusion

The sensory effects of glassware with three nucleation point treatments and the impact of time on the sensory profiles of eight SWs were assessed in this study. Air-dried, etched, and paper towel-dried glassware showed no significant difference in overall aroma and flavor intensity, indicating that nucleation points applied to glassware by paper towel drying or etching did not significantly affect the perception of SWs.

With regard to time, SWs assessed at 1 and 5 min showed a significant difference in all wines. This difference was characterized by a decrease in bubble attributes and allowed for greater differences within the sample set; thus, at 5 min there was a greater differentiation among the wines. No correlations between bottle pressure and sensory attributes were found.

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