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Cooling Shock for Bottled Wine. How Dramatic Is This before Tasting?

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† This paper is dedicated to the memory of the late Wolfgang Pfeifer, whose devotion to understanding enology was unsurpassed.

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Abstract: Adjusting the wine temperature is a routine procedure before opening a wine bottle. In many situations wine requires quick cooling, which occasionally raises disturbing questions among consumers and wine professionals. In particular, there are certain concerns that too rapid cooling of wine for some reasons may negatively affect its sensory characteristics and compromise the wine evaluation. To scientifically confirm of disprove this myth, we conducted a sensory analysis of six wines, cooled slowly in a refrigerator and quickly in an ice–water–salt mixture. Two sparkling wines, two white, and two red still wines with different aroma profiles were included in the research. Results of the *triangle tests* and *3-AFC tests* demonstrated no perceivable differences between the quickly and slowly cooled wine samples. These outcomes may be useful for scientists, who perform wine sensory evaluations, as well as wine producers, experts, and the foodservice industry in general.

Keywords: wine; cooling; sensory analysis; serving temperature

1. Introduction

Variation of wine serving conditions can influence the sensorial impression of wine. For example, shape of wine glasses [1] and wine serving temperature are among the factors that affect the perception of wine attributes. Extensive empirical experience suggests drinking red wines at room temperature or slightly cooler, between 18 °C and 22 °C. The exceptions are light fruity red wines, which require a somewhat lower serving temperature of 15 °C. A suitable serving temperature for white wines is between 8 °C and 12 °C, while for many rosé wines it is expected about 15 °C [2]. Various scientific investigations support these recommendations and provide certain explanations for these phenomena. In this introduction, we consider both olfactory and gustatory human perceptions, which respond to the variation of wine serving temperature. Moreover, some culture-related expectations may also have an impact on the preferred temperatures for wine consumption [3].

Manipulations with the wine serving temperatures make possible to improve the wine sensory experience. This helps to balance the principal in-mouth sensory attributes, such as sweetness, acidity, bitterness, and astringency. Wine temperature affects various receptors that are involved in the taste perception [4]. The recent publication of Green and Nachtigal confirms that cooling a sugar solution to 5–12 °C can directly reduce the sweetness intensity, while mild cooling rather increase the sweet taste adaptation [5]. A lower serving temperature is expected to diminish the sweet sensation of wines and increase their freshness, highlighting the acidity. Therefore, sweet desert wines are recommended to be served even several degrees cooler than dry white wines in order to reach a better sweetness/acidity balance [2]. In addition, the cool wine temperature itself can induce freshness [2].

Bitterness and astringency are usually more prominent in red wines. These attributes become less noticeable in wine at room temperature compared to cooled wine samples [6]. However, this effect depends on the nature of the compounds since different types of receptors may be involved. Wine tannins are usually perceived less bitter at room temperature, whereas for alkaloids solutions such as caffeine, the opposite trend is observed [7]. The authors of the latter work examined not only the temperature of the studied solution, but also the tongue temperature. This approach reflects the concept of "thermal taste" and shows that warming or cooling the tongue can evoke phantom taste sensations by itself, including sweetness [8]. The following study showed that individuals able to perceive the "thermal taste" are also more sensitive to other gustatory and olfactory stimuli compared to people who do not experience the "thermal taste" phenomena [9]. It is important to mention that there are various theories which have developed over time and have contributed to the understanding the chemistry, genetics, and physiology of gustatory perceptions, such as sour taste [10], sweet taste [11] in general, and astringency and bitterness of polyphenols in wine [12].

As for sparkling wines, a low serving temperature is also desirable in order to balance the sweetness/acidity perception and increase their freshness. Effervescence is another aspect that can be affected by the serving temperature. The perception of carbonation on the palate feels more intense at lower temperatures [13]. The nature of carbonation sensation in aqueous solutions is complex and was found to be rather nociceptive in quality (pungent, chemesthetic, "pain" sensation) than tactile. The nociceptive sensations were amplified by cooling. In addition, the aqueous solutions were perceived cooler with increasing of CO_2 level [14]. On the other hand, the sparkling wine cooling to 4 °C demonstrated a significant reduction of losses of dissolved CO_2 during the serving process [15]. Further CO_2 losses from the glass are also diminished at low temperature, which provides better retention of effervescence and extended prickling sensation of the steady carbon dioxide release [16]. These studies are a scientific basis for the empirical recommendations on the optimal sparkling wines serving temperature at 4–8 °C.

In addition to gustatory perception, the wine serving temperature significantly affects also the olfactory perception of wines. Hundreds of aromatic compounds and wine constituents exhibit different volatility depending on the wine temperature. Generally, lowering of wine temperature diminishes the volatility of chemical substances, and hence reduces the perceived aroma intensity [6,17]. At the same time, the vapor pressure during wine cooling changes differently for various aroma compounds, which alters the ratio of volatile substances in the glass headspace. This leads to the dominance of certain aromas depending on the wine serving temperature. For example, the evaluation of Lemberger red wines demonstrated that aroma descriptors "spicy" and "berry" were used more often by panelists for the samples served at higher temperatures, 16 °C and 22 °C, compared to 10 °C counterparts. Simultaneously, "leather" aroma was more frequently mentioned by the tasters in the warmest wine variant at 22 °C [6]. The intensity perception of 4-ethyl phenol and ethyl acetate at various wine temperatures was also studied and discussed [18,19]. It was shown, that the suppression of the fruity wine bouquet was observed by 4-ethyl phenol at all wine temperatures [18]. In case of sparkling wines, the cooling as low as 4–8 °C can help to intensify the perception of desirable toasty aromas [2]. Another example is a kerosene-diesel aroma of 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN) in Riesling wines. The sensory studies revealed that TDN aroma recognition was easier in the wine served at 11 °C compared to the same samples at room temperature [20]. In addition, orthonasal and retronasal approaches to assessing wine aromas also often lead to different results, as the volatility of aroma compounds increases in the mouth due to higher temperatures.

All the mentioned above, studies showed that the wine serving temperature affect olfactory and gustatory perceptions. However, to our knowledge, there are no research on how the rate of wine cooling influence the sensory characteristics of wine. This knowledge gap allows the myths about the rapid wine cooling to circulate in the wine and food industries, e.g., that the fast wine cooling is stressful for wine and can be detrimental for its balance; that the aroma perception and mouthfeel of wine can be altered; and that the optimal effervescence in sparkling wine can be compromised. In the current work we aimed to examine these myths and in order to explore these questions, we carried out a series of sensory analyzes of wines subjected to the cooling at slow and fast rates.

2. Materials and Methods

2.1. Wines

Six commercial wines with various aroma and taste profiles were selected for the sensory analysis:

(1) Medium aromatic, brut sparkling wine—Riesling Sekt "Villa Monrepos", 2015 (Weingut Hochschule Geisenheim, Rheingau, Deutscher Sekt b.A.).
(2) High aromatic, sweet sparkling wine—Asti Spumante Millesimato, Moscato Bianco, 2016 (Canti, Asti D.O.C.G., Italy).
(3) Young, dry white wine—Riesling "Von Lade", 2016 (Weingut Hochschule Geisenheim, Rheingau, Deutscher Qualitätswein).
(4) Aged, sweet white wine—Riesling "Villa Monrepos" Alte Reben, 2014 (Weingut Hochschule Geisenheim, Rheingau, Deutscher Qualitätswein).
(5) Light body, dry red wine—Frühburgunder "Villa Monrepos", 2015 (Weingut Hochschule Geisenheim, Rheingau, Deutscher Qualitätswein).
(6) Medium body, dry red wine—Garanoir "Villa Monrepos", 2015 (Weingut Hochschule Geisenheim, Rheingau, Deutscher Qualitätswein).

This variability was important in order to cover a wide range of sensory attributes, which might alter due to the quick wine cooling. The sparkling wines considerably differed in aroma intensity and sugar level. Both still white wines were Rieslings, but with various sugar levels and aroma profiles (young and aged). As for the red still wines, the main differences were in aroma and tannins composition. Frühburgunder was chosen as a light body and fruity wine of Pinot Noir style, while Garanoir represented classic red wines with a more intense mouthfeel and a somewhat spicy aroma profile.

We had an opportunity to choose the mentioned wines according to the given profiles from a range of commercial wines produced by the winery of our university. Wines of different varieties and vintages were available. The selection of wines was performed through the tasting by the team of authors of this article according to the basic descriptive sensory analysis. It included the following parameters: level of aroma intensity, correspondence of aroma bouquet to the wine age, level of sweetness, perception of wine body, and wine balance perception. Then, the most appropriate wines, which corresponded to the initially defined wine profiles, were determined by consensus. The only wine style that was missing from the own range of commercial wines was (2) high aromatic, sweet sparkling wine. This wine (Asti Spumante, Italy) was selected and bought in the local wine shop.

The basic physicochemical analysis, which is usually done for commercial wines, was performed in the laboratory of the Department of Enology, Hochschule Geisenheim University (Table 1). Total acidity and pH were measured by the automatic titrator "848 Titrino plus" connected to the "869 compact Sample Changer" (Metrohm, Herisau, Switzerland). Sugar content was analyzed according to the Rebelein method [21]. Alcohol content was determined using a refractometer (Carl Zeiss, Oberkochen, Germany) coupled to the density meter DMA 48 (Anton Paar, Graz, Austria).

Table 1. Principal parameters of the commercial wines used for the sensory analysis.

Type of Wine	Wine	Vintage	Alcohol, %	Sugar, g/L	Total Acidity, g/L	pH
Sparkling wine	Riesling Sekt (brut)	2015	13	11.6	7.6	3.4
	Asti Spumante (sweet)	2016	12	82	5.9	3.1
Still white wine	Young Riesling (dry)	2016	13	8.7	7.2	3.2
	Aged Riesling (sweet)	2014	11	54	8.3	3
Still red wine	Frühburgunder (dry)	2015	14.5	3.8	5	3.7
	Garanoir (dry)	2015	13	1.5	2.3	3.3

2.2. Panel and Facilities for the Sensory Analysis

The main panel consisted of 21 tasters: 13 male and 8 female. All the panelists were wine professionals, and employees or students of the Hochschule Geisenheim University (Germany). Absolute majority of the panelists were from Germany. The tasters had extensive wine experience and were familiar with different wine styles. No special training or panelists' selection was done since there was no definite wine attributes in the focus of the experiment. The number of panelists (21) was maximum possible due to the limitation of the wine volume in bottles. The panel #2 for the additional sensory evaluation was a regularly trained sensory panel of Hochschule Geisenheim University and comprised 17 tasters (7 male and 10 female). The panelists were also wine professionals and employees of the Hochschule Geisenheim University. The tasters of the main panel and panel #2 were different people.

The specialized sensory analysis room in the Department of Enology of Hochschule Geisenheim University (Germany) was used for the sensory evaluations. It was well-lit (white light), odor-free and comprised 30 individual booths for panelists. The main and the additional sensory evaluations were conducted on 5 May 2017 and 6 July 2017, respectively. The room temperature during both tastings was about 22 °C.

2.3. Sensory Analysis Panel and Facilities for the Sensory Analysis

Triangle tests and *3-AFC tests* were chosen for the evaluation of sensory differences between the slowly and quickly cooled wines. The application of both test types aimed to investigate various aspects of the wine samples assessment. First part of the sensory session comprised six *triangle tests* (Figure 1), which targeted to define any difference in the sensory parameters of the wine samples: visual, aroma, or taste descriptors. Therefore, the question for the *triangle tests* was general "Which of the three presented samples is different from the other two?". The samples were randomized for all the panelists according to the Latin square design randomization.

After a 15 min break, the sensory evaluation continued, and six *3-AFC tests* were performed. The question for the *3-AFC tests* stated, "Which of the three samples is more aromatic?" The *3-AFC tests* were carried out due to the several reasons. First, it was to focus panelists' attention on the aroma composition, which is usually more susceptible to the manipulations with wine than taste. Second, we wanted to double check potential differences between the samples of the same wines. Third, *3-AFC tests* are expected to have a higher proportion of correct answers compared to *triangle tests* (if the difference between the samples is perceivable), since the question is more targeted and focused on the specific attribute. Therefore, *3-AFC tests* might show statistical differences for the wine samples, which were indistinguishable in *triangle tests* (so-called "skimming effect"). According to the question posed, each *3-AFC test* included the randomized samples of two quickly and one slowly cooled wines. The latter is believed to maintain a better wine balance and aroma composition. The entire sensory session lasted about 90 min, including the introduction part and discussion of the results. The study was conducted using paper questionnaires. The panelists were provided with water and neutral matzo bread to refresh the pallet.

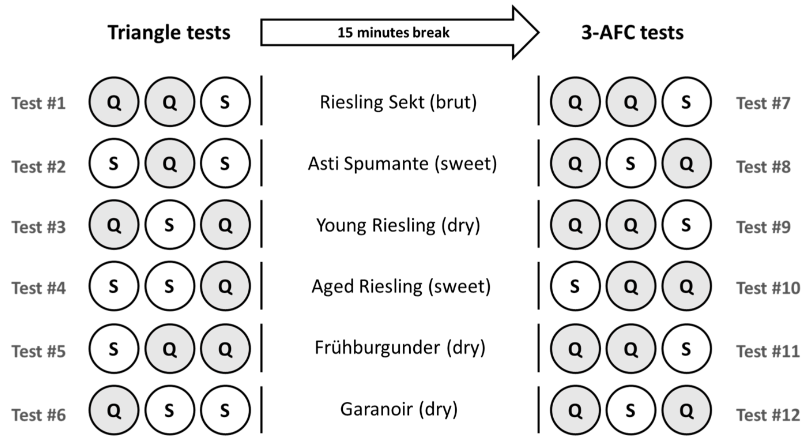

Figure 1. Design of the sensory analysis (with examples of the wine samples randomization: Q—quickly cooled samples, S—slowly cooled samples).

After the statistical analysis of results, two additional questions raised to the *3-AFC tests* with Riesling Sekt and Garanoir wines (discussed in Results and Discussion section). Therefore, an additional sensory evaluation was performed with the panel #2. The tasting comprised two *3-AFC tests* with the mentioned wines.

2.4. Preparation of the Wines for the Sensory Analysis

All wine bottles were left overnight before the tasting day in the laboratory of sensory analysis at 24 °C. In order to avoid the variability between different bottles, the next morning the still wines were homogenized. Seven bottles of each wine were poured into a stainless-steel 10 L container, mixed and bottled into the transparent green glass bottles with MCA finish type (supplied by Richard Wagner GmbH + Co. KG, Alzey, Germany) and MCA screw caps. Initially, the still wines were bottled with the micro-agglomerated stoppers guaranteeing no "cork taint defect" due to 2,4,6-trichloroanisole.

Four bottles of each still wine were prepared for the *triangle tests* and three bottles for the *3-AFC tests*. For the sparkling wines, the number of bottles was five and four, respectively, in order to have an extra bottle in case of cork taint or other wine faults. The sparkling wines were not homogenized for preserving the original effervescence. All the bottles were labeled with a random three-digit number and cooled according to the Table 2.

Table 2. Cooling methods of still and sparkling wines.

Type of Wine	**Wine Cooling**			**Start- and Targeted End-Wine Temperatures, °C**
	Rate	**Method**	**Time, Minutes**	
Sparkling wine	Slow	Refrigerator, 4 °C	200	24 → 9 ± 1
	Quick	Ice–water–salt, –7 °C	21	
Still white wine	Slow	Refrigerator, 4 °C	140	24 → 9 ± 1
	Quick	Ice–water–salt, –7 °C	13	
Still red wine	Slow	Refrigerator, 4 °C	75	24 → 14 ± 1 [1]
	Quick	Ice–water–salt, –7 °C	7	

[1]—serving temperature for the *3-AFC test* with Frühburgunder was 15 ± 1 °C.

The slow cooling of the wine bottles was done in the refrigerator (Liebherr FKvsl 3610, Bulle, Switzerland) at 4 °C. The quick cooling was reached by immersing the bottles into an ice–water–salt mixture of the following composition: 4 kg of ice (commercial ice for food, cubes about 5 cm), 4 L of water (local tap water), and 0.5 kg of salt (commercial kitchen salt of sodium chloride). The ice–water–salt mixture was placed into an insulating plastic food container of about 20 L. Each set of the wine bottles was cooled immediately prior serving the wine to the panelists. During the quick cooling process, the bottles were removed once from the cooling mixture and turned several times upside down for homogenization. The entire optimization of the cooling methods was studied in the previous work in the same laboratory facilities [22]. About 35 mL of each wine sample were poured into the wine tasting glasses (ISO 3591) placed in front of each panelist. The serving temperature of the sparkling wines and still white wines was 9 ± 1 °C, while the still red wines were offered at 14 ± 1 °C. These temperatures were chosen so that the wine temperatures in the glasses during the tastings were about 11 °C and 16 °C, respectively. The preliminary study showed that wine heats up relatively fast by about 2 °C after being poured into a glass [22]. The wines were evaluated immediately after being poured into the glasses; therefore, no lids were required to cover the glasses.

2.5. Processing of the Data

Fizz software 2.51a 86 (2016, Biosystemes, Couternon, France) was used for the preparation and processing of questionnaires and for the following statistical analysis of the data.

3. Results and Discussion

In order to achieve a statistically significant difference in the sensory tests with 21 panelists, at least 12 participants had to answer correctly (* $p < 0.05$). The results of six *triangle tests* demonstrated that the panelists as a group were not able to find any visual (including effervescence for the sparkling wines), olfactory, or gustatory differences between the quickly and slowly cooled wines (Table 3). The short discussion with the panel before the break also revealed no obvious differences in the wine balance (sour/sweet perception) or other mouthfeel aspects (bitterness and wine body) for the employed wines independently on the principal wine parameters (Table 1). At the same time, some panelists commented that certain samples had lower aroma intensity or slight aroma deviations. However, it was not confirmed by the statistical analysis of the *triangle tests'* results. The highest number of correct answers were obtained for the Riesling Sekt, Aged Riesling, and Frühburgunder wines with 10, 11, and 10 correct answers, respectively. These results were close to the statistical significances * $p < 0.05$. Therefore, if the difference between the samples was really perceived by some panelists, then it was probable to get statistically significant results for these wines in the *3-AFC tests*, as they usually provide more accurate evaluations.

Table 3. Results of *triangle* and *3-AFC* sensory analysis tests: alpha risks and significant differences (* $p < 0.05$).

Type of Wine	Wine	*Triangle Tests*	*3-AFC Tests*
Sparkling wine	Riesling Sekt (brut)	0.1248	0.0212 */0.1719 [1]
	Asti Spumante (sweet)	0.7514	0.0557
Still white wine	Young Riesling (dry)	0.8788	0.1248
	Aged Riesling (sweet)	0.0557	0.3992
Still red wine	Frühburgunder (dry)	0.1248	0.3992
	Garanoir (dry)	0.3992	0.0212 */0.5223 [1]

[1]—additional sensory evaluation with the panel #2: repetition of two *3-AFC tests*.

The *3-AFC tests* required from the panelists to focus on the wine aroma composition, which is usually considered as the most sensitive to changes during the wine storage or production. The results of the *3-AFC tests* revealed no statistically significant differences for the Aged Riesling and Frühburgunder wines, as well as for the Young Riesling and Asti Spumante. These outcomes proved that quickly and slowly cooled samples of these four wines are indistinguishable. At the same time, the differences were found for the Riesling Sekt and Garanoir wines with a significance level of 95% (* $p < 0.05$). These results mean either that the sensory differences between the samples were actually present or that the other factors could have an influence on the sensory evaluation. In the case of the Riesling Sekt, the wine was not homogenized, and after two years of storage some bottles could develop slightly differently. This fact might be a reason of the variation between the bottles. As for Garanoir, it was unclear what other factors might had influenced the samples. Since the statistical significance for both wines was on the lowest level with 12 correct answers, it was decided to repeat these two *3-AFC tests* with other panelists (panel #2). As in the case of the main panel, the tasters of the panel #2 were also wine professionals and employees of Hochschule Geisenheim University. Additionally, they belonged to the regular panel and were systematically trained for descriptive wine evaluations. This aspect was important, as our plan was to carry out later a descriptive wine evaluation of the wines, if the panel #2 would also find differences for the quickly/slowly cooled Riesling Sekt and Garanoir wines. The additional sensory evaluation showed no statistical significance for both wines (Table 3). This repetition of two *3-AFC tests* allowed us to minimize factors other than the wine cooling rate. The descriptive analysis for the slowly/quickly cooled wines was no longer required as no sensory differences were observed.

Summarizing the mentioned above results of both sensory analyses it can be concluded that the quick and slow cooled samples of the six tested wines in the end were indistinguishable. As was described in the introduction, the perception of certain aromas in wine bouquet can be highlighted depending on the serving temperature [2,6,18–20]. This effect can be explained by different air–wine partitioning coefficients ($K_{air/wine}$) depending on the temperature. The concept of $K_{air/wine}$ implies the ratio of the respective equilibrium concentrations of an aroma compound in the headspace above the wine and in the wine. During the second discussion after the *3-AFC tests*, our panelists reported no obvious dominance of any aroma descriptors in the evaluated wines. As with the *triangle tests*, some tasters commented about the difference in aroma intensity in general also in the *3-AFC tests* or more petrol aroma in certain Riesling samples. However, these comments were sporadic and were not confirmed by the statistical analysis.

In the actual study, we focused only on the sensory effects, as the most relevant for the practical aspects in the wine industry. At the same time, investigations of possible changes in the physicochemical wine parameters depending on the wine cooling rate may be the subject of further research. To our knowledge, there are no scientific publications on this topic. From our point of view, it is unlikely that the typical chemical and physical wine parameters can differ significantly depending on the cooling rate within the relatively small temperature range of 10–20 °C (e.g., density, pH, wine color, concentration of chemical compounds, etc.). At least our panels did not observe noticeable sensory deviations in the assessed slowly/quickly cooled wines. On the other hand, the examination of more specific parameters such as viscosity or air–wine partitioning coefficients ($K_{air/wine}$) of aroma compounds may be of theoretical interest.

In general, the potential product alterations depending on the cooling rate are of concern not only to the wine industry, but also to food producers. Unlike wine, it has been observed that certain foods actually change their properties in a response to the cooling rate. Thus, the sensory properties of the slowly cooled raw milk may be different due to the prolonged microbial growth [23]. Another study revealed that the rapid cooling of the processed cheese mixture after packaging affects its texture by improving the spreadability and increasing the stickiness [24]. In the field of the meat science, it was found that the beef tenderness is also affected by the cooling rate (and the temperature/pH index) at the onset of rigor mortis [25]. Despite all these relevant studies, the demonstrated results cannot be extrapolated to the wine characteristics, as changes in dairy and meat products during the cooling processes were associated either with their rheological properties or with the activity of microorganisms. In addition to research on food cooling, there are also a number of articles devoted to the freezing processes of grapes, juices, and other food products. However, these studies were not considered in the current discussion, as freezing completely modifies the product matrix due to a change in the state of matter.

4. Conclusions

Wine serving temperature is an important parameter for optimizing the sensory wine characteristics. In order to reach lower serving temperatures, wines are often quickly cooled. In the current study, we demonstrated that the rate of wine cooling does not affect noticeably the wine sensory properties: visual, olfactory, or gustatory wine parameters. It was proven by the *triangle* and *3-AFC sensory tests* of six different wines cooled with a different cooling rate. The six wines were selected to cover various types and styles: white and red, aromatic and neutral, still and sparkling, dry and sweet, and light and medium body. As a result, the panels were ultimately unable to detect the differences between the quick and slow cooled wines. These outcomes can have practical applications in the wine industry and gastronomy, where wine cooling is a routine procedure (e.g., wine tastings, restaurants, etc.). For example, it will be not necessary to place the wines in advance in refrigerators, which volume is usually limited, but to cool the corresponding bottles quickly and immediately before the consumption. In addition, these results can assist scientists who prepare and interpret sensory evaluations of wines.

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