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Abstract

White wines and their wine reductions are popular flavoring agents in both traditional and modern cooking. The range of wines is wide and the type of wine or reduction may influence the sensory properties of the food. In this paper, four white wines with distinct differences in composition (Chardonnay, Riesling, Sauvignon blanc and a blended wine) and their corresponding reductions were studied to determine whether original wine aroma influences reduction aroma or whether it is the non-volatile components of wine reductions that dominate reduction flavor. Sensory evaluation and volatile and non-volatile analyses were performed on the wines and wine reductions. The study shows that by reducing wines, certain flavors get enhanced whereas others diminish. Although the volatile profiles of the wine reductions were significantly different from the wines they were made from, aroma plays an important role in the flavor perception of wine reductions. The study confirms that the wine a reduction is made from influences both the volatile and non-volatile profile of the reduction, and therefore also the reduction's perceived flavor. However, the volatile profile is significantly reformulated during the reduction process, in addition to tastants being concentrated during the same process.

Keywords	White wine; wine reduction; food science; sensory science; culinary arts; molecular gastronomy

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Dear Editor

Thank you for providing reviews of our article. We have read the remarks of the reviewers, and have made changes to the manuscript accordingly. The following text below sums up our comments to the feedback from the reviewers.

First of all, there is a discrepancy in the feedback from the reviewers. Most of the feedback is specific, whereas others are less specific comments concerning larger parts of the article. At this point, it is harder to respond to these less specific comments than to the specific ones. We have made changes to all the larger parts of the article, but hope the article is suitable for publishing without full restructuring and rephrasing of the results and discussion sections. We have tried our best to accommodate the comments from the reviewers, and thank them for many constructive comments, which have improved our manuscript.

<u>Comments to Reviewer 1</u>:

- We agree with the reviewer that it would be relevant to include non-volatile analyses of the wines and reductions to the study, not just Foss WineScan (spectroscopic) data of the wines. We discussed the possibility to include such analyses during the work with the study, but prioritizations had to be made, which did not allow us to include this type of analysis. However, pH measurements of the wine reductions are included under section 3.2. Limitations regarding the Foss WineScan preciseness concerning the sweetness measurements of the blended wine was discussed with a specialist, who did not believe it would cause any important discrepancies at the current sugar level, but it could lead to incorrect results at higher residual sugar concentrations.
- The caption of Table 3 has been rewritten to provide more information about the table contents.
- The reference for the book Neuroscience has been reviewed.
- Acetic acid and volatile analysis: We have already explained the reason why acetic acid was not detected in the wines in the volatile analysis, but by the Foss Wine scan in the manuscript: «The detected concentrations of organic acids in the volatile analysis may also deviate from their actual concentration in the wines and wine reductions, as their volatility depend on the pH. An example is acetic acid, which was not detected in three of the four wines in the volatile analysis, but in all the wine reductions. This is why acetic acid is labelled as «formed» in three of the wines in Table 3. However, the spectroscopic results in Table 1 shows the presence of volatile acids in all the wines, where acetic acid is the most important contributor. The analysis of volatiles has therefore certain limitations, and the list of compounds detected in the wines and wine reductions (Table 3) can therefore not be regarded as a complete list of volatiles present in the wines and reductions, due to collection and detection limit obstacles». We hope this is explanation is satisfactory.
- Comments to the volatile analysis:
    - The Reviewer writes: «It would also have been good to use reference standards to quantify the volatiles on the GC-MS. This would strengthen the results and enable comparison to sensory thresholds». We agree that it would be the ideal situation, but it requires an enormous amount of work. It would have involved running several reference samples of each compound at different concentrations, and in our study we identified over 70 compounds. It could have

allowed us to make more direct comparisons between the volatile analysis and the sensory data. On the other hand, when humans smell and perceive, we perceive the aroma compounds in mixtures, as from a wine (and not the compounds on by one as in a GC-MS). In such mixtures, mixture effects come into play, which in any case makes direct comparison of volatile concentrations and perceived aroma challenging.

    - Regarding retention indices and reference: We referred to the following databases for retention indices in the result section, flavornet.org, odor.org.uk and pherobase.com, but we have also added information to materials and methods.
    - Regarding referencing to detection limit from literature: The detection limit, which is taken from the reference Zhang et al. is in fact determined on the same equipment as used for our analysis, situated at Copenhagen University, and using almost identical methods. Detection limits may therefore be compared.

- Number of deciliters have been converted to the more appropriate unit milliliter.
- Thanks to the reviewer for discovering misspelled words in the manuscript. These are now corrected.

Comments to Reviewer 2:

General considerations:

- Several of the captions have been rewritten to provide more information.
- Text has been removed from the result section to make it shorter.

Detailed comments:

- Reduction criterion: As written in materials and methods, the reduction criterion is time, 40 minutes. However, during this time the wines obtained significantly different reduction weights, due to the different alcohol concentrations, as reported in Table 2. We have added some clarification to the materials and methods section: «For each batch, 1400 grams of wine (holding 3 °C) was used. The wines were reduced to approximately 700 grams during a fixed reduction time of 40 minutes».
- Specification about sugars and acids is added to paragraph 2.2.1.
- The Folin index values for the wines have been removed from Table 1, as the information is not discussed in the text.
- Table 2 and significant differences: It is written in the caption that «Different superscript letters represent significant differences», and as superscript letters are only found in one column, namely the column for Average weight, we thought this was self-explanatory, but we have added clarification to the caption to avoid confusion: «Different superscript letters represent significant differences between average reduction weights».
- Figure 2 regarding numbers: All the numbers that cannot be discerned (due to clustering) in all figures are listed in the figure captions. These numbers and their corresponding chemical compounds are listed in Table 3 as explained in the text «In Table 3, all volatile compounds found in the wines and wine reductions are listed (together with their allotted numbers for labelling and identification purposes in subsequent figures (column #))». We thought this was the best solution, instead of

including zoomed images. The captions for Figures 1, 2 and 3 have been rewritten to include more information about the volatiles listed in the clusters.

- Table 3: The table has been arranged in accordance with the reviewer's suggestions and the caption has been rewritten.
- The word sensory has been added to the title in paragraph 3.4
- Regarding descriptor sets and paragraph 3.4: Not all the descriptors used to evaluate the wine reductions were used on the wines, as they represented new aromas induced by the heating process, which were not relevant for the wines. Other descriptors, such as alcohol, was not relevant for the wine reductions. The two sets of descriptors were determined by the sensory panel in training sessions. This is the reason for the two slightly different sets of descriptors, and all the descriptors are listed in Table 4. As written in the caption for the table; « The symbol '-' signifies that the descriptor was not used in assessment of the product in question». However, we have added some clarification to the text: «Two slightly different sets of descriptors were used in the sensory analysis of the wines and the reductions, as a few of the descriptors were only relevant for the wine reductions due to new flavors introduced by the reduction process, as explained further below» and «New flavors were observed in the reductions, which had not been perceptible in the wines. These flavors were evaluated using the descriptor types 'cooked', 'forest' and 'fermented grains', which were only used to analyze the wine reductions».
- The reviewers suggest to look for correlations between the sensory data and volatile analysis, for example using a PCA plot. It was discussed in the project group also, but was dismissed, because the sensory analysis used two slightly different sets of descriptors and the overlapping descriptors do not express all the reduction specific aroma.
- Statistical analysis: As explained in the materials and methods, we did ANOVA using a General Linear Model. The reason for using GLM on our data, was because of lacking data in the sensory matrix, caused by the two slightly different sets of descriptors.
- Standardization of data: By standardizing the data, the standard deviation of all variables is set to 1. The data was standardized for example to adjust for assessors using the scale slightly differently in the sensory analysis, but was largely unnecessary because the panel was trained to use the scale uniformly.
- Selection criteria for the wines: As Reviewer 3 suggested, the selection criteria from the result section have been moved to materials and methods. This provides better information about the selection of the wines in the materials and methods.
- We do not understand the reviewer's confusion regarding the discussion concerning the descriptor 'Blackcurrant leaves/nettle (o)'.
- The sentence starting with «Based on the results from the…» has been rewritten as not include conclusions in the result section.

<u>Comments to Reviewer 3</u>:

- The newest reference in the bibliography is from 2015, not 2012 (Zhang et al.).
- The introduction has been reorganized, and redundant information removed.
- Materials and methods for the wine reduction:
    - The introduction has been removed, as it, as the reviewer correctly commented, included aims.
    - To reproduce the samples we made in our study, it is necessary both to state which machine we used and which settings were applied. We therefore do not

feel that this is redundant information. We agree with the reviewer that the temperature on the machine is not the temperature profile in the reduction, but to reproduce the samples, it is the machine settings (including temperature) which is the useful information, not the actual temperature profile. The Kenwood machine is one of very few kitchen machines that allows stirring and heating at the same time, which permit standardization of many kitchen processes, which until now have been done by hand. The other brand names have been removed from the section.

- The materials and methods for the descriptive sensory analysis has been restructured.
- Regarding panel evaluation: Nofima's panel is a highly trained, very stable panel, where the assessors are solely hired as tasters (a part time job), and some of the assessors have more than 20 years of experience. The panel performance is assessed frequently, and checked for every project. This ensures the quality of the panelists' assessments, based on three important qualities: their ability to differentiate the products (discrimination), consistently (repeatable) and consensually (in agreement). We therefore mean it is not necessary to include more information about panel performance in the article.
- The selection criteria for the wines has been moved from the result section to materials and methods. The section still contains the price of the wines, as it represents a point of reference, but excess information has been removed.
- Changes has been made to the paragraph on spectrometric analysis and pH measurements.

We hope our comments and the changes made to the manuscript are satisfactory, and we hope for a positive response.

Best regards,
The authors

RESEARCH ARTICLE

From wine to wine reduction: Sensory and chemical aspects

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Abstract: White wines and their wine reductions are popular flavoring agents in both traditional and modern cooking. The range of wines is wide and the type of wine or reduction may influence the sensory properties of the food. In this paper, four white wines with distinct differences in composition (Chardonnay, Riesling, Sauvignon blanc and a blended wine) and their corresponding reductions were studied to determine whether original wine aroma influences reduction aroma or whether it is the non-volatile components of wine reductions that dominate reduction flavor. Sensory evaluation and volatile and non-volatile analyses were performed on the wines and wine reductions. The study shows that by reducing wines, certain flavors get enhanced whereas others diminish. Although the volatile profiles of the wine reductions were significantly different from the wines they were made from, aroma plays an important role in the flavor perception of wine reductions. The study confirms that the wine a reduction is made from influences both the volatile and non-volatile profile of the reduction, and therefore also the reduction's perceived flavor. However, the volatile profile is significantly reformulated during the reduction process, in addition to tastants being concentrated during the same process.

Keywords: White wine; wine reduction; food science; sensory science; culinary arts; molecular gastronomy

1 Introduction

Wine is a highly appreciated and versatile drink, which has been produced for several thousand years in Europe (Clarke, 2008). Wine is the product obtained after fermentation of grape must. The Greeks and Romans spread grape cultivation in Europe, and today grape growing and wine production has spread way outside Europe to new, suitable climates, popularly called the 'new world'. The long tradition of wine production has given wine a strong position among beverages. Wine, at its best, reflects distinct aroma/flavor experiences, and for a long time wine has held a unique position as high quality beverage for food accompaniment.

Wine serves several functions when appreciated with food in a meal; it enhances or complements flavor, and it fulfills social protocols (Pettigrew & Charters, 2006). The strong connection between wine and food has resulted in wine mainly being consumed with food and in connection with meals (Nygren, Gustafsson, Haglund, Johansson, & Noble, 2001; Pettigrew & Charters, 2006).

Although wine is normally used as a beverage, many famous dishes also call for wine as an ingredient, because of the wine flavor, which includes both volatile aroma compounds and non-volatile tastants. These dishes are often richly flavored, and today the use of wine as an ingredient is often associated with authenticity and quality.

In some dishes, wine is used as it is, i.e. 'raw', while other recipes call for the use of wine reductions. A wine reduction is wine that has been boiled, which reduces the liquid volume. In the reduction process, water, ethanol and other volatile compounds evaporate from the liquid, which alters the composition and the flavor. Wine may be reduced alone or together with other ingredients when making a wine reduction, and to what extent the volume is reduced depends on the practice of the chef (Rognså, 2014). Common additional ingredients in wine reductions are wine vinegar, vegetables, such as onions, and spices, such as bay leaf and peppercorns.

Industrial wine reductions are not readily available in many countries, and there is no standardized way of producing wine reductions. Wine reductions are thus normally made by chefs or people cooking at home, and a high degree of culinary variation exists. Many factors, such as the ingredient selection, the ingredient ratios and the reduction time may vary from chef to chef, which is also reflected in culinary literature (Carême, 1854; Child, Bertholle, & Beck, 1961; Escoffier, 1921; Larousse, 1993; Peterson, 2008; The Culinary Institute of America, 2011). How to make a wine reduction may therefore represent a topic of discussion among culinary professionals, because the importance of the different factors and their influence on the properties of the final product has been unclear.

The perceived aroma of a wine is generally complex, and is the result of aroma molecules of different origins; aroma compounds found in the grape, aroma compounds produced during grape processing (chemical, thermal and enzymatic reactions in the must), during the alcoholic fermentation (fermentation aroma) and during the maturation of the wine (maturation aroma) (Rapp, 1990). Aromas are perceived by humans because they reach the olfactory epithelium and a prerequisite for this that the component is volatile. The volatility of aroma compounds depends on the compounds' chemical structure and interaction with the media from which they are liberated, as well as other factors such as temperature.

When a wine reduction is made, the process of aroma liberation is sped up, and aroma is liberated into the air due to elevated temperature and the effect of water evaporation. Correspondingly, in chemical terms, one can imagine that the impact of the reduction process is a loss of volatile components, i.e. aroma compounds, accompanied by increased concentration of the non-volatiles, i.e. taste components. Therefore, by reducing wines, one can imagine the aroma profiles to become more similar, due to significant evaporation of volatile components. On the other hand, the profiles of non-volatile components may diverge as their concentrations are increased due to the evaporation of water, ethanol and other volatile compounds. Finally, the effect of chemical reactions taking place while heating, represents an unknown factor, influencing the flavor of the reduction in an unknown direction. The basic question is thus whether the reduction process enhances differences and variation, or diminishes the variation of the overall sensory characteristics. Limited research work has previously been performed in the area of wine reductions (Snitkjær et al., 2011; Taylor, Barber, & Broz, 2010).

The present study focuses on the production of wine reductions from white wines, and aims to evaluate how the flavor changes from wine to wine reduction and whether the process enhances or suppresses the aroma and taste differences between the wines. Four white wines, based on the grape varieties Riesling, Sauvignon blanc, Chardonnay and a blended wine, were selected, reduced and studied both from chemical and sensory points of view. The wines represented different aroma and non-volatile profiles. The aim of the study is to gather information about the wine reduction process and to obtain knowledge about the influence of the wine on the corresponding wine reduction. This knowledge may confirm or contradict chefs' experience and habits, and further provide directions for cooking.

2 Materials and methods

2.1 Ingredients

2.1.1 Wines

White table wines may represent large spans in both volatile and non-volatile composition. These differences are caused by many factors such as grape variety, *terroir* influences, the choices of the *vigneron* in the vineyard and all the reactions taking place before, during and after fermentation, carefully controlled by the winemaker. Four white wines with satisfying diversity of volatile and non-volatile profiles were selected for this study, based on knowledge of the different grape varieties and certain vinification parameters, in addition to preliminary sensory testing by the authors.

Four wines were selected and used; A Sauvignon blanc wine from Sancerre (Domaine Fouassier Les Grands Champs 2011, Sancerre, France, 27 USD), an oaked Chardonnay wine from California (Byron 2006 Chardonnay, Byron Vineyards and Winery, Santa Maria, California, USA, 48 USD), a dry Riesling from Rheingau (Reinhartshausen 2010 Riesling trocken, Rheingau, Germany, 22 USD) and a German medium (lieblich) wine, Blend (H. Sichel Söhne Blue Nun 2011, Germany, 13 USD). Approximate blend: 40% Müller Thurgau, 25% Riesling, 25% Silvaner, 5% Kerner and 5% Gewürztraminer, which is a special blend for the Norwegian market). All wines were bought at the same time (tax included in the purchase price), and 34 bottles of each wine type were purchased for the study. The wine price was converted to the closest whole number of US dollars (in November 2013).

The selected wines were chosen according to criteria of acidity, sweetness, aroma/flavor profiles and oak maturation, and the object was to select wines representing some of the great variation in white table wines. A German blended wine (called Blend) was chosen because of its relative high concentration of residual sugar. A German Riesling was chosen to exemplify a dry wine, but where both organic acid and residual sugar concentrations were quite high. The French Sauvignon blanc wine was selected for its dryness, while the American Chardonnay was selected in order to include a mature, oaked wine, but due to its high price, it is doubtful whether this wine would be used for cooking in a restaurant kitchen. The two wines Sauvignon blanc and Chardonnay were expected to be the most similar in terms of acidity and sweetness, but all wines were, in addition to their different sweetness and acidity profiles, also chosen to represent different aroma profiles.

2.1.2 Wine reductions

The wine reductions were made using wine as a single ingredient. Wine reductions were prepared in an induction stand mixer (Kenwood Cooking Chef, Kenwood Electronics Europe B.V.) from each of the four wines. For each batch, 1400 grams of wine (holding 3 °C) was used. The wines were reduced to approximately 700 grams during a fixed reduction time of 40 minutes (Settings on Kenwood Cooking Chef stand mixer: 110 °C, stir speed 2, balloon whisk. Splashguard was not used, as not to prevent evaporation). After this time the reductions were removed from the bowl and transferred to a container placed in an ice bath. The reductions were cooled down to 10 °C and weighed. The cold wine reductions were then vacuum packed in a chamber vacuum machine and frozen (-22 °C) until use. Before use, the reductions were thawed in room temperature. Bottles of the Riesling wine contained various amounts of precipitation (probably salts (K and Ca) of tartaric acid), and the crystals were removed by passing the wine through a cloth sieve before reduction.

2.2 Analyses

2.2.1 Spectrometric analysis and pH measurements

The concentration of non-volatile compounds such as sugars and acids, volatile acidity, alcohol content and pH in the wines was analyzed using a spectrometer (Foss WineScan™ FT 120, Foss A/S). The analysis is based on FTIR (Fourier Tranformation Infrared Spectroscopy) technology, followed by mathematical modeling. The wines were analyzed at room temperature, immediately after bottle opening. All samples were analyzed in duplicates from one bottle of each type, and the WineScan produced duplicate spectra for each parallel, resulting in four parallel results. A pH-meter (SG8 SevenGo pro™, Mettler-Toledo AG) was used to analyze the pH of the reductions in triplicates.

Total acidity measurements reflect the total proton concentration in the wines. Acid anions were measured by spectroscopy, and the total acidity was calculated by multiplying these anion concentrations by the respective numbers of dissociable protons (Boulton, 1980). This number includes all protons. pH, on the other hand, is a measure of the free proton concentration (dissociated) in the solution. In addition to the measurements of total acidity and pH, the concentrations of tartaric, malic, and lactic acids were measured for all wines by the spectrometric analysis.

2.2.2 Descriptive sensory analysis

Descriptive analysis (DA) was conducted by a trained sensory panel (n=11, Nofima, Ås, Norway) according to Generic Descriptive Analysis as described by Lawless and Heymann (Lawless & Heymann, 2010). All assessors are selected and trained in accordance with ISO 8586-1 (ISO, 1993). The sensory laboratory is designed in accordance with ISO 8589 (ISO, 2007).

Assessors were trained in the evaluation of wines and wine reductions before evaluation. Two slightly different lists of descriptors, for the wines and wine reductions respectively, were developed during training sessions, where both panel leader and assessors were present (see paragraph 3.4 for lists of descriptors). The list of wine descriptors was chosen based on the Wine Aroma Wheel (Noble et al., 1987) and the White Wine Aroma Wheel (Fischer & Association of German Oenologists), and was further adapted to suit wine reduction evaluation, with additional descriptors for odor and flavor attributes. By the end of the training sessions the assessors were able to discriminate between samples, exhibited repeatability during trials and reached agreement with the other members of the group. Panel Check version 1.2.1 (www.panelcheck.com) was used for evaluation of panel performance, both during training sessions and evaluation.

The sensory evaluation was performed in three sessions for both the wines and the wine reductions (6 sessions in total), with a total of eight wines and eight wine reductions (four products in replicate for both wines and wine reductions). A dummy sample was served at the beginning of each evaluation. A session consisted of three wines or wine reductions served together. The sensory evaluation was performed between 10 a.m. and 14 p.m, with all six sessions completed in one day. All samples were labeled with a three-digit random code. The samples were served in randomized order for all assessors. Each sample consisted of 50 ml liquid (18 ±1 °C) served in white wine glasses (Glass measurements: volume: 350 ml; total height: 22.5 cm;

diameter bowl opening: 5.4 cm; diameter bowl: 8.5 cm; height bowl: 11.5 cm) with lids.

The assessors were instructed to evaluate the odor of the product, before tasting a mouthful to rate the remaining attributes. All samples were expectorated, and unsalted crackers and lukewarm water were available for rinsing. Cucumber and melon cubes were available for mouth cleansing between sessions.

The samples were monadically evaluated at individual speed, and responses were registered continuously. Sensory attributes were evaluated using an unstructured line scale with labeled endpoints ranging from no intensity (1) on the left side, to high intensity (9) on the right side. Each assessor evaluated all samples at individual speed using EyeQuestion v3.8.13 (Logic8, Holland) for direct recording of data.

2.2.3 Analysis of volatiles

The content of volatile compounds in the wines was analyzed in triplicate samples from one bottle, and from duplicate batches with triplicate sampling for the wine reductions. Samples of 20 grams were placed in 100 mL flasks, and were put to equilibrium at 37 °C in a circulating water bath, while stirred at 220 rpm. 1 mL 4-methyl-1-pentanol (5 ppm) was added as internal standard. The temperature of 37 °C was chosen to mimic body temperature and the release of aromas in the oral cavity. The samples were purged for 20 minutes at 100 mL.min^{-1}. Volatiles from samples were adsorbed on Tenax-TA traps (room temperature). Traps contained 250 mg of Tenax-TA with mesh size 60/80 and a density of 0.37 g.mL^{-1} (Buchem bv, Apeldoorn, The Netherlands, www.buchem.com). All traps were dry-purged for 10 minutes, to remove trapped water before GC analysis, as this may cause analytical problems.

Trapped volatiles were desorbed using an automatic thermal desorption unit (ATD 400, Perkin Elmer, Norwalk, USA, www.perkinelmer.com). Primary desorption was carried out by heating traps to 250 °C with a flow (60 mL.min^{-1}) of carrier gas (H_2) for 15.0 minutes. The stripped volatiles were trapped in a Tenax-TA cold trap (30 mg held at 5°C), which was subsequently heated at 300°C for 4 minutes (secondary desorption, outlet split 1:10). This allowed rapid transfer of volatiles to a gas chromatograph-mass spectrometer (GC-MS, 7890A GC-system interfaced with a 5975C VL MSD with Triple-Axis detector from Agilent Technologies, Palo Alto, California, www.agilent.com) through a heated (225°C) transfer line.

Separation of volatiles was carried out on a DB-Wax capillary column 30 m long x 0.25 mm internal diameter, 0.50 µm film thickness. The column pressure was held constant at 2.4 psi resulting in an initial flow rate of approximately 1.2 mL.min^{-1} using hydrogen as carrier gas. The column temperature program was: 10 minutes at 40°C, from 40°C to 240°C at 8°C min^{-1}, and finally 5 minutes at 240°C. The mass spectrometer operated in the electron ionization mode at 70 eV. Mass-to-charge ratios between 15 and 300 were scanned. Volatile compounds were identified by probability based matching of their mass spectra with those of a commercial database (Wiley275.L, HP product no. G1035A), and retention indices compared to databases (flavornet.org, odor.org.uk and pherobase.com). The software program, MSDChemstation (Version E.02.00, Agilent Technologies, Palo Alto, California, www.agilent.com), was used for data analysis. Peak areas were used as relative measurements of concentrations.

2.2.4 Statistical analysis

Panel Check 1.3.2. (Nofima, Norway, www.panelcheck.com) was used to evaluate the panel performance. Tucker-1 plots were used to evaluate the consensus of sensory attributes among assessors.

Analysis of variance (ANOVA) using a General Linear Model (GLM) (Minitab Inc, USA) was applied to study significant differences between products based on results from the analyses. Tukey's Multiple Comparisons Test (Minitab Inc, USA) was applied to determine which attributes were rated significantly different between the products. Significance was defined at $\alpha \leq 0.05$.

Multivariate data analysis (principal component analysis) was performed on data using Unscrambler® X v10.2 (Camo AS, Norway) to study the main sources of systematic variation in the average descriptive profiling data. The volatile analysis data was centered and standardized prior to PCA analysis.

3 Results

The basic question in this study is how the composition of the initial wine and the reduction process influence the characteristics of the wine reduction, when aroma components and alcohol evaporate and non-volatile compounds get concentrated. A combination of instrumental chemical and volatile analysis and descriptive sensory analysis was employed on both starting wines and the reductions to pursue this question.

3.1 Non-volatile profile of wines

The wines were analyzed using a NIR based Foss Wine scan, which represents a convenient and versatile way of making basic chemical characterization of wines. The results are shown in Table 1.

The chemical analysis confirmed that Blend had the highest content of residual sugars and the Riesling the highest concentration of organic acids (c.f. Table 1). The Chardonnay and Sauvignon blanc contained similar concentrations of total acidity and reducing sugars.

Sweetness in wine is normally closely related to alcohol content, as yeast metabolize glucose and fructose into ethanol (Bird, 2010). The wines contained from 8.8% (Blend) to 14.8% (Chardonnay) ethanol (alcohol by volume). The Blend, which contained a relatively high concentration of unfermented sugar, had a correspondingly low alcohol content (however, enrichment is allowed in QbA wines (Robinson, 2006)).

All the wines contained more fructose than glucose, as yeasts (most importantly *Saccharomyces cerevisiae*) normally prefer glucose over fructose during fermentation, and fructose therefore represents the major sweetening agent in wine (Bird, 2010). Glycerol, a slightly sweet triol, contributes to sweetness in wine from a concentration of approximately 5 g/L (Margalit, 2012), and varied from 4.2 (Blend) to 6.8 g/L (Chardonnay) in the wines. In contrast to common belief, glycerol is not an important contributor to wine viscosity (Margalit, 2012).

Combinations and the ratios of the acids form the chemical basis for the acidity differences in the wines. All the wines presented low concentrations of volatile acidity, which main contributor is acetic acid. Volatile acidity is characterized as a wine fault if present in high concentrations (Bird, 2010).

The Chardonnay was the only wine that had undergone noticeable malolactic fermentation (MLF), where malic acid is transformed into lactic acid and carbon dioxide by lactic acid bacteria. A low concentration of malic acid and a correspondingly higher concentration of lactic acid are indications of malolactic fermentation. Full-bodied chardonnay wines are often allowed to undergo MLF, and the butter aroma compound diacetyl is produced as a by-product (Margalit, 2012). Wines that are made to offer crisp acidity are normally not allowed to undergo MLF, which corresponds with the observed results for the Riesling and Sauvignon blanc, as they had noticeably higher malic acid concentrations than the Chardonnay wine.

Dryness, or lack of sweetness, seems to be one of the most important qualities for chefs when selecting a white wine for reduction purposes (Larousse, 1993; Peterson, 2008). Perception of sweetness in wines is highly influenced by the organic acid concentrations, and vice versa (Lawless & Heymann, 2010). Thus, dryness in wines depend on the ratio between acid and sugar concentrations. Consequently, the more acidic the wine, the more sugar the wine can contain and still be characterized as dry. The explanation for this effect is mixture suppression effects between sweet and sour taste modalities, meaning that sweetness and sourness together in a mixture results in both decreased perception (inhibition) of the sweetness and the sourness (Keast & Breslin, 2002; Lawless, 1986). All the three wines Sauvignon blanc, Chardonnay and Riesling were considered dry, although their sugar and acid concentrations were different (Table 1).

The basic chemical characterization of the wines was consistent with criteria used for selecting the four starting wines. The selected wines showed sufficient variation in concentrations of sugars and acids in order to represent distinctly different non-volatile wine profiles.

TABLE 1

3.2 Wine reductions

Different final weights were obtained after reduction of the four wines. Although minor differences in heating regimes may have occurred during production due to the use of kitchen machinery, the weight differences seemed to be largely correlated to the ethanol content of the wines, which evaporated when the wines were boiled. This is consistent with the results, as the alcoholic Chardonnay showed lower reduction weights than the low alcoholic Blend. Table 2 shows the average reduction weights and standard deviations for the wine reductions. The reduction weights were significantly different from each other, except for the Sauvignon blanc versus the Riesling reduction. Higher concentration of non-volatiles might influence the boiling point and the release of volatiles (Atkins & de Paula, 2010). The reduction weights varied between 49.4% and 53.2% of initial weight, but the variation was considered acceptable for the purpose of the study. In the following sections, reductions are labeled with the name of the wine it was made from followed by an 'R' for 'reduction' (example Blend R).

TABLE 2

The influence of the reduction process on the acidity was measured by pH. The results showed a typical drop in pH of 0.13 to 0.34 upon reduction, compared to the wines (pH $_{\text{Chardonnay R}}$ = 3.31 ± 0.03, pH $_{\text{Riesling R}}$ = 2.91± 0.07, pH $_{\text{Sauvignon blanc R}}$ = 3.01 ± 0.04, pH $_{\text{Blend R}}$ = 2.97 ± 0.06 (The pH in the wine reductions were measured using a Mettler Toledo AG pH-meter on duplicate batches, with triplicate sampling from each batch)). This was attributed the increase in concentration of the various acids in the reduction compared to the wine and the buffering capacity of the weak acids.

3.3 Volatile analysis

Analysis of volatiles was performed to quantify and qualify the composition of the wine aroma compounds. The volatile profiles of the wine reductions were also studied, in order to evaluate differences in terms of presence and concentration of volatiles between wines and their corresponding reductions. Any newly formed volatile compounds in the reductions were of special interest.

The volatile analysis confirmed the presence of a total of 76 aroma compounds in the wines and the wine reductions, but one of these compounds was unknown and could not be identified by comparing mass spectra and retention indexes to databases (Wiley275.L, flavornet.org, odor.org.uk and pherobase.com). The aroma compounds were quantified by averaged (n=3 for wines and n=6 for wine reductions) relative areas, and identified by probability matching of mass spectrum with the Wiley database and/or by comparison with retention indexes from literature. Volatile analysis is a quite complex exercise, and the process used here identified volatile compounds present in the wines and their concentrations in arbitrary units. By this, knowledge of the volatile composition was obtained, but these results did not reveal the importance of each of the volatile compounds for aroma perception by panelists, as it is influenced by several factors, such as the compounds' odor threshold values.

In Table 3, all volatile compounds found in the wines and wine reductions are listed (together with their allotted numbers for labelling and identification purposes in subsequent figures (column #)). The table also contains information about important changes in the volatile profiles between the wines and the reductions. The volatiles represent several classes of aroma compounds. The least expensive wine, Blend, contained the highest number of volatile compounds. This may be explained by the fact that this wine was produced as a blend of five grape varieties. For all wines, a large number of volatiles were seemingly lost during reduction, as their concentrations were below the detection limit of the method, which was estimated at below 1 ppb (µg/L) (Zhang et al., 2015). Many of these compounds were esters. The Chardonnay yielded the reduction characterized by the highest number of volatiles, whereas the Blend lost the highest number of compounds during the reduction process.

TABLE 3

Numerous compounds were lost from wine to the corresponding reduction, but important variations between the reductions were observed (Table 3). A high number of the evaporated compounds were esters. Esters constitute a group of compounds being very important for wine flavor, as esters give wines fruity and floral characters. They are mainly formed during fermentation, through chemical reactions between alcohols and acids, but their presence also depends on the grape variety (Bakker & Clarke, 2012). Because of the important decrease in concentration or elimination of such volatiles in the reductions, a corresponding decrease in fruity and flowery aromas was therefore expected in the sensory analysis.

In addition to complete disappearance of many volatiles (below detection limit), the majority of the other compounds decreased in concentration during reduction. All compound classes (see Table 3) were affected, and the volatile profiles of the reductions were therefore less complex both in composition and concentration than the wine profiles.

Chemical reactions may take place when making reductions, due to the presence of reactive compounds and the use of high temperature. Such reactions may alter both color and flavor. It was therefore expected that wine reductions might contain new volatiles not present in wines. By comparing wine and reduction profiles, eight novel volatiles were found in the reductions: butanal (4), 2-butanone (6), 2,3-butadione (13), 2-pentylfuran (30), acetic acid (46), 2-undecanone (56), acetophenone (61) and trans-2-dodecenal (67). The number of formed compounds was low, considering the total number of volatiles, and in addition, the compounds were not formed/found in all reductions.

In addition to the presence of some completely new molecules in the reductions, other compounds were found in higher concentrations in the reductions than in the wines, which partly may be explained by a concentration effect, i.e. water evaporated faster than these compounds. However, as many of these compounds were concentrated with more than a factor of two compared to the initial concentration, it also indicates the involvement of chemical reactions. The heating process may accelerate chemical reactions already taking place in the wines at lower temperatures.

The majority of the volatile compounds were found in all wines, which underline the importance of compound concentration and smaller compositional differences, resulting in aroma perception differences. Figure 1 and Figure 2 show the systematic variation and distribution of volatiles in wines and wine reductions respectively.

Figure 1 confirms the variation in the wine volatile profiles, but contrary to the impression during the wine selection process, results showed important similarities in the profiles of the Riesling and Sauvignon blanc wines. Most the variance in the wine profiles was explained by the first component in the PCA plot (59%), separating the Blend from the three other wines. The Blend wine contained the highest number of volatiles, including many esters in higher concentration compared to the other wines, as seen by the compounds labeled group B in Figure 1. The Chardonnay profile was characterized by the highest concentrations of compounds related to butter aroma, diacetyl (13) and acetoin (35), which can be attributed the malolactic fermentation. It is believed that compounds labeled as group A were responsible for the typical matured wine and oak aromas of the Chardonnay wine.

FIGURE 1

In the wine reduction PCA plot, Figure 2, most the variance was explained by the first component (60%), which separated the Chardonnay R from the three other reductions. In contrast to the case for the original wines, Figure 1, Riesling R, Sauvignon Blanc R and Blend R were more alike. Chardonnay R had a distinctly different volatile profile compared to the others.

The flavor characteristics of the Chardonnay wine and the Chardonnay reduction were probably caused by higher concentrations of the following compounds compared to the other reductions; 2,3-butanedione (diacetyl) (13), 1-propanol (18), 2-heptanone (26), 3-hydroxy-2-butanone (acetoin) (35), 2-furanmethanol (60), ethyl benzoate (62), pentanoic acid (63), diethyl succinate (64), benzeneethanol (71), and octanoic acid (72).

FIGURE 2

Figure 3 represents a joint PCA plot of the volatiles in the wines and the reductions. This plot enables the comparison of reductions and wines, and thereby provides information about the differences between the starting wines and the resulting reductions. In terms of the volatile profiles, the initially quite different wines became more similar during reduction, as many volatile compounds responsible for original differences were boiled away.

FIGURE 3

The analysis of the volatiles confirmed that substantial changes take place when reducing white wines. Volatiles decreased in concentration, were eliminated, concentrated or formed during reduction. The Blend, initially characterized by the largest number of aroma compounds also underwent the largest changes upon reduction. The Sauvignon blanc and Riesling had the most similar volatile profiles both before and after the heat-treatment. Elements of the Chardonnay's typical volatile profile were conserved during reduction. The impact of these changes on perception was evaluated by the sensory analysis. Results are presented in the following paragraph.

3.4 Descriptive sensory analysis

Two slightly different sets of descriptors were used in the sensory analysis of the wines and the reductions, as a few of the descriptors were only relevant for the wine reductions due to new flavors introduced by the reduction process, as explained further below. All descriptors are listed in Table 4.

The results from the sensory analysis showed that both the wines and wine reductions, respectively, were significantly different with regard to numerous descriptors. Significant differences between the wines were registered by 20 descriptors out of 24 and by 17 out of 27 descriptors for the wine reductions. The results from the sensory analysis of wines are shown in the PCA bi-plot Figure 4. The wine reduction results are presented in Figure 5. In general, only small differences between replicate assessments were observed for both the wines and the reductions, confirming both small batch variations for the reductions and satisfactory panel performance.

TABLE 4

FIGURE 4

Figure 4 shows the perceptual profiles of the wines. The Chardonnay wine was, as expected, rated more spicy, buttery and woody than the other wines, which is consistent with the vinification processes, including malolactic fermentation (MLF), barrel fermentation and batônnage, which strongly influences the wine flavor. The wine's slow oxygenation through barrel storage and aging in corked bottles led to maturation of the fruit aromas, which were characterized as 'dried fruit' and 'spicy' flavors by the panel, in addition to the 'wood' flavors. The three wines Riesling, Sauvignon blanc and Blend were characterized by ‘green’ aromas as well as citrus, and fruit aromas. Sauvignon blanc scored highest for the descriptor ‘green’, but both it and Riesling were characterized by this aroma and citrus. These two wines were given similar scores for sweetness and sourness, although their non-volatile profiles were different. The Blend was rated the fruitiest and sweetest wine.

The Sauvignon blanc wine was selected because of its typical Sancerre wine aroma in addition to its non-volatile profile. One dominant aroma characteristic in this wine was what could be described as blackcurrant leaves or nettle aroma. The descriptor ‘Blackcurrant leaves/nettle (o)’ was therefore chosen as a specific descriptor to separate this wine from the others. Some confusion in the panel about this descriptor became apparent during training, and led to specific training with a Sauvignon blanc wine from New Zealand (Squealing Pig Sauvignon blanc 2012, Squealing Pig Wines, Marlborough, New Zealand, 20 USD), where this aroma characteristic was more pronounced. Despite the extra training, the results from the sensory evaluation showed no significant differences between wines for this descriptor ($p=0.44$). Further inspection of the assessors’ individual evaluations showed that there was disagreement among assessors regarding the use of this descriptor. More training before the evaluation could have led to another result. During training sessions on wine reductions, the assessors did not find any aroma of blackcurrant leaves or nettles in these products, and the descriptor was therefore not included in the descriptor list for the wine reduction evaluation.

The wine reductions were all reduced to approximately 51% (of initial weight) over 40 minutes, and a central question was how much of the original aroma remained in the reductions. The results from the sensory evaluation of the wine reductions show that there were important differences between the reductions in terms of perceived aroma (see Figure 5). If aroma compounds had not played a role in the perception of wine reduction, one would only have seen significant differences in basic taste properties and descriptors such as astringency and pungency. As this is not the case, when reduced according to the parameters in this study, aromas still play an important role for the overall aroma and flavor of white wine reductions. If reduction degrees or times were increased, one could imagine the products to contain even lower concentrations of volatile components, which would probably result in more similar aroma profiles.

FIGURE 5

The reductions were characterized by different descriptors, as observed in Figure 5, which confirms the influence of the starting wine on the sensory profile of the reduction. The Riesling and Sauvignon blanc reductions were evaluated similarly, just like their corresponding wines. By comparing PCA plots of the wines (Figure 4) and the wine reductions (Figure 5) a general tendency was observed. Aromas were responsible for most the perceived differences in the wines, whereas this was shifted towards basic tastes modalities in the perception of the wine reductions. This effect can be observed by comparing PC-1 and PC-2 in Figures 4 and 5. In the wines (Figure 4), variation in basic taste modalities and astringency accounted for only 17% of the perceived and significant differences (separation along PC-2), while variation in aroma qualities explained the scattering of the data along PC-1 (75% of the variation). As volatiles evaporated from the wines during the reduction, basic taste modalities became the most important sensory qualities in the wine reductions (Figure 5), as the main separation of the data was seen in basic taste differences along PC-1, 62%. Nonetheless, aroma qualities still represented 32% of the perceived variation (seen along PC-2), which was more than expected.

Although aromas did contribute to reduction flavor, some aroma attributes, which were important for distinguishing the wines, were not evaluated differently for the wine reductions. Examples were ‘green’ (o/f), ‘butter (o)’, ‘fruit (o)’, ‘spicy (o)’, ‘fruit (o)’ and ‘chemical (o)’. Evaporation of volatile aroma compounds is thought to be responsible for the reduction of these aroma differences. Some descriptors were both evaluated ortho- and retronasally (example ‘fruit (o)’ and ‘fruit (f)’). In the wine reductions, more significant differences were found when samples were analyzed retronasally compared to orthonasal evaluation (see Table 4). When a sample is taken into the mouth, it is heated up and set in motion, which aids aroma release and detection of more minute variations. The ‘wood’ aroma/flavor was well retained in the wine reduction made from Chardonnay wine.

Reductions were given lower scores for nearly all aroma-related attributes, ‘fruit’ and ‘floral’ included, but some reductions were given higher scores of ‘dried fruit’, ‘spicy’ and ‘wood’ than the corresponding wines. All reductions were rated more sour than the corresponding wines (see Figure 6), and all reductions were rated less sweet. These tendencies were seen in all products, independent of the acidity, sugar concentrations and the relative rations between these concentrations in the original wine, which were surprising results. All reductions were rated bitterer than the wine, except the Chardonnay reduction.

New flavors were observed in the reductions, which had not been perceptible in the wines. These flavors were evaluated using the descriptor types ‘cooked’, ‘forest’ and ‘fermented grains’, which were only used to analyze the wine reductions. ‘Cooked’ was used for the aroma/flavor of cooked fruits and ‘forest’ for the aroma/flavor of moist forest floor, including wet moss and mushrooms. The wine reductions also exhibited some beer-like aromas/flavors, which were evaluated using the descriptor ‘fermented grains’. The wine reductions were not significantly different with respect to the attributes ‘cooked’ (o) and (f) and ‘forest (o)’ (see Table 4). However, the wine reductions made from Riesling, Sauvignon blanc and Chardonnay were more pronounced with respect to the significant specific reduction flavors than the Blend (see Table 5). These new aromas/flavors were not necessarily produced by newly formed volatiles in the reduction, as these were few (see 3.3), but could be a result of the changed volatile composition.

TABLE 5

FIGURE 6

Figure 6 shows a PCA bi-plot containing sensory data for both wines and their respective reductions, and this plot thus enables comparison between wines and reductions for overlapping descriptors. The results from the wine reduction evaluation showed that the wines and the corresponding wine reductions were characterized by the same overlapping descriptors. It is noteworthy that wines and reductions were not separated into distinct groups in the bi-plot. Rather, the points corresponding to wines and reductions were situated relatively close to each other (see Figure 6). In other words, from a sensory perspective the reductions resemble the wines they are made from. However, as only overlapping descriptors were plotted Figure 6 (reduction specific attributes excluded), wines and reductions were more different on a perceptual level than can be observed in this figure.

In general, when making wine reductions, volatile compounds are lost, which make the aromas of the products more similar than the aromas of the original wines, but there were still important aroma differences between the reductions.

4 Discussion

When wines are reduced, the non-volatile components become more concentrated and dominate the flavor picture. Since it is the relative balance between sugar and organic acid concentrations that determines whether the wine is perceived as sweet or acidic, the balance between sugar and acid concentrations in the wine is an important factor to consider when selecting a wine for reduction purposes. Dry white wines are often selected for reductions, but it is the concentration of residual sugar in the wine that determines the final sourness, astringency and bitterness of the reduction (see Figure 6). The lower the concentration of sugars compared to acids, the more the reductions will taste sour, bitter and astringent. A question to evaluate before selecting wines for wine reductions, is therefore whether these flavor characteristics may become too dominant in the final product if 'bone' dry wines are selected.

The mutual suppression effect of sweetness and sourness is clearly seen in the sensory PCA plot for the wines, Figure 4. Riesling and Blend were the two wines containing the highest concentrations of acids and sugars of the four. The Riesling was the wine with the highest sourness, and although it contained more sugars than acids as determined in grams per liter (see Table 1), the wine is considered dry. The panel judged the wine as the most sour one, and also low on sweetness. If sugar concentration in this wine had been lower, the wine would have tasted even more sour. Correspondingly, the Blend was evaluated the most sweet and least sour wine, although the wine had the second highest acid concentration as determined instrumentally, and second only to the Riesling. In this wine, the sugar concentration exceeded by far the acid concentration, and perception of acidity was therefore suppressed. When the wines were reduced, the ratios between sweetness and sourness in the wines were altered, which resulted in all reductions being assessed both more sour and less sweet than the wines. This was also true even for the Blend, although this wine contained 29.5 g/L of residual sugar and only 3.9 g/L in total acid concentration, which was a somewhat unexpected result.

Psychometric functions determine the perception of sweetness and sourness. A psychometric function is the relationship between perceived taste and the receptor stimuli. If psychometric functions may produce a stronger response for sourness versus sweetness, this may explain the results in this study. If this is the case, it would implicate that a doubling of a concentration of acids would generate a stronger sourness response than the perceived sweetness produced by a doubling in sugar concentration. This observation illustrates the complexity of taste-taste interactions, and it is known that three different effects are observed when combining two or more tastants (Stevenson, 2009). First of all, we have the mixture suppression effects (Keast and Breslin, 2003), where a taste quality (such as sweet or sour) is perceived weaker in a mixture compared to alone. Secondly, it is known that the overall taste intensity of a mixture is weaker than the sum of the individual taste intensities (Bartoshuk, 1975). Thirdly, the suppression in a mixture can be asymmetric, meaning that one taste quality can be suppressed more than another (Schifferstein and Frijters, 1990). Schifferstein and Frijters' study showed that the suppression in sucrose/citric acid mixtures was asymmetric. They found that the citric acid suppresses the perception of sweetness, whereas the perceived sourness depended on both the concentration of sucrose and citric acid. Further research should focus on taste interactions between sugars and acids and how one taste modality or the other dominates at different concentrations and ratios, as this may provide explanations for the sweetness and sourness results obtained in this study.

In the present study, sugar and acid concentrations were not measured in the reductions, but parallels can be drawn to a study on red wine reductions, where it was concluded that non-volatiles were concentrated in reductions, but not necessarily with the same factor (Snitkjær et al., 2011). In general, it is believed that acids and sugars were present in the reductions with a concentration factor between 1 and 2 compared to the wines, depending on substrate consumption in chemical reactions during reduction and because volume was reduced by approximately 50%.

Sensory evaluation yielded similar sensory profiles for the Riesling and Sauvignon blanc wines, and one contributing factor was the assessment of the 'blackcurrant leaves/nettle (o)' descriptor. Volatile analysis of the wines also gave similar results for the Riesling and Sauvignon blanc wines (see Figure 1). None of the volatile compounds typical for Sauvignon blanc, such as methoxypyrazines or thiols, were detected in the volatile analysis. Their odor thresholds have been reported to be very low (odor thresholds for 3-isobutyl-2-methoxypyrazine have been reported from 0.5 to 10 ng/L and at 0.8 ng/L for 4-mercapto-4-methylpentan-2-one (Margalit, 2012)), which may have resulted in detection difficulties. Based on this, one cannot exclude the possibility that there were still other volatile compounds having low thresholds escaping detection.

No significant differences in alcohol content was found in the sensory analysis of the wines (Table 4). In retrospect, it might have been better to assess the intensity of alcohol in the mouth rather than by smelling. In this way, the warming or burning sensation of alcohol in the mouth would have been included in the sensation, which may have made the assessment easier. A relatively high sugar content in wines can, on the other side, suppress the warming sensation of alcohol in the mouth. Alcohol content was not assessed for the wine reductions by the sensory analysis, as most the ethanol evaporated during the 40 minutes long heat treatment, due to its lower boiling point compared to water, which was confirmed by the volatile analysis (results not shown). Plotting of overlapping descriptors for wine and wine reductions (Figure 6) gave information about similarities between the two product groups.

The distribution pattern of wines and reductions from the sensory analysis contrasted the corresponding instrumental volatile analysis bi-plot, Figure 3, where reductions and wines were separated into two distinct groups along the PC-1-axis in the bi-plot. From the sensory analysis one can get the impression that wines and reductions were perceived similarly, but the overview in Figure 6 is somewhat misleading. First of all, all attributes were given equal importance in the sensory plots, although some descriptors may be more important than others for perception. In addition, non-overlapping descriptors were not plotted in Figure 6. Ethanol, present in the wines but only in low concentrations in the reductions, is one example. Ethanol stimulates the trigeminal nerve, in addition to olfactory and gustatory receptors, and can therefore be characterized as an irritant (Mattes & DiMeglio, 2001; Purves *et al.*, 2011). In this case, the effect of the ethanol and its role in perception was a specific characteristic of wine flavor and not part of reduction profiles. The reduction-specific descriptors, 'cooked', 'forest' and 'fermented grains' was not included in Figure 6, which also disguised perceptual differences of the wine versus reductions.

Although tastants are the most important for reduction flavor, aroma still plays an important part in reduction flavor (see Figure 5), and some aroma characteristics could be used to describe both the wine and its reduction. The difference in perceived aroma between the wines and wine reductions was probably due to a combination of three effects observed in the volatile analysis; the elimination of some aroma compounds, the concentration effect of others and the creation of new aroma molecules. All the three processes: evaporation, breakdown and reactions where volatile compounds act as reactants in chemical reactions, may cause elimination of compounds. These changes in volatile composition led to the sensory panels' need for new attributes, named 'cooked', 'forest' and 'fermented grains', to describe the reduction aroma. The creation of new compounds during reduction was limited in number, and it is therefore probable that the change in concentration (either up or down) of the other volatiles was the main reason for changes in the perceived aroma between the wines and the reductions.

Numerous esters were found in the wines, but many of them were not detected in the wine reductions, which probably explain a significant portion of the aroma differences between the wines and reductions. Elimination of esters may either be caused by evaporation or hydrolysis. Similar results were observed in a previous study concerning red wine reductions (Snitkjær et al., 2011). The changes in ester concentrations in the volatile profiles from the wines to reductions were correlated with a decrease in fruity and floral characters as observed in the sensory analysis.

Eight of the volatile compounds identified in the wines and wine reductions were furan and furanone-related compounds. These compounds have several origins, as they may be found in the fruit, produced during fermentation or extracted from oak during maturation. Furanone-related compounds can also be formed during Maillard reactions (Barham et al., 2010). 2-Furanmethanol (60) was only found in the Chardonnay. It decreased slightly in concentration during reduction, and it is believed that this compound was present in the wine as a result of this wine's oak barrel regime combined with malolactic fermentation (Margalit, 2012). The oak influence is also believed to be the origin of the high concentration of 2-furancarboxaldehyde (furfural) (48) in the Chardonnay wine, where it was found in an over 13 times higher concentration compared to the other wines. Although this compound decreased in concentration during reduction of the Chardonnay wine, it increased significantly in concentration for the other wines. This formation may be the result of Maillard reactions. These complex reactions can also be the origin of 2-pentylfuran (30), which were not present in any of the wines, but in all reductions. The availability of reactants (such as reducing sugars) for the Maillard reactions probably influences formation of the related products, and may explain the great increase (1331%) of furfural (48) in the Blend reduction. Except for γ-butyrolactone (58), furfural and 2-pentylfuran, all other furanone-related compounds decreased in concentration during the reduction process.

Some compounds, which could be expected to appear in the volatile analysis of an oaked wine such as the Chardonnay, were not detected. Examples are compounds such as 4-hydroxy-3-methoxybenzaldehyde (vanillin) and compounds known as oak lactones. Such compounds are relatively large and have elevated boiling points, which explains why they were not detected. They could not be liberated from the wine in large enough concentrations to exceed the limit of detection during the purge and trap period (which was estimated at below 1 ppb (µg/L) (Zhang et al., 2015)). The detected concentrations of organic acids in the volatile analysis may also deviate from their actual concentration in the wines and wine reductions, as their volatility depend on the pH. An example is acetic acid, which was not detected in three of the four wines in the volatile analysis, but in all the wine reductions. This is why acetic acid is labelled as «formed» in three of the wines in Table 3. However, the spectroscopic results in Table 1 shows the presence of volatile acids in all the wines, where acetic acid is the most important contributor. The analysis of volatiles has therefore certain limitations, and the list of compounds detected in the wines and wine reductions (Table 3) can therefore not be regarded as a complete list of volatiles present in the wines and reductions, due to collection and detection limit obstacles.

In this project, the wine was reduced in large batches and therefore over a longer period of time compared to common culinary practice, where wine reductions often are prepared for a single sauce at a time. It is clear that this may influence the volatile profile of the reduction, but it remains difficult to predict batch size influence on volatile profile based on present results. Longer reduction times will most likely enhance the flavor tendencies found in this study. This means that the more a reduction is reduced, the more the reduction-specific aromas will dominate the aroma of the reduction. However, as taste plays the major role in reduction flavor, sourness, bitterness and astringency will control the flavor of the reduction. It seems like the impact of these taste modalities are controlled by the sugar content of the original wine, as observed in the Blend reduction, which scored lowest on sourness, bitterness and astringency of all the reductions.

As mentioned in the introduction, considerable culinary variation exists regarding reduction preparation among chefs, a topic also discussed elsewhere (Rognså, 2014). Most chefs would include additional ingredients such as vinegar and shallots in the kitchen. However, in this study, white wines were reduced without commonly used additional ingredients such as shallots, peppercorns, bay leaf and vinegar. Clearly, these ingredients may also contribute to reduction flavor. The use of other ingredients may diminish the importance of wine related aroma in a reduction, but may also give reductions more complex flavors than observed in the model reductions in this study. The use of several ingredients in reductions may also lead to formation of new volatile compounds, as ingredient components may represent a broader range of substrates, which may react in chemical reactions during reduction. Using additional ingredients may also alter the palate profile of reductions, as onions are a source of sugars, while vinegars contribute with different acids. Finally, the impact of wine or wine reduction aroma in a dish will depend several factors, such as the amount to be used and the composition of the dish, as the matrix is known to influence aroma release. This study shows that reduction aroma and flavor depends on the wine composition from which it was made. In delicately flavored and light (low amount of fat) dishes, one may therefore reflect more on wine choice and reduction degree than in robustly flavored and high-fat dishes.

5 Conclusion

Contrary to what one could expect in respect to reduction time and evaporation of aroma compounds, volatile compounds play a significant role in the perception of white wine reductions. Although the volatile profiles were dramatically changed when white wines were reduced, many aroma characteristics were conserved in the corresponding reductions to varying extents. Examples are fruity, floral and citrus flavors. Oak aromas were also preserved, but did not result in higher bitterness compared to other reductions.

The aroma of white wine reductions depended on the original wine aroma and reducing-time, which led to evaporation of some volatile compounds, concentration of other and formation of new ones. As water evaporated from the reduction, non-volatile compounds such as acids and sugars became concentrated, thus increasing their importance for flavor. The composition of non-volatiles was therefore the most important factor for reduction flavor. All reductions produced in this study tasted more sour and less sweet than the wines, independent of the wine’s sugar concentration, which is a noteworthy result. The use of dry wines may in addition to a marked sourness, result in bitter and astringent reductions, but the dominance of these parameters can be reduced by sweetness. Based on these findings, we can conclude that original wine composition matters both for the volatile and non-volatile composition of white wine reductions, and thus also for perceived aroma and flavor.

Bibliography

Atkins, P. & de Paula, J. (2010), Physical Chemistry (9th ed.): Oxford University Press.

Bakker, J., & Clarke, R. J. (2012). *Wine Flavour Chemistry* (2nd ed.): Wiley-Blackwell.

Barham, P., Skibsted, L. H., Bredie, W. L. P., Frøst, M. B., Møller, P., Risbo, J., Snitkjær, P & Mortensen, L. M. (2010). Molecular gastronomy: A new emerging scientific discipline. *Chem. Rew., 110*, 2313-2365.

Bartoshuk, L. M. (1975). Taste mixtures: Is mixture suppression related to compression? *Physiol. Behav., 14*(5), 643-649.

Bird, D. (2010). *Understanding Wine Technology – The Science of Wine Explained* (3rd ed.): DBQA Publishing.

Boulton, R. (1980). The relationship between total acidity, titrable acidity and pH in wine. *Am. J. Enol. Vitic., 31*, 76-80.

Carême, M. A. (1854). *L'art de la cuisine fraçaise au dix-neuvième siècle* (Vol. 3): Elibron Classics. Unabridged facsimile, 2006.

Child, J., Bertholle, L., & Beck, S. (1961). *Mastering the Art of French Cooking*: Alfred A. Knoph.

Clarke, O. (2008). *Grapes and Wines – A Comprehensive Guide to Varieties and Flavours* (Rev. ed.): Pavilion Books.

Escoffier, A. (1921). *Le guide culinaire*: Flammarion. Unabridged facsimile, 2009.

Fischer, U., & Association of German Oenologists. White wine aroma wheel (Modification of the Wine Aroma Wheel by Ann Noble): German Wine Institute. *Available at http://www.deutscheweine.de*. Retrieved 09.05.14.

ISO. (1993). Geneva: International Organisation fo Standardisation *Sensory analysis – Methodology – general guidance for the selection, training and monitoring of assessors, Ref. No. ISO 8586-1:1993 (E)*.

ISO. (2007). Ref. No. ISO 8589:2007 (E) *Sensory analysis – General guidance for the design of test rooms*. Geneva: International Organisation for Standardisation.

Keast, R. S. J., & Breslin, P. A. S. (2003). An owerview of binary taste-taste interactions. *Food Qual. Pref., 14*, 111-124.

Larousse, D. P. (1993). *The Sauce Bible – Guide to the Saucier's Craft*: John Wiley & Sons.

Lawless, H. T. (1986). Sensory interactions in mixtures. *J. Sens. Stud., 1*, 259-274.

Lawless, H. T., & Heymann, H. (2010). *Sensory Evaluation of Food – Principles and Practice*: Springer.
Margalit, Y. (2012). *Concepts in Wine Chemistry* (3rd ed.): The Wine Appreciation Guild.
Mattes, R. D., & DiMeglio, D. (2001). Ethanol perception and ingestion. *Physiol. Behav.*, *72*, 217-229.
Purves, D., Augustine, G. J., Fitzpatrick, D., Katz, L. C., LaManita, A.-S., McNamara, J. O. & Williams, S. M., Eds., (2011), *Neuroscience*, 349: Sinauer Associates Inc.
Noble, A. C., Arnold, R. A., Buechsenstein, J., Leach, E. J., Schmidt, J. O., & Stern, P. M. (1987). Modification of a standardized system of wine aroma terminology. *Am. J. Enol. Vitic.*, *38*, 143-146.
Nygren, I. T., Gustafsson, I.-B., Haglund, Å., Johansson, L., & Noble, A. C. (2001). Flavor changes produced by wine and food interactions: Chardonnay wine and Holladaise sauce. *J. Sens. Stud.*, *16*, 461-470.
Peterson, J. (2008). *Sauces – Classical and Contemporary Sauce Making* (3rd ed.): John Wiley & Sons.
Pettigrew, S., & Charters, S. (2006). Consumer's expectations of food and alcohol pairing. *British Food Journal*, *108*, 169-180.
Rapp, A. (1990). Natural flavors of wine: Correlation between instrumental analysis and sensory perception. *Fresenius J. Anal. Chem.*, *337*, 777-785.
Robinson, J. (2006). *The Oxford Companion to Wine* (3rd ed.): Oxford University Press.
Rognså, G. H. (2014). *Emulsions From a Culinary Perspective – The Case of Hollandaise Sauce and its Derivatives.* PhD thesis. University of Copenhagen.
Schifferstein, H. N. J., & Frijters, J. E. R. (1990). Sensory integration in citric acid/sucrose mixtures. *Chem. Senses*, *15*(1), 87-109.
Snitkjær, P., Risbo, J., Skibsted, L. H., Ebeler, S., Heymann, H., Harmon, K., & Frøst, M. B. (2011). Beef stock reduction with red wine – Effects of preparation method and wine characteristics. *Food Chem.*, *126*, 183-196.
Stevenson, R. J. (2009). *The Psychology of Flavour* (Reprint edition 2014 ed.): Oxford University Press.
Taylor, D. C., Barber, N., & Broz, C. (2010). Sensory evaluation of a wine's quality in the preparation of a reduction: A subjective and objective study. *J. Culin. Sci. Technol.*, *8*, 219-228.
The Culinary Institute of America. (2011). *The Professional Chef* (9th ed.): Wiley.
Zhang, S., Petersen, M. A. , Liu, J., Toldam-Andersen, T. B. (2015). Influence of pre-fermentation treatments on wine volatile and sensory profile of the new disease tolerant cultivar Solaris. *Molecules*, *20*, 21609-21625.

Table 1: Non-volatile composition of the wines and ethanol content. The analysis was performed by spectroscopy (Foss WineScanTM). All values are given as average of four measurements. Results with different superscript letter within each column are significantly different (p<0.05).

Wine	Ethanol	Malic acid	Tartaric acid	Lactic acid	Volatile acids	Total acid	Fructose	Glucose	Reducing sugar	Glycerol	Density	pH
	% vol	g/L	g/L	g/L	g/L	g/L	g/L	g/L	g/L	g/L	g/ml	
Chardonnay	14.81 ^{a}	0.67 ^{a}	1.00 ^{a}	1.21 ^{a}	0.39 ^{a}	3.27 ^{a}	2.96 ^{a}	0.00 ^{a}	3.61 ^{a}	6.48 ^{a}	0.990 ^{a}	3.59 ^{a}
Riesling	11.56 ^{b}	3.56 ^{b}	2.31^{b}	0.26 ^{b}	0.16 ^{b}	5.06 ^{b}	5.74 ^{b}	0.87 ^{b}	8.18 ^{b}	4.97 ^{b}	0.995 ^{b}	3.06 ^{b}
Sauvignon blanc	12.78 ^{c}	2.38 ^{c}	1.18 ^{c}	0.17 ^{c}	0.22 ^{c}	3.67 ^{c}	1.88 ^{c}	0.14 ^{a}	3.33 ^{c}	6.43 ^{a}	0.991 ^{c}	3.22 ^{c}
Blend	8.83 ^{d}	2.22 ^{d}	3.40 ^{d}	0.25 ^{b}	0.12 ^{d}	3.86 ^{d}	15.78 ^{d}	15.00 ^{d}	29.47 ^{d}	4.21 ^{c}	1.007 ^{d}	3.25 ^{d}

Table 2: Wine reduction weights. Reduction weights varied significantly with the starting wine. Different superscript letters represent significant differences between average reduction weights ($p \leq 0.05$). n refers to the number of reduction batches.

Reductions	n	Average weight (g) ± SD	Reduction degree (% of initial weight) ± SD
Chardonnay	7	690.9 ± 10.5 [a]	49.4 ± 0.7
Riesling	6	716.5 ± 8.8 [b]	51.2 ± 0.6
Sauvignon blanc	7	725.6 ± 11.5 [b]	51.8 ± 0.8
Blend	6	745.2 ± 16.9 [c]	53.2 ± 1.2

Table 3: Comparisons between the volatile profiles of the wine reductions and the wines. Values are given as percentages, showing the relative concentration difference of each volatile compound in the reduction compared to the wine. Numbers smaller than 100 signifies therefore a decrease in concentration from wine to reduction, while numbers higher than 100 describes an increase in concentration, either as a concentration effect, or due to novel formation through chemical reactions. The compounds are classed according to their chemical class. All compounds are given an identification number (column #), and these numbers are also used to identify the volatile compounds in other parts of the paper (see PCA plots of volatile analysis results). Consult table information below for information on cell colors and signs.

#	Compound class	Ident. method	Compound	Blend	Chardonnay	Riesling	Sauvignon blanc
39	Unknown	MS	Unknown			-	
1	Aldehydes	MS, RI	Propanal	159	52	171	237
4		MS, RI	Butanal	117			427
21		MS, RI	Hexanal	77	56	244	253
27		MS, RI	Heptanal		49	27	
37		MS, RI	Octanal		10		
44		MS, RI	Nonanal		5		
45		MS, RI	2-Octenal		-	-	-
52		MS, RI	Benzaldehyde	192	53	129	20
54		MS, RI	*trans*-2-Nonenal	-		-	-
67		MS, RI	*trans*-2-Dodecenal	-		-	-
9	Alcohols	MS, RI	Ethanol	6	12	5	13
18		MS, RI	1-Propanol	2	2	2	4
22		MS, RI	2-Methylpropanol	N	N	N	N
29		MS, RI	3-Methylbutanol	N	N	N	N
42		MS, RI	Hexanol		N		
71		MS, RI	Benzeneethanol	136	287	134	163
74		MS	Phenol	58	45	40	68
5	Esters	MS, RI	Ethyl acetate	2	1	1	8
7		MS, RI	2-Methylbutanal	175	46	145	53
8		MS, RI	3-Methylbutanal	23	27	71	32
10		MS, RI	Ethyl propanoate		N		N
11		MS, RI	Ethyl 2-methylpropanoate				
12		MS, RI	Propyl acetate				
14		MS, RI	Methyl butanoate				
16		MS, RI	2-Methylpropyl acetate				
17		MS, RI	Ethyl butanoate				
19		MS, RI	Ethyl 2-methylbutanoate				
20		MS, RI	Butyl acetate			-	-
23		MS, RI	3-Methylbutyl acetate		N	N	N
25		MS	Pentyl acetate		-		
31		MS, RI	Ethyl hexanoate				
34		MS, RI	Hexyl acetate				
40		MS, RI	*cis*-3-Hexenyl acetate				
41		MS, RI	Ethyl lactate	23	68	22	35
47		MS, RI	Ethyl octanoate				
50		MS	Ethyl sorbate isomer 1			-	-
51		MS	Ethyl sorbate isomer 2		-	-	-
59		MS, RI	Ethyl decanoate				
62		MS	Ethyl benzoate		13		4
64		MS, RI	Diethyl succinate	6	26	8	14
65		MS, RI	Ethyl-9-decenoate			-	
69		MS, RI	2-Phenylethyl acetate				
30	Furans and lactones	MS, RI	2-Pentylfuran				
48		MS, RI	2-Furancarboxaldehyde	1331	29	524	282
58		MS, RI	γ-Butyrolactone	124	154	134	134
60		MS, RI	2-Furanmethanol	-	90	-	-
66		MS	2(5H)-Furanone	34	61	-	50
68		MS, RI	γ-Heptalactone			-	-

72		MS, RI	γ-Octalactone		6		
75		MS, RI	γ-Nonalactone				
2	Ketones	MS, RI	2-Propanone	826	179	746	614
6		MS	2-Butanone				
13		MS, RI	2,3–Butanedione		104	351	384
26		MS, RI	2-Heptanone	17	15	17	9
35		MS, RI	3-Hydroxy-2-butanone	52	192	32	35
36		MS, RI	2-Octanone		39		
38		MS	1-Hydroxy-2-propanone		-	-	-
43		MS	2-Nonanone		8		
56		MS, RI	2-Undecanone				
61		MS, RI	Acetophenone				
15	Terpenes and related compounds	MS, RI	α-Pinene	-	-	255	
24		MS, RI	Myrcene		-		
28		MS, RI	Limonene	12	23	27	45
32		MS, RI	β-Ocimene		-	-	-
33		MS, RI	o-Cymene		-		-
49		MS, RI	Neroloxide				
46	Organic acids	MS, RI	Acetic acid	10			
53		MS, RI	Propanoic acid		7		
55		MS, RI	Isobutyric acid		-	5	30
57		MS, RI	Butanoic acid	3	11	1	2
63		MS, RI	Pentanoic acid	-	34	15	-
70		MS, RI	Hexanoic acid	2	5	N	1
73		MS	Heptanoic acid		15		
76		MS	Octanoic acid		10		N
3	Other	MS	Sulfur dioxide	2	4	N	2
Number of volatiles in the wine				67	61	57	60
Number of volatiles in the wine reduction				30	46	35	35

Table information: N refers to values lower than 1%, while '-' signifies that the compound was not found in neither the wine nor in the reduction. Cell colors: black – compounds present in the wine but not in the reduction (lost), dark grey – compounds present in the reduction but not in the wine (formed), light gray – compounds present in the reduction in a higher concentration than in the wine. Method of identification (in the column named "Ident. method"); 'MS' refers to compounds identified by probability based matching of mass spectrum with the Wiley database and 'RI' refers to identification confirmed by comparison with retention index from literature.

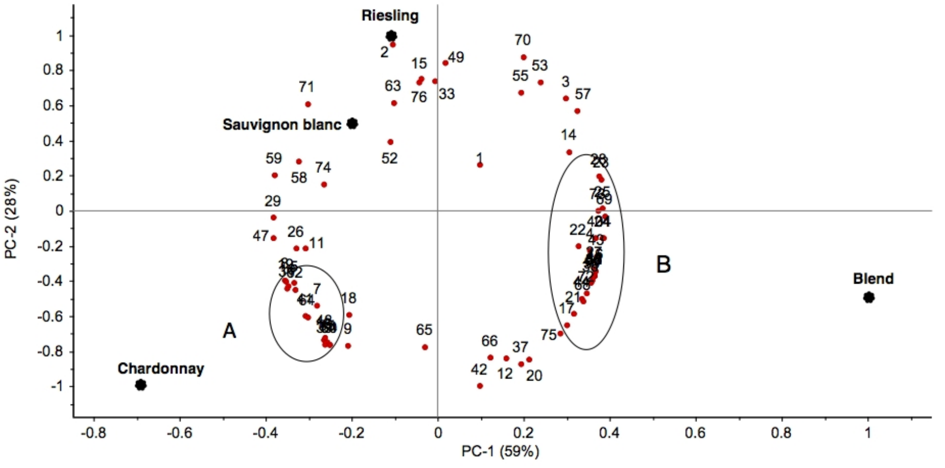
Table 4: Sensory analysis results and descriptors used to evaluate the wines and wine reductions. Values written in bold letters represent descriptors where significant differences were experienced between the wines and the wine reductions respectively. Significance was defined at $p \leq 0.05$. Different subscript letters represent significant differences. The * represents descriptors were ANOVA-testing resulted in significant difference, but where post-testing by Tukey's test did not find significant differences between samples. This may be due to scattering of the data. (o) (odor) and (f) (flavor) represent descriptors evaluated by orthonasal and retronasal olfaction respectively. The symbol '-' signifies that the descriptor was not used in assessment of the product in question. The descriptor 'sourness' was used to describe the taste of organic acids in the wines and wine reductions. However, in the wine business it is common to use the word 'acidity' (low, medium or high) to describe the same taste quality.

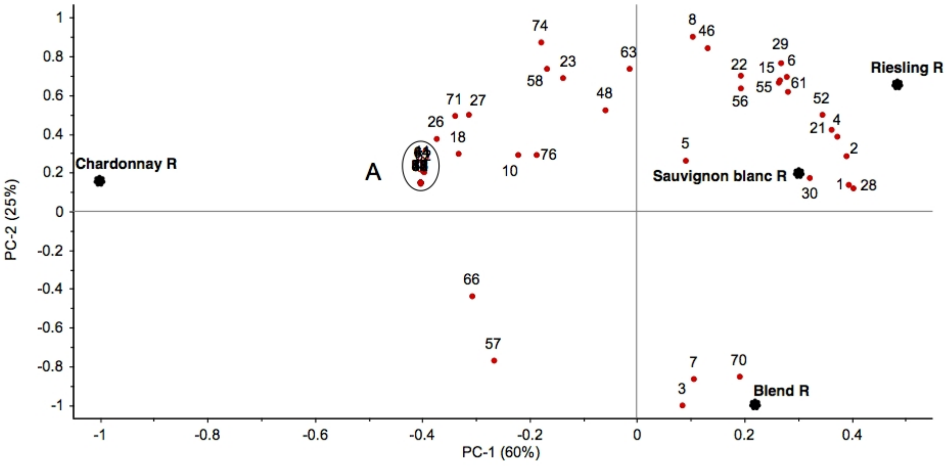
Descriptors	Wines				Wine p-values	Wine reductions				Wine reduction p-values	Descriptor definition
	Chardonnay	Riesling	Sauvignon blanc	Blend		Chardonnay	Riesling	Sauvignon blanc	Blend		
Alcohol (o)	5.14	4.05	4.27	3.33	0.079	-	-	-	-	-	Aroma of alcohol (ethanol)
Citrus (o)	**2.28** ^{b}	**3.13** ^{ab}	**3.90** ^{a}	**3.40** ^{a}	**0.003**	**2.13** ^{b}	**2.54** ^{ab}	**3.24** ^{a}	**3.10** ^{ab}	**0.030**	Aroma of lemons and limes
Blackcurrant leaves/nettle (o)	2.76	2.28	2.81	2.74	0.444	-	-	-	-	-	Aroma of blackcurrant leaves and nettle leaves
Green (o)	**2.21** ^{b}	**3.67** ^{a}	**3.84** ^{a}	**3.54** ^{ab}	**0.020**	**2.02** ^{a}	**2.06** ^{a}	**2.96** ^{a}	**2.83** ^{a}	0.047 *	Aroma of green apples, gooseberries, rhubarb, grass
Fruit (o)	**2.81** ^{b}	**2.88** ^{b}	**3.87** ^{ab}	**4.19** ^{a}	**0.005**	2.40	2.45	2.90	3.71	0.070	Aroma of fresh fruits (pears, apricots, peaches, pineapple and pass
Dried fruit (o)	**4.64** ^{a}	**2.33** ^{b}	**2.40** ^{b}	**2.24** ^{b}	**<0.001**	**4.17** ^{a}	**3.44** ^{ab}	**2.90** ^{b}	**2.89** ^{b}	**0.024**	Aroma of dried and over ripe fruit (prunes, raisins and banana)
Floral (o)	3.36	3.39	4.21	3.96	0.104	2.86	2.86	2.84	3.67	0.087	Aroma of acacia, linden, hawthorn and thin acacia honey
Spicy (o)	**3.85** ^{a}	**2.08** ^{b}	**2.37** ^{b}	**2.31** ^{b}	**0.012**	2.94	2.60	2.19	2.36	0.062	Aroma of spices (vanilla, cloves and pepper)
Wood (o)	**4.29** ^{a}	**2.26** ^{a}	**2.20** ^{b}	**2.27** ^{b}	**<0.001**	**4.56** ^{a}	**3.11** ^{b}	**2.76** ^{b}	**2.76** ^{b}	**0.002**	Aroma of wood and oak barrels
Butter (o)	**3.12** ^{a}	**1.26** ^{b}	**1.45** ^{b}	**1.38** ^{b}	**<0.001**	2.40	1.91	1.30	1.94	0.085	Aroma of fresh butter
Chemical (o)	**1.80** ^{ab}	**2.39** ^{a}	**1.47** ^{b}	**1.63** ^{ab}	**0.027**	1.70	1.43	1.48	1.25	0.609	Aroma of chemicals (petroleum and sulfur)
Cooked (o)	-	-	-	-	-	3.35	3.13	2.92	3.01	0.677	Aroma of cooked fruits (apple and pears)
Forest (o)	-	-	-	-	-	**2.94** ^{a}	**2.91** ^{a}	**2.61** ^{a}	**2.12** ^{a}	0.048 *****	Aroma of damp forest floor (wet moss) and mushrooms
Fermented grain (o)	-	-	-	-	-	**2.27** ^{ab}	**3.14** ^{a}	**3.02** ^{ab}	**2.04** ^{b}	**0.027**	Aroma of malt, beer, yeast and sourdough
Sweetness	**3.61** ^{b}	**3.34** ^{b}	**3.14** ^{b}	**5.27** ^{a}	**<0.001**	**2.91** ^{b}	**2.61** ^{b}	**2.37** ^{b}	**4.70** ^{a}	**<0.001**	Taste of dilute aqueous solutions of sucrose
Sourness	**3.98** ^{bc}	**5.18** ^{a}	**4.69** ^{ab}	**3.29** ^{c}	**<0.001**	**4.71** ^{b}	**6.25** ^{a}	**6.01** ^{a}	**3.98** ^{b}	**<0.001**	Taste of dilute aqueous solutions of acids
Bitterness	**5.36** ^{a}	**4.33** ^{ab}	**5.23** ^{a}	**3.36** ^{b}	**0.008**	**4.84** ^{a}	**4.80** ^{a}	**5.15** ^{a}	**3.28** ^{b}	**0.013**	Taste of dilute aqueous solutions of substances such as quinine and
Citrus (f)	**2.54** ^{b}	**4.64** ^{a}	**3.62** ^{ab}	**4.24** ^{a}	**0.003**	**2.81** ^{b}	**4.34** ^{a}	**3.82** ^{ab}	**3.42** ^{ab}	**0.005**	Flavor of lemons and limes
Green (f)	**2.17** ^{b}	**3.75** ^{a}	**3.87** ^{a}	**4.17** ^{a}	**<0.001**	2.13	3.33	3.41	3.09	0.144	Flavor of green apples, gooseberries, rhubarb and grass
Fruit (f)	**2.91** ^{b}	**2.66** ^{b}	**3.43** ^{ab}	**4.42** ^{a}	**<0.001**	**2.44** ^{b}	**1.97** ^{b}	**2.16** ^{b}	**3.56** ^{a}	**0.005**	Flavor of fresh fruits (pears, apricots, peaches, pineapple and passi
Dried fruit (f)	**5.12** ^{a}	**1.92** ^{b}	**2.53** ^{b}	**2.08** ^{b}	**<0.001**	**4.12** ^{a}	**2.60** ^{b}	**2.49** ^{b}	**3.15** ^{ab}	**0.004**	Flavor of dried and over ripe fruit (prunes, raisins and banana)
Floral (f)	3.41	3.09	3.58	4.1	0.123	**2.38** ^{b}	**2.10** ^{b}	**2.59** ^{ab}	**3.47** ^{a}	**0.004**	Flavor of acacia, linden, hawthorn and thin acacia honey
Spicy (f)	**4.84** ^{a}	**2.62** ^{b}	**3.15** ^{b}	**2.13** ^{b}	**<0.001**	**3.01** ^{a}	**2.21** ^{b}	**1.86** ^{b}	**2.41** ^{ab}	**0.009**	Flavor of spices (vanilla, cloves and pepper)

Wood (f)	**4.60** [a]	**2.20** [b]	**2.56** [b]	**2.24** [b]	**<0.001**	**4.76** [a]	**2.97** [b]	**2.60** [b]	**3.21** [b]	**<0.001**	Flavor of wood and oak barrels
Butter (f)	**2.67** [a]	**1.17** [b]	**1.37** [b]	**1.26** [b]	**<0.001**	**1.97** [a]	**1.53** [a]	**1.21** [a]	**2.04** [a]	**0.042**	Flavor of fresh butter
Cooked (f)	-	-	-	-	-	3.28	2.78	2.43	3.09	0.091	Flavor of cooked fruits (apple and pears)
Forest (f)	-	-	-	-	-	**2.94** [a]	**2.94** [a]	**2.92** [a]	**2.11** [b]	**0.008**	Flavor of damp forest floor (wet moss) and mushrooms
Fermented grain (f)	-	-	-	-	-	**2.46** [ab]	**3.06** [a]	**3.00** [a]	**1.92** [b]	**0.006**	Flavor of malt, beer, yeast and sourdough
Pungent	**6.16** [a]	**3.99** [b]	**4.20** [b]	**3.69** [b]	**<0.001**	-	-	-	-	-	Sharp and pricking feeling in the mouth
Astringent	**5.08** [a]	**4.96** [a]	**5.12** [a]	**3.42** [b]	**<0.001**	**4.27** [b]	**5.86** [a]	**5.85** [a]	**3.59** [b]	**<0.001**	Feeling of dryness and contractions in the mouth

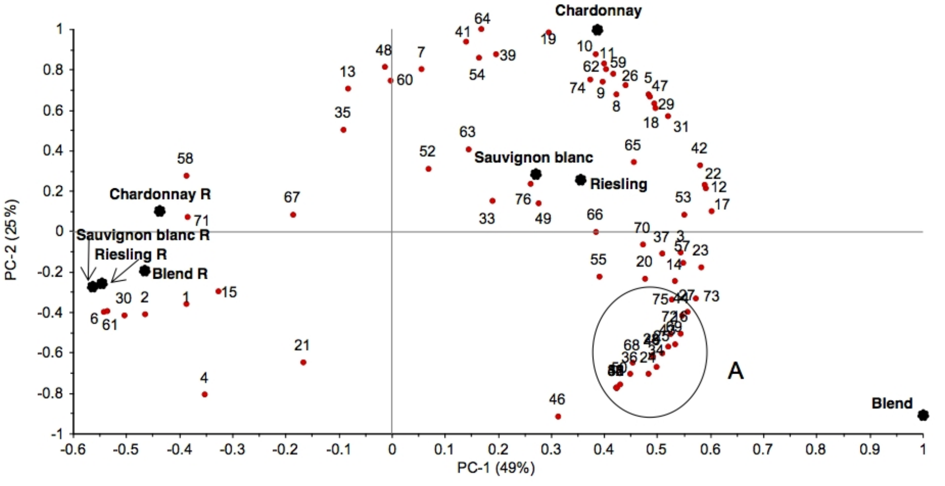
Table 5: Sensory analysis scores for specific and significantly different wine reduction attributes. Different superscript letters represent significant difference ($p \leq 0.05$).

Reduction	Fermented grains (o)	Fermented grains (f)	Forest (f)
Chardonnay R	2.27 ^{b}	2.46 ^{ab}	2.94 ^{a}
Riesling R	3.14 ^{a}	3.06 ^{a}	2.94 ^{a}
Sauvignon blanc R	3.02 ^{ab}	3.00 ^{a}	2.92 ^{a}
Blend R	2.04 ^{b}	1.92 ^{b}	2.11 ^{b}
P-value	0.03	< 0.01	< 0.01

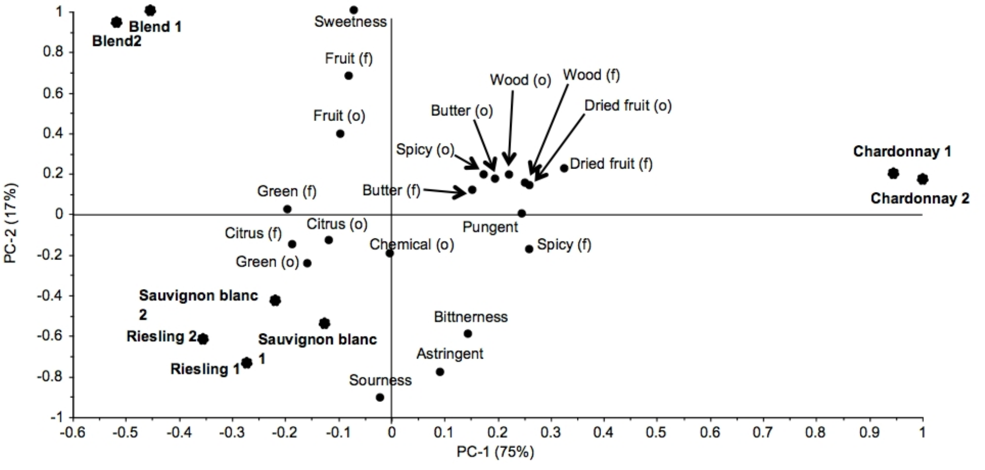

Riesling
Sauvignon blanc
Chardonnay
Blend
A
B
PC-1 (59%)
PC-2 (28%)
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
-1

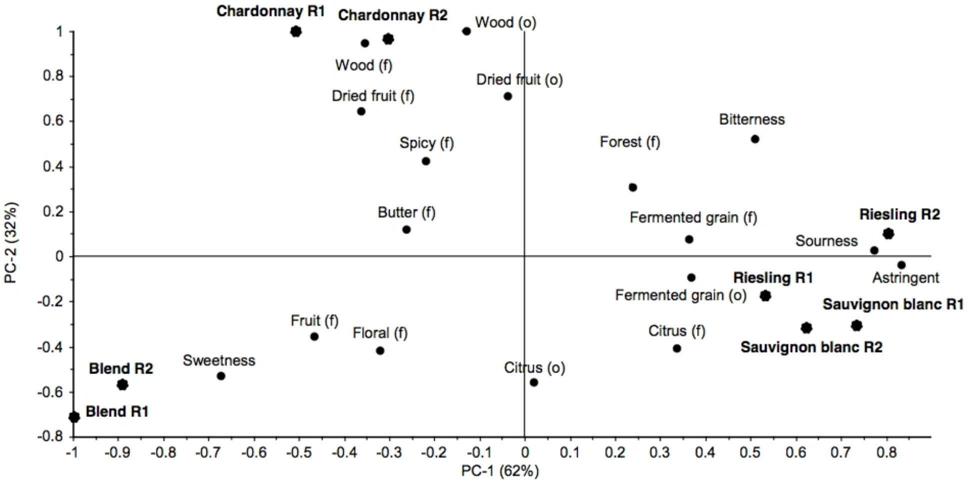


PC-2 (25%)
PC-1 (60%)
Chardonnay R
Riesling R
Sauvignon blanc R
Blend R
A
74
23
58
63
48
71
27
26
18
10
76
8
46
29
22
15
6
55
61
56
52
4
21
2
5
30
1
28
66
57
7
70
3



Chardonnay
Sauvignon blanc
Riesling
Chardonnay R
Sauvignon blanc R
Riesling R
Blend R
Blend
A
PC-2 (25%)
PC-1 (49%)


Blend 1
Blend2
Sweetness
Fruit (f)
Fruit (o)
Wood (o)
Wood (f)
Butter (o)
Dried fruit (o)
Spicy (o)
Dried fruit (f)
Chardonnay 1
Chardonnay 2
Green (f)
Butter (f)
Pungent
Citrus (o)
Citrus (f)
Chemical (o)
Spicy (f)
Green (o)
Sauvignon blanc 2
Riesling 2
Sauvignon blanc 1
Riesling 1
Bittnerness
Astringent
Sourness
PC-2 (17%)
PC-1 (75%)


Chardonnay R1
Chardonnay R2
Wood (o)
Wood (f)
Dried fruit (o)
Dried fruit (f)
Bitterness
Spicy (f)
Forest (f)
Butter (f)
Fermented grain (f)
Riesling R2
Sourness
Riesling R1
Astringent
Fermented grain (o)
Sauvignon blanc R1
Fruit (f)
Floral (f)
Citrus (f)
Sauvignon blanc R2
Sweetness
Citrus (o)
Blend R2
Blend R1
PC-2 (32%)
PC-1 (62%)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

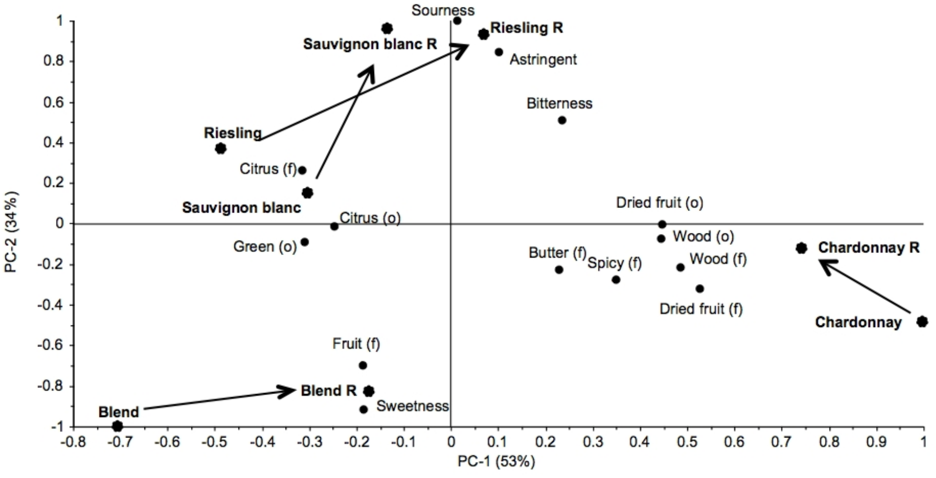

Sourness
Riesling R
Sauvignon blanc R
Astringent
Bitterness
Riesling
Citrus (f)
Sauvignon blanc
Citrus (o)
Green (o)
Dried fruit (o)
Wood (o)
Chardonnay R
Butter (f)
Spicy (f)
Wood (f)
Dried fruit (f)
Chardonnay
Fruit (f)
Blend R
Sweetness
Blend
PC-2 (34%)
PC-1 (53%)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

FIGURE CAPTIONS:

Figure 1: Principal component analysis (PCA) bi-plot of the wines and their volatile components (standardized). Group A contains the following volatile components: 5, 7, 8, 10, 13, 19, 31, 35, 39, 41, 48, 60, 62, 64. Group B: 4, 16, 17, 21, 22, 23, 24, 25, 27, 28, 32, 34, 36, 38, 40, 43, 44, 45, 46, 50, 51, 56, 68, 69, 72, 73. The list of volatile components and their allotted numbers is found in Table 3. 87% of the variance was explained by the two first components.

Figure 2: PCA bi-plot of the wine reductions correlated with the volatiles (standardized). Group A contains the following volatile components: 9, 13, 35, 36, 37, 41, 42, 43, 44, 53, 60, 62, 64, 67, 72, 73. The list of volatile components and their allotted numbers is found in Table 3. 85% of the variance was explained by the two first components.

Figure 3: PCA bi-plot of the wine and wine reductions and their volatiles (standardized). Group A contains the following volatile components: 16, 24, 25, 27, 28, 32, 34, 36, 38, 40, 43, 44, 45, 50, 51, 56, 68, 69, 72, 75. The list of volatile components and their allotted numbers is found in Table 3.

Figure 4: PCA bi-plot of the wine sensory results. Only significant descriptors are plotted. 92% of variance is explained by the two first components. According to these results, Sauvignon blanc and Riesling wines were the most similar of the wines. Replicates are denoted «1» and «2».

Figure 5: PCA bi-plot of the wine reduction sensory data. Only significant descriptors are plotted. 94% of variance is explained by the two first components. Compared to the wine evaluation results, Riesling and Sauvignon blanc reductions were still the most similar products. Replicates are denoted «1» and «2».

Figure 6: PCA bi-plot showing the relation between wines and wine reductions. Only significant and overlapping descriptors are plotted (Green (o) was included although it was not significantly different for wine reductions according to Tukey’s post test). Replicates were averaged in this plot.