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Abstract

Wine is often used as an ingredient in butter sauces such as hollandaise sauce, but normally in its reduced form. Hollandaise sauce is an emulsion, and roughly consists of a continuous phase (water based ingredients) and a dispersed phase (fat). In addition, hollandaise sauce contains varying amounts of incorporated air, seen as air bubbles in the sauce. In this study, the influence of wines and wine reductions on sauce flavor was studied. Butter sauces, where the aqueous phase of the sauces varied, were made and analyzed. Four different types of white wine (Chardonnay, Riesling, Sauvignon blanc and a blended wine) and these wines' corresponding wine reductions were incorporated in butter sauce to produce model products (eight sauces in total). In the reductions, approximately 51 % of the volume was removed by evaporation. The wines were selected based on both non-volatile composition and aroma differences. A trained sensory panel (n=10) evaluated sauce flavor and texture. Volatile profiles of sauces were studied by GC-MS, and sauce texture was evaluated by texture analysis, microscopy and dry matter measurements. Results showed that the degree of reduction is more important for sauce flavor than the wine type.

Keywords	Wine; vinegar; hollandaise sauce; food science; culinary arts; molecular gastronomy

Corresponding Author	Morten Sivertsvik
Corresponding Author's Institution	Nofima
Order of Authors	Guro Helgesdotter Rognså, Morten Rathe, Mikael Agerlin Petersen, Knut-Espen Misje, Dagmar Brüggemann, Margrethe Hersleth, Morten Sivertsvik, Jens Risbo

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File Name [File Type]

Letter to Editor revision.docx [Response to Reviewers]

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Figure 2.pdf [Figure]

Figure 3.pdf [Figure]

Figure 4.pdf [Figure]

Figure 5.pdf [Figure]

Figure 6.pdf [Figure]

Figure 1 revised.pdf [Figure]

Figure captions revised.docx [Figure]

Dear Editor,

Thank you for providing a swift review of our article. We have read the remarks of the reviewers, and have made changes to the manuscript accordingly. The following text sums up our comments to the reviewers.

First of all, there were several comments related to the reference (Rognså et al. Forthcoming 2017). This review concerns the second of two articles written based on the results from the research project in question, and both articles were submitted to IJGFS the same day. We hope both articles will be suitable for publishing in the journal. Since this article is the second of the two, we suggest that the other article will be published first or in the same issue as this article. This explains why we have given more detailed information about for example methods in the first article, (Rognså et al. Forthcoming 2017). We sent information about the two articles to Juan Carlos Arboleya the same day as submission, but this is the first article we have received back from review.

- Both reviewers have commented on the length of the supporting text for some of the figures and tables. We have reviewed and shortened several of these texts or moved text to footnotes below the tables. However, Table 2 and 3 contain much information, and need their information texts. Reviewer 2 commented the absence of two arrows in Figure 1, and these are now where they should be. The same reviewer also commented that the numbers in cluster A in Figures 2 and 3 are not visible. This is correct, but the compound numbers comprised in groups are listed in the figure text instead.

Responses to questions from Reviewer 1:

- **Viscometer versus texture analyzer**. During the experimental phase of the project, analyses with both viscometer and texture analyzer were performed, and both methods may be used to analyze textural properties of sauces. We have only included the results obtained with the texture analyzer here, and for us this proved to be a suitable method. This method may be used, not only for gels and solids, but also for fluids, and the probe applied in this work is designed for textural analysis of fluids.

- **Number of sauces in the sensory analysis**: The panel evaluated 16 sauces in total (not counting dummy samples). There were 4 wine sauces and 4 reduction sauces, and each sauce product was evaluated twice by the panel. Clarifications to the manuscript have been made.

- **Number of attributes in the sensory analysis (29 different descriptors)**: The panel used in the sensory analysis is a highly trained panel. We agree that we used a high number of descriptors. However, this panel is trained to analyze up to 30 descriptors during descriptive analyses of food products, and we also checked the panel performance in training sessions.

- **Conclusion**: We disagree with the reviewer regarding the lack of specificity of the conclusion. We feel the conclusion is too the point and sums up the article in an appropriate way.

Responses to questions from Reviewer 2:

- **The absence of key volatile compounds in the volatile analysis, such as whiskey lactone and thiols**: There are several explanations for the absence of the compounds the reviewer has listed. The reason for the absence of Sauvignon blanc thiols is the detection limit of the method, which is approximately 1 ppb. Any compound present in the samples in concentrations lower than the limit of detection could not be detected, although such compounds may have been sensed by the sensory panel due to very low odor thresholds. Volatile and sensory analyses therefore complement each other. Although the detection limit of the method is low, it is a generally known problem that some compounds have so low thresholds, for which special techniques are required, for example derivatization.

  The reason why some lactones or other large molecules are not detected are their high boiling points, which explains why the compounds did not evaporate onto the trap in large enough concentrations to be detected. Vanillin for example cannot, therefore, be determined using the current purge and trap analysis. To be able to overcome these limits of the analysis method, three or more different analysis methods would have been needed, which is unrealistic. All these detection difficulties are well-known and accepted.

  In the case of butter sauces, larger volatile compounds may also have affinition for the lipid phase of the emulsion, which may explain why the compounds did not evaporate and adsorb onto the trap in large enough concentrations. We have included information about the limitations of the volatile analysis in (Rognså et al. Forthcoming 2017).

- **Acidity:** Information about the pH, total acidity and volatile acidity of the wines is included in (Rognså et al. Forthcoming 2017)

- **Volatile analysis for ingredients:** The same volatile analysis method was used for both the sauces and the ingredients, and a clarification regarding this has been added to the manuscript.

- **The url odor.org.uk**: The letter "u" in "odour" was missing, and we have corrected this in the manuscript.

- We have changed the phrasing in the text below in the manuscript, to avoid confusion. We admit that the original text was not clear enough.

  "Several of the volatiles found in the wine sauces were observed in lower concentrations in the reduction sauces, or could not be detected at all. Other volatiles increased in concentration in the reduction sauces. Table 2 illustrates these important changes in compound composition between wine and reduction sauces."

- **Figure 5**: In Figure 5 PC-1 explains 88%, not 92%, in which Reviewer 2 is correct. The manuscript has been corrected.

- **Regarding Table 2:**

  - **Alcohol in Chardonnay reduction sauce**: We agree with the Reviewer that it may seem strange that the wine reduction sauce contained 2 % more ethanol than the wine sauce. Both sauces have been through a heat treatment over 7 minutes during the sauce making. In this process, ethanol will also evaporate from the wine. However, we went back and analyzed the raw data over again, and we found that one of the parallel samples showed irregularities regarding the analysis of ethanol (only). This parallel was therefore removed from the data analysis. The new calculations are therefore based on 5 parallels from two batches, and gave a decrease in alcohol content to 52 percent, which is more in line with the other sauce systems (Blend, Sauvignon blanc and Riesling). Since the Chardonnay wine was the wine with the highest ethanol content, 14.8 % abv, it is not surprising that the reduction sauce from Chardonnay was the sauce with the highest ethanol content compared to the wine sauce. We thank the Reviewer for the observation.

  - **Regarding the sentence**: "The result show that numerous similar changes to the volatile profiles can be observed when comparing the four sauce systems". What we mean to say is that the comparisons (in pairs) of the wine sauce and the wine reduction sauce have many similarities for the four sauce pairs – based on Chardonnay, Sauvignon blanc, Riesling and Blend. The sentence has been rewritten and moved from the caption to the results section.

- **Regarding the sentence**: "the wine reductions were assessed more sour and less sweet compared to the wines". We agree with the Reviewer that it is logical, due to the evaporation of water, but it may not always be the case, as it depends on complex taste-taste interactions, which we discussed in the text that followed the sentence. All wine reductions will therefore not necessarily taste more sour and less sweet, as it depends not only on the acidity of the wine but also on other factors, such as the sugar concentration. However, in our study the same pattern was seen for all wine reductions, even if the wines contained different sugar concentrations.

We hope our comments answer the reviewers' concerns with the manuscript, and we hope for a positive response.

Best regards,
The authors

RESEARCH ARTICLE

From wine to hollandaise sauce: Does the nature of the wine or wine reduction influence sensory attributes?

Guro Helgesdotter **Rognså** [1,2], Morten **Rathe** [1], Mikael Agerlin **Petersen** [2], Knut-Espen **Misje** [3], Dagmar A. **Brüggemann** [4]**,** Margrethe **Hersleth** [5], Morten **Sivertsvik** [6] *, Jens **Risbo** [2]

[1] The Culinary Institute of Norway, Richard Johnsensgate 4, 4021 Stavanger, Norway
[2] Department of Food Science, University of Copenhagen, Rolighedsvej 26, 1958 Frederiksberg C, Denmark
[3] Terroir Wines, Randabergveien 134, 4027 Stavanger
[4] Faculty of Life Science, Rhine-Waal University of Applied Sciences, Marie-Curie Straße 1, 47533 Kleve, Germany
[5] Nofima AS, P.O. Box 5003, 1432 Ås, Norway
[6] Nofima AS, P.O. Box 8034, 4068 Stavanger, Norway
* Corresponding author: Tel. +47 51844637, E-mail address: morten.sivertsvik@nofima.no

Abstract: Wine is often used as an ingredient in butter sauces such as hollandaise sauce, but normally in its reduced form. Hollandaise sauce is an emulsion, and roughly consists of a continuous phase (water based ingredients) and a dispersed phase (fat). In addition, hollandaise sauce contains varying amounts of incorporated air, seen as air bubbles in the sauce. In this study, the influence of wines and wine reductions on sauce flavor was studied. Butter sauces, where the aqueous phase of the sauces varied, were made and analyzed. Four different types of white wine (Chardonnay, Riesling, Sauvignon blanc and a blended wine) and these wines' corresponding wine reductions were incorporated in butter sauce to produce model products (eight sauces in total). In the reductions, approximately 51 % of the volume was removed by evaporation. The wines were selected based on both non-volatile composition and aroma differences. A trained sensory panel (n=10) evaluated sauce flavor and texture. Volatile profiles of sauces were studied by GC-MS, and sauce texture was evaluated by texture analysis, microscopy and dry matter measurements. Results showed that the degree of reduction is more important for sauce flavor than the wine type.

Keywords: Wine, vinegar, hollandaise sauce, food science, culinary arts, molecular gastronomy.

1 Introduction

Hollandaise sauce is a classic emulsified butter sauce made from egg yolk, butter and an aqueous phase containing various acidic ingredients such as lemon juice, white wine or a reduction of white wine and vinegar. It was classified as a *mother sauce* in the French sauce system by the famous chef Escoffier (Larousse, 1993), from which numerous sauces are derived, for example béarnaise sauce.

The composition the aqueous phase constitutes a space of variation and gastronomic uniqueness in hollandaise sauce. Although the butter type and ingredient amounts in general may vary from one recipe to another, the main disagreements among chefs regarding hollandaise composition is centered around the aqueous phase (Ruhlman, 2012). There are many possible options regarding this phase's composition and preparation, and practice may vary substantially from one chef to another. It is common to flavor a hollandaise sauce with lemon juice towards the end of the preparation, but the composition of the aqueous phase to create the emulsion varies substantially. Numerous aqueous phase possibilities exists (aqueous ingredients present at the beginning of the procedure); wine (reduced or not) (Engelbrecht, 2013), water and vinegar (reduced or not) (The Culinary Institute of America, 2011, Escoffier, 1921), wine and vinegar reduction (Ruhlman, 2012, The Culinary Institute of America, 2011), water (Larousse, 1993, Peterson, 2008, Robuchon and Noce, 2006, 2007), water and lemon juice (Child et al., 1961) or just egg yolks (for this option, addition of aqueous ingredients to the sauce during preparation is necessary to create a stable emulsion) (Carême, 1854). Some chefs believe that wine reductions should not be used in hollandaise sauce, and that only derivate sauces such as béarnaise sauce call for wine reductions. Still others think that a reduction in hollandaise sauce adds flavor complexity (Ruhlman, 2012).

Wines are normally reduced when used in hollandaise sauce. When wines are reduced, their aroma is changed mainly through evaporation of volatile compounds such as esters, and at the same time non-volatile components are concentrated by water evaporation ((Snitkjær et al., 2011, Rognså et al., Forthcoming 2017)). Wine reductions made from both white and red wines are widely used in sauces and stocks (Peterson, 2008). It has been estimated that «48% of French classical sauces contain wine» (as cited in (This, 2013)). Wine and wine reductions contribute with basic taste compounds and aromas to products where they are included. The impact of wine and wine reductions on the sensory properties of a product is probably dependent on several factors, such as how the wine or wine reduction is made or added, the amount used, and on the structure and fat concentration of the product. A study from 2010 showed that wine reduced alone and then added to stock versus wine reduced together with the stock resulted in two quite different products (Snitkjær et al., 2011).

Some cookbooks emphasize the importance of choosing the right wine type to use in a wine reduction for sauce purposes (Peterson, 2008, Larousse, 1993). In this study, we focus on the effect of the aqueous phase on hollandaise sauce – More specifically the effect of addition of a diverse selection of white wines and their reductions is investigated. In a recent study, white wines selected on the basis of sweetness, sourness and grape variety was investigated with respect to the changes induced by the reduction process (Rognså et al., Forthcoming 2017).

Hollandaise sauces are emulsions with a fat content among the highest found in mixed food products. The fat content may be as high as 70 – 80 % (see paragraph 2.2). In emulsions, the fat content influences aroma release, and thus the emulsion's perceived aroma and flavor. Butter itself contains many different aroma compounds, but the fat content also influences the release of aroma compounds originating from other ingredients or compounds created during preparation. Emulsions with high and low fat contents may therefore taste different (Malone et al., 2003). When the fat concentration decreases, the concentration of fat-soluble molecules significantly increases in the headspace (Widder and Fischer, 1997). In addition to influencing aroma intensity, fat also affects the emulsion's temporal aroma profile (Malone et al., 2003). The fat phase may therefore influence the release of aroma compound from the aqueous phase of hollandaise sauces and thereby modify the effect of this phase on the gastronomic outcome.

In the present study four wines and their corresponding wine reductions were incorporated into butter sauces, constituting the sauces' aqueous phase. The wines and wine reductions used in this study have been evaluated elsewhere (Rognså et al., Forthcoming 2017). The study combined sensory analysis of products with analysis of volatile profile and texture analyses to evaluate how wine and wine reductions affect sauce characteristics and perception. The aim was to obtain rationally based information on the relationship between culinary practice and the gastronomic outcome in terms of perceived and measurable properties and thereby answer the question: To which extent does the nature of the wine or the wine reduction matter in hollandaise sauce?

2 Materials and methods

2.1 Sauce preparation

Hollandaise sauce can be produced in a number of ways (Rognså et al., 2014). In this study, sauces were made based on a sabayon, as it yields airy sauces. This method was chosen because of its popularity among chefs today (Rognså et al., 2014).

Sauces were made in an induction stand mixer (Kenwood Cooking Chef, Kenwood Electronics Europe B.V.), which made a high degree of standardization of procedures and sauces possible. The machine was equipped with a balloon whish (Kenwood Power whisk 45002, accessory to the Kenwood Cooking Chef KM070 machine), which allowed incorporation of air into the sabayon while heating.

TABLE 1

2.2 Sauce recipe

Sauces were made using the following ingredients and amounts: 130g egg yolks, 120 g aqueous phase (each of the four wines and the four wine reductions in turn), 580 g clarified butter and 6 g salt. The total water content in the sauce ingredients was approximately 23 % (weight). The sauces contained approximately 73% fat in total (from egg yolks and butter, evaporation of water during preparation disregarded).

All sauces were made using the same method and ingredient amounts. The only varying factor was the composition of the aqueous phase, and a total of eight difference sauces types were produced (four wine sauces and four wine reduction sauces). For the analyses, two replicates or batches were made of each sauce type.

2.3 Sauce ingredients

2.3.1 Egg yolks

Egg yolks were isolated from fresh eggs (3-10 days old, from hen of the Dekalb breed from Gudmestad’s farm, 4365 Nærbø, Norway). Eggs from the same livestock were used throughout the study. The egg yolks were separated from the albumen by hand, and adherent albumen was removed using filter towel. Yolk membranes were gently punctuated using a balloon whip on the egg yolks in a bowl, and the yolks were further passed through a sieve to remove the chalazas. Correct amounts of egg yolk were weighed out and stored at 3 °C (under cling film) until use. Eggs were shelled the same day as the sauce preparation.

2.3.2 Butter

Butter was clarified 1-3 days prior to use. In a large casserole, unsalted butter («Usaltet smør», TINE SA, Norway), produced from fresh cream, was slowly melted on low heat. The butter’s aqueous phase was not permitted to boil. After complete melting, the butter was removed from the heat, and allowed to separate from the water phase at room temperature for one hour. The clarified butter was ladled out, and packed in heat resistant piping bags (Kee-seal™ Ultra) and vacuum sealed. Packed butter was stored at 3°C until use. Butter was warmed in a temperature controlled water bath (55

°C) until the external temperature was reached in the butter. The butter contained 2,1 percent water by weight (n=6, SD=1,3) after clarification. Home-clarified butter may contain traces of proteins and carbohydrates in addition to water.

2.3.3 Wines and wine reductions

The selected wines comprised an oaked Chardonnay wine (48 $, Byron 2006 Chardonnay, Byron Vineyards and Winery, Santa Maria, California, USA), a dry Riesling wine (22 $, Reinhartshausen 2010 Riesling trocken, Rheingau, Germany), a dry Sauvignon Blanc wine (27 $, Domaine Fouassier Les grand champs 2011, Sancerre, France) and a medium (sweet) blended wine (13 $, H. Sichel Söhne, Blue Nun 2011, Germany. Approximate blend: 40 % Müller Thurgau, 25% Riesling, 25 % Silvaner, 5 % Kerner and 5% Gewürztraminer, a customized blend for the Norwegian market). All the wines were bought in Norway, and their price converted to the closest whole number of US dollars. The aim of the wine selection was to include wines with different volatile and non-volatile profiles.

Wine reductions from each of the four wines were prepared in an induction stand mixer (Kenwood Cooking Chef, Kenwood Electronics Europe B.V., Uithoorn, The Netherlands). 1400 g wine was reduced to an average of 51.3 % ± 1.6 of the original weight during 40 minutes (Settings on Kenwood Cooking Chef stand mixer: 110 °C, stir speed 2, balloon whisk). Reductions were cooled to 10 °C in an ice bath, weighed, vacuum packed (on a Helmut Boss machine) and frozen (-22 °C) until use. Reductions were melted in room temperature before use.

The wines and wine reductions have previously been characterized by volatile and sensory analysis (Rognså et al., Forthcoming 2017).

2.4 Analyses

2.4.1 Dry matter measurements

The sauces were weighed out in suitable steel containers, left to dry at 105 °C until constant weight (>12 hours) and weighed again to determinate the water content of the sauces. Each product was made in duplicates, and triplicate samples were taken from each batch.

2.4.2 Texture analysis

Texture analyses, more specifically compression tests of the sauces, were performed on a texture analyzer (TA-XT2s-pro Texture Analyzer, Stable Micro System Ltd., Surrey, UK) equipped with a 5 kg load cell, using a modified version of the «Back extrusion rig». The analyzer was rigged with a «Compression platen» (cylindrical probe, d=7.5 cm, aluminum, P/75) on the load arm, and 400 mL of sauce was placed in a 600 mL beaker (internal d=8.2 cm, Pyrex) which was fixed onto the testing platform directly under the compression platen. The probe was lowered 3 cm into the sauce with a speed of 1 mm/sec, and was lifted back up to initial position with a speed of 10 mm/sec. The force (g, 0.1 g ≈ 1 mN) necessary to uphold the speed was recorded continuously, with 500 points per second. Two batches of each sauce type were analyzed in triplicates. Sauces were kept in a heating cabinet (55 °C) between analyses.

2.4.3 Microscopy

Confocal laser scanning microscopy (CLSM) was carried out on an inverted Leica TCS SP5 II (Leica Lasertechnik GmbH, Heidelberg, Germany). Excitation wavelength 514 nm and a 10.0 x HC PL APO, NA 0.4 (dry) objective was used. Pinhole was set to 1 Airy unit, and image resolution was 1024 x 1024 pixel. All samples were analyzed at 43 °C. All images were recorded at the same gain and offset settings.

2.4.4 Analysis of volatiles

The composition of the sauces' volatile profiles and the key ingredients was evaluated by dynamic headspace GC-MS. The sauces were analyzed immediately after preparation, and two batches of each product were analyzed with triplicate sampling.

20 g sauce (or sauce ingredient such as butter and egg yolk) was placed in 100 mL flasks, and stirred at 220 rpm at 37 °C (circulating water bath). 1 mL 4-methyl-1-pentanol (5 ppm) was used as internal standard in all samples. The samples were purged for 30 minutes with nitrogen (inert gas) at 150 $mL.min^{-1}$ flow. Volatile compounds were adsorbed on Tenax-TA traps (at room temperature). Traps consisted of 250 mg of Tenax-TA with mesh size 60/80 and a density of 0.37 $g.mL^{-1}$ (Buchem bv, Apeldoorn, The Netherlands). To remove trapped water (as this may cause analytical problems) before GC analysis, the samples were dry-purged for 10 minutes. The remaining methodology was performed according to the analysis of volatiles described in Rognså et al. (Forthcoming 2017). Peak areas were used as relative measurements of amounts.

2.4.5 Descriptive sensory analysis

Descriptive analysis was performed by a trained sensory panel (n=10, Nofima, 1430 Ås, Norway) according to Generic Descriptive Analysis described by Lawless and Heymann (Lawless and Heymann, 2010). The sensory laboratory was designed in accordance with ISO 8589 (ISO, 2007) and all assessors were selected and trained in accordance with ISO 8586-1 (ISO, 1993). The assessors used an unstructured line scale with labeled endpoints (ranging from no intensity (1) on the left to high intensity (9) on the right) to evaluate each of the sensory attributes. Samples were assessed using EyeQuestion v3.8.13 (Logic8, Holland). Prior to analysis, all assessors were trained in butter sauce evaluation, and the panel leader and assessors developed a list of 29 descriptors during these training sessions (see Table 3). Panel performance was evaluated using PanelCheck (v1.2.1). The sensory evaluation took place between 10 a.m. and 14 p.m. and consisted of six sessions with a total of 16 sauces (duplicates of 4 wine sauces and 4 reduction sauces). The test was introduced by a dummy sample. Two to three samples were served in the sessions every 10 minutes and assessors evaluated the samples monadiacally at individual speed. Each sample consisted of 50 ml sauce served in warm (55 °C ±1 °C) porcelain bowls with lids (55 °C ±1 °C). The assessors used plastic spoons. The samples were labeled with a unique three-digit random code and served in the same randomized order. All assessors evaluated therefore simultaneously the same samples because of practical limitations regarding sauce preparation. The assessors evaluated the sauce viscosity on the spoon before assessing the other attributes. All samples were expectorated, and the assessors used unsalted crackers and lukewarm for rinsing between samples.

2.4.6 Statistical analysis

Analysis of Variance (ANOVA), using a General Linear Model (Minitab Inc, USA), was applied to study differences between product results. Post-testing by Tukey's Multiple Comparisons Test (Minitab Inc, USA) was applied to determine significant differences in pairwise comparisons of products. Significant differences were defined at $p \leq 0.05$.

Multivariate data analysis, Principal Component Analysis (PCA) (Unscrambler® X v10.2, Camo AS, Norway), was used to study the main sources of variation in the results obtained from the analysis of volatiles and the sensory analysis. Only the aroma data were standardized in this analysis (Næs et al., 2010).

2.5 Evaluation of culinary professionals’ practices and preferences

A total number of 18 chefs (Average age: 27.6 years. Average experience: 10.6 years) from the Culinary Institute of Norway (n=5), the Norwegian Junior and Senior Culinary Teams (n=11) and other experienced chefs (n=2) answered a detailed questionnaire about ingredient and procedural choices and practice in relation to hollandaise and béarnaise sauce preparation.

3 Results

The impact of the different aqueous phases on hollandaise sauce properties were studied and evaluated. As seen in the introduction, hollandaise sauce can be made using a range of different water phases, and chefs are known to disagree on the composition of this main constituent, acting as the continuous phase in the emulsified hollandaise sauce.

3.1 Evaluation of culinary professionals’ practices and preferences

Chefs were contacted to gather information about their thoughts and habits regarding butter sauce preparation. Norwegian chefs were asked in detail about their wine choices in relation to butter sauce making, and 89% of the chefs replied that they use white wine in hollandaise sauce. 56% of the chefs answered that they do not pay much attention to the wine region or style, and a further 22% answered that they use any affordable white wine available to them in the kitchen in hollandaise and béarnaise sauces. However, as many as 50% of the chefs specifically commented that the wine should be «dry», a further 17% thought the wine «should not be sweet» and 22% of the chefs also mentioned that the wine should have «good acidity». Dryness of the wine seems therefore to be an important selection factor for white wine intended for butter sauces. Although special wine regions and grape varieties were not of particular importance to the chefs, they mentioned several regions/styles as suitable wine examples; Chablis (Chardonnay), Muscadet (Melon de Bourgogne), Sancerre (Sauvignon blanc) dry Riesling and Champagne (Chardonnay, Pinot noir and Pinot meunier). It can be concluded from the survey that the chefs focused on the wine’s taste, and they generally preferred dry and non-sweets wines for hollandaise sauce preparation, whereas less or no emphasis was put on the aroma characteristics of the wine (for example fruitiness).

In order to gain insight on the rational basis of the effect of the aqueous phase, hollandaise sauces, based on the selected wines and their reductions, were characterized by volatile analysis, sensory evaluation, water measurements, textural analysis and microscopy.

3.2 Analysis of volatiles

The GC-MS analyses detected 53 volatile compounds in the sauces (see Table 2 for the list of compounds). The volatiles were quantified by averaged raw areas (n=6, 3 replicates for each batch of sauce (n=2)), and identified by probability matching of mass spectra with the Wiley database and/or by comparison with retention indexes from literature (flavornet.org, odour.org.uk and pherobase.com).

The variation in volatile components between all the sauces is shown as a Principal Component Analysis (PCA) plot in Figure 1. The PCA plot clearly shows that the sauces fall into two distinct main groups, the sauces based on wines and the sauces based on wine reductions, and the two groups are mainly separated by PC1 (38%). The second component, PC 2 (30%), separates out the sauces based on Chardonnay wine and Chardonnay wine reduction from sauces based on the other three wines and wine reductions.

FIGURE 1

Data from the wine sauces and the reduction sauces were then analyzed separately, and Figure 2 shows the distribution of volatile components in the wine sauces. The four sauces were separated into three groups as sauces based on Sauvignon blanc and Riesling had similar volatile profiles and formed one group. The Chardonnay wine sauce was characterized by higher concentrations of the volatile components clustered together to form the group labeled A. Although Chardonnay was the wine containing the highest concentration of ethanol (volatile no. 9), the highest concentration of this compound in the sauces was detected in the Blend sauce. The sauces based on Sauvignon blanc and Riesling were characterized by lower concentrations of volatile components compared to the two other wine sauce types.

FIGURE 2

For the sauces based on wine reductions (see Figure 3) the tendency was clear. The sauces based on Chardonnay reductions were distinctly different from the three other types of reduction sauces. The Chardonnay reduction sauce was characterized by higher concentrations of numerous volatile components compared to the other reduction sauce types. Many of these volatiles were the same as the compounds observed in the A group in the wine sauce PCA plot, Figure 2. PC1 (66%) separated the Chardonnay reduction sauce from the other sauces. The three other types of reduction sauces had much more similar volatile profiles compared to the Chardonnay R sauce, although smaller differences could be detected. Contrary to the case of the wine sauces, the Blend R and Riesling R sauces had the most similar volatile profiles.

FIGURE 3

Both groups labeled A in Figure 2 and Figure 3 contained several shared compounds: 1, 4, 5, 10, 17, 19, 27, 29, 32, 40, 42 and 44, and these volatiles were present in higher concentration in the Chardonnay wine and reduction sauces. These volatiles could therefore originate from the Chardonnay's distinct vinification process; oak maturation, malo-lactic fermentation (MLF) and bâtonnage, as the other ingredients in the sauces as well as the preparation procedure were the same for all sauces. Oak maturation would normally be related to higher contents of lactones, whereas MLF is related to the content of ethyl lactate and diacetyl. However, some of these compounds were not present in the Chardonnay wine and/or in the wine reduction. It therefore seems that some of the volatiles were formed by contact of the Chardonnay wine and wine reduction with the other sauce ingredients during the sauce-making process. The A groups contained therefore compounds both originating from the wine or wine reduction and the sauce-making processes.

The ketone 2-pentanone (12) was present in all the wine sauces, but in none of the wines. It was found in very low amounts in raw egg yolk compared to the wine sauces and it is therefore likely that the compound was produced in the wine sauces during sauce making. The comparison of wine versus reduction sauces also revealed that some volatiles appeared exclusively in the reduction sauces, without being detected in the wine sauces. These volatiles were compound 24 in the Chardonnay R sauce, volatiles 45 and 50 in the Blend R sauce, compound 53 in the Riesling R sauce and 37 and 53 in the Sauvignon blanc sauce. Compounds 24 and 45 are typical lipid oxidation products.

Several of the volatiles found in the wine sauces were observed in lower concentrations in the reduction sauces, or could not be detected at all. Other volatiles increased in concentration in the reduction sauces. Table 2 illustrates these changes in compound concentration and composition between wine and reduction sauces. The results show that numerous similar changes to the volatile profiles can be observed when comparing the four sauce systems (made with either wine or wine reduction based on Chardonnay, Blend, Riesling and Sauvignon blanc). Some compounds were present in all the wine sauces, but not present in detectable concentrations in any of the reduction sauces; 11, 12, 15, 16, 21, 28 and 33. The majority of these compounds are esters. Esters are volatile, but may also be degraded by hydrolysis in an acidic solution. All of these volatiles, except number 12 (2-pentanone), were detected in the volatile analysis of the wines (Rognså et al., Forthcoming 2017), but they were absent or only observed in very low concentrations (compared to the wines) in the wine reductions. The absence of these volatiles in the wine reduction sauces is therefore thought to be a result of the wine reduction process. As seen in Table 2, many of the shifts in volatile concentration (increase/decrease in concentration or absence) between wine sauces and wine reduction sauce were also observed when comparing the wines to their respective wine reductions (labeled with an * in Table 2) (Rognså et al., Forthcoming 2017). These observations support the hypothesis that the volatile profile of the aqueous phase directly influences the volatile profile of hollandaise sauce. However, it is clear that the other ingredients in the sauce, butter and egg yolks, together with the sauce production process also contribute to the volatile profile of the sauces and influences the volatiles' distribution in the sauce phases.

Numerous compounds detected in the volatile analysis of the wines and wine reductions (Rognså et al., Forthcoming 2017) were not identified in any of the sauces, such as propyl acetate, methyl butanoate, butyl acetate, myrcene, pentyl acetate, beta-ocimene, 2-octanone, octanal, 1-hydroxy-2-propanone, cis-3-hexenyl acetate, 2-nonanone, nonanal, 2-octenal, ethyl octanoate, neroloxide, ethyl sorbate isomer 1, ethyl sorbate isomer 2, trans-2-nonenal, isobutyric acid, 2-undecanone, ethyl decanoate, ethyl-9-decenoate, 2(5H)-furanone and heptanoic acid. An explanation for this observation may be that the larger compounds had affinity to the lipid phase of the emulsion. They were therefore retained in the sauces and could not be detected by the analysis of volatiles. The smaller acetate esters, on the other hand, are water soluble, but highly volatile, and may have been lost from the sauce through evaporation.

When comparing volatile profiles of wines and reductions to their respective sauces, most volatiles had lower peak areas (varying with different factors) in the sauces (results not shown). This observation was unsurprising, since the aqueous phase only constituted approximately 14 percent of the sauces' total ingredient weight and because of the affinity of volatiles to the lipid phase of the system. However, some volatiles had higher peak areas in the sauces compared to the wine or wine reduction used in the sauce, which underlines the involvement of other ingredients and the process in the construction of the product aroma.

TABLE 2

Results from the volatile analysis showed numerous differences in the volatile profiles of the wine sauces compared to the reduction sauces. These differences were both caused by the changes in volatile profile originating from the reducing process and by the sauce-making process (probably a combination of ingredient mixing and heating). Patterns were observed when comparing the changes in the volatile profile between the four wine and reduction sauce pairs. The volatile analysis showed that the largest differences in volatile profile were observed between the wine sauces and the wine reduction sauces, rather than between sauces in the two groups. However, the sauces based on Chardonnay wine and reduction had distinctive volatile profiles compared to the other sauces. Based on this analytical technique it is impossible to predict the influences of the complex volatile differences between sauces on aroma and flavor perception. In the following paragraph, results from the sensory analysis will provide information about this.

3.3 Descriptive sensory analysis

Descriptive sensory analysis of the sauces was performed to evaluate their perceptual differences. A list of 29 descriptors for appearance, texture, odors and flavors was used for the evaluation (Table 3). When comparing the sauces within each of the groups separately, the wine and the reduction sauces respectively, the results showed only a few significant differences (Table 3).

TABLE 3

The wine sauces were significantly different with respect to six sensory properties (cf. Table 3 and Figure 4). Most of these properties were taste related: «bitterness», «astringency», «pungency» and «aftertaste». In this context, it is noteworthy that bitterness was the only significantly different *basic taste property* in the sauces, as the wines contained important concentration differences of residual sugar and acids (evaluated both instrumentally and by sensory analysis (Rognså et al., Forthcoming 2017)). Wood was the only aroma-related attribute («wood» (o) and «wood» (f)) being significantly different between the wine based sauces. The oaked Chardonnay wine apparently transferred some of its oaky flavors to the sauce.

FIGURE 4

No significant differences were observed between the wine reduction sauces for sweetness, sourness and bitterness, which was somewhat surprising because of the larger basic taste differences in the reductions compared to the wines (Rognså et al., Forthcoming 2017). The butter (fat) therefore appears not only to have decreased the aroma release from the sauces, but it also disguised taste differences. Although oaked aromas were conserved during the reduction process (Rognså et al., Forthcoming 2017), no significant differences for wood attributes were seen in the reduction sauces.

Certain attributes were introduced in the sensory profiling of the wine reductions to evaluate specific properties of wine reduction flavor compared to their wine counterparts (Rognså et al., Forthcoming 2017). Some of these descriptors were also used to evaluate the sauces; «cooked (f)», «forest (f)» and «fermented grains (f)». No significant differences were observed between the sauces for these attributes, which means that some typical reduction flavors were well masked in the butter sauces.

The sauces made with wine and wine reductions were also compared to each other (Table 3 and Figure 5). When the two groups were compared, significant differences were observed for 17 descriptors. The largest differences between the two groups were observed along PC-1 (88%) in Figure 5 and represented alcohol, aroma, flavor, textural and color differences. The wine reduction sauces had stronger butter and egg aromas and flavors than the wine sauces, while wine-based sauces scored higher on dried fruit aromas (odor and flavor) in addition to alcohol odor. The dried fruit aromas of the wine sauces were believed to be caused by association to the ethanol aroma present in the wine sauces, as panelists commented that these sauces had «rum-raisin», «sweet» and «essence-like» aromas. These sauces had clear alcohol aromas compared to the reduction sauces. If one wants to use unreduced wine in food, it is therefore recommended to give the wine a quick boil unless the product is meant to simmer for a while, to reduce alcohol content and the «boozy» aroma. Several panelists commented that the wine reduction sauces had fresh «sponge cake-like» aromas. According to the results presented in Figure 5, the sauce based on the Blend wine was the wine sauce resembling the reduction sauces the most.

When comparing the wine and reduction sauces their perceived intensity of basic tastes were of special interest. The two sauce groups were different regarding bitterness and sourness, but not all differences were significant when comparing the sauce pairs (wine versus corresponding reduction sauce). The reduction sauces were in general perceived more sour than the wine sauces, but the wine sauces scored the highest on bitterness. All sauces were evaluated very similarly in sweetness. No significant differences were observed regarding saltiness, which is consistent with sauces being added the same amount of salt.

FIGURE 5

The sensory panel evaluated the two groups of products (wine sauces and reduction sauces) differently regarding their physical appearance and texture; color intensity, whiteness and viscosity. The wine sauces were evaluated paler, whiter and more viscous than the wine reduction sauces. The working hypothesis was that the alcohol content of the wine was responsible for this effect. The sensory analysis results showed that increasing alcohol content of the wine was correlated with high sauce viscosity scores (Table 4). From these results, it was also clear that the sauce based on the Riesling reduction was more viscous than the other reduction sauces. As the reductions did not contain high concentrations of ethanol due to the production process, the increased viscosity of the Riesling R sauce was caused by something else. The concentration of acids in this wine/reduction may be the explanation, as acids influence the degree of protein denaturation, which in turn may affect the sauce consistency.

TABLE 4

3.4 Texture analysis

Texture analysis and dry matter measurements were performed to further investigate the observations made by the sensory panel regarding the texture differences in wine versus reduction sauces.

Firstly, the aqueous content of the sauces was evaluated. As ethanol is more volatile than water due to a lower boiling point, evaporation of ethanol during sauce making could result in different water phase percentages between the two sauce groups. Results (Table 5) showed that this effect was not significant (P=0.051 at 95 percent level).

TABLE 5

Texture analysis was then performed. This measurement evaluated the sauces with respect to the following properties: Firmness (the maximum force during compression applied to sample (g)), consistency (the area under the applied force curve during compression (g.s)), cohesiveness (the maximum force applied to withdraw the probe from the sample (g)) and index of viscosity (the area under the withdrawal force curve (g.s)). Although sauces were kept in a heating cabinet (55°C) between each texture analysis, the temperature dropped many degrees (7.7 °C ± 0.7 for the wine reduction sauces and 5.4 °C ± 0.4 for the wine sauces in average) from prior to the first to prior to the third analysis, due to handling and resting. Because butter sauce viscosity is largely dependent of temperature, it was concluded that only the first analysis of the two batches of each product should be included in the result analysis. In Table 6 results are given as averages for the wine based sauces and wine reduction sauces grouped together respectively.

TABLE 6

Results (Table 6) showed that all properties firmness, consistency, cohesiveness and index of viscosity were significantly different between wine and wine reduction sauces. The wine sauces gave higher values for all properties, which means that more force had to be applied to push the probe into and withdraw it from the sauce, confirming the increased viscosity of these sauces. These results confirmed the sensory analysis viscosity results.

An analysis of each product for itself established that only the Sauvignon blanc and Chardonnay wine sauces were significantly different from the corresponding wine reduction sauces (Table 7). It seems therefore it was necessary to have a rather high alcohol concentration in the wine before the ethanol effect on egg yolk proteins was distinguishable from other denaturation factors (acids, salt, mechanical and heat treatments during sauce production). For the Riesling wine and reduction sauces, only one parameter (cohesiveness) was significantly different. The Riesling wine had the lowest wine pH, and the pH of the reduction was even lower, and also this time it was the lowest of the wine reductions (Rognså et al., Forthcoming 2017). The high acidity of both wine and reduction may be the reason why it was not possible to observe texture differences between the Riesling and Riesling R sauces.

TABLE 7

3.5 Microscopy

Based on the observation of textural differences between the wine and wine reduction sauces, the sauces containing the Chardonnay wine and its corresponding reduction were submitted to microscopy evaluation. As the presence of ethanol in the wines was believed to be responsible for this effect, the Chardonnay wine was selected for the analysis as this wine had the highest ethanol content (14.8% v.v). The autofluorescence micrographs (Figure 6) of the sauces show large differences ascribed increased protein denaturation (white areas in the micrographs). Although the wine reduction was more acidic than the wine (measured by pH), due to water evaporation, this analysis showed the important influence of ethanol in the denaturation of egg yolk proteins, which resulted in more viscous and elastic sauces.

FIGURE 6

4 Discussion

Chefs today report that they prefer dry wines with «good acidity» for reductions intended for hollandaise and béarnaise sauces. The changes to the wines induced by the reduction process have recently been studied (Rognså et al., Forthcoming 2017). This study showed that the volatile profile of wines is significantly altered during reduction. The evaporation of numerous volatile components (among others many esters responsible for fruity flavors) results in a convergence of the aroma when comparing wine reductions made from different wines. This reformulation of the volatile profile also leads to perception of new flavors, not being present in the wines. While the wines' original aroma differences became smaller during reduction, the opposite was true for the basic taste modalities. Although the wines contained different concentrations of acids and residual sugar, the wine reductions were assessed more sour and less sweet compared to the wines. This was also true for the Blend, in which the residual sugar concentration far exceeded the total acidity concentration (by a factor of approximately 7.5). These results showed that there are several other factors controlling perceived intensity of basic tastes other than their concentration, a phenomenon known as taste-taste interactions (Stevenson, 2009).

The central question in the present study has been how the flavor differences of the previously studied wines and wine reductions influence the flavor of hollandaise sauce. The results showed that although the aqueous phase only constituted approximately 14 percent of the sauce weight, the composition of the phase affected volatile profile, flavor, texture and appearance in the sauce. When comparing the wine sauces, only a few descriptors were assessed significantly different, which means that the many and large differences (in aroma, flavor and basic tastes) between the table wines were disguised in the sauces. The only aroma-related descriptor which was assessed significantly different between the wine sauces was «wood». Of the basic taste modalities, only bitterness varied significantly between the wine sauce. The most surprising results were that the sauces were not significantly different regarding sourness nor sweetness, although the wines were quite different with respect to these properties (Rognså et al., Forthcoming 2017).

None of the sensory descriptors were assessed significantly different for the wine reduction sauces. This was an even greater surprise compared to the wine sauces, as the reductions were more concentrated and more different with respect to basic taste properties than the wines (Rognså et al., Forthcoming 2017). These results show that basic taste properties are well masked in a product such as hollandaise sauce. There may be several explanations for this effect; either the total concentrations of sugars and acids were too low to produce a veritable effect (e.g. the amount of the aqueous phase was too low compared to the total sauce weight), or the large portion of fat may have a mouth-coating effect, which is known to reduce the perception of sweetness and acidity (Valentová and Pokorný, 1998, Lynch et al., 1993).

In contrast to the separate evaluations of the sensory data, the comparison of all sauces yielded numerous significant results, which separated the sauces into the two groups. This means that relatively large variations in the composition of the aqueous phase of a hollandaise sauce are necessary to yield perceptible sauce differences. No significant differences in sweetness were observed between the sauces, but the Riesling reduction sauce was significantly sourer than the wine sauces in addition to the Chardonnay reduction sauce. The concentrating effect caused by the reduction process, tilted the perceived intensities of sourness and sweetness and led to all the wine reductions being perceived more sour and less sweet. All wine reduction sauces were perceived sourer than the wine sauces, corresponding with the findings in Rognså et al.

(Forthcoming 2017). In addition, all the reduction sauces were perceived less sweet than the wine sauces, except for the Blend reduction sauce, which were assessed slightly (non-significantly) sweeter than the wine sauce. The Blend reduction, on the other hand, was assessed less sweet than the wine.

The wine and wine reduction sauces were significantly different regarding texture and appearance, which was mainly caused by the denaturation of egg yolk proteins by the ethanol in the wines. Although the texture of the wine sauces (higher viscosity) was evaluated positively by the chefs, the ethanol-related odors and flavors should be limited in hollandaise sauce, as they represent an unfamiliar element in a savory product. However, they may not result in negative associations in sweet products such as dessert sabayons (French, called zabaglione in Italian). The effect of the ethanol on egg yolk proteins is probably used as an advantage in the preparation of such desserts. The sweet sabayon is a heat-treated foam of egg yolks, sugar and wine or spirits. The ethanol content of the wine used in sweet sabayons can range from Moscato d'Asti (minimum 5.5 % ethanol) to fortified wines such as Marsala (up to 20 % ethanol), and even liqueurs such as rum (above 40 % ethanol) or Grand Marnier (40 % ethanol). The wine or liqueur types mentioned above vary in sugar content, which may also influence textural parameters. The influence of ethanol on the functional properties of egg proteins in sabayons seems therefore to be of utmost importance for this product's texture.

It is believed that the ethanol content of the wine sauces also influenced the assessment of flavor attributes (aftertaste, astringent, pungent and dried fruit), which contributed to the wine sauces being significantly different from the wine reduction sauces. In addition, wine sauces were given higher bitterness scores compared to the corresponding reduction sauces, which were unexpected results. The bitterness of the sauces may have been influenced by of the ethanol content of the wines.

The volatile analysis of the sauces showed that the Chardonnay sauces (both wine and reduction based) had different properties than the others, but the seemingly large differences in the volatile analysis results were not observed in the sensory results, although the Chardonnay wine sauce was given the highest «wood» (o and f) scores. The previous study showed that some of the oak/maturation/MLF aromas were conserved during reduction of the wine (Rognså et al., Forthcoming 2017), but all the wine sauces were given higher wood (o and f) scores than the Chardonnay reduction sauce. Volatile analysis showed that the Chardonnay sauces (both wine and reduction based) had the most complex volatile profiles, but this complexity was not detected by the sensory analysis. Based on these results, one can suggest that the perceived flavor of high-fat products, such as hollandaise sauce, does not justify the use of expensive and complex wines, as the wine's flavor complexity is not likely to be expressed in the final product. However, by using additional descriptors in the sensory analysis, any higher flavor complexity in the Chardonnay sauces might have been better assessed. In matrices with lower fat content, wine flavors would probably influence the flavor profile to a higher extent. Oaked wines are not recommended for cooking due to their bitterness (Winbladh and Sandström, 2013), but interestingly, the Chardonnay wine sauce was only evaluated significantly more bitter than the Blend sauce and not bitterer than the Riesling and Sauvignon blanc based sauces.

Deeper yellow colored sauces have previously been rated higher in butter flavors than whiter ones (Rognså et al., 2014), and it was speculated whether this was caused by a psychological effect – the association between yellow color and butter flavor. The same tendency was seen in this study, as reduction sauces were rated higher in butter and egg flavors than the whiter wine sauces. It is believed that the whiteness of the wine sauces was caused by more light scattering, produced by the higher air bubble content (unmeasured results) of these sauces, which is thought to be a result of the ethanol's effect on the sauce texture. On the other hand, we cannot eliminate the possibility that the reduction sauces really had more intense egg and butter flavors than the wine sauces. The volatile analysis of the sauces showed that all reduction sauces contained at least double the concentration of diacetyl compared to the wine sauces, and diacetyl is known to be a key odor compound in butter (Schieberle et al., 1993). However, the volatile results were unclear regarding other butter aroma compounds. Assessment of these sauces while obscuring the color have to be performed in order to evaluate whether the wine reduction sauces really had stronger butter and egg flavors compared to the wine sauces. Until then, the cross-modal interaction between seeing a yellow sauce color and perceiving butter and egg flavors more intensely cannot be ignored.

This work has evaluated the culinary traditions and current practice regarding hollandaise sauce preparation, and found that important changes in ingredient composition has taken place during time. The selection of the aqueous phase for hollandaise sauce represents therefore a historic evolution. Vinegar reductions were commonly used in hollandaise sauce for a long period of time (La Varenne, 1651, Beeton, 1861, Peterson, 2008), but today reductions based on white wine is the prevailing choice among chefs. In response to the questionnaire, chefs answered that they preferred to use dry wines with marked acidity in butter sauces. Based on the sensory analysis results, the wine or wine reduction may contain relatively high levels of both sugars and acids before it is perceived in the corresponding sauce. These results show that wine type and reduction degree have relative small effects on the perception of basic taste properties in sauces, and chefs may therefore use fairly sweet table wines without it being perceptible in the final product. This is in contrast to common practice among chefs. Although the reduction sauces were sourer than the wine sauces, the effect was so small that chefs will have to add more acidity by means of vinegar or lemon juice in order to obtain the desired sourness and freshness in hollandaise sauce, which may explain the practice of flavoring finished butter sauces with lemon juice. As sweetness and sourness easily can be altered in the sauce by addition of pure compounds, the chefs should therefore rather consider the other qualities of the wine when selecting a wine for the use in food.

Results from the volatile analysis showed that many aroma compounds in the wines and wine reductions were not found in their corresponding sauces, which may indicate retention of the volatiles in the oil-phase of the emulsion. The flavor of a specific wine or wine reduction may therefore be expressed very differently in a sauce compared to on its own, due to altered flavor release from the new matrix (the sauce). The fat content is therefore a key factor to consider when selecting the other ingredients in cooking. In addition, several volatiles present in the wine sauces were not found in the reduction sauces, and were related to the changes in volatile profile induced by the reduction process. However, the volatile analysis of the sauces also showed that numerous volatiles were present in higher concentrations in the wine reduction sauces compared to the wine sauces. Due to all these differences, the volatile profiles of wine-based and reduction-based sauces were quite distinct.

This study has shown the need for further studies into the many modulating effects of fat, both in relation to aroma and basic tastes. The important disguising effects of the basic taste properties were somewhat surprising, and is a property deserving further attention, as it seems that the fat influenced the perception of the basic taste modalities differenty. Knowledge about such questions may be gained by performing studies where model sauces containing different amounts of fat are added successivly higher concentrations of aromas and tastants and by assessing the response by a sensory panel. These disguising effects of fat is probably highly dependent on the fat concentration in a product, which may suggests that wine selection in relation to cooking is more important for products containing less fat or higher amount of wine compared to the other ingredients than the ratios used in hollandaise sauce. This may also be true for other richly flavored and rather expensive ingredients such as stocks. More research is also neeeded to fully understand the perception of sweetness and sourness of dilute and mixed solutions of acids and sugars, here represented by the wines and wine reductions. The perception of basic tastes in such systems is an example of complex taste-taste interactions. This study may also have detected a vision-taste interaction in the evaluation of butter and egg flavors of the deeper yellow sauces. These topics are examples of information which may be highly relevant for the food industry, as they provide knowledge about product composition versus perceived flavor.

5 Conclusion

From this study one can conclude that different wine types result in quite similarly flavored butter sauces, as very few significant differences were observed between the wine-based sauces in the sensory analysis. None of the wine reduction sauces were significantly different from each other according to the sensory results. The degree of reduction is therefore more important for sauce flavor than the wine type, as there were several significant perceptual differences between the wine and the reduction sauces. This suggests that the ingredients included in the water phase of a butter sauce *do* influence sauce flavor and texture, and composition therefore matters. Therefore, the many different water phase alternatives for hollandaise sauce found in the culinary literature will probably result in perceivable differences.

Only minor basic taste differences were experienced in the sensory analysis of the wine and reduction sauces, although the wines contained quite different concentrations of sugars and acids. In a matrix such as hollandaise sauce, this effect was attributed the high amount of milkfat. However, the minor taste differences may also be related to the limited amount of the aqueous phase (14% of total weight) compared to the total ingredient weight. These results may make it more appropriate to use leftover wines in the production of wine reductions intended for butter sauces in restaurant kitchen, as the study showed that it was hard to detect wine–specific flavor differences. In addition, as the observed differences were relatively small, it is not necessary to use expensive wines in butter sauces, as their complex aromas most likely will not be expressed in the sauce. In this study, lemon juice was not added to the sauces before serving, which most likely would have made any flavor differences due to wine choice even smaller. The same conclusion is also valid for other ingredients commonly used in wine reductions, such as vinegar, shallots, pepper and bay leaf.

Although only small differences between sauces were seen in this study, the choice of wine or wine reduction may be of higher importance in recipes and /or products where the fat content is lower or where the amount of wine or reduction is higher. However, this study underlines the complexity and numerous effects on product flavor and texture produced by relatively small alterations in the ingredient composition, making definite predictions impossible.

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Table 1: Sauce preparation procedure step by step.

Sauce preparation procedure	
Time from start	Procedure
0	130 g egg yolks were placed in the bowl. Stirring speed was set a level 4 (stirring continued during the successive steps)
10 sec	120 g water phase was added to the yolks (wine or wine reduction)
1 min	The temperature was set to 80 °C on the machine
2-4 min	Heating period. At the end of this step the temperature in the sabayon was 66-67 °C
4-6 min	The stirring speed was reduced to level 2. 580 g warm butter (55 °C) was added to the sabayon
6-7 min	6 g salt was added to the sauce. Stirring continued
7 min	The finished sauce was transferred to a new bowl to prevent aggregation of the sauce on the warm bowl surface

Table 2: Comparison of the volatile profiles of the wine sauces and the reduction based sauces †.

Nr.	Compound name	Chardonnay	Blend	Riesling	Sauvignon blanc	Contributing ingredients
1	Propanal	96 *	90	77	88	Egg, butter
2	2-Propanone	162 *	117 *	88	105 *	Egg, butter
3	Sulfur dioxide	221	126	619	136	Butter, egg
4	Butanal	110	100	78	96	Egg, butter
5	Ethyl acetate	1 *	1 *	1 *	1 *	Butter, egg
6	2-Butanone	444	276	311	286	Butter, egg
7	2-Methylbutanal	124	92	91	72 *	-
8	3-Methylbutanal	26 *	28 *	24 *	13 *	-
9	Ethanol	52*	25 *	38 *	33 *	Butter, egg
10	Ethyl propanoate	N *	*	*		-
11	Ethyl 2-methylpropanoate	*	*	*	*	-
12	2-pentanone (Q) (MS, RI)					-
13	2,3–Butanedione (diacetyl)	339 *	239	251 *	225 *	Butter
14	α-Pinene	203	129	160 *	170	Butter
15	2-Methylpropyl acetate	*	*	*	*	-
16	Ethyl butanoate	*	*	*	*	-
17	1-Propanol	4 *	2 *	2 *	3 *	-
18	Ethyl 2-methylbutanoate	*	-	*	*	-
19	Hexanal	120	96 *	76	96	Egg, butter
20	2-Methylpropanol	N *		N *	N *	-
21	3-Methylbutyl acetate	*	*			-
22	3-Carene (Q) (MS, RI)	126	97	115	122	Butter
23	2-Heptanone	144	76 *	91 *	81 *	Butter
24	Heptanal		-	-	-	Butter
25	Limonene	102	84 *	94 *	127	Butter, egg
26	3-Methylbutanol	N *		N *	N *	Butter, egg
27	2-Pentylfuran	106	83	51	79	Butter
28	Ethyl hexanoate	*	*	*	*	-
29	o-Cymene	116	170	114	114	-
30	Hexyl acetate	-	*	-	-	-
31	3-Hydroxy-2-butanone (acetoin)	153 *	136	101	152	Butter
32	Ethyl lactate	82 *	30 *	27 *	45 *	-
33	Hexanol		*	*	*	-
34	Acetic acid	157	398	47	513	Butter, egg
35	2-Furancarboxaldehyde (furfural)	25 *	292 *	130 *	99	-
36	Benzaldehyde	91 *	84	83	43 *	Egg, butter
37	Propanoic acid	48 *	-	-		-
38	Butanoic acid	132	96 *	66 *	278	Butter, egg
39	γ-Butyrolactone	153 *	224 *	128 *	216 *	Butter
40	2-Furanmethanol	105	- *	- *	- *	-
41	Acetophenone	69	113	112	100	Butter, egg
42	Ethyl benzoate	109	-	-	-	Egg, butter
43	Pentanoic acid		- *	-	- *	-
44	Diethyl succinate	12 *	-			-
45	trans-2-Dodecenal	-		- *	- *	-
46	γ-Heptalactone	*	-	- *	- *	-

47	Hexanoic acid	105	117	62	143	Butter, egg
48	Benzeneethanol	116 *	123 *	77	130 *	-
49	γ-Octalactone		-	-	-	-
50	δ-Octalactone (Q) (MS, RI)			192	-	Butter
51	Phenol	116	134	89 *	83 *	Butter, egg
52	γ-Nonalactone	*	-	-	-	-
53	Octanoic acid	69 *	110			Butter, egg

† Values are given as percentages, showing the relative concentration difference of each detected volatile in the wine reduction sauce compared to the wine-based sauce. Numbers above 100 signify a higher concentration of the compound in the reduction sauce compared to the wine sauce, and vice versa, numbers smaller than 100, a lower concentration of a volatile in the reduction sauce. N refers to percentages between 0 and 1, while «-» means that the compound could neither be detected in the wine nor in the reduction sauce. Cell colors: light grey are compounds present in higher concentrations in the reduction sauce compared to the wine sauce, dark grey are compounds detected in the reduction sauces but not in the wine sauces and black are volatiles present in the wine sauces but not detected in the reduction sauces. The asterisk (*) symbolizes similar behavior in volatile concentration (increase, decrease or absence) between the wine and reduction sauces as between the wine and reduction (related to the results from Rognså et al. (Forthcoming 2017)). The column «Contributing ingredients» lists the ingredients (clarified butter or raw egg yolk) where the volatile in question was also detected (the ingredient with the highest concentration is listed first). Methods of identification of volatiles are listed in Rognså et al. (Forthcoming 2017). Three compounds were only identified in the sauces. These compounds are marked with (Q), and identification methods for these compounds are listed after compound name («MS» refers to probability matching of mass spectrum with the Wiley database, and «RI» to identification confirmation by comparison with retention indexes from literature).

Table 3: Descriptors used to evaluate the hollandaise sauces made from different wines and wine reductions and statistical analysis of averaged scores †.

Descriptors	Wine sauces				Comparison between the wine sauces. p-values (n=)	Wine reduction sauces				Comparison between the wine reduction sauces. p-values (n=)	Comparison between the wine sauces and wine reduction sauces. p-values	Descriptor definition
	Chardonnay	Riesling	Sauvignon blanc	Blend		Chardonnay	Riesling	Sauvignon blanc	Blend			
Alcohol (o)	6.29 ^{A}	5.12 ^{A}	6.28 ^{A}	4.86 ^{A}	0.058	1.27 ^{B}	1.33 ^{B}	1.34 ^{B}	1.30 ^{B}	0.853	**<0.001**	Aroma of alcohol (ethanol)
Citrus (o)	1.89	1.84	1.91	2.37	0.358	2.23	2.27	2.38	2.42	0.758	0.318	Aroma of lemons and limes
Fruit (o)	2.00	2.59	2.26	2.68	0.283	1.32	2.00	1.59	1.86	0.359	0.056	Aroma of fresh fruits (pears, apricots, peaches, pineapple and passion fruit)
Dried fruit (o)	2.98 ^{A}	2.71 ^{A}	2.89 ^{A}	2.09 ^{AB}	0.165	1.19 ^{B}	1.29 ^{B}	1.18 ^{B}	1.23 ^{B}	0.919	**<0.001**	Aroma of dried and over ripe fruit (prunes, raisins and banana)
Wood (o)	1.98 ^{a}	1.58 ^{ab}	1.48 ^{b}	1.90 ^{ab}	**0.030**	1.20	1.43	1.41	1.23	0.503	0.059	Aroma of wood and oak barrels
Butter (o)	3.66 ^{D}	3.75 ^{CD}	3.73 ^{CD}	4.25 ^{BCD}	0.114	5.72 ^{A}	4.99 ^{ABCD}	5.11 ^{ABC}	5.34 ^{AB}	0.462	**<0.001**	Aroma of fresh butter
Egg (o)	3.69 ^{B}	3.77 ^{B}	3.68 ^{B}	4.05 ^{AB}	0.339	4.77 ^{A}	4.20 ^{AB}	4.25 ^{AB}	4.41 ^{AB}	0.226	**0.020**	Aroma of malt, beer, yeast and sourdough
Sweetness	3.74	3.61	3.53	3.56	0.720	3.44	3.23	3.34	3.73	0.050	0.127	Taste of dilute aqueous solutions of sucrose
Saltiness	5.92	5.90	6.00	5.83	0.960	5.98 ^{a}	6.55 ^{a}	6.50 ^{a}	5.87 ^{a}	**0.048***	0.140	Taste of dilute aqueous salty (NaCl) solutions
Sourness	2.89 ^{B}	3.11 ^{B}	2.88 ^{B}	2.82 ^{B}	0.718	3.26 ^{B}	4.16 ^{A}	3.46 ^{AB}	3.60 ^{AB}	0.061	**0.001**	Taste of dilute aqueous solutions of acids
Bitterness	5.19 $^{a\,A}$	4.38 $^{ab\,AB}$	5.13 $^{a\,A}$	3.72 $^{b\,BC}$	**0.023**	3.09 C	3.17 C	3.32 BC	3.05 C	0.563	**<0.001**	Taste of dilute aqueous solutions of substances such as quinine and caffeine
Citrus (f)	2.18 ^{C}	2.66 ^{BC}	2.40 ^{C}	2.43 ^{C}	0.500	3.28 ^{ABC}	4.02 ^{A}	3.00 ^{ABC}	3.72 ^{AB}	0.127	**0.002**	Flavor of lemons and limes
Green (f)	1.33	1.67	1.49	1.38	0.449	1.32	1.65	1.53	1.77	0.176	0.574	Flavor of green apples, gooseberries, rhubarb and grass
Fruit (f)	1.61	2.17	1.92	1.94	0.251	1.30	1.76	1.32	1.81	0.109	0.065	Flavor of fresh fruits (pears, apricots, peaches, pineapple and passion fruit)
Dried fruit (f)	2.58 ^{A}	2.42 ^{A}	2.55 ^{A}	1.87 ^{AB}	0.068	1.11 ^{B}	1.26 ^{B}	1.13 ^{B}	1.36 ^{B}	0.629	**<0.001**	Flavor of dried and over ripe fruit (prunes, raisins and banana)
Floral (f)	1.46	1.49	1.42	1.43	0.961	1.21	1.27	1.28	1.37	0.566	0.528	Flavor of acacia, linden, hawthorn and thin acacia honey
Spicy (f)	2.21	2.43	2.36	2.03	0.438	1.72	2.16	1.80	1.84	0.378	0.115	Flavor of spices (vanilla, cloves and pepper)
Wood (f)	2.57 $^{a\,A}$	2.06 $^{ab\,AB}$	2.13 $^{ab\,AB}$	1.71 $^{b\,ABC}$	**0.048**	1.14 ^{C}	1.32 ^{BC}	1.42 ^{BC}	1.32 ^{BC}	0.398	**<0.001**	Flavor of wood and oak barrels
Cooked (f)	1.88	1.86	1.85	1.88	**	1.62	1.72	1.76	1.71	0.752	0.141	Flavor of cooked fruits such as apple and pears
Forest (f)	1.42	1.10	1.23	1.26	0.327	1.33	1.28	1.36	1.21	0.246	0.650	Flavor of damp forest floor (wet moss) and mushrooms
Fermented grains (f)	1.63 ^{A}	1.66 ^{A}	1.71 ^{A}	1.74 ^{A}	0.863	1.41 ^{A}	1.08 ^{A}	1.21 ^{A}	1.04 ^{A}	0.244	0.020*	Flavor of malt, beer, yeast and sourdough
Butter (f)	4.14 ^{D}	4.42 ^{CD}	4.15 ^{D}	4.80 ^{BCD}	0.065	6.03 ^{A}	5.54 ^{AB}	5.42 ^{ABC}	5.67 ^{AB}	0.225	**<0.001**	Flavor of fresh butter
Egg (f)	3.93 ^{BC}	4.15 ^{ABC}	3.75 ^{C}	4.28 ^{ABC}	0.116	5.18 ^{A}	4.55 ^{ABC}	4.60 ^{ABC}	4.86 ^{AB}	0.260	**0.003**	Flavor of damp forest floor (wet moss) and mushrooms

Color intensity	6.39 ^{A}	6.59 ^{A}	6.62 ^{A}	6.61 ^{A}	0.599	7.32 ^{A}	7.39 ^{A}	7.20 ^{A}	7.45 ^{A}	0.882	0.017*	Flavor of malt, beer, yeast and sourdough
Whiteness	3.72 ^{A}	3.68 ^{AB}	3.56 ^{AB}	3.30 ^{AB}	0.053	2.68 ^{AB}	2.78 ^{B}	2.64 ^{AB}	2.62 ^{B}	0.968	**0.008**	Surface color using NCS system as reference
Viscosity	5.66	5.13	5.19	4.24	0.395	3.00	4.21	3.10	2.82	0.308	**0.021**	Mechanical texture attribute related to flow resistance
Pungent	4.59 $^{a\ A}$	3.84 $^{a\ AB}$	4.45 $^{a\ A}$	2.78 $^{b\ BC}$	**<0.001**	2.27 ^{C}	3.00 ^{BC}	2.48 ^{C}	2.45 ^{C}	0.139	**<0.001**	Sharp and pricking feeling in the mouth
Astringent	4.14 $^{a\ A}$	3.60 $^{ab\ AB}$	4.13 $^{a\ A}$	3.09 $^{b\ AB}$	**0.004**	2.66 ^{B}	3.54 ^{AB}	3.14 ^{AB}	2.88 ^{B}	0.198	**0.002**	Feeling of dryness and contractions in the mouth
Aftertaste	5.87 $^{a\ A}$	5.49 $^{a\ AB}$	5.85 $^{a\ A}$	4.81 $^{b\ BCD}$	**0.002**	4.44 ^{D}	5.30 ^{ABC}	4.90 ^{BCD}	4.55 ^{CD}	0.103	**<0.001**	Flavor intensity of sample still present in the mouth 15 seconds after expect

† P-values are given for three types of comparisons; wine- and wine reduction-based sauces analyzed separately and together. 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. ** Satterthwaite approximation gave negative square sum, hence no calculation of p-value. (o) (odor) represents descriptors evaluated orthonasally, and (f) (flavor) descriptors evaluated retronasally. Minuscule superscript letters represent significant differences when the wine and wine reduction sauces were compared separately and p-values are found in the adjacent columns. Majuscule superscript letters refer to significant differences when all products were compared to each other, and p-values are listed in the column «Comparison between the wine sauces and wine reduction sauces. p-values».

Table 4: Relation between ethanol contents of the wines and sauce viscosity scores obtained by sensory analysis of hollandaise sauces made from different wines and wine reductions †.

Order	Ethanol content (% v.v)	Sauce product	Viscosity score
1	~ 0.5 *	Blend R	2.82 a
2	~ 1.8 *	Chardonnay R	3.00 ab
3	~ 1.7 *	Sauvignon blanc R	3.10 ab
4	~ 0.6 *	Riesling R	4.21 ab
5	8.8	Blend	4.24 ab
6	11.6	Riesling	5.13 ab
7	12.8	Sauvignon blanc	5.19 ab
8	14.8	Chardonnay	5.66 b

† Letters a and b corresponds to statistical significant differences determined by Tukey's test. R stands for reduction. Results are averaged over individual panelists and replicates. The ethanol concentrations of the wines were measured by Foss WineScan (Rognså et al., Forthcoming 2017). * These estimated values of the reductions' alcohol content are calculated based on the measured alcohol content of the wines and the estimated alcohol content of the reductions obtained from the volatile analysis results in (Rognså et al., Forthcoming 2017).

Table 5: Dry matter measurements of wine and wine reduction sauces. The average water phase content in wine sauces was 20.4% (± 0.5) and 20.7%(± 0.5) in wine reduction sauces.

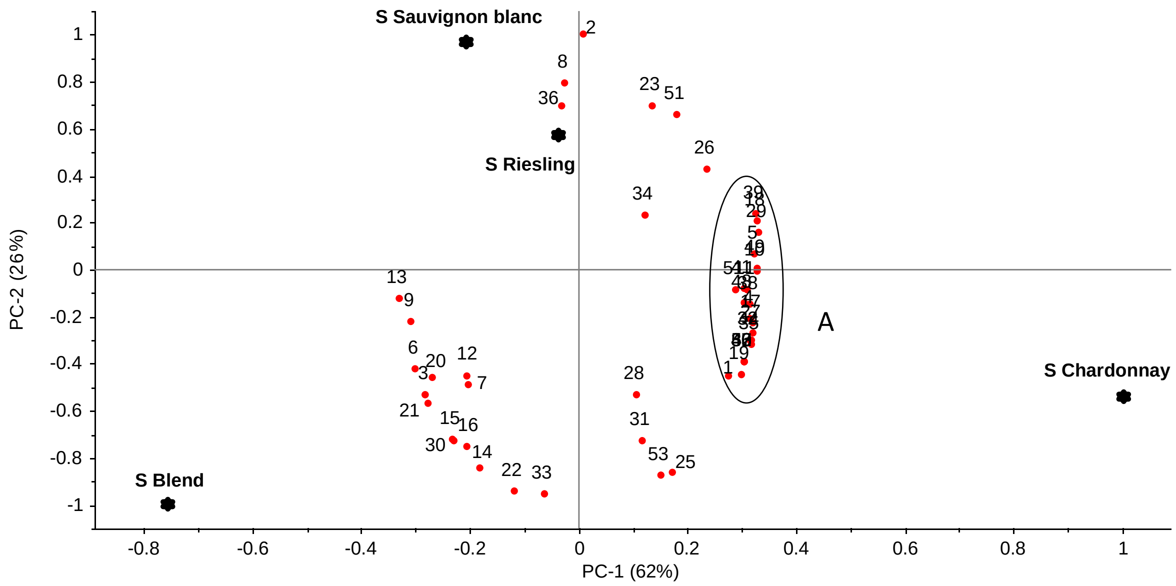
	Ethanol content in the wine (% v.v)	Aqueous phase percentage in **wine** sauces (% weight, ± sd)	Aqueous phase percentage in **wine reduction** sauces (% weight, ± sd)
Chardonnay	14.8	20.3 ± 0.6	20.8 ± 0.5
Sauvignon blanc	12.8	20.7 ± 0.7	20.5 ± 0.4
Riesling	11.6	20.4 ± 0.3	21.2 ± 0.2
Blend	8.8	20.4 ± 0.2	20.7 ± 0.3

Table 6: Texture measurements of the wine and wine reduction sauces. Each wine or reduction sauce was made two times (two batches), and all wine sauces (in total n=8) and all reduction sauces (in total n=8) were then averaged respectively.

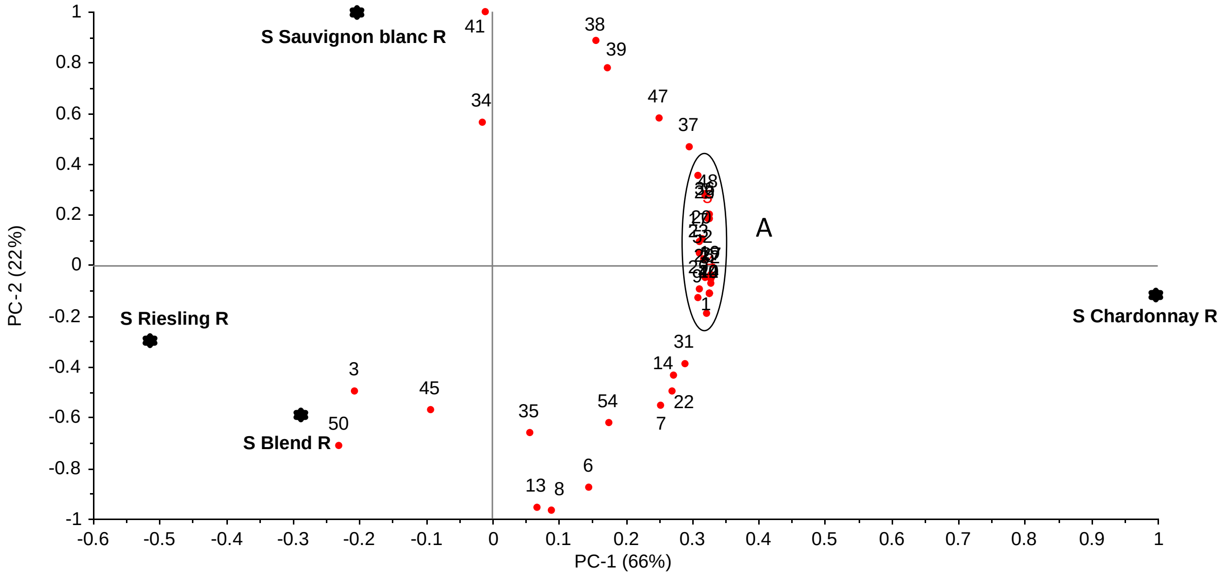
Product	Firmness (g) (± sd)	Consistency (g.s) (± sd)	Cohesiveness (g) (± sd)	Index of viscosity (g.s) (± sd)
Wine sauces (n=8)	73.7 ±10.2	2010.0 ± 299.0	-119.7 ± 27.4	-389.9 ± 114.7
Wine reduction sauces (n=8)	61.5 ± 8.3	1612.4 ± 234.4	-71.2 ±18.0	-231.2 ± 101.4
P-value	0.02	0.01	<0.01	0.01

Table 7: Textural differences between sauces made with wine and the corresponding wine reduction. Results are based on analysis of two batches for each sauce product. Bold P-values confirms significant differences for the textural property at 95 % level.

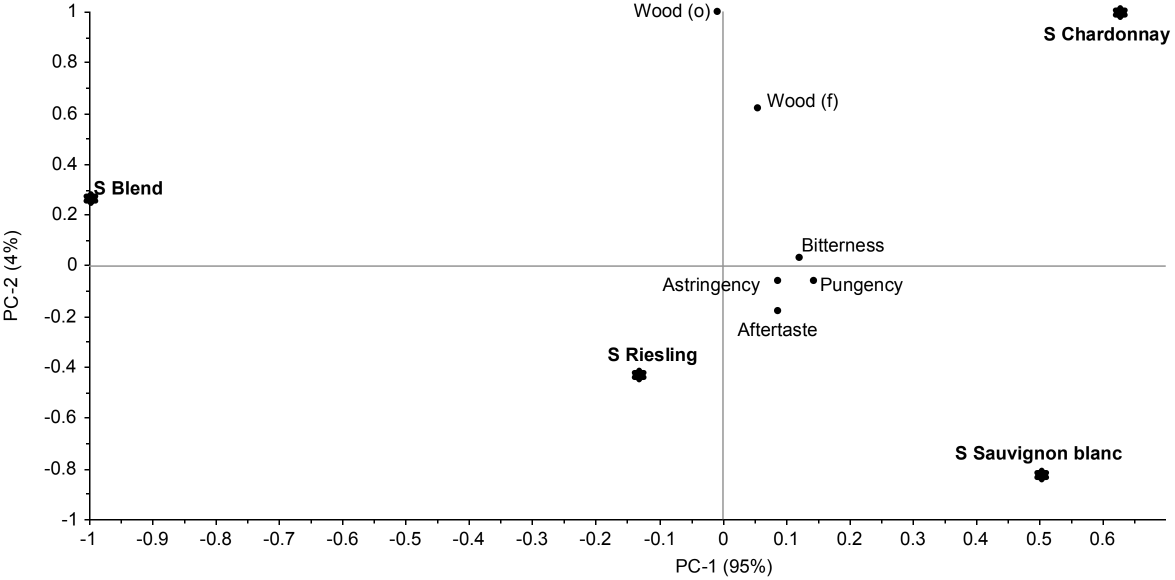
	Product	Firmness	Consistency	Cohesiveness	Index of viscosity
P-values for comparisons of wine and wine reduction sauces	Blend	1.00	1.00	0.40	1.00
	Riesling	0.51	0.25	**< 0.01**	0.33
	Sauvignon blanc	**0.03**	**0.01**	**< 0.01**	**0.03**
	Chardonnay	**0.01**	**< 0.01**	**< 0.01**	**< 0.01**



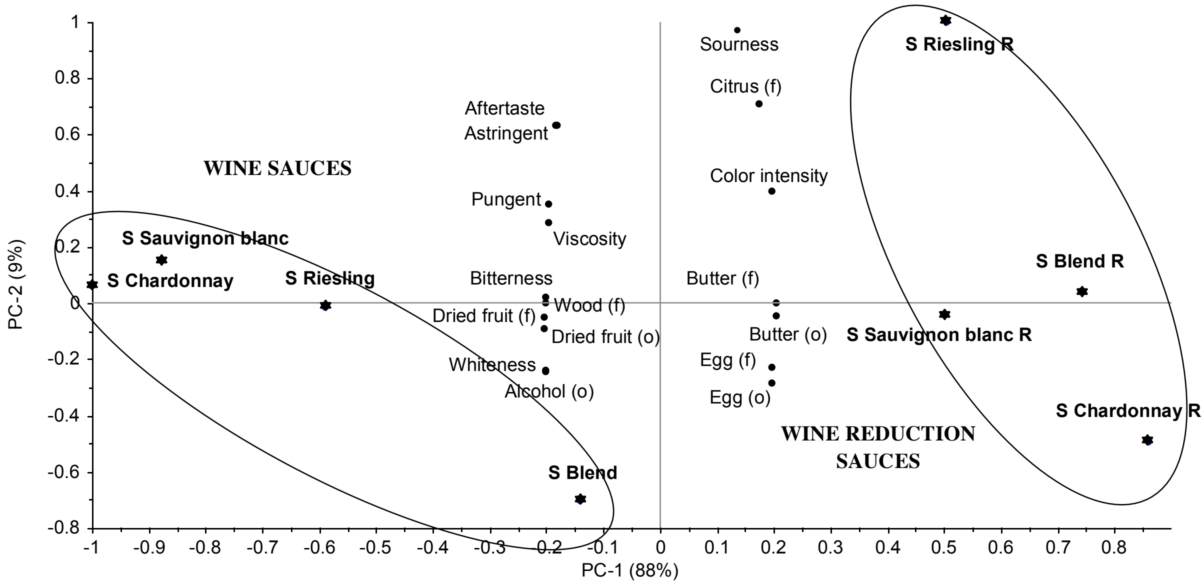
S Sauvignon blanc
S Riesling
S Blend
S Chardonnay
A
PC-1 (62%)
PC-2 (26%)

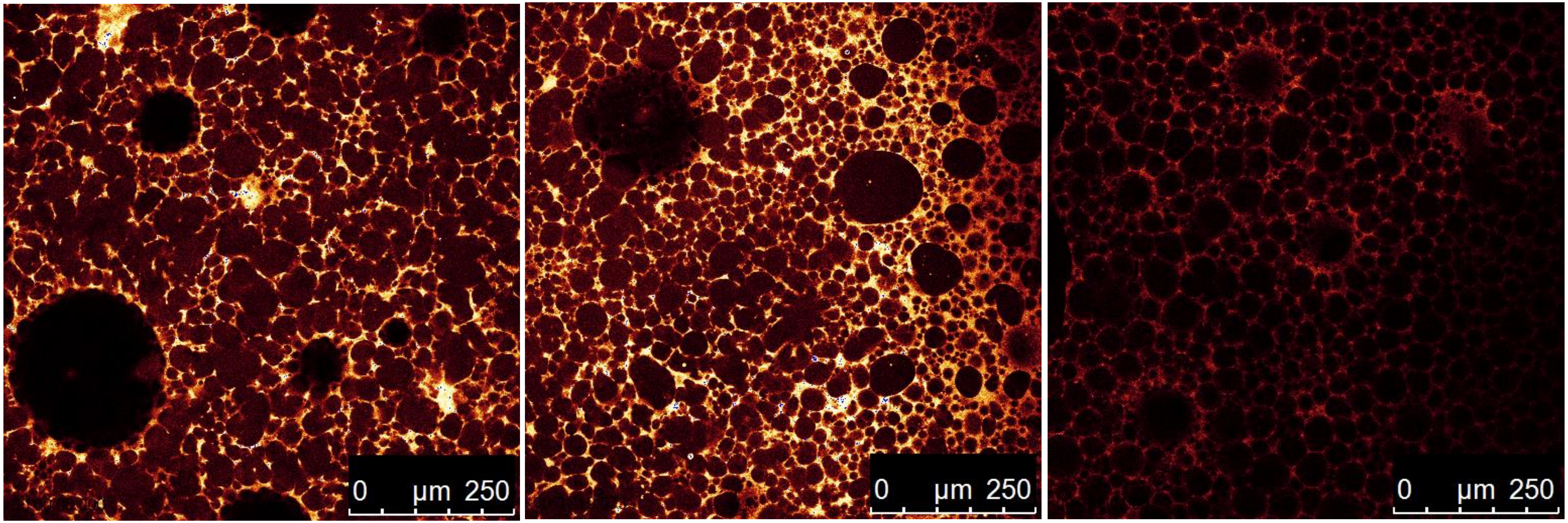


S Sauvignon blanc R
S Riesling R
S Blend R
S Chardonnay R
A
PC-1 (66%)
PC-2 (22%)



Wood (o)
S Chardonnay
Wood (f)
S Blend
Bitterness
Astringency
Pungency
Aftertaste
S Riesling
S Sauvignon blanc
PC-2 (4%)
PC-1 (95%)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.9
-0.7
-0.5
-0.3
-0.1
0.1
0.2
0.3
0.4
0.5
0.6


WINE SAUCES
WINE REDUCTION SAUCES
S Sauvignon blanc
S Chardonnay
S Riesling
S Blend
S Riesling R
S Blend R
S Sauvignon blanc R
S Chardonnay R
Sourness
Citrus (f)
Aftertaste
Astringent
Color intensity
Pungent
Viscosity
Bitterness
Butter (f)
Wood (f)
Dried fruit (f)
Dried fruit (o)
Butter (o)
Whiteness
Egg (f)
Alcohol (o)
Egg (o)
PC-2 (9%)
PC-1 (88%)
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


0 µm 250
0 µm 250
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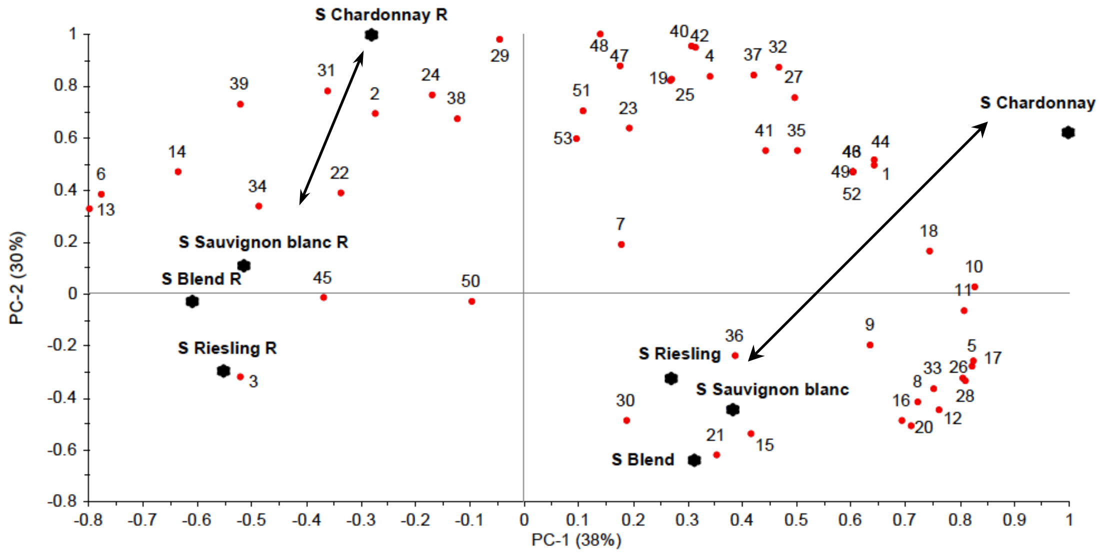
S Chardonnay R
S Chardonnay
S Sauvignon blanc R
S Blend R
S Riesling R
S Riesling
S Sauvignon blanc
S Blend
PC-1 (38%)
PC-2 (30%)

FIGURE CAPTIONS:

Figure 1: Principal component analysis (PCA) bi-plot of volatiles in the wine and wine reduction sauces (standardized). The S in the product names stand for «sauce», and reduction sauces are labeled with an R after the grape variety the wine is made of. 68% of the variance was explained by the two first components. The arrows underline the difference between the Chardonnay sauces and the other sauces in their respective groups. Values for two batches were averaged before plotting. A list of numbers and corresponding compound names is provided in Table 2.

Figure 2: PCA bi-plot of wine-based sauces and their volatiles (standardized). Group A includes the following compounds; 1, 4, 5, 10, 11, 17, 18 19, 27, 29, 32, 35, 37, 39, 40, 41, 42, 43, 44, 46, 47, 48, 49, 50 and 52. A list of numbers and corresponding compound names is provided in Table 2. 88 percent of the variance was explained by the two first components. Values for two batches were averaged before plotting.

Figure 3: PCA bi-plot of wine reduction sauces and their volatiles (standardized). Group A includes the following volatiles; 1, 2, 4, 5, 9, 10, 17, 19, 20, 23, 24, 25, 26, 27, 29, 32, 40, 42, 44 and 51. A list of numbers and corresponding compound names is provided in Table 2. 88 percent of the variance was explained by the two first components. Values for two batches were averaged before plotting.

Figure 4: PCA bi-plot of wine sauce sensory data. Only descriptors representing significant differences are plotted. 99 percent of the variance was explained by the two first components. Values for two batches were averaged before plotting.

Figure 5: Sensory results of the wine and wine reduction sauces presented as PCA bi-plot. Only significant descriptors are plotted. 97 percent of the variance was explained by the two first components. Results were averaged over individual panelists and replicates, and roughly separated the wine based sauces and wine reduction sauces into two groups with different characteristics, visualized by the two ellipses. The «R» identifies the reduction-based sauces.

Figure 6: Confocal Laser Scanning micrographs obtained by recording the autofluorescence of denatured proteins in the aqueous phase of the sauces. All images were taken using the same microscope settings. Therefore, the degree of denaturation is directly proportional to the intensity of the white signal in the images. Pictures to the left and in the middle show two different views of a sauce made with the Chardonnay wine, and the picture to the right a butter sauce made with reduced Chardonnay wine.