Hindawi
Australian Journal of Grape and Wine Research
Volume 2024, Article ID 9843225, 22 pages
https://doi.org/10.1155/2024/9843225

AUSTRALIAN SOCIETY OF VITICULTURE AND OENOLOGY | ASVO

Research Article

The Influence of Prefermentation Skin Contact, Stabulation, and Skin Fermentation on the Aromatic Behaviour and Phenolic Compounds of Important Austrian White Wine Cultivars

Christian Philipp, Phillip Eder, Sezer Sari, Karin Korntheuer, and Reinhard Eder

Federal College and Research Institute for Viticulture and Pomology, Wienerstraße 74, Klosterneuburg 3400, Austria

Correspondence should be addressed to Christian Philipp; christian.philipp@weinobst.at

Received 13 November 2023; Revised 29 February 2024; Accepted 3 April 2024; Published 15 April 2024

Academic Editor: Paul Kilmartin

Many varietal aromas of wine are located in the berry skin. In the present study, we evaluated four important Austrian grape varieties: Grüner Veltliner, Sauvignon Blanc, Traminer, and Pinot Blanc. We assessed whether prefermentation skin contact, fermentation with the skin (only for Grüner Veltliner), and stabulation (lees stirring; only for Sauvignon Blanc, Traminer, and Pinot Blanc) could enhance the varietal aromas of the different grape cultivars. The aim was to intensify the varietal aromas without extracting the undesirable phenols. We performed a detailed analytical characterisation of approximately 100 volatile and phenolic compounds as well as a sensory characterisation. Although mash fermentation significantly increased the spicy aromas of Grüner Veltliner, which are affected by climate change (especially the sesquiterpene rotundone), it markedly decreased the fruitiness and increased the bitterness; therefore, it cannot be recommended for this cultivar. For Sauvignon Blanc, stabulation is a possible option; the varietal aromas (thiols and methoxypyrazines) were increased in the final wines of these variants. For Pinot Blanc and Traminer, prefermentation skin contact yielded the best results: for Traminer, it produced the highest content of monoterpenes (especially z-rose oxide), and for Pinot Blanc, it produced the highest content of ethyl esters. To summarise, stabulation will not completely replace classic skin contact, and mash fermentation is certainly not an alternative for the production of standard Grüner Veltliner wine. However, additional investigations are necessary with regard to other grape varieties, terroirs, and vintages before we can make final recommendations.

1. Introduction

Austria has all the necessary factors to produce world-class wines. Due to the highly complex landscape and varied climatic conditions between the eastern slopes of the Alps, the Danube, Lake Neusiedl, the Carpathian Mountains, and the border regions with Hungary and Slovenia, wine from Austria is extremely diverse [1]. This diversity is also reflected in the varieties. Grüner Veltliner is Austria's most important and significant autochthonous grape variety, with about 14,500 ha of cultivated area (about 32.5% of Austria's total cultivated area of approximately 45,000 ha) [2]. A total of 26 white and 14 red grape varieties are permitted for Austrian land wines (*Landwein*; corresponds to a protected geographical indication) and quality wines (corresponds to a protected designation of origin); moreover, an additional 10 grape varieties can be used for varietal wines [3]. In contrast to many wine-growing countries in the world, this enormous diversity is also reflected in the individual wineries. Briefly, many wineries produce wine from very different grape varieties, which poses a certain oenological challenge. Among a selection of different methods in the cellar, contact with the grape skin (prefermentation skin contact) or contact with particles of the grape skin (stirring of the grape must or so-called stabulation) or fermentation on the skins can intensify the varietal aromas and increase the complexity of the wines. It can bring out varietal differences and promote diversity [4]. There has been extensive

international research since the end of the 1960s [5–7] to recently [8–13] on this complex topic. However, there are very few studies that have dealt with these techniques in the context of different Austrian grape varieties and the influence on varietal aromas and the phenolic profile on wine quality. This article focuses on the effect of prefermentation skin contact, stabulation, and skin fermentation for different grape varieties important for Austria. The grape varieties used for the current experiment were Grüner Veltliner (32.5% of the area under cultivation), Pinot Blanc (4.2% of the area under cultivation, but uniquely represented in all areas), Sauvignon Blanc (3.8% of the area under cultivation, from which it is the most important grape variety in the wine-growing regions of Styria), and Traminer (0.6% of the area under cultivation, but the most important grape variety in the wine-growing village of Klöch) [2].

The berry skin is rich in volatile compounds and aroma precursors, but also in undesirable phenolic compounds [14]. Thus, extraction of these aroma precursors and volatile compounds can play a crucial role in winemaking. However, this is not always the case, so it is important to know which volatile compounds are responsible for the typicity of each wine. It is also important to find the right balance between the extraction of the desirable aroma compounds and the undesirable phenols. The aroma of Grüner Veltliner is characterised by its fruitiness (citrus, grapefruit, green or ripe apple, pear, quince, melon, dried fruit, and baked apple), spiciness, and soil-associated impressions (e.g., mineral, earthy, and loess like). There are very few other white wine varieties that are so often described with the attribute of spicy, peppery notes as Grüner Veltliner. There is even an Austrian term for it: *Pfefferl* is used by the marketing department of the DAC Weinviertel (in Latin: *Districtus Austriae Controllatus* (controlled Austrian designation of origin)) for peppery notes. It certainly characterises the unmistakable character of the wines produced from this grape from the Weinviertel region [15]. While the sesquiterpene rotundone is mainly responsible for this peppery note [15, 16], fruity thiol compounds and esters are likely to play a decisive role in the fruitiness of Grüner Veltliner wines. Austrian Pinot Blanc wines have been very well described [17]. They have attributes such as pear, apple, quince, banana, apricot, caramel, nut, bread, or citrus. These wines are rather delicate, and the aroma is considered neutral. The aroma in neutral wines is created by interactions between the flavours rather than by individual intense aromas (aroma impact compounds) [18]. Aroma substances or aroma substance families (compounds with a synergistic effect) can take on different roles. Thus, there are no varietal aromas, but in various studies markers have been found for the increase in typicity, whereby in principle fermentation aromas such as ethyl esters are important. For example, Philipp et al. [19] showed that a selection of Austrian Pinot Blanc wines had higher ethyl octanoate and isobutyl acetate concentrations than other Austrian white wines. For Sauvignon Blanc, green characteristics, such as green asparagus and green pepper, are enhanced by the presence of methoxypyrazines (MPZ), in particular 2-methoxy-3-isobutylpyrazine (IBMP), while tropical fruit (citrus and passion fruit) and black currant aromas are enhanced by various fruity thiols (e.g., 3-sulfanylhexan-1-ol [3-SH], 3-sulfanylhexyl acetate [3-SHA], and 4-methyl-4-sulfanylpentan-2-one [4-MSP]) [20, 21]. Besides these varietal aromas, other fermentation aromas such as higher alcohols, fatty acids, and esters play a supporting role for the characteristics [22]. Last but not least, Traminer (Gewürztraminer, Red Traminer Traminer, or Yellow Traminer) wines are aromatic and especially known for their distinctive rose flavour. Various monoterpenes and especially cis-rose oxide are responsible for the distinctive bouquet [23]. In summary, the four described grape cultivars have clearly different aroma compounds. We are not aware of any study that has evaluated different forms of skin contact in such diverse grape varieties.

Usually, prolonged contact with the skins could lead to a more effective extraction of terpenes, which results in an increase in varietal aromas and improved wine quality. This relationship was confirmed in the 1980s for monoterpenes (the free and bound forms) [24–26]. Recently, Sochor et al. [27] showed that the content of free and bound monoterpenes in Traminer could be augmented by increasing the maceration time. However, there are no studies that have compared the maceration time with stabulation (lees stirring) in wines.

Stirring the grape must (stabulation) is a possible step in white wine production: with this approach, the existing lees are stirred before sedimentation. This is usually done under cooled conditions, preferably at +2°C. The sediment is stirred for up to 7 days (in extreme cases, up to 2 weeks). The lees are constantly kept in suspension. In oenological practice, an agitator connected to the tank is usually used and stirred several times a day. At the end of the process, the lees are allowed to settle as normal and the must is clarified before being reheated for fermentation. The theoretical effect of stirring is that more aroma substances and precursors are extracted from the lees into the must [11, 28]. Originally developed for making rose wines from Provence [28], this technique is also important in New Zealand, Austria, and France for white wine varieties such as Sauvignon Blanc [29]. This method is said to increase the thiol content in the wine. However, little is known about the actual effect on the varietal aromas of Sauvignon Blanc, Traminer, and Pinot Blanc, and there are few scientific studies on this method. Some winemaker reports are available, but there are almost no peer-reviewed studies.

Mash fermentation (MF) for white wine, or the so-called production of orange wine, is a traditional way of winemaking in Georgia, but due to the attention around natural wines, it is starting to gain importance in other parts of the world. Parallel to this increasing consumer interest in such wines, there has been increased scientific focus on this subject. This method produces white wine with a completely different taste and aroma [30]. Through alcohol extraction, the aromas and phenols are extracted from the grape skins more than through classic skin contact. Thus, it was oenologically possible to increase the rotundone content of Grüner Veltliner wine [12]. This is important because rotundone is apolar and researchers have already shown that normal skin contact

and probably other forms of aqueous extraction are unlikely to significantly increase rotundone levels in wine [31]. For this reason, in the present study, we examined various forms of fermentation on the skins of Grüner Veltliner grapes. However, the question that remains to be answered in the present work is how the aroma and phenolic composition of the wines change as a result of this process.

The aim of this study is to contribute to a better understanding of the extraction of varietal aromas and general fermentation aromas as well as phenols from the grape skin during prefermentation skin contact, stabulation, and fermentation on the skin of the main Austrian varieties Grüner Veltliner, Pinot Blanc, Sauvignon Blanc, and Traminer. We analysed a large number of relevant aromatic substances as well as the sensory characteristics. We then synthesised these data to make recommendations for each wine variety. For Pinot Blanc, Sauvignon Blanc, and Traminer, we compared the classic variant with skin contact and stabulation, whereas for Grüner Veltliner, we compared the classic variant with skin contact and partial as well as complete mash fermentation. The reason for the divergent approach was that rotundone is difficult to extract from grape skins [12, 31]. In addition to these treatment effects, we evaluated the influence of the fermentation temperature on the extraction behaviour during mash fermentation. A lower temperature could lead to the extraction of fewer phenols. We hypothesise that stabulation will intensify the aroma of Sauvignon Blanc, Traminer, and possibly Pinot Blanc compared with the control variant, but at the same time the undesirable phenols will not be extracted to the same extent as prefermentation skin contact. On the other hand, we hypothesise that partial mash fermentation at cooler temperatures with Grüner Veltliner will intensify the spiciness with less phenol extraction than full mash fermentation at high fermentation temperatures.

2. Materials and Methods

2.1. Grape Material. Twenty-five hundred kilograms of Grüner Veltliner, 1500 kg of Pinot Blanc, 1200 kg of Sauvignon Blanc, and 1500 kg of Traminer (a mixture of yellow, red, and Gewürztraminer) grapes from experimental vineyards of the Federal College and Research Centre for Viticulture and Pomology (48°17′44″ N; 16°19′31″ E) in 2019 were harvested by hand in boxes (20–25 kg per box). The grapes were free from rot, sulphitised with 65 mg SO_2 per kilogram (using potassium pyrosulphite (Preiziso, RWA Raiffeisen Ware Austria Aktiengesellschaft, Vienna, Austria)) and cooled overnight at 2°C in the boxes. Table 1 shows the data of the must analyses using Fourier-transform infrared (FT-IR) spectroscopy according to OIV/OENO Resolution 390/2010 (FOSS WineScan FT 120 Reference Manual, Foss, Hamburg, Germany) [32].

2.2. Experimental Plan. Table 2 provides an overview of the tested factors. Table S1 contains the complete list of abbreviations for the individual variants.

2.3. Experimentation

2.3.1. Grüner Veltliner. All trials were carried out in triplicate, including the treatment and fermentation. The Grüner Veltliner grapes were homogenised as much as possible (mixing the small boxes in larger boxes for each variant, depending on the location in the vineyard), processed separately for the individual repetitions, and manually shovelled into the destemmer (Gamma 80 RM Niro standard version, Fuhrmann, Steinebrunn, Austria). The mash for GV C was transferred directly into the press (Hydro press Lancmann VSPIX 120 l (Leonstein, Austria) operated with maximum air pressure of 2 bar, three pressing cycles, with manual fluffing in between) with a bucket. The entire destemming process up to the start of the pressing programme lasted for 20 min. The pressing took about 25 min. Only after the end of the pressing programme was the next trial started. For the GV SC variants, the mash was stored in large boxes covered with plastic foil at 15°C for 12 or 24 h. FMF and PMF took place in 50 l fermentation containers (filled with 35 l of mash) and the variants were not clarified, while GV C and the SC variants were clarified by means of sedimentation overnight at 15°C using pectolytic enzyme (Novoclair Speed, dosage 1.2 g/hl, Novozymes, Warsaw, Poland), and the homogenised blank must was divided into 34-l glass balloons (filled with 30 l of must). For fermentation, the pure culture yeast "Oenoferm Klosterneuburg" (Erbslöh, Geisenheim, Germany) was added at 10 g yeast per 30 l of must or 35 l of mash (85% yield). Rehydration of the yeast was carried out in contrast to the manufacturer's specifications by adding 10 times the must quantity at 38°C and 10 g of Go-Ferm (a yeast nutrient from Lallemand, Montreal, Canada). To support fermentation, 10 g of yeast complex nutrient (Fermaid AT, Lallemand) per 30 l of must or 35 l of mash was added. Fermentation of all variants took place at 15 or 25°C in a controlled environment. The process was monitored daily with a hand-bending oscillator (DMA 35, Anton Paar, Ostfildern-Scharnhausen, Germany). GV PMF was drawn off through a sieve when 50% of the Oechsle degrees had been removed (day 2 for 25°C, day 3 for 15°C). There was no pressing of the mash in this variant. As soon as the measurements with the hand-bending oscillator suggested the end of fermentation, FT-IR spectroscopy was carried out according to OIV/OENO Resolution 390/2010 [32]. If the residual sugar content was less than 1 g/l, then the wines were prefiltered or GV FMF was pressed, as described above, and then filtered. The young wine was removed from the tank, centrifuged (SA1-01-175, Siebtechnik Zentrifugen West, Mülheim an der Ruhr, Germany), prefiltered using a layer filter (PILOT37046, Seitz, Pall/Filtra, Guntramsdorf, Austria) with layers (type 700, Pall/Filtra, Guntramsdorf, Austria), and added to 20 l glass balloons. Young wine was sulphitised with 65 mg/l SO_2 in the form of potassium pyrosulphite (Preziso, RWA Raiffeisen Ware Austria Aktiengesellschaft). The wines were stored at −0.5°C for 3 weeks for tartaric stabilisation and then adjusted to 50 mg/l free SO_2, subjected to sterilisation filtration using a candle filter (CUNO, Fuhr GmbH, Klein-

Table 1: Must analyses of grape material used in this study.

Parameter	Grüner Veltliner	Pinot Blanc	Sauvignon Blanc	Traminer
Sugar content (°Brix)	20.7 ± 0.4	23.7 ± 0.2	21.3 ± 0.1	21.9 ± 0.1
Glucose (g/l)	108.7 ± 1.7	116.7 ± 1.2	107.7 ± 1.0	110.0 ± 1.0
Fructose (g/l)	112.0 ± 1.9	129.2 ± 0.8	112.4 ± 0.7	117.4 ± 0.7
Titratable acidity c.a. tartaric acid (g/l)	6.1 ± 0.6	6.3 ± 0.3	5.3 ± 0.5	4.6 ± 0.3
pH	3.10 ± 0.07	3.41 ± 0.13	3.30 ± 0.06	3.29 ± 0.08
Yeast assimilable nitrogen (mg/l)	162 ± 14	255 ± 10	241 ± 5	223 ± 5

Table 2: Experimental plan and treatment variants.

Cultivar	Classic	Prefermentation skin contact		Stabulation		Mash fermentation		Fermentation temperature
Unit		12 h	24 h	3 days	7 days	Partial	Full	°C
Grüner Veltliner (GV)	x	x				x	x	15/25
Pinot Blanc (PB)	x	x		x	x			15
Sauvignon Blanc (SB)	x	x	x	x	x			15
Traminer (TR)	x	x	x	x	x			15
Abbreviations	C	SC		ST		MF		
Abbreviations	C	SC 12 h	SC 24 h	ST 3D	ST 7 D	PMF	FMF	

x = this variant was carried out on the respective grape variety.

Winterheim bei Meinz, Germany), added to 0.5 l screw-top bottles, labelled, and stored at 4°C until sensory and analytical characterisation (10–12 months after the harvest).

2.3.2. Pinot Blanc, Sauvignon Blanc, and Traminer. All experiments were carried out in triplicate, including the treatment and fermentation. After randomisation, the grape material was crushed, as described above. The SC variants were divided into 50 kg harvest boxes, stored at 15°C for 12 or 24 h, and then pressed, as described above. The C and ST variants were pressed immediately as described for Grüner Veltliner and then clarified at 15°C overnight. The ST variants were cooled to 2°C and stirred three times a day by turning the glass container (34 l). After stabulation for 3 or 7 days, the juice was clarified in the same way as for the C and SC variants. The remaining steps—fermentation at 15°C, filtration, and filling—were the same as used for Grüner Veltliner.

2.4. Chemical and Sensory Profile of the Wines

2.4.1. Analysing the Volatile Profile. A total of 70 volatile compounds—esters, higher alcohols, carboxylic acids, carbonyl compounds, free monoterpenes, rotundone, fruity thiols, and MPZ—were determined in the final wines with six different methods. Three gas chromatograph systems from Agilent Technologies (Santa Clara, CA, USA) were used for the analysis of the different volatile compounds. The first system, consisting of a 6890 N gas chromatograph with a 5975 inert mass selective detector (MSD) and a CTC Analytics autosampler (Zwingen, Switzerland), was equipped with a ZB-Wax plus column (length 60 m, internal diameter 0.25 mm, df 0.25 μm) from Phenomenex (Torrance, CA, USA). It was used to quantify the main aroma substances (higher alcohols, carboxylic acids, carbonyl compounds, and some major ethyl esters; in the milligram per litre range). The second system, consisting of a 7890A gas chromatograph with a 5975C inert MSD with a triple axis detector and a CTC Analytics autosampler (Zwingen), was used to analyse ester compounds (in the microgram per litre range) and free monoterpenes. This system was equipped with a ZB-5MS column (length 60 m, internal diameter 0.25 mm, df 0.25 μm) from Phenomenex. The third system included a gas chromatograph (type 7890 B A) with an injector, controller, and a CTC Analytics autosampler (Zwingen) and a triple quad mass spectrometer (TQMS) detector (7010B GC/MSMS Triple Quad, Agilent Technologies). The system was equipped with a ZB-5MS column (length 60 m, internal diameter 0.25 mm, df 0.25 μm) from Phenomenex to analyse MPZ and rotundone or a Zebron-FFAP capillary column (length 30 m, internal diameter 0.25 mm, df 0.25 μm) from Phenomenex to analyse thiols.

The substances were identified and quantified via calibration with standards. Analytical standards were used for all compounds; calibration was performed against an internal standard (in some cases labelled with deuterium), and the methods were validated. Information on calibration and validation can be found in Tables S2 and S3. The exact protocols of the methods can be found in the publications. All analyses were carried out in duplicate, except for the very complex rotundone and thiol analysis. Here, every fifth sample was repeated. At least one calibration standard and a blank sample were included in each sample series per day as a backup. Briefly, 14 relevant monoterpenes were quantified according to a published method [17] using headspace solid-phase microextraction gas chromatography selective ion monitoring-mass spectrometry (HS-SPME-GC-SIM-MS). Thirty-two ester compounds were determined by a partial stable isotope dilution assay (SIDA)-HS-SPME-GC-SIM-MS [19]. The main aroma compounds, such as relevant higher alcohols, relevant short- and medium-chain carboxylic acids, carbonyl compounds, and some major ester compounds, were quantified by using

a partial SIDA-HS-SPME-GC-MS method [33]. Rotundone analysis is based on a solid phase extraction followed by solid-phase microextraction determined by stable isotope dilution assay with multiple reaction monitoring-triple quad mass spectrometry (SPE-SPME-SIDA-GC-MRM-TQMS) developed by Nauer et al. [15] and refined by Philipp et al. [12]. IBMP was quantified according to a published method [34] with an adaptation regarding quantification using GC-MRM-TQMS instead of gas chromatography-selective ion monitoring-mass spectrometry (GC-SIM-MS) based on the limit of detection and quantification [34]. The transitions were taken from Hjelmeland et al. [35]. Thiols—only 3-SH and 3-SHA—were quantified based on a published protocol [36] using GC-MRM-TQMS.

2.4.2. Phenol Analysis of the Wines. For the phenol analysis, hydroxycinnamic and hydroxybenzoic acids and some monomeric flavonoid phenols were determined by high-pressure liquid chromatography (HPLC, type 1200, Agilent Technologies) using an RP column (type Poroshell 120 SB-C18 2.1 × 150 mm 2.7 μm, Agilent Technologies) and a diode array detector (type DAD SL, 1200 Series, Agilent Technologies) at 280 nm (gallic acid, tyrosol, catechin, procyanidin B1, procyanidin B2, ethyl gallate, and epicatechin) or 320 nm (caftaric acid, caffeic acid, *p*-coumaric acid, and ferulic acid; *c*-coutaric acid, *t*-coutaric acid, and fertaric acid are calculated as caftaric acid). The method was developed by Vrhovsek et al. [37] and most recently adapted by Berghold et al. [38]. The total phenolic content was determined with the Folin–Ciocalteu reagent [39] with an 8453 spectrophotometer (Agilent Technologies) at 765 nm. The content is given in grams per litre, calculated as caffeic acid.

2.4.3. Sensory Analysis of the Wines. The sensory assessment of the samples is intended to provide support for the interpretation of the analytical results. The data were generated by an expert panel and not a descriptively trained panel. Accordingly, all samples of the trial were analysed by using the check-all-that-apply (CATA) method. With this testing method, products are described by using a given vocabulary. The testers taste the samples and use a list of sensory terms to mark all the characteristics that apply to the respective product. After tasting, the number of testers who marked each characteristic is counted. The most frequent terms are the most important for the product description. The advantage of this method is that it is quick and the testers do not have to be trained as in a descriptive panel [40]. The aroma terms used for each grape variety are presented in Table S4.

Before testing, a pooled sample was prepared from three replicates. The samples were given three-digit codes and tasted blind. The wines from each trial were tasted in tandem. The test was carried out with 24 testers (19 men, age range: 21–48 years). The testers were students of the Viticulture, Enology, and Winegrowing course at the University of Natural Resources and Applied Life Sciences, employees of the HBLA Klosterneuburg, or winegrowers. All testers were official, certified wine tasters; were part of the sensory panel for DAC Weinviertel (Grüner Veltliner) wines; stated that they have been part of the panel at various evaluating wine tastings (State Wine Tasting, Austrian Wine Challenge among others); and stated that they regularly drink Austrian Grüner Veltliner, Sauvignon Blanc, Traminer, and Pinot Blanc and know about the typicity of these wines. Therefore, the tasting was conducted by an expert panel. The sensory analysis was carried out in a sensory laboratory accredited according to ISO 17025. The tasting took place simultaneously in January 2020 and was carried out in accordance with the Declaration of Helsinki (1964). The experiments were conducted with the knowledge and consent of the subjects and were approved by the Ethics Committee at the Federal College and Research Institute for Viticulture and Pomology in Klosterneuburg.

2.5. Statistics. The statistical analyses were carried out with XLSTAT (Lumivera, Denver, CO, USA), SPSS Statistics version 26.0 (IBM, Armonk, NY, USA), and Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA). A statistical evaluation of the analysed concentrations of volatile compounds and phenols was carried out for each grape variety, as well as a separate evaluation of the organoleptic results to support the interpretation. Analysis of variance (*F*-test) was used to determine whether the treatment had a significant influence on the component. Due to the large number of dependent variables tested, the results were corrected according to the Benjamin–Hochberg method. If the significance remained after this correction, then the post hoc Tukey B test was used for pairwise comparisons between the variants [41]. For Grüner Veltliner, multivariate analysis (two factors: treatment and temperature) followed by Benjamin–Hochberg correction was used to determine whether the temperature had a significant influence on each compound. Furthermore, the effect of the grape variety (two factors: treatment and grape variety) was evaluated. To simplify the presentation of the results of the numerous substances, a principal component analysis was carried out using XLSTAT; the results are presented with scatter and loading plots. The sensory results were also evaluated with a principal component analysis; a biplot was chosen for visualisation.

3. Results

3.1. Chemical Profile

3.1.1. Sauvignon Blanc. Figure 1 shows the principal component analysis of the volatile and phenolic compounds in the Sauvignon Blanc variants. The three replicates of each experimental variant cluster together and the results indicate a separation of the variants.

Table 3 shows the content of volatile and phenolic compounds and the sum parameters for each variant. The analysed concentrations of each volatile and phenolic compound are included in Table S5. The table indicates the variables that were significantly influenced by the treatment; different letters indicate significant differences between the

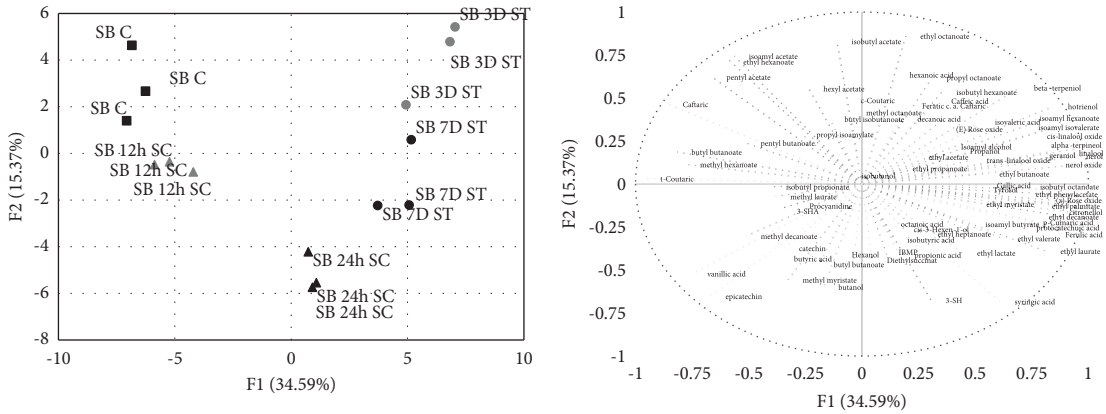

Figure 1: Principal component analysis of Sauvignon Blanc, showing the (a) scatter plot and (b) loading plot. SB C: control; SB 12 h SC: 12 h of prefermentation skin contact; SB 24 h SC: 24 h of prefermentation skin contact; SB 3D ST: 3 days of stabulation; SB 7D ST: 7 days of stabulation.

treatment variants. There were significant differences in MPZ, thiols, esters, free monoterpenes, and phenols, but not in carboxylic acids and higher alcohols.

The aroma of Sauvignon Blanc is essentially characterised by sulphanyl compounds (thiols) and MPZ [20]. Two important sulphanyl compounds are 3-SHA, which was not significantly influenced by the treatment, and 3-SH, which was significantly influenced by the treatment. The 3-SH content was lowest in SB C (522 ng/l), SB 12 h SC (560 ng/l), and SB 3D ST (497 ng/l) and significantly higher for SB 24 h SC (641 ng/l) and SB 7D ST (726 ng/l). The IBMP content was lowest in SB C (3 ng/l), followed by SB 3D ST (4 ng/l), SB 24 h SC (5 ng/l), SB 12 h SC (6 ng/l), and SB 7D ST (6 ng/l). Thus, IBMP could be significantly increased by mash contact or contact with berry skin components.

The overall fruitiness of Sauvignon Blanc is also determined by the presence of free monoterpenes. The content of all 12 detectable monoterpenes was significantly influenced by the treatment. The sum of free monoterpenes was lowest in SB C (25.1 μg/l) and highest in SB 3D ST (75.3 μg/l). Moreover, the content was around 50 μg/l for SB 24 h SC or SB 7D ST, while SB 12 h SC had almost the same content (27.4 μg/l) as SB C.

In the case of the ester compounds, the sum of the minor esters but not the major ethyl esters was affected by the treatment. Among the minor esters, in particular the sum of aromatic esters, the sum of acetate esters of higher alcohols and isoamyl esters of medium-long-chain carboxylic acids was significantly affected by the treatment. In total, the measured concentration of 15 of 32 analysed minor ester compounds was significantly dependent on the treatment. SB 24 h SC had the lowest minor ester content (3438 μg/l), while the minor ester content of SB C, SB 3D ST, and SB 7D ST was almost equal (approximately 4500 μg/l). The minor ester content in SB 12 h SC was exactly in the middle (approximately 4000 μg/l). The acetate ester content was highest in SB C and lowest in SB 12 h SC and SB 24 h SC; this was particularly noticeable for isoamyl acetate. The results for the ethyl esters with carboxylic acids with an even number of carbon atoms are also interesting. The long-chain compounds from ethyl laurate up to ethyl palmitate were significantly increased compared with SB C, especially in the stabulation variants, while the opposite occurred for the medium-chain compounds (especially ethyl hexanoate). The content of medium-long-chain compounds was notably lower after skin contact, which led to an overall lower ethyl ester content in these variants. The aromatic ester content was very much increased by stabulation.

Ten of the 15 phenolic compounds that could be determined by HPLC were significantly influenced by the treatment, but not the total phenolic content, determined with the Folin–Ciocalteu reagent, and catechin, which is important for bitterness in white wine. In general, there was no clear trend: the content of some compounds was highest in SB C (e.g., caftaric acid), the skin contact variants (e.g., vanillic acid), and the stabulation variants (e.g., tyrosol).

3.1.2. Traminer. Figure 2 shows the principal component analysis of the volatile and phenolic compounds in the Traminer variants. Similar to Sauvignon Blanc, the replicates of the variants match each other quite well. There are three groups: the TR SC group with relatively weak separation of the 12 h and 24 h variants, the TR C and TR 3D SC group, and the TR 7D ST group. It is also interesting to note that the compounds geraniol and cis-rose oxide, which are important for the typicity of Traminer, are highest in the skin contact group.

Table 4 shows the content of volatile and phenolic compounds and the sum parameters for each variant. The analysed concentrations of each volatile and phenolic compound are included in Table S6. The table indicates the variables that were significantly influenced by the treatment; different letters indicate significant differences between the treatment variants.

The aroma of Traminer is significantly characterised by free monoterpenes—cis-rose oxide and geraniol are especially relevant to the Traminer odour [23]. Nine monoterpenes were

Table 3: Average content of volatile and phenolic compounds and the sum parameters of the Sauvignon Blanc variants (the entire dataset is shown in Table S5).

	SB C	SB 12 h SC	SB 24 h SC	SB 3D ST	SB 7D ST
3MHA (ng/l)	24 ± 8	19 ± 5	23 ± 4	15 ± 8	18 ± 8
3MH (ng/l)	522a ± 25	560a ± 12	641b ± 18	497a ± 38	726c ± 46
IBMP (ng/l)	3a ± 0	6d ± 1	5bc ± 1	4ab ± 0	6cd ± 1
Rotundone (ng/l)	<2	<2	<2	<2	<2
Sum free monoterpenes (μg/l)	25.1a ± 1.8	27.4a ± 0.9	49.7b ± 4.1	75.3c ± 3.9	52.7b ± 4.3
Sum aromatic esters (μg/l)	1.0a ± 0.1	0.9a ± 0.1	1.5b ± 0.1	1.8c ± 0.1	1.8c ± 0.1
Sum acetate esters of higher alcohols (μg/l)	1.336, 6c ± 86.9	1.186, 2bc ± 28.1	801.9a ± 28.4	1.111, 4b ± 89.2	1.150, 7bc ± 135.1
Sum ethyl esters of carboxylic acids with an even number of C atoms (μg/l)	3.238, 4 ± 326.6	2.844, 3 ± 85.5	2.620, 5 ± 161.4	3.401, 4 ± 262.7	3.412, 1 ± 119.7
Sum esters of higher alcohols and medium-length chain carboxylic acids (μg/l)	5.7 ± 0.4	5.9 ± 0.4	5.8 ± 0.1	5.8 ± 0.2	6.1 ± 0.2
Sum ethyl esters of carboxylic acids with an odd number of C atoms (μg/l)	1.2 ± 0.1	1.2 ± 0.1	1.5 ± 0.1	1.3 ± 0.1	1.4 ± 0.1
Sum ester of branched carboxylic acids (μg/l)	2.2 ± 0.2	2.0 ± 0.2	2.1 ± 0.1	2.1 ± 0.1	2.0 ± 0.1
Sum isoamyl ester of medium-long chain carboxylic acids (μg/l)	1.4a ± 0.1	1.5a ± 0.1	1.4a ± 0.1	1.9b ± 0.2	1.9b ± 0.1
Sum methyl esters (μg/l)	3.5 ± 0.2	3.7 ± 0.2	3.5 ± 0.2	3.0 ± 0.1	3.4 ± 0.3
Sum minor esters (μg/l)	4.590, 0b ± 377.3	4.045, 7ab ± 113.5	3.438, 2a ± 189.7	4.528, 6b ± 344.7	4.579, 5b ± 253.4
Sum higher alcohols (mg/l)	94.31 ± 9.08	100.89 ± 8.27	93.75 ± 4.92	108.92 ± 5.77	99.22 ± 4.49
Sum C6 compounds (mg/l)	0.79 ± 0.08	0.81 ± 0.08	0.83 ± 0.04	0.77 ± 0.03	0.83 ± 0.06
Sum major ethyl esters (mg/l)	71.74 ± 9.60	72.50 ± 3.08	72.26 ± 8.16	77.33 ± 5.66	76.94 ± 5.79
Sum carbonacids (mg/l)	32.05 ± 0.44	34.54 ± 0.77	33.98 ± 1.55	34.80 ± 2.25	33.42 ± 0.84
Total phenols (g/l)	0.067 ± 0.012	0.067 ± 0.006	0.063 ± 0.006	0.063 ± 0.006	0.060 ± 0.000

SB C: control; SB 12 h SC: 12 h of prefermentation skin contact; SB 24 h SC: 24 h of prefermentation skin contact; SB 3D ST: 3 days of stabulation; SB 7D ST: 7 days of stabulation; n.d., not detectable. $N = 3$ per treatment variant. The same letter indicates no significant difference. The data were analysed with one-way analysis of variance with the Benjamin–Hochberg correction followed by the Tukey B test for pairwise comparisons ($p < 0.05$).

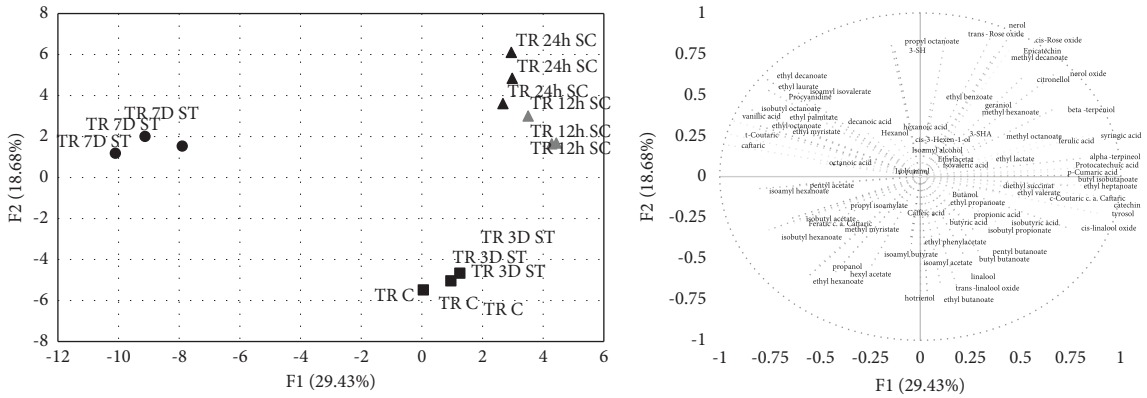

Figure 2: Principal component analysis of Traminer, showing the (a) scatter plot and (b) loading plot. TR C: control; TR 12 h SC: 12 h of prefermentation skin contact; TR 24 h SC: 24 h of prefermentation skin contact; TR 3D ST: 3 days of stabulation; TR 7D ST: 7 days of stabulation.

significantly dependent on the treatment, including the two aforementioned compounds. The content of geraniol and cis-rose oxide and the sum of free monoterpenes were highest in TR 24 h SC (geraniol: 74.5 μg/l; cis-rose oxide: 3.9 μg/l; total monoterpene content: 226.3 μg/l) and lowest in TR C (geraniol: 49.9 μg/l; cis-rose oxide: 1.9 μg/l; total monoterpene content: 128.0 μg/l). The total monoterpene content was almost the same for TR 12 h SC (197.6 μg/l) and TR 3D ST (192.2 μg/l) but significantly lower for TR 7D ST (141.5 μg/l), almost as low as TR C (128.0 μg/l). Interestingly, the cis-rose oxide to geraniol concentration ratio of the variants behaved differently than the sum of free monoterpenes. The two TR SC variants had the highest cis-rose oxide content (12 h: 3.7 μg/l; 24 h: 3.9 μg/l), while the two TR ST variants had a cis-rose oxide content in the middle (2.6 μg/l for both variants). However, TR 3D ST variant had the second highest geraniol content (67.6 μg/l) after TR 24 h SC, while the geraniol content in TR C (49.9 μg/l), TR 12 h SC (54.1 μg/l), and TR 7D ST(55.9 μg/l) was not significantly different.

There were also significant differences in the ester compounds. Similar to Sauvignon Blanc, the sum of minor esters, but not the sum of major ethyl esters, was significantly different. Here, only diethyl succinate had a significantly higher content in TR 12 h SC and TR 3D ST. In the case of minor esters, the sum of aromatic esters, the sum of acetate esters of higher alcohols, the sum of the ethyl esters of even- and odd-chain carboxylic acids, the sum of esters of higher alcohols with medium-length carboxyl chains, and the sum of methyl esters were significantly dependent on the treatment. In total, 17 of 32 detectable esters were significantly influenced by the treatment. The sum of the minor esters was highest in TR 7D ST (5018.4 μg/l) and lowest in TR 12 h SC (3349.6 μg/l). There was no significant difference between TR C (3831.5 μg/l), TR 24 h SC (4126.5 μg/l), and TR 3D ST (3926.0 μg/l). We also noted results that were interesting, and similar to Sauvignon Blanc, for the ethyl esters with carboxylic acids with an even number of carbon atoms. The long-chain compounds from ethyl octanoate to ethyl palmitate were significantly increased with the treatments compared with TR C, especially TR 7D ST, while the opposite was observed for the small-chain compounds (especially ethyl butanoate). The same can be said, but to a lesser extent, for the ethyl esters of odd carboxylic acids: we only examined medium-length chain compounds, but these were also increased in TR C.

For the acetate esters, TR C (sum of acetate esters of higher alcohols: 1433.1 μg/l; isoamyl acetate: 427.0 μg/l) and TR 3D ST (sum of acetate esters of higher alcohols: 1530.8 μg/l; isoamyl acetate: 519.2 μg/l) showed the highest content; it was clearly higher than TR 12 h SC (sum of acetate esters of higher alcohols: 1048.9 μg/l; isoamyl acetate: 279.3 μg/l).

Thirteen of the 15 phenolic compounds were significantly influenced by the treatment. Moreover, the total phenolic content and catechin were also influenced by the treatment. In general, there was no clear trend for the phenols. TR 3D ST and TR 7D ST had the highest total phenolic content, while the maceration variants showed the highest catechin content.

3.1.3. Pinot Blanc. Figure 3 shows the principal component analysis of the volatile and phenolic compounds in the Pinot Blanc variants. As with Sauvignon Blanc and Traminer, the reproducibility within the replicates of each variant is very good. There is separation of the variants, although the differentiation of all variants does not appear to be straightforward. Factor 2 (the *y*-axis) is probably crucial for separation of PB C. It is interesting that the compounds isobutyl acetate, ethyl octanoate, and ethyl decanoate, which are important for the typicity of Pinot Blanc, point strongly towards a positive factor 2 value, and PB 24 h SC and PB 12 h SC show the highest positive factor 2 value.

Table 5 shows the content of volatile and phenolic compounds and the sum parameters for each treatment variant. The analysed concentrations of each volatile and

Table 4: Average content of volatile and phenolic compounds and the sum parameters for Traminer variants (the entire dataset is shown in Table S6).

	TR C	TR 12 h SC	TR 24 h SC	TR 3D ST	TR 7D ST
(Z)-rose oxide (μg/l)	1.9a ± 0.1	3.7c ± 0.2	3.9c ± 0.2	2.6b ± 0.2	2.6b ± 0.1
Geraniol (μg/l)	49.9a ± 3.6	54.1a ± 1.6	74.5c ± 5.1	67.6b ± 1.7	55.9a ± 1.2
Sum free monoterpenes (μg/l)	128.0a ± 12.3	197.6b ± 18.7	226.3b ± 33.1	192.2b ± 17.7	141.5a ± 5.1
3MHA (ng/l)	7 ± 3	6 ± 1	7 ± 1	4 ± 2	5 ± 2
3MH (ng/l)	183 ± 29	207 ± 10	225 ± 21	167 ± 3	212 ± 8
Sum aromatic esters (μg/l)	3.2c ± 0.4	2.7b ± 0.3	2.1ab ± 0.1	1.9a ± 0.1	2.4ab ± 0.3
Sum acetate esters of higher alcohols (μg/l)	1.433, 1bc ± 55.3	1.048, 9a ± 51.9	1.315, 9b ± 41.1	1.530, 8c ± 73.6	1.380, 1b ± 52.2
Sum ethyl esters of carboxylic acids with an even number of C atoms (μg/l)	2.381, 7a ± 150.3	2.285, 2a ± 84.8	2.795, 4b ± 150.4	2.381, 5a ± 24.8	3.623, 0c ± 229.0
Sum esters of higher alcohols and medium-length chain carboxylic acids (μg/l)	5.6c ± 0.2	5.2bc ± 0.2	4.9ab ± 0.1	4.6a ± 0.2	5.6c ± 0.4
Sum ethyl esters of carboxylic acids with an odd number of C atoms (μg/l)	1.8c ± 0.1	1.5b ± 0.1	1.6bc ± 0.2	1.5ab ± 0.1	1.3a ± 0.0
Sum ester of branched carboxylic acids (μg/l)	2.2 ± 0.1	2.4 ± 0.3	2.2 ± 0.1	2.1 ± 0.3	1.8 ± 0.1
Sum isoamyl ester of medium-long chain carboxylic acids (μg/l)	1.6 ± 0.2	1.4 ± 0.1	1.4 ± 0.1	1.4 ± 0.1	1.8 ± 0.2
Sum methyl esters (μg/l)	2.4a ± 0.1	2.4a ± 0.1	2.9b ± 0.1	2.4a ± 0.1	2.4a ± 0.1
Sum minor esters (μg/l)	3.831, 6b ± 205.9	3.349, 6a ± 92.3	4.126, 5b ± 190.0	3.926, 0b ± 86.6	5.018, 4c ± 273.1
Sum higher alcohols (mg/l)	104.52 ± 11.45	101.76 ± 13.99	100.45 ± 7.37	95.18 ± 10.39	105.29 ± 1.84
Sum C6 compounds (mg/l)	0.81 ± 0.03	0.84 ± 0.08	0.82 ± 0.08	0.76 ± 0.03	0.86 ± 0.02
Sum major ethyl esters (mg/l)	76.69 ± 4.63	76.84 ± 3.69	72.53 ± 5.62	67.11 ± 4.20	72.78 ± 4.89
Sum carbonacids (mg/l)	35.54 ± 1.16	33.24 ± 0.65	36.30 ± 2.51	34.16 ± 0.60	36.87 ± 0.68
Total phenols (g/l)	0.067ab ± 0.006	0.060a ± 0.000	0.060a ± 0.000	0.077b ± 0.006	0.077b ± 0.006

TR C: control; TR 12 h SC: 12 h of prefermentation skin contact; TR 24 h SC: 24 h of prefermentation skin contact; TR 3D ST: 3 days of stabulation; TR 7D ST: 7 days of stabulation. $N = 3$ per treatment variant. The same letter indicates no significant difference. The data were analysed with one-way analysis of variance with the Benjamin–Hochberg correction followed by the Tukey B test for pairwise comparisons ($p < 0.05$).

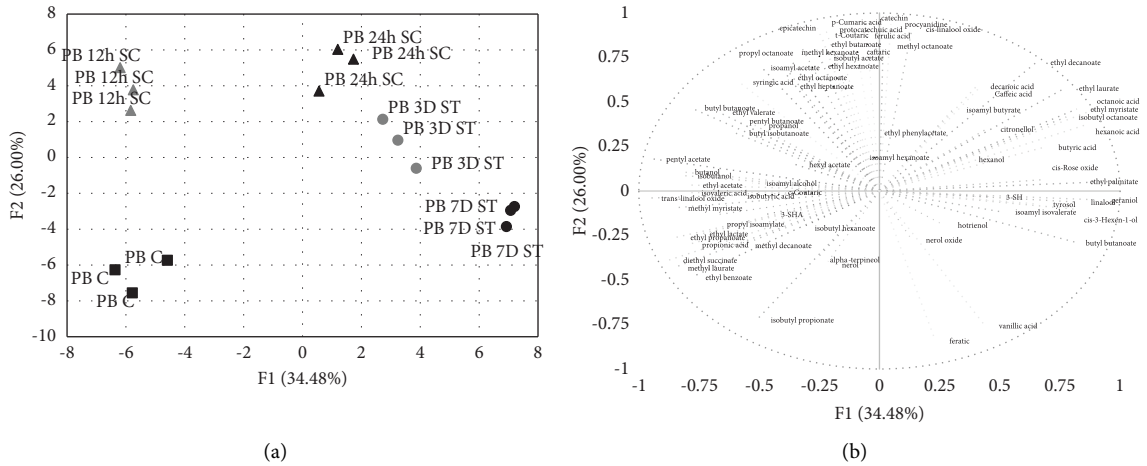

FIGURE 3: Principal component analysis of the Pinot Blanc treatment variants, showing the (a) scatter plot and (b) loading plot. PB C: control; PB 12 h SC: 12 h of prefermentation skin contact; PB 24 h SC: 24 h of prefermentation skin contact; PB 3D ST: 3 days of stabulation; PB 7D ST: 7 days of stabulation.

phenolic compound are included in Table S7. The table indicates the variables that were significantly influenced by the treatment; different letters indicate significant differences between the treatment variants. There are significant differences in the esters, higher alcohols, carboxylic acids, and phenols, but not in the free monoterpenes, thiols, C6 alcohols, rotundone, and MPZ (the latter two were below the limit of quantification). Esters are important for the varietal character [17]. The sum of minor esters—15 of 32—but not the sum of major ethyl esters was significantly impacted by the treatment. Of the ester groups, methyl esters and ethyl esters of odd-chain and even-chain carboxylic acids showed the greatest differences based on the treatment. As with the other grape varieties, the ethyl esters of even-chain carboxylic acids are particularly interesting. The content of ethyl esters with longer carboxylic acid chains increased in PB 3D ST and PB 7D ST compared with PB C, PB 12 h SC, and PB 24 h SC, while the content of ethyl esters of shorter-chain carboxylic acids was altered in these variants. It is remarkable that overall, the content of the PB ST variants was increased compared with PB C, but due to the very high contents of some esters, the PB SC variants showed the highest content of ethyl esters with even-chain carboxylic acids (PB 24 h SC: 3629.8 μg/l; PB 12 h SC: 3453.6 μg/l; PB 3D ST: 3294.3 μg/l; PB 7D ST: 3150.9 μg/l; PB C: 2453.2 μg/l). Of note, PB C had a higher methyl ester content compared with the other variants.

The sum of the higher alcohols was clearly increased in PB 12 h SC compared with the other variants. This resulted from a higher value of all the analysed higher alcohols. The sum of the carboxylic acids, on the other hand, was highest in PB 24 h SC, PB 3D ST, and PB 7D ST and lowest in PB C.

Eleven of the 15 phenols were significantly influenced by the treatment, including the catechin content. However, there were no significant differences in the total phenolic content between the treatment variants. With the exception of tyrosol and vanillic acid, the PB SC variants had the highest total phenolic content.

3.1.4. Grüner Veltliner. Figure 4 shows the principal component analysis of the volatile and phenolic compounds in the Grüner Veltliner variants. As with the other wine varieties, the replicates of the variants match each other, and there is a separation of the variants. Factor 1 (the *x*-axis) separates the classical variants (C and SC) from the MF variants (PMF and FMF), while factor 2 (the *y*-axis) shows the dependence on temperature (25 vs 15°C). It is interesting that rotundone, which is important for the typicity of Grüner Veltliner [15, 16], is extracted more from the grape skin by MF, while the ester compounds (ethyl esters and acetate esters), which are also important for the typicity of this variety, are increased in the classic variants (C and SC). It seems that the content of only a few fermentation aromas is responsible for the temperature effect, while many more compounds are responsible for the differentiation of the variants. This is also reflected in the contribution to the explanation of the variance of the two factors: much larger for factor 1 (52.76%) than factor 2 (13.48%).

Tables 6 and 7 show the content of volatile and phenolic compounds and the sum parameters for each variant and each fermentation temperature (15 and 25°C). The analysed concentrations of each volatile and phenolic compound are included in Tables S8 and S9. The tables indicate the variables that were significantly influenced by the treatment; different letters indicate significant differences between the treatment variants. The data from the two fermentation temperatures are presented separately, and we also performed a multivariate analysis to determine the effects of treatment and fermentation temperature as well as the treatment × temperature interaction (Table S10). At 25°C, there were significant differences in all aroma groups: rotundone; fruity thiols; the sums of the C6 alcohols, higher alcohols, carboxylic acids, esters, and monoterpenes; and total phenols. Only the IBMP content was below the limit of quantification of 2 ng/l and thus could not be compared between the variants. Similar to 25°C, at 15°C, there was a significant difference in all aroma groups except for MPZ.

Table 5: Average content of volatile and phenolic compounds and the sum parameters for Pinot Blanc variants (the entire dataset is shown in Table S7).

	PB C	PB 12 h SC	PB 24 h SC	PB 3D ST	PB 7D ST
Sum aromatic esters (μg/l)	1.2 ± 0.1	1.2 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	1.0 ± 0.2
Sum acetate esters of higher alcohols (μg/l)	1.302, 5 ± 136.2	1.334, 7 ± 27.9	1.404, 7 ± 60.4	1.286, 5 ± 93.6	1.147, 5 ± 115.3
Sum ethyl esters of carboxylic acids with an even number of C atoms (μg/l)	2.453, 2a ± 10.8	3.453, 6bc ± 274.1	3.629, 8c ± 206.3	3.294, 3bc ± 79.9	3.150, 9b ± 173.7
Sum esters of higher alcohols and medium-length chain carboxylic acids (μg/l)	5.2 ± 0.3	5.4 ± 0.3	5.2 ± 0.1	5.1 ± 0.0	5.3 ± 0.2
Sum ethyl esters of carboxylic acids with an odd number of C atoms (μg/l)	0.9bc ± 0.1	1.1c ± 0.1	1.0bc ± 0.1	0.9b ± 0.1	0.7a ± 0.0
Sum ester of branched carboxylic acids (μg/l)	2.3 ± 0.1	2.3 ± 0.0	2.3 ± 0.1	2.1 ± 0.2	2.1 ± 0.2
Sum isoamyl ester of medium-long chain carboxylic acids (μg/l)	1.2 ± 0.0	1.4 ± 0.1	1.3 ± 0.1	1.2 ± 0.1	1.4 ± 0.1
Sum methyl esters (μg/l)	11.5d ± 0.9	9.0c ± 0.1	8.9c ± 0.5	6.9b ± 0.7	5.0a ± 0.3
Sum minor esters (μg/l)	3.778, 0a ± 145.6	4.808, 7bc ± 273.3	5.054, 2c ± 259.6	4.598, 0bc ± 173.7	4.313, 7b ± 279.4
Sum free monoterpenes (μg/l)	19.3 ± 2.9	18.6 ± 1.7	18.7 ± 1.6	18.5 ± 0.6	19.7 ± 0.7
IBMP (ng/l)	<2	<2	<2	<2	<2
3MHA (ng/l)	9 ± 4	7 ± 2	8 ± 1	5 ± 3	5 ± 3
3MH (ng/l)	159 ± 40	168 ± 23	196 ± 25	149 ± 40	228 ± 21
Rotundone (ng/l)	<2	<2	<2	<2	<2
Sum higher alcohols (mg/l)	110.32a ± 9.28	134.74b ± 4.74	96.58a ± 6.99	102.92a ± 3.96	103.63a ± 7.44
Sum C6 compounds (mg/l)	0.73 ± 0.06	0.78 ± 0.09	0.77 ± 0.01	0.85 ± 0.04	0.82 ± 0.09
Sum major ethyl esters (mg/l)	85.45 ± 9.14	87.61 ± 6.37	76.45 ± 4.00	69.50 ± 1.67	70.06 ± 4.68
Sum carbonacids (mg/l)	19.89a ± 1.47	28.35b ± 1.31	33.53c ± 2.82	34.44c ± 1.86	33.98c ± 0.73
Total phenols (g/l)	0.070 ± 0.000	0.070 ± 0.010	0.057 ± 0.006	0.060 ± 0.010	0.057 ± 0.006

PB C: control; PB 12 h SC: 12 h of prefermentation skin contact; PB 24 h SC: 24 h of prefermentation skin contact; PB 3D ST: 3 days of stabulation; PB 7D ST: 7 days of stabulation; n.d., not detectable. $N = 3$ per treatment variant. The same letter indicates no significant difference. The data were analysed with one-way analysis of variance with the Benjamin–Hochberg correction followed by the Tukey B test for pairwise comparisons ($p < 0.05$).

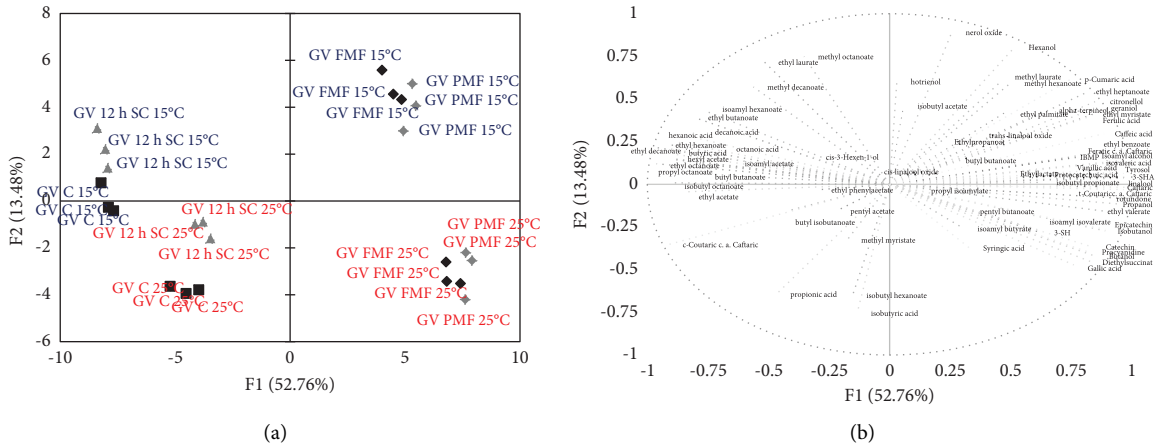

FIGURE 4: Principal component analysis of Grüner Veltliner, showing the (a) scatter plot and (b) loading plot. The results are shown in blue for treatment at 15°C and red for treatment at 25°C. GV C: control; GV 12 h SC: 12 h of prefermentation skin contact; GV PMF: partial mash fermentation; GV FMF: full mash fermentation.

In particular, the sesquiterpene rotundone, which is important for the spiciness and the "pepper note" in Grüner Veltliner, was very strongly extracted by MF at both fermentation temperatures, and the concentration in the finished wine was much higher. The difference between the classic and MF variants was even more pronounced at the lower fermentation temperature (significant effect), although in absolute terms the higher fermentation temperature led to a higher rotundone content. In contrast, the content of minor esters, which are important for the fruitiness of the wines, was more than twofold higher in the C and SC variants than in the MF variants. This difference was greater at the lower fermentation temperature (significant effect), although in absolute terms the MF at 25°C variants had the lowest ester content. In general, the fermentation temperature exerted a significant effect on the minor esters, rotundone, higher alcohols, C6 alcohols, carbon acids, and the total phenolic content. For minor esters, major ethyl esters, C6 alcohols, carboxylic acids, and the total phenolic content, the treatment × temperature interaction was also significant. Overall, 41 out of 68 quantifiable volatile compounds and 14 out of 15 quantifiable phenols were significantly influenced by the treatment, 38 volatile compounds and 11 phenols were significantly influenced by the temperature, and 25 volatile compounds and 9 phenols had a significant treatment × temperature interaction. Overall, it can be said that the phenols, but also many skin-associated aroma compounds such as monoterpenes, thiols, and rotundone, were increased in the PMF and FMF variants, while the ester compounds, which are important for the fruitiness, were increased in the C and SC variants.

3.1.5. Sensory Results. Figures S1–S4 and Tables S11–S14 present the CATA analysis and the database. For Sauvignon Blanc, SB C, SB 7D ST, and SB 12 h SC showed negative values on the *x*-axis, with the highest rating for yellow fruit, while SB 24 h SC, SB 12 h SC, and SB 7D ST showed the highest ratings for the main varietal expressions green pepper (11, 8, and 6 mentions, respectively) and passion fruit (14, 12, and 10 mentions, respectively). For Traminer, the skin contact variants had positive values on the y-axis of the biplot (Figure S2) and the highest scores for the main grape variety expressions of rose (12 mentions TR 24 h SC and 11 mentions TR 12 h SC). For Pinot Blanc, PB 24 h SC and PB 3D ST showed negative values on the *y*-axis, with the highest rating for the most important varietal expression yellow fruit (7 mentions for each variant), while PB 7D ST, PB 3D ST, and PB C showed no clear sensory characteristics. In general, the differences were very small. However, the sensory results for Grüner Veltliner correlate very strongly with the analytical results. The MF variants were perceived as bitter but more peppery (both black pepper and green pepper) while the classic variants (C and SC) were perceived as more fruity (green apple, yellow fruit, and tropical fruit).

3.1.6. Varietal Differences. Figure 5 compares the C and SC 12 h at 15°C variants of the four grape varieties. There is a clear grouping according to the grape variety, and there is a distinction between the C and SC 12 h variants for each grape variety. In terms of the aromatic compounds, IBMP, 3-SH, and 3-SHA cluster correctly for Sauvignon Blanc, the monoterpenes geraniol and cis-rose oxide cluster correctly for Traminer, and rotundone clusters correctly for Grüner Veltliner. In fact, the statistical analysis revealed a significant influence of the grape variety for 60 of the 65 volatile compounds, while only 18 volatile compounds were significantly influenced by the treatment. Nevertheless, 28 compounds showed a significant grape variety × treatment interaction. For phenols, all individual compounds were influenced by the grape variety, but not the total phenolic content, while 6 of the 15 individual phenols were significantly dependent on the treatment and 10 compounds showed a significant grape variety × treatment interaction (Table S15).

Table 6: Average content of volatile and phenolic compounds and the sum parameters of Grüner Veltliner variants (15°C) (the entire dataset is shown in Table S8).

	GV C 15°C	GV 12 h SC 15°C	GV PMF 15°C	GV FMF 15°C
Rotundone (ng/l)	4a ± 1	5b ± 0	30d ± 0	28c ± 1
3MHA (ng/l)	2a ± 1	9b ± 2	30c ± 5	28c ± 5
3MH (ng/l)	150 ± 6	155 ± 8	159 ± 6	151 ± 6
IBMP (ng/l)	<2	2 ± 0	2 ± 0	2 ± 0
Sum free monoterpenes (μg/l)	6.6a ± 0.2	9.0b ± 0.5	13.9c ± 0.3	14.7c ± 0.8
Sum aromatic esters (μg/l)	4.5a ± 0.1	7.1c ± 0.6	6.1bc ± 0.7	5.3ab ± 0.5
Sum acetate esters of higher alcohols (μg/l)	673.2b ± 16.0	1.211, 5c ± 95.1	402.4a ± 5.1	434.2a ± 13.7
Sum ethyl esters of carboxylic acids with an even number of C atoms (μg/l)	3.178, 0b ± 77.0	3.515, 1c ± 225.8	1.245, 0a ± 41.1	1.362, 6a ± 83.8
Sum esters of higher alcohols and medium-length chain carboxylic acids (μg/l)	7.4 ± 0.1	7.9 ± 0.2	7.4 ± 0.2	7.4 ± 0.2
Sum ethyl esters of carboxylic acids with an odd number of C atoms (μg/l)	1.8a ± 0.1	2.4b ± 0.2	3.6c ± 0.2	3.5c ± 0.2
Sum ester of branched carboxylic acids (μg/l)	6.2 ± 0.3	7.1 ± 0.4	5.9 ± 0.8	6.8 ± 0.5
Sum isoamyl ester of medium-long chain carboxylic acids (μg/l)	1.9b ± 0.1	2.2c ± 0.1	1.5a ± 0.2	1.4a ± 0.1
Sum methyl esters (μg/l)	4.2 ± 0.2	4.7 ± 0.3	4.6 ± 0.3	4.8 ± 0.2
Sum minor esters (μg/l)	3.877, 1b ± 87.8	4.757, 9c ± 281.7	1.676, 4a ± 43.5	1.826, 0a ± 97.2
Sum higher alcohols (mg/l)	97.56a ± 6.58	102.09a ± 3.97	149.57b ± 3.34	159.46c ± 2.14
Sum C6 compounds (mg/l)	0.80a ± 0.02	0.80a ± 0.01	1.05b ± 0.06	1.09b ± 0.01
Sum major ethyl esters (mg/l)	72.09 ± 4.19	71.79 ± 1.32	66.44 ± 2.70	65.04 ± 2.14
Sum carbonacids (mg/l)	32.40b ± 0.77	35.13c ± 1.31	15.17a ± 0.80	16.77b ± 1.45
Total phenols (g/l)	0.06a ± 0.00	0.07b ± 0.00	0.15c ± 0.01	0.14b ± 0.01

GV C: control; GV 12 h SC: 12 h of prefermentation skin contact; GV PMF: partial mash fermentation; GV FMF: full mash fermentation. $N = 3$ per treatment variant. The same letter indicates no significant difference. The data were analysed with one-way analysis of variance with the Benjamin–Hochberg correction followed by the Tukey B test for pairwise comparisons ($p < 0.05$).

Table 7: Average content of volatile and phenolic compounds and the sum parameters of Grüner Veltliner variants (25°C) (the entire dataset is shown in Table S9).

	GV C 25°C	GV 12 h SC 25°C	GV PMF 25°C	GV FMF 25°C
Rotundone (ng/l)	8a ± 1	9a ± 0	41b ± 1	43c ± 1
3MHA (ng/l)	10a ± 1	12a ± 2	35b ± 3	33b ± 3
3MH (ng/l)	104a ± 1	181b ± 3	228d ± 2	224c ± 2
IBMP (ng/l)	<2	<2	<2	<2
Sum free monoterpenes (μg/l)	7.3a ± 0.6	10.2b ± 0.9	13.2c ± 1.4	12.4c ± 0.3
Sum aromatic esters (μg/l)	6.1a ± 0.5	7.9b ± 0.8	5.5a ± 0.4	5.6a ± 0.4
Sum acetate esters of higher alcohols (μg/l)	566.3b ± 15.0	962.2c ± 103.3	352.0a ± 13.3	356.1a ± 10.2
Sum ethyl esters of carboxylic acids with an even number of C atoms (μg/l)	1.941, 8b ± 118.7	2.002, 8b ± 96.4	765.8a ± 9.4	725.1a ± 43.5
Sum esters of higher alcohols and medium-length chain carboxylic acids (μg/l)	7.5 ± 0.1	7.5 ± 0.5	7.4 ± 0.1	7.4 ± 0.2
Sum ethyl esters of carboxylic acids with an odd number of C atoms (μg/l)	2.4a ± 0.2	2.5a ± 0.3	3.6b ± 0.1	3.5b ± 0.0
Sum ester of branched carboxylic acids (μg/l)	7.0 ± 0.5	7.2 ± 0.2	6.7 ± 0.3	6.4 ± 0.2
Sum isoamyl ester of medium-long chain carboxylic acids (μg/l)	1.4 ± 0.1	1.4 ± 0.2	1.3 ± 0.1	1.2 ± 0.1
Sum methyl esters (μg/l)	3.5 ± 0.1	4.1 ± 0.3	4.1 ± 0.2	4.1 ± 0.2
Sum minor esters (μg/l)	2.536, 0b ± 131.3	2.995, 5c ± 166.1	1.146, 3a ± 5.2	1.109, 3a ± 53.6
Sum higher alcohols (mg/l)	104.49a ± 3.76	129.04b ± 7.34	170.91c ± 5.99	165.24c ± 3.34
Sum C6 compounds (mg/l)	0.71a ± 0.02	0.76ab ± 0.04	0.83c ± 0.01	0.80bc ± 0.02
Sum major ethyl esters (mg/l)	85.21b ± 2.50	85.12b ± 1.61	57.04a ± 0.10	54.06a ± 1.43
Sum carbonacids (mg/l)	20.20b ± 1.64	27.50c ± 0.59	12.98a ± 0.79	12.75a ± 0.46
Total phenols (g/l)	0.06a ± 0.00	0.06a ± 0.00	0.21b ± 0.00	0.21b ± 0.01

GV C: control; GV 12 h SC: 12 h of prefermentation skin contact; GV PMF: partial mash fermentation; GV FMF: full mash fermentation. $N = 3$ per treatment variant. The same letter indicates no significant difference. The data were analysed with one-way analysis of variance with the Benjamin–Hochberg correction followed by the Tukey B test for pairwise comparisons ($p < 0.05$).

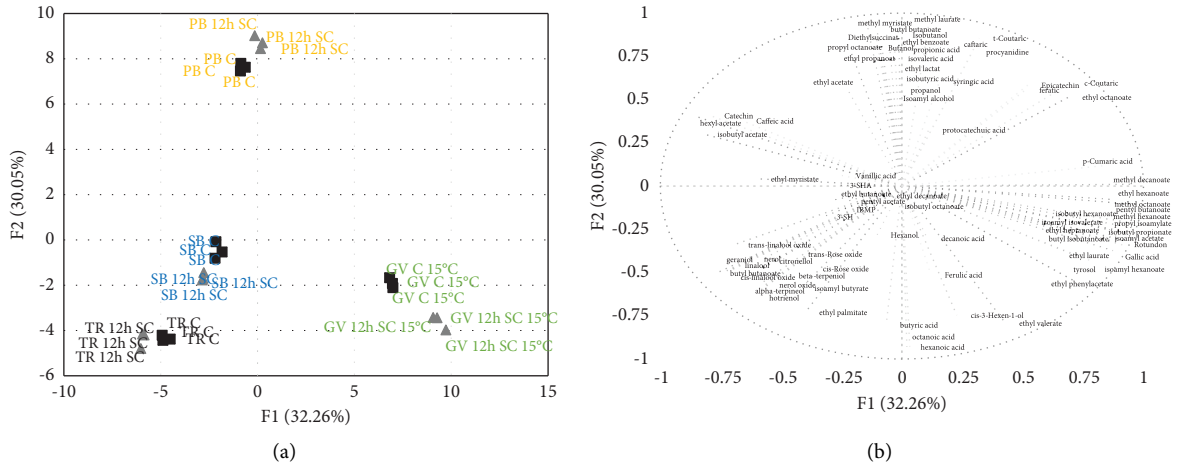

FIGURE 5: Principal component analysis of the control (C) and 12 h of skin contact at 15°C (12 h SC) variants of the four grape varieties, showing the (a) scatter plot and (b) loading plot. Sauvignon Blanc (SB) is shown in blue, Traminer (TR) is shown in black, Pinot Blanc (PB) is shown in yellow, and Grüner Veltliner (GV) is shown in green.

4. Discussion

4.1. Response to the Hypotheses. Table 8 presents a comparison of the results of the different grape varieties and treatment variants. It is a summary of Tables 3–7 and S11–S14. Based on this table, we can accept our hypothesis to a limited extent, namely, we collected sufficient data to obtain a good overview of Austrian white wine varieties and to make recommendations. The table also shows the rate of increase from the lowest to highest values of individual compounds. We ranked the significant differences with lowercase letters, starting with a, which indicates the lowest content. For the sensory analysis, only the number of mentions is ranked, with 1 indicating the fewest mentions. Note that we did not subject the sensory results to statistical analysis.

Fermentation on the skin of Grüner Veltliner grapes increased the spiciness of the wines, which was measurable both analytically as a markedly higher rotundone content and sensorily as more perceived black pepper and green pepper. However, these variants showed significantly lower fruitiness both organoleptically and analytically, which can be attributed to the significantly lower ester content. The PMF and FMF variants showed a clear increase in bitter substances (assessed analytically and sensorily). We cannot make a general recommendation for MF of Grüner Veltliner grapes based on the data because the clear decrease in fruitiness and the increase in bitterness are not characteristics of this variety. Analytically, the influence of temperature on individual aroma compounds, especially rotundone, the thiol content (3-SH), and phenols, was much more pronounced than the sensory results suggest. These negative effects (increased bitterness and decreased fruitiness) were not considerably lower at the lower fermentation temperature as well as with PMF. Therefore, this treatment is not suitable to compensate for the lower rotundone content in Grüner Veltliner wines due to climate change [12, 16].

For Sauvignon Blanc, SB 7D ST and SB 12 h SC showed a 100% increase in the varietal aromatic IBMP compared with SB C and the highest content of thiols (especially 3-SH), approximately 50%, compared with SB C. These results were partially confirmed with the sensory analysis. SB 7D ST was in second place for the descriptor passion fruit (after the SB 24 h SC). Although there was a significant analytical difference between these two variants, both showed enhanced sensory characteristics compared with SB C. For the descriptor green pepper, SB 7D ST was in third place after SB 12 h SC and SB 24 h SC. Analytically, all three variants showed significant increases compared with SB C, and there was no significant difference between SB 24 h SC and SB 7D ST. Based purely on these findings, 7 days of stabulation can be recommended for Sauvignon Blanc. Three days of stabulation might be too short.

In the case of Traminer, the sum of monoterpenes was increased in the TR SC and TR ST variants compared with TR C. Both TR SC variants increased cis-rose oxide compared with the TR ST variants (by approximately 50%) and TR C (by approximately 100%). However, this was not the case for the key compound geraniol: it was not increased in TR 12 h SC and TR 7D ST compared with TR C, and the increase for TR 24 h SC was rather modest (<25% compared with the control variant). From a sensory point of view, the prefermentation skin contact variants had the most pronounced rose flavour. Hence, for Traminer, we recommend increasing the prefermentation maceration time.

The aroma of Pinot Blanc is characterised by various ester compounds. In the present study, prefermentation skin contact increased minor esters as well as the very important ethyl esters compared with the control variant; the contents were also somewhat higher than the PB ST variants (especially 7 days of stabulation). The PB SC variants also performed the best for the important sensory descriptor yellow fruit, although the sensory results suggest only minor differences between the variants.

Table 8: Comparison of the main results for each cultivar.

Cultivar	Parameter	Increase ratio from the lowest to the highest concentration for Grüner Veltliner (15°C/25°C)	C	12 h SC	PMF	FMF
Grüner Veltliner	Rotundone	650%/438%		a/a	b/a	d/b	c/c
	Thiols (3-SH)	–/119%		a/a	a/b	a/d	a/c
	Esters (sum of minor esters)	184%/170%		b/b	c/c	a/a	a/a
	Free monoterpenes	123%/80%		a/a	b/b	c/c	c/c
	Phenols (total)	150%/250%		a/a	b/a	c/b	b/b
	Sensory results—fruity aromas (sum of tropical fruit, green apple, and yellow fruit)			4/3	4/4	2/1	1/2
	Sensory results—black pepper			1/2	2/1	4/4	3/3
		Increase ratio from the lowest to the highest concentration for Sauvignon blanc, Traminer and Pinot blanc	C	12 h SC	24 h SC	3D ST	7D ST
Sauvignon Blanc	MPZ (IBMP)	100%	a	d	bc	ab	cd
	Thiols (3-SH)	46%	a	a	b	a	c
	Sum of free monoterpenes	200%	a	a	b	c	b
	Sum of minor esters	34%	b	ab	a	b	b
	Phenols (total)	—	a	a	a	a	a
	Sensory results—passion fruit		1	3	5	2	4
	Sensory results—green pepper		1	5	4	2	3
Traminer	Sum of free monoterpenes	77%	a	b	b	b	a
	Sum of minor esters	50%	b	a	b	b	c
	Phenols (total)	15%	ab	a	a	b	b
	Sensory results—rose		2	3	4	2	1
Pinot Blanc	Sum of minor esters	33%	a	bc	c	bc	b
	Sum of higher alcohols	40%	a	b	a	a	a
	Phenols	—	a	a	a	a	a
	Sensory results—yellow fruit		1	3	4	2	1

C: control variant; 12 h SC: 12 h or prefermentation skin contact; 24 h SC: 24 h of prefermentation skin contact; PMF: partial mash fermentation; FMF: full mash fermentation; 3D ST: 3 days of stabulation; 7D ST: 7 days of stabulation. The same letter indicates no significant difference; a indicates the lowest content. The sensory analyses are ranked according to the number of mentions, with 1 indicating the fewest mentions.

4.2. Integration of the Results

4.2.1. Rotundone. Rotundone is responsible for the peppery smell in wine. Grüner Veltliner, Austria's leading grape variety, is known for its spicy-peppery aroma. Mattivi et al. [16] reported a rotundone concentration of 66–266 ng/l in Grüner Veltliner wine, while in a broad study (>100 examined wines of different vintages), the range was 9–85 ng/l [15]. In the latter study, the authors noted that the rotundone content in very dry warm vintages fell below the assumed perception threshold of 15 ng/l [15]. Based on this finding, researchers tested the influence of various cellar management factors, including extended prefermentation skin contact, on the rotundone concentration in Grüner Veltliner. They found that conventional oenological measures cannot influence the rotundone concentration [22]. The present study confirmed the results of a previous publication [42]. None of the factors tested in that study for Syrah wine, including the use of pectolytic enzymes and cold maceration, significantly increased the rotundone concentration. In addition, Fauster et al. [43] used a pulsed electric field (PEF) and enzymatic mash treatment, but it did not affect the rotundone content. Due to the very strong hydrophobic nature of rotundone, this compound is difficult to extract; moreover, unlike other aroma compounds, it is only found in the berry skin [44]. MF is necessary to increase the extraction rate [45]. Siebert and Solomon [46] showed that most of the rotundone is extracted between days 2 and 5 of fermentation, which is why we also evaluated PMF in the present study. MF markedly increased the rotundone content. For Syrah wine, Geffroy et al. [42] showed that rose wine had only 13% of the rotundone content of the control variant (MF). In our experiments, the control variant (classic white wine) had only 15%–22% of the rotundone content of the skin fermented white wine depending on the fermentation temperature. The difference was smaller at the higher fermentation temperature, but the absolute numbers were approximately the same time. In contrast to Grüner Veltliner, rotundone could not be detected in Pinot Blanc, Sauvignon Blanc, and Traminer (the measured concentrations were below the limit of quantification (2 ng/l)). For Sauvignon Blanc, our data confirm previous findings [47, 48]. For Pinot Blanc and Traminer, we are not aware of any comparative results.

4.2.2. Fruity Thiols. Due to the very low odour threshold, thiols play a key role in the primary aroma of white wines. The smell of box tree, grapefruit, citrus fruit, and passion fruit originates from these compounds [49]. These thiols are released from their odourless cysteine or glutathione precursors. Two important free thiols are 3-SH and 3-SHA, which we investigated in the present study. However, we did not analyse another important compound, namely, 4-MSP. All three thiols mentioned play a key role in the varietal aroma of Sauvignon Blanc, but they are important for all white wines. For example, Carlin et al. [50] showed that the ratio of 3-SH to 3-SHA is important for the intensity of citrus/grapefruit and tropical fruit sensations of Müller Thurgau. While in the present study the 3-SH content in Sauvignon Blanc and Grüner Veltliner (25°C fermentation temperature) was significantly influenced by the treatment, there was no significant influence for Traminer, Pinot Blanc, and Grüner Veltliner (15°C fermentation temperature). Investigations on Chenin Blanc showed that prefermentation skin contact but not MF at 15°C had a significant influence on the 3-SH concentration [51]. However, Murat et al. [52] showed that MF of Merlot and Cabernet Sauvignon increased the content of 3-SHA precursors at a higher temperature (25°C); thus, the fermentation temperature had an influence on the extraction. We found similar results with Grüner Veltliner: the increase in the 3-SH content between the conventional and MF variants was significant at 25°C, but not at 15°C. While Peyrot des Gachons et al. [53] showed that the cysteine precursors of 3-SH in Sauvignon Blanc are found exclusively in the berry skin, Roland et al. [54] also showed their presence in the pulp, but interestingly not in Melon Blanc, in which only the glutathione precursor of 3-SH is found in the pulp. These possible varietal, site, and vintage differences may explain why there was no significant influence of the treatment on Pinot Blanc and Traminer. However, in a broad practical trial by the company Laffort, where the influence of stabulation and enzyme treatments was tested in 21 different locations, there were similarly inhomogeneous results. Twelve of the 21 experimental wines showed a significant difference from the control. The thiol content was sometimes increased and sometimes decreased by the stabulation procedure [55]. In addition, according to the literature, the results regarding prefermentation skin contact are not homogeneous. This heterogeneity can also be explained by the fact that there is no clear correlation between the precursor concentration and the free thiol concentration. High precursor concentrations are not a guarantee of a highly aromatic wine. When testing 55 different juice/wine couples, Pinu et al. [56] found no correlation between the precursors in juice and the final thiols in wine.

4.2.3. MPZ. In Sauvignon Blanc, typical green aromas come from MPZ, whereas IBMP is considered to be the compound responsible for the green pepper descriptor. We evaluated this compound, but only Sauvignon Blanc (3–6 ng/l) showed levels above the limit of quantification. We are not aware of any additional studies on Grüner Veltliner or Traminer in this respect. For Pinot Blanc, the concentration of 2 ng/l was not exceeded in a previous study [17]. Chardonnay and Chenin Blanc, two white wine varieties, also have <2 ng/l IBMP [57]. For Sauvignon Blanc, treatment significantly influenced the IBMP content—the maceration time as well as stabulation increased it. Interestingly, the IBMP content decreased after >12 h of skin contact, but it increased from 3 to 7 days of stabulation. This finding is in line with a previous study: the authors found that too long of an extraction (>1 day extraction) did not lead to a further increase in IBMP [58]. There is indirect evidence for the latter finding on stabulation: juice settling and extraction decrease the IBMP content [59], so during stabulation, IBMP is extracted from the lees into the must.

4.2.4. Monoterpenes. Monoterpenes represent a very broad aromatic group in wine and are responsible for the varietal characteristics of several grape varieties, including Traminer (>100 μg/l sum of free monoterpenes). The monoterpene content in Grüner Veltliner and Pinot Blanc was low (<20 μg/l sum of free monoterpenes) while the content in Sauvignon Blanc was intermediate (20–100 μg/l sum of free monoterpenes). In Grüner Veltliner (both fermentation temperatures), Sauvignon Blanc, and Traminer, treatment significantly influenced monoterpenes. Since the 1980s, a number of studies have examined the influence of skin contact and MF on the monoterpene content [60–62]. Sochor et al. [27] specifically studied the extraction behaviour of monoterpenes in Traminer. Interestingly, the free monoterpene content increased with the maceration time (up to 36 h). We observed something similar with Traminer and Sauvignon Blanc: the concentration increased from 12 to 24 h of maceration. In Grüner Veltliner, MF actually improved monoterpene extraction compared with prefermentation skin contact. However, there were contradictory results regarding the treatment × temperature interaction in terms of the extent to which FMF or PMF increased the monoterpene content. Lukić et al. [63] also found that MF and alcohol extraction intensified monoterpene extraction, but there are limited data available on the speed of extraction and the influence of temperature during fermentation.

4.2.5. Esters and Other Fermentation Aromatic Compounds. Esters are important compounds for fruitiness in wine [18]. While the major ethyl esters were hardly influenced by the treatment (except for MF of Grüner Veltliner), the minor ester content was very much influenced by each treatment. The sum of minor esters was significantly lower with MF, but the results were not so clear for prefermentation skin contact and stabulation. The skin contact variants of Pinot Blanc, for which esters are very important due to the small amount of other varietal aromas, and Grüner Veltliner showed the highest minor ester content. For Sauvignon Blanc, the control variant showed the highest minor ester content. Finally, for Traminer, both the stabulation and the skin contact variants showed a higher minor ester content. The ester content can only be indirectly influenced by the must composition, so the variability in the ester content can be explained by the variability of the amino acid and acid extraction from the grape skin and pulp and the different fermentation conditions between must and MF [64]. Of note, there are controversial results for esters for different grape varieties [13, 65–67] and it is not easy to predict how the content will change. The same applies to the higher alcohols and carboxylic acids, for which there were only a few significant differences.

4.2.6. Phenols. Wine consists of nonvolatile and volatile compounds. Among the nonvolatile compounds, phenols play a particularly important role, more so in red wine, but also in white wine, especially when the bitter content is too high and thus the taste is negatively affected. An important indicator of bitterness in white wine is catechin [68, 69]. The catechin content was significantly influenced by the treatment in different ways. It increased markedly with MF—a finding consistent with previous studies [10, 51, 70]—but was variable for the prefermentation skin contact and stabulation variants. For Pinot Blanc, the prefermentation skin contact variants showed the highest catechin content, while the control variant showed the lowest content. In the case of Traminer, the skin contact variants also showed the highest catechin content, but the stabulation variants showed the lowest content. Finally, there were no significant differences between the Sauvignon Blanc variants. These variable results are consistent with the literature. In general, the treatment effects on the analysed phenols as well as the total phenolic content are very different and congruent with the results of the investigations of other grape varieties.

4.2.7. Sensory Results. In the course of this work, we employed CATA analysis to investigate the presence of typical descriptors for the respective grape varieties. For Grüner Veltliner, the testers reported increased spiciness with a strong decrease in fruitiness during MF. This correlates well with the analytical results, namely, an increased rotundone concentration and a decreased ester concentration. For Traminer, there was an increased perception of varietal aromas in the skin contact variants, which is due to the higher monoterpene concentration. In the case of Sauvignon Blanc, the varietal aromas were increased through stabulation and skin contact, which is also consistent with the analytical results. It should be noted that the experimental design does not allow for statistical testing with regard to these statements, but these results are nevertheless indicative and confirm statements from the literature with similar results on the enhancement of varietal flavours [4]. At this point, we must also mention that we only considered the flavour and aroma descriptors of the wines and not the overall sensory quality. In general, an intensification of the aroma can simultaneously lead to an increase in uncleanliness and off-flavours.

5. Conclusion

We evaluated how prefermentation skin contact and stabulation treatments of Sauvignon Blanc, Traminer, and Pinot Blanc and skin contact and MF treatments of Grüner Veltliner altered the varietal and fermentation aromas. For Grüner Veltliner, MF contributed to a strong increase in spiciness but a decrease in fruitiness and an increase in bitterness, as confirmed with the sensory and chemical-analytical approaches. Therefore, it cannot be recommended as a standard treatment, also because PMF produced these positive and negative effects to a comparable extent as FMF, and fermentation at a lower temperature (15°C) did not significantly decrease bitterness. Additional oenological methods should be evaluated to increase the spiciness to an acceptable level because this characteristic of Grüner Veltliner is threatened by climate change. Particularly in Sauvignon Blanc, stabulation produced very good

chemical-analytical results in terms of increasing the varietal aromas of thiols and MPZ. Stabulation, especially for 7 days, also improved the sensory evaluation. Overall, stabulation can be recommended if the general conditions are appropriate for Sauvignon Blanc. For Pinot Blanc and Traminer, prefermentation skin contact produced excellent chemical-analytical results. Longer prefermentation skin contact was advantageous for Traminer. The differences between all Pinot Blanc variants were the smallest of the examined grape varieties. Therefore, prefermentation skin contact is not necessarily recommended for this variety. To summarise, stabulation will not completely replace classic skin contact, and MF is certainly not an alternative for the production of standard Grüner Veltliner wine. However, additional investigations are necessary with regard to other grape varieties, terroirs, and vintages before we can make final recommendations.

Data Availability

All relevant data are included in the article or in supplementary material. The authors will be happy to provide information or additional data upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

CP was responsible for conceptualisation, methodology, supervision, validation, data curation, and original draft preparation. PE was responsible for methodology, investigation, and formal analysis. SS and KK were responsible for investigation and formal analysis. RE was responsible for resources and review and editing.

Acknowledgments

Special thanks are due to Walter Brandes, MA, and the team for support during optimisation of the analysis and method. We would also like to thank the members of the various sensory analysis panels, without whose support the realisation of this paper would not have been possible. In addition, we are grateful to a number of undergraduate students for their assistance in tasting and vinification of the wines.

Supplementary Materials

Table S1: list of abbreviations for the individual variants. Table S2: information concerning calibration and validation of volatile compounds (single ion modus methods). Table S3: information concerning calibration and validation of volatile compounds (multireaction monitoring methods). Table S4: descriptors for check-all-that-apply (CATA) analysis. Table S5: individual results for Sauvignon Blanc—significant differences are indicated by different letters in the row (Tukey B test; Benjamin–Hochberg correction, $\alpha = 0.05$ at df = 2). Table S6: individual results for Traminer—significant differences are indicated by different letters in the row (Tukey B test; Benjamin–Hochberg correction, $\alpha = 0.05$ at df = 2). Table S7: individual results Pinot Blanc—significant differences are indicated by different letters in the row (Tukey B test; Benjamin–Hochberg correction, $\alpha = 0.05$ at df = 2). Table S8: individual results Grüner Veltliner at 15°C—significant differences are indicated by different letters in the row (Tukey B test; Benjamin–Hochberg correction, $\alpha = 0.05$ at df = 2). Table S9: individual results Grüner Veltliner at 25°C—significant differences are indicated by different letters in the row (Tukey B test; Benjamin–Hochberg correction, $\alpha = 0.05$ at df = 2). Table S10: multivariate statistics for treatment and temperature for Grüner Veltliner. Table S11: mentions of the different sensory descriptors by 24 tasters for Sauvignon Blanc wines. Figure S1: biplot of the Sauvignon Blanc sensory results. SB C: control; SB 12 h SC: 12 h prefermentation skin contact; SB 24 h SC: 24 h prefermentation skin contact; SB 3D ST: 3 days stabulation; SB 7D ST: 7 days stabulation. Table S12: mentions of the different sensory descriptors by 24 tasters for Traminer wines. Figure S2: biplot of the Traminer sensory results. TR C: control; TR 12 h SC: 12 h prefermentation skin contact; TR 24 h SC: 24 h prefermentation skin contact; TR 3D ST: 3 days stabulation; TR 7D ST: 7 days stabulation. Table S13: mentions of the different sensory descriptors by 24 tasters for Pinot Blanc wines. Figure S3: biplot of the Pinot Blanc sensory results. PB C: control; PB 12 h SC: 12 h prefermentation skin contact; PB 24 h SC: 24 h prefermentation skin contact; PB 3D ST: 3 days stabulation; PB 7D ST: 7 days stabulation. Table S14: mentions of the different sensory descriptors by 24 tasters for Grüner Veltliner wines. Figure S4: biplot of the Grüner Veltliner sensory results. GV C: control; GV 12 h SC: 12 h prefermentation skin contact; GV PMF: partial mash fermentation; GV FMF: full mash fermentation. Table S15: multivariate statistics for treatment and cultivar. (*Supplementary Materials*)

References

[1] Österreich, "Österreich Wein," 2023, https://www.oesterreichwein.at/unser-wein/7-elemente.

[2] Österreich, "Riedenkarten Österreich," 2023, https://www.riedenkarten.at/1/oesterreich.

[3] Ris, "Verordnung der Bundesministerin für Nachhaltigkeit und Tourismus über Rebsorten für Qualitätswein, Landwein und Wein ohne geschützte Ursprungsbezeichnung oder geografische Angabe mit Rebsorten-oder Jahrgangsbezeichnung (Rebsortenverordnung 2018) StF: BGBl. II Nr. 184/2018: RIS-Rebsortenverordnung 2018 § 0-Bundesrecht konsolidiert, Fassung vom 06.10," 2023, https://www.ris.bka.gv.at/NormDokument.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20010268&FassungVom=2023-10-06&Artikel=&Paragraf=0&Anlage=&Uebergangsrecht=.

[4] A. Razungles, "Extraction technologies and wine quality," in *Managing Wine Quality Volume II: Oenology and Wine Quality*, A. Reynolds, Ed., pp. 28–102, Woodhead Publishing, Sawston, UK, 2022.

[5] C. S. Ough, "Substances extracted during skin contact with white musts. I. General wine composition and quality changes with contact time," *American Journal of Enology and Viticulture*, vol. 20, no. 2, pp. 93–100, 1969.

[6] R. A. Arnold and A. C. Noble, "Effect of pomace contact on the flavor of Chardonnay wine," *American Journal of Enology and Viticulture*, vol. 30, no. 3, pp. 179–181, 1979.

[7] J. O. Schmidt and A. C. Noble, "Investigation of the effect of skin contact time on wine flavor," *American Journal of Enology and Viticulture*, vol. 34, no. 3, pp. 135–138, 1983.

[8] M. Sokolowsky, A. Rosenberger, and U. Fischer, "Sensory impact of skin contact on white wines characterized by descriptive analysis, time–intensity analysis and temporal dominance of sensations analysis," *Food Quality and Preference*, vol. 39, pp. 285–297, 2015.

[9] J. Ruiz, F. Kiene, I. Belda et al., "Effects on varietal aromas during wine making: a review of the impact of varietal aromas on the flavor of wine," *Applied Microbiology and Biotechnology*, vol. 103, no. 18, pp. 7425–7450, 2019.

[10] P. Sancho-Galán, A. Amores-Arrocha, A. Jiménez-Cantizano, and V. Palacios, "Influence of the presence of grape skins during white wine alcoholic fermentation," *Agronomy*, vol. 11, no. 3, p. 452, 2021.

[11] C. Philipp, P. Eder, E. Patzl-Fischerleitner, and R. Eder, "Stabulation (lees stirring) in grape must as a method for aroma intensification: a comparison with skin contact and a classical version of Traminer and Sauvignon Blanc in Austria," *Proceedings WAC*, vol. 2022, 2022.

[12] C. Philipp, S. Nauer, P. Eder, S. Sari, and R. Eder, "Experiments with oenological methods to increase the spicy aroma in Austrian Grüner Veltliner wines," *BIO Web of Conferences*, vol. 68, 2023.

[13] V. Madžgalj, A. Petrović, U. Čakar, V. Maraš, I. Sofrenić, and V. Tešević, "The influence of different enzymatic preparations and skin contact time on aromatic profile of wines produced from autochthonous grape varieties Krstač and Žižak," *Journal of the Serbian Chemical Society*, vol. 88, no. 1, pp. 11–23, 2023.

[14] P. Darriet, C. Thibon, D. Dubourdieu, H. Gerós, M. M. Chaves, and S. Delrot, "Aroma and aroma precursors in grape berry," in *The Biochemistry of the Grape Berry*, H. Gerós, M. M. Chaves, and S. Delrot, Eds., pp. 111–136, Bentham Books, UAE, 2012.

[15] S. Nauer, W. Brandes, S. H. Elsa–Patzl-Fischerleitner, and R. Eder, "Analyse von (-)-Rotundon Mittels Spe-Spme-Gc-Ms in Österreichischen Qualitätsweinen der Rebsorte 'Grüner Veltliner," *Mitteilungen Klosterneuburg*, vol. 68, pp. 107–119, 2018.

[16] F. Mattivi, L. Caputi, S. Carlin et al., "The sesquiterpene rotundone is an impact aroma in Grüner Veltliner and other peppery wines," in *Proceedings of the 16th International Enology Symposium*, pp. 63–66, Bolzano/Bozen, Italy, July 2011.

[17] C. Philipp, P. Eder, S. Sari, N. Hussain, E. Patzl-Fischerleitner, and R. Eder, "Aromatypicity of Austrian Pinot blanc wines," *Molecules*, vol. 25, no. 23, p. 5705, 2020.

[18] V. Ferreira, A. de la Fuente, and M. P. Sáenz-Navajas, *Wine Aroma Vectors and Sensory Attributes*, A. Reynolds, Ed., pp. 3–39, Woodhead Publishing, Sawston, UK, 2022.

[19] C. Philipp, S. Nauer, S. Sari, P. Eder, E. Patzl-Fischerleitner, and R. Eder, "Quantification of 38 volatile ester compounds by means of SIDA-HS-SPME-GC-MS in 'Pinot blanc' wines and comparison with other important Austrian varieties," *Mitteilungen Klosterneuburg*, vol. 69, no. 2, pp. 93–114, 2019.

[20] C. Coetzee and W. J. du Toit, "A comprehensive review on Sauvignon blanc aroma with a focus on certain positive volatile thiols," *Food Research International*, vol. 45, no. 1, pp. 287–298, 2012.

[21] Y. He, X. Wang, P. Li et al., "Research progress of wine aroma components: a critical review," *Food Chemistry*, vol. 402, 2023.

[22] P. C. Tsai, L. D. Araujo, and B. Tian, "Varietal aromas of Sauvignon Blanc: impact of oxidation and antioxidants used in winemaking," *Fermentation*, vol. 8, no. 12, p. 686, 2022.

[23] M. M. Chigo-Hernandez, A. DuBois, and E. Tomasino, "Aroma perception of rose oxide, linalool and α-terpineol combinations in Gewürztraminer wine," *Fermentation*, vol. 8, no. 1, p. 30, 2022.

[24] G. Versini, S. Inama, and G. Sartori, "Indagine gascromatografica in colonna capillare dei costituenti terpenici del Riesling renano del Trentino Alto Adige: distribuzione dell'acino, passaggio del mosto e presenza nel vino a seconda di diverse tecniche di vinificazione. Considerazioni organolettiche [A capillary column gaschromatographic research into the terpenes constituents of Riesling Renano (Rhine Riesling) wine from Trentino Alto Adige: their distribution within berries, their passage into must and their presence in the wine according to different wine-making procedures]," *Organoleptic Considerations*, vol. 23, no. 133, pp. 189–211, 1981.

[25] J. Marais, "Terpene concentrations and wine quality of Vitis vinifera L. cv. Gewurztraminer as affected by grape maturity and cellar practices," *Vitis*, vol. 26, pp. 231–245, 1987.

[26] J. Marais and A. Rapp, "Effect of skin-contact time and temperature on juice and wine composition and wine quality," *South African Journal for Enology and Viticulture*, vol. 9, no. 1, pp. 22–30, 1988.

[27] J. Sochor, M. Baron, L. Sochorova, and M. Kumsta, "Study of the aromatic profile of traminer rot (gewürztraminer) by GC-MS," *International Journal of Biology and Biomedical Engineering*, vol. 11, pp. 55–60, 2017.

[28] G. Masson and R. Schneider, "Key compounds of Provence rosé wine flavor," *American Journal of Enology and Viticulture*, vol. 60, no. 1, pp. 116–122, 2009.

[29] N. Walsh and K. Arnedt, "Exploring the effects of stabulation in Sauvignon blanc," 2020, https://winemakersresearchexchange.com/library/fermentation/exploring-the-effects-of-stabulation-in-sauvignon-blanc-2020.

[30] S. Salemnia, "Red, white, and orange? A new look into an old wine," Doctoral dissertation, California State University, Northridge, 2019.

[31] S. Nauer, E. Patzl-Fischerleitner, C. Philipp, S. Hann, and R. Eder, "Investigation of the influence of enological factors on the Rotundone concentration of wines of the variety Gruner Veltliner," *Mitteilungen Klosterneuburg*, vol. 71, no. 3, pp. 222–239, 2021.

[32] International Organization of Vine and Wine, *OIV/OENO Resolution 390/2010*, International Organization of Vine and Wine, Dijon, France, 2010.

[33] C. Philipp, S. Sari, P. Eder, E. Patzl-Fischerleitner, and R. Eder, "Austrian Pinot blanc wines: typicity, wine styles and the influence of different oenological decisions on the volatile profile of wines," *BIO Web of Conferences*, vol. 15, 2019.

[34] K. Šuklje, G. Antalick, A. Buica et al., "Clonal differences and impact of defoliation on Sauvignon Blanc (Vitis vinifera L.) wines: a chemical and sensory investigation," *Journal of the Science of Food and Agriculture*, vol. 96, no. 3, pp. 915–926, 2016.

[35] A. K. Hjelmeland, P. L. Wylie, and S. E. Ebeler, "A comparison of sorptive extraction techniques coupled to a new quantitative, sensitive, high throughput GC–MS/MS method for methoxypyrazine analysis in wine," *Talanta*, vol. 148, pp. 336–345, 2016.

[36] C. Coetzee, A. Schulze, L. Mokwena, W. J. Du Toit, and A. Buica, "Investigation of thiol levels in young commercial South African Sauvignon Blanc and Chenin Blanc wines using propiolate derivatization and GC-MS/MS," *South African Journal for Enology and Viticulture*, vol. 39, no. 2, pp. 180–184, 2018.

[37] U. Vrhovsek, S. Wendelin, and R. Eder, "Quantitative bestimmung von hydroxyzimtsäuren und hydroxyzimtsäurederivaten (hydroxycinnamaten) in Weißweinen mittels HPLC," *Mitteilungen Klosterneuburg Rebe und Wein, Obstbau und Früchteverwertung*, vol. 47, no. 5, pp. 164–172, 1997.

[38] S. Berghold, S. Wendelin, and R. Eder, "Comparison of two sample preparation methods for analyses of grape phenols with HPLC. Mitteilungen Klosterneuburg, Rebe und Wein," *Obstbau und Früchteverwertung*, vol. 68, no. 4, pp. 241–249, 2018.

[39] A. L. Waterhouse, "Determination of total phenolics," *Current Protocols in Food Analytical Chemistry*, vol. 6, no. 1, pp. I1.1.1–I1.1.8, 2002.

[40] E. Derndorfer and E. Buchinger, *Schnellmethoden der Lebensmittelsensorik*, Springer Spektrum, Cham, 2020.

[41] D. Thissen, L. Steinberg, and D. Kuang, "Quick and easy implementation of the Benjamini-Hochberg procedure for controlling the false positive rate in multiple comparisons," *Journal of Educational and Behavioral Statistics*, vol. 27, no. 1, pp. 77–83, 2002.

[42] O. Geffroy, T. Siebert, A. Silvano, and M. Herderich, "Impact of winemaking techniques on classical enological parameters and rotundone in red wine at the laboratory scale," *American Journal of Enology and Viticulture*, vol. 68, no. 1, pp. 141–146, 2017.

[43] T. Fauster, C. Philipp, K. Hanz et al., "Impact of a combined pulsed electric field (PEF) and enzymatic mash treatment on yield, fermentation behaviour and composition of white wine," *European Food Research and Technology*, vol. 246, no. 3, pp. 609–620, 2020.

[44] L. Caputi, S. Carlin, I. Ghiglieno et al., "Relationship of changes in rotundone content during grape ripening and winemaking to manipulation of the 'peppery' character of wine," *Journal of Agricultural and Food Chemistry*, vol. 59, no. 10, pp. 5565–5571, 2011.

[45] O. Geffroy, D. Kleiber, and A. Jacques, "Peppery wines be the spice of life? A review of research on the 'pepper' aroma and the sesquiterpenoid rotundone," *OENO One*, vol. 54, no. 2, pp. 245–262, 2020).

[46] T. E. Siebert and M. Solomon, "Rotundone: development in the grape and extraction during fermentation," in *Proceedings of the 14th Australian Wine Industry Technical Conference*, Adelaide, Australia, July 2010.

[47] H. Takase, K. Sasaki, H. Shinmori et al., "Analysis of rotundone in Japanese Syrah grapes and wines using stir bar sorptive extraction (SBSE) with heart-cutting two-dimensional GC-MS," *American Journal of Enology and Viticulture*, vol. 66, no. 3, pp. 398–402, 2015.

[48] G.A. Logan, "Rotundone in New Zealand Vitis vinifera L. Syrah: fruit, fermentation and functional food chemistry," Doctoral dissertation, University of Auckland, Auckland, New Zealand, 2015.

[49] T. Tominaga, A. Furrer, R. Henry, and D. Dubourdieu, "Identification of new volatile thiols in the aroma of Vitis vinifera L. var. Sauvignon blanc wines," *Flavour and Fragrance Journal*, vol. 13, no. 3, pp. 159–162, 1998.

[50] S. Carlin, M. Piergiovanni, E. Pittari et al., "The contribution of varietal thiols in the diverse aroma of Italian monovarietal white wines," *Food Research International*, vol. 157, 2022.

[51] J. L. Aleixandre-Tudo, C. Weightma, H. Nieuwoudt, W. du Toit, and W. J. Du Toit, "Effect of skin contact before and during alcoholic fermentation on the chemical and sensory profile of South African Chenin blanc white wines," *South African Journal for Enology and Viticulture*, vol. 36, no. 3, pp. 366–377, 2015.

[52] M. L. Murat, I. Masneuf, P. Darriet, V. Lavigne, T. Tominaga, and D. Dubourdieu, "Effect of *Saccharomyces cerevisiae* yeast strains on the liberation of volatile thiols in Sauvignon blanc wine," *American Journal of Enology and Viticulture*, vol. 52, no. 2, pp. 136–139, 2001.

[53] C. Peyrot des Gachons, T. Tominaga, and D. Dubourdieu, "Sulfur aroma precursor present in S-glutathione conjugate form: identification of S-3-(hexan-1-ol)-glutathione in must from Vitis vinifera L. cv. Sauvignon blanc," *Journal of Agricultural and Food Chemistry*, vol. 50, no. 14, pp. 4076–4079, 2002.

[54] A. Roland, R. Schneider, A. Razungles, and F. Cavelier, "Varietal thiols in wine: discovery, analysis and applications," *Chemical Reviews*, vol. 111, no. 11, pp. 7355–7376, 2011.

[55] J. Ting, "Varietal thiols in wine: interventions in the vineyard and winery," 2020, https://wine-makersresearchexchange.com/learn/varietal-thiols-in-wine-interventions-in-the-vineyard-and-winery.

[56] F. R. Pinu, S. Jouanneau, L. Nicolau, R. C. Gardner, and S. G. Villas-Boas, "Concentrations of the volatile thiol 3-mercaptohexanol in Sauvignon blanc wines: no correlation with juice precursors," *American Journal of Enology and Viticulture*, vol. 63, no. 3, pp. 407–412, 2012.

[57] P. Alberts, M. A. Stander, S. O. Paul, and A. de Villiers, "Survey of 3-Alkyl-2-methoxypyrazine content of South African Sauvignon blanc wines using a novel LC– APCI-MS/MS method," *Journal of Agricultural and Food Chemistry*, vol. 57, no. 20, pp. 9347–9355, 2009.

[58] C. Sala, O. Busto, J. Guasch, and F. Zamora, "Influence of vine training and sunlight exposure on the 3-Alkyl-2-methoxypyrazines content in musts and wines from the*Vitis vinifera*variety Cabernet Sauvignon," *Journal of Agricultural and Food Chemistry*, vol. 52, no. 11, pp. 3492–3497, 2004.

[59] Y. Kotseridis, M. Spink, I. D. Brindle et al., "Quantitative analysis of 3-alkyl-2-methoxypyrazines in juice and wine using stable isotope labelled internal standard assay," *Journal of Chromatography A*, vol. 1190, no. 1-2, pp. 294–301, 2008.

[60] G. Versini, S. Inama, and G. Sartori, "A capillary column gaschromatographic research into the terpene constituents of Riesling Renano (Rhine Riesling) wine from Trentino Alto Adige: their distribution within berries, their passage into must and their presence in the wine according to different wine-making procedures," *Organoleptic Considerations*, vol. 23, pp. 189–211, 1981.

[61] J. Marais, "Terpenes in the aroma of grapes and wines: a review," *South African Journal for Enology and Viticulture*, vol. 4, no. 2, pp. 49–58, 2017.

[62] J. Maraisa and A. Rapp, "Effect of skin-contact time and temperature on juice and wine composition and wine quality," *South African Journal for Enology and Viticulture*, vol. 9, no. 1, pp. 22–30, 2017.

[63] I. Lukić, C. Lotti, and U. Vrhovsek, "Evolution of free and bound volatile aroma compounds and phenols during fermentation of Muscat Blanc grape juice with and without skins," *Food Chemistry*, vol. 232, pp. 25–35, 2017.

[64] G. Antalick, M. C. Perello, and G. de Revel, "Development, validation and application of a specific method for the quantitative determination of wine esters by headspace-solid-phase microextraction-gas chromatography–mass spectrometry," *Food Chemistry*, vol. 121, no. 4, pp. 1236–1245, 2010.

[65] T. Cabaroglu and A. Canbas, "The effect of skin contact on the aromatic composition of the white wine of Vitis vinifera L. cv. Muscat of Alexandria grown in Southern Anatolia," *Acta Alimentaria*, vol. 31, no. 1, pp. 45–55, 2002.

[66] M. Maggu, R. Winz, P. A. Kilmartin, M. C. Trought, and L. Nicolau, "Effect of skin contact and pressure on the composition of Sauvignon Blanc must," *Journal of Agricultural and Food Chemistry*, vol. 55, no. 25, pp. 10281–10288, 2007.

[67] S. Selli, A. Canbas, T. Cabaroglu, H. Erten, and Z. Günata, "Aroma components of cv. Muscat of Bornova wines and influence of skin contact treatment," *Food Chemistry*, vol. 94, no. 3, pp. 319–326, 2006.

[68] J. L. Robichaud and A. C. Noble, "Astringency and bitterness of selected phenolics in wine," *Journal of the Science of Food and Agriculture*, vol. 53, no. 3, pp. 343–353, 1990.

[69] U. Fischer and A. C. Noble, "The effect of ethanol, catechin concentration, and pH on sourness and bitterness of wine," *American Journal of Enology and Viticulture*, vol. 45, no. 1, pp. 6–10, 1994.

[70] Z. Bene and M. Kállay, "Polyphenol contents of skin-contact fermented white wines," *Acta Alimentaria*, vol. 48, no. 4, pp. 515–524, 2019.