applied sciences

MDPI

Review

Pre-Fermentative Cryogenic Treatments: The Effect on Aroma Compounds and Sensory Properties of Sauvignon Blanc and Chenin Blanc Wine—A Review

Valmary M. van Breda [1,2,*], Francois P. van Jaarsveld [2] and Jessy van Wyk [1]

[1] Department of Food Science and Technology, Cape Peninsula University of Technology, Bellville 7535, South Africa; vanwykj@cput.ac.za
[2] Post-Harvest and Agro-Processing Technologies Division, Agricultural Research Council Infruitec-Nietvoorbij, Stellenbosch 7599, South Africa; vjaarsveldf@arc.agric.za
* Correspondence: vbredav@arc.agric.za; Tel.: +27-21-809-3039

Highlights:

- **Pre-fermentative** cryogenic treatments as a tool to increase the varietal thiol levels in Sauvignon blanc and Chenin blanc wines.
- **Cryogenic** pre treatment technologies as an innovative method for wine production.

Abstract: Low-temperature treatments preceding alcoholic fermentation are becoming increasingly popular and have been used in winemaking as a tool to improve wine colour, aroma, and quality. Additionally, the pre-fermentative treatment of grapes with cryogenic agents protects the grape juice (must) from oxidation by reducing the diffusion of atmospheric oxygen into the liquid phase during the winemaking process. Resultant wines were reported to have enhanced varietal aromas, increased complexity, and higher thiol levels. Indications are that increased contact time between skin and juice improves the extraction of the compounds and/or precursors. Recently, there has been considerable interest in the production of wines with enhanced varietal aromas and improved quality by applying innovative winemaking technologies. This review aims to provide an overview of the aroma and organoleptic quality of Sauvignon blanc and Chenin blanc wines produced from grapes that were subjected to pre-fermentative cryogenic treatments including the impact aroma compounds, i.e., volatile thiols and methoxypyrazines.

Keywords: varietal thiols; cryogenic technologies; sensory analysis; methoxypyrazines; Sauvignon blanc; Chenin blanc

check for updates

Citation: van Breda, V.M.; van Jaarsveld, F.P.; van Wyk, J. Pre-Fermentative Cryogenic Treatments: The Effect on Aroma Compounds and Sensory Properties of Sauvignon Blanc and Chenin Blanc Wine—A Review. *Appl. Sci.* **2024**, *14*, 1483. https://doi.org/10.3390/app14041483

Academic Editors: Monica Gallo and Alessandro Genovese

Received: 16 October 2023
Revised: 3 February 2024
Accepted: 6 February 2024
Published: 12 February 2024

1. Introduction

Wine complexity and sensory quality can be attributed to many flavour compounds from several sources and wine production practices, i.e., grape variety, viticulture, oenology, and climatic conditions [1–3]. These practices are known to influence the development and concentration of flavour compounds within the grape berry during and after ripening and throughout processing and organoleptic quality of the wine [4–7]. The grapevine species *Vitis vinifera* has between 5000 and 10,000 different varieties; however, only a fraction of the varieties have commercial significance for wine and table grape production [8,9]. Though each grape variety has its unique characteristics, the wine producer has the ability to utilise agricultural practices and winemaking technologies to influence the chemical composition of the grape berry and the organoleptic profiles of the wines [1,2,10].

Viticultural and oenological practices are of great importance to the levels of flavour compounds in the grape berry whilst yeast strains used for fermentation influence the final wine organoleptic quality [11–14]. Parr et al. [11] demonstrated the association between viticultural and oenological factors and their effect on the final expression of Sauvignon blanc wines from New Zealand, particularly related to vineyard location, vineyard row orientation, and grape processing operation (hand vs. machine harvesting). Cerreti et al. [15] found that the S-cysteinylated and S-glutathionylated thiol precursors increased with total soluble solids during grape ripening, in high-flavour cultivars, such as Sauvignon blanc, and in a moderate-flavour cultivar, such as Grechetto. No differences were observed in the precursor compounds related to berry ripening in a low-flavour cultivar such as Malvasia del Lazio. Moreover, they were the first to identify and quantify S-3-(4-methyl-4-sulfanyl-pentan2-ol)-glutathione in all three cultivars as a glutathione-conjugated precursor of 4-methyl-4-sulfanylpentan-2-ol (4MSPOH). Rice et al. [16] reported on the differences found in the aroma profiles of Brianna and Frontenac Gris (white grape cultivars) wines when harvested at different degrees of ripeness, which directly influenced the variation in key odour-active compounds for both cultivars.

Fungal diseases, i.e., downy mildew and powdery mildew, are known to negatively affect the grapevine and the grape berry composition [17]. Therefore, fungicides are used as standard viticultural management practices to control such fungal growth but could influence the grape aroma compounds and wine quality [17,18]. Research conducted by Dzedze et al. [18] on Chenin blanc grapes treated with different chemical sprays, i.e., Methyl-1H-pyrazole carboxylic acid phenylethyl amide, boscalid, and penconazole, with an extract of *Gelania Africana* highlighted that the different sprays affected wine yeast protein expression. This is important because yeast-derived proteins are needed to release certain wine-aroma-enhancing compounds (metabolites), particularly volatile thiols, during fermentation, therefore influencing the aroma profile of the wine [14,19]. Differences in metabolite levels meant that the fungicide treatments affected the yeast's ability to express proteins, which influenced the wine's aroma and flavour [18]. Although fungi are generally associated with spoilage of wine grapes, *Botrytis cinerea* (grey mould) causes noble rot under favourable conditions to produce botrytised wines [20–23]. Previous studies found that wines made from botrytised grapes had significant amounts of volatile thiols, especially 3-SH, largely due to the concentration effect that *Botrytis* has on the grape berries [21–23].

Moreover, grape growers and winemakers are continuously confronted with new challenges as climate change affects grape physiology and viticultural practices. These, in addition to advances in winemaking technologies, influence the development of varietal aroma and flavour metabolites in wines [24,25]. Numerous volatile aroma compounds are formed during the processing of grapes and grape juice (must), which contribute to the aroma of the wine together with the primary aromas to form the typical varietal aromas [10,24,25]. Therefore, winemakers should consider interactions between viticultural (climate, soil, water, cultivar, and grape-growing practices) and oenological (pre-fermentation treatments, and post-fermentation treatments) practices to produce wines with sought-after organoleptic quality, as opposed to exclusively focusing on the contribution of the cultivar type [26–30]. Of particular interest are studies where low-temperature, pre-fermentative maceration was applied to white wine grapes to increase contact between grape skins and juice. This allowed for an increased extraction of aroma compounds and their precursors that are mainly located in the skin of the grape berries [29–35].

The cold maceration process is used during white wine production to enhance the varietal character of the wines [32,33,36–38]. Although cold maceration increases the concentration of aromatic compounds, it also extracts components that can cause undesirable characteristics [33,35]. A modification of this technique, known as cryofreezing or cryoextraction, involves the freezing of grapes [39–41]. Wines produced using this method had a higher aroma intensity and better stability of taste properties than wines prepared using traditional maceration [31,41]. The perceived enhanced varietal taste and aromas of the wines resulted from the cryogenically frozen grapes, which were buffered from oxidation as well as undesirable odour compounds. Wines were acceptable, well balanced, and better-rounded, with a fuller mouthfeel [31–35].

Most studies produced inconclusive results as no direct correlation between the levels of precursors in grapes and the levels of varietal thiols in wine was found [26,30,34,36].

Consequently, vineyard and/or winemaking technologies for enhancing such aroma compounds in wines are required. Moreover, the use of low-temperature treatment of grapes using cryogenic technologies has the potential to be a useful option for the wine industry, based on the use of cryogenic processing technologies applied in other beverage industries, i.e., fruit juice, coffee, tea extract, and aroma extract industries [42–48]. Therefore, this review aims to provide an overview of wine technological processes, with an emphasis on pre-fermentative cryogenic treatment and its influence on grape aroma compounds linked to the aroma and organoleptic quality of Sauvignon blanc and Chenin blanc wine.

2. Cryogenic Technologies

Pre-fermentative cold maceration is a technique used during white wine production, to enhance the varietal character of the wine [25,31,35]. The treatment involves subjecting whole grapes and macerated grapes to rapid cooling (5 °C and below) and holding it at the desired temperature for hours or days, thus improving the extraction of compounds (phenolic compounds and primary aroma) contained within the grape skins [35–40]. Cryoextraction or cryofreezing is a modification of this conventional cold maceration process and involves the freezing of grape berries [41]. During the freezing process, grapes are frozen and ice crystals are formed, which tear the pectocellulose walls, disorganizing the tissues, thus facilitating the extraction of compounds from the grape skin [32]. Cryogenic treatments have been applied using various methods, i.e., large-capacity refrigerators/chambers, freeze-concentration technology, blast-freezing, or by adding cryogenic agents in a solid or liquid state, i.e., nitrogen (N_2) or carbon dioxide (CO_2) [32,40] (Table 1).

Conventional freezing involves the use of large refrigerators/chambers for cooling/freezing. However, this leads to increased costs and energy consumption due to cooling taking place at a much slower rate, ranging from hours to days [32,41]. Consequently, this increases the risk of the development of undesirable flavours due to continuous biochemical changes taking place within the grape berry as well as the risk of oxidation [42]. In addition, during conventional or slow freezing, large ice crystals are formed, which damage cells in the berry; therefore, the speed of freezing should be considered when applying this technique. Nonetheless, conditions can be controlled when using large freezing chambers, which reduces the extraction of bitter tannins transferred to the wine [42].

Freeze-concentration is a technology involving solid–liquid phase separation at low temperatures (<0 °C) for recovering a food solute from a solution, based on the separation of pure ice crystals from a freeze-concentrated liquid phase [43,44,48]. The process takes place at low temperatures, therefore resulting in high-quality concentrates since heat-sensitive volatile compounds are protected. The process involves three steps, ice crystal formation, ice crystal growth, and the separation of ice crystals from the solution. Based on ice crystal formation, two methods of freeze-concentration exist, i.e., suspension freeze-concentration and progressive freeze-concentration [47]. Following suspension freeze-concentration, fewer soluble solids remain in the ice crystal, making this technology easier to use on an industrial scale [49]. This technology can be valuable for the wine industry because the process is conducted at a low temperature where no vapour/liquid interface exists, therefore resulting in a minimal loss of volatiles [44,48].

Table 1. Summary of the cryogenic technologies used in winemaking and the effect on targeted aroma compounds.

Cryogenic Technology	Temperature (°C)/Time	Advantages	Disadvantages	Aroma Compounds Affected	Resultant Increase/ Decrease	References
Large capacity refrigerators	−8 to −20/9 h to 4 months	Cool large quantities of grapes/must/juice Conditions can be controlled	Increased costs and energy consumptionSlower rate of cooling Increased risk of undesirable flavour development	Bitter tannins	Decreases	[32,34,41,42,50]
Freeze-concentration	<0/10 min to 12 h	Wines produced from concentrated grape juice were superior in terms of chemical and sensory profiles Wineries with fermentation tanks with cooling systems have the potential to perform freeze-concentration without purchasing new equipment	High energy consumption, depending on the technology applied	Volatiles	Increase	[40,42–49]
Blast-freezing	−10 to −120/<25 min to 20 h	Allows for quick freezing of grape berries, <25 min	High energy consumption	Proanthocyanidins	Increase	[42,51,52]
Cryogenic agents, i.e., carbon dioxide (CO_2) and nitrogen (N_2)	−20/8 s to 24 h	Creates an inert atmosphere, protecting the grapes from oxidation Final wines were more aromatic than control wines	Increased cost	Terpenoids, hydroxylic compounds, fatty acids, anthocyanins	Increase	[32,36,42,53,54]

Most wineries have fermentation tanks with cooling systems in which ice can be crystallised and, therefore, have the potential to perform freeze-concentration without purchasing new equipment [47]. Zhang et al. [39] used suspension freeze technology to concentrate grape juice and discovered that wines produced from the concentrated grape juice were superior to control wines in terms of chemical and sensory profiles.

Blast-freezing is a rapid freezing technique used to preserve food before transportation and has also been used as a pre-fermentation treatment in the wine industry [42]. During the conventional freezing process, water within the food structure crystallises and forms large ice crystals, which cause the cell walls of food materials to burst, affecting the food quality and flavour [51]. The speed of freezing is, therefore, an important aspect to consider, since it is directly related to the degree of the disorganisation of the food and in the case of grapes, the berry structure [42,51]. Rapid freezing within a blast-freezer causes the formation of very small ice crystals, which causes less damage and preserves food at a higher quality [53]. Blast-freezing used as a pre-fermentative cryogenic treatment for wine grapes is conducted by blasting cold air with temperatures ranging between −10 °C and −120 °C directly onto whole grape bunches. This freezing method allows all individual berries to be frozen within 1–2 h [42,51].

Cryogenic agents, i.e., carbon dioxide (CO_2) and nitrogen (N_2), are commonly added to whole grapes before crushing or during crushing in a solid state (dry ice or solid CO_2) or using the direct injection of the cryogenic agent in liquid form [32]. The use of both these cryogens, solid CO_2 and liquid N_2, induces a thermal shock, leading to an increase in the degradation of the cell structure of grape berries [29,32,42]. This is advantageous as it prolongs the contact time between the grape pulp and must, thus protecting the grapes from oxidation [42]. If dry ice is used for the pre-fermentation skin contact, the cell walls are disrupted and "disorganised", which enables the extraction of compounds located within the grape skin [32]. The freezing process causes an increase in the intracellular liquids, therefore disrupting the membranes, allowing for the release of aromatic and phenolic compounds. Cryomaceration with cryogens was found to be the most effective method because they are heavier than oxygen, they displace the air, and they create an inert atmosphere, protecting the grapes from oxidation [32,42].

3. Effect of Cryogenic Technologies on Physicochemical and Aroma Compounds of Grape Must and Wine

3.1. Physicochemical Parameters

Total soluble solids (TSSs) of must were shown to be the least affected by freezing, as no difference was observed for storage periods less than six months [25,35,42,50,51]. However, in a study conducted by the authors of [32], different freezing techniques, i.e., involving liquid nitrogen as opposed to ultra-fast mechanical freezing, resulted in significant differences in TSS values. Total acidity (TA) of grape must was lower in cryogenic-treated samples, which validated the earlier findings of Olarte Mantilla et al. [50], Santesteban et al. [42], and Zhang et al. [25]. This was related to the precipitation of potassium (K^+) salts during the freezing process and the lower solubility of acidic salts during defrosting of the grapes. Additionally, higher pH levels observed in must obtained after freezing and defrosting complemented previous studies [25,32,35,42,51]. Moreover, the chemical parameter most affected by freeze storage was found to be titratable acidity [35].

Research conducted by Naviglio et al. [51] and Naranjo et al. [52] involved the rapid cooling of Bianchello del Metauro grapes by sparging the grapes with liquid CO_2 before crushing and destemming. The white wines produced from these treated grapes were not statistically different from the control wines in terms of alcohol, pH, titratable acidity, and volatile acidity [55,56]. This was similar to findings observed in earlier research. However, significant differences were observed for malic acid [42,51]. Previous research showed that the physicochemical parameters of wine produced from fresh and frozen grapes as well as grape juice had significant differences in tartaric acid, but not alcohol content [42,51].

Moreover, studies conducted by Zhang et al. [25] and Pedrosa-López et al. [34] found differences in alcohol levels in final wines produced from previously frozen whole grapes and macerated grapes. These differences were attributed to the extraction of compounds, which affected the fermentation process. Zhang et al. [25] further found that wines produced from cold-macerated grapes had higher pH and glycerol levels compared to the control and skin-macerated treatments. This is similar to previous findings [42,51], although it differed from the findings of Carillo et al. [36] and other research, which showed that wines produced from grapes subjected to cold maceration did not show significant differences in chemical parameters when compared to the control [32,35,38,51].

It should, however, be noted that these effects were not necessarily only due to the freezing treatment but resulted from the storage time, duration of skin contact, and grape cultivar [25,32,42]. Furthermore, the type of cryomaceration treatment applied as well as type of berries used, i.e., whole berries or macerated grapes or juice, influence must and wine physicochemical parameters as conflicting results were observed between studies [25,32]. Furthermore, this was not the focus of this review and will not be further discussed.

3.2. Effect of Cryogenic Technologies on Grape Aroma Compounds

Aroma compounds or odourants can be classified according to the different stages of wine grape and/or juice processing that they originated from (Table 2), namely varietal (cultivar), pre-fermentative (processing), fermentation (yeast and bacteria during alcoholic and malo-lactic fermentation), and post-fermentation (aging and maturation in wood, wine bottle storage, and preservation) aromas [6,7,57]. These compounds are often present in the grape as odourless or non-volatile precursors and are released during winemaking, specifically during the alcoholic fermentation process [57,58].

The three major classes of odourants that contribute significantly to varietal characteristics in wines are monoterpenes, methoxypyrazines, and volatile thiols [28,59]. Volatile thiol compounds, also considered impact odourants, can either have a positive (tropical-, passionfruit-, guava-like) or negative influence (rotten egg, cooked vegetables, onion, cabbage) depending on their concentration in wines [60]. Other compounds also present in wine and found to play a significant role in its aroma are esters, fatty acids, higher alcohols, and aldehydes [28,57,61].

Table 2. Aroma development stage, compounds, and their origin.

Aroma Development Stage	Compound	Origin
Varietal	Precursors (free or bound)	Grape berry (skin and pulp)
Pre-fermentative	C_6 compounds	Enzymatic/catalytic reactions due to processing (crushing of berries)
Fermentation	Ethyl esters, fusel alcohols, fatty acids, thiols	Microorganism metabolism (yeast and bacterial)
Post-fermentation	Oxidation of volatile aroma compounds; increase in fatty acids, esters, aldehydes, ketones, and polyphenols	Wine aging (bottle, barrel, storage, aging on lees)

Adapted from [28,62].

Over the past three decades, there has been considerable interest and research into the volatile thiol aroma compounds and their precursors [57,60,62]. Grape aroma compounds are predominantly located in the grape skin and require an extraction process to be released. The extraction of a compound is dependent on the nature of the compound, the concentration in the berry, the location within the berry, and the method used during processing [63–65]. Winemakers usually achieve this by using a maceration step whereby the compounds are transferred from the solid components to the juice. Pre-fermentative cold maceration is another technique that has gained popularity during the white wine production process and was shown to enhance the varietal character of the wines produced [29,31,34].

Research conducted by Carillo et al. [36] showed significant differences in phenolic acid (gallic, caftaric, coutaric, caffeic, and syringic acid) and polyphenol concentrations between wines produced from frozen and fresh grapes. Zhang et al. [25], Naviglio et al. [51], and Ruiz-Rodríguez et al. [31] had similar observations regarding polyphenol concentrations, which confirms the earlier findings. Ruiz-Rodríguez et al. [31] found significant differences in acetaldehyde concentrations between their wines, which supported earlier research. Ouellet and Pedneault [63] investigated the impact of frozen storage on 22 free volatile compounds of two table grape varieties, i.e., Thompson Seedless and Flame Seedless. The free volatile compound profile of the frozen grapes and juice was significantly different from the fresh juice [63]. It was further shown that the different freezing treatments affected the volatile profiles of juice differently and that the grape variety played a role. When analysing the volatile profiles of grape juice, fresh juice is preferable to frozen juice [63]. However, should long-term storage be required, storage under liquid N_2 or at a temperature of -80 °C is advised to reduce biochemical reactions from altering the free volatile compounds [63]. Alti Palacious et al. [29] and Pedrosa-López et al. [34] found that extractable anthocyanins, total phenolics, and terpenic alcohols were among the compounds most affected by the freezing process. Alti Palacious et al. [29] further found that the differences observed in the concentration of aroma compounds in their research between vintages could be more related to climatic and geographical factors.

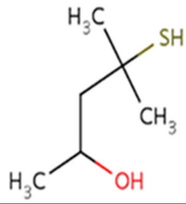
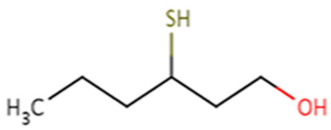
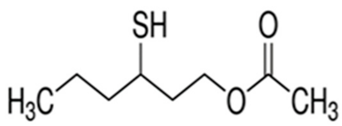
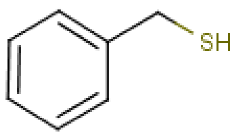
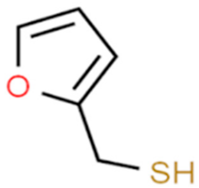
3.3. Effect of Cryogenic Technologies on Varietal Thiols

Varietal thiols are sulphur compounds found in grapes in a bound form that originate from fatty acids [6,19]. These sulphur-containing compounds are originally associated with off-odours resulting from hydrogen sulphide (H_2S), methylmercaptan (methanethiol), ethanethiol, and methionol [58]. They are considered the main compounds involved in the aroma of wine and responsible for its archetypal flavour [30]. These volatile sulphur compounds are typically divided into two categories, i.e., highly volatile compounds, most of which are associated with aroma defects (carbon sulphide, ethanethiol, methanethiol, hydrogen sulphide), and low-volatile compounds, including the main desirable sulphur compounds that contribute to the enhancement of the sensorial quality of wines. Thiols are "bound" with glutathione or cysteine and released by the yeast during the fermentation process via the carbon–sulphur lyase (C-S) enzyme. Therefore, the quantification of their natural precursors in the must is important and can help the wine producer determine the aromatic potential of the grapes. An accurate quantification of these natural and deuterated compounds, i.e., 4-sulfanyl-4-methylpentan-2-one precursors (S-4-(4-methylpentan-2-one)-L-cysteine and S-4-(4-methylpentan-2-one)-glutathione), is achieved using SIDA (stable isotope dilution assay) that involves labelled analogues [6,64]. Key thiols present in Sauvignon blanc and responsible for its varietal aromas are 4-methyl-4-sulfanylpentan-2-one (4-MSP), 3-sulfanylhexan-1-ol (3-SH), and 3-sulfanylhexyl acetate (3-SHA) with perception thresholds of 0.8 ng L^{-1}, 60 ng L^{-1}, and 4 ng L^{-1}, respectively (Table 3). They are predominantly responsible for the "tropical" (gooseberry, grapefruit, and passion fruit) characteristics associated with Sauvignon blanc [56]. However, it is interesting to note that when present in excessive concentrations, they often impart less desirable strong, sweaty aromas resembling "cat urine" [54,56]. Furthermore, research conducted on South African (SA) Chenin blanc revealed the presence of the varietal thiols 3-SH and 3-SHA in concentrations above their aroma thresholds, indicating that these two compounds also contribute significantly to the aroma of Chenin blanc wines [65–67].

Varietal thiols are present in grape juice in the form of aroma-inactive, non-volatile precursors and are released by yeast enzymes during the fermentation process [12,38,56,68–70]. Pinu et al. [58] showed that the production of varietal thiols and other aroma compounds in Sauvignon blanc wines is not necessarily only dependent on nitrogenous and sulphur compounds but is also influenced by other juice metabolites such as carboxylic and fatty acids. Their research demonstrated that concentrations of wine aroma compounds can be modified using pre-fermentative treatments to produce different wine styles from the same grape varietal based on the metabolic profile of the juice, thus altering the metabolite levels. In addition, juice modulation through new winemaking practices, i.e., metabolite supplementation or blending, could be seen as a useful tool to create new wine styles [58].

Pre-fermentative cold maceration has gained popularity in white wine production as it was shown to enhance the varietal characteristic of the wines [30,34,54]. Two volatile precursors of 3-SH (3-S-cysteinylhexan-1-ol (Cys-3-SH) and 3-S-glutathionylhexan-1-ol (Glut-3-SH) were significantly higher in frozen thawed berries than in the juice of fresh berries as well as in the frozen juice of fresh berries [30,34]. Glut-3-SH was fourfold higher in frozen grapes stored at −20 °C for two months compared to that found in frozen or fresh juices [30,34]. Capone et al. [71,72] made similar observations where a fivefold difference was found in precursor concentrations between freezing whole grapes and freezing juice, especially for the Glut-3-SH precursor, whilst no significant difference was found in the concentrations of the Cys-3-SH precursor. These results revealed that berry damage was the primary cause of the differences, and the major contributor was the glutathione conjugate formation rather than the extraction process resulting from the freezing and thawing processes [71,72]. The results suggested that the Cys-3-SH precursor was already present in the grape berry whereas the Glut-3-SH precursor was formed because of berry damage [71,72]. Although numerous studies have been conducted using cryogenic pre-treatment techniques on whole grapes and grape juice, their focus was on the overall aroma compounds and precursor formation in the grape juice. However, the effect of such treatments shows no direct relationship between the levels of precursors in the grape juice and the levels of varietal thiols in the wine. Therefore, this warrants further investigation and understanding [30,34,53,71–73].

Table 3. Varietal thiols present in Sauvignon blanc and Chenin blanc wines: aroma description, perception, and range in wine.

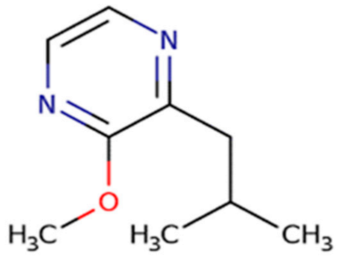
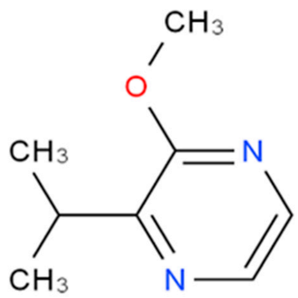
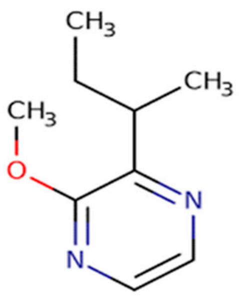
Cultivar	Compound & Chemical Structure	Aroma Description	Aroma Perception in Wine (ng L^{-1})	Range in Wine (ng L^{-1})	Range in SA [1] Wine (ng L^{-1})
Sauvignon blanc	4–methyl–4–sulfanylpentan–2–one (4MSP) 	Boxwood, blackcurrant	0.8	0–88	0–21.9
Chenin blanc				0–23	n.d. *
Sauvignon blanc	3–sulfanylhexyl acetate (3SHA) 	Passionfruit, tropical, boxwood	4	0–106	23–151
Chenin blanc				0–100	5–253
Sauvignon blanc	3–sulfanylhexan–1–ol (3SH) 	Grapefruit, tropical, passionfruit	60	350–5664	178–904
Chenin blanc				10–1368	99–1124
Sauvignon blanc	benzyl mercaptan (BM) 	Smoke, toasty, struck flint	0.3	0.6–5.5	n.d. *
Chenin Blanc				30–40	n.d. *
Sauvignon blanc	2–furfurylthiol (FFT) 	Roasted Coffee	0.4	1–36	n.d. *
Chenin blanc				14	n.d. *

[1] South Africa * Not detected; adapted from [53,57,70].

3.4. Effect of Cryogenic Technologies on Methoxypyrazines

Methoxypyrazines (MPs) are volatile nitrogen-containing heterocyclic compounds found in plants, insects, fungi, and bacteria [74,75]. They are primarily responsible for the vegetative, grassy, green pepper, capsicum, and asparagus aromas present in Sauvignon blanc [6,28,75,76]. The perception of green attributes is seen as positive and adds complexity to Sauvignon blanc [28,76,77]. The most essential MP found in grapes and wines is 2-methoxy-3-*iso*butylpyrazine (ibMP), the main contributor to the vegetative, grassy, green pepper, capsicum, and asparagus aromas in Sauvignon blanc [28,74–77]. It is typically present in wine as free volatile compounds in concentrations ranging from 2 to 30 ng L^{-1} (Table 4).

Table 4. Methoxypyrazines present in Sauvignon blanc wines: aroma description, perception, and range in wine.

Compound & Chemical Structure	Aroma Description	Aroma Perception in Water (ng L^{-1})	Aroma Perception in Wine (ng L^{-1})	Range in Wine (ng L^{-1})
2–methoxy–3–*iso*butylpyrazine (ibMP) 	vegetative, green pepper	1–2	2–163	2–30
2–methoxy–3–*iso*propylpyrazine (ipMP) 	earthy, mushroom, cooked, or canned asparagus, green beans	1–2	2–16	<10
2–methoxy–3–sec–butylpyrazine (sbMP) 	green (peas, bell pepper, galbanum), ivy leaves, bell pepper	1–2	2–16	<10

Adapted from [28,74–76].

Moreover, two additional MPs present in must and wine at lower concentrations are 2-methoxy-3-*iso*propylpyrazine (ipMP) and 2-methoxy-3-*sec*-butylpyrazine (sbMP), which contribute to the earthy, asparagus aromas [28,74,75]. Sensory detection thresholds for ibMP, ipMP, and sbMP are typically very low, i.e., 1–2 ng L^{-1} in water and 2–16 ng L^{-1} in wine [28,74,75]. Interestingly, during literature searches, the authors noted no publications investigating the effect of cryogenic treatments on MPs, which warrants further investigation and understanding as MPs are major contributors to the aroma profile of Sauvignon blanc wines. Previous research incorporating cryogenic practices focused mainly on their effect on major aroma compounds, i.e., polyphenols, terpenes, esters, higher alcohols, fatty acids, as well as the varietal thiols, i.e., 3-SH, 3-SHA, and 4-MSP [28,31,59,77,78].

4. Effect of Cryogenic Technologies on Sensory Properties of Wine

Wine quality and consumer acceptance of wine are frequently determined by organoleptic properties (aroma, colour, and taste), particularly the aroma profile [26,28,78–81]. In most cases, wines produced from grapes subjected to pre-fermentative cryomaceration treatments had a higher aroma intensity, improved mouthfeel, improved colour, oxygen stability, as well as enhanced aroma characteristics related to the cultivar [29,32–35,56,81]. This is due to an increase in the extraction of the aroma and flavour compounds, i.e., terpenes, thiols, esters, phenols, etc., present in the grape skin [29,32,34–37,78]. Alti Palacious et al. [29] demonstrated that cold pre-fermentation maceration treatments prior to vinification were capable of modifying the nutrient composition of the grape must, therefore enhancing the formation of aroma compounds, resulting in wines with an enhanced final quality.

In addition to the discussion on how cryogenic pre-treatment techniques affect the sensory profiles of the final wines [36], it was shown that wines produced from whole grape bunches sprayed with liquid CO_2 (inertized wine (IW)) whilst passing through a cooling tunnel had a better colour than the untreated wine. This was confirmed by analysing the total phenol concentration and the lowest value of gallic acid. Moreover, non-trained judges (preference test) preferred the IW wines. Inertized wines were found to achieve a good quality standard, capable of satisfying consumer preferences [36]. Furthermore, the research conducted by Alti Palacious et al. [29] further found that treating grape must with dry ice (solid CO_2) assisted in modulating the aroma compounds, therefore enhancing the aromatic quality and complexity of the final wines. Overall, the general trend observed from the literature shows that freezing techniques produced wines of a more intense aroma when compared to wines obtained using traditional methods. Moreover, the cryogenic method affected the overall quality of the wines [31].

5. Concluding Remarks and Future Prospects

Various scientific and wine technological developments have occurred in the wine industry to improve the varietal aroma and flavour profiles as well as the quality of wines. These advances have given rise to innovative wine styles being produced from the same grape varieties through either the direct manipulation of the grape berry before the winemaking process, or a combination of processes during wine production. However, the ability to manage the development of flavour compounds, i.e., varietal thiols, and their association with the sensory quality of wine using viticultural or oenological practices is yet to be demonstrated. The literature reported that a combination of these practices could influence varietal thiols and their precursors. Subsequently, most procedures demonstrated varied results, with the number of precursors in grapes not directly reflected in the varietal thiols quantified in the final wine. Therefore, specific vineyard and winemaking practices for increasing thiol and aroma compound concentrations in wines are still needed.

Moreover, the cryogenic treatment of grapes as a pre-fermentation treatment could be a useful alternative based on cryogenic processing technologies already applied in the beverage industry. Previous studies demonstrated its potential for thiol management in Sauvignon blanc, with thiol precursors increasing by four times in frozen grapes stored at $-20\ ^\circ C$ for two months compared to that found in frozen or fresh juices. Subsequently, studies using dry ice for the pre-fermentative cryomaceration of Sauvignon blanc grapes must also show an increase in 3-SH and 3-SHA concentrations in the resulting wine. However, it should be noted that although these new winemaking technologies greatly contribute to the increase in the extraction of aroma compounds, the grape variety used is still largely responsible for the aroma profile of the final wine due to differences in their skin cell layers and sizes. Moreover, there is a lack of information on the effect of these treatments on methoxypyrazines, which needs to be addressed as they are major compounds contributing to the varietal style of Sauvignon blanc and other wine grape varieties.

Furthermore, it is recommended that future research applications combine ultrasound technology, microwave-assisted extraction, and pulsed electric field technology with cryogenic pre-treatment technologies to further improve the extraction of aroma compounds to produce innovative wine styles. These technologies could add value to the wine industry as they showed promise in the acceleration of aroma extraction from oak chips, for the reduction in microbiological populations, reducing SO_2 usage, as well as the acceleration of aging on the lees. However, current studies are only being conducted on a small or laboratory scale and further optimisation on an industrial scale is needed to verify the reliability of results.

Author Contributions: Writing—review and editing, V.M.v.B.; visualization, V.M.v.B.; supervision, F.P.v.J. and J.v.W.; project administration, F.P.v.J.; funding acquisition, F.P.v.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by South Africa Wine grant number [P04000266].

Acknowledgments: Thanks to the Agricultural Research Council (ARC), Infruitec-Nietvoorbij for providing the infrastructure and financial support; the industry partner, i.e., South Africa Wine, for financial support; Rodney Hart (Post-Harvest and Agro-processing Technologies Division, Agricultural Research Council Infruitec-Nietvoorbij) for continuous technical support, mentorship, and motivation; Carien Coetzee (Basic Wine) for consultation services and technical support.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Neethling, E.; Petitjean, T.; Quénol, H.; Barbeau, G. Assessing local climate vulnerability and winegrowers' adaptive processes in the context of climate change. *Mitig. Adapt. Strat. Glob. Chang.* **2017**, *22*, 777–803. [CrossRef]
2. Kemp, B.; Botezatu, A.; Charnock, H.; Inglis, D.; Marchal, R.; Pickering, G.; Yang, F.; Willwerth, J. White winemaking in cold climates. In *White Wine Technology*; Academic Press: Cambridge, MA, USA, 2022; pp. 339–354, Chapter 26. [CrossRef]
3. Reynolds, A.G. Viticultural and vineyard management practices and their effects on grape and wine quality. In *Managing Wine Quality*, 2nd ed.; Woodhead Publishing: Sawston, UK, 2022; Volume 1, pp. 443–539, Chapter 11. [CrossRef]
4. Alem, H.; Rigou, P.; Schneider, R.; Ojeda, H.; Torregrosa, L. Impact of agronomic practices on grape aroma composition: A review. *J. Sci. Food Agric.* **2019**, *99*, 975–985. [CrossRef]
5. Pinu, F.R.; Tumanov, S.; Grose, C.; Raw, V.; Albright, A.; Stuart, L.; Villas-Boas, S.G.; Martin, D.; Harker, R.; Greven, M. Juice Index: An integrated Sauvignon blanc grape and wine metabolomics database shows mainly seasonal differences. *Metabolomics* **2019**, *15*, 3. [CrossRef]
6. Cataldo, E.; Salvi, L.; Paoli, F.; Fucile, M.; Mattii, G.B. Effect of agronomic techniques on aroma composition of white grapevines: A Review. *Agronomy* **2021**, *11*, 2027. [CrossRef]
7. Chen, K.; Li, J. A glance into the aroma of white wine. In *White Wine Technology*; Morata, A., Ed.; Academic Press: Cambridge, MA, USA, 2022; pp. 313–326. [CrossRef]
8. Robinson, J. Sauvignon Blanc Wine Grapes. 2021. Available online: https://www.jancisrobinson.com/learn/grape-varieties/white/sauvignon-blanc/ (accessed on 30 April 2021).
9. Perestrelo, R.; Silva, C.; Pereira, J.; Câmara, J.S. Healthy effects of bioactive metabolites from *Vitis vinifera* L. grapes: A review. In *Grapes: Production, Phenolic Composition and Potential Biomedical Effects*; Câmara, J.S., Ed.; Nova Science Technology: Hauppauge, NY, USA, 2014; pp. 305–338.
10. Prusova, B.; Humaj, J.; Sochor, J.; Baron, M. Formation, Losses, Preservation and Recovery of Aroma Compounds in the Winemaking Process. *Fermentation* **2022**, *8*, 93. [CrossRef]
11. Parr, W.V.; Schlich, P.; Theobald, J.C.; Harsch, M.J. Association of selected viniviticultural factors with sensory and chemical characteristics of New Zealand Sauvignon blanc wines. *Food Res. Int.* **2013**, *53*, 464–475. [CrossRef]
12. Hart, R.S.; Jolly, N.P.; Ndimba, B.K. Characterisation of hybrid yeasts for the production of varietal Sauvignon blanc wine-A review. *J. Microbiol. Methods* **2019**, *165*, 105699. [CrossRef] [PubMed]
13. Coetzee, C. Yeast and Its Ability to Release Thiols. 2021. Available online: https://www.wineland.co.za/yeast-and-its-ability-to-release-thiols/ (accessed on 5 March 2021).
14. Průšová, B.; Sochor, J.; Baroň, M.; Kumšta, M. Effect of yeasts on the aroma profile of Sauvignon blanc varietal wine. *Acta Univ. Agric. Silvic. Mendel. Brun.* **2018**, *66*, 889–896. [CrossRef]
15. Cerreti, M.; Esti, M.; Benucci, I.; Liburdi, K.; De Simone, C.; Ferranti, P. Evolution of S-cysteinylated and S-glutathionylated thiol precursors during grape ripening of *Vitis vinifera* L. cv. Grechetto, Malvasia del Lazio and Sauvignon blanc. *Aust. J. Grape Wine Res.* **2015**, *21*, 411–416. [CrossRef]
16. Rice, S.; Tursumbayeva, M.; Clark, M.; Greenlee, D.; Dharmadhikari, M.; Fennell, A.; Koziel, J.A. Effects of harvest time on the aroma of white wines made from cold-hardy brianna and frontenac gris grapes using headspace solid-phase microextraction and gas chromatography-mass spectrometry-olfactometry. *Foods* **2019**, *8*, 29. [CrossRef] [PubMed]
17. Steel, C.C.; Blackman, J.W.; Schmidtke, L.M. Grapevine bunch rots: Impacts on wine composition, quality, and potential procedures for the removal of wine faults. *J. Agric. Food Chem.* **2016**, *61*, 5189–5206. [CrossRef] [PubMed]
18. Dzedze, N.; van Breda, V.; Hart, R.S.; van Wyk, J. Wine chemical, sensory, aroma compound and protein analysis of wines produced from chemical and biological fungicide treated Chenin blanc grapes. *Food Control* **2019**, *105*, 265–276. [CrossRef]
19. Hart, R.S.; Ndimba, B.K.; Jolly, N.P. Characterisation of thiol-releasing and lower volatile acidity-forming intra-genus hybrid yeast strains for Sauvignon blanc wine. *S. Afr. J. Enol. Vitic.* **2017**, *38*, 144–155. [CrossRef]

20. Magyar, I.; Soos, J. Botrytized wines–current perspectives. *Int. J. Wine Res.* **2016**, *8*, 29–39. [CrossRef]
21. Avizcuri-Inac, J.M.; González-Hernández, M.; Rosáenz-Oroz, D.; Martínez-Ruiz, R.; Vaquero-Fernández, L. Chemical and sensory characterisation of sweet wines obtained by different techniques. *Cienc. Tec. Vitivinic.* **2018**, *33*, 15–30. [CrossRef]
22. Dankó, T.; Szelényi, M.; Janda, T.; Molnár, B.P.; Pogány, M. Distinct volatile signatures of bunch rot and noble rot. *Physiol. Mol. Plant Pathol.* **2021**, *114*, 101626. [CrossRef]
23. Santos, H.; Augusto, C.; Reis, P.; Rego, C.; Figueiredo, A.C.; Fortes, A.M. Volatile metabolism of wine grape Trincadeira: Impact of infection with *Botrytis cinerea*. *Plants* **2022**, *11*, 141. [CrossRef]
24. Cosme, F.; Gonçalves, B.; Inês, A.; Jordão, A.M.; Vilela, A. Grape and wine metabolites: Biotechnological approaches to improve wine quality. *Grape Wine Biotechnol.* **2016**, 187–214. [CrossRef]
25. Zhang, S.; Petersen, M.A.; Liu, J.; Toldam-Andersen, T.B. Influence of pre-fermentation treatments on wine volatile and sensory profile of the new disease tolerant cultivar Solaris. *Molecules* **2015**, *20*, 21609–21625. [CrossRef]
26. Vilanova, M.; Escudero, A.; Graña, M.; Cacho, J. Volatile composition and sensory properties of Northwest Spain white wines. *Food Res. Int.* **2013**, *54*, 562–568. [CrossRef]
27. Chen, L.; Capone, D.L.; Tondini, F.A.; Jeffery, D.W. Chiral polyfunctional thiols and their conjugated precursors upon winemaking with five *Vitis vinifera* Sauvignon blanc clones. *J. Agric. Food Chem.* **2018**, *66*, 4282–4674. [CrossRef]
28. Ruiz, J.; Kiene, F.; Belda, I.; Fracassetti, D.; Marquina, D.; Navascués, E.; Calderón, F.; Benito, A.; Rauhut, D.; Santos, A.; et al. Effects on varietal aromas during wine making: A review of the impact of varietal aromas on the flavor of wine. *Appl. Microbiol. Biotechnol.* **2019**, *103*, 7425–7450. [CrossRef]
29. Alti-Palacios, L.; Martínez, J.; Teixeira, J.A.; Câmara, J.S.; Perestrelo, R. Influence of cold pre-fermentation maceration on the volatilomic pattern and aroma of white wines. *Foods* **2023**, *12*, 1135. [CrossRef]
30. Chen, L.; Capone, D.L.; Nicholson, E.L.; Jeffery, D.W. Investigation of intraregional variation, grape amino acids, and pre-fermentation freezing on varietal thiols and their precursors for *Vitis vinifera* Sauvignon blanc. *Food Chem.* **2019**, *295*, 637–645. [CrossRef]
31. Ruiz-Rodríguez, A.; Durán-Guerrero, E.; Natera, R.; Palma, M.; Barroso, C.G. Influence of two different cryoextraction procedures on the quality of wine produced from muscat grapes. *Foods* **2020**, *9*, 1529. [CrossRef] [PubMed]
32. Bestulić, E.; Rossi, S.; Plavša, T.; Horvat, I.; Lukić, I.; Bubola, M.; Peršurić, A.S.I.; Jeromel, A.; Radeka, S. Comparison of different maceration and non-maceration treatments for enhancement of phenolic composition, colour intensity, and taste attributes of Malvazija istarska (*Vitis vinifera* L.) white wines. *J. Food Compos. Anal.* **2022**, *109*, 104472. [CrossRef]
33. Malićanin, M.; Danilović, B.; Stamenković Stojanović, S.; Cvetković, D.; Lazić, M.; Karabegović, I.; Savić, D. Pre-Fermentative Cold Maceration and Native Non-*Saccharomyces* Yeasts as a Tool to Enhance Aroma and Sensory Attributes of Chardonnay Wine. *Horticulturae* **2022**, *8*, 212. [CrossRef]
34. Pedrosa-López, M.D.C.; Aragón-García, F.; Ruíz-Rodríguez, A.; Piñeiro, Z.; Durán-Guerrero, E.; Palma, M. Effects from the freezing of either whole or crushed grapes on the volatile compounds contents in Muscat wines. *Foods* **2022**, *11*, 1782. [CrossRef] [PubMed]
35. Aleixandre-Tudo, J.L.; du Toit, W. Cold maceration application in red wine production and its effects on phenolic compounds: A review. *LWT Food Sci. Technol.* **2018**, *95*, 200–208. [CrossRef]
36. Carillo, M.; Formato, A.; Fabiani, A.; Scaglione, G.; Pucillo, G.P. An inertizing and cooling process for grapes cryomaceration. *Electron. J. Biotechnol.* **2011**, *14*, 2–14. [CrossRef]
37. Benucci, I.; Cerreti, M.; Liburdi, K.; Nardi, T.; Vagnoli, P.; Ortiz-Julien, A.; Esti, M. Pre-fermentative cold maceration in presence of non-*Saccharomyces* strains: Evolution of chromatic characteristics of Sangiovese red wine elaborated by sequential inoculation. *Food Res. Int.* **2018**, *107*, 257–266. [CrossRef] [PubMed]
38. JagatiÄ, A.M.; Prusina, T.; IviÄ, S. Influence of cold maceration treatment on aromatic and sensory properties of Vugava wine (*Vitis vinifera* L.). *J. Microbiol. Biotechnol. Food Sci.* **2020**, *10*, 49–53. [CrossRef]
39. Zhang, Q.; Sun, X.; Sheng, Q.; Chen, J.; Huang, W.; Zhan, J. Effect of suspension freeze-concentration technology on the quality of wine. *S. Afr. J. Eno. Vitic.* **2016**, *37*, 39–46. [CrossRef]
40. Tomaz, I.; Šeparović, M.; Štambuk, P.; Preiner, D.; Maletić, E.; Karoglan Kontić, J. Effect of freezing and different thawing methods on the content of polyphenolic compounds of red grape skins. *J. Food Process. Preserv.* **2018**, *42*, e13550. [CrossRef]
41. Tian, R.R.; Li, G.; Wan, S.B.; Pan, Q.H.; Zhan, J.C.; Li, J.M.; Zhang, Q.H.; Huang, W.D. Comparative study of 11 phenolic acids and five flavan-3-ols in cv. Vidal: Impact of natural icewine making versus concentration technology. *Aust. J. Grape Wine Res.* **2009**, *15*, 216–222. [CrossRef]
42. Santesteban, L.G.; Miranda, C.; Royo, J.B. Influence of the freezing method on the changes that occur in grape samples after frozen storage. *J. Sci. Food Agric.* **2013**, *93*, 3010–3015. [CrossRef] [PubMed]
43. Petzold, G.; Niranjan, K.; Aguilera, J.M. Vacuum-assisted freeze concentration of sucrose solutions. *J. Food Eng.* **2013**, *115*, 357–361. [CrossRef]
44. Petzold, G.; Moreno, J.; Lastra, P.; Rojas, K.; Orellana, P. Block freeze concentration assisted by centrifugation applied to blueberry and pineapple juices. *Innov. Food Sci. Emerg. Technol.* **2015**, *30*, 192–197. [CrossRef]
45. Deshpande, S.S.; Cheryan, M.; Sathe, S.K.; Salunkhe, D.K.; Luh, B.S. Freeze concentration of fruit juices. *Critical Reviews in Food Sci. Nut.* **1984**, *20*, 173–248. [CrossRef]

46. Miyawaki, O.; Kato, S.; Watabe, K. Yield improvement in progressive freeze-concentration by partial melting of ice. *J. Food Eng.* **2012**, *108*, 377–382. [CrossRef]
47. Ye, D.; Zhang, L.; Sun, S.; Chen, J.; Fang, T. Production of high-aroma instant tea powder using various innovative technologies. *J. Food Proc. Eng.* **2014**, *37*, 273–284. [CrossRef]
48. Dempsey, P.; Bansal, P. The art of air blast freezing: Design and efficiency considerations. *Appl. Therm. Eng.* **2012**, *41*, 71–83. [CrossRef]
49. Mencarelli, F.; Bellincontro, A. Recent advances in postharvest technology of the wine grape to improve the wine aroma. *J. Sci. Food Agric.* **2020**, *100*, 5046–5055. [CrossRef]
50. Olarte Mantilla, S.M.; Collins, C.; Iland, P.G.; Kidman, C.M.; Jordans, C.; Bastian, S.E.P. Comparison of sensory attributes of fresh and frozen wine grape berries using Berry Sensory Assessment. *Aust. J. Grape Wine Res.* **2013**, *19*, 349–357. [CrossRef]
51. Naviglio, D.; Formato, A.; Scaglione, G.; Montesano, D.; Pellegrino, A.; Villecco, F.; Gallo, M. Study of the grape cryo–maceration process at different temperatures. *Foods* **2018**, *7*, 107. [CrossRef]
52. Naranjo, A.; Martínez-Lapuente, L.; Ayestarán, B.; Guadalupe, Z.; Pérez, I.; Canals, C.; Adell, E. Aromatic and sensory characterization of Maturana Blanca wines made with different technologies. *Beverages* **2021**, *7*, 10. [CrossRef]
53. Jeffery, D.W. Spotlight on varietal thiols and precursors in grapes and wines. *Aust. J. Chem.* **2016**, *69*, 1323–1330. [CrossRef]
54. Benkwitz, F.; Nicolau, L.; Lund, C.; Beresford, M.; Wohlers, M.; Kilmartin, P.A. Evaluation of key odorants in Sauvignon blanc wines using three different methodologies. *J. Agric. Food Chem.* **2012**, *60*, 6293–6302. [CrossRef] [PubMed]
55. Robinson, A.L.; Boss, P.K.; Solomon, P.S.; Trengove, R.D.; Heymann, H.; Ebeler, S.E. Origins of grape and wine aroma. Part 1. Chemical components and viticultural impacts. *Am. J. Enol. Vitic.* **2014**, *65*, 1–24. [CrossRef]
56. Coetzee, C.; du Toit, W.J. A comprehensive review on Sauvignon blanc aroma with a focus on certain positive volatile thiols. *Food Res. Int.* **2012**, *45*, 287–298. [CrossRef]
57. October, F.M. Effect of Yeasts and Oenological Parameters on Acetaldehyde Production during Alcoholic Fermentation of South African Grape Musts. Master's Thesis, Stellenbosch University, Stellenbosch, South Africa, 2020.
58. Pinu, F.R.; Edwards, P.J.; Jouanneau, S.; Kilmartin, P.A.; Gardner, R.C. Villas-Boas, S.G. Sauvignon blanc metabolomics: Grape juice metabolites affecting the development of varietal thiols and other aroma compounds in wines. *Metabolomics* **2014**, *10*, 556–573. [CrossRef]
59. Moreno-Pérez, A.; Vila-López, R.; Fernández-Fernández, J.I.; Martínez-Cutillas, A.; Gil-Muñoz, R. Influence of cold pre-fermentation treatments on the major volatile compounds of three wine varieties. *Food Chem.* **2013**, *139*, 770–776. [CrossRef]
60. Aleixandre-Tudo, J.L.; Weightman, C.; Panzeri, V.; Nieuwoudt, H.H.; Du Toit, W.J. Effect of skin contact before and during alcoholic fermentation on the chemical and sensory profile of South African Chenin blanc white wines. *S. Afr. J. Enol Vitic.* **2015**, *36*, 366–377. [CrossRef]
61. Olejar, K.J.; Fedrizzi, B.; Kilmartin, P.A. Influence of harvesting technique and maceration process on aroma and phenolic attributes of Sauvignon blanc wine. *Food Chem.* **2015**, *183*, 181–189. [CrossRef] [PubMed]
62. Ferreira, V.; Lopez, R. The actual and potential aroma of winemaking grapes. *Biomolecules* **2019**, *9*, 818. [CrossRef] [PubMed]
63. Ouellet, É.; Pedneault, K. Impact of frozen storage on the free volatile compound profile of grape berries. *Am. J. Enol. Vitic.* **2016**, *67*, 239–244. [CrossRef]
64. Bonnaffoux, H.; Delpech, S.; Rémond, E.; Schneider, R.; Roland, A.; Cavelier, F. Revisiting the evaluation strategy of varietal thiol biogenesis. *Food Chem.* **2018**, *268*, 126–133. [CrossRef]
65. Wilson, C.L. Chemical Evaluation and Sensory Relevance of Thiols in South African Chenin Blanc Wines. Ph.D. Thesis, Stellenbosch University, Stellenbosch, South Africa, 2017. Available online: https://hdl.handle.net/10019.1/101250 (accessed on 15 March 2021).
66. Coetzee, C.; Schulze, A.; Mokwena, L.; Du Toit, W.J.; Buica, A. Investigation of thiol levels in young commercial South African Sauvignon blanc and Chenin blanc wines using propiolate derivatization and GC-MS/MS. *S. Afr. J. Enol. Vitic.* **2018**, *39*, 180–184. [CrossRef]
67. Wilson, C.; Brand, J.; du Toit, W.; Buica, A. Matrix effects influencing the perception of 3-mercaptohexan-1-ol (3MH) and 3-mercaptohexyl acetate (3MHA) in different Chenin blanc wines by Projective Mapping (PM) with Ultra Flash profiling (UFP) intensity ratings. *Food Res. Int.* **2019**, *121*, 633–640. [CrossRef]
68. Hart, R.S.; Jolly, N.P.; Mohamed, G.; Booyse, M.; Ndimba, B.K. Characterisation of *Saccharomyces cerevisiae* hybrids selected for low volatile acidity formation and the production of aromatic Sauvignon blanc wine. *Afr. J. Biotechnol.* **2016**, *15*, 2068–2081. [CrossRef]
69. Visan, L.; Tamba-Berehoiu, R.M.; Popa, C.N.; Danaila–Guidea, S.M.; Culea, R. Aromatic compounds in wines. *Sci. Papers* **2018**, *18*, 423–430.
70. Dimopoulou, M.; Troianou, V.; Toumpeki, C.; Gosselin, Y.; Dorignac, É.; Kotseridis, Y. Effect of strains from different *Saccharomyces* species used in different inoculation schemes on chemical composition and sensory characteristics of Sauvignon blanc wine. *OENO One* **2020**, *54*, 745–759. [CrossRef]
71. Capone, D.L.; Jeffery, D.W. Effects of transporting and processing Sauvignon blanc grapes on 3-mercaptohexan-1-ol precursor concentrations. *J. Agric. Food Chem.* **2011**, *59*, 4659–4667. [CrossRef]
72. Capone, D.L.; Ristic, R.; Pardon, K.H.; Jeffery, D.W. Simple quantitative determination of potent thiols at ultratrace levels in wine by derivatization and high-performance liquid chromatography-tandem mass spectrometry (HPLC-MS/MS) analysis. *Anal. Chem.* **2015**, *87*, 1226–1231. [CrossRef]

73. Casassa, L.F.; Sari, S.E. Sensory and chemical effects of two alternatives of pre-fermentative cold soak in Malbec wines during winemaking and bottle ageing. *Int. J. Food Sci. Technol.* **2015**, *50*, 1044–1055. [CrossRef]
74. Suklje, K.; Gobler, N.; Coetzee, Z.; Lisjak, K.; Deloire, A. Methoxypyrazines and Greenness in Wines: Myth or Reality? A Few Perspectives. *Wineland*. 2013. Available online: https://www.wineland.co.za/methoxypyrazines-greenness-wines-myth-reality-perspectives/ (accessed on 2 December 2021).
75. Sidhu, D.; Lund, J.; Kotseridis, Y.; Saucier, C. Methoxypyrazine analysis and influence of viticultural and enological procedures on their levels in grapes, musts, and wines. *Crit. Rev. Food Sci. Nutr.* **2015**, *55*, 485–502. [CrossRef] [PubMed]
76. Lei, Y.; Xie, S.; Guan, X.; Song, C.; Zhang, Z.; Meng, J. Methoxypyrazines biosynthesis and metabolism in grape: A review. *Food Chem.* **2018**, *245*, 1141–1147. [CrossRef]
77. Aleixandre-Tudo, J.L.; Alvarez, I.; Lizama, V.; Nieuwoudt, H.; Garcia, M.J.; Aleixandre, J.L.; Du Toit, W.J. Modelling phenolic and volatile composition to characterize the effects of pre-fermentative cold soaking in Tempranillo wines. *LWT Food Sci. Technol.* **2016**, *66*, 193–200. [CrossRef]
78. Baron, M.; Prusova, B.; Tomaskova, L.; Kumsta, M.; Sochor, J. Terpene content of wine from the aromatic grape variety 'Irsai Oliver' (*Vitis vinifera* L.) depends on maceration time. *Open Life Sci.* **2017**, *12*, 42–50. [CrossRef]
79. Robinson, A.L.; Boss, P.K.; Solomon, P.S.; Trengove, R.D.; Heymann, H.; Ebeler, S.E. Origins of grape and wine aroma. Part 2. Chemical and sensory analysis. *Am. J. Enol. Vitic.* **2014**, *65*, 25–42. [CrossRef]
80. Karabagias, I.K.; Sykalia, D.; Mannu, A.; Badeka, A.V. Physico–chemical parameters complemented with aroma compounds fired up the varietal discrimination of wine using statistics. *Eur. Food Res. Technol.* **2020**, *246*, 2233–2248. [CrossRef]
81. Baiano, A.; Terracone, C.; Longobardi, F.; Ventrella, A.; Agostiano, A.; Del Nobile, M.A. Effects of different vinification technologies on physical and chemical characteristics of Sauvignon blanc wines. *Food Chem.* **2012**, *135*, 2694–2701. [CrossRef] [PubMed]