

Pre-Fermentative Cryogenic Treatments

Subjects: [Food Science & Technology](#)

Contributor: Valmary M. van Breda , Francois P. van Jaarsveld , Jessy van Wyk

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.

varietal thiols

cryogenic technologies

sensory analysis

methoxypyrazines

Sauvignon blanc

Chenin blanc

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

1.1. 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 ^{[1][2][3][4][5]}. However, in a study conducted by the authors of ^[6], 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. ^[4], Santesteban et al. ^[3], and Zhang et al. ^[1]. 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 ^{[1][2][3][5][6]}. Moreover, the chemical parameter most affected by freeze storage was found to be titratable acidity ^[2].

Research conducted by Naviglio et al. ^[5] and Naranjo et al. ^[7] involved the rapid cooling of Bianchello del Metauro grapes by sparging the grapes with liquid CO₂ 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 ^{[8][9]}. This was similar to findings observed in earlier research. However, significant differences were observed for malic acid ^{[3][5]}. 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 [3][5].

Moreover, studies conducted by Zhang et al. [1] and Pedrosa-López et al. [10] 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. [1] 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 [3][5], although it differed from the findings of Carillo et al. [11] 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 [2][5][6][12].

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 [1][3][6]. 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 [1][6].

1.2. 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 1**), 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 [13][14][15]. 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 [15][16].

The three major classes of odourants that contribute significantly to varietal characteristics in wines are monoterpenes, methoxy-pyrazines, and volatile thiols [17][18]. 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 [19]. Other compounds also present in wine and found to play a significant role in its aroma are esters, fatty acids, higher alcohols, and aldehydes [15][17][20].

Table 1. 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

Aroma Development Stage	Compound	Origin
Post-fermentation	Oxidation of volatile aroma compounds; increase in fatty acids, esters, aldehydes, ketones, and polyphenols	and bacterial) Wine aging (bottle, barrel, storage, aging on lees)

compound, the concentration in the berry, the location within the berry, and the method used during processing [22][23][24]. 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 [10][25][26].

1.3. Effect of Cryogenic Technologies on Varietal Thiols

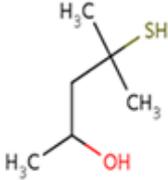
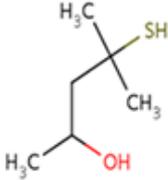
Varietal thiols are sulphur compounds found in grapes in a bound form that originate from fatty acids [13][27]. These sulphur-containing compounds are originally associated with off-odours resulting from hydrogen sulphide (H₂S), methylmercaptan (methanethiol), ethanethiol, and methionol [16]. They are considered the main compounds involved in the aroma of wine and responsible for its archetypal flavour [28]. 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 [13][23]. Key thiols present in Sauvignon blanc and responsible for its varietal aromas are 4-methyl-4-sulfanylpentan-2-one (4-MSP), 3-sulfanylhexas-1-ol (3-SH), and 3-sulfanylhexasyl acetate (3-SHA) with perception thresholds of 0.8 ng L⁻¹, 60 ng L⁻¹, and 4 ng L⁻¹, respectively (**Table 2**). They are predominantly responsible for the “tropical” (gooseberry, grapefruit, and passion fruit) characteristics associated with Sauvignon blanc [9]. However, it is interesting to note that when present in excessive concentrations, they often impart less desirable strong, sweaty aromas resembling “cat urine” [9][29]. 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 [24][30][31].

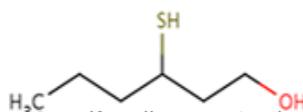
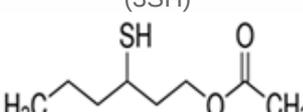
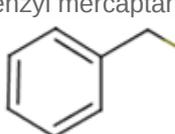
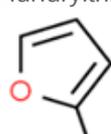
Varietal thiols are present in grape juice in the form of aroma-inactive, non-volatile precursors and are released by yeast enzymes during the fermentation process [9][12][32][33][34][35]. Pinu et al. [16] showed that the production of varietal thiols and other aroma compounds in Sauvignon blanc wines is not necessarily only dependent on nitrogenous and sulphur compounds but is also influenced by other juice metabolites such as carboxylic and fatty

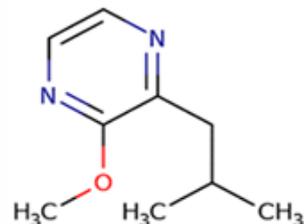
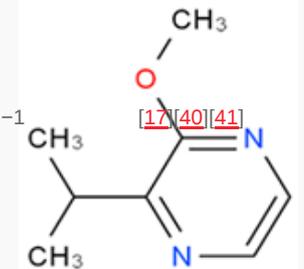
acids. Their research demonstrated that concentrations of wine aroma compounds can be modified using pre-fermentative treatments to produce different wine styles from the same grape varietal based on the metabolic profile of the juice, thus altering the metabolite levels. In addition, juice modulation through new winemaking practices, i.e., metabolite supplementation or blending, could be seen as a useful tool to create new wine styles [16].

Pre-fermentative cold maceration has gained popularity in white wine production as it was shown to enhance the varietal characteristic of the wines [10][28][29]. Two volatile precursors of 3-SH (3-S-cysteinylohexan-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 [10][28]. Glut-3-SH was fourfold higher in frozen grapes stored at $-20\text{ }^{\circ}\text{C}$ for two months compared to that found in frozen or fresh juices [10][28]. Capone et al. [36][37] 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 [36][37]. 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 [36][37]. 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 [10][28][36][37][38][39].

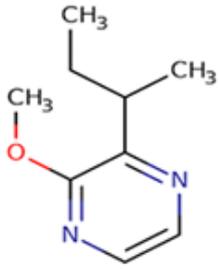
Table 2. Varietal thiols present in Sauvignon blanc and Chenin blanc wines: aroma description, perception, and range in wine.

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		Passionfruit, tropical, boxwood	4	0–106	23–151

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)
Chenin blanc				0–100	5–253
Sauvignon blanc	3-sulfanylhexan-1-ol (3SH)	Grapefruit, tropical, passionfruit		350–5664	178–904
Chenin blanc			60	10–1368	99–1124
Sauvignon blanc	benzyl mercaptan (BM)	roasty, struck flint		0.6–5.5	n.d. *
Chenin Blanc			0.3	30–40	n.d. *
Sauvignon blanc	2-furfurylthiol (FFT)	Roasted Coffee		1–36	n.d. *
Chenin blanc			0.4		

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-isobutylpyrazine (ibMP) 	vegetative, green pepper	1–2	2–163	2–30
2-methoxy-3-isopropylpyrazine (ipMP) 	earthy, mushroom, cooked, or canned asparagus, green beans	1–2	2–16	<10

fatty acids, as well as the varietal thiols, i.e., 3-SH, 3-SHA, and 4-MSP [17][18][26][43][44].

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)	References
2-methoxy-3-sec-butylpyrazine (sbMP) 	green (peas, bell pepper, galbanum), ivy leaves, bell pepper [17][44][45][46][47][48]	1–2 [2][6][10][11][25][44][50]	2–16 [25]	<10 [2][6][9][10][25][48]	s (aroma, m grapes mouthfeel, ls, esters, cold pre-ion of the nced final quality.

In addition to the discussion on how cryogenic pre-treatment techniques affect the sensory profiles of the final wines [11], it was shown that wines produced from whole grape bunches sprayed with liquid CO₂ (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 [11]. Furthermore, the research conducted by Alti Palacios et al. [25] further found that treating grape must with dry ice (solid CO₂) 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 [26].

References

- 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.
- 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.
- 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.
- 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.

5. Naviglio, D.; Formato, A.; Scaglione, G.; Montesano, D.; Pellegrino, A.; Vilecco, F.; Gallo, M. Study of the grape cryo-maceration process at different temperatures. *Foods* 2018, 7, 107.
6. 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.
7. 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.
8. 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.
9. 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.
10. 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.
11. 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.
12. 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.
13. 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.
14. 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.
15. 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.
16. 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.
17. 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.
18. 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.
 19. 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.
 20. 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.
 21. Ferreira, V.; Lopez, R. The actual and potential aroma of winemaking grapes. *Biomolecules* 2019, 9, 818.
 22. 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.
 23. 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.
 24. 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).
 25. 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.
 26. 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.
 27. 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.
 28. 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.
 29. 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.

30. 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.
31. 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.
32. 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.
33. 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.
34. 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.
35. 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.
36. 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.
37. 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.
38. Jeffery, D.W. Spotlight on varietal thiols and precursors in grapes and wines. *Aust. J. Chem.* 2016, 69, 1323–1330.
39. 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.
40. 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).
41. 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.

42. 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.
43. 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.
44. 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.
45. 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.
46. 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.
47. 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.
48. 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.
49. 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.
50. 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.

Retrieved from <https://encyclopedia.pub/entry/history/show/125543>