Techniques for Dealcoholization of Wines

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To adapt to the trends in wine styles, and the effect of climate change on wine alcohol content, different techniques have been used at the various stages of winemaking, among which the physical dealcoholization techniques, particularly membrane separation (nanofiltration, reverse osmosis, evaporative perstraction, and pervaporation) and thermal distillation (vacuum distillation and spinning cone column), have shown promising results and hence are being used for commercial production.

Keywords: dealcoholization ; reduced-alcohol wine ; alcohol-free wine ; non-alcoholic wine ; phenolic composition ; volatile composition ; aroma compounds ; sensory quality

1. Introduction

Wine is an alcoholic beverage popularly produced from fermented grape juice. Wines can be classified as red, rose (pink), or white based on their color, and they can also be classified as table (red, rose, or white), sparkling, or fortified based on their alcohol level or carbon dioxide content [1]. Table wines are wines that are neither fortified nor sparkling and are typically served with food [2]. Fortified wines are made by adding alcohol (usually between 16% and 23%) [1][2][3]. Wines can also be classified based on how much carbon dioxide they contain. Those that contain carbon dioxide (about 10 g/L CO_2) [4] are classified as sparkling wines, while those that do not contain carbon dioxide are classified as "still" wines [1]. The carbon dioxide can be produced naturally during fermentation or added artificially. Based on alcoholic content, wines can further be classified as alcohol-free (< 0.5% v/v), low-alcohol (0.5% to 1.2% v/v), reduced-alcohol (1.2% to 5.5% or 6.5% v/v), lower-alcohol (5.5% to 10.5% v/v), and alcoholic wines (> 10.5% v/v) [5][6]. In addition, wines are also classified according to their sugar content: dry (maximum of 4 g/L sugar), medium dry (between 4 g/L and 12 g/L sugar), semi-sweet (between 12 g/L and 45 g/L sugar), and sweet (minimum of 45 g/L sugar) [7]. However, these classifications are not explicit and may vary between most wine producing countries and the applicable legislations. In the UK, for example, wines with an alcohol content of 1.2% alcohol by volume (ABV) or less are classified as low alcohol wines, while wines with an alcohol content of less than 0.5% ABV are referred to as non-alcoholic wines. In contrast, China classifies low alcohol wines as wines with 1.0% to 7.0% ABV and non-alcoholic wines as wines with 0.5% to 1.0% ABV [8].

From several studies (in vitro and in vivo), there is a positive consent of the beneficial impact of wine consumption on neurological diseases, cardiovascular disease, osteoporosis, diabetes, and longevity [9][10][11][12][13][14]. When consumed in adequate amounts and together with a meal, wine plays a vital role in mitigating oxidative stress and vascular endothelial damage induced by a high-fat meal [15]. According to Boban et al. [15], red wine consumption may help prevent heart diseases as well as type two diabetes, allowing consumers to enjoy better health and an increased lifespan as they age. A Chinese study on alcohol and mortality in middle-aged men discovered a 19% reduction in deaths with no more than two drinks per day [16]. Furthermore, a study conducted by Buettner and Skemp [17] on blue zones revealed adequate wine intake as one of the nine lifestyle habits in populations around the world that are known for their long lifespan and healthy aging. Despite the benefits associated with wine consumption, some consumers perceive wine to be harmful to human health because it contains alcohol [18].

High concentrations of ethanol in wine increase the sensation of hotness and bitterness, while decreasing acidity and masking the sensitivity of certain essential aroma compounds such as esters, higher alcohols, and monoterpenes [19][20][21]. Furthermore, high alcohol wines are subject to higher import duties and taxes in some countries [22]. For example, in the United States, wine with 14% alcohol or less is taxed at USD 1.07 per gallon, while wine with 14.1% to 21% alcohol is taxed at USD 1.57 per gallon [23]. There is a common view all over the world that the consumption of alcoholic wine should lessen in favor of low or non-alcoholic wines [24][25][26]. This is currently being witnessed globally as there is a growing popularity of low- or non-alcoholic wines and beverages, particularly in Europe and North America (www.factmr.com/report/4532/non-alcoholic-wine-market, accessed on 1 September 2021). Consumer preferences are shifting with consumers in the non-alcoholic wine market wanting new product offerings and alternatives. There is also an increasing percentage of the adult population seeking lower alcohol wines and beverages more frequently, which has boosted non-alcoholic wine sales. This trend has prompted producers to introduce new non-alcoholic wine products with fruity and floral notes. Additionally, the global non-alcoholic wine market size is valued at USD 20 billion with a compound annual growth rate (CAGR) of over 45% in 2018 and is projected to increase at a remarkable CAGR of over 7% during the forecast period (2019–2027), reaching a value pool of over USD 30 billion [24]. According to another school of thought (www.factmr.com/report/4532/non-alcoholic-wine-market, accessed on 1 September 2021), the global market will continue to grow steadily, with a CAGR of 10.4% from 2021 to 2031, up from an 8.8% CAGR from 2016 to 2020. Therefore, for wine producers to meet consumers' demands and adapt to the rising non-alcoholic wine market, they need to produce high-quality alcohol-free or low-alcoholic wines (**Figure 1**).

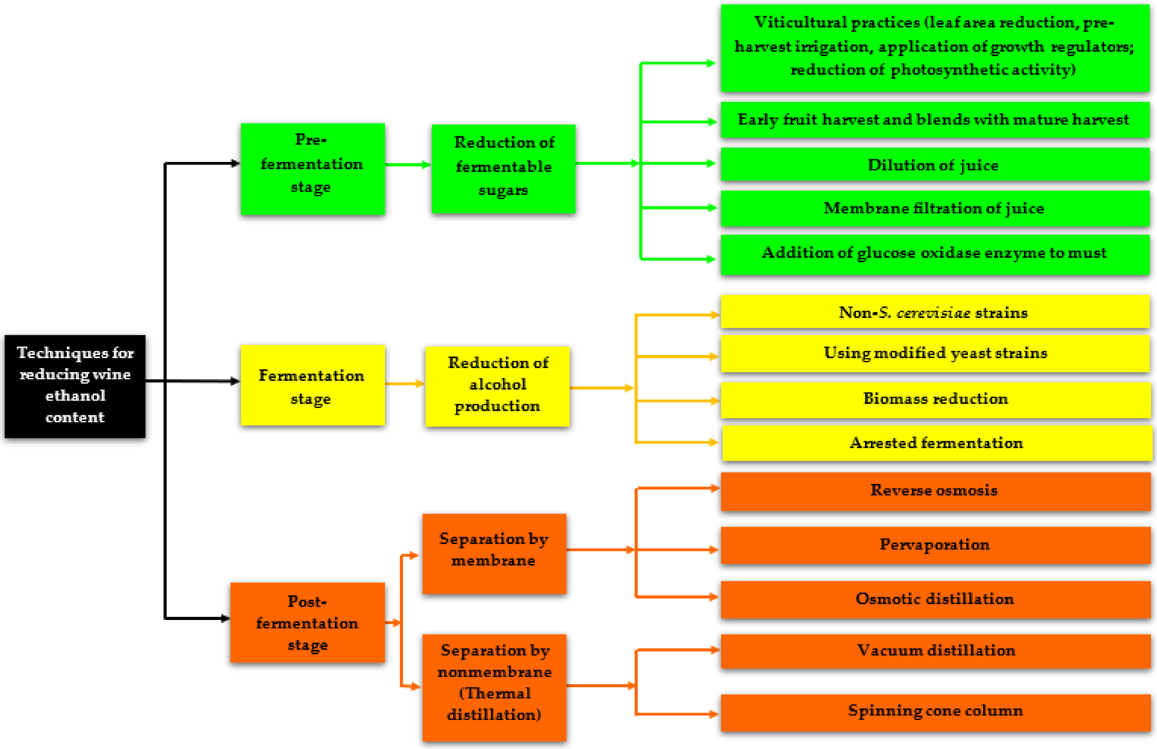

Figure 1. Techniques for alcohol reduction in wines and fermented beverages.

2. Techniques for Wine Alcohol Reduction

A summary of some techniques commonly used for the dealcoholization of wines at the various stages (pre-fermentation stage, fermentation stage, and post-fermentation stage) of wine production and their extent of ethanol removal is shown in **Table 1**.

Table 1. Different techniques to reduce wine alcohol content in the several stages of wine production.

Stage of Wine Production	Ethanol Removal Process	Technology	Alcohol Content Reduction	References
Pre-fermentation	Reduction of fermentable sugars	Viticultural practices (leaf area reduction, pre-harvest irrigation, application of growth regulators; reduction in photosynthetic activity)	Up to 2% v/v	[27][28][29][30][31][32][33][34][35][36][37][38][39][40][41][42][43][44][45]
		Early fruit harvest and blends with mature harvest	Up to 3% v/v	[46][47][48][49][50][51][52][53][54][55][56]
		Dilution of grape must	Up to 7% v/v	[51][52][53][57][58][59][60][61][62][63]
		Filtration of must	Up to 5% v/v	[64][65][66][67][68][69][70][71][72][73]
		Addition of enzyme (glucose oxidase)	Up to 4% v/v	[5][74][75][76][77][78][79]
Fermentation	Reduction of alcohol production	Use of Non-*Saccharomyces cerevisiae* yeasts	Up to 2% v/v	[80][81][82][83][84][85][86][87][88][89][90][91][92][93][94][95][96][97][98][99][100][101][102][103][104][105][106][107][108][109][110]
		Use of modified yeast strains	Up to 3.6% v/v	[111][112][113][114][115][116][117][118][119][120][121][122]
		Biomass reduction	Up to 4% v/v	[123][124][125]
		Arrested fermentation	High reduction	[5][126]
Post-fermentation	Separation by membrane	Nanofiltration (NF)	Up to 4% v/v	[67][127][128][129][130][131][132]
		Reverse osmosis (RO)	Up to 0.5% v/v or less	[22][133][134][130][135][136][137][138]
		Osmotic distillation (OD)	Up to 0.5% v/v or less	[133][139][140][138][141][142][143][144][145][146]
		Pervaporation (PV)	Up to 0.5% v/v or less	[147][148][149][150][151][152][153]
		Vacuum distillation (VD)	Up to 1% v/v or less	[154][155][156]
		Spinning cone column (SCC)	Up to 0.3% v/v	[157][158][159][160][161][162]

Stage of Wine Production	Ethanol Removal Process	Technology	Alcohol Content Reduction	References
		Multi-stage membrane-based systems	Up to 0.5% v/v or less	[70][136][163][164][165][166]

3. Impact of Dealcoholization Techniques on Wine Quality

3.1. Impact on phenolic composition

The phenolic composition of wine is made up of flavonoids and non-flavonoids [167]. Flavonoids include flavones, flavanols ((+)-catechin and (−)-epicatechin), flavonols (quercetin, myricetin, kaempferol, and rutin), anthocyanins, and proanthocyanidins while non-flavonoids are mainly resveratrol (3,4,5-trihydroxystilbene), hydroxybenzoic acids (p-hydroxybenzoic, vanillic, syringic, gallic, gentisic, salicylic, and protocatechuic acids), and hydroxycinnamic acids (caffeic, coumaric, and ferulic acids) [29][168][169][170][171][172]. Regarding wine quality, especially red wine, phenolic compounds play a vital role by contributing to organoleptic properties such as astringency and color [173]. Health-wise, phenolic compounds can be effective in the prevention of cardiovascular diseases [174][175][176]. Although changes in alcohol content do not generally affect basic wine parameters such as density, pH, titratable acidity, and volatile acidity [164][177], these changes have been reported to influence wine phenolic compounds [144][159][164][178]. Important findings from some studies on the phenolic composition of wines dealcoholized by physical dealcoholization methods are summarized in **Table 2**.

Table 2. Some reported changes in wine phenolic compounds using different dealcoholization processes.

Wine Type	Dealcoholization Process	Alcohol Reduction		Reported Effects on Phenolic Composition	Reference
		Co (% v/v)	Cf (% v/v)		
Red wine	NF	12.0	6.0–4.0	Reduction in wine alcohol volume by a factor of 4 leads to 2.5–3 times more anthocyanins and resveratrol in the wine concentrates	[128]
Cabernet Sauvignon–Merlot–Tempranillo red wine	RO	12.7	4.0–2.0	No significant differences were observed in total anthocyanins and phenolic compounds for both original and dealcoholized wines. Colour intensity increased by around 20% in dealcoholized wines (due to the concentration effect from the removal of ethanol as well as the retention of anthocyanins by the membrane), while the tonality diminished by around 15%	[179]
Cabernet Sauvignon red wine	RO	14.8	13.8–12.8	The total phenolic index, total proanthocyanidins, and percentages of procyanidins, prodelphinidins, and galloylation of partially dealcoholized wines and the control wine remains almost unchanged and did not differ. Control wine and partially dealcoholized wines have statistically similar total anthocyanin concentrations with no observed color differences between these wines	[22]

Wine Type	Dealcoholization Process	Alcohol Reduction		Reported Effects on Phenolic Composition	Reference
		Co (% v/v)	Cf (% v/v)		
Grenache–Carignan red wine	RO	16.2	15.1–14.1	The total phenolic index and total proanthocyanidins of partially dealcoholized wines and the control wine remain almost unchanged and do not differ. Slight but statistically significant differences were observed in the percentages of procyanidins, prodelphinidins, and galloylation during alcohol reduction. Total anthocyanin concentrations of partially dealcoholized wines were statistically significantly higher than that of the control wine	[22]
Montepulciano d'Abruzzo red wine	RO	13.2	9.0	Increase in total phenols and decrease in total anthocyanins during ethanol reduction in wine samples. Color intensity increases during ethanol removal	[138]
Aglianico red wine	OD/EP	12.8	4.9–0.4	Higher amount of total phenols in dealcoholized wine samples compared to the original wine. Color intensity decreased slightly at the end of dealcoholization	[180]
Aglianico red wine	OD/EP	15.4	13.5–10.8	The alcohol removal process did not affect the content of vanillin reactive flavans and total phenolics. A loss of 49% of total monomeric anthocyanins was observed after dealcoholization while total anthocyanins remained almost unchanged with no significant differences. Color parameters of dealcoholized wines were not significantly different compared to the original wine after alcohol removal	[144]
Merlot red wine	OD/EP	13.8	11.1–8.9	The alcohol removal process did not affect the content of vanillin reactive flavans and total phenolics. A loss of 57% of total monomeric anthocyanins was observed after dealcoholization while total anthocyanins remained almost unchanged with no significant differences. Color parameters of dealcoholized wines were not significantly different compared to the original wine after alcohol removal	[144]

Wine Type	Dealcoholization Process	Alcohol Reduction		Reported Effects on Phenolic Composition	Reference
		Co (% v/v)	Cf (% v/v)		
Piedirosso red wine	OD/EP	13.6	11.5–8.4	The alcohol removal process did not affect the content of vanillin reactive flavans and total phenolics. A loss of 52% of total monomeric anthocyanins was observed after dealcoholization while total anthocyanins remained almost unchanged with no significant differences. Color parameters of dealcoholized wines were not significantly different compared to the original wine after alcohol removal	[144]
Aglianico red wine	OD/EP	12.5	10.6	No significant differences between base wine and dealcoholized wine in terms of total polyphenols and color intensity	[146]
Barbera red wine	OD/EP	15.2	5.0	Higher contents of total anthocyanins and total flavonoids compared to the original wine. Color: the intensity increases and the hue decreases (loss of orange notes) due to the increased content of total anthocyanins	[155]
Langhe Rosè wine	OD/EP	13.2	5.0	Higher contents of total anthocyanins and total flavonoids compared to the original wine. Color: the intensity increases and the hue decreases (loss of orange notes) due to the increased content of total anthocyanins	[155]
Verduno Pelaverga red wine	OD/EP	14.6	5.0	Higher contents of total anthocyanins and total flavonoids compared to the original wine. Color: the intensity increases and the hue decreases (loss of orange notes) due to the increased content of total anthocyanins	[155]
Falanghina white wine	OD/EP	12.5	9.8–0.3	At different alcohol content levels of wines, the total phenols and flavonoids do not differ significantly as they remain almost unchanged during the alcohol removal process	[140]
Montepulciano d’Abruzzo red wine	OD/EP	13.2	8.3–5.4	Both total phenols and total anthocyanins decrease in dealcoholized wines with no significant differences compared to the original wine. The color intensity remains almost unchanged during ethanol removal	[138]

Wine Type	Dealcoholization Process	Alcohol Reduction		Reported Effects on Phenolic Composition	Reference
		Co (% v/v)	Cf (% v/v)		
Montepulciano d'Abruzzo red wine	OD/EP	13.2	8.3–2.7	Flavonoids and phenolic compounds remain almost unchanged in all dealcoholized samples compared to the base wine with no significant differences. Color intensity (evaluated by flavonoids and phenolic compounds) decrease slightly in all dealcoholized samples	[139]
Langhe Rosè wine	VD	13.2	5.0	Higher contents of total anthocyanins and total flavonoids compared to the original wine. Color the intensity increases and the hue decreases (loss of orange notes) due to the increased content of total anthocyanins	[155]
Barbera red wine	VD	15.2	5.0	Higher contents of total anthocyanins and total flavonoids compared to the original wine. Color: the intensity increases and the hue decreases (loss of orange notes) due to the increased content of total anthocyanins	[155]
Verduno Pelaverga red wine	VD	14.6	5.0	Higher contents of total anthocyanins and total flavonoids compared to the original wine. Color the intensity increases and the hue decreases (loss of orange notes) due to the increased content of total anthocyanins	[155]
Red wine	SCC	14.0	< 0.3	Increase in phenolic compounds, total phenolic, flavonol, tartaric ester, and anthocyanin contents by approximately 24%. Higher content of resveratrol than the original wine	[159]
Rose wine	SCC	14.0	< 0.3	Increase in phenolic compounds, total phenolic, flavonol, tartaric ester, and anthocyanin contents by approximately 24%. Higher content of resveratrol than the original wine	[159]
White wine	SCC	14.0	< 0.3	Increase in phenolic compounds content by approximately 24%	[159]
Montepulciano d'Abruzzo red wine (cv.)	RO–OD/EP	13.2	7.1–5.5	Total phenols increase while total anthocyanins decrease in the dealcoholized wine samples. Color intensity increases during ethanol removal	[138]
Cabernet Sauvignon red wine	RO–OD/EP	14.1	12.5	Significantly increase in color intensity due to increased content of anthocyanins during alcohol reduction compared to the base wine	[164]

Wine Type	Dealcoholization Process	Alcohol Reduction		Reported Effects on Phenolic Composition	Reference
		Co (% v/v)	Cf (% v/v)		
Shiraz red wine	RO–OD/EP	15.2	12.6	Increase in color intensity due to increased content of anthocyanins during alcohol reduction compared to the base wine	[164]

Co = original alcohol content; Cf = final alcohol content; NF = nanofiltration; RO = reverse osmosis; OD = osmotic distillation; EP = evaporative perstraction; VD = vacuum distillation; SCC = spinning cone column.

The dealcoholization of white, rose, and red wines by SCC distillation at pilot plant scale was reported to cause minimal damage to phenolic compounds such as flavonols, tartaric esters, stilbenes (specifically *trans*- and *cis*- resveratrol), flavonols (i.e., rutin, quercetin, and myricetin), flavan-3-ols (mainly (+)-catechin and (−)-epicatechin), anthocyanins (in particular malvidin 3-glucoside), and non-flavonoids (including gallic, caffeic, and p-coumaric acids) [159]. Additionally, the technique increased the concentrations of these compounds in the wines after dealcoholization [159]. Phenolic compounds such as polyphenols and anthocyanins were not lost during the dealcoholization (at 5% v/v ethanol) of Rosé, Pelaverga, and Barbera red wines using a membrane contactor and VD method [124]. Recently, Liguori et al. [140] studied the main quality parameters of white wine (cv Falanghina, 12.5% v/v) dealcoholized at different ethanol concentration levels ranging from 9.8% to 0.3% by an osmotic distillation process. There were no significant differences in flavonoids, total phenols, total acidity, and organic acids between the wine samples at different alcohol content levels. Similar results were obtained in a red wine dealcoholized at different alcohol levels [139]. Furthermore, when RO-EP treatment was used in the partial dealcoholization (i.e., a reduction of 0.5% to 5.0% ABV) of red wine, it resulted in increased phenolics, color intensity, and organic acids [164]. In contrast, a significant change in the color of red wines dealcoholized by RO was observed [179]. The increase in phenolic compounds in wine, particularly anthocyanins, after dealcoholization noted in most of these studies may be due to reduced precipitation of wine tartrate salts [22], as wine tartrate salts can absorb polyphenols [181]. It has also been reported that dealcoholization at a low temperature (20 °C) can lead to higher retention of polyphenols in wine [128]. In addition, the increment can be attributed to the concentration effect produced by the removal of ethanol from the wine [159].

3.2. Impact on Volatile Composition

The composition of volatile compounds influences the overall aroma and flavor of wine [182][183][184][185][186]. Wine contains over 1000 volatile compounds of various chemical classes (alcohols, esters, fatty acids, aldehydes, terpenes, ketones, and sulfur compounds), and wine fermentation produces approximately 400 volatile compounds [187]. During dealcoholization, the removal of alcohol from wine is usually accompanied by the removal of water and some volatile compounds as well [188]. **Table 3** summarizes some findings regarding the volatile composition of wines during the dealcoholization process. In the case of membrane contactor techniques such as RO, NF, PV, and OD that use a membrane for ethanol removal, a greater pressure difference across the membrane than the osmotic pressure difference causes ethanol and water from the wine to pass through the membrane [157].

Table 3. Some reported changes in wine volatile compounds using different dealcoholization processes.

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction		Volatile Composition		Sampling and Analytical Method	Reference
				Co (% v/v)	Cf (% v/v)	Volatile Compounds	Estimated Average Losses (%)		
NF	White model wine	TORAY–UB70	Batch retentate–recycling mode T = 15 P = 10	12.0	8.4	Diethyl succinate 2–phenyl–ethanol *cis*–3–hexenol Isovaleric acid	2.4 2.9 12.6 11.7	HS/SPME–GC/MS	[130]
	Red Wine	Polyamide, NF9, Alfa Laval	T = 30 P = 16	12.0	9.1	Total volatile aroma**	30.0	GC–FID	[189]
RO	Model wine	Osmonics–SE	Batch retentate–recycling mode T = 15 P = 17–29	12.0	8.4	Diethyl succinate 2–phenyl–ethanol *cis*–3–hexenol Isovaleric acid	0.6–1.6 2.5–3.5 7.8–11 11.9–18.1	HS/SPME–GC/MS	[130]
	Red Wine	Cellulose acetate, CA995PE	T = 30◦C P = 16	12.0	8.4	Total aroma**	90.0	GC–FID	[189]
	Montepulciano d'Abruzzo red wine	RO membrane (100 DA)	T = 10 P = ns Time = 40	13.2	9.0	Alcohols Acids Esters Phenols Lactones	30.0 22.0 8.0 13.0 14.0	SPME–GC/MS	[138]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction		Volatile Composition		Sampling and Analytical Method	Reference
				Co (% v/v)	Cf (% v/v)	Volatile Compounds	Estimated Average Losses (%)		
OD/EP	Model wine	Polyvinylidene fluoride (PVDF) Memcor	Qf = 0.053 Qs = 0.093 T = 30 Time = 60	13.0	8.1	Isoamyl alcohol Ethyl acetate	44.0 70.0	GC–FID	[190]
	Falanghina white wine	Liqui–Cel 0.5 × 1, PP hollow fiber	Qf = 0.07 Qs = 0.14 T = 10 Time = 240	12.5	9.8–0.3	Higher alcohols Acids Esters Ketones lactones	49.5–98.9 60.5–98.7 71.5–99.0 67.1–99.9 73.6–98.2	LE–GC/MS, LE–GC/FID	[140]
	Xarelo white wine	Liqui–Cel ExtraFlow	Qf = 10 Qs = 10 T = room temperature Time = 20	11.5	10.1	Isoamyl acetate Ethyl hexanoate Ethyl octanoate Ethyl decanoate	27.0 37.0 28.0 24.0	SBSE–GC/MS	[142]
	Soave white wine	PTFE hollow fiber (Teflon, Verona, Italy)	Qf = 0.2 Qs = 0.2 T = 20 Time = ns	ns	*	Alcohols Acids Esters Terpenes	12.6–32.2 5.6–16.4 34.0–58.4 22.0–26.0	SPE–GC/MS	[191]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction		Volatile Composition		Sampling and Analytical Method	Reference
				Co (% v/v)	Cf (% v/v)	Volatile Compounds	Estimated Average Losses (%)		
	Verdicchio white wine	PTFE hollow fiber (Teflon, Verona, Italy)	Qf = 0.2 Qs = 0.2 T = 20 Time = ns	ns	*	Alcohols Acids Esters Terpenes	8.9–25.8 8.0–15.8 40.0–54.1 21.0–28.0	SPE–GC/MS	[191]
	Aglianico red wine	Liqui–Cel Extra–flow, PP hollow fiber	Qf = 0.583 Qs = 0.183 T = 20 Time = 283	13.8	11.6–8.8	Alcohols Esters Acids Terpenes *Others:* Benzaldehyde ?–Butyrolactone	8.4–31.8 42.9–60.9 12.5–17.1 13.8–32.3 55.3–65.9 4.5–13.6	SPE–GC/MS	[133]
	Aglianico red wine	Liqui–Cel Extra–flow, PP hollow fiber	Qf = 0.583 Qs = 0.183 T = 20 Time = 283	15.5	13.5–10.8	Alcohols Esters Acids Terpenes *Others:* Benzaldehyde ?–Butyrolactone Vitispirane	9.2–13.7 33.8–50.6 11–18.5 3.6–14.5 nf 12.9 Unc	SPE–GC/MS	[133]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction		Volatile Composition		Sampling and Analytical Method	Reference
				Co (% v/v)	Cf (% v/v)	Volatile Compounds	Estimated Average Losses (%)		
	Aglianico red wine	Liqui–Cel 0.5×1, PP hollow fiber	Qf = 0.07 Qs = 0.14 T = 20 Time = 255	13.0	6.5–0.2	Alcohols Acids Esters Sulfur compounds Phenols Ketones and lactones Aldehydes	57.9–99.9 23.6–78.9 12.8–89.9 2.1–78.7 66.7–100 23.6–97.9 unc–100	LE–GC/MS, LE–GC/FID	[145]
	Merlot red wine	Liqui–Cel Extra–flow, PP hollow fiber	Qf = 5.8 Qs = 8.1 T = 20 Time = 60	13.4	11.3	Ethyl acetate Isoamyl acetate Isoamyl alcohol Ethyl hexanoate Ethyl octanoate Linalool 2–Phenylethyl acetate	37.4 34.9 13.7 33.0 67.8 14.5 13.6	HS/SPME–GC/MS	[141]
	Barbera red wine	Polypropylene hollow fibers (JU.CLA.S. LTD, Verona, Italy)	Qf = 1.6 Qs = 0.8 T = 10 Time = 360	14.6	5.0	Alcohols Acids Esters	63.9 17.4 23.8	SPE–GC/FID	[155]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction		Volatile Composition		Sampling and Analytical Method	Reference
				Co (% v/v)	Cf (% v/v)	Volatile Compounds	Estimated Average Losses (%)		
	Tempranillo red wine	Liqui–Cel ExtraFlow	Qf = 5.8 Qs = 5.8 T = room temperature Time = 60	13.3	9.0	Isoamyl alcohol Ethyl hexanoate	21.0 20.0	SBSE–GC/MS	[142]
	Garnacha red wine	Liqui–Cel ExtraFlow	Qf = 5 Qs = 5 T = room temperature Time = 60	13.9	9.3	Isoamyl acetate Ethyl hexanoate	24.0 36.0	SBSE–GC/MS	[142]
	Verduno Pelaverga red wine	Polypropylene hollow fibers (JU.CLA.S. LTD, Verona, Italy)	Qf = 1.6 Qs = 0.8 T = 10 Time = 360	14.6	5.0	Alcohols Acids Esters	59.9 23.6 45.2	SPE–GC/FID	[155]
	Montepulciano d’Abruzzo red wine	Liqui–Cel 0.5×1, PP hollow fiber	Recycling mode Qf = 1.5 Qs = 0.5 T = 10 Time = 240	13.2	8.3–2.7	Alcohols Acids Esters Lactones Phenols *Others:* Benzaldehyde α–Terpineol	56.0–84.0 18.0–23.0 64.0–85.0 11.0–37.0 11.0–37.0 2.0–26.0 5.0–49.0	SPE– LE–GC/MS/FID	[139]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction		Volatile Composition		Sampling and Analytical Method	Reference
				Co (% v/v)	Cf (% v/v)	Volatile Compounds	Estimated Average Losses (%)		
	Montepulciano d'Abruzzo red wine	Liqui–Cel mini module 1.7x5.5 Membrana	Recycling mode Qf = 1.5 Qs = 0.5 T = 10 Time = 120	13.2	8.3–5.4	Alcohols Acids Esters Phenols Lactones	2.0–3.0 18.0–25.0 15.0–19.0 5.0–10.0 7.0–25.0	SPME–GC/MS	[138]
	Langhe Rosè wine	Polypropylene hollow fibers (JU.CLA.S. LTD, Verona, Italy)	Qf = 1.6 Qs = 0.8 T = 10 Time = 360	13.2	5.0	Alcohols Acids Esters	60.4 30.9 47.8	SPE–GC/FID	[155]
PV	Tokaji Hárslevelű white wine	PERVAP.Sulzer 1060 PDMS	"Carrier gas mode" under atmospheric pressure T = 40–70	13.1	0.1	Total volatile aroma**	70.0	Distillation/LE–GC/MS	[147]
	Cabernet Sauvignon red wine	PDMS JS–WSM–8040 (JiuSi High–Tech, Nanjing, China)	Batch operation T = 45 VP = 0.05	12.5	0.5	Alcohols Acids Esters	19.7–39.5 12.7–28.2 48.0–99.9	GC/MS	[192]

Co = original alcohol content; Cf = final alcohol content; T = temperature; P = pressure; VP = vacuum pressure; PP = polypropylene; ns = not specified; Verdicchio white wine 1 = sample 1 of 3; Cabernet Sauvignon red wine A = sample 1 of 5; OD = osmotic distillation; EP = evaporative perstraction; SCC = spinning cone column; NF = nanofiltration; RO = reverse osmosis; PV = pervaporation; PDMS = polydimethylsiloxane; unc = unchanged; nf = not found; *ethanol content removal between 2% and 4% v/v; **no values of the individual volatile aroma compound losses were provided; SPE = solid phase extraction; GC = gas chromatography; MS = mass spectrometry; LE = liquid extraction; FID = flame ionization detector; SBSE = stir bar sorptive extraction; HS = headspace; SPME = solid phase micro extraction; – means not applicable. Units: Concentration = (%v/v); Vacuum pressure/Pressure = bar; Rejection = %; T = °C; Flowrate = L/min; Time = min.

Several studies have reported on the use of membrane techniques in wine dealcoholization and their subsequent effect on the dealcoholized wine volatile compositions [147][133][139][140][130][135][138][145][155][190]. A low alcohol content apple cider was produced by RO with a polyamide membrane AFC99 in both batch and diafiltration configurations [135]. The process was operated at 15 °C and 45 bar with a feed flow of 200 L h^{-1}. During the batch configuration process, 50% of ethanol was removed with an estimated loss of 77% of total higher alcohols, 20% of total aldehydes, 25% of total acids, and 25% of total esters. In the diafiltration configuration, estimated losses of 96% total higher alcohols, 43% total aldehydes, 18.5% total acids, and 28% total esters accompanied the removal of 75% ethanol. However, losses in these volatile compounds were deemed insignificant in both configurations [135]. Takács et al. [147] used PV in the total dealcoholization of a Tokaji Hárslevelű wine (13.11% v/v), resulting in a 70% loss of the total aroma compounds, but the loss of individual aroma compounds was not reported. When Sun et al. [192] used PV technology to reduce the alcohol content of a Cabernet Sauvignon red wine from 12.5% to 0.5%, they discovered losses of volatile compounds, specifically alcohols (40%), acids (28%), and esters (99%). After dealcoholization with a polyvinylidene fluoride membrane, Varavuth et al. [190] found losses of 47% to 70% and 23% to 44% of ethyl acetate and isoamyl alcohol, respectively, in a model wine solution. Diban et al. [141] used the same polyvinylidene fluoride membrane to measure the losses of eight volatile compounds in wine and wine model solution after a 2% v/v ethanol reduction, but only losses were observed in model solution after a 5% v/v ethanol reduction. Furthermore, Belisario-Sánchez et al. [158] found that after dealcoholization by SCC, the total volatile aroma compounds of Tempranillo red wine, Cabernet Sauvignon rose wine, and Chardonnay white wine were lost by approximately 18%, 4%, and 9%, respectively.

During dealcoholization, volatile compounds are lost in the same way as ethanol. As a result, their original contents are lost during dealcoholization due to vaporization and diffusion [133][190]. In addition, some losses of 2% to 3% have been attributed to their adsorption onto the membrane [141]. This is due to their high affinity for the membrane and high volatility, which allows them to pass through the membrane more easily. Through a non-covalent interaction between the polyphenols and the aromatic ring of aromatic compounds, the non-volatile matrix of wine, particularly polyphenols, can also aid in the stability and retention of volatile compounds [133]. This best explains why a 50% reduction in the ethanol content of a 13% v/v Aglianico wine by a membrane contactor technique did not affect the amount of 2-phenylethanol in the dealcoholized wine [145]. However, when higher ethanol concentrations were removed, a drastic decrease in the 2-phenylethanol concentration was observed, which was attributed to weaker ?–? stacking caused by the decrease in ethanol content (7% v/v) of the wine.

The operating conditions used during the dealcoholization process can also have an impact on the concentrations of wine volatile compounds. A change in some operating conditions of an OD process, such as lowering the temperature from 20 °C to 10 °C and changing the positions of the feed and stripping streams from a previous study [145], helped to decrease the loss of volatile aroma compounds by about 2.8% during the dealcoholization of a 12.5% v/v white wine [140]. From the findings, it is evident that the physical technologies used in the dealcoholization of wines can result in significant losses of volatile compounds due to the reduction in alcohol levels. However, the significance and extent of the changes can also depend on the operating conditions applied, the type of membrane used, and the non-volatile matrix of the wine.

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Alcohol Reduction Cf (% v/v)	Volatile Composition: Volatile Compounds	Volatile Composition: Estimated Average Losses (%)	Sampling and Analytical Method	Reference
	Barbera red wine	–	T = 15	15.2	5.0	Alcohols Acids Esters	50.4 13.7 19.8	SPE–GC/FID	[155]
VD	Verduno Pelaverga red wine	–	T = 15	14.6	5.0	Alcohols Acids Esters	53.6 2.9 19.5	SPE–GC/FID	[155]
	Langhe Rosé wine	–	T = 15	13.2	5.0	Alcohols Acids Esters	51.4 2.5 22.9	SPE–GC/FID	[155]
	White wine	–	T = 25 VP = 0.08 Time = 60	10.6	0.3	Aliphatic alcohols Aromatic alcohols Acids Esters Ketones	98.0 3.0 25.0 53.0 71.0	LLE–GC/FID	[160]
SCC	Chardonnay white wine	–	T = 30 VP = 0.04 Time = 60	ns	ns	Total aroma**	1.0–9.0	HS/SPME–GC/MS	[158]
	Tempranillo red wine	–	T = 30 VP = 0.04 Time = 60	ns	ns	Total aroma**	3.0–18.0	HS/SPME–GC/MS	[158]
	Cabernet Sauvignon rose wine	–	T = 30 VP = 0.04 Time = 60	ns	ns	Total aroma**	1.0–4.0	HS/SPME–GC/MS	[158]

3.3. Impact on Sensory Characteristics

Ethanol is the most abundant of the volatile compounds in wine and its concentration can influence the perception of wine aroma and flavor as well as several mouthfeel and taste sensations [141][177][194][195]. Higher ethanol concentrations in wine typically enhance sensitivity to body, bitterness, and hotness, whereas lower concentrations can reduce the perception to aroma, flavor, acidity, and astringency [19][20][196][197][198]. Some studies have been conducted to investigate the sensory quality of wines or wine model solutions during ethanol removal [147][130][141][144][159][160][178][190][180]. The sensory profile of wine after partial or total dealcoholization is primarily determined by the amount of alcohol remaining in the dealcoholized wine [157][191][199][200]. **Table 4** summarizes the key findings from some of these studies on the sensory changes caused by dealcoholization.

Table 4. Summary of the main results of some studies on the sensory changes caused by the removal of ethanol from wine by various dealcoholization processes.

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Alcohol Reduction Cf (% v/v)	Findings on Sensory Characteristics	Reference
NF	Red Wine	Polyamide, NF97, NF99 HF Alfa Laval	T = 30 P = 16	12.0	9.1	Increase in astringency and unbalanced aroma and taste due to alcohol reduction	[189]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Alcohol Reduction Cf (% v/v)	Volatile Composition: Volatile Compounds	Volatile Composition: Estimated Average Losses (%)	Sampling and Analytical Method	Reference
RO-OD/EP	Shiraz red wine	Memstar AA MEM–074 and Liqui–Cel 2.5×8 Extra–flow PP hollow fiber	Qf = ns Qs = ns T = ns P = ns Time = ns	16.3	13.3–10.4	Alcohols Esters Monoterpenes C13–Norisoprenoids Lactones Others: Dimethyl sulfide	14.9–38.9 29.8–49.5 9.2–20.8 9.4–14.5 17.1–21.4 52.6–71.9	HS–SPME–GC/MS	[193]
	Montepulciano d'Abruzzo red wine	RO membrane (100 DA) and Liqui–cel mini module 1.7×5.5 Membrane	Recycling mode Qf = 1.5 Qs = 0.5 T = 10 P = ns Time = 120	13.2	7.1–5.5	Alcohols Acids Esters Phenols Lactones	17.0–27.0 19.0–24.0 15.0–22.0 16.0–18.0 unc–14.0	SPME–GC/MS	[138]
	Barossa Valley Shiraz – Cabernet Sauvignon red wine	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	14.1	12.5	Alcohols Acids Esters	15.5 20.0 5.1	SPME–GC/MS	[164]
	McLaren Vale Cabernet Sauvignon red wine	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	17.1	14.5	Alcohols Acids Esters	13.6 6.1 18.8	SPME–GC/MS	[164]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Alcohol Reduction Cf (% v/v)	Findings on Sensory Characteristics	Reference
RO	Syrah red wine	ns	T = ns P = ns	12.7	11.1–9.6	Decrease in wine length in the mouth and increase in red fruits and then woody and blackcurrant perceptions (using TDS and attributed to alcohol reduction). Decrease in heat and sweetness intensity (attributed to alcohol reduction) and red fruit intensity (attributed to RO)	[178]
	Merlot red wine	ns	T = ns P = ns	13.4	11.8–10.2	Decrease om wine length in the mouth and increase in astringent and then of fruity perceptions (using TDS and attributed to alcohol reduction). Decrease in heat and texture intensity (attributed to alcohol reduction) and increase in acid intensity (attributed to RO)	[178]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Alcohol Reduction Cf (% v/v)	Volatile Composition Volatile Compounds	Volatile Composition Estimated Average Losses (%)	Sampling and Analytical Method	Reference
	Adelaide Hills Shiraz red wine	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	14.9	14.2	Alcohols Acids Esters	7.0 0.4 8.6	SPME–GC/MS	[164]
	Barossa Valley Shiraz red wine	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	15.2	12.6	Alcohols Acids Esters	11.0 5.6 21.2	SPME–GC/MS	[164]
	McLaren Vale Shiraz red wine	Spiral wound 4040 and hollow fiber perstractive membrane	Qf = ns Qs = ns T = 55 P = 30 Time = 90	14.7	12.3	Alcohols Acids Esters	7.1 2.5 9.7	SPME–GC/MS	[164]
	Cabernet Sauvignon red wine A	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	17.0	14.5	Alcohols Acids Esters	8.2 15.9 17.4		[165]
	Cabernet Sauvignon red wine B	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	15.5	13.3	Alcohols Acids	3.8 12.0		[165]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Alcohol Reduction Cf (% v/v)	Findings on Sensory Characteristics	Reference
	Syrah red wine	ns	T = ns P = ns	13.4	11.4–7.9	Decrease in persistence, complexity, number of aromas and increase in balance, harmony, and familiarity. Decrease in familiarity and harmony after 4% v/v reduction	[201]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Alcohol Reduction Cf (% v/v)	Volatile Composition: Volatile Compounds	Volatile Composition: Estimated Average Losses (%)	Sampling and Analytical Method	Reference
	Cabernet Sauvignon red wine C	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	14.9	13.3	Alcohols	16.4		[165]
	Cabernet Sauvignon red wine D	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	14.5	13.2	Alcohols Acids Esters	7.1 4.7 16.5		[165]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Alcohol Reduction Cf (% v/v)	Findings on Sensory Characteristics	Reference
OD/EP							
	white wine	PTFE hollow fiber (Teflon, Verona, Italy)	Qf = 0.2 Qs = 0.2 T = 20 Time = ns	ns	*	Floral, fruity, and vegetable notes, as well as acidity, saltiness, and bitterness, were not significantly influenced. Decrease in wine body, persistence, and honey note.	[191]
	Falanghina white wine	Liqui-Cel 0.5x1, PP hollow fiber	Qf = 0.07 Qs = 0.14 T = 10 Time = 240	12.5	9.8–0.3	Decrease in odor, sweetness, and body, resulting in unbalanced taste and overall unacceptable, with an unpleasant aftertaste	[140]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction		Findings on Sensory Characteristics	Reference
				Co (% v/v)	Cf (% v/v)		
	Aglianico red wine	Liqui-Cel Extra-flow, PP hollow fiber	Qf = 0.583 Qs = 0.183 T = 20 Time = 283	13.8	11.6–8.8	Decrease in cherry, red fruits, and sweet notes. Increase in flowers notes only within 2% v/v reduction. Increase in grass and cooked notes and increase in astringency within 5% v/v reduction. Increase in bitterness and acid sensations within 3% v/v reduction	[133]
	Aglianico red wine	Liqui-Cel Extra-flow	Qf = ns Qs = ns T = ns Time = 180	12.8	4.9–0.4	Decrease in sweet and solvent aroma series (due to alcohol reduction) which characterize the wine	[180]
	Aglianico red wine	Liqui-Cel Extra-flow, PP hollow fiber	Qf = 0.583 Qs = 0.183 T = 20 Time = 283	15.5	13.5–10.8	Decrease in cherry, red fruits, flowers, and grass notes. Increase in acid and astringent sensations	[133]

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction		Findings on Sensory Characteristics	Reference
				Co (% v/v)	Cf (% v/v)		
	Montepulciano d'Abruzzo red wine	Liqui-Cel 0.5×1, PP hollow fiber	Recycling mode Qf = 1.5 Qs = 0.5 T = 10 Time = 240	13.2	8.3–2.7	Increase in acidity, a decrease in red fruits and spices notes, astringency, bitterness, and sweetness, resulting in lower acceptability	[139]
PV	Cabernet Sauvignon red wine	PDMS JS-WSM-8040 (JiuSi High-Tech, Nanjing, China)	Batch operation T = 45 VP = 0.05	12.5	0.5	High retention of fruit aroma, producing wine with better smell and taste	[192]
SCC	Chardonnay white wine	–	ns	14.9	14.6–12.9	Decrease in overall aroma intensity and hot mouthfeel sensation	[202]

Co = original alcohol content; Cf = final alcohol content; T = temperature; P = pressure; VP = vacuum pressure; PP = polypropylene; ns = not specified; Cabernet Sauvignon red wine A = sample 1 of 5; OD = osmotic distillation; EP = evaporative perstraction; SCC = spinning cone column; NF = nanofiltration; RO = reverse osmosis; PV = pervaporation; PDMS = polydimethylsiloxane; unc = unchanged; *ethanol content removal between 2% and 4% v/v. Units: Concentration = (%v/v); Vacuum pressure/Pressure = bar; Rejection = %; T = °C; Flowrate = L/min; Time = min.

References

1. Joshi, V.K.; Sharma, S.; Thakur, A.D. Wines: White, Red, Sparkling, Fortified, and Cider. In Current Developments in Biotechnology and Bioengineering: Food and Beverages Industry; Elsevier: Amsterdam, The Netherlands, 2016; pp. 353–406.
2. Jackson, R.S. Wines: Types of Table Wines, 1st ed.; Elsevier: Amsterdam, The Netherlands, 2015.
3. Pereira, V.; Pereira, A.C.; Marques, J.C. Emerging Trends in Fortified Wines: A Scientific Perspective. In Alcoholic Beverages: Volume 7: The Science of Beverages; Elsevier: Amsterdam, The Netherlands, 2019; pp. 419–470.
4. Jackson, R.S. Innovations in Winemaking; Elsevier: Amsterdam, The Netherlands, 2017.
5. Pickering, G.J. Low and Reduced-Alcohol Wine: A Review. J. Wine Res. 2000, 11, 37–41.
6. Saliba, A.J.; Ovington, L.A.; Moran, C.C. Consumer Demand for Low-Alcohol Wine in an Australian Sample. Int. J. Wine Res. 2013, 5, 1–8.
7. OIV. International Standard for the Labelling of Wines, 2022nd ed.; OIV Publications: Paris, France, 2021.
8. Wine Australia. Low Alcohol Wine; Wine Australia: Adelaide, Australia, 2021.
9. Taborsky, M.; Ostadal, P.; Petrek, M. A Pilot Randomized Trial Comparing Long-Term Effects of Red and White Wines on Biomarkers of Atherosclerosis (In Vino Veritas: IVV Trial). Bratisl. Lek. List. 2012, 113, 156–158.
10. Di Renzo, L.; Carraro, A.; Valente, R.; Iacopino, L.; Colica, C.; De Lorenzo, A. Intake of Red Wine in Different Meals Modulates Oxidized LDL Level, Oxidative and Inflammatory Gene Expression in Healthy People: A Randomized Crossover Trial. Oxidative Med. Cell. Longev. 2014, 2014, 1–9.
11. World Health Organisation. Global Status Report on Alcohol and Health 2018; WHO: Geneva, Switzeland, 2018; Volume 65.
12. World Health Organisation. Global Status Report on Alcohol and Health 2014. 2014, pp. 1–392. Available online: https://doi.org//entity/substance_abuse/publications/global_alcohol_report/en/index.html (accessed on 31 December 2020).

13. Snopek, L.; Mlcek, J.; Sochorova, L.; Baron, M.; Hlavacova, I.; Jurikova, T.; Kizek, R.; Sedlackova, E.; Sochor, J. Contribution of Red Wine Consumption to Human Health Protection. Molecules 2018, 23, 1684.

14. Artero, A.; Artero, A.; Tarín, J.J.; Cano, A. The Impact of Moderate Wine Consumption on Health. Maturitas 2015, 80, 3–13.

15. Boban, M.; Stockley, C.; Teissedre, P.-L.; Restani, P.; Fradera, U.; Stein-Hammer, C.; Ruf, J.C. Drinking Pattern of Wine and Effects on Human Health: Why Should We Drink Moderately and with Meals? Food Funct. 2016, 7, 2937–2942.

16. Yuan, J.-M.; Ross, R.K.; Gao, Y.-T.; Henderson, B.E.; Yu, M.C. Follow up Study of Moderate Alcohol Intake and Mortality among Middle Aged Men in Shanghai, China. BMJ 1997, 314, 18–23.

17. Buettner, D.; Skemp, S. Blue Zones: Lessons from the World's Longest Lived. Am. J. Lifestyle Med. 2016, 10, 318–321.

18. Stockley, C.S. Is It Merely a Myth That Alcoholic Beverages Such as Red Wine Can Be Cardioprotective? Sci. Food Agric. 2012, 92, 1815–1821.

19. Escudero, A.; Campo, E.; Fariña, L.; Cacho, J.; Ferreira, V. Analytical Characterization of the Aroma of Five Premium Red Wines. Insights into the Role of Odor Families and the Concept of Fruitiness of Wines. J. Agric. Food Chem. 2007, 55, 4501–4510.

20. Frost, R.; Quiñones, I.; Veldhuizen, M.; Alava, J.I.; Small, D.; Carreiras, M. What Can the Brain Teach Us about Winemaking? An FMRI Study of Alcohol Level Preferences. PLoS ONE 2015, 10, e0119220.

21. Robinson, A.L.; Ebeler, S.E.; Heymann, H.; Boss, P.K.; Solomon, P.S.; Trengove, R.D. Interactions between Wine Volatile Compounds and Grape and Wine Matrix Components Influence Aroma Compound Headspace Partitioning. J. Agric. Food Chem. 2009, 57, 10313–10322.

22. Gil, M.; Estévez, S.; Kontoudakis, N.; Fort, F.; Canals, J.-M.; Zamora, F. Influence of Partial Dealcoholization by Reverse Osmosis on Red Wine Composition and Sensory Characteristics. Eur. Food Res. Technol. 2013, 237, 481–488.

23. Alston, J.M.; Fuller, K.B.; Lapsley, J.T.; Soleas, G.; Tumber, K.P. Splendide Mendax: False Label Claims About High and Rising Alcohol Content of Wine. J. Wine Econ. 2015, 10, 275–313.

24. Report FACT4532MR. Non-Alcoholic Wine Market Forecast, Trend Analysis & Competition Tracking. Global Market Insights 2019 to 2027; Market Forecast R: London, UK, 2020.

25. Ruf, J.-C. The Implementation of the OIV Standards at the International Level and in the Framework of Innovation in the Wine Sector, CEICS-Tarragona; OIV: Paris, France, 2011; Volume 33.

26. Thompson, D. Wine Intelligence Report Brochure. Lower Alcohol Wines a Multi-market Perspective; Wine Intelligence: London, UK, 2016.

27. Jones, G.V.; White, M.A.; Cooper, O.R.; Storchmann, K. Climate Change and Global Wine Quality. Clim. Change 2005, 73, 319–343.

28. Martínez De Toda, F.; Balda, P. Delaying Berry Ripening through Manipulating Leaf Area to Fruit Ratio. Vitis J. Grapevine Res. 2013, 52, 171–176.

29. Palliotti, A.; Panara, F.; Silvestroni, O.; Lanari, V.; Sabbatini, P.; Howell, G.S.; Gatti, M.; Poni, S. Influence of Mechanical Postveraison Leaf Removal Apical to the Cluster Zone on Delay of Fruit Ripening in Sangiovese (Vitis Vinifera L.). Grapevines. Aust. J. Grape Wine Res. 2013, 19, 369–377.

30. Novello, V.; de Palma, L. Viticultural strategy to reduce alcohol levels in wine. In Alcohol Level Reduction in Wine—Oenoviti International Network; Vigne Et Vin Publications International: Bordeuax, France, 2013.

31. Poni, S.; Gatti, M.; Bernizzoni, F.; Civardi, S.; Bobeica, N.; Magnanini, E.; Palliotti, A. Late Leaf Removal Aimed at Delaying Ripening in Cv. Sangiovese: Physiological Assessment and Vine Performance. Aust. J. Grape Wine Res. 2013, 19, 378–387.

32. Kliewer, W.M.; Dokoozlian, N.K. Leaf Area/Crop Weight Ratios of Grapevines: Influence on Fruit Composition and Wine Quality. Am. J. Enol. Vitic. 2005, 56, 170–181.

33. Liguori, L.; Russo, P.; Albanese, D.; Di Matteo, M. Production of Low-Alcohol Beverages: Current Status and Perspectives; Elsevier Inc.: Amsterdam, The Netherlands, 2018.

34. Zhang, P.; Wu, X.; Needs, S.; Liu, D.; Fuentes, S.; Howell, K. The Influence of Apical and Basal Defoliation on the Canopy Structure and Biochemical Composition of Vitis Vinifera Cv. Shiraz Grapes and Wine. Front. Chem. 2017, 5, 1–9.

35. Filippetti, I.; Allegro, G.; Movahed, N.; Pastore, C.; Valentini, G.; Intrieri, C. Effect of Late-Season Limitations Induced by Trimming and Antitranspirants Canopy Sray on Grape Composition during Ripening in Vitis Vinifera Cv. Sangiovese

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Alcohol Reduction Cf (% v/v)	Findings on Sensory Characteristics	Reference
RO-OD/EP	Shiraz red wine	Memstar AA MEM-074 and Liqui-Cel 2.5 × 8 Extra-flow PP hollow fiber	Qf = ns Qs = ns T = ns P = ns Time = ns	16.3	13.3–10.4	Increase in dark fruit, raisin/prune, alcohol, and astringency in all dealcoholized wines with no significant effects. Increase in black pepper note and overall aroma intensity, and decrease in herbaceous note within 6% v/v reduction off alcohol	[193]
	Cabernet Sauvignon red wine A	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	17.0	14.5	Increase in dark fruit aroma and decrease of green aroma, dried fruit, and chocolate flavors with no significant difference in the overall intensity. A small decrease in acidity. Small but significant decreases in sweetness and saltiness. Increase in the sensation of astringency	[165]

Progr. Agric. Vitic. Hors Série Spec. 2011, 17, 259–262.

36. Böttcher, C.; Harvey, K.; Forde, C.G.; Boss, P.K.; Davies, C. Auxin Treatment of Pre-Veraison Grape (Vitis Vinifera L.) Berries Both Delays Ripening and Increases the Synchronicity of Sugar Accumulation. Aust. J. Grape Wine Res. 2011, 17, 1–8.
37. Palliotti, A.; Poni, S.; Berrios, J.G.; Bernizzoni, F. Vine Performance and Grape Composition as Affected by Early-Season Source Limitation Induced with Anti-Transpirants in Two Red Vitis Vinifera L. Cultivars. Aust. J. Grape Wine Res. 2010, 16, 426–433.
38. Martínez De Toda, F.; Sancha, J.C.; Zheng, W.; Balda, P. Leaf Area Reduction by Trimming, a Growing Technique to Restore the Anthocyanins: Sugars Ratio Decoupled by the Warming Climate. Vitis J. Grapevine Res. 2014, 53, 189–192.
39. Stoll, M.; Lafontaine, M.; Schultz, H.R. Possibilities to Reduce the Velocity of Berry Maturation through Various Leaf Area to Fruit Ratio Modifications in Vitis Vinifera L. Riesling. Progrès Agric. Vitic. 2010, 127, 68–71.
40. Stoll, M.; Bischoff-Schaefer, M.; Lafontaine, M.; Tittmann, S.; Henschke, J. Impact of Various Leaf Area Modifications on Berry Maturation in Vitis Vinifera L. "Riesling.". Acta Hortic. 2013, 978, 293–300.
41. Sun, Q.; Sacks, G.L.; Lerch, S.D.; van den Heuvel, J.E. Impact of Shoot and Cluster Thinning on Yield, Fruit Composition, and Wine Quality of Corot Noir. Am. J. Enol. Vitic. 2012, 63, 49–56.
42. Parker, A.K.; Hofmann, R.W.; van Leeuwen, C.; Mclachlan, A.R.G.; Trought, M.C.T. Manipulating the Leaf Area to Fruit Mass Ratio Alters the Synchrony of Total Soluble Solids Accumulation and Titratable Acidity of Grape Berries. Aust. J. Grape Wine Res. 2015, 21, 266–276.
43. Palliotti, A.; Cini, R.; Leoni, F.; Silvestroni, O.; Poni, S. Effects of Late Mechanized Leaf Removal above the Clusters Zone to Delay Grape Ripening in "Sangiovese" Vines. Acta Hortic. 2013, 978, 301–308.
44. De Toda, F.M.; Sancha, J.C.; Balda, P. Reducing the Sugar and PH of the Grape (Vitis Vinifera l. Cvs. "Grenache" and 'Tempranillo') through a Single Shoot Trimming. South African J. Enol. Vitic. 2013, 34, 246–251.
45. De Palma, L.; Tarricone, L.; Muci, G.; Limosani, P.; Savino, M.; Novello, V. Leaf Removal, Vine Physiology and Wine Quality in Cv. Negroamaro (Vitis Vinifera L.). Progrès Agric. Vitic. 2011, 17, 231–234.
46. Bindon, K.; Varela, C.; Kennedy, J.; Holt, H.; Herderich, M. Relationships between Harvest Time and Wine Composition in Vitis Vinifera L. Cv. Cabernet Sauvignon 1. Grape and Wine Chemistry. Food Chem. 2013, 138, 1696–1705.
47. Bindon, K.; Holt, H.; Williamson, P.O.; Varela, C.; Herderich, M.; Francis, I.L. Relationships between Harvest Time and Wine Composition in Vitis Vinifera L. Cv. Cabernet Sauvignon 2. Wine Sensory Properties and Consumer Preference. Food Chem. 2014, 154, 90–101.
48. Martínez de Toda, F.; Balda, P. Decreasing the alcohol level in quality red wines by the "double harvest" technique. In Proceedings of the 17th International Symposium Giesco, Asti, Italia, 29 August–2 September 2011.
49. Kontoudakis, N.; Esteruelas, M.; Fort, F.; Canals, J.-M.; Zamora, F. Use of Unripe Grapes Harvested during Cluster Thinning as a Method for Reducing Alcohol Content and PH of Wine. Aust. J. Grape Wine Res. 2011, 17, 230–238.
50. Asproudi, A.; Ferrandino, A.; Bonello, F.; Vaudano, E.; Pollon, M.; Petrozziello, M. Key Norisoprenoid Compounds in Wines from Early-Harvested Grapes in View of Climate Change. Food Chem. 2018, 268, 143–152.
51. Schelezki, O.J.; Antalick, G.; Šuklje, K.; Jeffery, D.W. Pre-Fermentation Approaches to Producing Lower Alcohol Wines from Cabernet Sauvignon and Shiraz: Implications for Wine Quality Based on Chemical and Sensory Analysis. Food Chem. 2019, 309, 125698.
52. Schelezki, O.J.; Šuklje, K.; Boss, P.K.; Jeffery, D.W. Comparison of Consecutive Harvests versus Blending Treatments to Produce Lower Alcohol Wines from Cabernet Sauvignon Grapes: Impact on Wine Volatile Composition and Sensory Properties. Food Chem. 2018, 259, 196–206.
53. Schelezki, O.J.; Deloire, A.; Jeffery, D.W. Substitution or Dilution? Assessing Pre-Fermentative Water Implementation to Produce Lower Alcohol Shiraz Wines. Molecules 2020, 25, 2245.
54. Piccardo, D.; Favre, G.; Pascual, O.; Canals, J.M.; Zamora, F.; González-Neves, G. Influence of the Use of Unripe Grapes to Reduce Ethanol Content and PH on the Color, Polyphenol and Polysaccharide Composition of Conventional and Hot Macerated Pinot Noir and Tannat Wines. Eur. Food Res. Technol. 2019, 245, 1321–1335.
55. Teslić, N.; Patrignani, F.; Ghidotti, M.; Parpinello, G.P.; Ricci, A.; Tofalo, R.; Lanciotti, R.; Versari, A. Utilization of 'Early Green Harvest' and Non-Saccharomyces Cerevisiae Yeasts as a Combined Approach to Face Climate Change in Winemaking. Eur. Food Res. Technol. 2018, 244, 1301–1311.
56. Longo, R.; Blackman, J.W.; Antalick, G.; Torley, P.J.; Rogiers, S.Y.; Schmidtke, L.M. Harvesting and Blending Options for Lower Alcohol Wines: A Sensory and Chemical Investigation. J. Sci. Food Agric. 2018, 98, 33–42.

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Alcohol Reduction Cf (% v/v)	Findings on Sensory Characteristics	Reference
	Cabernet Sauvignon red wine B	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	15.5	13.9	Decreases in hotness, bitterness, and body (attributed to lower ethanol level) Decrease in confection and chocolate aromas. Significant decrease in the overall flavor intensity (largely due to the decreased intensity of dark fruit, sweet spice, and chocolate flavors) with no significant effect on the overall intensity	
	Cabernet Sauvignon red wine C	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	14.9	13.3	Decrease in hotness (attributed to lower ethanol level) Decrease in confection, dried fruit, and chocolate aromas with no significant difference in the overall intensity. Decrease in the sensation of astringency	[165]

57. Petrie, P.R.; Teng, B.; Smith, P.A.; Bindon, K.A. Sugar Reduction: Managing High Baume Juice Using Dilution. Wine Vitic. J. 2019, 34, 36–37.
58. Heymann, H.; Licalzi, M.; Conversano, M.R.; Bauer, A.; Skogerson, K.; Matthews, M.; Cellars, B.W.; Street, W. Effects of Extended Grape Ripening with or Without Must and Wine Alcohol Manipulations on Cabernet Sauvignon Wine Sensory Characteristics. South African J. Enol. Vitic. 2013, 34, 86–99.
59. Gardner, J.M.; Walker, M.E.; Boss, P.K.; Jiranek, V. The Effect of Grape Juice Dilution on Oenological Fermentation. bioRxiv 2020.
60. Teng, B.; Petrie, P.R.; Nandorfy, D.E.; Smith, P.; Bindon, K. Pre-Fermentation Water Addition to High-Sugar Shiraz Must: Effects on Wine Composition and Sensory Properties. Foods 2020, 9, 1193.
61. Teng, B.; Petrie, P.R.; Smith, P.A.; Bindon, K.A. Comparison of Water Addition and Early-Harvest Strategies to Decrease Alcohol Concentration in Vitis Vinifera Cv. Shiraz Wine: Impact on Wine Phenolics, Tannin Composition and Colour Properties. Aust. J. Grape Wine Res. 2020, 26, 158–171.
62. Salomon, A. Techniques to Achieve Moderate Alcohol Levels in South African Wine, Cape Wine Masters (Diplome Assignment): Sandton, South Africa, 2006.
63. Harbertson, J.F.; Mireles, M.S.; Harwood, E.D.; Weller, K.M.; Ross, C.F. Chemical and Sensory Effects of Saignée, Water Addition, and Extended Maceration on High Brix Must. Am. J. Enol. Vitic. 2009, 60, 450–460.
64. García-Martín, N.; Perez-Magariño, S.; Ortega-Heras, M.; González-Huerta, C.; Mihnea, M.; González-Sanjosé, M.L.; Palacio, L.; Prádanos, P.; Hernández, A. Sugar Reduction in Musts with Nanofiltration Membranes to Obtain Low Alcohol-Content Wines. Sep. Purif. Technol. 2010, 76, 158–170.
65. García-Martín, N.; Perez-Magariño, S.; Ortega-Heras, M. Sugar reduction in white and red musts with nanofiltration membranes. Desalin. Water Treat. 2011, 27, 167–174.
66. Mihnea, M.; González-SanJosé, M.L.; Ortega-Heras, M.; Pérez-Magariño, S.; García-Martin, N.; Palacio, L.; Prádanos, P.; Hernández, A. Volatile Composition of Verdejo Wines. J. Agric. Food Chem. 2012, 60, 7050–7063.
67. Mira, H.; Guiomar, A.; Geraldes, V.; De Pinho, M.N. Membrane Processing of Grape Must for Control of the Alcohol Content in Fermented Beverages. J. Membr. Sci. Res. 2017, 3, 308–312.
68. Salgado, C.; Carmona, F.J.; Palacio, L.; Prádanos, P.; Hernández, A. Evaluation of Nanofiltration Membranes for Sugar Reduction in Red Grape Must. Procedia Eng. 2012, 44, 1716–1717.
69. Salgado, C.M.; Fernández-Fernández, E.; Palacio, L.; Hernández, A.; Prádanos, P. Alcohol Reduction in Red and White Wines by Nanofiltration of Musts before Fermentation. Food Bioprod. Process. 2015, 96, 285–295.
70. Salgado, C.M.; Fernández-Fernández, E.; Palacio, L.; Carmona, F.J.; Hernández, A.; Prádanos, P. Application of Pervaporation and Nanofiltration Membrane Processes for the Elaboration of Full Flavored Low Alcohol White Wines. Food Bioprod. Process. 2017, 101, 11–21.
71. Salgado, C.M.; Palacio, L.; Prádanos, P.; Hernández, A.; González-Huerta, C.; Pérez-Magari, S. Comparative Study of Red Grape Must Nanofiltration: Laboratory and Pilot Plant Scales. Food Bioprod. Process. 2015, 94, 610–620.
72. Cassano, A.; Mecchia, A.; Drioli, E. Analyses of Hydrodynamic Resistances and Operating Parameters in the Ultrafiltration of Grape Must. J. Food Eng. 2008, 89, 171–177.
73. Salgado, C.; Palacio, L.; Carmona, F.J.; Hernández, A.; Prádanos, P. In Fluence of Low and High Molecular Weight Compounds on the Permeate Flux Decline in Nano Filtration of Red Grape Must. Desalination 2013, 315, 124–134.
74. Biyela, B.N.E.; du Toit, W.J.; Divol, B.; Malherbe, D.F.; van Rensburg, P. The Production of Reduced-Alcohol Wines Using Gluzyme Mono® 10.000 BG-Treated Grape Juice. South African J. Enol. Vitic. 2009, 30, 124–132.
75. Pickering, G.J.; Heatherbell, D.A.; Barnes, M.F. The Production of Reduced-Alcohol Wine Using Glucose Oxidase-Treated Juice. Part III. Sensory. Am. J. Enol. Vitic. 1999, 50, 307–316.
76. Pickering, G.J.; Heatherbell, D.A.; Barnes, M.F. Optimising Glucose Conversion in the Production of Reduced Alcohol Wine Using Glucose Oxidase. Food Res. Int. 1998, 31, 685–692.
77. Röcker, J.; Schmitt, M.; Pasch, L.; Ebert, K.; Grossmann, M. The Use of Glucose Oxidase and Catalase for the Enzymatic Reduction of the Potential Ethanol Content in Wine. Food Chem. 2016, 210, 660–670.
78. Ruiz, E.; Busto, M.D.; Ramos-Gómez, S.; Palacios, D.; Pilar-Izquierdo, M.C.; Ortega, N. Encapsulation of Glucose Oxidase in Alginate Hollow Beads to Reduce the Fermentable Sugars in Simulated Musts. Food Biosci. 2018, 24, 67–72.
79. Pickering, G. The Production of Reduced-Alcohol Wine Using Glucose Oxidase. Ph.D. Thesis, Lincoln University, Lincoln, UK, 1997.

Dealcoholization Process	Wine Type	Membrane	Operating Mode/Conditions	Alcohol Reduction Co (% v/v)	Cf (% v/v)	Findings on Sensory Characteristics	Reference
	Cabernet Sauvignon red wine D	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	14.5	13.2	Decrease in hotness (attributed to lower ethanol level). Increase in red fruit aroma with no significant difference in the overall intensity	[165]
	Cabernet Sauvignon red wine E	Spiral wound 4040 and hollow fiber perstractive membrane (VA Filtration, Nuriootpa, Australia)	Qf = ns Qs = ns T = 55 P = 30 Time = 90	16.0	14.2	Decrease in hotness (attributed to lower ethanol level). Decrease in overall flavor intensity with no significant difference in the overall intensity. Small but significant decreases in sweetness and saltiness	[165]

80. Al Daccache, M.; Koubaa, M.; Salameh, D.; Vorobiev, E.; Maroun, R.G.; Louka, N. Control of the Sugar/Ethanol Conversion Rate during Moderate Pulsed Electric Field-Assisted Fermentation of a Hanseniaspora Sp. Strain to Produce Low-Alcohol Cider. Innov. Food Sci. Emerg. Technol. 2020, 59, 102258.

81. Canonico, L.; Comitini, F.; Oro, L.; Ciani, M. Sequential Fermentation with Selected Immobilized Non- Saccharomyces Yeast for Reduction of Ethanol Content in Wine. Front. Microbiol. 2016, 7, 278.

82. Ferraro, L.; Fatichenti, F.; Ciani, M. Pilot Scale Vinification Process Using Immobilized Candida Stellata Cells and Saccharomyces cerevisiae. Process Biochem. 2000, 35, 1125–1129.

83. García, V.; Vásquez, H.; Fonseca, F.; Manzanares, P.; Viana, F.; Martínez, C.; Ganga, M.A. Effects of Using Mixed Wine Yeast Cultures in the Production of Chardonnay Wines. Rev. Argent. Microbiol. 2010, 42, 226–229.

84. Gonzalez, R.; Quirós, M.; Morales, P. Yeast Respiration of Sugars by Non-Saccharomyces Yeast Species: A Promising and Barely Explored Approach to Lowering Alcohol Content of Wines. Trends Food Sci. Technol. 2013, 29, 55–61.

85. Kutyna, D.R.; Varela, C.; Henschke, P.A.; Chambers, P.J.; Stanley, G.A. Microbiological Approaches to Lowering Ethanol Concentration in Wine. Trends Food Sci. Technol. 2010, 21, 293–302.

86. Lemos, W.J.F., Jr.; Nadai, C.; Tamara, L.; Sales, V.; Oliveira, D.; Dupas, A.; Matos, D.; Giacomini, A.; Corich, V. Potential Use of Starmerella bacillaris as Fermentation Starter for the Production of Low-Alcohol Beverages Obtained from Unripe Grapes. Int. J. Food Microbiol. 2019, 303, 1–8.

87. Magyar, I.; Tóth, T. Comparative Evaluation of Some Oenological Properties in Wine Strains of Candida Stellata, Candida zemplinina, Saccharomyces uvarum and Saccharomyces cerevisiae. Food Microbiol. 2011, 28, 94–100.

88. Maturano, Y.P.; Mestre, M.V.; Kuchen, B.; Toro, M.E.; Mercado, L.A.; Vazquez, F.; Combina, M. Optimization of Fermentation-Relevant Factors: A Strategy to Reduce Ethanol in Red Wine by Sequential Culture of Native Yeasts. Int. J. Food Microbiol. 2019, 289, 40–48.

89. Milanovic, V.; Ciani, M.; Oro, L.; Comitini, F. Starmerella Bombicola Influences the Metabolism of Saccharomyces cerevisiae at Pyruvate Decarboxylase and Alcohol Dehydrogenase Level during Mixed Wine Fermentation. Microb. Cell Factories 2020, 11, 10–13.

90. Morales, P.; Rojas, V.; Quirós, M.; Gonzalez, R. The Impact of Oxygen on the Final Alcohol Content of Wine Fermented by a Mixed Starter Culture. Appl. Microbiol. Biotechnol. 2015, 99, 3993–4003.

91. Quirós, M.; Rojas, V.; Gonzalez, R.; Morales, P. Selection of Non-Saccharomyces Yeast Strains for Reducing Alcohol Levels in Wine by Sugar Respiration. Int. J. Food Microbiol. 2014, 181, 85–91.

92. Canonico, L.; Solomon, M.; Comitini, F.; Ciani, M.; Varela, C. Volatile Profile of Reduced Alcohol Wines Fermented with Selected Non-Saccharomyces Yeasts under Different Aeration Conditions. Food Microbiol. 2019, 84, 103247.

93. Tofalo, R.; Schirone, M.; Torriani, S.; Rantsiou, K.; Cocolin, L.; Perpetuini, G.; Suzzi, G. Diversity of Candida zemplinina Strains from Grapes and Italian Wines. Food Microbiol. 2012, 29, 18–26.

94. Varela, C. The Impact of Non-Saccharomyces Yeasts in the Production of Alcoholic Beverages. Appl. Microbiol. Biotechnol. 2016, 100, 9861–9874.

95. Ciani, M.; Comitini, F. Use of Non-Saccharomyces Yeasts in Red Winemaking. In Red Wine Technology; Academic Press: Cambridge, MA, USA, 2019; pp. 51–68.

96. Varela, J.; Varela, C. Microbiological Strategies to Produce Beer and Wine with Reduced Ethanol Concentration. Curr. Opin. Biotechnol. 2019, 56, 88–96.

97. Contreras, A.; Hidalgo, C.; Schmidt, S.; Henschke, P.A.; Curtin, C.; Varela, C. The Application of Non-Saccharomyces Yeast in Fermentations with Limited Aeration as a Strategy for the Production of Wine with Reduced Alcohol Content. Int. J. Food Microbiol. 2015, 205, 7–15.

98. Ciani, M.; Comitini, F.; Mannazzu, I.; Domizio, P. Controlled Mixed Culture Fermentation: A New Perspective on the Use of Non-Saccharomyces Yeasts in Winemaking. FEMS Yeast Res. 2010, 10, 123–133.

99. Wang, C.; Mas, A.; Esteve-Zarzoso, B. Interaction between Hanseniaspora Uvarum and Saccharomyces cerevisiae during Alcoholic Fermentation. Int. J. Food Microbiol. 2015, 206, 67–74.

100. Belda, I.; Ruiz, J.; Alastruey-Izquierdo, A.; Navascués, E.; Marquina, D.; Santos, A. Unraveling the Enzymatic Basis of Wine “Flavorome”: A Phylo-Functional Study of Wine Related Yeast Species. Front. Microbiol. 2016, 7, 1–13.

101. Hu, K.; Zhu, X.L.; Mu, H.; Ma, Y.; Ullah, N.; Tao, Y.S. A Novel Extracellular Glycosidase Activity from Rhodotorula mucilaginosa: Its Application Potential in Wine Aroma Enhancement. Lett. Appl. Microbiol. 2016, 62, 169–176.

102. Masneuf-Pomarede, I.; Bely, M.; Marullo, P.; Albertin, W. The Genetics of Non-Conventional Wine Yeasts: Current Knowledge and Future Challenges. Front. Microbiol. 2016, 6, 1563.

103. Comitini, F.; Gobbi, M.; Domizio, P.; Romani, C.; Lencioni, L.; Mannazzu, I.; Ciani, M. Selected Non-Saccharomyces Wine Yeasts in Controlled Multistarter Fermentations with Saccharomyces cerevisiae. Food Microbiol. 2011, 28, 873–882.

104. Oro, L.; Ciani, M.; Comitini, F. Antimicrobial Activity of Metschnikowia Pulcherrima on Wine Yeasts. J. Appl. Microbiol. 2014, 116, 1209–1217.

105. Alonso, A.; Belda, I.; Santos, A.; Navascués, E.; Marquina, D. Advances in the Control of the Spoilage Caused by Zygosaccharomyces Species on Sweet Wines and Concentrated Grape Musts. Food Control 2015, 51, 129–134.

106. Contreras, A.; Hidalgo, C.; Henschke, P.A.; Chambers, P.J.; Curtin, C.; Varela, C. Evaluation of Non-Saccharomyces Yeasts for the Reduction of Alcohol Content in Wine. Appl. Environ. Microbiol. 2014, 80, 1670–1678.

107. Contreras, A.; Curtin, C.; Varela, C. Yeast Population Dynamics Reveal a Potential 'Collaboration' between Metschnikowia pulcherrima and Saccharomyces uvarum for the Production of Reduced Alcohol Wines during Shiraz Fermentation. Appl. Microbiol. Biotechnol. 2014, 99, 1885–1895.

108. Di Maio, S.; Genna, G.; Gandolfo, V.; Amore, G.; Ciaccio, M.; Oliva, D. Presence of Candida zemplinina in Sicilian Musts and Selection of a Strain for Wine Mixed Fermentations. South African J. Enol. Vitic. 2012, 33, 80–87.

109. Englezos, V.; Rantsiou, K.; Torchio, F.; Rolle, L.; Gerbi, V.; Cocolin, L. Exploitation of the Non-Saccharomyces Yeast Starmerella Bacillaris (Synonym Candida zemplinina) in Wine Fermentation: Physiological and Molecular Characterizations. Int. J. Food Microbiol. 2015, 199, 33–40.

110. Englezos, V.; Rantsiou, K.; Cravero, F.; Torchio, F.; Ortiz-julien, A.; Gerbi, V.; Rolle, L.; Cocolin, L. Starmerella bacillaris and Saccharomyces cerevisiae Mixed Fermentations to Reduce Ethanol Content in Wine. Appl. Microbiol. Biotechnol. 2016, 100, 5515–5526.

111. De Barros Lopes, M.; Ata-ur-Rehman, A.; Gockowiak, H.; Heinrich, A.J.; Langridge, P.; Henschke, P.A. Fermentation Properties of a Wine Yeast Over-Expressing the Saccharomyces cerevisiae Glycerol 3-Phosphate Dehydrogenase Gene (GPD2). Aust. J. Grape Wine Res. 2000, 6, 208–215.

112. Ehsani, M.; Fernández, M.R.; Biosca, J.A.; Julien, A.; Dequin, S. Engineering of 2,3-Butanediol Dehydrogenase to Reduce Acetoin Formation by Glycerol-Overproducing, Low-Alcohol Saccharomyces cerevisiae. Appl. Environ. Microbiol. 2009, 75, 3196–3205.

113. Puškaš, V.S.; Miljić, U.D.; Djuran, J.J.; Vučurović, V.M. The Aptitude of Commercial Yeast Strains for Lowering the Ethanol Content of Wine. Food Sci. Nutr. 2020, 8, 1489–1498.

114. Ozturk, B.; Anli, E. Different Techniques for Reducing Alcohol Levels in Wine: A Review. BIO Web Conf. 2014, 3, 02012.

115. Geertman, J.M.A.; van Maris, A.J.A.; van Dijken, J.P.; Pronk, J.T. Physiological and Genetic Engineering of Cytosolic Redox Metabolism in Saccharomyces cerevisiae for Improved Glycerol Production. Metab. Eng. 2006, 8, 532–542.

116. Heux, S.; Sablayrolles, J.M.; Cachon, R.; Dequin, S. Engineering a Saccharomyces cerevisiae Wine Yeast That Exhibits Reduced Ethanol Production during Fermentation under Controlled Microoxygenation Conditions. Appl. Environ. Microbiol. 2006, 72, 5822–5828.

117. Heux, S.; Cachon, R.; Dequin, S. Cofactor Engineering in Saccharomyces cerevisiae: Expression of a H2O-Forming NADH Oxidase and Impact on Redox Metabolism. Metab. Eng. 2006, 8, 303–314.

118. Rossouw, D.; Heyns, E.H.; Setati, M.E.; Bosch, S.; Bauer, F.F. Adjustment of Trehalose Metabolism in Wine Saccharomyces cerevisiae Strains to Modify Ethanol Yields. Appl. Environ. Microbiol. 2013, 79, 5197–5207.

119. Tilloy, V.; Ortiz-Julien, A.; Dequin, S. Reduction of Ethanol Yield and Improvement of Glycerol Formation by Adaptive Evolution of the Wine Yeast Saccharomyces cerevisiae under Hyperosmotic Conditions. Appl. Environ. Microbiol. 2014, 80, 2623–2632.

120. Tilloy, V.; Cadière, A.; Ehsani, M.; Dequin, S. Reducing Alcohol Levels in Wines through Rational and Evolutionary Engineering of Saccharomyces cerevisiae. Int. J. Food Microbiol. 2015, 213, 49–58.

121. Varela, C.; Kutyna, D.R.; Solomon, M.R.; Black, C.A.; Borneman, A.; Henschke, P.A.; Pretorius, I.S.; Chambers, P.J. Evaluation of Gene Modification Strategies for the Development of Low-Alcohol-Wine Yeasts. Appl. Environ. Microbiol. 2012, 78, 6068–6077.

122. Hou, J.; Lages, N.F.; Oldiges, M.; Vemuri, G.N. Metabolic Impact of Redox Cofactor Perturbations in Saccharomyces cerevisiae. Metab. Eng. 2009, 11, 253–261.

123. Nogueira, A.; Le Quéré, J.M.; Gestin, P.; Michel, A.; Wosiacki, G.; Drilleau, J.F.; Brew, J.I. Slow Fermentation in French Cider Processing Due to Partial Biomass Reduction. J. Inst. Brew. 2008, 114, 102–110.

124. Nogueira, A.; Mongruel, C.; Rosana, D.; Simões, S. Effect of Biomass Reduction on the Fermentation of Cider. Brazilian Arch. Biol. Technol. 2007, 50, 1083–1092.

125. Fan, G.; Shengyun, T.; Rong, W.; Qingbin, L.; Jinsheng, Z.; Xiaodong, Y.; Yang, L. Fermentation Process of Low-Alcohol Cider by Biomass Reduction. China Brew. 2012, 31, 186–190.

126. Malfeito-Ferreira, M. Yeasts and Wine Off-Flavours: A Technological Perspective. Ann. Microbiol. 2011, 61, 95–102.

127. Banvolgyi, S.; Kiss, I.; Bekassy-Molnar, E.; Vatai, G. Concentration of Red Wine by Nanofiltration. Desalination 2006, 198, 8–15.

128. Banvolgyi, S.; Savaş Bahçeci, K.; Vatai, G.; Bekassy, S.; Bekassy-Molnar, E. Partial Dealcoholization of Red Wine by Nanofiltration and Its Effect on Anthocyanin and Resveratrol Levels. Food Sci. Technol. Int. 2016, 22, 677–687.

129. Conidi, C.; Castro-Muñoz, R.; Cassano, A. Nanofiltration in Beverage Industry. In Nanotechnology in the Beverage Industry; Elsevier: Amsterdam, The Netherlands, 2020; pp. 525–548.

130. Labanda, J.; Vichi, S.; Llorens, J.; López-Tamames, E. Membrane Separation Technology for the Reduction of Alcoholic Degree of a White Model Wine. LWT Food Sci. Technol. 2009, 42, 1390–1395.

131. Mangindaan, D.; Khoiruddin, K.; Wenten, I.G. Beverage Dealcoholization Processes: Past, Present, and Future. Trends Food Sci. Technol. 2018, 71, 36–45.

132. Takács, L.; Korány, K.; Vatai, G. Process Modelling in the Production of Low Alcohol Content Wines by Direct Concentration and Diafiltration Using Nanofiltration Membranes. Acta Aliment. 2010, 39, 397–412.

133. Lisanti, M.T.; Gambuti, A.; Genovese, A.; Piombino, P.; Moio, L. Partial Dealcoholization of Red Wines by Membrane Contactor Technique: Effect on Sensory Characteristics and Volatile Composition. Food Bioprocess Technol. 2013, 6, 2289–2305.

134. Bui, K.; Dick, R.; Moulin, G.; Galzy, P. A Reverse Osmosis for the Production of Low Ethanol Content Wine. Am. J. Enol. Vitic. 1986, 37, 297–300.

135. Lopez, M.; Alvarez, S.; Riera, F.A.; Alvarez, R.; Julia, C. Production of Low Alcohol Content Apple Cider by Reverse Osmosis. Ind. Eng. Chem. Res. 2002, 41, 6600–6606.

136. Massot, A.; Mietton-peuchot, M.; Peuchot, C.; Milisic, V. Nanofiltration and Reverse Osmosis in Winemaking. Desalination 2008, 231, 283–289.

137. Pilipovik, M.V.; Riverol, C. Assessing Dealcoholization Systems Based on Reverse Osmosis. J. Food Eng. 2005, 69, 437–441.

138. Russo, P.; Liguori, L.; Corona, O.; Albanese, D.; DiMatteo, M.; Cinquanta, L. Combined Membrane Process for Dealcoholization of Wines: Osmotic Distillation and Reverse Osmosis. Chem. Eng. Trans. 2019, 75, 7–12.

139. Corona, O.; Liguori, L.; Albanese, D.; Di Matteo, M.; Cinquanta, L.; Russo, P. Quality and Volatile Compounds in Red Wine at Different Degrees of Dealcoholization by Membrane Process. Eur. Food Res. Technol. 2019, 245, 2601–2611.

140. Liguori, L.; Albanese, D.; Crescitelli, A.; Di Matteo, M.; Russo, P. Impact of Dealcoholization on Quality Properties in White Wine at Various Alcohol Content Levels. J. Food Sci. Technol. 2019, 56, 3707–3720.

141. Diban, N.; Athes, V.; Bes, M.; Souchon, I. Ethanol and Aroma Compounds Transfer Study for Partial Dealcoholization of Wine Using Membrane Contactor. J. Memb. Sci. 2008, 311, 136–146.

142. Diban, N.; Arruti, A.; Barceló, A.; Puxeu, M.; Urtiaga, A.; Ortiz, I. Membrane Dealcoholization of Different Wine Varieties Reducing Aroma Losses. Modeling and Experimental Validation. Innov. Food Sci. Emerg. Technol. 2013, 20, 259–268.

143. Ferrarini, R.; Maria, G.; Camin, F.; Bandini, S.; Gostoli, C. Variation of Oxygen Isotopic Ratio during Wine Dealcoholization by Membrane Contactors: Experiments and Modelling. J. Memb. Sci. 2016, 498, 385–394.

144. Gambuti, A.; Rinaldi, A.; Lisanti, M.T.; Pessina, R.; Moio, L. Partial Dealcoholisation of Red Wines by Membrane Contactor Technique: Influence on Colour, Phenolic Compounds and Saliva Precipitation Index. Eur. Food Res. Technol. 2011, 233, 647–655.

145. Liguori, L.; Russo, P.; Albanese, D.; Di Matteo, M. Evolution of Quality Parameters during Red Wine Dealcoholization by Osmotic Distillation. Food Chem. 2013, 140, 68–75.

146. Liguori, L.; Russo, P.; Albanese, D.; Di Matteo, M. Effect of Process Parameters on Partial Dealcoholization of Wine by Osmotic Distillation. Food Bioprocess Technol. 2013, 6, 2514–2524.

147. Takács, L.; Vatai, G.; Korány, K. Production of Alcohol Free Wine by Pervaporation. J. Food Eng. 2007, 78, 118–125.

148. Karlsson, H.O.E.; Trägårdh, G. Applications of Pervaporation in Food Processing. Trends Food Sci. Technol. 1996, 7, 78–83.

149. Verhoef, A.; Figoli, A.; Leen, B.; Bettens, B.; Drioli, E.; Van der Bruggen, B. Performance of a Nanofiltration Membrane for Removal of Ethanol from Aqueous Solutions by Pervaporation. Sep. Purif. Technol. 2008, 60, 54–63.

150. Castro-Muñoz, R.; Ahmad, M.Z.; Cassano, A. Pervaporation-Aided Processes for the Selective Separation of Aromas, Fragrances and Essential (AFE) Solutes from Agro-Food Products and Wastes. Food Rev. Int. 2021, 1–27.

151. Castro-Muñoz, R. Pervaporation-Based Membrane Processes for the Production of Non-Alcoholic Beverages. Food Sci. Technol. 2019, 56, 2333–2344.

152. Castro-Muñoz, R. Pervaporation: The Emerging Technique for Extracting Aroma Compounds from Food Systems. J. Food Eng. 2019, 253, 27–39.

153. Catarino, M.; Mendes, A. Non-Alcoholic Beer—A New Industrial Process. Sep. Purif. Technol. 2011, 79, 342–351.

154. Németh, L.; Jóvér, B.; Doleschall, S.; Pap, G.; Gáti, G.; Juhász, I.; Sápi, I.; Százhalombatta Sándor Kovacs, K.; Horváth, K. Product and Process for Production of Alcohol-Free Wines or Alcohol Reduced Wines and Brandy. U.S. Patent 5,093,141, 3 March 1992.

155. Motta, S.; Guaita, M.; Petrozziello, M.; Ciambotti, A.; Panero, L.; Solomita, M.; Bosso, A. Comparison of the Physicochemical and Volatile Composition of Wine Fractions Obtained by Two Different Dealcoholization Techniques. Food Chem. 2017, 221, 1–10.

156. Taran, N.; Stoleicova, S.; Soldatenco, O.; Morari, B. The Influence of Pressure on Chemical and Physical Parametres of White and Red Wines Obtained by Dealcoholization Method. J. Agroaliment. Proc. Technol. 2014, 20, 215–219.

157. Schmidtke, L.M.; Blackman, J.W.; Agboola, S.O. Production Technologies for Reduced Alcoholic Wines. J. Food Sci. 2012, 77, 25–41.

158. Belisario-Sánchez, Y.Y.; Taboada-Rodríguez, A.; Marín-Iniesta, F.; Iguaz-Gainza, A.; López-Gómez, A. Aroma Recovery in Wine Dealcoholization by SCC Distillation. Food Bioprocess Technol. 2012, 5, 2529–2539.

159. Belisario-Sánchez, Y.Y.; Taboada-Rodríguez, A.; Marín-Iniesta, F.; López-Gómez, A. Dealcoholized Wines by Spinning Cone Column Distillation: Phenolic Compounds and Antioxidant Activity Measured by the 1,1-Diphenyl-2-Picrylhydrazyl Method. J. Agric. Food Chem. 2009, 57, 6770–6778.

160. Gómez-Plaza, E.; López-Nicolás, J.M.; López-Roca, J.M.; Martínez-Cutillas, A. Dealcoholization of Wine. Behaviour of the Aroma Components during the Process. LWT Food Sci. Technol. 1999, 32, 384–386.

161. Huerta-Pérez, F.; Pérez-Correa, J.R. Optimizing Ethanol Recovery in a Spinning Cone Column. J. Taiwan Inst. Chem. Eng. 2018, 83, 1–9.

162. Margallo, M.; Aldaco, R.; Barceló, A.; Diban, N.; Ortiz, I.; Irabien, A. Life Cycle Assessment of Technologies for Partial Dealcoholisation of Wines. Sustain. Prod. Consum. 2015, 2, 29–39.

163. Longo, R.; Blackman, J.W.; Antalick, G.; Torley, P.J.; Rogiers, S.Y.; Schmidtke, L.M. A Comparative Study of Partial Dealcoholisation versus Early Harvest: Effects on Wine Volatile and Sensory Profiles. Food Chem. 2018, 261, 21–29.

164. Pham, D.-T.; Stockdale, V.J.; Wollan, D.; Jeffery, D.W.; Wilkinson, K.L. Compositional Consequences of Partial Dealcoholization of Red Wine by Reverse Osmosis-Evaporative Perstraction. Molecules 2019, 24, 1404.

165. Pham, D.-T.; Ristic, R.; Stockdale, V.J.; Jeffery, D.W.; Tuke, J.; Wilkinson, K. Influence of Partial Dealcoholization on the Composition and Sensory Properties of Cabernet Sauvignon Wines. Food Chem. 2020, 325, 126869.

166. Wollan, D. Alcohol Reduction in Beverages. U.S. Patent 2008/0272041 A1, 6 November 2008.

167. Ma, T.; Sun, X.; Gao, G.; Wang, X.; Liu, X.; Du, G.; Zhan, J. Phenolic Characterisation and Antioxidant Capacity of Young Wines Made From Different Grape Varieties Grown in Helanshan Donglu Wine Zone (China). S. Afr. J. Enol. Vitic. 2014, 35, 321–331.

168. Suo, H.; Tian, R.; Li, J.; Zhang, S.; Cui, Y.; Li, L.; Sun, B. Compositional Characterization Study on High-Molecular -Mass Polymeric Polyphenols in Red Wines by Chemical Degradation. Food Res. Int. 2019, 123, 440–449.

169. Cuzmar, P.D.; Salgado, E.; Ribalta-Pizarro, C.; Olaeta, A.; Eugenio, L.; Pastenes, C.; Alejandro, C. Original Article Phenolic Composition and Sensory Characteristics of Cabernet Sauvignon Wines: Effect of Water Stress and Harvest Date. Int. J. Food Sci. Technol. 2018, 53, 1–10.

170. Ivanova, V.; Stefova, M.; Chinnici, F. Determination of the Polyphenol Contents in Macedonian Grapes and Wines by Standardized Spectrophotometric Methods. J. Serb. Chem. Soc. 2010, 75, 45–59.

171. Cozzolino, D. The Role of Visible and Infrared Spectroscopy Combined with Chemometrics to Measure Phenolic Compounds in Grape and Wine Samples. Molecules 2015, 20, 726–737.

172. Basli, A.; Chaher, N.; Chibane, M.; Monti, J.; Richard, T. Wine Polyphenols: Potential Agents in Neuroprotection. Oxidative Med. Cell. Longev. 2012, 2012, 1–14.

173. Vidal, S.; Francis, L.; Noble, A.; Kwiatkowski, M.; Cheynier, V.; Waters, E. Taste and Mouth-Feel Properties of Different Types of Tannin-like Polyphenolic Compounds and Anthocyanins in Wine. Anal. Chim. Acta 2004, 513, 57–65.

174. Sakaki, J.; Melough, M.; Lee, S.G.; Pounis, G.; Chun, O.K. Polyphenol-Rich Diets in Cardiovascular Disease Prevention. In Analysis in Nutrition Research: Principles of Statistical Methodology and Interpretation of the Results; Elsevier Inc.: Amsterdam, The Netherlands, 2018; pp. 259–298.

175. Doonan, B.B.; Iraj, S.; Pellegrino, L.; Hsieh, T.-C.; Wu, J.M. 22. The French Paradox Revisited: Cardioprotection via Hormesis, Red Wine and Resveratrol. In Handbook of Nutrition in Heart Health; Human Health Handbooks; Wageningen Academic Publishers: Wageningen, The Netherlands, 2017; Volume 14, pp. 22–467.

176. Stephan, L.S.; Almeida, E.D.; Markoski, M.M.; Garavaglia, J.; Marcadenti, A. Red Wine, Resveratrol and Atrial Fibrillation. Nutrients 2017, 9, 190.

177. Pickering, G.J.; Heatherbell, D.A.; Vanhanen, L.P.; Barnes, M.F. The Effect of Ethanol Concentration on the Temporal Perception of Viscosity and Density in White Wine. Am. J. Enol. Vitic. 1998, 49, 306–318.

178. Meillon, S.; Urbano, C.; Schlich, P. Contribution of the Temporal Dominance of Sensations (TDS) Method to the Sensory Description of Subtle Differences in Partially Dealcoholized Red Wines. Food Qual. Prefer. 2009, 20, 490–499.

179. Bogianchini, M.; Cerezo, A.B.; Gomis, A.; López, F.; García-Parrilla, M.C. Stability, Antioxidant Activity and Phenolic Composition of Commercial and Reverse Osmosis Obtained Dealcoholised Wines. LWT Food Sci. Technol. 2011, 44, 1369–1375.

180. Liguori, L.; Attanasio, G.; Albanese, D.; Di Matteo, M. Aglianico Wine Dealcoholization Tests. In Computer Aided Chemical Engineering; Elsevier: Amsterdam, The Netherlands, 2010; Volume 28, pp. 325–330.

181. Vernhet, A.; Dupre, K.; Boulange-Petermann, L.; Cheynier, V.; Pellerin, P.; Moutounet, M. Composition of Tartrate Precipitates Deposited on Stainless Steel Tanks During the Cold Stabilization of Wines. Part I. White Wines. Am. J. Enol. Vitic. 1999, 50, 391–397.

182. Sánchez-Palomo, E.; Delgado, J.A.; Ferrer, M.A.; Viñas, M.A.G. The Aroma of La Mancha Chelva Wines: Chemical and Sensory Characterization. Food Res. Int. 2019, 119, 135–142.

183. Duan, W.-P.; Zhu, B.-Q.; Song, R.-R.; Zhang, B.; Lan, Y.-B.; Zhu, X.; Duan, C.-Q.; Han, S.-Y. Volatile Composition and Aromatic Attributes of Wine Made with Vitisvinifera l.Cv Cabernet Sauvignon Grapes in the Xinjiang Region of China: Effect of Different Commercial Yeasts. Int. J. Food Prop. 2018, 21, 1423–1441.

184. Cadot, Y.; Caillé, S.; Samson, A.; Barbeau, G.; Cheynier, V. Analytica Chimica Acta Sensory Dimension of Wine Typicality Related to a Terroir by Quantitative Descriptive Analysis, Just About Right Analysis and Typicality Assessment. Anal. Chim. Acta 2010, 660, 53–62.

185. Maitre, I.; Symoneaux, R.; Jourjon, F.; Mehinagic, E. Sensory Typicality of Wines: How Scientists Have Recently Dealt with This Subject. Food Qual. Prefer. 2010, 21, 726–731.

186. Laborde, B.; Moine-Ledoux, V.; Richard, T.; Saucier, C.; Dubourdieu, D.; Monti, J.P. PVPP-Polyphenol Complexes: A Molecular Approach. J. Agric. Food Chem. 2006, 54, 4383–4389.

187. Flanzy, C. Enologia Fundamentos Cientificos y Tecnológicos, AMV ed.; Mundi-Prensa: Madrid, Spain, 2003.

188. Longo, R.; Blackman, J.W.; Torley, P.J.; Rogiers, S.Y.; Schmidtke, L.M. Changes in Volatile Composition and Sensory Attributes of Wines during Alcohol Content Reduction. J. Sci. Food Agric. 2017, 97, 8–16.

189. Catarino, M.; Mendes, A. Dealcoholizing Wine by Membrane Separation Processes. Innov. Food Sci. Emerg. Technol. 2011, 12, 330–337.

190. Varavuth, S.; Jiraratananon, R.; Atchariyawut, S. Experimental Study on Dealcoholization of Wine by Osmotic Distillation Process. Sep. Purif. Technol. 2009, 66, 313–321.

191. Fedrizzi, B.; Nicolis, E.; Camin, F.; Bocca, E.; Carbognin, C.; Scholz, M.; Barbieri, P.; Finato, F.; Ferrarini, R. Stable Isotope Ratios and Aroma Profile Changes Induced Due to Innovative Wine Dealcoholisation Approaches. Food Bioprocess Technol. 2014, 7, 62–70.

192. Sun, X.; Dang, G.; Ding, X.; Shen, C.; Liu, G.; Zuo, C.; Chen, X.; Xing, W.; Jin, W. Production of Alcohol-Free Wine and Grape Spirit by Pervaporation Membrane Technology. Food Bioprod. Process. 2020, 123, 262–273.

193. Jordão, A.; Vilela, A.; Cosme, F. From Sugar of Grape to Alcohol of Wine: Sensorial Impact of Alcohol in Wine. Beverages 2015, 1, 292–310.

194. Nurgel, C.; Pickering, G. Contribution of Glycerol, Ethanol and Sugar to the Perception of Viscosity and Density Elicited by Model White Wines. J. Texture Stud. 2005, 36, 303–323.

195. Fontoin, H.; Saucier, C.; Teissedre, P.L.; Glories, Y. Effect of PH, Ethanol and Acidity on Astringency and Bitterness of Grape Seed Tannin Oligomers in Model Wine Solution. Food Qual. Prefer. 2008, 19, 286–291.

196. Goldner, M.C.; Zamora, M.C.; Lira, P.D.L.; Gianninoto, H.; Bandoni, A. Effect of Ethanol Level in the Perception of Aroma Attributes and the Detection of Volatile Compounds in Red Wine. J. Sens. Stud. 2009, 24, 243–257.
197. Fischer, U.; Noble, A.C. The Effect of Ethanol, Catechin Concentration, and PH on Sourness and Bitterness of Wine. Am. J. Enol. Vitic. 1994, 45, 6–10.
198. Coulter, A.; Henschke, P.A.; Simos, C.A.; Pretorius, I. When the Heat Is on, Yeast Fermentation Runs out of Puff. Aust. New Zeal. Wine Ind. J. 2008, 23, 26–30.
199. King, E.S.; Dunn, R.L.; Heymann, H. The Influence of Alcohol on the Sensory Perception of Red Wines. Food Qual. Prefer. 2013, 28, 235–243.
200. Meillon, S.; Urbano, C.; Guillot, G.; Schlich, P. Acceptability of Partially Dealcoholized Wines—Measuring the Impact of Sensory and Information Cues on Overall Liking in Real-Life Settings. Food Qual. Prefer. 2010, 21, 763–773.
201. Meillon, S.; Viala, D.; Medel, M.; Urbano, C.; Guillot, G.; Schlich, P. Impact of Partial Alcohol Reduction in Syrah Wine on Perceived Complexity and Temporality of Sensations and Link with Preference. Food Qual. Prefer. 2010, 21, 732–740.
202. King, E.S.; Heymann, H. The Effect of Reduced Alcohol on the Sensory Profiles and Consumer Preferences of White Wine. J. Sens. Stud. 2014, 29, 33–42.