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REVIEW

Dealcoholized Wine: A Scoping Review of Volatile and Non-Volatile Profiles, Consumer Perception, and Health Benefits

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Abstract
The dealcoholization technique has gained more attention in the wine industry as it can significantly influence wine compositions and quality beyond alcohol level reduction. However, the changes occurring in the various processes of dealcoholization are not fully understood yet. This work summarizes the literature published in the last 10 years (2013–2023) about changes in color, sulfur dioxide (SO_2), phenolic composition, losses of desirable volatile aroma compounds, and sensory characteristics of wine after the removal of ethanol by different processes/techniques. Several factors can influence the final characteristics of wine during the process, including physico-chemical parameters such as the initial alcohol level, the retention properties of the wine non-volatile matrix, and the characteristics of aroma components. Additionally, the quality of dealcoholized wine can be affected by the choice of dealcoholization techniques, distillation temperature, operating pressure, and membrane properties, including filtration and pore size. Low- and zero-alcohol products have the potential to expand the market and cater to diverse consumer segments. This comprehensive review would help winemakers in choosing the best techniques to produce dealcoholized wine, limiting the adverse effects, and meeting the needs of consumers.

Keywords Dealcoholized wine · Volatile composition · Non-volatile composition · Sensory profile · Health benefits

Introduction

International Organisation of Vine and Wine (OIV) defines "wine as the beverage resulting exclusively from the partial or complete alcoholic fermentation of fresh grapes, whether crushed or not, or of grape must. Its actual alcohol content shall not be less than 8.5% vol" (OIV, 2017). Similarly, European Union (EU) regulation defines wine as "the product obtained exclusively from the total or partial alcoholic fermentation of fresh grapes, whether or not crushed, or of grape must with an actual alcoholic strength of not less than 8.5% volume" (EU Regulation No 1308/2013, p. 809, 2013). In previous studies, different wine categories were proposed based on the alcohol content as alcoholic (> 10.5% v/v ethanol), lower-alcohol (5.5 to 10.5% v/v ethanol), reduced-alcohol (1.2 to 5.5% or 6.5% v/v ethanol), low-alcohol (0.5 to 1.2% v/v ethanol), and alcohol-free (0.5% v/v ethanol) wine to consider potential social and health benefits for consumers (Pickering, 2010; Saliba et al., 2013); however, there were no official regulations at that time, and these categories were loosely based on labeling and legislative requirements and may vary between most wine-producing countries. Most recently, the EU introduced the category of "dealcoholized wine," including wines where "for actual alcoholic strength no more than 0.5% v/v ethanol," and "partially dealcoholized" "for actual alcoholic strength above 0.5% v/v ethanol is below the minimum actual alcoholic strength of the wine category" (EU Regulation No 2117/2021, p. 270, 2021). In Australia, wines are categorized based on their alcohol content. Those with an alcohol concentration above 4.5% abv are typically labeled as "wine." The range between 1.15 and 0.5% abv falls under the category of "low-alcohol wine," while alcohol content below 0.5% abv is generally described as "alcohol-free," "non-alcoholic," or "dealcoholized wines" (AWRI, 2022). In the United States, wines encompass a range of categories with varying ethanol content. "Wine" typically refers to products with alcohol content between 14 and 7% abv; also, "Table wine" and "light wine" fall

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within this range. "Low-alcohol wine" is used for products with alcohol content less than 8.5% abv, and "alcohol-free," "non-alcoholic," or "dealcoholized" are labels applied to wines below 0.5% abv (AWRI, 2022). The UK classifies wine based on ethanol content as well, designating wines exceeding 8.0% abv as "wine," those below 1.2% abv as "low-alcohol wine," and less than 0.5% abv as "dealcoholized," with the "alcohol-free" label reserved for wines below 0.05% abv (UK Gov, 2018).

The demand for non-alcoholic wine has increased at an unprecedented rate, driven by a growing interest in healthy living, and as a response to higher alcohol content in wine caused by climate change (Fact.MR, 2022; Liguori et al., 2013). This demand is also influenced by prohibitions on drinking due to medical advice (e.g., during pregnancy, for individuals with cardiovascular or hepatic disorders, and for athletes), driving regulations, and ethical/religious considerations (Piornos et al., 2020). Furthermore, several nations impose higher import taxes or tariffs on alcoholic beverages, and these taxes can often vary based on the alcohol content of the products. The non-alcoholic wine market was worth more than US$ 1.6 billion in 2021, and it is predicted to grow at a compound annual growth rate (CAGR) of 10.4% to reach a valuation of US$ 4.5 billion by 2031, compared to a CAGR of 8.8% for 2016 to 2020. According to the latest Fact.MR report, during 2021–2031, the market for non-alcohol wine in the USA, Australia, France, Italy, and Germany is projected to grow at 9.6%, 12.2%, 11%, 9.9%, and 9% CAGR, respectively (Fact.MR, 2022). The prominent alcohol-free and dealcoholized wine brands in the market encompass a range of appealing options. Noteworthy selections include "YOURS Non-Alcoholic California Red Blend," "Ariel Non-Alcoholic Cabernet Sauvignon," "Be Well Cabernet Sauvignon Non-Alcoholic Red Wine," "Giesen 0%," "Thomson & Scott Noughty Rouge Dealcoholized Wine," "St. Regis Non-Alcoholic Cabernet Sauvignon," and "Leitz Eins Zwei Zero Riesling." Additionally, "Starla Wines" stands out for presenting a trio of varietals, including Red Blend, Sauvignon Blanc, and Sparkling Rosé.

Dealcoholization is the process of removing the alcohol from wine, which can be achieved either in a single run or through a series of repeated cycles. A dealcoholization cycle represents the time taken to achieve a desired ethanol concentration in wine. There are several processing techniques for producing wines with lower, reduced, low, and no alcohol. These techniques can be implemented at pre-fermentation, fermentation, and post-fermentation stages of wine production, each with different dealcoholization efficiency, as summarized in Fig. 1. In terms of post-fermentation techniques, the EU regulation 2021/2117 permits the dealcoholization of wine using partial vacuum evaporation, membrane techniques, and distillation

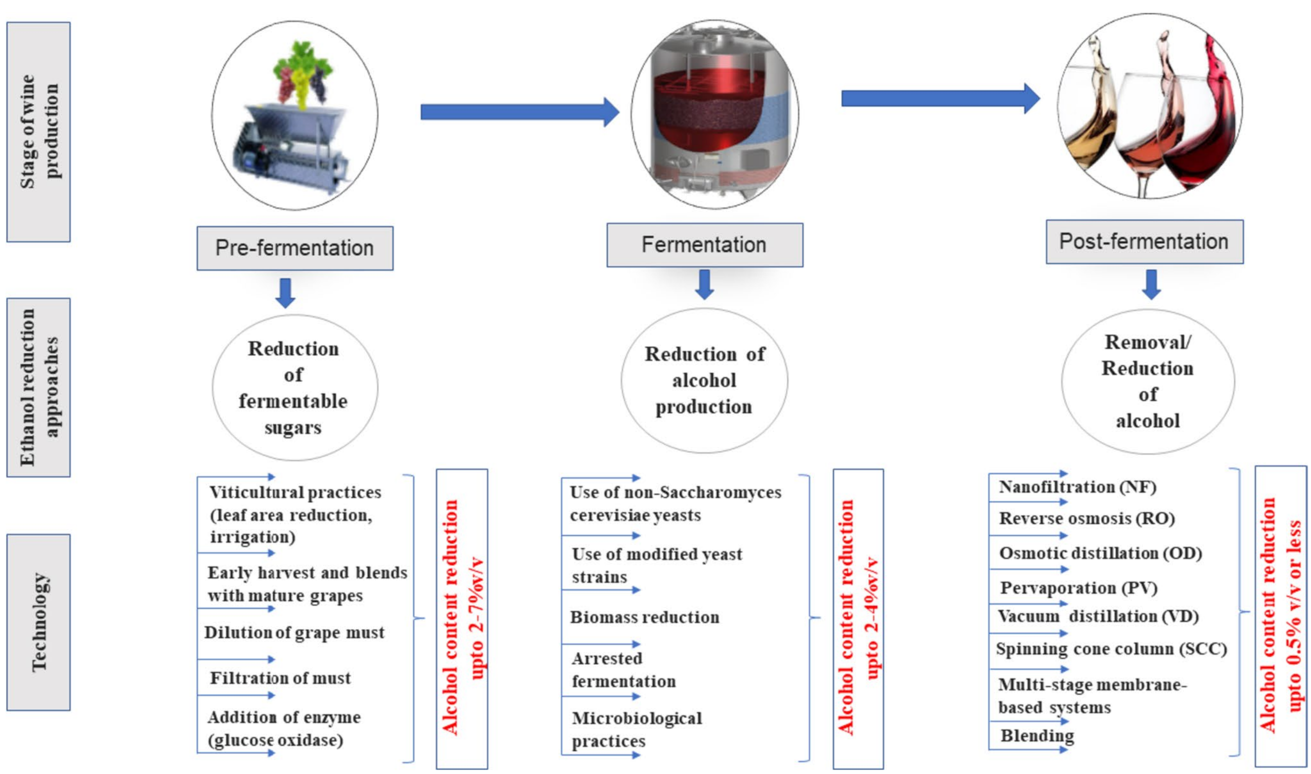

Fig. 1 Techniques for alcohol reduction in winemaking

processes. Practically, several approaches are discussed: reverse osmosis (RO), nanofiltration (NF), pervaporation (PV), vacuum distillation (VD), osmotic distillation (OD), spinning cone column (SCC), and multi-stage membrane systems (Akyereko et al., 2021; Mangindaan et al., 2018; Sam et al., 2021a, b; Schmitt & Christmann, 2022). Moreover, Fig. 2 illustrates a typical scheme of different post-fermentation techniques utilized in the production of low-alcohol wines. These dealcoholization processes may impact the wine composition, affecting its flavor, taste, and mouthfeel, sometimes yielding inconsistent results in terms of wine palatability (Lisanti et al., 2013). However, some well-known post-fermentation techniques, such as RO and OD, have been utilized to remove alcohol concentrations to levels lower than 5% v/v ethanol without substantially altering the main quality parameters of the wine (Catarino & Mendes, 2011; Corona et al., 2019; Liguori et al., 2019).

The present review aims to summarize the changes in the basic composition (such as pH, color, SO_2), phenolic composition, losses of desirable volatile aroma compounds, and sensory characteristics of wine during the removal of ethanol by different post-fermentation techniques. It also focuses on consumer perception and health benefits of low- and zero-alcohol wines.

A systematic search was conducted using several databases including PubMed, Scopus, ScienceDirect, and Web of Science from 2013 to 2023. The studies were specifically chosen to examine the volatile and non-volatile profiles and to compare changes in the sensory characteristics, considering the wealth of available information and the significant differences observed in outcomes after ethanol removal. The search terms used in combination with the term "wine" included dealcoholization, dealcoholized, low alcohol, zero alcohol, and ethanol removal. The detailed information to be extracted was the first author's name, publication year, sample source, type of wine, sample size, dealcoholized technique, number of dealcoholization cycles, consumer behavior/perception, health benefits, and results of volatile and non-volatile profile. The eligibility process was described in a PRISMA flow diagram (Supplementary Fig. 1). Fifty-three records met the inclusion criteria and provided information about one or more of the following topics: the impact of dealcoholization on acidity, SO_2, color, and total phenolic of wine ($n = 15$); the impact of dealcoholization on volatile compounds of wine ($n = 18$); the impact of dealcoholization on the sensory profile of the wine ($n = 15$); and consumer acceptance and health benefits of low- and zero-alcohol wines ($n = 28$).

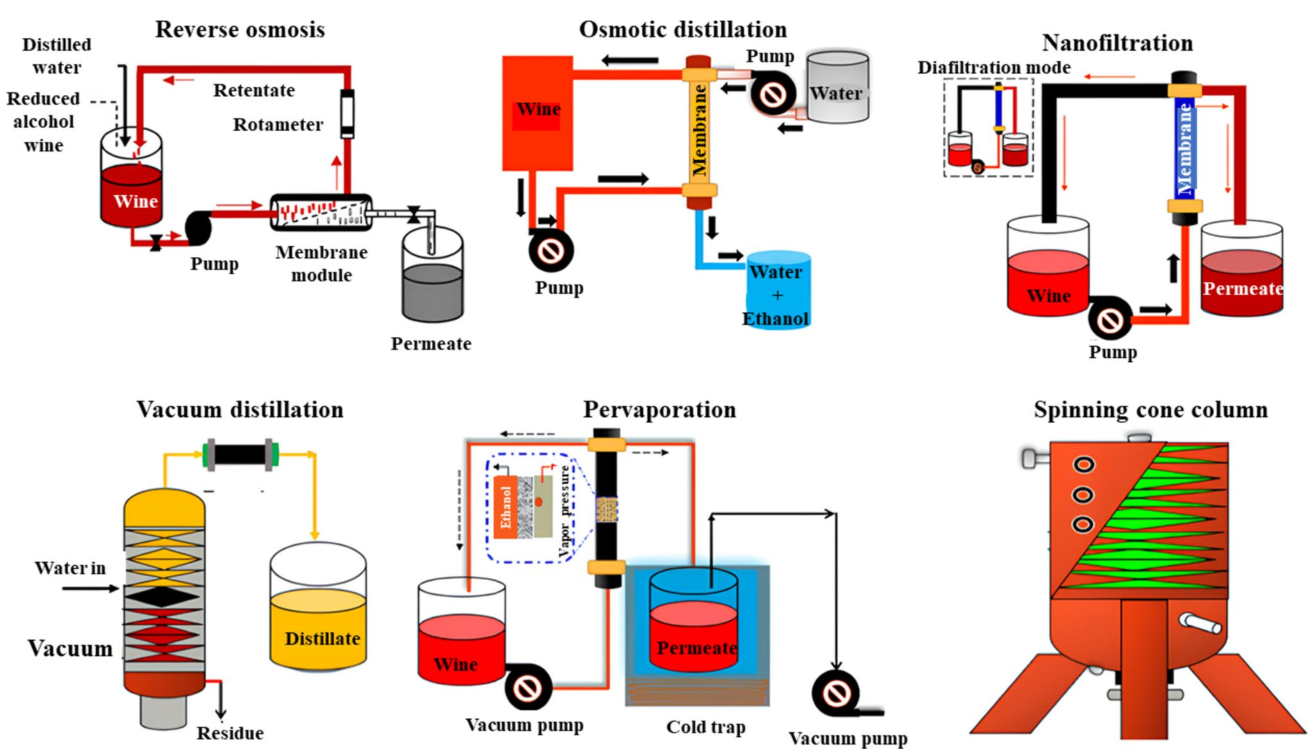

Fig. 2 Scheme of different integrated systems for wine dealcoholization (reprinted from Sam et al. (2021b) under open access Creative Common CC BY license)

Impact of Dealcoholization on Acidity and SO_2 of Wine

Physico-chemical parameters like pH, total acidity, and SO_2 are key determinants of wine characteristics. The effect of different dealcoholization techniques on the physico-chemical parameters of wines is summarized in Fig. 3 and Supplementary Table 1. Figure 3 (alluvial diagram) shows that most studies were conducted on red wines using membrane-based techniques, highlighting that the effect of dealcoholization on physico-chemical parameters mostly depends on the type of wine, percent ethanol removed, type of dealcoholization technique, and operating conditions (such as temperature, pressure, and membrane size). The pH increased during the dealcoholization of Merlot, Chardonnay, and Pinot Noir wines by RO and VD (Sam et al., 2021a) and Lange, Verduno Pelaverga, and Barbera wines by MC and VD (Motta et al., 2017). The change in pH and acidity affects the overall wine sensory properties (Varela et al., 2015), including the color of wine, which depends on the equilibrium between the different forms of anthocyanins (see the "Impact of Dealcoholization on Color and Total Phenolic of Wine" section for details on wine color). Falanghina white wine treated with OD (ethanol from 12.5 to 0.3% v/v ethanol) showed a change in pH (3.22–3.26) and total acidity (5.81–6.02 g/L); however, during the sensory assessment, the panelists scored dealcoholized wine as sourer compared to original wine (Liguori et al., 2019). In a study of Montepulciano d'Abruzzo red wine, a small change in pH (from 3.56 to 3.49) and total acidity (from 4.9 to 5.1 g/L) was found after removing ethanol from 13.23 to 4.0% v/v ethanol by OD. Dealcoholized wines were observed by panelists with higher sourness and less bitterness as compared to control wine (Corona et al., 2019). This perception may be due to the lower alcohol content in dealcoholized wines, which can result in an imbalance with the acid level, leading consumers to perceive them as sourer. Additionally, Gawel et al. (2013) studied the effect of pH, alcohol, and phenolics on the perception of Riesling and Chardonnay wine. They observed that the combined effect of phenolic content and alcohol concentration on astringency and bitterness was additive, suggesting that alcohol directly contributes to these attributes in white wines. Higher alcohol wine resulted in lower bitterness. Wines with a low pH (3) were perceived as more astringent than those with a high pH value (3.3), probably due to a drop in saliva's viscosity at low pH, which results in increasing astringency (Wang et al., 2020; Zhao et al., 2023).

Total SO_2 (Fig. 3 and Supplementary Table 1) content generally decreased with the dealcoholization of Verdejo by NF-PV and PV (Calvo et al., 2022), Aglianico by MC (Lisanti et al., 2013), Merlot by RO (Sam et al., 2023), and Merlot, Chardonnay, and Pinot Noir rosé wines by RO and VD (Sam et al., 2021a). The decrease could be due to oxidation of SO_2 or volatilization of molecular SO_2. In

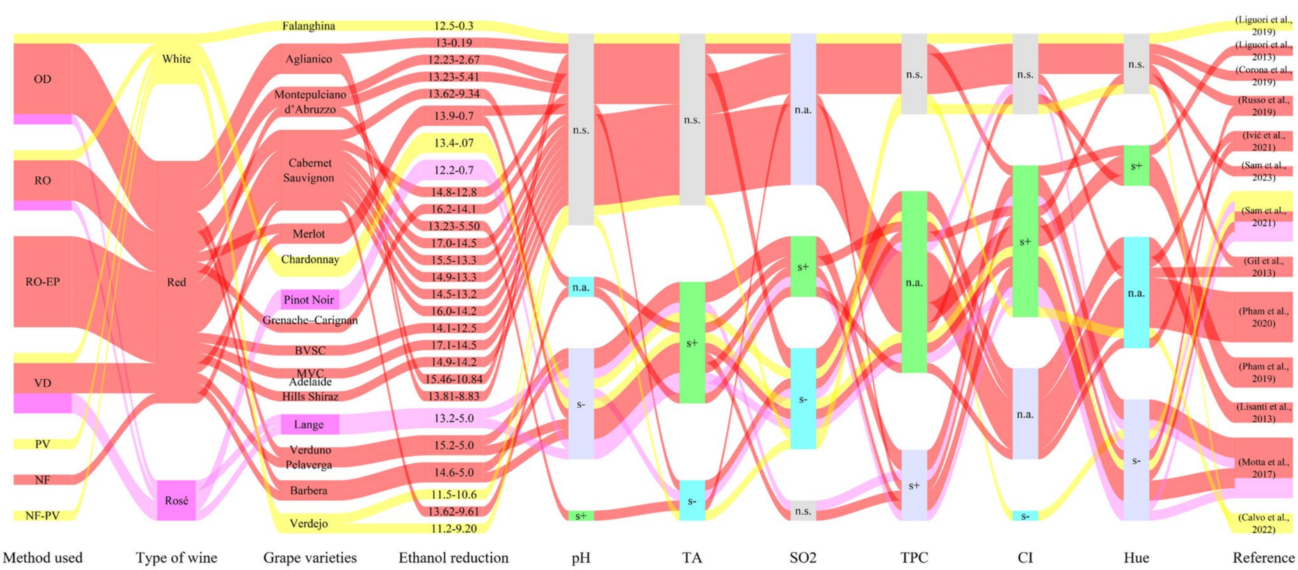

Fig. 3 Alluvial diagram: effect of different dealcoholization processes on the basic composition of wines. Legend: n.a. data not available; n.s. not significant change; s + significant increase; s- significant decrease; TA total acidity; VA volatile acidity; TPC total phenolic content; CI color intensity; RO-EP reverse osmosis-evaporative perstraction; RO reverse osmosis; VD vacuum distillation; OD osmotic distillation; PV pervaporation; NF + PV nanofiltration-pervaporation; BVSC Barossa Valley Shiraz Cabernet Sauvignon; MVC McLaren Vale Cabernet Sauvignon; *x*–*y* means ethanol removed from *x* to *y*, for e.g., "12.5–0.3" means ethanol removed from 12.5 to 0.3% v/v

contrast, Ivić et al. (2021) observed an increase in the total SO_2 content of Cabernet Sauvignon by removing 4% ethanol using RO and NF. Similarly, Motta et al. (2017) observed an increase in the total SO_2 of Lange (by VD), Verduno Pelaverga (by MC), and Barbera (by MC and VD) by removing 5% v/v ethanol. Moreover, there was no free SO_2 found in the Barossa Valley Shiraz Cabernet Sauvignon (14.1% abv) and McLaren Vale Cabernet Sauvignon (17.1% abv) after the removal of ethanol up to 2.6% abv by RO-EP (Pham et al., 2019a, 2020). The differences between the results of the studies mentioned above could be due to the dealcoholization techniques used, the degree of alcohol reduction, and the type of wine, as well as the initial free and total SO_2 content of the original wines prior to dealcoholization.

Impact of Dealcoholization on Color and Total Phenolic of Wine

It is well-known that phenolic compounds play a significant role in wine's bitterness, astringency, and color. These compounds are also important for the preservation of wines and are the foundation of lengthy aging (Allegro et al., 2021; Merkytė et al., 2020; Waterhouse, 2002; Zoecklein et al., 1990).

Dealcoholization significantly affects wine color and total phenolics, which varies according to the type of wine and techniques used (Fig. 3 and Supplementary Table 1). The color intensity ($A420+A520+A620_{nm}$) increased during the dealcoholization of Aglianico wine by OD (Liguori et al., 2013); Merlot wine by RO (Sam et al., 2023); Lange, Pelaverga, and Barbera wines by MC and VD (Motta et al., 2017); Montepulciano d'Abruzzo wine by RO-OD (Russo et al., 2019); and Merlot and Pinot Noir wines by VD (Sam et al., 2021a). Concurrently, wine hue ($A420/A520_{nm}$) decreased. The increase in color intensity varied from 17 to 98% (Supplementary Table 1). The increase in wine color intensity during the dealcoholization process can be justified by the concentration effect produced by the removal of ethanol from the wine (Sam et al., 2021a, b). Moreover, the color increase can be related to oxygen intake which can lead to the oxidation of wine pigments and compounds, while the loss of SO_2 can result in reduced protection against color degradation (Liguori et al., 2013; Pham et al., 2019a, b).

The concentration of phenolic compounds such as polyphenols, anthocyanins, and flavonoids either remains the same or increases significantly in dealcoholized wine (Fig. 3 and Supplementary Table 1). Rosé (Langhe) and red (Verduno, Pelaverga and Barbera) wines obtained after dealcoholization (final ethanol level 5% v/v) using MC and VD showed higher concentrations of phenolic compounds such as total flavonoid (MC: 6–13%; VD: 57–84%) and total anthocyanin (MC: 8–13%; VD: 58–62%) than the original wine (Motta et al., 2017). The increase in phenolic compounds (particularly, the anthocyanin content increased by approximately 11 to 50%) in red wine after the removal of 2% ethanol by RO may be attributed to the removal of wine tartrate salts, which can otherwise trap polyphenols (Gil et al., 2013). Also, Banvolgyi et al. (2016) reported that partial removal of ethanol (4–6% v/v final ethanol level) by NF at a lower temperature (20 °C) can result in better retention of polyphenols in wine. The solubility of phenolics in wine depends on several factors, including the wine pH, temperature, and ethanol concentration (Forino et al., 2020; Gawel et al., 2013; Medina-Plaza et al., 2019). Polyphenols may display a spectrum of polarity, with certain compounds exhibiting a greater hydrophilic character than others. The presence of ethanol generally contributes to an enhanced solubility of polyphenols. However, anthocyanins represent a unique class of polyphenols, as they incorporate one or more sugar moieties into their chemical structure, endowing them with water solubility even in the absence of ethanol.

Impact of Dealcoholization on Volatile Compounds of Wine

The aroma and flavor of wine are primarily associated with several classes of volatile compounds, including esters, alcohols, acids, terpenes, phenols, aldehydes, ketones, norisoprenoids and lactones (Ferreira & Lopez, 2019; Polášková et al., 2008; Robinson et al., 2014; Styger et al., 2011; Villamor & Ross, 2013).

The impact of ethanol removal using different techniques, such as RO, VD, OD, RO-EP, RO-MC, NF, and PV, on the volatile composition of dealcoholized wine is summarized in Table 1. The losses in the volatile compounds during the dealcoholization are unavoidable due to the existence of favorable concentration gradients for these components between both membrane sides. Moreover, it depends on the synergy between the physical and chemical (i.e., chemical structure, boiling point, water solubility, hydrophobicity) properties of volatile compounds and how they interact with the wine matrix during the process, the alcohol concentration, and the affinity to the membrane (Esteras-Saz et al., 2021, 2023). The volatile compounds do not undergo complete disappearance during dealcoholization process; instead, they remain associated with the removed fraction, rendering them available for potential reintegration as needed. RO and VD were used to produce non-alcoholic wine from Chardonnay (13.4% v/v ethanol), Pinot Noir rosé (12.2% v/v ethanol), and wine from Merlot (13.9% v/v ethanol); all wines were dealcoholized to 0.7% v/v ethanol (Sam et al., 2021a). The findings demonstrated that RO-treated wines had losses in the overall ester concentration of 92, 81, and 87% and VD-treated wines had losses of 96, 98, and

Table 1 Overview of the reviewed literature on volatile compounds and sensory attributes of wines with different methods of dealcoholization

Method used	Type of wine	Ethanol range: start → end (%v/v)	Effects on volatiles		Effects on sensory attributes	References
			Aroma compounds	Estimated average losses (%)		
RO	Merlot (red)	13.9 → 0.7	Total esters	87	• Color intensity, astringency, and acidity perception increased • Hotness, bitterness, wine body, sweetness, aroma intensity, the perception of red fruit notes, and overall acceptability decreased	(Sam et al., 2021a)
			Total higher alcohols	75		
			Total acids	75		
			Total terpenes and C13-norisoprenoids	70		
	Pinot Noir (rosé)	12.2 → 0.7	Total esters	81	• Color intensity, astringency, and acidity perception increased • Wine body, hotness, aroma intensity, bitterness, red fruits, and overall acceptability decreased	
			Total higher alcohols	57		
			Total acids	91		
			Total terpenes and C13-norisoprenoids	48		
	Chardonnay (white)	13.4 → 0.7	Total esters	92	• Hotness, bitterness, wine body, sweetness, and overall acceptability decreased • Color intensity and acidity increased	
			Total higher alcohols	67		
			Total acids	73		
			Total terpenes and C13-norisoprenoids	54		
	Pinot Noir (rosé)	12.2 → 0.7	Total esters	85	• Decrease in acidity and astringency perception • Overall acceptability, wine body, hotness, bitterness, red fruits notes, and aroma intensity decreased • No effect on color intensity and sweetness	(Ma et al., 2022)
			Total higher alcohols	55		
			Total acids	83		
			Total terpenes and C13-norisoprenoids	61		
			Total carbonyl compounds	34		
VD	Merlot (red)	13.9 → 0.7	Total esters	96	• Color intensity, astringency, and acidity perception increased • Hotness, bitterness, wine body, sweetness, aroma intensity, notes of red fruits, and overall acceptability decreased	(Sam et al., 2021a)
			Total higher alcohols	94		
			Total acids	91		
			Total terpenes and C13-norisoprenoids	96		
	Pinot Noir (rosé)	12.2 → 0.7	Total esters	98	• Color intensity, astringency, and acidity perception increased • Wine body, hotness, aroma intensity, bitterness, red fruits, and overall acceptability decreased	
			Total higher alcohols	85		
			Total acids	89		
			Total terpenes and C13-norisoprenoids	92		
	Chardonnay (white)	13.4 → 0.7	Total esters	96	• Hotness, bitterness, wine body, sweetness, and overall acceptability decreased • Color intensity and acidity increased	
			Total higher alcohols	95		
			Total acids	85		
			Total terpenes and C13-norisoprenoids	94		
	Rheingau Riesling	11.53 → 0.21	n.a.*		• No significant change in perception of citrus, apple, and peach fruit notes • Body/fullness, bitterness, and sweetness decreased	(Schmitt et al., 2023)

Table 1 (continued)

Method used	Type of wine	Ethanol range: start → end (%v/v)	Effects on volatiles		Effects on sensory attributes	References
			Aroma compounds	Estimated average losses (%)		
OD	Falanghina (white)	12.5 → 0.3	Total esters	99	• Overall acceptability, appearance, odor, aftertaste, body, and sweetness decreased • Acidity perception increased	(Liguori et al., 2019)
			Total higher alcohols	99		
			Total acids	98		
			Total ketones and lactones	99		
	Aglianico (red)	13 → 0.19	Total esters	90	• n.a.*	(Liguori et al., 2013)
			Total higher alcohols	99		
			Total acids	79		
			Total ketones and lactones	99		
	Aglianico (red)	15.46 → 13.46 → 12.46 → 10.46	Total esters	54.5–59	• Astringency and acidity increased • Viscosity, flowers, cherry, and red fruits notes (n.s within 2% v/v reduction) decreased	(Lisanti et al., 2013)
			Total higher alcohols	15.5–35		
			Total acids	35–53		
			Total terpenes	18–29		
		13.81 → 11.81 → 10.81 → 8.83	Total esters	49–62	• Decrease of cherry, red fruits, and flowers notes. Increase of acid and astringent perceptions	
			Total higher alcohols	19–45		
			Total acids	15–24		
			Total terpenes	20–32		
	Montepulciano d'Abruzzo red	13.23 → 2.67	Total esters	85	• n.s. on color intensity • Overall acceptability, sweetness, spices, and red fruit note decreased, and acidity increased	(Corona et al., 2019)
			Total higher alcohols	84		
			Total acids	23		
			Total ketones and lactones	36		
	Montepulciano d'Abruzzo red	13.23 → 5.41	Total esters	19	• n.a.*	(Russo et al., 2019)
			Total higher alcohols	2		
			Total acids	23		
			Total lactones	25		
	Verdicchio red	Removed up to 2–4%	Total esters	40–45	• n.s. on acidity, saltiness, and bitterness • Wine body, persistence, and honey scent depleted	(Fedrizzi et al., 2014)
			Total higher alcohols	9–26		
			Total acids	8–16		
			Total terpenes	21–28		

Table 1 (continued)

Method used	Type of wine	Ethanol range: start → end (%v/v)		Effects on volatiles		Effects on sensory attributes	References
				Aroma compounds	Estimated average losses (%)		
	Barbera red	14.6 → 5		Total esters	24	• n.a.*	(Motta et al., 2017)
				Total higher alcohols	64		
				Total acids	17		
	Barbera red	15.4 → 13.6		Total esters	66	• n.a.*	(Rolle et al., 2018)
				Total higher alcohols	11		
	Muscat white	Removed up to 6.15		Total esters	24	• Decrease in aroma intensity, aroma purity, and wine body • No significant change in aftertaste	(Ju et al., 2023)
				Total higher alcohols	7		
				Total aldehydes	16		
				Total terpenoids	42		
				Total ketones	29		
RO-EP/OD/MC	Cabernet Sauvignon (red)	17 → 14.5 15.5 → 13.3 14.9 → 13.3 14.5 → 13.2 16 → 14.2		Total volatiles Ethyl octanoate Butanoic acid	5–20 ≈ 30 ≈ −45	• No effect on the overall intensity • A minor decrease in wine body, dried fruit, and chocolate flavor	(Pham et al., 2019a, 2020)
	Shiraz Cabernet Sauvignon blend (60:40) Shiraz	16 → 14.4 16 → 14.2		n.s, on volatile profile		In both the wines • n.s on fruity, acid fruit, sweet, soap, green, grass, rose, banana, floral, sweet perfume aroma • Decrease in green apple and berry aroma	(Pham et al., 2019a, b)
	Shiraz red (7 months after bottling)	Middle harvest	13.5 → 10.5	Total esters	30	In all three wines • n.s. on eucalyptus, red fruit, nutty/almonds, green olive, floral, and plum aroma • Increase in acidity • Decrease in dark fruit, raisin/prune, black pepper, herbaceous, and overall aroma density and astringency	(Longo et al., 2018b)
				Total higher alcohols	41		
				Total lactones	33		
				Total monoterpenes	29		
				Total C13-norisoprenoids	n.s		
		Late Harvest	16.5 → 10.5	Total esters	47		
				Total higher alcohols	40		
				Total lactones	21		
				Total monoterpenes	21		
				Total C13-norisoprenoids	15		
			16.5 → 13.5	Total esters	34		
				Total higher alcohols	22		
				Total lactones	17		
				Total monoterpenes	10		
				Total C13-norisoprenoids	n.s		

Table 1 (continued)

Method used	Type of wine	Ethanol range: start → end (%v/v)	Effects on volatiles: Aroma compounds	Effects on volatiles: Estimated average losses (%)	Effects on sensory attributes	References
	Verdelho red	Late Harvest 13.5 → 9	Total esters	61	• n.s. on buttery/nutty, citrus, apple/pears aroma, and acidity • Decrease in tropical fruit, hay, peach/apricot, herbaceous, floral, overall aroma density, bitterness taste	(Longo et al., 2018a)
			Total higher alcohols	39		
			Total lactones	n.s		
			Total monoterpenes	36		
			Total C13-norisoprenoids	52		
	Petit Verdot	13 → 10.5	Total esters	33	• n.s. on eucalyptus, green paper, floral, dark fruit, cooked aroma, and acidity • Decrease in red fruit, raisin/prune, black pepper, overall aroma intensity, and astringency	
			Total higher alcohols	26		
			Total lactones	31		
			Total monoterpenes	50		
			Total C13-norisoprenoids	n.s		
PV	Cabernet Sauvignon(red)	12.5 → 0.5	Total esters	99	• High retention of fruit aroma, producing wine with better smell and taste	(Sun et al., 2020)
			Total higher alcohols	39.5		
			Total acids	28.2		
SCC	Chardonnay (white)	14.9 → (14.6–12.9)	n.a.*		• Decrease in overall aroma intensity and hot mouthfeel sensation	(King & Heymann, 2014)
	Shiraz Sangiovese	15.1 → 0.3	Total fermentation volatiles	n.s	• Decreased in fruit aroma, fruit flavor, and hotness • Increased smoke aroma, oxidized aroma, and acidity • n.s. in astringency and woody aftertaste	(Puglisi et al., 2022)
	Petit Verdot Sangiovese	14.2 → 0.3	Total fermentation volatiles	24	• Decreased in fruit aroma, fruit flavor, astringency, and hotness • Increased smoke aroma, oxidized aroma, and acidity • n.s. in woody aftertaste	
	Chardonnay Syrah	13.8 → 7.8 → 1.8 13.5 → 7.5 → 1.5	n.a.*		• Syrah wine with 1.5% shows no intense aroma and tastes less • Chardonnay and Syrah wines reach undesirable levels when their ethanol concentrations reach 2.8% v/v and 7.0% v/v, respectively, according to the consumer rejection threshold approach	(Geffroy et al., 2022)
	Tempranillo rosé	11.44 → 0.52	Total esters	64	• n.a.*	(Osorio Alises et al., 2023)
			Total C6 alcohols	87		
			Total terpenic	34		
			Total benzenes	26		
			Total C13-norisoprenoids	19		
			Total higher alcohols	14		
			Total acids	47		
			Total lactones	15		

Legend: *n.a.** data not available, *n.s.* not significant change, *RO-EP/MC* reverse osmosis-evaporative perstraction/membrane contactor, *SCC* spinning cone column, *RO* reverse osmosis, *VD* vacuum distillation, *OD* osmotic distillation, *PV* pervaporation

96% in white, rosé, and red wines respectively. Wine dealcoholized by VD had a higher loss of esters compared to RO, possibly due to the evaporation and condensation processes inherent to VD distillation. Apart from that, the concentration of total alcohol was decreased by 84, 85, and 95% in VD-treated and 75, 58, and 68% in RO-treated red, rosé, and white wines, respectively. The loss of total organic acid concentration in red, rosé, and white wines was 91, 89, and 85% for VD treated and 76, 91, and 73% for RO-treated wine, respectively. Similarly, a decrease in volatile compounds was observed in Tempranillo rosé wine subsequent to the application of ethanol removal to attain a level of 0.03% v/v ethanol using SCC (Osorio Alises et al., 2023). RO membrane has small-sized pores (typically between 0.0001 and 0.001 microns) and a high molecular weight cutoff (MWCO) value that helps retain low molecular weight molecules, which may explain why it retains more volatile compounds than VD. However, this may cause critical membrane fouling and increase energy consumption (Banvolgyi et al., 2016). In addition, higher temperatures (35 °C) used in VD might have contributed to a higher loss of volatile compounds as it can accelerate thermal degradation and evaporation of volatile and other wine constituents.

Lisanti et al. (2013) partially dealcoholized two red wines made from Aglianico grapes varieties having different initial amounts of alcohol (15.46% and 13.81%) by two, three, and 5% ethanol strength using OD. The decrease in total aromatic alcohol concentration varied from 15.5 to 35% and 19–45% for wine having the initial amount of alcohol 15.46%, and 13.81%, respectively. At all stages of dealcoholization, 2-phenylethylethanol was the only alcohol in both wines that did not deplete, which is responsible for a pleasant aromatic note of rose. Furthermore, the decrease in total ester concentration in wine having initial amounts of alcohol 15.46% and 13.81% with different amounts of ethanol removal varied from 54.5 to 59% and 49–62%, respectively. At all stages of dealcoholization, ethyl vanillate (aroma of vanilla) does not change in both wines. A drastic decrease in the total aromatic alcohol concentration, especially 2-phenylethanol, was attributed to weaker π–π stacking triggered (due to solvent effects, hydrogen bonding competition, and solubility effects) by the reduction in ethanol concentration (7% v/v ethanol) of the wine (Longo et al., 2017). In a recent study, Ju et al. (2023) produced a Muscat white wine with 6% v/v ethanol content through meticulous fermentation control and distillation. The distilled wine exhibited notable reductions in various total volatile compounds, including total alcohols (− 7%), total esters (− 24%), total aldehydes (− 16%), and total terpenoids (− 42%). Furthermore, Esteras-Saz et al. (2023) mentioned that the behavior of each volatile compound and chemical families during OD is adequately correlated with their Henry-s constant (H^i) values, where high H^i values indicate great water solubility and lower loss.

Moreover, Russo et al. (2019) studied the effect of dealcoholization on the volatile profile of Montepulciano d'Abruzzo red wine. The wine was partially dealcoholized from 13.23 to 5.41% v/v ethanol by OD. The results showed that the concentration of acids (23%), esters (19%), lactones (7–25%), and total alcohols (2%) decreased with ethanol removal. The removal of ethanol by 2, 3, and 4% v/v ethanol from a Verdicchio white wine by OD resulted in a loss of the volatile compounds such as esters (40–54%), terpenes (21–28%), total alcohols (9–26%), and acids (8–16%) (Fedrizzi et al., 2014). Additionally, a dealcoholized wine with 5% v/v ethanol produced from Barbera red wine (14.6% v/v ethanol), using OD, led to a decrease in total alcohol (64%), ester (24%), and acid (17%) concentration (Motta et al., 2017), whereas after removing 2% v/v ethanol from Barbera red wine (15.4% v/v ethanol) led to a decrease in total alcohol (11%) and esters (66%) (Rolle et al., 2018). Acids exhibited lower loss than alcohols and esters due to their higher Henry's constant in comparison to esters and alcohols (Esteras-Saz et al., 2023).

A dealcoholized wine with 0.5% v/v ethanol produced from Cabernet sauvignon red wine (12.5% v/v ethanol), using PV, led to a decrease in total alcohol (39.5%), ester (99%), and acid (28.2%) concentration (Sun et al., 2020). Shiraz red wine produced from the middle harvest and late harvest showed a decrease in total alcohols (22–41%), total easter (30–47%), total lactones (17–33%), and total monoterpenes (10–29%) after removing ethanol by 3 to 6% v/v ethanol using RO-MC (Longo et al., 2018b). Similarly, late-harvest Verdelho and Petit Verdot red wines showed a significant change in volatile profile after removing ethanol by 4.5% v/v ethanol and 2.5% v/v ethanol, respectively (Longo et al., 2018a). The authors further mentioned that the significant loss of ethyl esters can be primarily attributed to their highly hydrophobic nature. This characteristic makes them prone to diffuse through the air gaps in the pore structure of the polypropylene membrane contactor, as well as their high volatility, which further facilitates their movement. Consequently, these ethyl esters condense into the stripping solution, leading to their loss. Additionally, a 2–3% loss can occur due to their absorption onto the surface of the membrane (Diban et al., 2008). The different losses noted throughout the wine's dealcoholization can be associated with the various vapor pressure values of the process (Sam et al., 2021a, b). According to above explained results, commenting on the best technique to use for dealcoholization is challenging due to the fact that all the techniques result in a higher loss of volatile compounds when there is a significant removal of ethanol. These findings suggest that, despite improvements in the production of low-alcohol wine, more work is required (such as a change in the physico-chemical characteristics of the aroma and its interaction with other components during the process) to maintain acceptable wine composition for larger ethanol reductions.

Impact of Dealcoholization on the Sensory Profile of the Wine

Ethanol removal from wine can cause sensory changes due to a significant drop in volatile compounds, particularly esters and terpenes, as well as the impact that ethanol has on sensory characteristics (Fedrizzi et al., 2014; Meillon et al., 2010). Furthermore, removing ethanol from wine may facilitate the binding of aroma compounds to proteinaceous substances, reducing their volatility and significantly impacting the finished wines sensory characteristics (Longo et al., 2017). The re-addition of the volatile fraction can result in making the final product organoleptically desirable. The amount of re-addition of the volatile compound depends on the type of wine and its needs to be addressed in the future. Table 1 summarizes the most recent findings regarding the sensory changes that occur in wines following the alcohol reduction, highlighting differences between original and dealcoholized wines based on the sensory characteristics, including color intensity, sweetness, fruity/floral notes, acidity, bitterness, astringency, wine body (viscosity), red fruit notes, spices, and overall acceptability. Wine dealcoholized by RO, VD, and OD to ≤ 1% v/v ethanol resulted in a decrease in overall acceptability, sweetness, fruity/floral notes, wine body (viscosity), red fruit notes, and spices and increased in acidity, astringency, and color intensity compared to original wine (Liguori et al., 2019; Ma et al., 2022; Sam et al., 2021a). The decrease in above-mentioned sensory parameters was due to a higher loss of volatile compounds during the dealcoholization process, while the increase in acidity and astringency perception parameters was due to changes in pH, total acidity, and masking effect of the sweetening, softening, and harmonizing notes of ethanol. The loss of total esters around 85% during alcohol reduction (from 13.23 to 2.67%v/v) by OD in Montepulciano d'Abruzzo red wine resulted in a decrease of red fruits olfactory notes; furthermore, the sensation of acidity increased significantly (Corona et al., 2019). For most of the wines discussed above (dealcoholized by RO, VD, and OD), the vastly decreased olfactory qualities were "Fruity & Floral" and "Red fruits," and both descriptors are particularly crucial for the ultimate sensory quality of wines. After the removal of ethanol concentration by 1–3%, white wine showed minor changes in overall taste and flavor; further removal of ethanol by 5–6% showed a significant difference in sensory characteristics compared to the original wine. A partial dealcoholization (ethanol removal of 2–4% v/v) of Verdicchio red wine using OD led to a decrease in wine body, persistency, and honey attributes (Fedrizzi et al., 2014). Recently, Ju et al. (2023) found that distilled Muscat wine (6.15% v/v ethanol) had less body, aroma intensity, and aroma purity compared to the Muscat wine produced through controlled fermentation during alcoholic fermentation. Cabernet Sauvignon red wines that were partially dealcoholized (1–2% v/v ethanol) by RO-EP showed a non-significant change in sensory profile (Pham et al., 2019a, b).

Geffroy et al. (2022) conducted a study using SSC to remove ethanol in Chardonnay and Syrah wines. The results of the study showed that Chardonnay and Syrah wines become undesirable when their ethanol concentrations reach 2.8% v/v ethanol and 7.0% v/v ethanol, respectively, according to the consumer rejection threshold approach. King and Heymann (2014) observed an overall reduction in aroma intensity and hot mouthfeel perception after the removal of ethanol from 14.9 to 12.9% v/v ethanol in Chardonnay wine by SCC. Shiraz Sangiovese (15.1% v/v ethanol) and Petit Verdot Sangiovese (14.2% v/v ethanol) red wines exhibited a reduction in fruit aroma, fruit flavor, and hotness, along with an increase in smoky, oxidized aroma, and acidity levels following the reduction of ethanol to 0.3% using SCC (Puglisi et al., 2022). These parameters could have been affected by variations in the composition of the phenolic matrix, non-volatiles in wines, the operating vacuum pressure, and temperature during the process, particularly its phenolic content, as the results of the following studies. Muñoz-González et al. (2014, 2015) have shown that phenolics can alter the perception of aroma in red wines. The following explained studies have shown that, when compared to the original wines, reduced-alcohol wines usually have poor sensory qualities, including a lack of wine body, flavor imbalance, diminished heat perception, bitterness, increased astringency, and excessive acidity.

Consumer Acceptance and Health Benefits of Low- and Zero-Alcohol Wines

Low- and zero-alcohol wines have become increasingly popular in recent years due to changing consumer acceptance and in relation to specific social-health benefits perceived (Bucher et al., 2018; Deroover et al., 2021). Table 2 provides an overview of the reviewed publications focusing on consumers' perceptions and behavior toward wines with reduced alcohol content. The innovation in the production process led to improvement in the production quality of low- and zero-alcohol wines. However, there is no systematic study of markets which give more preference to low- and zero-alcohol wines. According to an online survey conducted on 851 adult Australian wine consumers, approximately 16% of the participants expressed relative acceptance of low-alcohol wine. However, a significant 40% of the respondents stated that they would be willing to purchase a low-alcohol wine, if it possessed the same taste as standard wine (Saliba et al., 2013). Bucher et al. (2020) examined consumer perception and behavior toward Sauvignon Blanc wine with low alcohol

Table 2 Overview of the reviewed publications on consumer perceptions and behavior towards low- and zero-alcohol wine

Study type and setting	Population	Measure	Findings	References
An online questionnaire regarding their wine purchasing and consumption habits, demographics, level of knowledge, and reasons for consuming wine	851 adult Australian wine consumers	Knowledge and perception	Approximately 70% of respondents viewed low-alcohol wine as ranging between 3 and 8%, while 21% were unaware of the alcohol percentage in the wine they typically consumed 38% of respondents chose "I am not interested in low-alcohol wine," while the relative acceptance of low-alcohol wine was 16% in their study. However, this acceptance increased significantly to 40% if the taste were equivalent to that of standard wine products	(Saliba et al., 2013)
Wine tasting (Sauvignon Blanc) and randomized controlled trials	90 Australian participants	Willingness, consumption, and perception	Participants showed similar liking and consumption of both low-alcohol wine and standard wine A total of 8% of participants demonstrated a significant desire to decrease their alcohol consumption	(Bucher et al., 2020)
An online survey	637 Australian residents (81.5% consumed alcohol and 18.5% did not)	Consumption, perception	Among the participants, 39% had tried non-alcoholic wine, and 44% had tried low-alcohol wine The overall value of the product is of utmost importance to all consumers	(Shaw et al., 2023)
Based on Spanish household purchase data	18,954 Spanish households	Purchasing and perception	A subgroup of 1271 households newly began purchasing non-alcoholic wine After adopting no-alcohol wine purchases, the households' average alcohol consumption decreased by 8.2 g per household per day of purchase The reduction in purchased grams of alcohol was more significant among older households and those with lower social grades compared to younger households and higher social grades	(Anderson & Kokole, 2022)
Based on adult alcohol per capita consumption data from the World Health Organization	The UK and Spain	Consumption	The quantity of wine substituted with non-alcoholic alternatives increased by 41.8 mL per adult in British households per year and by 45.7 mL per adult in Spanish households per year	(Rehm et al., 2023)

Table 2 (continued)

Study type and setting	Population	Measure	Findings	References
Face-to-face survey (closed ended questions) conducted in the malls and outside the restaurants in the Bukit Bintang area of Kuala Lumpur	200 (100 Muslim, 100 non-Muslim) Malaysian citizens	Perception, consumption, and purchase motivation	The dealcoholized wine was consumed by 8.5% of participants, and 22% were aware of it Reasons for not drinking dealcoholized wine: “it is not halal”: 42.5%, “more expensive”: 23%, “bad mouthfeel”: 12% or “people don’t know what it is”: 45.5%	(Chan et al., 2012)
Consumer-based survey, collected at shopping malls, specialty stores and supermarkets	330 individuals in Apulia, Italy	Purchase, willingness, and perception	Only 10% are willing to buy dealcoholized wine Most people are not willing to buy dealcoholized wine due to a lack of understanding and higher product pricing when compared to standard wines The second most significant reason for interest in dealcoholized wine was health, following the primary reason of being able to drive	(Stasi et al., 2014)
Questionnaire-based survey by an internet research company with registered panels in both countries	342 (54% male, 46% female) Korean participants and 327 (50% male, 50% female) Australian participants	Preference and consumption	Korean consumers tend to prioritize health enhancement when selecting wine products Women showed a preference for lower alcohol consumption and a higher likelihood of abstaining from wine compared to men	(Yoo et al., 2013)
Questionnaire-based survey	626 South African Generation Y	Preferences and motivation	Taste was the most important attribute Aftertaste, “price”, and “I have tried it before” were essential criteria while purchasing dealcoholized wines Participants considered low-alcohol wines as a favorable option to enjoy the taste of wine without the adverse effects of alcohol	(Filter & Pentz, 2023)
A review	-	Motivation	The acceptability of low-alcohol wine depends on taste, price, cultural differences, marketing, and labeling	(Bucher et al., 2019)
Online surveys through advertisements placed in free newspapers and based on a blind tasting	51 participants (45% female and 55 male)	Consumption	The average typicality judgments decrease as the alcohol content decreases: 2.9 for a wine with 9% alcohol, 1.7 for a wine with 6% alcohol, and 1 for a wine with 0.2% alcohol under sensory conditions	(Masson & Aurier, 2015)

Table 2 (continued)

Study type and setting	Population	Measure	Findings	References
Experimental, longitudinal, in the home setting	66 regular red wine consumers, France	Consumption	Quantities of wine consumed under blind conditions: 1st fortnight: low-alcohol wine (9.5%): 15.1 cl (SD = 8.5); standard wine (13.5%): 15.8 cl (SD = 12.6) (*p*-value = 0.75) 2nd fortnight: low-alcohol wine (9.5%): 15.1 cl (7.5); standard wine (13.5%): 16.1 cl (SD = 7.6) (*p*-value = 0.62) Quantities of wine consumed when information on alcohol content was provided: 3rd fortnight: low-alcohol wine (9.5%): 15.3 cl (SD = 7.5); standard wine (13.5%): 16.4 cl (SD = 6.9) (*p*-value = 0.57) 4th fortnight: low-alcohol wine (9.5%): 14.9 (SD = 7.9); standard wine (13.5%): 16.3 cl (SD = 7.0) (*p*-value = 0.50)	(Masson & Aurier, 2017)

content in 90 Australian consumers. The findings revealed that only 8% of participants expressed a strong desire to cut back on their alcohol use. Both (standard and low-alcohol) wines received high acceptance ratings during the evaluations, but for low-alcohol wines, participants were willing to pay less. In a recent study conducted by Shaw et al. (2023) among 637 Australian residents, it was found that 39% of the participants had tried no-alcohol wine, while 44% had tried low-alcohol wine. The authors emphasized that from a functional standpoint, the overall quality of the product is of utmost importance to all consumers.

Anderson and Kokole (2022) examined the purchasing behavior of lower-strength alcohol wine within 18,954 Spanish households and showed a subgroup of 1271 households that newly started purchasing no-alcohol wine. The introduction of no-alcohol wine was associated with a significant decrease in the purchases of all other wines. Furthermore, the households' overall alcohol consumption was reduced by an average of 8.2 g per adult per household per day of purchase following the initiation of no-alcohol wine purchases. Rehm et al. (2023) mentioned based on adult alcohol per capita consumption data from the World Health Organization that the amount of wine substituted with no alcohol rose by 41.8 mL per adult per British household per year and by 45.7 mL per adult per Spanish household per year.

Chan et al. (2012) conducted a religion-based (100 Muslim and 100 non-Muslim respondents) study in Malaysia to know the consumer perception toward dealcoholized wine. The findings revealed that 8.5% of participants had consumed dealcoholized wine, and 22% were already aware of it. Among the respondents, 13% who identified as Muslim and 32% who identified as non-Muslim expressed their willingness to consume dealcoholized wine under the condition that it tastes and costs the same as regular wine. The majority of respondents said they would not drink dealcoholized wine because it is not halal (42.5%), more expensive (23%), and bad mouthfeel (12%), or because most people do not know what it is (45.5%). According to a consumer survey (conducted at shopping malls, specialty stores, and supermarkets) of 330 individuals in Apulia, Italy, just 10% of consumers were willing to buy dealcoholized wine (Stasi et al., 2014). The authors noted that people are not willing to purchase dealcoholized wine due to a lack of understanding and higher product pricing when compared to standard wines (Stasi et al., 2014). Additionally, Yoo et al. (2013) showed that Koreans were more likely to choose wine based on health-enhancement properties compared to Australians.

Recently, Filter and Pentz (2023) conducted a questionnaire-based survey of 626 South African Generation Y consumers (born between 1980 and 2000) to explore their purchase criteria for dealcoholized wine. The findings revealed that the essential criteria while purchasing dealcoholized wines were "Taste," "Price," and "I have tried it before." Reduced- and low-alcohol wines offer a favorable option for those who want to enjoy the taste of wine without the adverse effects of alcohol. Similarly, Bucher et al. (2019) mentioned that the acceptability of low-alcohol wine depends on taste, price, cultural differences, marketing, and labeling. Many consumers also appreciate the convenience of being able to drink without worrying about the impact of alcohol, such as impaired judgment or a hangover, driving after alcohol, and lessening the adverse effect of alcohol (Anderson et al., 2021). Some consumers may also choose zero-alcohol wine for religious or cultural reasons (Haseeb et al., 2017). Masson and Aurier (2015) observed that wines with less alcohol are less likely to be considered "wine," whether they're evaluated under sensory or non-sensory conditions. The average typicality judgments decrease (on a 10-point scale) as the alcohol content decreases: 2.9 for a wine with 9% alcohol, 1.7 for a wine with 6% alcohol, and 1 for a wine with 0.2% alcohol under sensory conditions. Further, Masson and Aurier (2017) conducted an experimental study on 66 regular red wine consumers to investigate the impact of low-alcohol wine on the volume consumed. They examined both the cognitive effect of a low-alcohol label (non-sensory effect) and the physiological effect of consuming low-alcohol wine (sensory effect). This research stands out by employing behavioral measures instead of self-reporting and by studying wine consumption in a home setting. The findings indicated that the volume consumed of lower alcohol wine did not significantly differ from that of standard wine, regardless of whether non-sensory information was provided or not. Therefore, an indication of lower alcohol content did not negatively affect wine consumption.

In terms of health benefits, dealcoholized and zero-alcohol wines may offer several advantages over traditional/standard wines. The consumption of excessive amounts of alcohol has been associated with cardiovascular problems such as cardiomyopathy, hypertension, coronary artery disease, and stroke (Hay et al., 2023; Lucas et al., 2005). According to the most recent WHO report, the consumption of alcohol caused 3 million deaths worldwide in 2016 (World Health Organization, 2018). On the other hand, recent research reveals that moderate alcohol use may provide some cardioprotection, especially against coronary heart disease and ischemia–reperfusion injury (Hoek et al., 2022). In addition, zero-alcohol wine consumption may be beneficial, particularly for pregnant women and those with underlying medical problems (Okaru & Lachenmeier, 2022). Table 3 provides an overview of the reviewed publications on the health benefits of low- and zero-alcohol wine.

Barden et al. (2018) found that dealcoholized red wine did not affect any specialized pro-resolving mediators of inflammation (SPMs) measured when compared to standard red wine and water. The plasma levels of 18-hydroxy eicosapentaenoic acid (18-HEPE), E-series resolvins, 17-hydroxy docosahexaenoic acid (17-HDHA), or D-series resolvins in patients with type 2 diabetes did not change substantially after consuming dealcoholized red wine. Noguer et al. (2012) remarked that alcohol-free red wine with a sufficient level of phenolic could be a good source of antioxidants to protect humans from oxidative stress (cancer, diabetes, Alzheimer, etc.). Also, the wine's antioxidant and cardioprotective characteristics remained unchanged when its alcohol concentration was reduced from 12 to 6% (Lamont et al., 2012). Chiva-Blanch et al. (2012) involving 73 men demonstrated that diastolic and systolic blood pressure significantly decreased after consuming dealcoholized red wine for four weeks, which was associated with an increase in plasma nitric oxide levels. In a further study, Chiva-Blanch et al. (2013) demonstrated that a moderate intake of red wine (equivalent to 30 g of alcohol per day), as well as consumption of dealcoholized red wine, led to a reduction in a homeostasis model assessment of insulin resistance (HOMA-IR) values and plasma insulin levels after a 4-week period involving 67 men who were at a high risk of cardiovascular issues. These findings imply that the favorable outcomes might be attributed to the presence of antioxidant compounds in red wine, with alcohol playing a less crucial role in achieving these effects. Similarly, Blalock et al. (2022) highlighted that the consumption of wine with low alcohol content and making even slight reductions in alcohol intake can result in lowered systolic blood pressure. Moreover, substantial decreases in alcohol consumption have been connected to reduced rates of morbidity and mortality (Blalock et al., 2022). One study was conducted on the antidiabetic effects of Portuguese red wine in vitro by Xia et al. (2017). The results showed that dealcoholized red wine had strong inhibitory effects on the α-glucosidase, which catalyzes the cleavage of glucose from disaccharide, and α-amylase, which breaks down long-chain carbohydrates, respectively. The major molecules responsible for these effects were monomeric and oligomeric flavan-3-ol compounds (Xia et al., 2017). Similarly, Mihailovic-Stanojevic et al. (2016) mention that alcohol-free red wine can boost antioxidant efficiency and lessen plasma's susceptibility to lipid peroxidation in spontaneously hypertensive rats (in vivo). The concentration of phenolics did not change significantly during alcohol removal from standard wine, and these polyphenols have favorable impacts on human health, including anti-inflammatory, anticarcinogenic, and cardioprotective effects (Buljeta et al., 2023; Vacca et al., 2023) Recently, Anderson et al. (2023) mentioned that as such, no safe amount of alcohol consumption for cancer and health can be established. The potential risk of cancer and other illnesses linked to alcohol usage should be clearly disclosed to consumers. In response to the growing demand for low- and zero-alcohol content wine, it is evident that consumers are increasingly interested in these products.

Table 3 Overview of the reviewed publications on health benefits of low- and zero-alcohol wine

Aim of study	Findings	References
Influence of dealcoholized red wine on plasma lipid mediators of inflammation resolution in individuals with type 2 diabetes mellitus	No effect on specialized pro-resolving mediators of inflammation (SPMs) measured compared to standard wine No effect on the plasma levels of 18-hydroxy eicosapentaenoic acid (18-HEPE), E-series resolvins, 17-hydroxy docosahexaenoic acid (17-HDHA), or D-series resolvins (RvD1, 17R-RvD1, RvD2, RvD5)	(Barden et al., 2018)
Effect of alcohol-free red wine on antioxidant enzyme activities in a human	Increase in activity of the antioxidant enzymes due to polyphenol present in alcohol-free wine Protect humans from oxidative stress (cancer, diabetes, Alzheimer, etc.)	(Noguer et al., 2012)
Impact of reduced alcohol cabernet sauvignon wine (6% v/v) on cardioprotective properties	No change in wine's antioxidant and cardioprotective characteristics Reduce risks associated with higher alcohol consumption	(Lamont et al., 2012)
Effect of dealcoholized red wine on systolic and diastolic blood pressure and plasma nitric oxide in men at high cardiovascular risk	Regular consumption of dealcoholized red wine may have potential benefits in preventing low to moderate hypertension Significant reduction in both systolic blood pressure (SBP) and diastolic blood pressure (DBP) (p-value = 0.0001 and 0.017, respectively) after the intervention with dealcoholized red wine Plasma nitric oxide increased after the DRW intervention (p-value = 0.041)	(Chiva-Blanch et al., 2012)
Effect of light–moderate alcohol consumption (red wine, dealcoholized red wine, and gin) on glucose metabolism	Dealcoholized red wine decreased plasma insulin and HOMA-IR values	(Chiva-Blanch et al., 2013)
Effects of alcohol reduction interventions on blood pressure	Lowered systolic blood pressure and reduced rates of morbidity and mortality	(Blalock et al., 2022)
The antidiabetic effects of Portuguese dealcoholized red wine in vitro	Inhibitory effects on the α-glucosidase, which catalyzes the cleavage of glucose from disaccharide, and α-amylase, which breaks down long-chain carbohydrates, respectively	(Xia et al., 2017)
Effects on systemic hemodynamics, lipid profile, and oxidative stress after consumption of alcohol-free red wine	Boost antioxidant efficiency and lessen plasma's susceptibility to lipid peroxidation Bioavailability of nitric oxide increases No change in blood pressure No effect on cholesterol and triglyceride levels	(Mihailovic-Stanojevic et al., 2016)
Comments on health and cancer risks associated with low levels of alcohol intake	Protective effect for cardiovascular diseases or type 2 diabetes Reduces the risk of cancer	(Anderson et al., 2023)

However, additional promotional and educational endeavors might be necessary to raise consumer awareness about the availability and advantages of these products. Further research is needed to determine the safe levels of consumption for reduced- and zero-alcohol content wine.

Challenges and Future Work

The several intriguing avenues for future research emerge. One of the foremost challenges lies in the delicate balance between reducing alcohol content while preserving the intricate aroma and flavor compounds that contribute to the sensory characteristics of wine. As research advances, innovative strategies must be developed to ensure that dealcoholization methods not only achieve the desired alcohol reduction but also safeguard the unique characteristics that distinguish different wine varietals/cultivars. Another challenge pertains to the impact of dealcoholization on wine maturation. The aging process of wine involves complex chemical reactions that contribute to its overall quality as well as stability, and understanding how different dealcoholization techniques influence these maturation processes is a vital area for further exploration. So, investigations into the long-term stability and aging potential of dealcoholized wines, coupled with advanced analytical techniques, could shed light on the complex chemical changes occurring over time. Additional investigations are needed to address the intricacies of consumer perception and acceptance, examining the perceptual thresholds that influence preferences and the role of contextual factors in shaping consumer attitudes toward dealcoholized wines. Finally, the potential health benefits, especially in terms of low-calorie intake and alcohol-related health risks, need continued investigation through well-designed clinical studies.

In addition, the modeling approach needs to be introduced in future studies to comprehend the kinetic phenomena related to the removal of ethanol and volatile compounds through various methods and at different time intervals during ethanol reduction. Collectively, these future research directions hold the promise of not only advancing scientific understanding but also influencing industry practices and consumer choices in the evolving landscape of dealcoholized wine consumption.

Conclusion

In conclusion, our review has provided a comprehensive analysis of existing research in the field. Majority of studies have traditionally centered on examining the differences in initial and final changes in wine characteristics. This review discusses the variations in color, pH, acidity, SO_2 levels, volatile compounds, and sensory attributes across a range of ethanol concentrations. Overall, with the removal of ethanol content of wine by a few percentages between 1 and 4% v/v ethanol, dealcoholized wines are able to retain a substantial amount of phenolics, volatile compounds, and sensory attributes. Furthermore, the taste of the product is typically almost identical to that of wine. Besides, dealcoholized wine with ethanol content below 3% v/v ethanol showed more than 90% loss in volatile compounds and was poor in terms of sensory quality. In addition, low-alcohol and alcohol-free wine could be an excellent source of antioxidants to protect people suffering from oxidative stress, such as cancer, diabetes, and Alzheimer, who should not consume alcohol, but further education about such innovations is needed from the industry.

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Declarations

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