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Low and zero alcohol "wines": impact of different dealcoholization processes on phenol profile and health benefits

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Abstract. The market of non-alcoholic wine has notably increased in the last years. Several processes have been developed at different stages of winemaking to obtain alcohol-free or low alcoholic products. To date, few data have been published on the impact of the dealcoholization processes on wine composition, palatability, and health benefits. The aim of this review was to collect the available scientific data on the most significant changes occurring on the phenolic fraction after dealcoholization processes, and the relative impact on human health. Thirty-three studies were collected: twenty-eight of them evaluated the effects of dealcoholization techniques on polyphenols and quality of wine; only five papers reported human studies. Dealcoholization processes affected mainly the anthocyanin and flavan-3-ols patterns. Nanofiltration and vacuum distillation, applied at the post-fermentation stage and allowed by the EU regulation, showed the best results in maintaining the chemical and sensory characteristics of wine. Compared to the standard wine, the health benefits of dealcoholized wines were maintained; they contribute at the reduction of the oxidative stress and the improvement of endothelial function, attributed to polyphenols.

1. Introduction

Wine is defined by the OIV 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."[1]. This definition is in line with EU regulation [2]. Until 2021, no official regulations were given for low and zero alcohol wines; as a consequence, the definitions of these categories could vary between countries. With the regulation No 2117/2021, the EU introduced the category of: a) "dealcoholized wine," when "the actual alcoholic strength is not more than 0.5% v/v"; b) "partially dealcoholized wine" when "the actual alcoholic strength is above 0.5% v/v and is below the minimum actual alcoholic strength of the category [3].

Several human studies have shown a positive correlation between wine consumption and some non-communicable diseases [4, 5, 6]. When consumed in moderate amounts during meals, wine can contribute to the reduction of oxidative stress, vascular endothelial impairment and improvement of insulin response [7,8]. These beneficial effects are mainly associated with ethanol and the polyphenol content, composed by flavonoids, phenolic acids and phytoalexins [9]. On the other hand, since 2009, the WHO adopted a global strategy to reduce the harmful use of alcohol [10].

In agreement with WHO'objectives, also the OIV started promoting the study of benefical effects associated with grape-based non alcoholic beverages. An increasing number of consumers perceive wine negatively for the health implications of alcohol. As a consequence, consumers' demand for non-alcoholic wine has notably increased in the last years. Firstly, some consumers ask low-alcoholic beverages, including wine, as a response to alcohol-related controls (for example when the consumer must drive) [11]. Secondly, low-alcohol beverages could be considered as an alternative to alcoholic ones for consumers who choose a calorie-restricted diet. Moreover, the alcohol intake must be limited by medical physiological/pathological conditions (e.g., pregnancy, diabetes, hepatic disorders). Finally, high import taxes on alcoholic beverages are imposed by several countries.

For these reasons, the non-alcoholic wine market has increased exponentially in 2024 and is estimated a further grow by +10.5% yearly between 2024 and 2034 [12, 13].

To meet consumers demand and the growing dealcoholized wine market, several producers started developing new technological processes. Dealcoholization process is based on alcohol removal from wine, that can be obtained either in a single stage or through a series of repeated cycles [14]. Several techniques can be used to reduce or eliminate alcohol from wines and could be applied at pre-fermentation, fermentation and post-fermentation stages of winemaking (Figure 1).

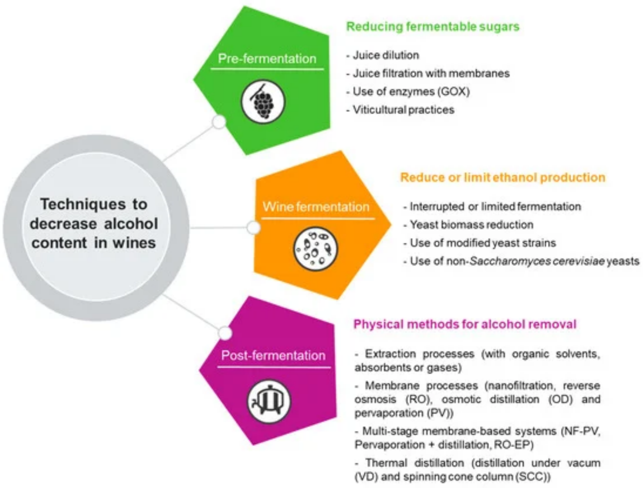

Figure 1. Techniques for reducing alcohol content in wine (from Afonso et al., 2024) [15]

Dealcoholization process at the pre-fermentation and fermentation stages are based on the reduction of fermentable sugars and alcohol production, respectively. Briefly, alcohol reduction by pre-fermentation techniques can be obtained by reducing vine leaves in the plant (which has a strong impact on the rate of sugar accumulation in berries), early grape harvest, nanofiltration of grape juice, and addition of the enzyme glucose oxidase (converting glucose in gluconic acid). Other techniques applied during fermentation have been investigated: 1-use of non-*Saccharomyces cervisiae* yeasts, that are less effective in consuming sugars and producing ethanol; 2-biomass reduction by centrifugation, resulting in a lower concentration of yeast population responsible for sugar fermentation; 3- limited fermentation by controlling temperature and time.

All these techniques allow to obtain wines with alcohol content ranging between 0.5 and 1.2 % (v/v) [14]. Conversely, post-fermentation techniques based on separation of alcohol by specific membranes, allow an alcohol reduction to value below 5% (v/v). The EU Regulation 2117/2021 allowed the use of post-fermentation techniques including reverse osmosis, nanofiltration and vacuum or osmotic distillation [3].

The dealcoholization systems as a whole can differently affect the chemical profile, sensory properties and quality of wines but few information are currently available about the changes in healthy effects. In this review the studies reporting the effect of alcohol reduction in wines and their impact on health are summarized and discussed.

2. Methods

The literature search was performed using scientific databases including PubMed, Embase, Web of Science and CabAbstract from 1970 to 2024. The key words used were "wine" in combination with "dealcoholization", "dealcoholized", "low alcohol", zero "alcohol", "alcohol-free" "ethanol removal", "phenolic composition", "polyphenols", "health". Alcoholic beverages different from wine were excluded.

3. Results and discussion

3.1. Impact of dealcoholization on wine polyphenol profile

Tables 1-2 summarize the selected twenty-eight studies reporting the impact of different dealcoholization approaches on wine phenolic composition. Despite only post-fermentative techniques are allowed by the EU (Reg. 2117/2021) [3] (Table 2), this review will include also those methods currently under investigation.

Table 1. Changes in wine phenolic compounds after dealcoholization processes applied at pre-fermentation and fermentation stages

Type of wine	Method	Impact of dealcoholization on phenolic profile	Ref.
Red wine (Barbera)	Defoliation	Phenolic compound unchanged	[16]
Red wines (Merlot, Teran, Plavac Mali)	Defoliation	Increased levels of gallic acid, catechin, glycosidic form of malvidin, delphinidin, peonidin	[17]
Red wine (Pinot-noir)	Defoliation	No significant changes	[18]
Red wine (Pinit-noir)	Defoliation	Increase of tannins, flavan-3-ols and proanthocyanidins	[19]
Red wine Merlot	Early grape harvest	Decrease of anthocyanin content	[20]
Red wine (Pinot noir)	Early grape harvest	Decrease of acylated derivatives of anthocyanins and flavanols	[21]
Red wine (Shiraz)	Grape must dilution	Decrease in tannins and anthocyanins	[22]
Red wine	Non-*Saccharomyces cervisiae* yeasts	Formation of more stable pigments (e.g. vitisin)	[23]

Leaf removal is a technique generally used to increase the quality of grapes; the process can be carried out manually or through mechanical methods. Some conflicting results have been found in papers reporting the use of this technique in the vineyards [24]. Osrecak et al. (2016) reported a higher levels of gallic acids and glycosylated form of some anthocyanins in dealcoholized wines (DW) [17], while others observed no significant change [16, 18]. In addition, time of leaf removal and local climate conditions may affect the levels od some polyphenols. Kemp et al. (2011) found that leaf removal from Pinot Noir vines at day 7 after flowering resulted in a content of tannin and flavan-3-ols higher than that obtained by the same procedure at day 30 [19]. In conclusion, despite defoliation can reduce ethanol content, further studies must be conducted to evaluate the impact of defoliation on wine quality.

Early grape harvest can affect the phenolic composition of wine, since some polyphenols, such as anthocyanins and flavanols, reach their maximum concentration at the end of ripening [24]. At this stage these compounds undergo chemical modifications (glycosylation, methylation and acylation), which are responsible for an improved stability. Early time of harvest can reduce the concentration of those compounds, affecting, in parallel, wine sensory characteristics. For instance, some authors reported accentuated vegetative flavors in wines obtained from Cabernet Sauvignon varieties early harvested, with a negative impact on consumer preferences [25].

Grape must dilution with water seems to be associated with a decrease in color stability and tannin levels, affecting wine aging and astringency characteristics. The study conducted on Shiraz wines by Schelezchi et al. (2020) underlined the need of further research to investigate the different varietal responses to must dilution and the best ripening stages for applying this technique [22].

The use of yeasts different from *Saccharomices cervisiae* during fermentation stage seems to influence positively polyphenol profile and stability of wine. However, non-*Saccharomyces* yeasts exhibit limited fermentative power and shorter survival after fermentation compared with *Saccharomyces cerevisiae*. Compared to the *S. cerevisiae*, *Schizosaccharomyces pombe* was particularly effective in promoting anthocyanin condensation in pigments less sensitive to pH variations and temperature fluctuation during the shelf-life of wine [23]. Data on post-fermentation techniques regard mainly red wines and are summarized in Table 2.

Dealcoholization methods can variably affect the phenolic composition of wines, influencing both their organoleptic characteristics and the relative potential health benefits. Phenolic compounds, including anthocyanins in red/rosé wines, were not generally affected by dealcoholization processes. However, reverse osmosis (RO) and osmotic distillation (OD) were in some cases associated with a reduction of monomeric anthocyanins (49-57%) and color intensity, while flavans were generally unaffected. In Barbera wine, the content of total flavonoids was significantly reduced, causing a color shifting toward orange. The inconsistencies observed between the different studies can be explained by the specific properties of the membarnes used, the initial phenolic profile and condition used during dealcoholization processes. Wines dealcoholized by nanofiltration (NF) and vacuum distillation (VD) showed a general increase of polyphenol concentration due to the reduced precipitation of tartrate salts, as these compounds can absorb polyphenols [37]. On the other hand, even if VD showed to be an effective technique in lowering alcohol, it can reduce the content of aromatic compounds such as alcohols and esters by 71-98%. Some authors suggest to evaluate and modify operational parameters (e.g. temperature) in order to retain wine flavor and polyphenols [27].

Finally, some studies were performed combining different dealcoholization approaches, namely reverse osmosis and osmotic distillation. The results showed a general increase of the anthocyanin content but a loss of several aromatic compounds, especially in red wines (i.e. Shiraz and Montepulciano d'Abruzzo) [38]. A more suitable balance between the techniques must be carefully investigated to reduce alcohol content and, in parallel, preserve wine aromatic parameters.

Table 2. Changes in wine phenolic compounds after dealcoholization processes applied at post-fermentation stage.

Type of wine	Method	Impact of dealcoholization on phenolic profile	Ref.
Red wine (Montepulciano D'Abruzzo)	OD	Phenolic compound unchanged; color intensity decreased	[26]
Red wine (Table wine)	NF	No significant changes; increase of anthocyanins (2.5-3 times) and resveratrol in dealc. wine concentrates	[27]
Red wines (Cabernet Sauvignon, Merlot, Tempranillo)	RO	Colour intensity increased by around 20% in dealcoholized wines (due to the removal of ethanol)	[28]
Red wine (Cabernet Sauvignon)	RO	No significant difference between partially dealc. and control wines in total phenolic index, total proanthocyanidins, and percentages of procyanidins, prodelphinidins, and galloylation	[29]
Red wine (Grenache-Carignan)	RO	Slight but statistically significant differences were observed in the percentages of procyanidins, prodelphinidins, and galloylation during alcohol reduction	[29]
Red wine (Montepulciano)	RO	Increase in total phenols and decrease in total anthocyanins	[30]
Red wine (Montepulciano)	OD	Both total phenols and total anthocyanins showed a tendency towards reduction although it was not statistically significant	[30]
Red wine (Montepulciano)	OD	Both total phenols and total anthocyanins decreased but the differences among dealc. and control wine were not statistically significant.	[30]
Red wine (Aglianico; Merlot)	OD	Total phenols and flavans were unchanged. A loss of 49% of total monomeric anthocyanins was observed after dealcoholization	[31]
Red wine (Merlot)	OD	A loss of 57% of total monomeric anthocyanins was observed in dealc. wine. Other phenolics were unchanged	[31]
Red wine (Piedirosso)	OD	A loss of 52% of total monomeric anthocyanins was observed after dealcoholization while total anthocyanins remained almost unchanged	[31]

3.2. Health benefits of zero and low alcohol wines

To date, only few pubblications (n=5) reported data on the health benefits of zero and low alcohol wines (Table 3).

Several epidemiological studies have shown that moderate alcohol consumption has been associated with a lower risk for cardiovascular events due to the positive impact on platelet function, fibrinolytic parameters, oxidative stress and lipid profile [44, 45]. In addition, moderate amounts of red wine are able to improve insulin sensitity in subjects affected by type-2-diabetes or at risk of developing this disease [46,5]. A plethora of data have demonstered that ethanol is partially responsible for wine beneficial effects, mainly on cardiovascular system; on the other hand, several studies showed that polyphenols can exert a synergistic effect, thus enhancing the positive impact of moderate wine consumption. In fact, polyphenols can stimulate nitric oxide (NO) production, improving vasodilatation, and reduce oxidative stress, with potential positive implication on cardiovascular and other metabolic parameters [47]. Barden et al., (2018) showed that dealcoholized red wine (DRW) had no effects on inflammation mediators in T2D patients [39]; however, in a previous study, a significant reduction of the vasoconstrictive ecosanoid 20-HETE was found in healthy subjects after acute intake of DRW [43]. The authors concluded that alcohol could contribute to the increase of inflammatory markers. In addition, inflammation is strictly associated with oxidative stress; Noguer et al., (2012) found an increased activity of endogenous antioxidant enzymes glutathione reductase and superoxide dismutase, probably stimulated by polyphenols. In fact, these effects were measured only in DRW group [40]; in RW group, ethanol may be responsible for pro-oxidant activities, counteracting the polyphenol action on endogenous antioxidant enzymes.

The studies by Chiva-Blanch et al. underlined no differences among DRW and RW in improving insulin sensitivity in subjects at cardiovascular risk; on the other hand, RW and gin negatively impacted the plasmatic lipidic profile. In the same cohort, blood pressure decreased after DRW intake. These effects seems to be mediated by an enhancement of NO release [41, 42]. These findings are not confirmed by other studies, where no significant differences were found among RW and DRW [39].

The low number of human studies makes difficult the evaluation of the real impact of dealcoholized wine on human health, in comparison with standard wine. Some pre-clinical studies showed no changes in plasmatic antioxidant capacity among rabbits consuming low-alcohol cabernet Sauvignon wine (6% v/v) and the standard wine; the authors concluded that the reduction of ethanol does not seem to impact the polyphenol protective effects [48]. In a model of atherosclerosis, both red wine and the non-alcoholic equivalent, prevented plaque formation in hypercholesterolemic rabbits despite an increase of LDL cholesterol levels. The mechanisms proposed include the ability of flavonoids in reducing endothelial adhesion molecules and NO production [49].

Some *in vitro* studies have shown interesting and promising data about the modulation of glucose homeostasis and insulin sensitivity. Xia et al. (2017) showed that the phenolic fraction extracted by vacuum-dealcoholized Syrah was efficient in inhibiting alpha-glucosidase, but not alpha-amylase enzyme activity. The most active fraction was rich in quercetin and myricetin (IC_{50}=34.37 μg/mL) [50].

Our research group is currently investigating the bioactivity of polyphenols in grape by-products in inhibiting dipeptidyl peptidase IV (DPP-IV), target enzyme in glucose homeostasis [51]. Further studies will include also zero or low- alcohol content wines for a first evaluation of their potential impact on this parameter.

Table 3. Summary of the papers reporting studies performed in humans about healthy effect of zero and low alcohol wines.

Study design and intervention	Aim of the study	Main outcomes	Ref.
24 T2D patients Males (n= 12) received 300 mL/day red wine, or DRW, or water (4 wk each protocol) Females (n=12): 230 mL/day, or DRW, or water (cross-over study, 4 weeks each protocol)	To evaluate the effect of dealcoholized red wine on plasma lipid mediators of inflammation	No statistically significant effects after DRW period compared to control wine	[39]
Healthy subjects (n=8; 25-40 y) received 300 mL DRW/day + low polyphenol diet for 7 d or only low polyphenol diet for 7 d (cross-over study)	To study the effect of DRW on antioxidant enzymes (superoxide dismutase, catalase, glutathione peroxidase and glutathione reductase)	Significant increase in the activity of glutathione reductase and superoxide dismutase activity in DRW group	[40]
Males (n= 67; 55-75 y) at high cardiovascular risk randomized in: 1-diet+ red wine (30 g alcohol/d), 2-dealcoholized wine (272 mL), 3-gin (30 g alcohol/d) (cross-over study, 4 weeks each intervention)	To evaluate the effect of DRW on systolic and diastolic blood pressure and plasma nitric oxide	Significant reduction in both systolic (SBP) and diastolic blood pressure (DBP) (p-value = 0.0001 and 0.017, respectively) after DRW intervention. Plasmatic NO increased in parallel in the same group (p=0.041)	[41]
Males (n= 67; 55-75 y) at high cardiovascular risk randomized in : 1-diet+ red wine (30 g alcohol/d), 2-dealcoholized wine (272 mL), 3-gin (30 g alcohol/d) (cross-over study, 4 weeks each intervention)	To determine fasting plasma glucose,insulin, HOMA-IR, plasma lipoproteins, apolipoproteins and adipokines	Fasting glucose did not change throughout the study; mean plasma insulin and HOMA-IR decreased after RW and DRW. HDL cholesterol, Apolipoprotein A-I and A-II increased after RW and gin. Lipoprotein(a) decreased after RW intake	[42]
Healthy males (n=25; 56±5.6 y) randomly assigned to: 1-375 mL RW (41 g alcohol) or equivalent volumes of DRW or water with a light meal on 3 separate days	To examine the relationship between CYP450 eicosanoids and BP and compare the effect of a single drink of RW with DRW or water after 24 h	After 24 h BP significantly decreased only in RW group in the first 4 h (p = 0.001); plasmatic 20-HETE was lower in DRW than the other goups (p= 0.025	[43]

DRW=dealcoholized red wine; T2D=type 2-diabetes; BP=blood pressure; HOMA-IR= homeostasis model assessment of insulin resistance; CYP450=Cytochrome P450; 20-HETE=20-hydroxy eicosatrienoic acid

4. Conclusions

In the last decades WHO has promoted a strong action to control alcohol misuse/abuse, considering that chronic high intake of alcohol is responsible for 3 million death worldwide in 2016 [52]. Also the OIV, in the strategic plan 2020-2024, encourages studies focused on non alcoholic grape beverages/derivatives [53].

Some groups of consumers have increased the demand for zero and dealcoholized wines for different reasons including medical problems and/or physiological conditions (e.g. pregnant women).

In order to meet consumers request without compromising wine product quality, several dehalcolization processes, which can be performed at different stages of winemaking, have been set up. Although pre-fermentation and fermentation techniques provided promising results, the EU, allowed only post-fermentation techniques (partial vacuum evaporation, membrane techniques and distillation) [3].

Despite the majority of these techniques are able in maintaining the phenolic profile (especially nanofiltration and vacuum distillation), changes in color and loss of characteristic aromatic compounds were also found (e.g. osmotic distillation). Additionally, some authors reported an increased risk for microbial contamination due to alcohol reduction, fact that could also affect long-term stability of wine [14]. Further research is needed in order to better understand how the different technologies can be applied to better preserve wine characteristics.

Finally, some preliminary data on the potential health benefits of dealcoholized wines showed no significant changes in terms of antioxidant capacity and vasodilatation by NO production, confirming that alcohol is not the only responsible for cardiovascular protection. Other studies are in progress to evaluate the ability of polyphenols in dealcoholized wine in acting on enzymes involved in the pathway of glucose metabolism.

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