

Review

## From Sugar of Grape to Alcohol of Wine: Sensorial Impact of Alcohol in Wine

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**Abstract:** The quality of grapes, as well as wine quality, flavor, stability, and sensorial characteristics depends on the content and composition of several different groups of compounds from grapes. One of these groups of compounds are sugars and consequently the alcohol content quantified in wines after alcoholic fermentation. During grape berry ripening, sucrose transported from the leaves is accumulated in the berry vacuoles as glucose and fructose. The wine alcohol content continues to be a challenge in oenology, as it is also the study of the role of chemosensory factors in alcohol intake and consumer preferences. Several technical and scientific advances have occurred in recent years, such as identification of receptors and other important molecules involved in the transduction mechanisms of flavor. In addition, consumers know that wines with high alcohol content can cause a gustatory disequilibrium affecting wine sensory perceptions leading to unbalanced wines. Hence, the object of this review is to enhance the knowledge on wine grape sugar composition, the alcohol perception on a sensorial level, as well as several technological practices that can be applied to reduce the wine alcohol content.

**Keywords:** alcohol content; alcohol reduction technologies; grapes; sensory perception; sugar accumulation; wine

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## 1. General Introduction

The sugar composition of berries has a key role in wine quality, since they determine the alcohol content of the wines. Grape berry sugar composition and concentration change during grape ripening and can be influenced by many factors, such as environment and viticulture management.

Alcohol is the most abundant volatile compound in wine and it can modify both the sensory perception of aromatic attributes and the detection of volatile compounds [1]. Therefore, alcohol is important for wine sensory sensations but also by their interaction with other wine components, such as aromas [1] and tannins [2,3], also influencing wine viscosity and body [4] and our perceptions of astringency, sourness, sweetness, aroma, and flavor [5].

In the last years, the alcohol content in wines has tended to increase, due to different factors. One of them is the potential sugar increase in musts, attributed to the probable climate change [6,7]. However, at the same time, a great number of consumers from several countries, especially from Europe, demand more reduced alcohol beverages (9%–13% v/v) as a result of health and social concerns (*i.e.*, traffic penalties) [8–10]. The increasing alcohol levels in wine could be resolved using techniques to remove or lower the wine alcohol content. However, it is important to know the limitations of these techniques on the wine sensorial characteristics, as well as providing information related to wine quality and consumer acceptance of these wines.

Mouthfeel and texture are the major determinants for consumer's preference for foods, including beverages [11–13]. Viscosity, density, and surface tension are the essential rheological properties which affect the mouthfeel of liquid food products, such as wine. They also modify other sensory properties like saltiness, sweetness, bitterness, flavor, and astringency [14–16]. It is important to understand how and where the interactions are generated as they have impacts on the flavor perception and the key sensory profile of food products. There are physical interactions between the components in the food or beverage matrix influencing the volatiles release [17] and/or viscosity [18], and multi-modal interactions resulting from the cognitive or psychological integration of the anatomically-independent sensory systems [19].

Physical viscosity, density, and yield stress have also been used to give a more comprehensive profile of the rheological properties of fluids [20]. While white wine alcohol concentration was found to be highly correlated with the perceived intensity and physical measurements of viscosity and density, the perceived viscosity and perceived density maxima were best described by quadratic and cubic models, respectively [4]. Intensity maxima for viscosity and density occurred at 10% (v/v) and 12% (v/v) white wine alcohol concentration, respectively, although white wines of 7% (v/v) to 14% (v/v) alcohol concentration were not statistically differentiated for either attribute (perceived viscosity and density) [4]. For example, alcohol is commonly utilized in composing various beverages and flavored vodkas. For instance, in 2008, Finland Vodka Company noted a 30% increase in the sale of flavored vodkas, which contain herb extracts and essences, plant distillates, fruits and their juices, and volatile aromas [21]. According to the work of Pankiewicz and Jamroz [21], a link was found between the concentrations of alcohol in pure vodka and in its blends with pear nectar and the perceived sensory viscosity and density of the drink.

Thus, the intention of this review is to contribute to a better knowledge on the grape sugar composition, including the factors that influenced their accumulation during grape ripening, the alcohol perception on sensorial level, as well as technological practical to reduce the wine alcohol content.

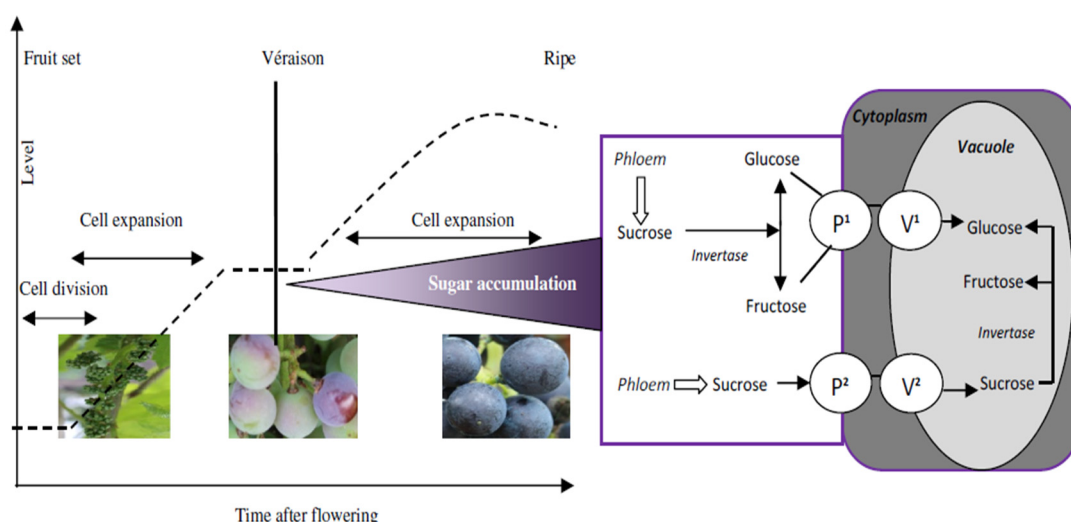
## 2. Grape Berry Composition—Sugars

Sugar accumulation in grape berries is an important phenomenon which has a great impact on the amount of alcohol in wine. In addition, in berries, total sugar is also an important fruit quality factor in table grapes. The predominant sugars that are present in grapes are glucose and fructose, with only trace content of sucrose in grape berries of most cultivars. Only a few high-sucrose content cultivars are detected in *Vitis rotundifolia* and hybrids between *Vitis labrusca* and *Vitis vinifera* [22–24]. Shiraishi *et al.* [25] identified two types of grapes based on sugar composition: hexose accumulators for which the glucose/(fructose + sucrose) ratio was  $>0.8$ , and sucrose accumulators for which this ratio was  $<0.8$ . According to Dai *et al.* [24], most *Vitis vinifera* cultivars have a glucose/fructose ratio of 1 at maturity, while this ratio varies from 0.47 to 1.12 in wild species. In addition, only few a species (*Vitis champinii* and *Vitis doaniana*) accumulate more glucose than fructose. Liu *et al.* [26] analyzed sugar concentration of 98 different grape cultivars and concluded that glucose and fructose were the predominant sugars in grape berries ranging from 45.86 to 122.89 mg/mL and from 47.64 to 131.04 mg/mL, respectively. Additionally, sucrose was present at trace amounts in most of the cultivars studied (except for two cultivars of hybrids between *Vitis labrusca* and *Vitis vinifera*, which contained large amounts of sucrose).

The accumulation of sugar in the form of glucose and fructose within the cellular medium, specifically in the vacuoles, is one of the main features of the ripening process in grape berries and is a major commercial consideration for the grape grower, winemaker, and dried grape producer. Thus, sugar content is an indicator often used to assess ripeness and to mark the harvest. Moreover, as most of the sugar is fermented to alcohol during the winemaking process, the measurement of sugar content, the so-called “must weight”, allows the control of alcohol content in the wine.

## 3. Sugar Accumulation during Grape Ripening

A schematic representation of grape berry development, sugar uptake, and metabolism during grape maturation is shown in Figure 1. Thus, during grape berry sugar accumulation, sucrose is produced in leaves by photosynthetic carbon assimilation and is transported to the berry in the phloem [27]. Sucrose is loaded into the phloem by either a symplastic or apoplastic mechanism [28]. The presence of an apoplastic step requires the involvement of membrane-located sugar transporter proteins (“hexose transporters” in Figure 1) mediating the exit of sucrose from the phloem, and the uptake and compartmentation of sugars across the plasma membrane and the tonoplast of flesh cells [29].



**Figure 1.** Schematic representation of grape berry development, sugar uptake, and metabolism during grape maturation. The curve indicates changes in berry size and two possible pathways are indicated for sugar uptake and metabolism. Legend: (-----) berry changes size. P<sup>1</sup> and V<sup>1</sup>—Hexose transporters; P<sup>2</sup> and V<sup>2</sup>—Sucrose transporters.

In the first phase of berry growth most of the sugar imported into the fruit is metabolized and grapes contain relatively low levels of sugars. However, at *véraison* sugar accumulation begins and the imported sucrose is converted into hexoses, which are stored in the vacuole. The grape berries accumulate glucose and fructose in equal amounts at a relatively constant rate during ripening [30]. According to several authors [31,32], massive accumulation of glucose and fructose in the vacuoles of mesocarp cells occurs after *véraison* and, twenty days after this period, the hexose content of the grape berry is close to 1 M, with a glucose/fructose ratio of 1. Since sucrose is the major translocated sugar in grape vine, the rapid accumulation of hexoses characterizing berry ripening must involve the activity of invertases. Their expression is high at early stages of berry development, but it declines greatly when hexose accumulation starts [28]. In addition, Hawker [33] found that invertase enzyme activity in Sultana berries increased immediately after flowering and that the activity peaked 6–7 weeks later, at *véraison*, when the rapid accumulation of hexoses commenced. According to the same author, another enzyme that might be involved in the breakdown of sucrose is sucrose synthase, which also increases during *véraison*, but their maximal activity is low compared to the level of invertase activity (200–300 times less). Invertases catalyze hydrolysis of sucrose provided by the phloem conducting complex into glucose and fructose. Different invertase isoforms are localized in the cell wall, cytoplasm, and vacuole. Hydrolysis of sucrose by cell wall invertase may promote unloading by preventing its retrieval by the phloem, and by maintaining the sucrose concentration gradient.

#### 4. Factors that Affect the Sugar Accumulation and Level in Grape Berries

Berry sugar accumulation is regulated by complex mechanisms. For example, the expression of disaccharide transporter genes (DSTs) and monosaccharide transporter genes (MSTs), sugar transporter proteins that mediate the exit of sucrose from the phloem and the uptake of sugars across the plasma membrane and the tonoplast of flesh cells, may be affected by various parameters,

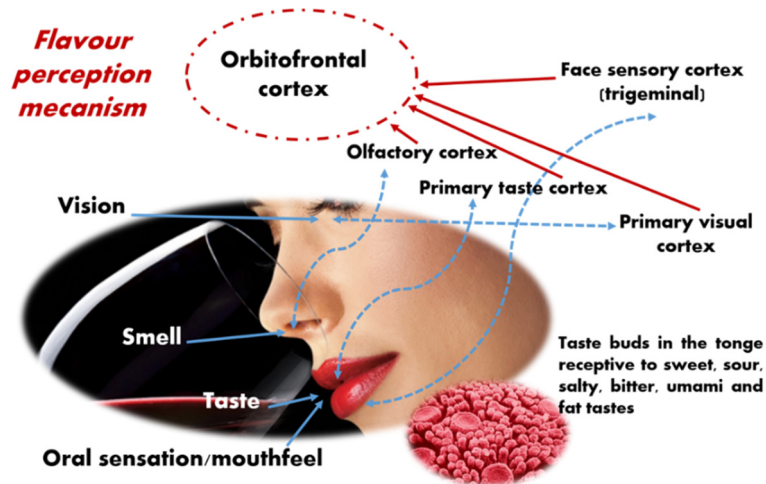
including light, water, and ion status, wounding, fungal and bacterial attacks, and hormones [34–36]. According to several authors [24,37] sugar composition is mainly determined by genotype, and sugar concentration is strongly affected by several factors, such as environment and cultural management. For example, irrigation has a variable effect on sugar accumulation in the grape berries. Thus, according to several studies [38–42], there is a variation in sugar concentration (increase, decrease or no changes) as a result of irrigation practice. Esteban *et al.* [39] analyzed the impact of water availability on the yield and must composition of *Vitis vinifera* L. cv. Tempranillo grapes during three-year period and concluded that total soluble solids, and the concentration of glucose and fructose were significantly higher in the irrigated vines than in the non-irrigated vines, mainly towards the end of ripening. On the other hand, Intrigliolo *et al.* [41] consider that the effects of irrigation on must and wine composition are largely dependent of climatic characteristics of each year, namely by the different rainfall amount and crop levels.

For several researchers [43,44] temperature is an important environmental factor that affects the grape sugar accumulation. For temperatures above 25 °C, net photosynthesis decreases even at constant sun exposure [45]. In addition, for temperatures above 30 °C, several authors [46,47] have reported a reduction of berry size and weight, and metabolic processes and sugar accumulation may completely stop. However, although high temperatures accelerate grape maturation, according to Coombe [47] temperature effects on final sugar accumulation are reported to be relatively small. Higher temperatures (30 °C) may lead to higher suspended solid concentrations, but Brix levels higher than 24–25 Brix (238.2 g/L of sugar to 249.7 g/L of sugar; 14.15% (v/v) estimated alcohol to 14.84% (v/v) estimated alcohol) are likely not due to photosynthesis and sugar transport from leaves and wood, but to concentration by evaporation [48,49]. In the last years, the alcohol content of wines tended to increase, due to different factors. One of them is the sugar increase in grapes and must, attributed to the climate change [50]. However, according to [44], the extremely high sugar concentrations reached at harvest today, especially in warm climates, may be rather associated with the desire to optimize technical or polyphenolic and/or aromatic maturity. Finally, moderate water deficit, UV-B radiation, and low temperatures (below 30 °C), have a positive effect during grape ripening by the increasing of sugar content in grape berries [51,52]. Duchêne and Schneider [53] showed that, over the last 30 years, the estimated alcohol level of Riesling grapes in Alsace, increased 2.5% (v/v) due to warmer ripening periods and earlier phenology. Additionally, Godden and Gishen [54] observed in Australian wines an increase in the alcohol content from 12.3% (v/v) to 13.9% (v/v) for red wines and from 12.2% (v/v) to 13.2% (v/v) for white wines, between 1984 and 2004.

## 5. Psychophysiology of Alcohol Perception

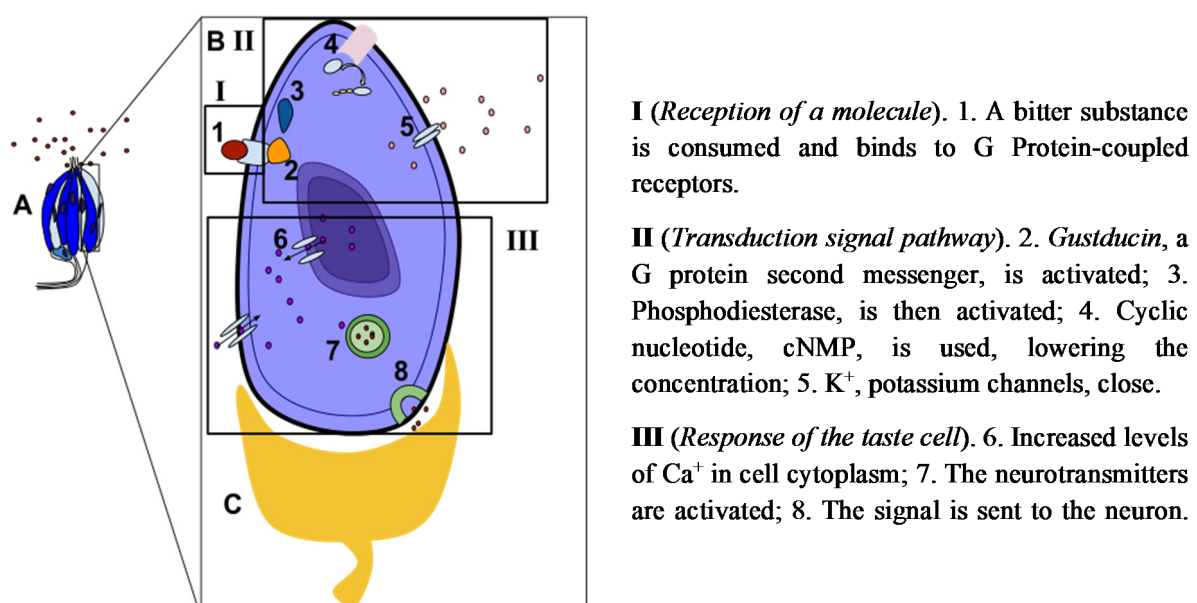
Taste strongly influences food intake [55], including alcohol consumption [56,57]. Alcohol activates olfactory, taste, and chemesthetic receptors and each modality is carried centrally by different nerves; these inputs affect the perception evoked by alcohol. Chemesthesis is defined as the chemical sensibility of the skin and mucous membranes. Chemesthetic sensations arise when chemical compounds activate receptors associated with other senses that mediate pain, touch, and thermal perception. Examples of chemesthetic sensations include the burn-like irritation from chili pepper, the coolness of menthol in mouthwashes and topical analgesic creams, the stinging or tingling of

carbonation in the nose and mouth, and the tear-induction of onions. The oral consumption of alcohol by humans is accompanied by chemosensory perception of flavor, which plays an important role in its acceptance or rejection. Three independent sensory systems, taste, olfaction, and chemosensory irritation, are involved in the perception of flavor in food and in wine in particular (Figure 2) [58].



**Figure 2.** Mechanism of flavor perception in food and wine intake. Adapted from Redondo *et al.* [59].

As reported by Allen *et al.* [60], humans perceive alcohol as a combination of sweet and bitter tastes odors (Figure 3), and oral irritation (burning sensation). However, several researchers like Lanier *et al.* [58] found that some people describe experiences of more bitterness and less sweetness when drinking alcohol, and this directly relates to the genes they have inherited and individual differences in bitterness and sweetness are predictors of alcohol liking and intake in young adults. In addition, the perception of bitterness and sweetness also vary as a function of alcohol concentration [61,62].



**Figure 3.** Diagram showing the signal transduction pathway of bitter taste. A, taste bud; B, taste cell; and C, neuron attached to B. Adapted from Hldavis4 [63].



Multiple studies [64,65] have linked variation in TAS2R (taste receptor, type 2) bitter receptor genes to alcohol intake. An important gene contributing to PTC (the ability to taste the bitterness of phenylthiocarbamide) perception has been identified [66]. The gene (TAS2R38—taste receptor, type 2, member 38), located on chromosome 7q36, is a member of the bitter taste receptor family. There are two common molecular forms (proline-alanine-valine (PAV) and alanine-valine-isoleucine (AVI)) of this receptor defined by three nucleotide polymorphisms that result in three amino acid substitutions: Pro49Ala, Ala262Val, and Val296Ile. Duffy *et al.* [67] reported that TAS2R38 haplotypes are associated with alcoholic intake, with AVI homozygotes, who perceive less bitterness from the bitter compound propylthiouracil (6-*n*-propylthiouracil (PROP) is a thiouracil-derived drug used to treat hyperthyroidism, including Graves' disease, by decreasing the amount of thyroid hormone produced by the thyroid gland) consuming, significantly, more alcoholic drinks than heterozygotes or PAV homozygotes. More recently, Dotson *et al.* [68] reported associations between TAS2R38 and TAS2R13 polymorphisms and alcohol intake derived from the Alcohol Use Disorders Identification Test (AUDIT) in head and neck cancer patients.

In addition, to bitter and sweet sensations, as we mentioned before, alcohol also causes irritation commonly described as burning or stinging [58]. Burning sensations in the mouth are due, in part, to activation of the transient receptor potential vanilloid receptor 1 (TRPV1) that is activated by noxious heat, capsaicin [69,70], and alcohol even at relatively low concentrations (0.1% to 3% v/v) [71]. When the TRPV1 gene is knocked out in mice, knockouts have a higher preference for alcohol and consume more than wild-type mice [72]. Collectively, these data suggest the TRPV1 receptor likely plays a role in the perception and acceptability of alcohol.

Many factors underlie the role that alcohol flavor plays in the development of alcohol preference and consumption patterns. Such factors include the activation of peripheral chemoreceptors by alcohol [70]; central mechanisms that mediate the hedonic responses to alcohol flavor [73]; learned associations of alcohol's sensory attributes and its post digestive effects and early postnatal exposure to alcohol flavor [74,75]; and genetically determined individual variation in chemosensation [21,61]. The study of the role of chemosensory factors in alcohol intake and preferences is of special interest because the past decade has witnessed significant technical and scientific advances, which include identification of receptors and other key molecules involved in the transduction mechanisms of olfaction [76,77], chemosensory irritation [78], and taste [79–82].

## 6. The Effects of Ethanol on the Body and Other Sensory Characteristics of Wines

The terms “body” and “fullness” are wine attributes frequently used to describe the in-mouth impression of both red and white table wines [83]. Wines are regularly classified as being light, medium, or full bodied. Presumably as wines of different style appeal to different market segments, and are consumed in different social and culinary contexts. However, despite its widespread use and application, there appears to be a lack of common understanding within the wine trade as to what sensory aspects contribute to wine body. Most importantly, there appears to be no agreed position on the necessary conditions for “fullness” in wine or other alcoholic beverages. Despite the apparent lack of agreement on what constitutes body in wine, Gawel [84] showed that experienced wine tasters, with extensive practical training, had an equivalent understanding of “body” in white wines, and considered

the feature important in distinguishing between the wines. It has long been speculated that alcohol strongly contributes to palate fullness in white wine [85]. Pickering *et al.* [4] were the first to formally test this premise. They found that the perceived density of a de-alcoholized wine generally increased with increasing alcohol over a 14% (v/v) range, while its perceived viscosity was highest at 10% (v/v) ethanol. Later work [86] using model wine solutions showed a positive monotonic effect of alcohol content on both perceived viscosity and density over the same alcohol range, further supporting the existence of a positive relationship between alcohol content and fullness in white wine.

The contribution of ethanol to wine sensory properties extends beyond that of possibly enhancing fullness. Ethanol affects the headspace concentrations of many wine volatiles [87], and also contributes to sweetness [88]. Furthermore, ethanol induced palate warmth and perceived viscosity may indirectly affect both aroma and flavor perception. Moreover, according to the work of Joshi and Sandhu [89] the results of sensory evaluation of different vermouths prepared with different ethanol concentrations, sugar levels and spices extract showed significant differences for various sensory quality parameters. The data obtained revealed that for color and appearance, 12% (v/v) and 15% (v/v) of alcohol with 2.5% (w/v) spices extract scored better, but for aroma virtually all the treatments were comparable. However, in total acidity vermouth with 18% (v/v) ethanol scored lower than those with 12% (v/v) and 15% (v/v). In bitterness and astringency, vermouths of all the treatments were comparable. In overall quality, apple vermouth with 15% (v/v) ethanol, 2.5% (w/v) spices extract, and 4% (v/v) sugar content scored the highest. So, bitterness, astringency, and total acidity are influenced by the alcohol vermouth concentration. However, for Noble [90], the higher concentrations of alcohol in wines contribute to enhance bitterness intensity, but have no effect on perception of astringency.

## 7. Technological Practical to Reduce the Wine Alcohol Content and Their Sensorial Impact

Alcohol fermentation is done by yeast and some types of bacteria. These microorganisms convert berry sugars into ethyl alcohol and carbon dioxide. Alcoholic fermentation begins after glucose enters the yeast cell (*Saccharomyces cerevisiae*). The glucose is broken down into pyruvic acid, which is then converted to carbon dioxide, ethanol, and energy for the cell. Humans have taken advantage of this process in making wine, bread and beer.

Nowadays, the market in general, appreciated full body red wines with intense and complex flavor profiles produced from grapes with adequate phenolic ripeness, optimal flavor balance and lower acidity [91–95], but the juice from such grapes also contains high sugar content and consequently leads to wines with high alcohol contents (14%–16%, v/v) [91,96]. Alcohol taste near or above this threshold is described as bitter or as sweet and/or sour [88]. Nevertheless, in recent years there is a consumer demand for wines with lower alcohol content (9%–13%, v/v), that apparently are healthier since the consumer's attitudes are changing [8,9,97]. In addition, consumers also perceive that high alcohol levels affects wine sensory perceptions, leading to unbalanced wines. On the other hand, wines made from grapes with high sugar levels will probably show low acidity and poor aromatic notes. These wines can be perceived as more hot on the palate and the volatility and sensory perception of other volatile compounds affects detection thresholds [5]. Additionally, in some countries, winemakers have to pay taxes when alcohol content in wine is over 14.5% (v/v), increasing in this way the wine final price [97].



Wines with higher alcohol levels changed their wine sensory profile [98], partly by decreasing the volatility of wine aroma compounds, since up to a certain level of alcohol a decrease in fruity aromas was observed, being that many of these wines considered out of balance, and dominated by alcohol-associated attributes [1]. The effect of alcohol on the sensory perception of fruitiness from a mixture composed by nine fruity compounds at the maximum concentrations found in the wines was evaluated by Escudero *et al.* [99]. According to these authors, when there is no alcohol in the mixture, the smell is strong; however, the intensity of the smell decreases with the content of alcohol in the mixture being at 14.5% (v/v) no longer perceived. It was also observed by other authors [2,5] that the bitterness intensity was higher when the alcohol content increased and astringency decreased linearly when the content of alcohol increased, too. However, Noble [90] showed also that higher concentrations of alcohol enhance bitterness intensity in wines, but observed no effect on perception of astringency. According to the author [90], subjects with high salivary flow rates perceived maximum intensity sooner and reported shorter duration of both bitterness and astringency than low-flow judges. In spite of the final quality and acceptance of wines, musts with high sugar content usually show additional oenological problems, as difficulty to carry out alcoholic fermentation, with sluggish fermentation, and even fermentation stops [100]. This fact gives origin to new problems, due to the microbiological instability of wines with high levels of residual sugars. In an effort to meet the demands of consumers for wines with lower alcohol, winemakers are searching for technological strategies to low the wine alcohol content. There are some technical procedures to reduce the alcohol content that could be done either by reducing the concentration of sugar present in grapes [50,101], or by removing alcohol from wine [92].

The grape sugar reduction involves harvesting grapes at an earlier stage of ripening [94]. However, the wine composition and quality changed due to fewer aromas flavor and color intensity, and increased acidity.

During alcoholic fermentation, respiration of sugars by non-*Saccharomyces* yeasts has been recently proposed for lowering alcohol levels in wine. Development of industrial fermentation processes based on such an approach requires the identification of yeast strains able to grow and respire under the relatively severe conditions found in grape must. In a work performed by Quirós *et al.* [102], physiological features of some strains of *Metschnikowia pulcherrima* and *Kluyveromyces* yeasts that constitute the main part of the microbiota of sound ripe grapes, and are known to predominate during the initial stages of wine fermentation [103], suggest that they are appropriate for lowering alcohol yields by respiration. Although the concentration of molecular oxygen is particularly low during fermentation, mainly due to carbon dioxide release, several practices employed during the first stages of winemaking such as pumping over, *délestage*, or macrooxygenation, can increase oxygen concentration. These, or *ad hoc* oxygenation practices, would allow for the partial respiration of grape sugars by the appropriate yeast strains. However, in a regular fermentation, *S. cerevisiae* usually dominates the fermentation, being this practice somewhat difficult and with poorer results.

For using *S. cerevisiae* strains in alcohol reduction, different techniques have been applied like expression of NADH-dependent lactate dehydrogenase or a bacterial NADH oxidase in yeast [104]. Although both techniques reduced alcohol production, the wine quality has been spoiled due to the detrimental byproducts, like lactic acid, acetaldehyde, and some oxidized compounds [104].

Non-genetically modified (non-GM) approaches, such as evolutionary engineering, has been practiced thanks to adaptive evolution [105]. Adaptive evolution can be applied by diversion of carbons towards the pentose phosphate (PP) pathway leading to lower availability of carbons for ethanol production by elimination of carbons in the form of carbon dioxide and reduced acetate production and increased ester formation. Another approach is evolutionary engineered yeasts with sugars diverted towards glycerol and 2,3-butanediol. According to Tilloy *et al.* [104] these engineered yeasts have ability to reduce the alcohol content of wine by 0.5% to 1% (v/v).

It is also possible to reduce the sugar in musts to obtain wines with a slight alcohol reduction by the use a several technologies, namely nanofiltration. Thus, according to García-Martín *et al.* [50] the sugar reduction in must by using the nanofiltration technology resulted in a satisfactory alcohol reduction in the resulting wine, but with a slight loss in the color and aroma.

Several membrane technologies have also been developed for alcohol removal from wine, in the winery. They are reported to allow the reduction of the alcohol content under soft conditions in order to try to preserve the sensory characteristic of the original wine [8,92,106]. Semi-permeable membranes by which alcohol can be separated from wine have been available since the 1970s [92]. The benefit of membrane technologies (nanofiltration, membrane contactor, reverse osmosis, and other membrane techniques) is the low operations cost, and the advantage to work at low to moderate temperatures, being limited by the negative effects on wine aroma chemical reactions or degradation [107]. This procedure will be used to reduce only 1% or 2% (v/v) of the alcohol content in order to obtain more balanced wines with complete aromatic potential and phenolic ripeness [93,108], as established by the European regulation (EC Reg. 606/2009) [109] reduction of the actual alcoholic strength by volume may not be more than 2% (v/v), but more recently this limit has been changed. Thus, according to the Commission Regulation (UE) N 144/2013 [110] the alcohol content may be reduced by a maximum of 20% (v/v), OIV-ECO 433-2012 [111]. The separating techniques that can be used to reduce the alcohol content according to OIV (Resolution OIV-Oeno 394A-2012) [112] are: partial vacuum evaporation, membrane techniques, and distillation. Of these, the most used in the wineries are the spinning cone column and reverse osmosis system to produce lower alcohol wines or to adjust the ethanol content [3,92]. Reverse osmosis, is a membrane separation process that is probably the most successfully-employed procedure for partial dealcoholization [113]. The results showed that this technique has the advantage of having a minimal negative influence on wine taste, by modifying only the wine alcohol content while the other parameters remained unaffected, since it is performed at low temperature [92]. Reverse osmosis could be a technique for improving a wine's balance in regions where wines can reach high alcohol content. However, this wine alcohol reduction process could also negatively affect the wine sensorial quality, leading in the worst cases to an unacceptability of the wine, by changing the complex equilibrium among organic compounds responsible for wine taste, flavor and mouth feel. The observed modifications in reduced alcohol wine sensorial characteristics could be due to the reduction in alcohol content, which plays an important role in wine taste [5], mouth feel [2,4], and olfactory wine properties [1,99]; and in the losses of volatile and polyphenolic compounds, during the alcohol reduction process [106,114]. Removal of alcohol from wine reduced fruity aromas, and enhanced vegetative and sweaty aromas in white wines [93]. According to King and Heymann [115] reducing the alcohol content of oaked white wine using spinning cone technology results in a minimal impact on sensory composition and consumer preferences since no perceptible

changes to the sensory profile were observed. These authors showed that panelists and consumers were unable to detect changes among wines with a 1% (v/v) difference. This work suggests that the use of technology to partially reduce the white wine alcohol content without reducing the wine quality is of beneficial use to the wine industry. However, Meillon *et al.* [3], using the reverse osmosis treatment to reduce the wine alcoholic degree of Merlot and Syrah wines, showed that the wine sensory perception and their appreciation/acceptability by consumers was modified, particularly a decrease in the perception of the wine balance was observed. According to the same authors, a significant impact on the sensory properties of red wines with a decrease in the perception of hotness, bitterness, aromas, and persistency in the mouth was observed, and also an increase in the perception of astringency and a decrease in the perception of wine complexity. Generally, alcohol reduction was less well accepted for red than for white wines, and it was also variable from one grape variety to another one. In this way, there are several kinds of interactions between alcohol and wine components that make difficult the generalization of alcohol reduction effect on the sensory perception of wines [3]. Lisanti *et al.* [116] concluded that wine alcohol reduction using the membrane contactor technique affected the red wine sensorial properties. The most reduced olfactory notes were those of cherry and red fruits, particularly in wine with 5% (v/v) alcohol reduction. The alcohol reduction process also increased the intensity of astringency, bitterness, and acidity. However, according to the same authors an alcohol reduction of 2% (v/v), has slightly affected the wine sensory profile.

## 8. Final Remarks

Grape sugar concentration is a parameter to predict grape and wine quality. However, in recent years, the sugar concentration has increased in grapes, attributed to climate change; therefore, the alcohol content of wines tended to increase. The high sugar concentrations reached at harvest today may, rather, be associated with the desire to optimize technical or polyphenolic and/or aromatic maturity.

Though, consumption of alcohol beverages is accompanied by chemosensory perception of flavor, which is an important factor for acceptance or rejection. Thus, the main factors for selection of the wine alcohol-reducing technique are maintaining quality, in terms of flavor, in the final wine, and lowest cost.

The request for less alcoholic wines has led to technological innovations to low alcohol content without changing the wine sensorial profile.

## Author Contributions

António M. Jordão, Alice Vilela and Fernanda Cosme equally contributed to the paper.

## Conflicts of Interest

The authors declare no conflict of interest.

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