Beverages **2015**, *1*, 292-310; doi:10.3390/beverages1040292

OPEN ACCESS

beverages

ISSN 2306-5710

www.mdpi.com/journal/beverages

Review

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

António M. Jordão [1], Alice Vilela [2] and Fernanda Cosme [2,*]

[1] Agrarian Higher School, Polytechnic Institute of Viseu (CI & DETS), Estrada de Nelas, Quinta da Alagoa, Ranhados, Viseu 3500-606, Portugal; E-Mail: antoniojordao@esav.ipv.pt

[2] CQ-VR, Chemistry Research Centre, School of Life Sciences and Environment, Department of Biology and Environment, Universidade de Trás-os-Montes e Alto Douro, Edifício de Enologia, Apartado 1013, Vila Real 5001-801, Portugal; E-Mail: avimoura@utad.pt

* Author to whom correspondence should be addressed; E-Mail: fcosme@utad.pt; Tel.: +351-259-350-657; Fax: +351-259-350-480.

Academic Editor: Lorenzo Stafford

Received: 30 August 2015 / Accepted: 23 October 2015 / Published: 2 November 2015

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 causes 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

---

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].

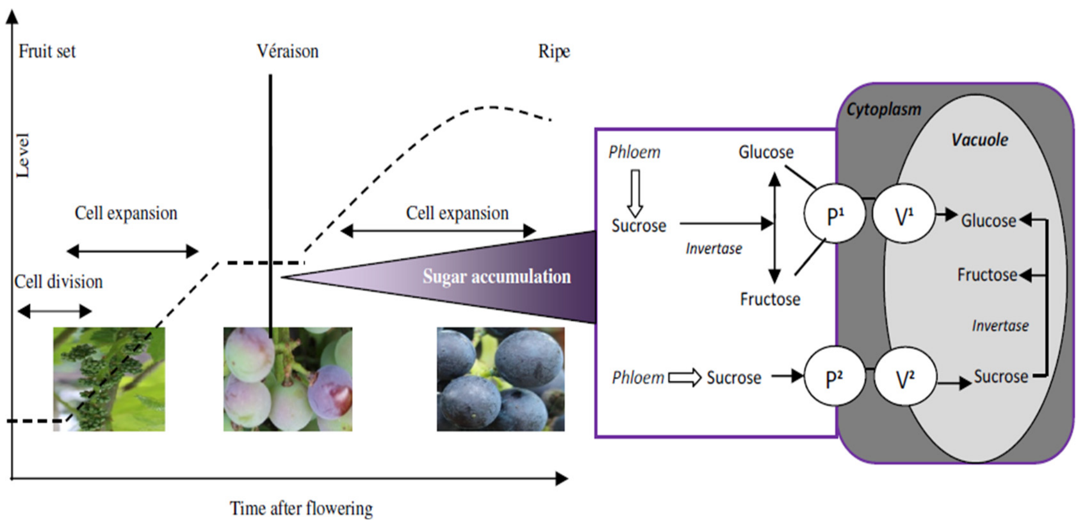


Figure 1. Schematic representation of grape berry development, sugar uptake, and metabolism during grape maturation. The curve indicates changes in berry size and two possible pathways are indicated for sugar uptake and metabolism. Legend: (-----) berry changes size. P^1 and V^1—*Hexose transporters*;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

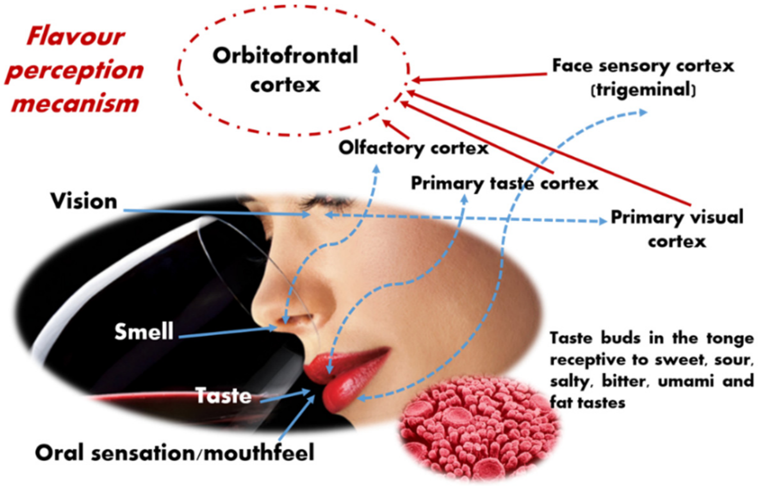
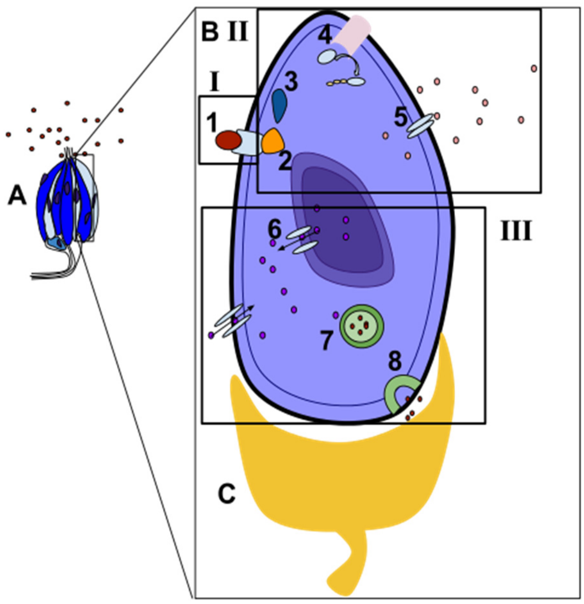


Figure 2. Mechanism of flavor perception in food and wine intake. Adapted from Redondo *et al.* [59].

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].



I (*Reception of a molecule*). 1. A bitter substance is consumed and binds to G Protein-coupled receptors.

II (*Transduction signal pathway*). 2. *Gustducin*, a G protein second messenger, is activated; 3. Phosphodiesterase, is then activated; 4. Cyclic nucleotide, cNMP, is used, lowering the concentration; 5. K^+, potassium channels, close.

III (*Response of the taste cell*). 6. Increased levels of Ca^+ in cell cytoplasm; 7. The neurotransmitters are activated; 8. The signal is sent to the neuron.

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 macrooxigenation, 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.

References

1. Goldner, M.C.; Zamora, M.C.; di Leo Lira, P.; Gianninoto, H.; Bandoni, A. Effect of ethanol level in the perception of aroma attributes and the detection of volatile compounds in red wine. *J. Sens. Stud.* **2009**, *24*, 243–257.
2. Fontoin, H.; Saucier, C.; Teissedre, P.L.; Glories, Y. Effect of pH, ethanol and acidity on astringency and bitterness of grape seed tannin oligomers in model wine solution. *Food Qual. Preference* **2008**, *19*, 286–291.
3. Meillon, S.; Urbano, C.; Schlich, P. Contribution of the temporal dominance of sensations (TDS) method to the sensory description of subtle differences in partially dealcoholized red wines. *Food Qual. Preference* **2009**, *20*, 490–499.
4. Pickering, G.J.; Heatherbell, D.A.; Vanhanen, L.P.; Barnes, M.F. The effect of ethanol concentration on the temporal perception of viscosity and density in white wine. *Am. J. Enol. Vitic.* **1998**, *49*, 306–318.
5. Fischer, U.; Noble, A.C. The effect of ethanol, catechin concentration, and pH on sourness and bitterness of wine. *Am. J. Enol. Vitic.* **1994**, *45*, 6–10.
6. Jones, G.V.; White, M.A.; Cooper, O.R; Storchmann, K. Climate change and global wine quality. *Clim. Chang.* **2005**, *73*, 319–343.
7. Koufos, G.; Mavromatis, T.; Koundouras, S.; Fyllasd, N.M.; Jones, G.V. Viticulture-climate relationships in Greece: The impacts of recent climate trends on harvest date variation. *Int. J. Climatol.* **2013**, *34*, 1445–1459.
8. Labanda, J.; Vichi, S.; Llorens, J.; López-Tamames, E. Membrane separation technology for the reduction of alcoholic degree of a white model wine. *LWT Food Sci. Technol*. **2009**, *42*, 1390–1395.
9. Masson, J.; Aurier, P.; D'hauteville, F. Effects of non-sensory cues on perceived quality: The case of low-alcohol wine. *Int. J. Wine Bus. Res.* **2008**, *20*, 215–229.
10. Saliba, A.J.; Ovington, L.A.; Moran, C.C. Consumer demand for low-alcohol wine in an Australian sample. *Int. J. Wine Res.* **2013**, *5*, 1–8.
11. Szczesniak, A.S. Classification of mouthfeel characteristics of beverages. In *Food Rheology and Texture*; Sherman, P., Ed.; Academic Press: London, UK, 1979; pp. 1–20.
12. Szczesniak, A.S. Psychorheology and texture as factors controlling the consumer acceptance of food. *Cereal Foods World* **1990**, *35*, 1201–1205.
13. Noble, A.C.; Arnold, R.A.; Buechsenstein, J.; Leach, E.J.; Schmidt, J.O.; Stern, P.M. Modification of a standardized system of wine aroma terminology. *Am. J. Enol. Vitic.* **1987**, *38*, 143–146.
14. Smith, A.K.; June, H.; Noble, A.C. Effects of viscosity on the bitterness and astringency of grape seed tannin. *Food Qual. Preference* **1996**, *7*, 161–166.
15. Hollowood, T.A.; Linforth, R.S.T.; Taylor, A.J. The effect of viscosity on the perception of flavour. *Chem. Senses* **2002**, *27*, 583–589.
16. Yanniotis, S.; Kotseridis, G.; Orfanidou, A.; Petraki, A. Effect of ethanol, dry extract and glycerol on the viscosity of wine. *J. Food Eng.* **2007**, *81*, 399–403.
17. Da Porto, C.; Cordaro, F.; Marcassa, N. Effects of carbohydrate and noncarbohydrate sweeteners on the orange spirit volatile compounds. *Food Sci. Technol.* **2006**, *39*, 159–165.

18. Walker, S.; Prescott, J. The influence of solution viscosity and different viscosifying agents of apple juice flavour. *J. Sens. Stud.* **2000**, *15*, 285–307.
19. Dalton, P.; Doolittle, N.; Nagata, H.; Breslin, P.A.S. The merging of the senses: Integration of subthreshold taste and smell. *Nat. Neurosci.* **2000**, *3*, 431–432
20. Cichero, J.A.Y.; Jackson, O.J.; Halley, P.J.; Murdoch, B.E. How thick is thick? Multicenter study of the rheological and material property characteristics of meal time fluids and videofluoroscopy fluids. *Dysphagia* **2000**, *15*, 188–200.
21. Pankiewicz, U.; Jamroz, J. Evaluation of Physicochemical and Sensory Properties of Ethanol Blended with Pear Nectar. *Czech J. Food Sci*. **2013**, *31*, 66–71.
22. Carroll, D.E.; Hoover, M.W.; Nesbitt, W.B. Sugar and organic acid concentrations in cultivars of muscadine grapes. *J. Am. Soc. Hortic. Sci.* **1971**, *96*, 737–740.
23. Shiraishi, M. Three descriptors for sugars to evaluate grape germplasm. *Euphytica* **1993**, *71*, 99–106.
24. Dai, Z.W.; Ollat, N.; Gomès, E.; Decroocq, S.; Tandonnet, J.-P.; Bordenave, L.; Pieri, P.; Hilbert, G.; Kappel, C.; van Leeuwen, C.; *et al*. Ecophysiological, genetic, and molecular causes of variation in grape berry weight and composition: A review. *Am. J. Enol. Vitic.* **2011**, *62*, 413–425.
25. Shiraishi, M.; Fujishima, H.; Chijiwa, H. Evaluation of table grape genetic resources for sugar, organic acid, and amino acid composition of berries. *Euphytica* **2010**, *174*, 1–13.
26. Liu, H.F.; Wu, B.H.; Fan, P.G.; Li, S.H.; Li, L.S. Sugar and acid concentrations in 98 grape cultivars analyzed by principal component analysis. *J. Sci. Food Agric.* **2006**, *86*, 1526–1536.
27. Conde, B.C.; Silva, P.; Fontes, N.; Dias, A.C.P.; Tavares, R.M.; Sousa, M.J.; Agasse, A.; Delrot, S.; Geros, H. Biochemical changes throughout grape berry development and fruit and wine quality. *Food* **2007**, *1*, 1–22.
28. Boss, P.K.; Davies, C. Molecular biology of sugar and anthocyanin accumulation in grape berries. In *Molecular Biology and Biotechnology of the Grapevine*; Roubelakis-Angelakis, K.A, Ed.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2001; pp. 1–33.
29. Williams, L.E.; Lemoine, R.; Sauer, N. Sugar transporters in higher plants—A diversity of roles and complex regulation. *Trends Plant Sci.* **2000**, *5*, 283–290.
30. Robinson, S.P.; Davies, C. Molecular biology of grape berry ripening. *Aust. J. Grape Wine Res.* **2000**, *6*, 175–188.
31. Coombe, B.G. Research on Development and Ripening of the Grape Berry. *Am. J. Enol. Vitic.* **1992**, *43*, 101–110.
32. Fillion, L.; Ageorges, A.; Picaud, S.; Coutos-Thevenot, P.; Lemoine, R.; Romieu, C.; Delrot, S. Cloning and expression of a hexose transporter gene expressed during the ripening of grape berry. *Plant Physiol.* **1999**, *120*, 1083–1093.
33. Hawker, J.S. Changes in the activities of enzymes concerned with sugar metabolism during the development of grape berries. *Phytochemistry* **1969**, *8*, 9–17.
34. Kühn, C.; Franceschi, V.R.; Schulz, A.; Lemoine, R.; Frommer, W.B. Macromolecular trafficking indicated by localization and turnover of sucrose transporters in enucleate sieve elements. *Science* **1997**, *275*, 1298–1300.
35. Delrot, S.; Atanassova, R.; Maurousset, L. Regulation of sugar, amino acid and peptide plant membrane transporters. *Biochim. Biophys. Acta* **2000**, *1465*, 281–306.

36. Octave, S.; Emborabé, B.E.; Fleurat-Lessard, P.; Bergès, T.; Roblin, G. Modifications of plant cell activities by polypeptides secreted by Eutypa lata, a vineyard fungal pathogen. *Physiol. Plant.* **2006**, *128*, 103–115.
37. Esteban, M.A.; Villanueva, M.J.; Lissarrague, J.R. Relalationships between different berry components in Tempranillo (*Vitis vinifera* L.) grapes from irrigated and non-irrigated vines during ripening. *J. Sci. Food Agric.* **2002**, *82*, 1136–1146.
38. Jordão, A.M.; Ricardo-da-Silva, J.M.; Laureano, O. Influência da rega na composição fenólica das uvas tintas da casta Touriga Francesa (*Vitis vinifera* L.). *Cienc. Tecnol. Aliment*. **1998**, *2*, 60–73.
39. Esteban, M.A.; Villanueva, M.J.; Lissarrague, J.R. Effect of Irrigation on Changes in Berry Composition of Tempranillo during Maturation. Sugars, Organic Acids, and Mineral Elements. *Am. J. Enol. Vitic.* **1999**, *50*, 418–434.
40. Orts, M.L.; Martínez-Cutillas, A.; López-Roca, J.M.; Gómez-Plaza, E. Effect of moderate irrigation on grape composition during ripening. *J. Agric. Res.* **2005**, *3*, 352–361.
41. Intrigliolo, D.S.; Castel, J.R. Effects of Irrigation on the Performance of Grapevine cv. Tempranillo in Requena. *Am. J. Enol. Vitic.* **2008**, *59*, 30–38.
42. Van Leeuwen, C.; Tregoat, O.; Choné, X.; Bois, B.; Pernet, D.; Gaudillère, J.-P. Vine water status is a key factor in grape ripening and vintage quality for red bordeaux wine. How can it be assessed for vineyard management purposes? *J. Int. Sci. Vigne Vin*. **2009**, *43*, 121–134.
43. Hawker, J.S. Effect of temperature on lipid, starch and enzymes of starch metabolism in grape, tomato and broad bean-leaves. *Phytochemistry* **1982**, *21*, 33–36.
44. De Orduña, R. Climate change associated effects on grape and wine quality and production. *Food Res. Int.* **2010**, *43*, 1844–1855.
45. Huglin, P.; Schneider, C. *Biologie et Ecologie de la Vigne*; Tec & Doc Lavoisier: Commune, France, 1998.
46. Kriedemann, P.; Smart, R. Effect of irradiance, temperature and leaf water potential on photosynthesis of vine leaves. *Photosynthetica* **1971**, *5*, 6–15.
47. Coombe, B. Influence of temperature on composition and quality of grapes. In *ISHS Acta Horticulturae*, Proceedings of the International Symposium on Grapevine Canopy and Vigor Management, Davis, CA, USA, 14 August 1986; Volume XXII IHC, pp. 23–35.
48. Keller, M. Managing grapevines to optimise fruit development in a challenging environment: A climate change primer for viticulturists. *Aust. J. Grape Wine Res.* **2009**, *16*, 56–69.
49. Keller, M. *The Science of Grapevines: Anatomy and Physiology*; Academic Press: New York, NY, USA, 2010.
50. García-Martín, N.; Perez-Magariño, S.; Ortega-Heras, M.; González-Huerta, C.; Mihnea, M.; González-Sanjosé, M.L.; Palacio, L.; Prádanos, P.; Hernández, A. Sugar reduction in musts with nanofiltration membranes to obtain low alcohol-content wines. *Sep. Purif. Technol.* **2010**, *76*, 158–170.
51. Castellarin, S.; Matthews, M.; Gaspero, G.; Gambetta, G. Water deficits accelerate ripening and induce changes in gene expression regulating flavonoid biosynthesis in grape berries. *Planta* **2007**, *227*, 101–112.

52. Berli, F.J.; Moreno, D.; Piccoli, P.; Hespanhol-Viana, L.; Silva, M.F.; Bressan-Smith, R.; Cavagnaro, J.B.; Bottini, R. Abscisic acid is involved in the response of grape (*Vitis vinifera* L.) cv. Malbec leaf tissues to ultraviolet-B radiation by enhancing ultraviolet-absorbing compounds, antioxidant enzymes and membrane sterols. *Plant Cell Environ.* **2010**, *33*, 1–10.
53. Duchêne, E.; Schneider, C. Grapevine and climatic changes: A glance at the situation in Alsace. *Agron. Sustain. Dev.* **2005**, *24*, 93–99.
54. Godden, P.; Gishen M. Trends in the composition of Australian wine. *Aust. N. Z. Wine Ind. J.* **2005**, *20*, 21–46.
55. Glanz, K.; Basil, M.; Maibach, E.; Goldberg, J.; Snyder, D. Why Americans eat what they do: Taste, nutrition, cost, convenience, and weight control concerns as influences on food consumption. *J. Am. Diet. Assoc*. **1998**, *98*, 1118–1126.
56. Moore, M.; Weiss, S. Reasons for non-drinking among Israeli adolescents of four religions. *Drug Alcohol Depend*. **1995**, *38*, 45–50.
57. Higgs, S.; Stafford, L.D.; Attwood, A.S.; Walker, S.C.; Terry, P. Cues that signal the alcohol content of a beverage and their effectiveness at altering drinking rates in young social drinkers. *Alcohol Alcohol*. **2008**, *43*, 630–635.
58. Lanier, S.A.; Hayes, J.E.; Duffy, V.B. Sweet and bitter tastes of alcoholic beverages mediate alcohol intake in of-age undergraduates. *Physiol. Behav.* **2005**, *83*, 821–831.
59. Redondo, N.; Gómez-Martíneza, S.; Marcos, A. Review Article—Sensory attributes of soft drinks and their influence on consumers' preferences. *Food Funct.* **2014**, *5*, 1686–1694.
60. Allen, A.L.; Hayes, J.E.; McGeary, J.E. Polymorphisms in TRPV1 and TAS2Rs associate with sensations from sampled ethanol. *Alcohol. Clin. Exp. Res.* **2014**, *38*, 2550–2560.
61. Bartoshuk, L.M.; Conner, E.; Grubin, D.; Karrer, T.; Kochenbach, K.; Palsco, M.; Snow, D.; Pelchat, M.; Danovski, S. PROP supertasters and the perception of ethyl alcohol. *Chem. Senses* **1993**, *18*, 526–527.
62. Mattes, R.D.; DiMeglio, D. Ethanol perception and ingestion. *Physiol. Behav.* **2001**, *72*, 217–229.
63. Hldavis4. Own Work & Template: Purves, Dale. Taste Receptors and the Transduction of Taste Signals. U.S. National Library of Medicine, n.d. Web. May–June 2015. Licensed under CC BY-SA 4.0 via Wikimedia Commons. Available online: https://commons.wikimedia.org/wiki/File:Signal_Transaction_of_Taste;_Bitter.svg#/media/File:Signal_Transaction_of_Taste;_Bitter.svg (accessed on 20 June 2015).
64. Wooding, S.; Kim, U.K.; Bamshad, M.J.; Larsen, J.; Jorde, L.B.; Drayna, D. Natural Selection and Molecular Evolution in PTC, a Bitter-Taste Receptor Gene. *Am. J. Hum. Genet.* **2004**, *74*, 637–646.
65. Drayna, D.; Coon, H.; Kim, U.K.; Elsner, T.; Cromer, K.; Otterud, B.; Baird, L.; Peiffer, A.P.; Leppert, M. Genetic analysis of a complex trait in the Utah Genetic Reference Project: A major locus for PTC taste ability on chromosome 7q and a secondary locus on chromosome 16p. *Hum. Genet*. **2003**, *112*, 567–572.
66. Kim, U.K.; Jorgenson, E.; Coon, H.; Leppert, M.; Risch, N.; Drayna, D. Positional cloning of the human quantitative trait locus underlying taste sensitivity to phenylthiocarbamide. *Science* **2003**, *299*, 1221–1225.

67. Duffy, V.B.; Davidson, A.C.; Kidd, J.R.; Kidd, K.K.; Speed, W.C.; Pakstis, A.J.; Reed, D.R.; Snyder, D.J.; Bartoshuk, L.M. Bitter receptor gene (TAS2R38), 6-*n*-propylthiouracil (PROP) bitterness and alcohol intake. *Alcohol. Clin. Exp. Res.* **2004**, *28*, 1629–1637.
68. Dotson, C.D.; Wallace, M.R.; Bartoshuk, L.M.; Logan, H.L. Variation in the gene TAS2R13 is associated with differences in alcohol consumption in patients with head and neck cancer. *Chem. Senses* **2012**, *37*, 737–744.
69. Tominaga, M.; Caterina, M.J.; Malmberg, A.B.; Rosen, T.A.; Gilbert, H.; Skinner, K.; Raumann, B.E.; Basbaum, A.I.; Julius, D. The cloned capsaicin receptor integrates multiple pain-producing stimuli. *Neuron* **1998**, *21*, 531–543.
70. Caterina, M.J.; Rosen, T.A.; Tominaga, M.; Brake, A.J.; Julius, D. A capsaicin-receptor homologue with a high threshold for noxious heat. *Nature* **1999**, *398*, 436–441.
71. Trevisani, M.; Smart, D.; Gunthorpe, M.J.; Tognetto, M.; Barbieri, M.; Campi, B.; Amadesi, S.; Gray, J.; Jerman, J.C.; Brough, S.J.; *et al*. Ethanol elicits and potentiates nociceptor responses via the vanilloid receptor-1. *Nat. Neurosci.* **2002**, *5*, 546–551.
72. Blednov, Y.; Harris, R. Deletion of vanilloid receptor (TRPV1) in mice alters behavioral effects of ethanol. *Neuropharmacology* **2009**, *56*, 814–820.
73. Ferraro, F.M.; Hill, K.G.; Kaczmarek, H.J.; Coonfield, D.L.; Kiefer, S.W. Naltrexone modifies the palatability of basic tastes and alcohol in outbred male rats. *Alcohol* **2002**, *27*, 107–114.
74. Mennella, J.A. The transfer of alcohol to human milk: Sensory implications and effects on mother-infant interaction. In *Alcohol and Alcoholism: Brain and Development*; Spear, N.E., Spear, L.P., Hanningan, J.H., Goodlett, C.R., Eds.; Erlbaum: Hillsdale, NJ, USA, 1999; pp. 177–198.
75. Molina, J.C.; Domínguez, H.D.; López, M.F.; Pepino, M.Y.; Faas, A.E. The role of fetal and infantile experience with alcohol in later recognition and acceptance patterns of the drug. In *Alcohol and Alcoholism: Brain and Development*; Spear, N.E., Spear, L.P., Hanningan, J.H., Goodlett, C.R., Eds.; Erlbaum: Hillsdale, NJ, USA, 1999; pp. 199–228.
76. Buck, L.; Axel, R. A novel multigene family may encode odourant receptors: A molecular basis for odour recognition. *Cell* **1991**, *65*, 175–187.
77. Menco, B.P.; Morrison, E.E. Morphology of the mammalian olfactory epithelium: Form, fine structure, function, and pathology. In *Handbook of Olfaction and Gustation*; Doty, R., Ed.; Marcel Dekker: New York, NY, USA, 2003; pp. 17–49.
78. Caterina, M.J.; Schumacher, M.A.; Tominaga, M.; Rosen, T.A.; Levine, J.D.; Julius, D. The capsaicin receptor: A heat-activated ion channel in the pain pathway. *Nature* **1997**, *389*, 816–824.
79. Li, X.; Staszewski, L.; Xu, H.; Durick, K.; Zoller, M.; Adler, E. Human receptors for sweet and umami taste. *Proc. Natl. Acad. Sci. USA* **2002**, *99*, 4692–4696.
80. Nelson, G.; Hoon, M.A.; Chandrashekar, J.; Zhang, Y.; Ryba, N.J.; Zuker, C.S. Mammalian sweet taste receptors. *Cell* **2001**, *106*, 381–390.
81. Nelson, G.; Chandrashekar, J.; Hoon, M.A.; Feng, L.; Zhao, G.; Ryba, N.J.; Zuker, C.S. An amino-acid taste receptor. *Nature* **2002**, *416*, 199–202.
82. Margolskee, R.F. Molecular mechanisms of taste transduction. *Pure Appl. Chem.* **2002**, *74*, 1125–1133.
83. Gawel, R.; van sluyter, S.; Waters, E.J. The effects of ethanol and glycerol on the body and other sensory characteristics of Riesling wines. *Aust. J. Grape Wine Res.* **2007**, *13*, 38–45.

84. Gawel, R. The use of language by trained and untrained experienced wine tasters. *J. Sens. Stud.* **1997**, *12*, 267–284.
85. Amerine, M.A.; Roessler, E.B. *Wines: Their Sensory Evaluation*; Freeman, W.H., Ed.; W. H. Freeman & Co.: San Francisco, CA, USA, 1983.
86. Nurgel, C.; Pickering, G. Contribution of glycerol, ethanol and sugar to the perception of viscosity and density elicited by model white wines. *J. Texture Stud.* **2005**, *36*, 303–325.
87. Guth, H.; Sies, A. Flavour of wines: Towards an understanding by reconstitution experiments and an analysis of ethanol's effect on odour activity of key components. In Proceedings of the Eleventh Australian Wine Industry Technical Conference, Adelaide, Australia, 7–11 October 2001; Australian Wine Industry Technical Conference Inc.: Adelaide, Australia, 2002; pp. 128–139.
88. Scinska, A.; Koros, E.; Habrat, B.; Kukwa, A.; Kostowski, W.; Bienkowski, P. Bitter and sweet components of ethanol taste in humans. *Drug Alcohol Depend*. **2000**, *60*, 199–206.
89. Joshi, V.K.; Sandhu, D.K. Influence of Ethanol Concentration, Addition of Spices Extract, and Level of Sweetness on Physico-chemical Characteristics and Sensory Quality of Apple Vermouth. *Braz. Arch. Biol. Technol.* **2000**, *43*, 537–545.
90. Noble, A.C. Why Do Wines Taste Bitter and Feel Astringent? In *Chemistry of Wine Flavour*; Waterhouse, A.L., Ebeler, S.E., Eds.; American Chemical Society: Washington, DC, USA, 1998; pp. 156–165.
91. Conibear, H. Rising alcohol levels in wine—Is this a cause for concern? *AIM Dig.* **2006**, *18*, 1–17.
92. Pickering, G.J. Low- and Reduced-alcohol Wine: A Review. *J. Wine Res*. **2000**, *11*, 129–144.
93. Meillon, S.; Viala, D.; Medel, M.; Urbano, C.; Guillot, G.; Schlich, P. Impact of partial alcohol reduction in Syrah wine on perceived complexity and temporality of sensations and link with preference. *Food Qual. Preference* **2010**, *21*, 732–740.
94. Kontoudakis, N.; Esteruelas, M.; Fort, F.; Canals, J.M.; Zamora, F. Use of unripe grapes harvested during cluster thinning as a method for reducing alcohol content and pH of wine. *Aust. J. Grape Wine Res.* **2011**, *17*, 230–238.
95. Casassa, L.F.; Beaver, C.W.; Mireles, M.; Larsen, R.C.; Hopfer, H.; Heymann, H.; Harbertson, J.F. Influence of Fruit Maturity, Maceration Length, and Ethanol Amount on Chemical and Sensory Properties of Merlot Wines. *Am. J. Enol. Vitic.* **2013**, *64*, 437–449
96. Moutounet, M.; Bes, M.; Escudier, J. Las tecnologías de elaboración de vinos con bajo nivel de etanol. Available online: http://www.acenologia.com/ciencia84.htm (accessed on 30 October 2015)
97. Massot, A.; Mietton-Peuchot, M.; Peuchot, C.; Milisic, V. Nanofiltration and reverse osmosis in winemaking. *Desalination* **2008**, *231*, 283–289.
98. King, E.S.; Dunn, R.L.; Heymann, H. The influence of alcohol on the sensory perception of red wines. *Food Qual. Preference* **2013**, *28*, 235–243.
99. Escudero, A.; Campo, E.; Fariña, L.; Cacho, J.; Ferreira, V. Analytical Characterization of the Aroma of Five Premium Red Wines. Insights into the Role of Odour Families and the Concept of Fruitiness of Wines. *J. Agric. Food Chem.* **2007**, *55*, 4501–4510.
100. Bisson, L.F. Stuck and sluggish fermentations. *Am. J. Enol. Vitic.* **1999**, *50*, 107–119.

101. Harbertson, J.F.; Mireles, M.S.; Harwood, E.D.; Weller, K.M.; Ross, C.F. Chemical and Sensory Effects of Saignée, Water Addition, and Extended Maceration on High Brix Must. *Am. J. Enol. Vitic.* **2009**, *60*, 450–460.
102. Quirós, M.; Rojas, V.; Gonzalez, R.; Morales, P. Selection of non-*Saccharomyces* yeast strains for reducing alcohol levels in wine by sugar respiration. *Int. J. Food Microbiol*. **2014**, *181*, 85–91.
103. Tamang, J.P.; Fleet, G.H. Yeasts diversity in fermented foods and beverages. In *Yeast Biotechnology: Diversity and Applications*; Satyanarayana, T., Kunze, G., Eds.; Springer: Dordrecht, The Netherlands, 2009; pp. 169–198.
104. Tilloy, V.; Cadiére, A.; Ehsani, M.; Dequin, S. Microbiological strategies to reduce alcohol levels in wines. In *Wine*; Alcohol Level Reduction in Wine; Oenoviti International: Bordeaux, France, 2013; pp. 29–32.
105. Kutyna, D.R.; Varela, C.; Henschke, P.A.; Chambers, P.J.; Stanley, G.A. Microbiological approaches to lowering ethanol concentration in wine. *Trends Food Sci. Technol.* **2010**, *21*, 293–302.
106. Diban, N.; Athes, V.; Bes, M.; Souchon, I. Ethanol and aroma compounds transfer study for partial dealcoholisation of wine using membrane contactor. *J. Membrane Sci*. **2008**, *311*, 136–146.
107. Catarino, M.; Mendes, A.; Madeira, L.M.; Ferreira, A. Alcohol removal from beer by reverse osmosis. *Sep. Sci. Technol.* **2007**, *42*, 3011–3027.
108. Meillon, S.; Urbano, C.; Guillot, G.; Schlich, P. Acceptability of partially dealcoholized wines—Measuring the impact of sensory and information cues on overall liking in real-life settings. *Food Qual. Preference* **2010**, *21*, 763–773.
109. Commission Regulation (EC) No. 606/2009 of 10 July 2009. Laying Down Certain Detailed Rules for Implementing Council Regulation (EC) No 479/2008 as Regards the Categories of Grapevine Products, Oenological Practices and the Applicable Restrictions. Available online: http://faolex.fao.org/docs/pdf/eur88930.pdf (accessed on 28 October 2015).
110. Commission Regulation (EU) No. 144/2013 of February 19. Amending Regulation (EC) No 606/2009 as Regards Certain Oenological Practices and the Applicable Restrictions and Regulation (EC) No 436/2009 as Regards the Registering of These Practices in the Documents Accompanying Consignments of Wine Products and the Wine Sector Registers to be Kept. Available online: http://faolex.fao.org/docs/pdf/eur120800.pdf (accessed on 28 October 2015).
111. Organisation Internationale de la Vigne et du Vin (OIV). *Codex Oenologique International*; Resolution OIV-ECO 433-2012; Organisation International de la Vigne et du Vin: Paris, France, 2012.
112. Organisation Internationale de la Vigne et du Vin (OIV). *Codex Oenologique International*; Resolution OIV-OENO 394A-2012; Organisation International de la Vigne et du Vin: Paris, France, 2012.
113. Gil, M.; Estévez, S.; Kontoudakis, N.; Fort, F.; Canals, J.M.; Zamora, F. Influence of partial dealcoholization by reverse osmosis on red wine composition and sensory characteristics. *Eur. Food Res. Technol.* **2013**, *237*, 481–488.
114. Liguori, L.; Russo, P.; Albanese, D.; di Matteo, M. Evolution of quality parameters during red wine dealcoholization by osmotic distillation. *Food Chem.* **2013**, *140*, 68–75.

115. King, E.S.; Heymann, H. The effect of reduced alcohol on the sensory profiles and consumer preferences of white wine. *J. Sens. Stud.* **2014**, *29*, 33–42.
116. Lisanti, M.T.; Gambuti, A.; Piombino, P.; Pessina, R.; Moio, L. Sensory study on partial dealcoholization of wine by osmotic distillation process. *Bull. OIV* **2011**, *84*, 95–105.

© 2015 by the authors; licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/4.0/).