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Review

Wine Minerality and Funkiness: Blending the Two Tales of the Same Story

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Abstract: In wines, minerality is a complex concept with increasing popularity in scientific research and the wine press. The flavour conceptual space of mineral wines comprises sulphur-reduced aromas, such as flint, wet stone or chalk associated with freshness and lingering mouth perceptions. Professionals do not consider the perception of sulphur-reduced flavours as an off-flavour. Indeed, this sort of reduction is a cue for the recognition of minerality under a likely top-down mental process. However, untrained consumers perceive these aromas as unpleasant. This different qualitative assessment hampers the communication between professionals and amateurs. This review aimed to describe the perceptions of minerality by experts and novices to promote their mutual understanding. Funkiness is proposed as a descriptor of mineral wines when tasted by unexperienced consumers. The chemical basis of minerality and winemaking options were explored to understand their implications on sensory perception. Mineral flavours have two main features. The first comprises ephemeral aromas that may be described as funky, given their association with sulphur-reduced molecules. The second is linked to the fresh and vivacious lingering mouthfeel perceptions that remain after the reductive aromas vanish. Consumers recognise this dual perception by demonstrating positive emotional responses of surprise during tasting. Then, the perception of minerality is a question of cognition and not of particularly developed sensory skills. Appropriate tasting approaches encompassing emotional responses and emergent properties (e.g., harmony, depth, persistence, complexity) appear essential to understand the nature of wine minerality and to determine when it may be regarded as a surrogate for fine wine quality.

Keywords: fine wines; minerality; funky flavours; olfactory conceptual spaces; consumer preferences; wine education

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1. Introduction

The utilisation of minerality as a sensory character of wines is relatively recent but it has been subjected to an increasing interest among wine sensory researchers [1]. The French noun "minéralité" only began to be mentioned in most French wine lexicons from 1988 [2]. However, it has been used in a philosophical essay first published in 1945 [3], showing its early recognition as a metaphor to describe certain wine styles. Presently, the Anglophone wine press has fostered its popularity becoming almost a mandatory descriptor of high-quality white wines [2,4]. Minerality even seems to be more frequently quoted than oaky, fruity [4] or terroir [2], probably resulting from a change in the fashionable metaphors used by influencers to describe high-quality wines [5].

Minerality has been used as an illustration of the European wine character [6] while its association with the praised terroir concept contributed to the wrong assumption that soil minerals absorbed by the plant may have a sensory impact in wines [7–9]. In particular, Chablis PDO (Burgundy, France) has been regarded as the most celebrated example of a region where minerality may be attained by winemakers irrespective of the mode of production [1]. This descriptor is more commonly ascribed to fine white wines, but it can also be present in reds and mass-produced wines [10].

Recent research has shown that the origin of minerality should be associated with sulphur-reduced molecules that seem to appear in higher concentrations in cooler climate regions, less ripened grapes and under higher sulphur dioxide usage [10,11]. The perception of these reduced molecules elicits flavour descriptors, such as rotten eggs, sulphur or stink that are not regarded as off-flavours by winemakers or experts, when present in low concentrations [1]. The perception of mineral wines by consumers has been relatively less studied [2]. It is noteworthy that experts or consumers did not associate the sulphur-reduced character to unpleasant flavours [4]. Contrarily, when tasted blind, first growth Chablis white wines or Burgundy red wines have been associated either with disliked flavours, leading to unpleasant emotional responses [12], or with the organic mode of production [13].

Given these different quality implications of minerality, it would be interesting to look for the possible causes of such opposite behaviours in the best interest of all involved in wine appreciation. Therefore, the aims of this review were (a) to compare the sensory and emotional reactions elicited by mineral fine wines by experts and consumers, and (b) to propose a tasting approach aimed at the rapid recognition of these wines by consumers. Hopefully, the present review will contribute to a better understanding of the minerality concept among wine professionals and consumers.

2. The Sensory Conceptual Space of Mineral Wines

The development of "olfactory conceptual spaces" to explore the similarities between diverse groups of wines has been successfully addressed for variety profiling [14,15], aged wine [16] and regional characterisation [17]. This approach has just been theoretically corroborated through the definition of "local conceptual spaces" [18]. Similarly, ill-defined concepts, such as "green" wines, have also been characterised [19]. Minerality should also be regarded as an ill-defined sensory concept, despite the apparent consistency emerging from verbal definitions by experts [20]. Moreover, dedicated research has also published descriptors that mineral wines should not have. This fact facilitates the task of identifying mineral wines by clarifying the limits between mineral and non-mineral wines, thus minimising the occasional fuzziness of boundary delimitation [21].

When minerality was not commonly used among experts, Chablis wines were described as being lean, austere and having weak aromas resembling flint or match struck [4]. Indeed, minerality is still minimally used by experts or trained panellists when they are not asked about it. According to Ballester et al. [20], wine professionals prefer to use terms globally related to reduction (e.g., reductive, cabbage, sulphur, cardboard, wet dog, wet mop or undergrowth). Thus, the definition of the sensory conceptual space should include all these descriptors.

In addition to aroma perceptions, minerality has also been associated with acidity/sourness, salinity and some bitterness, eliciting a sensation of freshness, tension and vivacity in the mouth [4]. Then, the sensory conceptual space of minerality is not limited to olfaction but also includes contributions from taste and mouth-feel perceptions.

The descriptions summarised in Table 1 enable a broad sensory representation of minerality, despite the differences in minerality description accountable to wine origin, grape varieties, tasting methodology or taster cultural background.

Table 1. Definition of the minerality sensory conceptual space based on wine tastings.

Type of Wine	Aroma		Taste and Mouthfeel		Reference
	Positive Contribution	Negative Contribution	Positive Contribution	Negative Contribution	
Sixteen Chardonnay wines from Burgundy	Gunflint, flint, iodine, less fruit, stone, wet stone, shellfish, chalky, austere aromas, flower, smoke, sea, honey, reductive, sulphur	-	Acidity, freshness, salty Tension, complexity, salivating, ripeness, dryness	-	[14]
Chardonnay, Riesling, Pinot gris, Sauvignon blanc from several countries	Citrus, fresh, wet stone, chemical aromas, reduced chalky, grassy	Butter, butterscotch, vanilla, oak aromas, barrel, caramel, honey, juicy fruit, musty and cat pee aromas	Acidity	-	[22]
Eight Sauvignon blanc from France and eight from New Zealand	Citrus, iodine, flint/smoky, chalk/calcareous, lead/graphite, sulphide	Passionfruit, sweet	Bitter, sour Fresh/zingy, concentration/weight	Astringency, sweet	[23]
Eight Chablis 1er Cru, four from each bank of the Serein river (one year old in bottle, stainless steel winemaking)	Gunflint, sulphur, wood, freshness/mint	Floral, spicy, sweet, yellow/tropical, undergrowth	-	-	[11]
Eleven white wines (a) and six red wines (b)	Empyreumatic, oxidation, plant-chlorophyll	Oak	-	-	[10]
(a) With oak aging and no malolactic fermentation: Riesling (Mosel, Austria), Sauvignon blanc (Loire), Godello, Treixadura, Xarello and Garnacha gris (Spain), Ribolla (Slovenia)	-	-	Sweetness by sugar and alcohol, acidity, freshness by acidity, body (weight), bitterness	Tannin (concentration), depth, balance	
(b) With oak aging and malolactic fermentation: Blaufrankisch (Austria), Syrah and Poulsard (France), Tinta del País, Granacha/Syrah and Syrah (Spain)	-	-	Alcohol (warmth), tannin (concentration), tannin (oak origin), depth, taste persistence	Acidity, freshness by acidity, tannin (astringency)	
One mineral white (Riesling, Mosel), one non-mineral white (Sauvignon blanc, Rueda)	Pencil lead, flint, slate, earthy, rock stone, chalk/plaster, nuts, gunpowder	White pulp fruit, citrus, tropical fruit, vegetal	Saline, high acidity	Freshness	[24]

Occasional variances in the descriptions may also result from vocabulary idiosyncrasies [22] or from the dissimilar saliency of certain aroma perceptions by experts [25]. These sensory driven features appear to be well consolidated among wine professionals since the same results may be attained when: (a) minerality is one among the other flavour descriptors [26], and (b) the conceptual characterisation is performed without tasting [23,27–29]. Then, by gathering overall positive and negative contributors, it is possible to organise a flavour wheel to illustrate the conceptual sensory space of minerality (Figure 1). This tool may be used as the base for developing tasting scripts by the specialised media and educational programs based on memorisation skills, as explained by Honoré-Chedozeau et al. [30]. The representative scripts provided by these authors were obtained by tasting with dark glasses without colour descriptions, which coincidently do not appear relevant for the definition of minerality as well.

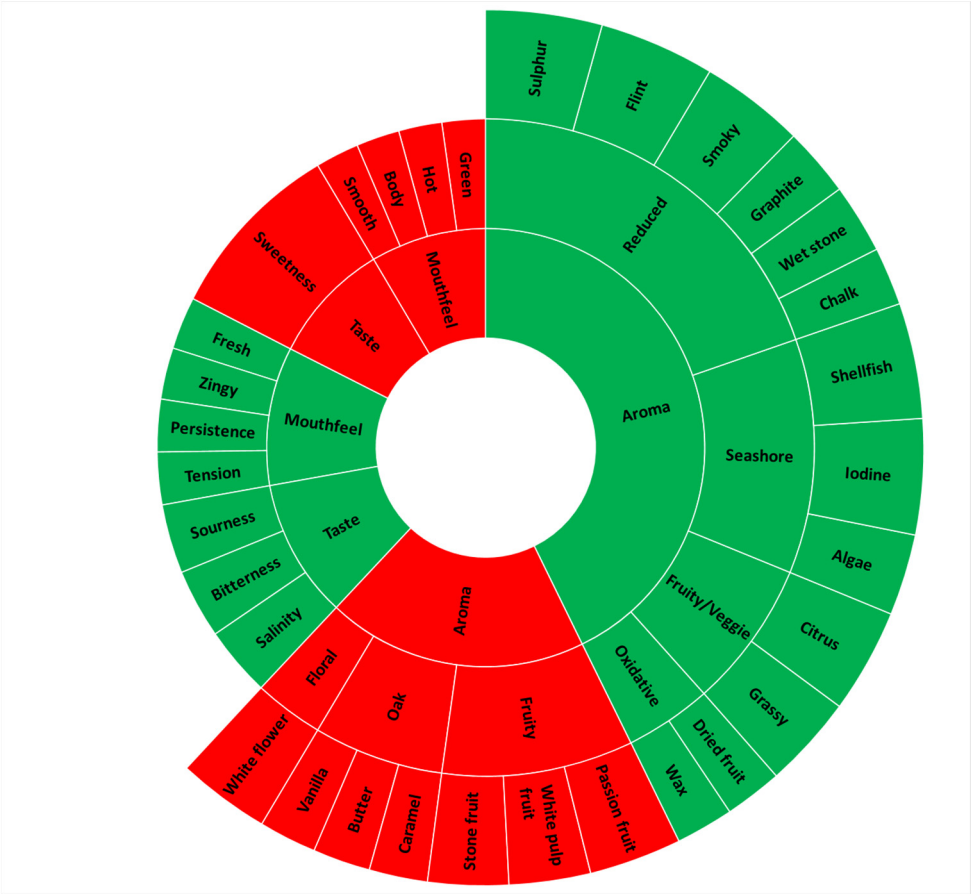

Figure 1. Proposal for a flavour wheel comprising most frequent positive (green) and negative (red) sensory descriptors for mineral white wines retrieved from references listed in Table 1.

3. The Physical–Chemical Basis of Minerality and Technological Implications

Parr et al. [4] recently reviewed the association of minerality perception with the physical–chemical wine composition. Moreover, winemaking technological options to promote minerality should also be consistent with both wine composition and the desired sensory outcome. Some of these relations highlight the consistency of the concept but occasional divergences among wine professionals may also be explained as described below.

3.1. The Ephemeral Reductive Aromas

The perception of reductive flavours clearly indicates that sulphur-reduced molecules should have a major role in minerality (see Table 1). Their reactivity and changes after bottling hamper the determination of the precise role of each molecule. Among these molecules, benzenemethanethiol (benzylmercaptan or BMT) elicited a flinty/smoky aroma in Sauvignon blanc wines [31], being added to wine matrixes to mimic the flinty/mineral/smoky percepts [32,33]. Later, Capone et al. [34] found a correlation between BMT and the perception of flint and wet stone notes in Australian Chardonnay. Similarly, hydrogen disulfanes and hydrogen trisulfanes were shown to contribute to flint in dry mineral white wine [35]. These molecules may be linked to both microbiological or chemical based reactions (including after bottling), releasing hydrogen sulphide (H_2S) and its mercaptan derivatives (e.g., methanethiol, ethanethiol) [36].

Seashore odours, although perceptually different from reduced aromas, may also have a similar origin. Rodrigues et al. [11] associated methanethiol with shellfish/chalky attributes. Later, Rodrigues et al. [1] described the odour of methanethiol as reminiscent of shellfish aroma. Interestingly, these aroma perceptions may also be associated with

the iodine off-flavour induced by a non-sulphur molecule (2-bromo-4-methylphenol). This molecule contributes to the smells described as seafood, iodine, chemical, plastic, chlorine, mouldy, mushroom, earth, rubber, burnt, pharmaceutical, mineral (chalk), and wet [37], which may also be found in mineral wines. Thus, it remains to be seen if 2-bromo-4-methylphenol may also be associated with minerality.

The specific character of fruitiness appears as a hallmark of minerality. While tropical, white and stone fruit aromas have negative impact, citrusy and grassy descriptors are regarded as typical. Non-sulphur molecules, such as ethyl esters and acetates, are well-known elicitors of fruitiness in non-mineral wines [38]. However, these fruitiness labels may also be linked to sulphur-reduced molecules (e.g., 2-furfurylthiol, 4-methyl-4-mercapto-2-pentanone, 3-mercaptohexyl acetate, 3-mercaptohexanol, BMT) that, even at low concentration, contribute to the fruity, fresh and green notes of white wines [39].

The empyreumatic notes described by Santamaría et al. [10] may add other sulphur-reduced compounds to the mineral character in the case of red wines. Indeed, dimethyl sulphide (DMS), 2-furanmethanethiol, and 3-sulfanylhexanol were shown to contribute to five key aromatic notes (undergrowth, truffle, fresh fruit, toasted, and empyreumatic) of red fine Bordeaux wines [16].

Contrary to the previous observations, Parr et al. [23,28] reported that volatile sulphur molecules did not elicit a higher minerality perception. These different results may be explained by the possible simultaneous identification of oxidised aromas [10] highlighting the difficulty in defining minerality when reductive ephemeral aromas are at stake.

3.2. The Persistence of Flavour Freshness

Mineral wines are consistently associated with a sensation of freshness encompassing citrusy aromas, acid or sour taste, and synthetic mouthfeel descriptors, such as zingy, zesty or vivacious (see Table 1). This sort of tension felt on the palate is popularly compared to the sensation of licking a battery. The formerly described reductive character contributes to this sensation but due to its ephemeral nature, this freshness sensation should depend more on the palate perception. Then, the association of minerality with the acidity measured by the titratable acidity (mainly tartaric, malic and lactic acids) or the pH is predictable [20,22]. In addition, succinic acid, or disodium succinate, is thought to add a salty or bitter perception [7,20], which would justify the use of umami as a taste linked to mineral wines. Minor acids, such as octanoic acid, were also associated with minerality [10]. However, lactate and succinate may also be associated with barrel and butterscotch/butter/caramel attributes [23] which are regarded as negative descriptors of minerality. These authors also reported sourness/acid taste as a negative descriptor of minerality further confirmed by Parr et al. [28]. Similarly, Santamaria et al. [24] reported citrus aroma and freshness as negative descriptors of minerality in white wines.

The mineral character of Sauvignon blanc is diminished by the perception of green and sourness in this variety [40]. Potentially, the unexpected mention of freshness as a negative descriptor by Santamaría et al. [24] was associated with the fresh character of Riesling and Sauvignon blanc used in the study because the same authors reported high acidity as a positive descriptor. In addition, sweetness is not indicative of minerality [23] but was reported as such by Santamaría et al. [10]. These authors posited that the sweet perception may not hinder minerality when wines are very acid, like in off-dry (5–7 g/L residual sugar) Rieslings from cool regions. Overall, the perception of minerality in relation to acidity depends on the wine, being more evident on low aromatic varieties, such as the Chardonnay from Burgundy, than on the exuberant New Zealand Sauvignon blanc [23]. The unexpected results of Parr et al. [28], showing that volatile thiols were not found to be negative descriptors and BMT was not a positive descriptor, can probably be explained by the strong varietal character of Sauvignon blanc. These results may also have a cultural explanation since New Zealand experts always reported equal or higher minerality scores than their French counterparts for the same wines [28].

Overall, the contradictory outcomes previously summarised demonstrate the difficulty to predict the minerality concept based on tasting contrarily to the broad conceptual agreement among experts.

3.3. The Influence of Origin and Technological Operations

The main indicators of minerality are reduced molecules and mouthfeel sensations derived from the acid fraction of wines. Then, cooler climates and reductive winemaking should be the main contributors to minerality together with the utilisation of odourless grape varieties.

The association of reduction with cooler climates may explain the positive impact of malic acid on minerality [20], while poorer nitrogen levels induce an increase in succinic acid [7]. These features are consistent with avoiding excessive ripening that would further promote the unwanted round/fatty/rich perceptions [1] and likely depend on soil, vintage and regional climate [26]. Even within one region (Chablis), orthonasal minerality is associated with the left bank of the Serein river with less sun exposure [11].

The utilisation of sulphur dioxide influences the redox status, thus affecting the production of reductive aromas being a descriptor of perceived minerality [22,28]. Copper diminishes reduced-sulphur volatiles [41] and may be used to lower reduced aromas to acceptable levels [1]. The negative influence of aromas of passion fruit and green explain why Sauvignon blanc or other wines with this fruity character are not associated with minerality [40]. Then, it is understandable to avoid low fermentation temperatures (<18 °C) or specific enzyme preparations (e.g., β-glucosidases) to prevent excessive fruity notes of this kind. Chablis winemakers also limit oak usage and lees contact to avoid oaky notes and fattiness masking minerality and keep the wine in a slightly reduced state to preserve shellfish aromas [1]. Indeed, when oak and buttery/creamy notes dominate Chablis (Chardonnay), it tends to be perceived as less mineral than wines from Riesling, Pinot Gris or Sauvignon blanc [22].

The use of technical cork closures or screw caps by affecting the accumulation of reduced molecules [42] may also have a positive influence on the perception of mineral flavours. However, the closure by itself should not be a factor determining minerality. Then, the mouthfeel sensations of tension and persistence appear to be more appropriate to evidence proper minerality when reductive flavours are due to bottle closures.

4. Minerality as an Aesthetic Wine Property

The perception of minerality is a multimodal flavour construct by gathering olfaction, taste and touch perceptions. Then, it should not be regarded as an analytic wine property, but has a synthetic/holistic one by comprising a wide diversity of sensations [43]. Moreover, given its association with fine wine quality, it might be appropriate to consider minerality as an emergent property with an aesthetic value [44]. Indeed, the categorisation of wine flavours in different families, although requiring individual analytic expertise, has not an aesthetic value in itself [25]. The overall characteristics of mineral wines may be consistent with those features that aesthetic objects should have, such as vagueness (e.g., presence of characteristics difficult to assess), being a moving target (e.g., evolve with time) and richness (e.g., valorisation of properties beyond a physical object) [44]. However, the use of emergent properties is relatively rare when addressing minerality, which is somewhat surprising given its association with fine wine quality. Indeed, only a small number of French-speaking wine professionals associated minerality with elegance, finesse or subtlety [2]. These authors also found a higher citation of the terms balance and complexity associated with the concept of terroir, but the overwhelming sensory mental associations were linked to analytic flavour descriptors [2].

When a sensory concept, such as minerality, is perceived differently in the same wines by different cohorts of wine professionals [2,4], it is not surprising that their responses might show some inconsistencies. We speculate that the difficulty in separating preference and familiarity from aesthetic judgements may explain the inconsistencies among professionals

in the definition of mineral wines. For instance, while Chablis producers aim for a lean character [1], Parr et al. [23] found that concentration/palate weight were good descriptors of Sauvignon blanc minerality while reductive flavours and sourness were not. Indeed, as previously described, the likely dominance of tropical fruits, body and lack of acidity is not consistent with minerality. In this case, the individual preference for Sauvignon blanc might have driven experts to associate it with the praised minerality descriptor. This behaviour was further evidenced by the assessment of two French wines that had been described as complex in the sorting task by New Zealand participants but not by French participants [23]. Given that these two wines were also described as faulty, this result suggests that New Zealand and French participants differed in the way that they evaluated complexity in relation to wines perceived as faulty.

Interestingly, Santamaría et al. [10] did not find an association of minerality with reduction probably because tasters considered it as a fault while fruity/floral aromas were reliably associated to non-mineral white wines. Moreover, in white wines, fine wine features, such as depth and balance, were considered as negative minerality descriptors [10]. These authors also used red wines and found that minerality was associated with higher ethanol (feeling of warmth in the mouth), tannin concentration and lack of acidity/freshness, which are not consistent with the concept of minerality. We speculate that the preference for these sensory features consistent with gold-awarded red wines [45] explains the inconsistency. For these experts, red wines with the highest perceived quality were "mineral" because it is a descriptor attached to fine wines, blurring the recognition of superior emergent properties (e.g., harmony, complexity). This sort of behaviour has already been described for other fine red wines [43].

Finally, the aesthetic expertise requires that wine experts should be able to make a proper judgment and have communication intelligibility to provide an explanation understandable by others [44], either wine professionals or unexperienced consumers.

5. Tasting Reduced Mineral Wines with Consumers

Among wine professionals that perceive the mineral reductive flavour profile, it is easy to communicate what the concept is. However, the problem comes when consumers, by recognising the unpleasantness of off-flavours, tend to find these wines obnoxious [46], or when experts associate occasional non-familiar reductive flavours to dirtiness. This opposed behaviour may be explained by the different odour brain processing, given that cognition affects perception. Indeed, while experts recognising typical mineral flavours rely on top-down processing, unexperienced subjects (both novices and experts not familiarised with the reductive aroma) depend on bottom-up processing, as illustrated in Figure 2 [43]. Overall, both experts and novices are able to recognize the same sensory conceptual space of mineral wines but with different quality inferences. Therefore, the problem of misunderstanding between both taster segments is not of perception but of cognition justifying the development of suitable educational tasting approaches to widen the range of perceived quality.

The understanding of mineral wines by consumers may be performed simply by showing the labels. The tasting of a Chablis Grand Cru under this condition would hardly elicit reactions of unpleasantness by consumers, happy to appreciate one of the most praised world white wines. This behaviour may be explained by the emotional nature of olfaction [48], where the sensory perception is heightened by the value of the object subjected to appraisal [49]. Indeed, an online survey asking 1697 French wine consumers about minerality did not mention the utilisation of devaluing descriptors and 217 defined it as consistently as experts [29]. Even, the use of "earthy" or "earthy taste" by 173 of these consumers did not appear to convey a negative connotation. However, informed tasting does not seem appropriate to perform in educational programs where wines are supposed to be assessed without label information. In this case, the approach should take in consideration the most likely reactions of disgust expressed by amateurs when tasting mineral wines dominated by reduced flavours.

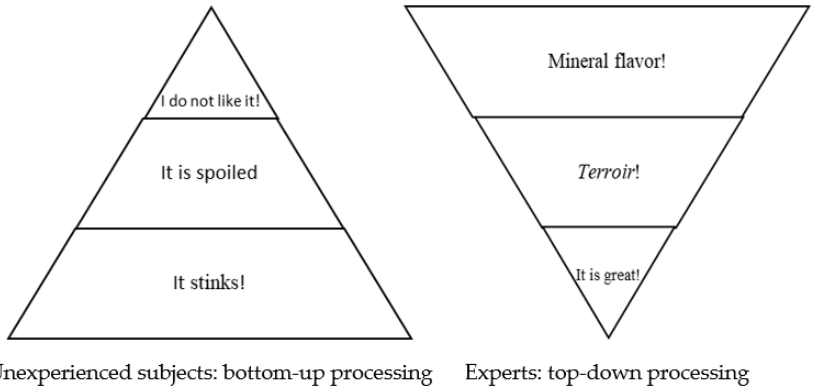

Figure 2. Hypothetical interpretation of a "mineral" white wine by experts or unexperienced subjects (novices or experts unaware of the reductive character) (adapted from Malfeito-Ferreira and Loureiro [47]).

The responses usually given by consumers to reduced mineral wines are shown in Table 2. The inclusion of a wine with fruity/flowery pleasant aromas and sweetish mouthfeel, in opposition to the mineral wine, is advised because the brain is very efficient in flavour discrimination contrarily to flavour identification [50]. This learning process using opposite poles seems to be very effective among consumers [51]. In addition, the method relies on the different emotional responses elicited by both wine styles [11,46]. When, at the end of the tasting, the labels are disclosed the surprise effect leads the brain to quickly find an explanation that should be given by the educator. Ultimately, the experience becomes memorable and wine unpleasantness will not be readily taken as spoilage on subsequent occasions.

The choice of mineral wines with reductive character usually recognised in Chablis PDO is essential for this purpose. According to our experience, non-reduced mineral wines dominated by freshness and acidity are not so unanimously found as unpleasant, thus reducing the mentioned surprise effect. This poses a problem because: (a) reductive phenomena may not be an indication of minerality, and (b) the typical minerality in Chardonnay may not correspond to the minerality in other grape varieties. The first case is illustrated by the increasing use of inert bottle closures (e.g., screw-cap, DIAM®) that has occurred concurrently with an increased use of the term mineral to describe wine, as explained by Parr et al. [4]. The latter case corresponds to our empirical observations when experts taste mineral wines with flavour profiles different from those they are familiar with. In both situations, the recognition of fine wine minerality should be based on the perception of emergent features, such as persistence, harmony, depth or complexity, that consumers accomplish when the wines are correctly chosen [11,46].

The existence of off-flavours in wines is not pursued by winemakers nor consciously appreciated by critics. Nevertheless, consumers correctly describe the reductive odours of mineral wines as obnoxious (see Table 2). Indeed, the molecules responsible for these odours are frequently reported in other environments where the malodorous odour labels make perfect sense [52–55]. However, the possibility to use "stinky" or "defective" to describe mineral wines by consumers or unfamiliarised experts does not seem suitable because it does not reflect the quality beyond the initial detection of off-flavours. Then, the proposal is to use "funky" because it is a metaphor with a dual sense. Here, the perception of unusual flavours does not lead automatically to product rejection but may hinder the discovery of particular wines. Interestingly, this adjective has been used to describe the volatiles produced by a wide diversity of fungal species, including cases that are related to wine, such as the mouldy smell elicited by geosmin [56]. Similarly, Bouchez and De Vuyst [57] described the desirable activities of acetic acid bacteria as imparting complexity and funkiness to sour beers.

Table 2. Examples of informal responses given by untrained consumers when tasting fruity attractive wines in comparison to mineral wines during educational workshops.

Characteristics	Attractive Wines		Mineral Wines	
	White	Red	White	Red
Visual	Beautiful yellow-green colour	Deep in colour. There's a big wine coming!	Yellow, it should be oxidized Hopeless	Open colour, it seems a "piquette" Hopeless
Odour intensity	Intense, fantastic, attractive, high expectation	Intense, fantastic, attractive, high expectation	Discreet, it stinks! Spoilt!	Discreet, it stinks! Spoilt!
Dominating odour	"Sweet" smell (fruity, flowery)	"Sweet" smell (dark or ripe fruit)	Stinky, awful, baby diapers, dirty socks, funky, urine, rotten eggs, latrine!	Stinky, rotten, mouldy, pungent!
Evolution	Stable	Stable	Improves!	Improves!
Expectation for the mouth	High	High	Low	Low
Sensation after tasting	Deception	Deception	Surprise	Surprise
Dominant perception	It is gone!	It is gone!	It is tasty!	It is tasty!
Mouth sensation	Sweet	Sweet	Acid	Acid
Overall appreciation	Soft, warm	Soft, warm	Irritating, cold	Irritating, cold
Reassessment	Good!	Good!	Aggressive, rough	Aggressive, rough
	High	High	Low	Low
	The wine smells and tastes to the same	The wine smells and tastes to the same	It improved! It is another wine!	It improved! It is another wine!
	Simple, short, and smooth	Simple, short, and smooth	Complex, persistent and vibrant	Complex, persistent and vibrant
Conclusions	Easy to understand and drink	Easy to understand and drink	It requires learning and time	It requires learning and time

Funkiness: The Metaphorical Sensory Space of Mineral Wines for Consumers

In wines, the use of funky appears to be restricted to popular online wine press mostly related to the natural wine movement. Furthermore, wine professionals are familiar with its meaning even if they have different views on its appropriateness to describe wines (see, for instance, https://vinepair.com/articles/funky-wine/, accessed on 30 October 2022). This recent trend related to the organic mode of production (e.g., natural, biodynamic, vegan, gluten-free, sulphite-free) has triggered an apparent higher leniency of popular press regarding the concomitant occasional faults (e.g., mousiness, volatile acidity, horse sweat) [58]. Indeed, just like the sound from vinyl records may be more appealing [59], wines with somewhat "dirty" flavours may be more appreciated. Actually, Romano et al. [13] showed that organic wines (red or white) were not depreciated by the unpleasantness driven by off-flavours. In the case of a commercial Chablis Premier Cru Montée de Tonnerre 2013, when labelled "organic", there was (a) a significant decrease in the frequency of citation of the "reductive" flavour family, and (b) a significant increase in the "freshness" family. In parallel, the tasted Pinot Noir AOC Burgundy 2015 showed a tendency to be more "animal/undergrowth" under the organic label. Tasters did not use the mineral attribute, but the descriptors were consistent with those of mineral wines from Burgundy. These observations showed that unpleasantness induced by the perception of off-flavours might not be an obstacle for wine appreciation, thus justifying the use of funkiness as a metaphor to describe mineral wines to consumers.

6. Limitations and Future Directions

The main limitation that should be addressed by future research is the proper determination of fine wine quality when in the presence of mineral reductive aromas. Due to top-down processing, experts may use these easily recognised aromatic features to conclude on the mineral character and infer higher fine wine quality. This inference may not be correct thus, requiring further studies because of the following three main observations:

6.1. The localisation of the Grand Crus Vineyards in Chablis

According to Rodrigues et al. [11], the wines from the left bank of the Serein river elicited higher orthonasal perception of minerality that was correlated with higher methanethiol and lower copper contents. However, the Grand Crus and some of the most highly rated Premiers Crus (Mont de Milieu, Montée de Tonnerre, Fourchaume) are located on the right bank, over southwest facing slopes with higher sun exposure and relatively less prone to reduction. Indeed, increasing temperatures during ripening season appear to

underlie the observed higher quality scores given by critics since 1991, being a notable case where climate change exerted a beneficial effect [60]. These right bank wines showed higher levels of norisoprenoids (β-damascenone, β-ionone and α-ionone) consistent with their higher floral and white fruit character [10] that would likely diminish the perception of minerality. Then, one should admit that minerality had relatively little relevance when the appellation grades were established and should not be solely regarded as a surrogate for fine wine quality assessment.

6.2. Critics Ratings and Descriptions

Contrary to the relatively scarce hedonic evaluation of mineral wines by experts in research studies, critics are expected to publish their liking scores. Even without scientific validation, these outputs and accompanying descriptions may be used as an empirical measure of fine wine quality, as exemplified by Heymann et al. [22] and Parr et al. [23] to select mineral wines. Moreover, the wines assessed by critics are among the most expensive Grand Cru or Premier Cru exemplars which are not usually tasted under scientific frameworks. As an example, the information retrieved from an auction company (https://www.klwines.com, accessed on 30 October 2022), shows that the most valued Chablis crus (both in price and scores) are not dominated by reductive notes, being commonly praised with references to flowery, oaky and liquorice notes, duly associated with mentions of freshness, acidity salinity and persistence. It would be interesting to have these wines tasted under laboratory conditions and compare the critics' descriptions with those of sensory researchers.

6.3. Recognition of Unusual Reductive Flavours

The preponderance of Chardonnay from Burgundy in educational programs to demonstrate minerality poses a difficulty when tasting mineral wines from other regions, colours (e.g., rosé, red, orange), or types (e.g., blends, sparkling and fortified wines) that may have different reductive flavours. In this case, experts tend to associate these flavours with a flaw and not with minerality. This makes little sense because if minerality is associated with a region, or a terroir, it should be equally perceived regardless of wine colour or type. Future research should include wines with these unfamiliar flavours, but that are consistent with the ephemeral nature of reductive aromas, to validate the association of minerality with a particular terroir.

The clarification of these observations demands for the application of adequate sensory methodologies. The fact that minerality may be better distinguished orthonasally [20] indicates that mouth perception is critical to judge the wines as a whole. The ephemeral nature of reductive aromas [61] strongly advises the use of approaches that take into account the unfolding of different flavours with time. For instance, approaches, such as temporal dominance of sensations [62–64], would give time to the disappearance of reductive notes and facilitate the perception of fine wine emergent qualities, such as complexity, harmony, depth or persistence. Further, these techniques are particularly suited to the study of red wines where minerality has barely been addressed.

7. Conclusions

The present market trend to valorise freshness in opposition to sweetish fruitiness, or austere acidic wines in opposition to full-body smooth wines, favours the recognition of minerality among consumers. However, the easy dissemination of wrong concepts by some of the popular online or written press is a challenge for sensory research when addressing the issue of mineral wines. The role of those involved in wine education should be, beforehand, to rule out any direct link to the absorption of minerals from the soil through the plant and into the wine. Keeping an open mind on research evolution, present evidence shows the primary role of sulphur molecules on minerality perception by imparting reduced odours. The easiness of their detection by experts or consumers is a necessary condition but does not suffice to recognise a fine mineral wine because one may

be in the presence of off-flavours. Thus, the ephemeral nature of these flavours and the constancy of synthetic and emergent properties (e.g., freshness, persistence, harmony or complexity) should be properly addressed in future research. In this way, it will be possible to clarify when the perception of minerality may be regarded as an indicator of superior fine wine quality. The utilisation of emotional reactions has the advantage of making this recognition quite swift, being easy to implement by professionals when explaining mineral fine wines to consumers. In this way, the apparent divergences in minerality appreciation by experts and amateurs may be promptly dissipated for the benefit of all that enjoy the pleasure of fine wine consumption.

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References

1. Rodrigues, H.; Valentin, D.; Otheguy, M.; Ballester, J. How to make a mineral wine? Relationship between production type in the Chablis vineyard and the search for a mineral wine style. *OENO One* **2022**, *56*, 29–45. [CrossRef]
2. Deneulin, P.; Bavaud, F. Analyses of open-ended questions by renormalized associativities and textual networks: A study of perception of minerality in wine. *Food Qual. Prefer.* **2016**, *47*, 34–44. [CrossRef]
3. Hamvas, B. *The Philosophy of Wine*; Sherwood, P., Translator; Medio Kiadó: Budapest, Hungary, 2016; p. 64.
4. Parr, W.; Maltman, A.; Easton, S.; Ballester, J. Minerality in wine: Towards the reality behind the myths. *Beverages* **2018**, *4*, 77. [CrossRef]
5. Temmerman, R. Verbalizing sensory experience for marketing success: The case of the wine descriptor minerality and the product name smoothie. *Terminology* **2017**, *23*, 132–154. [CrossRef]
6. Green, J.A.; Parr, W.; Breitmeyer, J.; Valentin, D.; Sherlock, R. Sensory and chemical characterization of Sauvignon Blanc wine: Influence of source of origin. *Food Res. Int.* **2011**, *44*, 2788–2797. [CrossRef]
7. Baroň, M.; Fiala, J. Chasing after minerality, relationship to yeast nutritional stress and succinic acid production. *Czech. J. Food Sci.* **2012**, *30*, 188–193. [CrossRef]
8. Maltman, A. Minerality in wine: A geological perspective. *J. Wine Res.* **2013**, *24*, 169–181. [CrossRef]
9. Matthews, M. *Terroir and Other Myths of Winegrowing*; University of California Press: Oakland, CA, USA, 2016; pp. 175–185.
10. Santamaría, E.Z.; Dagá, D.M.; Palacios-García, A.T. Statistical modelization of the descriptor "minerality" based on the sensory properties and chemical composition of wine. *Beverages* **2019**, *5*, 66. [CrossRef]
11. Rodrigues, H.; Sáenz-Navajas, M.P.; Franco-Luesma, E.; Valentin, D.; Fernández-Zurbano, P.; Ferreira, V.; Ballester, J. Sensory and chemical drivers of wine minerality aroma: An application to Chablis wines. *Food Chem.* **2017**, *230*, 553–562. [CrossRef]
12. Souza-Coutinho, M.; Brasil, R.; Souza, C.; Sousa, P.; Malfeito-Ferreira, M. Consumers associate high-quality (fine) wines with complexity, persistence, and unpleasant emotional responses. *Foods* **2020**, *9*, 452. [CrossRef]
13. Romano, M.; Chandra, M.; Harutyunyan, M.; Savian, T.; Villegas, C.; Minim, V.; Malfeito-Ferreira, M. Off-flavours and unpleasantness are cues for the recognition and valorization of organic wines by experienced tasters. *Foods* **2020**, *9*, 105. [CrossRef] [PubMed]
14. Ballester, J.; Dacremont, C.; Le Fur, Y.; Etiévant, P. The role of olfaction in the elaboration and use of the Chardonnay wine concept. *Food Qual. Pref.* **2005**, *16*, 351–359. [CrossRef]
15. Schüttler, A.; Friedel, M.; Jung, R.; Rauhut, D.; Darriet, P. Characterizing aromatic typicality of Riesling wines: Merging volatile compositional and sensory aspects. *Food Res. Int.* **2015**, *69*, 26–37. [CrossRef]

16. Picard, M.; Thibon, C.; Redon, P.; Darriet, P.; De Revel, G.; Marchand, S. Involvement of dimethyl sulfide and several polyfunctional thiols in the aromatic expression of the aging bouquet of red Bordeaux wines. *J. Agric. Food Chem.* **2015**, *63*, 8879–8889. [CrossRef]
17. Kustos, M.; Gambetta, J.M.; Jeffery, D.W.; Heymann, H.; Goodman, S.; Bastian, S.E. A matter of place: Sensory and chemical characterisation of fine australian chardonnay and shiraz wines of provenance. *Food Res. Int.* **2020**, *130*, 108903. [CrossRef] [PubMed]
18. Jraissati, Y.; Deroy, O. Categorizing smells: A localist approach. *Cogn. Sci.* **2021**, *45*, e12930. [CrossRef] [PubMed]
19. Sáenz-Navajas, M.P.; Arias-Pérez, I.; Ferrero-Del-Teso, S.; Escudero, A.; Ferreira, V.; Fernández-Zurbano, P.; Valentin, D. Access to wine experts' long-term memory to decipher an ill-defined sensory concept: The case of green red wine. *OENO One* **2021**, *55*, 69–79. [CrossRef]
20. Ballester, J.; Mihnea, M.; Peyron, D.; Valentin, D. Exploring minerality of Burgundy Chardonnay wines: A sensory approach with wine experts and trained panellists. *Aust. J. Grape Wine Res.* **2013**, *19*, 140–152. [CrossRef]
21. Jaffré, J.; Valentin, D.; Meunier, J.; Siliani, A.; Bertuccioli, M.; Le Fur, Y. The chardonnay wine olfactory concept revisited: A stable core of volatile compounds, and fuzzy boundaries. *Food Res. Int.* **2011**, *44*, 456–464. [CrossRef]
22. Heymann, H.; Hopfer, H.; Bershaw, D. An exploration of the perception of minerality in white wines by projective mapping and descriptive analysis. *J. Sens. Stud.* **2014**, *29*, 1–13. [CrossRef]
23. Parr, W.V.; Ballester, J.; Peyron, D.; Grose, C.; Valentin, D. Perceived minerality in sauvignon wines: Influence of culture and perception mode. *Food Qual. Prefer.* **2015**, *41*, 121–132. [CrossRef]
24. Santamaría, E.Z.; Dagá, D.M.; Palacios-García, A.T. The Influence of the bottle's price and label reported information on the perception of the minerality attribute in white wines. *Beverages* **2022**, *8*, 42. [CrossRef]
25. Barwich, A.S. Up the nose of the beholder? Aesthetic perception in olfaction as a decision-making process. *New Ideas Psych.* **2017**, *47*, 157–165. [CrossRef]
26. Willwerth, J.J.; Reynolds, A.G.; Lesschaeve, I. Sensory analysis of Riesling wines from different sub-appellations in the Niagara Peninsula in Ontario. *Am. J. Enol. Vitic.* **2015**, *66*, 279–293. [CrossRef]
27. Rodrigues, H.; Ballester, J.; Saenz-Navajas, M.P.; Valentin, D. Structural approach of social representation: Application to the concept of wine minerality in experts and consumers. *Food Qual. Pref.* **2015**, *46*, 166–172. [CrossRef]
28. Parr, W.V.; Valentin, D.; Breitmeyer, J.; Peyron, D.; Darriet, P.; Sherlock, R.; Ballester, J. Perceived minerality in sauvignon blanc wine: Chemical reality or cultural construct? *Food Res. Int.* **2016**, *87*, 168–179. [CrossRef]
29. Deneulin, P.; Le Fur, Y.; Bavaud, F. Study of the polysemic term of minerality in wine: Segmentation of consumers based on their textual responses to an open-ended survey. *Food Res. Int.* **2016**, *90*, 288–297. [CrossRef]
30. Honoré-Chedozeau, C.; Chollet, S.; Lelièvre-Desmas, M.; Ballester, J.; Valentin, D. From perceptual to conceptual categorization of wines: What is the effect of expertise? *Food Qual. Pref.* **2020**, *80*, 103806. [CrossRef]
31. Tominaga, T.; Guimbertau, G.; Dubourdieu, D. Contribution of benzenemethanethiol to smoky aroma of certain *Vitis vinifera* L. wines. *J. Agric. Food Chem.* **2003**, *51*, 1373–1376. [CrossRef]
32. Lund, C.M.; Thompson, M.K.; Benkwitz, F.; Wohler, M.W.; Triggs, C.M.; Gardner, R.; Heymann, H.; Nicolau, L. New zealand sauvignon blanc distinct flavor characteristics: Sensory, chemical, and consumer aspects. *Am. J. Enol. Vitic.* **2009**, *60*, 1–12. [CrossRef]
33. Parr, W.V.; Valentin, D.; Green, J.; Dacremont, C. Evaluation of French and New Zealand sauvignon wines by experienced french wine assessors. *Food Qual. Pref.* **2010**, *21*, 56–64. [CrossRef]
34. Capone, D.L.; Barker, A.; Williamson, P.O.; Francis, I.L. The role of potent thiols in Chardonnay wine aroma. *Aust. J. Grape Wine Res.* **2017**, *24*, 38–50. [CrossRef]
35. Starkenmann, C.; Chappuis, C.J.; Niclass, Y.; Deneulin, P. Identification of hydrogen disulfanes and hydrogen trisulfanes in H_2S bottle, in flint, and in dry mineral white wine. *J. Agric. Food Chem.* **2016**, *64*, 9033–9040. [CrossRef]
36. Müller, N.; Rauhut, D.; Tarasov, A. Sulfane sulfur compounds as source of reappearance of reductive off-odors in wine. *Fermentation* **2022**, *8*, 53. [CrossRef]
37. Barbe, J.; Tempere, S.; Riquier, L.; Lytra, G.; Marchand, S.; De Revel, G. 2-bromo-4-methylphenol, a compound responsible for iodine off-flavor in wines. *J. Agric. Food Chem.* **2014**, *62*, 11620–11627. [CrossRef]
38. González-Álvarez, M.; González-Barreiro, C.; Cancho-Grande, B.; Simal-Gándara, J. Relationships between godello white wine sensory properties and its aromatic fingerprinting obtained by GC-MS. *Food Chem.* **2011**, *129*, 890–898. [CrossRef]
39. Mateo-Vivaracho, L.; Zapata, J.; Cacho, J.; Ferreira, V. Analysis, occurrence, and potential sensory significance of five polyfunctional mercaptans in white wines. *J. Agric. Food Chem.* **2010**, *58*, 10184–10194. [CrossRef]
40. Parr, W.V.; Green, J.A.; White, K.G.; Sherlock, R.R. The distinctive flavour of new zealand sauvignon blanc: Sensory characterisation by wine professionals. *Food Qual. Pref.* **2007**, *18*, 849–861. [CrossRef]
41. Vela, E.; Hernández-Orte, P.; Franco-Luesma, E.; Ferreira, V. The effects of copper fining on the wine content in sulfur off-odors and on their evolution during accelerated anoxic storage. *Food Chem.* **2017**, *231*, 212–221. [CrossRef]
42. Furtado, I.; Lopes, P.; Oliveira, A.; Amaro, F.; Bastos, M.; Cabral, M.; Guedes-de-Pinho, P.; Pinto, J. The impact of different closures on the flavor composition of wines during bottle aging. *Foods* **2021**, *10*, 2070. [CrossRef]
43. Malfeito-Ferreira, M. Fine wine flavour perception and appreciation: Blending neuronal processes, tasting methods and expertise. *Trends Food Sci. Technol.* **2021**, *115*, 332–346. [CrossRef]

44. Burnham, D.; Skilleås, O. *The Aesthetics of Wine*; Wiley-Blackwell: Chichester, UK, 2012; 240p.
45. Malfeito-Ferreira, M.; Diako, C.; Ross, C. Sensory and chemical characteristics of 'dry' wines awarded gold medals in an international wine competition. *J. Wine Res.* **2019**, *30*, 204–219. [CrossRef]
46. Coste, A.; Sousa, P.; Malfeito-Ferreira, M. Wine tasting based on emotional responses: An expedite approach to distinguish between warm and cool climate dry red wine styles. *Food Res. Int.* **2018**, *106*, 11–21. [CrossRef] [PubMed]
47. Malfeito-Ferreira, M.; Loureiro, V. *Mastering the Art of Enjoying Wine, from Enology to Enosophy*; Cambridge Scholars Publishing: Newcastle upon Tyne, UK, 2022; p. 172.
48. Yeshurun, Y.; Sobel, N. An odor is not worth a thousand words: From multidimensional odors to unidimensional odor objects. *Ann. Rev. Psychol.* **2010**, *61*, 219–241. [CrossRef]
49. Skov, M. Aesthetic appreciation: The view from neuroimaging. *Empir. Stud. Arts* **2019**, *37*, 220–248. [CrossRef]
50. Young, B.D. Olfactory imagery: Is exactly what it smells like. *Phil. Stud.* **2020**, *177*, 3303–3327. [CrossRef]
51. Bianchi, I.; Branchini, E.; Torquati, S.; Fermani, A.; Capitani, E.; Barnaba, V.; Savardi, U.; Burro, R. Non experts' understanding of terms frequently used by experts to describe the sensory properties of wine: An investigation based on opposites. *Food Qual. Pref.* **2021**, *92*, 104215. [CrossRef]
52. Hamada, K.; Haruyama, S.; Yamaguchi, T.; Yamamoto, K.; Hiromasa, K.; Yoshioka, M.; Nishio, D.; Nakamura, M. What determines human body odour? *Experim. Dermat.* **2014**, *23*, 316–317. [CrossRef]
53. Lin, J.; Aoll, J.; Niclass, Y.; Velazco, M.; Wünsche, L.; Pika, J.; Starkenmann, C. Qualitative and quantitative analysis of volatile constituents from latrines. *Environ. Sci. Technol.* **2013**, *47*, 7876–7882. [CrossRef]
54. Chappuis, C.J.; Niclass, Y.; Cayeux, I.; Starkenmann, C. Sensory survey of key compounds of toilet malodour in switzerland, india and africa. *Flavour Fragr. J.* **2016**, *31*, 95–100. [CrossRef]
55. Rincón, C.A.; De Guardia, A.; Couvert, A.; Le Roux, S.; Soutrel, I.; Daumoin, M.; Benoist, J.C. Chemical and odor characterization of gas emissions released during composting of solid wastes and digestates. *J. Environ. Manag.* **2019**, *233*, 39–53. [CrossRef] [PubMed]
56. Inamdar, A.A.; Morath, S.; Bennett, J. Fungal volatile organic compounds: More than just a funky smell? *Ann. Rev. Microbiol.* **2020**, *8*, 101–116. [CrossRef]
57. Bouchez, A.; De Vuyst, L. Acetic acid bacteria in sour beer production: Friend or foe? *Front. Microbiol.* **2022**, *13*, 957167. [CrossRef] [PubMed]
58. Pelonnier-Magimel, É.; Mangiorou, P.; Darriet, P.; De Revel, G.; Jourdes, M.; Marchal, A.; Barbe, J. Sensory characterisation of bordeaux red wines produced without added sulfites. *OENO One* **2020**, *54*, 687–697. [CrossRef]
59. Enstroem, R.; Schmaltz, R. Vinyl as fine wine: The role of expectation on the perception of music format. *Front. Psychol.* **2022**, *13*, 873517. [CrossRef] [PubMed]
60. Biss, A.; Ellis, R. Modelling Chablis vintage quality in response to inter-annual variation in weather. *OENO One* **2021**, *55*, 209–228. [CrossRef]
61. Jiménez-Lorenzo, R.; Farines, V.; Sablayrolles, J.; Camarasa, C.; Bloem, A. New insights into the origin of volatile sulfur compounds during wine fermentation and their evolution during aging. *Fermentation* **2022**, *8*, 139. [CrossRef]
62. Sokolowsky, M.; Rosenberger, A.; Fischer, U. Sensory impact of skin contact on white wines characterized by descriptive analysis, time–intensity analysis and temporal dominance of sensations analysis. *Food Qual. Pref.* **2015**, *39*, 285–297. [CrossRef]
63. Correia, E.; Amorim, E.; Vilela, A. Structural Equation Modeling (SEM) and Temporal Dominance of Sensations (TDS) in the evaluation of DOC Douro red Wine's sensory profile. *Foods* **2022**, *11*, 1168. [CrossRef]
64. Wang, Q.J.; Niaura, T.; Kantono, K. How does wine ageing influence perceived complexity? Temporal-Choose-All-That-Apply (TCATA) reveals temporal drivers of complexity in experts and novices. *Food Qual. Pref.* **2021**, *92*, 104230. [CrossRef]