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Review

Impact of Fining Agents on Color, Phenolics, Aroma, and Sensory Properties of Wine: A Review

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Abstract: Fining agents are widely used in the wine industry to improve the quality and stability of wine by removing impurities and unwanted compounds. However, their impact on the color, phenolics, aroma, and sensory properties of wine remains poorly understood. This review aims to provide a comprehensive overview of the effects of fining agents on these critical wine attributes. We examine the role of different fining agents, including gelatin, pea proteins, and potato proteins, in modifying the color and phenolic profile of wine. Additionally, we discussed the impact of fining agents on the sensory properties of wine, including bitterness, astringency, sweetness, aroma and the flavor of wine. Our analysis highlights the importance of considering the origin, dosage, and composition of the wine when selecting fining agents to achieve optimal outcomes. Furthermore, we emphasize the need for preliminary trials and instrumental measurements to ensure the effectiveness of fining agents in different wine matrices. This review provides a valuable resource for winemakers and researchers seeking to optimize the use of fining agents in wine production.

Keywords: wine; fining agents; color; protein; volatiles; phenolics; haze; sensory characteristics

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1. Introduction

The winemaking process requires careful management to ensure a clear, stable, and desirable final product. Fining is the addition to wine of a reactive or an adsorptive substance (in some cases, two and even three fining agents are used simultaneously) to remove (or reduce the concentration of) one or more undesirable constituents. Fining agents, a diverse class of substances, play a key role in achieving these qualities [1,2]. During winemaking and storage, various unwanted substances can lead to issues such as haze formation, off-flavors, and undesirable textures. Proteins, for instance, can precipitate out of solution, causing haze, especially in white wines. This protein haze not only affects the aesthetic appeal but can also alter the sensory experience of the wine. Additionally, phenolic compounds, which contribute to the color, flavor, and mouthfeel of wine, can undergo oxidative reactions leading to browning, bitterness, and astringency. These phenolic oxidations are particularly problematic in red wines, where they can mask the desired fruit flavors and aromatics. Fining agents are added to wine to selectively remove unwanted components that can negatively impact visual clarity, stability, or sensory attributes. By removing these impurities, winemakers ensure that the wine remains visually appealing and sensorially pleasing throughout its shelf life [3].

Traditionally, winemakers have employed various fining agents, each targeting specific compounds for removal. Protein-based fining agents such as gelatin, egg whites, and isinglass have been used to reduce wine tannins and proteins, while bentonite, a clay mineral, is used to remove haze forming proteins, thereby resulting in stability of the wine. Polyvinylpolypyrrolidone (PVPP), a synthetic polymer, effectively reduces phenolic content, thereby mitigating astringency and bitterness [3,4].

While these traditional fining agents are effective, their potential impact on the wine's sensory characteristics has led to the exploration of alternative methods. Crossflow filtration and centrifugation offer physical removal of unwanted particles without introducing chemical additives. However, the degree to which these methods can precisely replicate the specific effects of fining agents on the wine's sensory profile remains an active area of investigation [5,6].

The complex interactions between fining agents and wine components can substantially influence various sensory attributes. Removing or modifying phenolic compounds, for instance, can alter the wine's color, causing shifts in hue or intensity [7,8]. Additionally, the adsorption or alteration of volatile aroma compounds during fining can subtly or significantly impact the aroma profile, potentially diminishing complexity or introducing new aromatic nuances [9,10]. These modifications in color, phenolic content, and aroma collectively shape the wine's overall taste, mouthfeel, and perceived quality.

This review aims to provide a comprehensive and current evaluation of the impact of fining agents on wine quality. By systematically examining existing scientific literature, this study will investigate the mechanisms by which fining agents interact with wine components, clarifying their effects on color, phenolics, aroma compounds, and the overall sensory experience. It will also explore the potential interactions between fining agents and other winemaking variables, such as grape variety and fermentation conditions, to offer a holistic understanding of their role in shaping the final product.

2. Fining Agents

Fining agents in winemaking are widely known for their ability to clarify wines, improve stability, eliminate off-flavors, remove hazardous compounds and pesticide residues, as well as reduce astringency and bitterness by modulating the phenolic composition, particularly in red wine [2,3,11,12]. The most well-known fining agents are categorized as follows based on their common characteristics: (a) earths, such as montmorillonite, bentonite, and kaolinite (also known as "ka-olin"); (b) animal proteins, such as caseins, gelatine (from pork, cow, and fish), egg albumin, and isinglass (from fish); (c) plant proteins, such as wheat gluten, soy, lupine, lupine, garden pea, potatoes, seaweeds, such as spirulina, and grape seeds; (d) wood charcoal (carbons); (e) synthetic polymers, such as polyvinylpolypyrrolidone (PVPP); and (f) silicon dioxide, also known as kieselsol) [2,13]. Table 1 summarizes the characteristics and dosages of different fining agents used in the wine industry.

The most commonly used fining agents in the wine industry are "bentonites" (mainly containing montmorillonite) and proteins that associate with tannins [13,14]. Bentonite is a naturally occurring clay mineral primarily composed of montmorillonite, a type of clay characterized by its laminar structure and exchangeable cations. Montmorillonite consists of platelets formed by aluminum hydrosilicate ($Al_2O_3 \times SiO_2 \times H_2O$). During processes like swelling and adsorption, various cations, including Ca^{2+}, Na^+, and K^+, are intercalated within the interlayer spaces of this structure [15]. Bentonite, containing sodium and calcium ions, carries a negative charge at the pH level of wine. This negative charge allows it to interact electrostatically with the positively charged proteins in wine. These interactions result in the adsorption of wine proteins onto the bentonite surface, leading to flocculation and subsequent removal of the proteins from the wine [7,16]. Protein-based fining agents exhibit varying affinities for different types of phenolic compounds in wine. Initially, proteins interact with these phenolic compounds through hydrogen bonding [17] and hydrophobic interactions, forming soluble complexes. Then, phenolic compounds are removed from the solution by precipitation. This happens either through the self-association of produced complexes or the development of insoluble protein aggregates. These aggregates are created by cross-linkages between proteins, which incorporate the target phenolic compounds [3,18].

Table 1. Summary of fining agents used in winemaking: characteristics and dosages.

Fining Agents	Wine Types	Dosage Range	Characteristics
Bentonite	White	20–100 g/hL	■ Average clarification ■ Treats and prevents protein and copper casse ■ Facilitates racking with proteins ■ Avoids over-fining
	Red	20–50 g/hL	■ Clarification of young wines ■ Eliminates colloidal coloring matter ■ Facilitates sedimentation of protein fining agents
	Rose	30–100 g/hL	■ Remove proteins and improve clarity and stability
Casein	Must and white	10–50 g/hL	■ Good clarification ■ Treats and prevents yellowing (maderization) ■ No over-fining ■ Removes undesirable odors and reduces color of white wines
Isinglass	White	1–2.5 g/hL	■ Good clarity ■ Intensifies yellow color ■ Light flakes, bulky, settles slowly
Siliceous earths	White	20–100 mL/hL	■ Acts on protective colloids in wines that are difficult to clarify ■ Used with protein fining agents, prevents over-fining and facilitates settling of the lees
Gelatins	Red	3–10 g/hL	■ Very good fining agent for tannic wines ■ Affects only the most aggressive tannins and reduces astringency ■ May make wine softer or thinner
Egg white	Red	5–15 g/hL (powder), 3–8 fresh egg whites per barrel (225 L)	■ Very good fining agent for tannic wines with some age ■ Sensitive to protective colloids
Maize zeins	Red	5–25 g/hL	■ No modification to sensorial properties
Grape seed extract	Red and white	5–20 g/hL	■ Could represent a risk to allergic consumers if residues remain in the wine after the fining treatment ■ Desirable effects on wine turbidity, color, oxidative stability ■ Improvement of wine sensory properties
Polyvinylpoly-pyrrolidone (PVPP)	Red,	10–45 g/hL	■ Eliminates odors described as mushroom-like, moldy, camphoric, or earthy in wines ■ Removes bitter compounds and browning precursors in both red and white wines. ■ Modulates the intensity and hue of the pink color and prevent some organoleptic degradation in rosé wine
	Rose´	-	
	White	10–80 g/hL	
Carbon	Juice, red and white	5–200 g/hL	■ Removes off-odors. ■ Effective in color reduction (browning and pinking).
Caseinates	Red and white	5–25 g/hL	■ Prevent oxidative browning in white wines
Legume, soybean, lupine, peanuts and pea protein	Red and white	5–30 g/hL	■ Represent a risk to allergic consumers except pea protein ■ Clarification, removing tannins and reduce astringency in red wines ■ Lower impact on fermentation aroma compounds

Modified table reproduced from [2,13,19–21].

Wine proteins: Proteins are present in low amounts in wines and contribute minimally to their nutritional value. However, white wine proteins significantly affect the transparency and stability of wines, playing a crucial role in haze formation [22,23]. Wine protein instability and haze formation have been linked to two major classes of grape proteins: (i) chitinases, glucanases, and other pathogenesis-related (PR) proteins, which are upregulated in response to disease pressure, and (ii) thaumatin-like proteins (TLPs), which are associated with grape ripening and berry softening [14,24]. These proteins have molecular weights ranging from 21 to 32 kDa [25,26]. In addition to PR proteins, several other factors can promote haze formation in wine: (i) The level of sulfate appears to be the most critical factor. As a kosmo-tropic ion, sulfate has a strong interaction with water that decreases the solubility of proteins in water. Excessive sulfate concentrations promote denaturation and aggregation of proteins [16]. (ii) Higher pH levels facilitate protein aggregation because PR proteins are positively charged at wine pH [16]. (iii) High concentrations of phenolic compounds, including tannins, phenolic acids/esters, and small flavonoids, have been demonstrated to significantly enhance haze formation [27,28]. However, there are several disadvantages to utilizing this fining agent, such as the amount of sediments produced, which can cause considerable wine losses due to their low level of compaction [6]. Additionally, fining agents in wine production can result in the reduction of various volatile, aromatic, and flavor compounds compared to untreated wine. This effect is mainly attributed to their impact on the concentration of varietal thiols [5,29]. The loss of aromas can occur either directly, through adsorption of the aromas to the fining agent, or indirectly, where aromas are fixed by proteins and, when these proteins are eliminated, they drag with them a proportion of the volatile pool [5,23,29].

3. Impact on Basic Characteristics

The basic characteristics of wine, including its pH, acidity, ethanol content, reducing sugar and sulfur dioxide (SO_2) levels, etc., play a crucial role in determining its overall quality [30]. These factors are significantly influenced by the use of fining agents during the winemaking process, which can alter the chemical composition and sensory attributes of the wine. The effects of different fining agents on the basic characteristics of wine are summarized in Table 2. The addition of 95 g/L of granular-activated sodium bentonite to the white (Malvazija Istarska) wine (post-fermentation) resulted in a decrease in pH from 3.36 to 3.31, while no significant change was observed in alcohol level, total extract, reducing sugar, total acidity, and volatile acidity [31]. Similarly, Wimalasiri et al. [8] observed no significant change in alcohol level, total acidity, or pH while studying the effect of different fining agents, such as sodium (Na) bentonite, calcium (Ca) bentonite, and a combination of sodium and calcium (NaCa) bentonite (0.5 g/L), at the pre-fermentation stage during the production of red (Pinot Noir) wine. In a further study by Cheng and Watrelot [32], red (Marquette) wine was produced from juice treated with sodium–calcium (NaCa) bentonite (1.32 g/L) and bottled in 750 mL green glass bottles. The wine was studied at the bottling stage and after 5 months of aging, with results compared to wine produced without bentonite treatment. At the bottling stage, wine from NaCa-treated juice showed a significant increase in pH and a decrease in malic acid concentration, while total acidity, tartaric acid, and ethanol concentration remained unaffected. After 5 months of aging, there was a slight increase in pH and malic acid, a slight reduction in ethanol and tartaric acid content, and no change in total acidity. The slight increase in pH is attributable to the addition of bentonite, which decreases the amount of H^+ and Na^+ in solution, thereby increasing the wine's pH [33]. On the other hand, Sauvignon Blanc wine treated with 100 g/hL bentonite (Bentogram AEB, San Polo, Italy) showed no significant change in pH, total acidity, volatile acidity, malic acid, lactic acid, or alcohol concentration [6].

Bandić et al. [15] studied the effect of bentonite agents on Sauvignon Blanc wine. After 2 months of storage, the wine was treated with sodium bentonite bentogran (50, 125, and 200 g/hL) and sodium-activated bentonite Ma-jorbenton (100, 200, and 300 g/hL). The fining treatment significantly reduced total acidity in comparison to the untreated wine. However, no significant differences in total acidity were detected among wines treated with varying types and doses of bentonite. Alcohol level, residual sugar, volatile acidity, ash, and free SO_2 were not significantly affected by bentonite treatment. In a further study by Ma et al. [10] on the effects of fining agents on Italian Riesling, it was found that the use of bentonite at a concentration of 1 g/L resulted in significant reductions in several key components of the wine. Specifically, there was a 4.7% decrease in total sugar, a 3.4% reduction in total acidity, and an 11.7% decrease in volatile acidity. In contrast, the application of soybean protein at a concentration of 0.5 g/L did not produce significant changes in total sugar or volatile acidity. However, it did lead to a 2.5% reduction in total acidity.

In a further study, Dumitriu et al. [34] investigated the impact of mesoporous nanomaterials and sodium bentonite on the chemical properties of Pedro Ximénez and Muscat Ottonel white wines. Pedro Ximénez white wine was treated with 100, 115, and 200 g/hL of mesoporous nanomaterials (labelled as Korea Institute of Technology-6 (KIT-6), Santa Barbara Amorphous-15 (SBA-15), and Mobil Composition of Matter-41 (MCM-41)), as well as 115 g/hL of sodium bentonite. Muscat Ottonel wine was treated with 75, 95, and 200 g/hL of mesoporous nanomaterials (KIT-6, SBA-15, and MCM-41) and 95 g/hL of sodium bentonite. In Pedro Ximénez wine, fining treatments resulted in a significant decrease in pH, with the lowest value observed in wine treated with sodium bentonite at 115 g/hL. Titratable acidity also significantly decreased following fining treatments, reaching its lowest level in the sodium bentonite-treated wine, showing a reduction of 9% at the same dosage. Additionally, volatile acidity notably decreased, with the most substantial reduction of 23.5% observed in wine treated with MCM-41 at 115 g/hL. In contrast, Muscat Ottonel wine treated with mesoporous nanomaterials showed no significant change in pH and total acidity. However, bentonite-treated Muscat Ottonel wine exhibited a slightly higher pH and lower titratable acidity. Volatile acidity decreased significantly following fining treatments in Muscat Ottonel wine, although there was no notable difference between samples treated with different dosages or fining agents. The observed decrease in titratable acidity in wines treated with bentonite is likely due to the ability of this agent to exchange cations, particularly Na^+ and Ca^{2+}. This cation exchange can alter the equilibrium of tartaric acid in the wine, leading to the precipitation of calcium tartrate and consequently reducing titratable acidity [34,35]. In further study, Parish et al. [36] observed that different fining treatments (activated carbon at 200/500 mg/L, gelatin at 60/600 mg/L, PVPP at 250/800 mg/L, and a mixture of bentonite, PVPP, and isinglass at 60/120 mg/L for free run and press fraction juices, respectively) did not result in significant changes in the pH, ethanol concentration, titratable acidity, volatile acidity, free SO_2, or total SO_2 of Marlborough Sauvignon Blanc wine. In general, the changes in basic characteristics of wine, including pH, acidity, ethanol content, reducing sugar, and sulfur dioxide (SO_2) levels, during the fining process are influenced by various factors beyond just the type and dosage of the fining agent. These factors include the contact time between the wine and the fining agent, the temperature at which fining is conducted, the initial composition of the wine, as well as the mixing and settling conditions.

Table 2. Key literature findings for the effects of fining on the basic characteristics of wine.

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
White (Malvazija istarska)	Granular-activated sodium bentonite	Post fermentation	95 g/L	▪ No significant change in alcohol level, total extract, reducing sugar, total acidity, and volatile acidity. ▪ pH significantly decreased from 3.36 to 3.31.	[31]
Red (Pinot Noir)	Sodium (Na) bentonite Calcium (Ca) bentonite Sodium and calcium combined (NaCa) bentonite	Pre-fermentation	0.5 g/L	▪ No significant change in alcohol level, total acidity, and pH.	[8]
Red (Marquette)	Sodium-calcium bentonite	Pre-fermentation	1.32 g/L	At bottling: ▪ pH increased ▪ No change in tartaric acid, total acidity and ethanol ▪ Malic significantly decreased At 5 months of aging: ▪ pH and malic acid concentration increased ▪ No change in total acidity ▪ Ethanol and tartaric acid significantly decreased	[32]

Table 2. *Cont.*

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
White (Sauvignon Blanc)	Sodium bentonite Bentogran	After 2 months of storage	50 g/hL	▪ Total acidity and pH significantly decreased, while there were no differences among treated wines independently of the type and dose of bentonite ▪ No significant change in alcohol level, residual sugar, volatile acidity, ash, or free SO_2	[15]
			125 g/hL		
			200 g/hL		
	Sodium-activated bentonite Majorbenton		100 g/hL		
			200 g/hL		
			300 g/hL		
Italian Riesling	Bentonite	Finished wine	1 g/L	▪ Significant reduction in total sugar (−4.7%), total acidity (−3.4%), and volatile acidity (−11.7%)	[10]
	Soybean protein		0.5 g/L	▪ No significant reduction in total sugar or volatile acidity, while total acidity (−2.5%) decreased	
White (Pedro Ximénez)	Mesoporous nanomaterials (SBA-15)	Post fermentation	100 g/hL	▪ pH significantly decreased, and the lowest value was observed for wine treated with sodium bentonite at 115 g/hL. ▪ Titratable acidity significantly decreased with fining treatment, and the lowest value was observed for wine treated with sodium bentonite (−9%) at 115 g/hL. ▪ Volatile acidity significantly decreased with fining treatment, and the lowest value was observed for wine treated with MCM-41 (−23.5%) at 115 g/hL.	[34]
			115 g/hL		
			200 g/hL		
	Mesoporous nanomaterials (KIT-6)		100 g/hL		
			115 g/hL		
			200 g/hL		
	Mesoporous nanomaterials (MCM-41)		100 g/hL		
			115 g/hL		
			200 g/hL		
	Sodium bentonite		115 g/hL		
White (Muscat Ottonel)	Mesoporous nanomaterials (SBA-15)		75 g/hL	▪ No significant change in pH or total acidity value with mesoporous nanomaterials fining agent, while bentonite-treated wine showed a slightly higher pH value and lower titratable acidity. ▪ Volatile acidity significantly decreased with fining treatment, while there was no significant effect between treated wine samples at different dosages and with different fining agents.	
			95 g/hL		
			200 g/hL		
	Mesoporous nanomaterials (KIT-6)		75 g/hL		
			95 g/hL		
			200 g/hL		
	Mesoporous nanomaterials (MCM-41)		75 g/hL		
			95 g/hL		
			200 g/hL		
	Sodium bentonite		95 g/hL		
White (Marlborough Sauvignon Blanc)	Activated carbon	Free run juice	200 mg/L	▪ No significant change in pH, ethanol concentration, titratable acidity, volatile acidity, free SO_2, or total SO_2 in any treated wine compared to untreated wine	[36]
	Gelatin		60 mg/L		
	PVPP		250 mg/L		
	mixture of bentonite, PVPP and isinglass		60 mg/L		
	Activated carbon	Press fraction	500 mg/L		
	Gelatin		600 mg/L		
	PVPP		800 mg/L		
	mixture of bentonite, PVPP and isinglass		120 mg/L		

Pre-fermentation: Addition of fining agents to the juice.

4. Impact on Color and Phenolic Profile

The color and phenolic profile of wine are crucial determinants of its quality. Color intensity, hue, and CIE Lab* parameters define the visual appeal, while phenolic compounds play a crucial role in wine's astringency, bitterness, mouthfeel, and color [3,37,38]. Table 3 summarizes the effects of various fining agents on the color and phenolic profile of wine. Cosme et al. [11] studied the effect of different bentonite fining agents on the quality of red and white wines. The fining agents used were activated carbon (100 g/hL), chitosan (10 g/hL), potassium caseinate (80 g/hL), and bentonite (120 g/hL), applied at the end of the fermentation process. For white wine, the a* value significantly decreased when treated with potassium caseinate, while other fining agents did not affect the a* value. The L* and b* values significantly decreased with the use of activated carbon and bentonite, while chitosan and potassium caseinate did not cause significant changes. White wine treated with activated carbon resulted in a ΔE* value of 4.8, which is perceptible to the human eye, whereas wines treated with other fining agents showed ΔE* values less than 2 [39], which are not perceptible to the human eye. For red wine, color intensity significantly decreased with all fining agents, with the greatest decrease observed in wine treated with bentonite (−13%). Red wine treated with potassium caseinate (ΔE* = 4.17) and bentonite (ΔE* = 4.80) showed ΔE* values higher than 1, which is perceptible to the human eye. The changes in chromatic characteristics of both wines can be explained by the alterations in total phenols, flavonoids, and non-flavonoid phenols after applying the fining agents. In white wines, activated carbon, potassium caseinate, and bentonite decreased the total phenols by 7%, 1.3%, and 2%, respectively. For activated carbon, the reduction in total phenols is attributed to the decrease in flavonoid phenols (3.8%) and non-flavonoid phenols (14.5%). The phenolic acids were removed in higher amounts by activated carbon, potassium caseinate, and bentonite were trans-caftaric and coutaric acids. In red wines, the levels of flavonoids, non-flavonoids, total phenols, and anthocyanins were significantly affected by the fining treatments, with anthocyanins being the most impacted phenolic compounds in the case of bentonite fining. Similarly, Lukić et al. [31] observed a loss in total phenols (−7%) and total flavonoids (−3.1%) in white (Malvazija istarska) wine treated with granular-activated sodium bentonite (95 g/L) after the end of fermentation. The reduction in total phenolic content with bentonite fining might be explained by the fact that bentonite can indirectly reduce phenolic levels by separating proteins that have been complexed with phenolics [17]. In a further study, Lisanti et al. [40] used activated charcoal (20 g/hL), PVPP (80 g/hL), and zeolite (20 g/hL) to decrease the levels of phenolic off-odor compounds, such as 4-ethylphenol (4-EP) and 4-ethylguaiacol (4-EG), in red wine (cv. Aglianico). The results indicated that 4-EG concentration was reduced by 11%, 5.4%, and 6% in wine treated with activated charcoal, PVPP, and zeolite, respectively, while 4-EP concentration was reduced by 18%, 10.5%, and 12.2% in wine treated with activated charcoal, PVPP, and zeolite, respectively. Total polyphenols decreased by 3.8% and 7% with activated charcoal and PVPP treatment, respectively. Total anthocyanins significantly decreased by 11.7% and 12.1% with activated charcoal and PVPP treatment, respectively. The addition of activated charcoal and PVPP significantly reduced the color parameters, such as absorbance at 420, 520, and 620 nm. The variation in the reduction percentage of 4-EP, 4-EG, total polyphenols, and total anthocyanins was due to the differing abilities and adsorbing capacities of the fining agents.

Wimalasiri et al. [8] examined the influence of pre-fermentative bentonite addition on the color and phenolic composition of Pinot noir wine. Three types of bentonites—sodium (Na), calcium (Ca), and a NaCa blend—were introduced at a rate of 0.5 g/L into grape must before a 5-day cold maceration period. Notably, no discernible impact was observed on the hue value or total phenolic concentration. However, a substantial reduction of 10–18% in the total anthocyanin concentration was observed in all wines treated with bentonite compared to the control. In addition, Cheng and Watrelot [32] produced red (Marquette) wine from juice treated with sodium–calcium (NaCa) bentonite (1.32 g/L) and bottled in 750 mL green glass bottles. The wine was studied at the bottling stage and after 5 months of aging, with results compared to wine produced without bentonite treatment. The findings revealed significant increases in hue and color intensity in the bentonite-treated wine at the bottling stage. Conversely, after 5 months of aging, there was a significant increase in hue but a decrease in color intensity. Notably, there were no significant changes observed in total phenolic and tannin concentrations. However, there was a substantial 34% decrease in total anthocyanin concentration in both instances. Furthermore, Saracino et al. [41] investigated the effects of sodium (Na) bentonite and dicarboxymethyl cellulose (DCMS) on the total phenolic index (TPI) of three white wine varieties: Encruzado, Viosinho, and Moscatel. For Encruzado, no significant change in TPI was observed due to bentonite fining across various concentrations (0.5, 1, 1.5, and 2 g/L), while DCMS treatment resulted in a significant reduction in TPI, irrespective of the dose. In Viosinho, bentonite fining at 0.5, 1, and 1.5 g/L did not significantly affect TPI, but a significant reduction was noted at 2 g/L. Similarly, DCMS treatment led to a significant reduction in TPI. For Moscatel, bentonite fining significantly reduced TPI, with no differences observed among the different doses, and DCMS treatment also caused a significant reduction in TPI. These findings highlight that both fining agents can influence phenolic content, with DCMS consistently reducing TPI across all wine varieties and doses, while the effect of bentonite varies depending on the concentration and wine variety.

Arenas et al. [42] investigated the effect of different fining agent on white (Albariño monovarietal) wine quality produced with pre-fermentative skin maceration (+PFSM) and without pre-fermentative skin maceration (−PFSM). Four different amounts of bentonite were added to the finished wine: 100 g/hL fungal chitosan, 120 g/hL of sodium bentonite, 120 g/hL of calcium bentonite, and 100 g/hL of k-carrageenan. For wines with pre-fermentative skin maceration, the application of fungal chitosan, sodium bentonite, and calcium bentonite significantly increased the L* value, indicating a lighter color, while k-carrageenan had no such effect. The absorbance (420 nm) value, which correlates with wine browning, decreased for all fining agents except k-carrageenan. Fungal chitosan and k-carrageenan did not significantly impact the a* value (red/green), whereas sodium and calcium bentonite led to a significant decrease. No significant changes were observed in the b* (yellow/blue) and ΔE* (total color difference) values, nor in total phenolics and non-flavonoid phenols. However, flavonoid phenols slightly decreased with fungal chitosan (−4.5%) and more notably with sodium bentonite (−22.7%). For wines without pre-fermentative skin maceration, fungal chitosan and k-carrageenan again reduced the absorbance (420 nm) value, while the L*, a*, and ΔE* values remained unchanged. There was no significant impact on the b* value by any fining agent except for a decrease observed with fungal chitosan (+21.5%). Total phenolics decreased significantly with all fining agents: fungal chitosan (−11.8%), k-carrageenan (−8.4%), sodium bentonite (−18.6%), and calcium bentonite (−11.8%). Flavonoid phenols remained unaffected by k-carrageenan and fungal chitosan but decreased with calcium bentonite (−9.3%) and sodium bentonite (−18.8%). Non-flavonoid phenols were significantly reduced by all fining agents. Similarly, Ren et al. [43] found that fining agents such as bentonite, gelatin, casein, egg albumin, and PVPP significantly affect the total phenols, color intensity, and antioxidant activity of mulberry wine. Among these agents, gelatin had the most negative impact, resulting in the greatest reductions in total phenols (16.61%), color intensity (32.26%), and antioxidant activity. On the other hand, Italian Riesling wine treated with bentonite showed a 20% and 4.8% decrease in color intensity and total phenolics, respectively, while wine treated with soybean protein showed a 9.5% and 7.5% reduction in color intensity and total phenolics compared to untreated wine [10].

Río Segade et al. [3] studied the effects of different fining agents—animal gelatin (GE), pea protein (PE), and potato protein (PT)—on the phenolic and colorimetric properties of various red wines. The results showed that for Primitivo wine, GE significantly decreased the total phenolic index (A280 nm), particularly at a 25 g/hL dose, resulting in an 8.6% loss. GE also reduced polymeric and oligomeric flavanols (PRO and FRV content) by 10.3 to 13.9% and 2.3%, respectively. In contrast, PE treatment resulted in a PRO reduction of 7.1

to 17.9% and an FRV reduction of 6.6 to 11.1%, while PT treatment led to a PRO reduction of 2.9 to 7.8% with no impact on FRV. Additionally, GE and PE treatments caused notable decreases in total anthocyanins, with GE reducing total anthocyanins by 6.8 to 7% and PE by up to 7.7% at the higher dose. PT had no significant impact on total anthocyanins. Minor decreases in color intensity were observed across treatments without changes in hue. In Montepulciano wine, GE did not significantly impact the total phenolic index but reduced PRO by 12 to 18.9% and FRV by 7 to 17.9%. PE reduced PRO and FRV by 6.7 to 8.9% and 6.9 to 10.8%, respectively, while PT resulted in reductions of 9.5 to 11.6% for PRO and 11.2 to 12.7% for FRV. Total anthocyanin reductions were less pronounced, with GE causing a 3.6 to 6.5% decrease and PE and PT causing up to 2.9% and 6.1% decreases, respectively. GE significantly decreased color intensity by up to 11% without altering hue. For Syrah, GE significantly decreased the total phenolic index, with reductions in PRO of 3.3 to 12.6% and FRV of 4.3 to 9.9%. PE treatments resulted in PRO and FRV reductions of 4.7 to 7.4% and 0.5 to 4%, respectively. PT reduced PRO by 5.1 to 15.3% and FRV by 7.9 to 10%. Total anthocyanins remained unaffected by all treatments, but color intensity decreased significantly, especially with higher doses of GE and PT (19%), without changes in hue. In Nebbiolo, GE significantly decreased the total phenolic index by 8.6% at 25 g/hL. PRO and FRV were reduced by 7.2 to 15.3% and 4.3 to 13.6%, respectively. PE treatment led to similar reductions, while PT reduced PRO by 8.4 to 8.7% and FRV by 3.3 to 7.4%. Total anthocyanins was significantly affected, with PE at high doses causing a 21.5% reduction, GE reducing total anthocyanins by 18.1%, and PT at high doses reducing total anthocyanins significantly. Furthermore, Gil et al. [44] investigated the impact of Polyvinylpolypyrrolidone (PVPP) on the color profile and targeted polyphenomics of commercial rosé wines from the 2015 vintage, sourced from various regions of France. The wines were treated with PVPP fining at a concentration of 80 g/hL. The treatment resulted in an average increase in lightness (L*) by 4%. Conversely, the parameters a*, b*, chroma, and hue exhibited significant average decreases of 24%, 34%, 26%, and 11%, respectively. Additionally, the PVPP treatment led to the adsorption of flavonols, flavanols, and anthocyanins by 42%, 64%, and 12%, respectively. Similarly, Aziz et al. [45] observed that a formulation treatment combining PVPP with bentonite (0.8 g/L) led to an 8% loss in color intensity, a 12% reduction in redness (a*), a 9% decrease in polymeric pigments, and a 9% increase in lightness (L*) in Moroccan Red Press Wine. In general, changes in color and phenolic profile during fining treatments depend on the origin of the phenolic compounds, formulation, dose applied, and also on the studied wine characteristics in terms of phenolic content and profile [46].

Table 3. Key literature findings for the effects of fining on color and phenolic profile of wine.

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
White and red	Activated carbon	Post fermentation	100 g/hL	▪ White wine: color (Abs420 nm), L*, and b* decreased, while a* remained unchanged ▪ White wine: total phenols, flavonoid phenols, and non-flavonoid phenols decreased by 7%, 3.8%, and 14.5%, respectively ▪ Red wine: color intensity decreased, and hue increased, while L*, a* and b* remained unchanged ▪ Red wine: total phenols and flavonoid phenols decreased by 2% and 1.3%, with no significant changes in non-flavonoid phenols	[11]

Table 3. *Cont.*

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
White and red	Chitosan	Post fermentation	10 g/hL	▪ White wine: no significant changes in color (Abs420 nm), L*, a*, or b* ▪ White wine: no significant changes in total phenols, flavonoid phenols, or non-flavonoid phenols ▪ Red wine: color intensity decreased, with no significant changes in Hue, L*, a* or b* ▪ Red wine: no significant changes total phenols or flavonoid phenols, while non-flavonoid phenols decreased by 3%	[11]
	Potassium caseinate	Post fermentation	80 g/hL	▪ White wine: color (Abs420 nm) decreased, while a* and b* decreased; L* remained unchanged ▪ White wine: total phenols and non-flavonoid phenols decreased by 1.3% and 6.3%, with no significant changes in flavonoid phenols ▪ Red wine: color intensity and a* decreased, while L* increased; hue and b* remained unchanged ▪ Red wine: total phenols, flavonoid phenols, and non-flavonoid phenols decreased by 3%, 2.2%, and 7.7%, respectively	
	Bentonite	Post fermentation	120 g/hL	▪ White wine: color (Abs420 nm), L*, and b* decreased, while a* remained unchanged ▪ White wine: total phenols decreased by 2%, with no significant changes in non-flavonoid phenols and flavonoid phenols ▪ Red wine: color intensity, a*, and b* decreased, while hue and L* increased ▪ Red wine: total phenols, flavonoid phenols, and non-flavonoid phenols decreased by 6.2%, 6.5%, and 5.2%, respectively	
Red (Pinot noir)	Sodium (Na) bentonite	Pre-fermentation	0.5 g/L	▪ Color density increased significantly ▪ No significant change in hue value ▪ No significant change in total phenolic concentration. ▪ Total anthocyanin significantly decreased (−10 to −18%), while calcium (Ca) bentonite additions showed highest reduction in total anthocyanin (−18%)	[8]
	Calcium (Ca) bentonite	Pre-fermentation			
	Sodium and calcium combined (NaCa) bentonite	Pre-fermentation			
Red (Marquette)	Sodium–calcium bentonite	Pre-fermentation	1.32 g/L	▪ Hue and color intensity significantly increased in bentonite treated wine at bottling stage ▪ Hue significantly increased, while color intensity decreased in bentonite treated wine at 5 months aging ▪ No significant change in total phenolic and tannin concentration. ▪ Total anthocyanin significantly decreased by 34% in both cases	[32]
White (Malvazija istarska)	Granular-activated sodium bentonite	Post fermentation	95 g/L	▪ Total phenols and total flavonoids decreased by 7% and 3.1%	[31]

Table 3. *Cont.*

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
White (Encruzado)	Sodium (Na) bentonite and Di-carboxymethyl cellulose (DCMS)	Bottling	0.5, 1, 1.5, and 2 g/L	▪ No significant change in the total phenolic index (TPI) due to bentonite fining ▪ Wine treated with DCMS showed a significant reduction in TPI; however, there were no differences among wines treated with different doses of DCMS	[41]
White (Viosinho)				▪ No significant change in the total phenolic index due to bentonite fining at concentrations of 0.5, 1, and 1.5 g/L, while using 2 g/L bentonite showed a significant reduction ▪ Wine treated with DCMS showed a significant reduction in TPI	
White (Moscatel)				▪ Wine treated with bentonite showed a significant reduction in TPI, while there were no differences among wines treated with different doses ▪ Wine treated with DCMS showed a significant reduction in TPI	
White (Albariño monovarietal); With Pre-Fermentative Skin Maceration	Fungal chitosan	Post fermentation	100 g/hL	▪ Abs 420 nm value decreased by fining except k-Carrageenan ▪ Significant increase in L* value of wine treated with fungal chitosan, sodium bentonite, and calcium bentonite, with no change by k-carrageenan ▪ No significant effect on a* value by fungal chitosan and k-carrageenan, while wine treated with Na and Ca showed a significant decrease ▪ No impact on b*, ΔE* value, or total phenolics ▪ No impact on flavonoid phenols by k-carrageenan and Ca bentonite, while it was slightly decreased by fungal chitosan (−4.5%) and Na bentonite (−22.7%) ▪ No significant impact on non-flavonoid phenols by fining, except an increase by Na bentonite (+23.5%)	[42]
	k-carrageenan		100 g/hL		
	Sodium bentonite		120 g/hL		
	Calcium bentonite		120 g/hL		
White (Albariño monovarietal); Without Pre-Fermentative Skin Maceration	Fungal chitosan		100 g/hL	▪ Abs 420 nm value decreased by fining except with k-carrageenan ▪ No significant change in L*, a* or ΔE* value ▪ No significant impact on b* value by fining, except a decrease by fungal chitosan (+21.5%) ▪ Significant decrease in total phenolics; fungal chitosan (−11.8%), k-carrageenan (−8.4%), sodium bentonite (−18.6%), and calcium bentonite (−11.8%) ▪ No impact on flavonoid phenols by k-carrageenan and fungal chitosan, while slightly decreased by Ca bentonite (−9.3%) and Na bentonite (−18.8%) ▪ Significant decreased in non-flavonoid phenols	
	k-carrageenan		100 g/hL		
	Sodium bentonite		120 g/hL		
	Calcium bentonite		120 g/hL		
Italian Riesling	Bentonite	Finished wine	1 g/L	▪ Color intensity and total phenols decreased by 20% and 4.8%, respectively	[10]
	Soybean protein		0.5 g/L	▪ Color intensity and total phenols decreased by 9.54% and 7.5%, respectively	

Table 3. *Cont.*

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
Red (Primitivo)	Animal gelatin (GE)	Finished wine	10 and 25 g/hL	▪ Total phenolic index (A280 nm) significantly decreased, and higher loss was observed at 25 g/hL dose of GE (−8.6%) Polymeric and oligomeric flavanols (PRO and FRV Content); ▪ By GE treatment PRO reduced by 10.3 to 13.9% and FRV reduced by 2.3% ▪ By PE treatment PRO reduced by 7.1 to 17.9% and FRV reduced by 6.6 to 11.1% ▪ By PT Treatment PRO reduced by 2.9 to 7.8% and no effect on FRV Total Anthocyanins (TA); ▪ GE reduced TA by −6.8% and −7% at 10 g/hL and 25 g/hL doses, respectively ▪ PE reduced TA by −7.7% at 18 g/hL and no change at 12 g/hL ▪ No significant impact of PT on TA ▪ Minor decrease was observed in color intensity, while no changes in hue were observed	[3]
	Pea Protein (PE)		12 and 18 g/hL		
	Potato Protein (PT)		10 and 25 g/hL		
Red (Montepulciano)	Animal gelatin (GE)		10 and 25 g/hL	▪ No significant impact on total phenolic index (A280 nm) Polymeric and oligomeric flavanols (PRO and FRV Content) ▪ By GE treatment, PRO reduced by 12 to 18.9% and FRV reduced by 7 to 17.9% ▪ By PE treatment, PRO reduced by 6.7 to 8.9% and FRV reduced by 6.9 to 10.8% ▪ By PT Treatment, PRO reduced by 9.5 to 11.6% and FRV reduced by 11.2 to 12.7% Total Anthocyanins (TA); ▪ GE reduced TA by −3.6% and −6.5% at 10 g/hL and 25 g/hL doses, respectively ▪ PE reduced TA by −1.5% and −2.9% at 18 g/hL and 12 g/hL doses, respectively ▪ PT reduced TA by −2.9% and −6.1% at 10 g/hL and 25 g/hL doses, respectively ▪ Significant decrease in color intensity, and higher loss was observed at 25 g/hL dose of GE (−11%), while no changes in hue were observed	
	Pea Protein (PE)		12 and 18 g/hL		
	Potato Protein (PT)		10 and 25 g/hL		
Red (Syrah)	Animal gelatin (GE)		10 and 25 g/hL	▪ Significant decrease in on total phenolic index (A280 nm) due to fining, while no significant change among treated wines Polymeric and oligomeric flavanols (PRO and FRV Content) ▪ By GE treatment, PRO reduced by 3.3 to 12.6% and FRV reduced by 4.3 to 9.9% ▪ By PE treatment, PRO reduced by 4.7 to 7.4% and FRV reduced by 0.5 to 4% ▪ By PT Treatment, PRO reduced by 5.1 to 15.3% and FRV reduced by 7.9 to 10 ▪ No significant change in total anthocyanins (TA); ▪ Significant decrease in color intensity, and higher loss was observed at 25 g/hL dose of GE and PT (−19%), while no changes in hue were observed	
	Pea Protein (PE)		12 and 18 g/hL		
	Potato Protein (PT)		10 and 25 g/hL		

Table 3. *Cont.*

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
Red (Nebbiolo)	Animal gelatin (GE)	Finished wine	10 and 25 g/hL	▪ Total Phenolic index (A280 nm) significantly decreased, and higher loss was observed at 25 g/hL dose of GE (−8.6%) Polymeric and oligomeric flavanols (PRO and FRV Content) ▪ By GE treatment, PRO reduced by 7.2 to 15.3% and FRV reduced by 4.3 to 13.6% ▪ By PE treatment, PRO reduced by 9.6 to 9.8% and FRV reduced by 7.4 to 10.4% ▪ By PT Treatment, PRO reduced by 8.4 to 8.7% and FRV reduced by 3.3 to 7.4% ▪ Total anthocyanins significantly reduced and PE at 18 g/hL showed higher loss, followed by gelatin at both low and high doses, and PT at high dose (−21.5% for PE at 18 g/hL, −18.1% for GE at 10 and 25 g/hL, and PT at 25 g/hL.) ▪ Minor decrease in color intensity and hue	[3]
	Pea Protein (PE)		12 and 18 g/hL		
	Potato Protein (PT)		10 and 25 g/hL		
Commercial rose‘	PVPP	Finished wine	80 g/hL	▪ Lightness L* increased by 4% ▪ The a* and b* decreased by 24% and 34%, respectively ▪ Chroma and hue decreased by 26% and 11%, respectively ▪ Flavonols, flavanols, and anthocyanins were adsorbed on average by 42%, 64%, and 12%, respectively	[44]

5. Impact on Volatile Profile of Wine

The volatile profile of wine, comprising various aroma and flavor compounds such as esters, alcohols, acids, terpenes, phenols, aldehydes, ketones, norisoprenoids, and lactones, plays a crucial role in determining its sensory characteristics [47,48]. Fining agents, substances added during winemaking to clarify and stabilize wines, can significantly impact this volatile profile, and their effects on the volatile profile are summarized in Table 4. A decrease in volatile compounds, specifically in free alcohols (−8.2%), fatty acids (−28%), acetate esters (−18%), and monoterpenes (−2%), was observed in white (Malvazija istarska) wine following the application of granular-activated sodium bentonite (95 g/L) post-fermentation [31]. The reduction in the concentration of volatile compounds during fining might be due to their adsorption and subsequent precipitation [35]. Furthermore, the addition of different types of bentonite (Na, Ca, and NaCa bentonite) at a concentration of 0.5 g/L prior to fermentation had no significant impact on the aroma profile of red (Pinot Noir) wine, except for a slight reduction in ethyl cinnamate, hexyl acetate, and cis-3-hexenol [8]. Similarly, Muñoz-Castells et al. [49] studied the impact of adding bentonite (5 g/hL) at the pre-fermentation stage on the volatile profile of white (Pedro Ximénez) wine. The results indicated that acetaldehyde and acetoin were significantly reduced by 34% and 35.7%, respectively, in bentonite-treated wines, while no significant impact was observed on diethyl succinate, 2-phenylethanol, and meso-2,3-butanediol. Notably, ethyl acetate (+32.8%), methanol (+25%), isobutanol (+6.8%), 2-methyl-1-butanol (+11.6%), and glycerol (+9.8%) increased.

Ubeda et al. [7] investigated the impact of adding sodium bentonite at different production stages on the volatile profile of sparkling wine (Chardonnay). Bentonite was added at three stages: pre-fermentation (8.5, 12.5, and 17 g/hL), during bottling (8.5, 12.5, and 17 g/hL), and after 9 months of storage (8.5, 12.5, and 17 g/hL). At the pre-fermentation stage, the addition of 8.5 g/hL of bentonite did not result in significant changes in the total esters, alcohols, acids, or terpenes compared to the base wine, although it significantly increased the total norisoprenoids. Higher doses of bentonite (12.5 and 17 g/hL) led to a significant decrease in total esters. During bottling, all wines treated with bentonite showed a significant decrease in total esters, with no significant differences among the different bentonite concentrations. The levels of total alcohols, acids, and terpenes remained unchanged, whereas norisoprenoids significantly increased. After nine months of storage, wines treated with 8.5 and 12.5 g/hL of bentonite exhibited no significant differences in total alcohols and terpenes compared to the base wine. However, the 17 g/hL dose resulted in a significant increase in alcohol content. Additionally, total acids significantly decreased, and norisoprenoids increased in the treated wines. The observed variations in the results likely stem from the timing and dosage of bentonite addition. These differences can be further explained by the complex interactions among volatile compounds, yeast proteins, and bentonite adsorption, which are influenced by their respective electrostatic charges and binding affinities [50]. Bandić et al. [15] examined the effects of different concentrations of sodium bentonite, Bentogran (50, 125, and 200 g/hL), and sodium-activated bentonite, Majorbenton (100, 200, and 300 g/hL), on the aroma profile of two months aged Sauvignon Blanc wine. For Bentogran, at 50 g/hL, total monoterpenes increased by 3% and total C-6 compounds by 32.5%, while total C-13 norisoprenoids decreased significantly by 48.5%. Increasing the concentration to 125 g/hL led to a 4% rise in total monoterpenes and a 31% increase in total C-6 compounds, with a 52.5% decrease in total C-13 norisoprenoids. At the highest concentration of 200 g/hL, total monoterpenes rose by 4.2% and total C-6 compounds by 9.8%, with a 54.1% reduction in total C-13 norisoprenoids. In contrast, for Majorbenton at 100 g/hL, total monoterpenes increased by 1.5% and total C-6 compounds by 44.3%, without significant changes in total C-13 norisoprenoids. At 200 g/hL, total monoterpenes decreased by 4.5%, total C-13 norisoprenoids by 34.4%, and total C-6 compounds increased by 34.8%. At the highest concentration of 300 g/hL, total monoterpenes decreased by 8%, total C-13 norisoprenoids by 41.4%, while total C-6 compounds increased by 32.9%. In further research conducted by Philipp et al. [12], the impact of various fining agents on the volatile composition of white (Gruener Veltliner 2018) and red (Zweigelt 2018) wines were evaluated. This study utilized various fining agents at different concentrations, including Absolut Wein (0.6 g/L), Reskue (0.6 g/L), Grandeco (1 g/L), NaCalit (1 g/L), CarboTec GE (1 g/L), Purity D (0.5 g/L), Granucol GE (0.2 g/L), and Flowpure (2 g/L). In the case of white wine, the addition of fining agents led to a significant decrease in free monoterpenes, with the exception of CarboTec GE and Reskue. The most substantial reduction, amounting to 28%, was observed in wines treated with Grandeco (Dal Cin, Milan, Italy). Monoterpenes are aromatic compounds naturally present in grapes and wines, contributing to their floral and fruity aromas. Interestingly, there were no significant impacts on higher alcohols observed across all fining agents. However, C6-alcohols, another type of alcohol compound, experienced a notable reduction (20%) only in wines treated with Grandeco. Moreover, both major and minor ethyl esters, which are responsible for fruity and floral aromas in wine, were significantly decreased following the addition of fining agents. Similarly, higher alcohol acetates, which contribute to the fruity aroma and flavor of wine, were significantly reduced, with Grandeco exhibiting the most pronounced effect (21.5% reduction). In the case of red wine, similar trends were observed regarding the impact of fining agents on free monoterpenes. Grandeco again exhibited the most substantial reduction, with a 30% decrease. However, there were no significant changes observed in higher alcohols and C6-alcohols, indicating a selective effect on certain chemical compounds. Furthermore, the addition of fining agents led to significant decreases in both major and minor ethyl esters, as well as well as higher alcohol acetates, in red wine. Once more, Grandeco demonstrated the most pronounced reduction in higher alcohol acetates, with a decrease of 22%. These results suggest that the application of fining agents can influence the volatile composition of red wine in a similar manner to white wine, potentially altering its aroma and flavor profile. Similarly, Pettinelli et al. [51] found a higher loss of total volatile compounds in Malvasia del Lazio (*Vitis vinifera* L.) wine produced from must treated with legume protein plus chitin from Aspergillus niger (−38%) and legume protein plus yeast extract (−27%) compared to wine produced from must treated with gelatin (GEL). In a further study, Ma et al. [10] evaluated the impact of different fining agents on the volatile profile of Italian Riesling wine. When Bentonite was used at a concentration of 1 g/L, there was a significant reduction in total esters, alcohols, acids, terpenes, carbonyls, and volatile phenols by 43.4%, 5.1%, 11.9%, 52.5%, 25.6%, and 52.3%, respectively. In contrast, the application of soybean protein at a concentration of 0.5 g/L also led to notable reductions, though to a lesser extent in some categories: total esters were reduced by 16.8%, alcohols by 3.8%, acids by 15.8%, terpenes by 11.7%, carbonyls by 28.2%, and volatile phenols by 41.5%.

Rihak et al. [52] studied the effects of various fining agents on the volatile composition of Hibernal grape wine. The use of polyvinylpolypyrrolidone at a concentration of 0.8 g/L resulted in a significant reduction in higher alcohols by 2%, C6 unsaturated alcohols by 20%, and ethyl esters by 5.5%. Pea protein, applied at a concentration of 0.3 g/L, led to a more pronounced decrease in higher alcohols by 5.5%, C6 unsaturated alcohols by 15.2%, and ethyl esters by 21.4%. In contrast, chitosan at a concentration of 0.1 g/L did not significantly affect the levels of higher alcohols and ethyl esters but did reduce C6 unsaturated alcohols by 18.75%. On the other hand, Lisanti et al. [40] reported that 4-vinylguaiacol, which contributes to a smoky flavor in wine, was adsorbed by charcoal (20 g/hL) and PVPP (80 g/hL) at rates of 61% and 44% of the initial concentration, respectively. In contrast, 4-vinylphenol, responsible for a medicinal flavor in wine, was reduced by 11.9% and 2.89% of the initial concentration by charcoal and PVPP, respectively. In general, the removal of volatile compounds during fining depends on many factors, such as the interaction between fining agents and free or bound aroma compounds. This interaction is influenced by several factors, including the physical and chemical characteristics of the fining agent, the chemical features of the target compound, and the possible interactions between volatiles and other macromolecules previously linked to the fining agent [53].

Table 4. Key literature findings for the effects of fining on volatile profile of wine.

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
White (Malvazija istarska)	Granular-activated sodium bentonite	Post fermentation	95 g/L	▪ Significant reduction in free alcohols (−8.2%), fatty acids (−28%), acetate esters (−18%), and monoterpenes (−2%).	[31]
Red (Pinot noir)	Sodium (Na) bentonite	Pre-fermentation	0.5 g/L	▪ No impact on the aroma profile except slight reduction in ethyl cinnamate, hexyl acetate and cis-3-hexenol	[8]
	Calcium (Ca) bentonite	Pre-fermentation			
	Sodium and calcium combined (NaCa) bentonite	Pre-fermentation			
White (Pedro Ximénez)	Bentonite	Pre-fermentation	5 g/hL	▪ Acetaldehyde (−34%) and acetoin (−35.7%) significantly reduced ▪ Ethyl acetate (+32.8%), methanol (+25%), isobutanol (+6.8%), 2-Methyl-1-butanol (+11.6%) and glycerol (+9.8) increased ▪ No significant effect on diethyl succinate, 2-Phenylethanol and 2,3-Butanediol meso	[49]

Table 4. *Cont.*

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
White (Sauvignon Blanc)	Sodium bentonite Bentogran	After 2 months of storage	50 g/hL	▪ Total monoterpenes (+3%) and total C-6- compounds (+32.5%) increased ▪ Total C-13 norisoprenoids significantly decreased by 48.5%	[15]
			125 g/hL	▪ Total monoterpenes (+4%) and total C-6- compounds (+31%) increased ▪ Total C-13 norisoprenoids significantly decreased by 52.5%	
			200 g/hL	▪ Total monoterpenes (+4.2%) and total C-6- compounds (+9.8%) increased ▪ Total C-13 norisoprenoids significantly decreased by 54.1%	
	Sodium-activated bentonite Majorbenton	After 2 months of storage	100 g/hL	▪ Total monoterpenes (+1.5%) and total C-6- compounds (+44.3%) increased ▪ No significant change in total C-13 norisoprenoids	
			200 g/hL	▪ Total monoterpenes (−4.5%) and total C-13 norisoprenoids (−34.4%) decreased ▪ Total C-6- compounds (+34.8%) increased	
			300 g/hL	▪ Total monoterpenes (−8%) and total C-13 norisoprenoids (−41.4%) decreased ▪ Total C-6- compounds (+32.9%) increased	
White (Chardonnay)	Sodium bentonite	Pre-fermentation	8.5 g/hL 12.5 g/hL 17 g/hL	▪ Total esters significantly decreased for bentonite doses of 12.5 and 17 g/hL, while no significant change was observed with a dose of 8.5 g/hL ▪ No significant difference in total alcohols, acids, or terpenes compared to base wine ▪ Total norisoprenoids significantly increased	[7]
		During bottling	8.5 g/hL 12.5 g/hL 17 g/hL	▪ Total esters significantly decreased, while there were no differences among bentonite treated wines. ▪ No significant difference in total alcohols, acids, or terpenes compared to base wine ▪ Total norisoprenoids significantly increased	
		After 9 months of storages	8.5 g/hL 12.5 g/hL 17 g/hL	▪ Total esters significantly decreased, while there were no differences among bentonite-treated wines with doses of 12.5 and 17 g/hL ▪ No significant difference in total alcohols and terpenes in wine treated with doses of 8.5 and 12.5 g/hL compared to the base wine, while alcohol significantly increased in wine treated with 17 g/hL of bentonite. ▪ Total acids significantly decreased and norisoprenoids increased	

Table 4. *Cont.*

<table>
<tr><th>Type of Wine</th><th>Type of Fining Agent</th><th>Time Point</th><th>Concentration</th><th>Effect</th><th>References</th></tr>
<tr><td rowspan="8">White (Gruener Veltliner 2018) and Red (Zweigelt 2018) wine</td><td>Absolut Wein</td><td rowspan="8">Bottling</td><td>0.6 g/L</td><td rowspan="8">White wine:
■ Free monoterpenes significantly decreased with all fining agents except CarboTec GE and Reskue, with the greatest reduction observed in wine treated with Grandeco (−28%)
■ No significant impact on higher alcohols
■ No significant reductions in C6-alcohols, except for the fining agent Grandeco (−20%)
■ Major and minor ethyl esters significantly decreased
■ Higher alcohol acetates significantly decreased, with the greatest reduction observed for Granucol GE (−21.5%)
Red wine:
■ No significant reductions in free monoterpenes, except for the fining agent Grandeco (−30%)
■ No significant impact on higher alcohols and C6-alcohols
■ Major and minor ethyl esters significantly decreased
■ Higher alcohol acetates significantly decreased, with the greatest reduction observed for Grandeco (−22%)</td><td rowspan="8">[12]</td></tr>
<tr><td>Reskue</td><td>0.6 g/L</td></tr>
<tr><td>Grandeco</td><td>1 g/L</td></tr>
<tr><td>NaCalit</td><td>1 g/L</td></tr>
<tr><td>CarboTec GE</td><td>1 g/L</td></tr>
<tr><td>Purity D</td><td>0.5 g/L</td></tr>
<tr><td>Granucol GE</td><td>0.2 g/L</td></tr>
<tr><td>Flowpure</td><td>2 g/L</td></tr>
<tr><td rowspan="2">Italian Riesling</td><td>Bentonite</td><td rowspan="2">Finished wine</td><td>1 g/L</td><td>■ Significant reduction in total esters (−43.4%), alcohols (−5.1%), acids (−11.9%), terpenes (−52.5%), carbonyls (−25.6%), and volatile phenols (−52.3%)</td><td rowspan="2">[10]</td></tr>
<tr><td>Soybean protein</td><td>0.5 g/L</td><td>■ Significant reduction in total esters (−16.8%), alcohols (−3.8%), acids (−15.8%), terpenes (−11.7%), carbonyls (−28.2%), and volatile phenols (−41.5%)</td></tr>
<tr><td rowspan="3">White (Hibernal grape)</td><td>Polyvinyl polypyrrolidone</td><td rowspan="3">In grape musts</td><td>0.8 g/L</td><td>■ Significant reduction in higher alcohol (−2%), C6 unsaturated alcohols (−20%), and ethyl esters (−5.5%)</td><td rowspan="3">[52]</td></tr>
<tr><td>Pea protein</td><td>0.3 g/L</td><td>■ Significant reduction in higher alcohol (−5.5%), C6 unsaturated alcohols (−15.2%), and ethyl esters (−21.4%)</td></tr>
<tr><td>Chitosan</td><td>0.1 g/L</td><td>■ No significant reduction in higher alcohol and ethyl esters, while C6 unsaturated alcohols reduced by −18.75%.</td></tr>
</table>

6. Impact on Sensory Characteristics

Wine's sensory characteristics, including aroma, flavor, and mouthfeel, are heavily influenced by its volatile composition. Volatile compounds like esters, alcohols, acids, and terpenes contribute to the wine's fruity, floral, and herbaceous notes. The use of fining agents in winemaking, intended to clarify and stabilize the wine, can significantly impact a wine's volatile profile and, consequently, its sensory properties. The impact of different fining agents on the sensory characteristics of wine were summarized in Table 5. The addition of Bentonite (5 g/hL) did not result in any significant alteration in the sight, taste, or overall quality of the white (Pedro Ximénez) wine. However, there was a notable decrease in the score attributed to the smell of the wine following the addition of Bentonite [49]. The observed disparities in smell scores across evaluated wines could be attributed to the impact of bentonite on the concentrations of key volatile components discharged into the medium. In the further study conducted by Bandić et al. [15], the effects of different concentrations of sodium bentonite, Bentogran (50, 125, and 200 g/hL), and sodium-activated bentonite, Majorbenton (100, 200, and 300 g/hL), on the sensory characteristics of two months aged Sauvignon Blanc wine was investigated. Wines treated with 50 g/hL of sodium bentonite Bentogran exhibited poor evaluations across multiple sensory parameters, including color quality, aroma intensity, persistence, taste, body, and overall impression. Increasing the dosage to 125 g/hL resulted in some improvements, with similar scores to untreated wine in several aspects. However, there were decreases noted in aroma persistence and aftertaste compared to the untreated counterpart. Interestingly, at 250 g/hL, while maintaining certain attributes such as color intensity, aroma intensity, and body, the wine received reduced scores in aroma and taste quality, aftertaste, and overall impression. In contrast, wines treated with sodium-activated bentonite Majorbenton showed consistently poor evaluations across all sensory parameters compared to control wines, regardless of dosage. Furthermore, Pettinelli et al. [51] studied the sensory characteristics of Malvasia del Lazio (*Vitis vinifera* L.) wine produced from must treated with gelatin (GEL), legume protein plus chitin from Aspergillus niger (LEGCHIT), and legume protein plus yeast extract (LEGYEAST). The results indicated that the best overall quality was observed in the LEGCHIT sample, which exhibited intermediate color intensity and low aroma intensity but was appreciated for its body, taste intensity, and low perceived astringency and green aroma notes. However, LEGYEAST wines were characterized by higher color intensity and astringency, leading to a significant reduction in overall quality. On the other hand, Italian Riesling wines treated with bentonite (1 g/L) and soybean protein (0.5 g/L) scored poorly in terms of color intensity, aroma intensity, complexity, fruity and floral notes, sweetness, acidity, persistence, and balance, but received higher scores for limpidity compared to untreated wine [10]. The poor sensory scores of treated wines might be due to a higher loss of volatile compounds that have a total odor active value greater than one.

Table 5. Key literature findings for the impact of fining on sensory characteristics of wine.

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
White (Pedro Ximénez)	Bentonite	Pre-fermentation	5 g/hL	■ No significant change in the score of sight, taste and overall quality of wine, while smell got a lower score after bentonite addition	[49]
White (Sauvignon Blanc)	Sodium bentonite Bentogran	After 2 months of storage	50 g/hL	■ Wine treated with 50 g/hL bentonite was poorly evaluated in terms of color quality, aroma intensity, aroma quality, aroma persistence, first impression, taste intensity, taste quality, body, balance, aftertaste and overall impression.	[15]
			125 g/hL	■ Wine treated with 125 g/hL bentonite showed similar scores for color quality, aroma intensity, aroma quality, body, balance and overall impression as compared to untreated wine. while got lower score in term of aroma persistence and after taste.	
			200 g/hL	■ Wine treated with 250 g/hL bentonite showed similar scores for color intensity, color quality, aroma intensity, aroma persistence, first impression, taste intensity, body, and balance, while got low score in term of aroma quality, taste quality, aftertaste and overall impression	
	Sodium-activated bentonite Majorbenton		100 g/hL	■ Treated wines were poorly evaluated regarding almost every sensory parameter (such as color quality, aroma intensity, aroma quality, aroma persistence, first impression, taste intensity, taste quality, body, balance, after taste and overall impression) compared to control wine	
			200 g/hL		
			300 g/hL		

Table 5. *Cont.*

Type of Wine	Type of Fining Agent	Time Point	Concentration	Effect	References
White (Malvasia del Lazio)	Gelatin (GEL), legume protein plus chitin (LEGCHIT) from Aspergillus niger, and legume (Pisum sativum L.) protein plus yeast extract (LEGYEAST)	After grape processing	-	■ LEGYEAST treated wine had higher scores in terms of color intensity, and taste astringency, while having the lowest scores for fruity aroma, body, and global quality among all treated wine. ■ GEL treated wine had higher scores in terms of fruity aroma, and flowery aroma, while having the lowest scores for color intensity among all treated wine ■ LEGCHIT treated wine had higher scores in terms of taste intensity and wine body, while having the lowest score for green aroma and taste astringency among all treated wine	[51]
Italian Riesling	Bentonite	Finished wine	1 g/L	■ Significant reduction in color intensity, aroma intensity, complicacy, fruity and floral, sweetness, acidity, persistence and balance ■ Significant increase in limpidity	[10]
	Soybean protein		0.5 g/L		
White (Malvazija istarska)	Bentonite	Into clear grape juice (JU)	100 g/hL	■ Bentonite-treated wines showed higher sensory scores for floral, fruity, tropical, spicy, honey, body, and typicity compared to the original wine. ■ Bentonite-treated wines received lower scores for herbaceous, acidity, bitterness, and astringency. ■ There was no significant impact on the freshness of the wine with bentonite.	[54]
		Beginning of fermentation (BE)			
		Middle of fermentation (MD)			
		End of fermentation (EN)			
Citrus wine	Gelatin and agar	Before clarification	30 and 125 mg/L	■ Lower ratings for the attributes of color, condition (nose), purity (nose), intensity (nose), purity (palate), intensity (palate), length, and bitterness compared to control wine. ■ Higher rating for the attributes of clarity, condition (palate), and balance ■ Treated wine had a lower mean rating in terms of aroma characteristics like citrus, apple, banana, peach, floral, traditional Chinese medicine, licorice, spices, and bitter almond compared to control	[55]
White (Sauvignon Blanc)	Activated carbon	Juice	1 g/L	■ Tropical/thiol, banana/pineapple, and toffee/caramel/honey all have higher mean ratings for the gelatin-treated wines. ■ Gelatin-treated wines give the lowest mean rating for the attribute floral/talcum powder. ■ Activated carbon-treated wine shows a similar rating to control wine for citrus, phenolic profile, toffee/caramel/honey, and tropical/thiol.	[56]
	Gelatin				

In a study by Horvat et al. [54], Malvazija Istarska (White) grape juice was treated with bentonite at a concentration of 100 g/hL at various stages of fermentation: the beginning (BE), middle (MD), and end (EN). The results demonstrated that bentonite-treated wines exhibited significantly higher sensory scores in attributes such as floral, fruity, tropical, spicy, honey, body, and typicity when compared to the untreated original wine. Conversely, these wines received lower scores for herbaceous notes, acidity, bitterness, and astringency. Importantly, the treatment did not significantly impact the perceived freshness of the wine. Furthermore, Bi et al. [55] found that treating citrus wine with 30 mg/L gelatin and 125 mg/L agar significantly decreased the concentrations of limonin and nomilin, which are responsible for the delayed bitter taste. The treated wine had lower ratings for attributes like color, aroma intensity, palate intensity, length, and bitterness compared to the control wine. However, it received higher ratings for clarity, condition on the palate, and balance. The treated wine also had lower mean ratings for aroma characteristics such as citrus, apple, banana, peach, floral, traditional Chinese medicine, licorice, spices, and bitter almond compared to the control. Furthermore, Parish et al. [56] investigated the influence of different fining agents on the sensory profile of Sauvignon Blanc. Activated carbon and gelatin were added to the juice at a rate of 1 g/L. The results indicated that the wine treated with activated carbon had similar ratings to the control wine in terms of citrus, phenolic profile, toffee/caramel/honey, and tropical/thiol attributes. In contrast, wines treated with gelatin had higher mean ratings for tropical/thiol, banana/pineapple, and toffee/caramel/honey attributes compared to the control and activated carbon-treated wines. However, the gelatin-treated wines received the lowest mean rating for the floral/talcum powder attribute. In general, the change in sensory characteristics during the fining of wines depends on factors such as the type of fining agent used (e.g., bentonite, gelatin, casein, egg whites), the dosage of the fining agent, the initial composition of the wine (pH, phenolic content, protein levels), the contact time between the fining agent and wine, the temperature during fining, and the timing of fining (before, during, or after fermentation), as these factors influence the interactions between the fining agent and various wine components that contribute to aroma, flavor, and mouthfeel.

7. Conclusions

In conclusion, fining agents like bentonite and gelatin significantly impact wine attributes, clarifying and stabilizing it while potentially altering color, aroma, and sensory profiles. The future of fining lies in innovative approaches, such as developing plant-based agents derived from grape materials, which may offer effective clarification while preserving inherent flavors. Advancements in nanotechnology and biotechnology hold promise for creating targeted fining agents that selectively remove specific compounds without compromising wine quality. Furthermore, the growing demand for sustainable wine production will drive the development of eco-friendly fining agents derived from abundant, renewable materials. These advancements will not only address consumer preferences but also contribute to environmentally conscious winemaking practices. The ongoing research and innovation in fining techniques and materials will be instrumental in adapting to challenges posed by climate change and evolving consumer tastes. The future of fining agents is poised to transform the industry, enabling the creation of high-quality wines that are both sustainable and sensorily pleasing.

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