Food Research International 242 (2026) 119900

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Review

Yeast derivative products in wine production: From composition to oenological applications and emerging challenges

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ARTICLE INFO

Keywords:
Wine stabilization
Fermentation
Antioxidant
Color stability
Sensory properties

ABSTRACT

Yeast derivative products (YDPs) are widely employed in modern oenology as technological tools to modulate fermentation performance, improve wine stability, and enhance sensory quality. Derived mainly from *Saccharomyces cerevisiae* and, more recently, even from non-*Saccharomyces* yeasts, YDPs encompass a heterogeneous group of products including inactivated yeasts, autolysates, yeast protein extracts, yeast hulls, and mannoproteins, which composition and functionality depend on yeast strain and manufacturing process. Despite their extensive use, a comprehensive understanding of the relationships among YDP composition, mechanisms of action, and oenological performance remains limited. In this context, this review aims to provide a critical and integrated overview of YDPs, covering their technological applications throughout the winemaking process. Particular attention is devoted to their role in fermentation management (alcoholic, malolactic and secondary fermentations), as well as to their antioxidant capacity. Their contribution to wine stabilization, including colloidal equilibrium, and tartaric, protein, and color stability, together with their impact on sensory properties was also explored. The multifactorial mechanisms underlying YDP activity, such as nutrient supply, adsorption of inhibitory compounds, release of polysaccharides and peptides, and redox modulation, are discussed to rationalize their technological effects. Overall, YDPs emerge as versatile tools that can support both wine quality improvement and process sustainability. Their effectiveness, however, is closely linked to wine and application conditions, highlighting the need for a more targeted and mechanistic approach to their use. Advancing the understanding of structure-function relationships will be essential to optimize their application and to foster the development of precision oenology strategies.

1. Introduction

The use of yeast derivative products (YDPs) in oenology has been well established for many years. These oenological preparations are obtained from *Saccharomyces cerevisiae* and non-*Saccharomyces* yeasts through controlled processes such as autolysis, enzymatic hydrolysis, pH change or thermal inactivation. Depending on the production process and degree of fractionation, YDPs can be classified into inactivated dry yeasts, yeast autolysates, yeast extracts, yeast hulls, and mannoproteins. These categories differ in solubility and composition, ranging from whole inactive cells to highly refined and soluble polysaccharidic fractions. Depending on the typology, YDPs can be rich in cell wall components and/or soluble intracellular compounds. YDPs have been developed through the years with the interest to replicate, modulate, and control the aging process on yeast lees while reducing the risk of microbial contamination and the formation of undesirable volatile compounds (Pozo-Bayón et al., 2009; Rigou et al., 2021). Nonetheless, YDPs also represent a valuable tool in the hands of the winemakers to achieve specific oenological purposes, given the quantity, specificity, and efficacy of the products available on the market. These purposes include alcoholic and malolactic fermentation enhancement, wine colloidal and color stabilization, wine antioxidant activity increase and wine sensory characteristics improvement. Even if the practice is well-known and largely carried out, the wine treatment with YDPs is still emerging thanks to their frequent multifactorial impact as well as their direct origin from *Saccharomyces cerevisiae* and non-*Saccharomyces* yeasts, providing winemakers with materials that aligns with the biochemical environment of wine. In particular, the use of YDPs from

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https://doi.org/10.1016/j.foodres.2026.119900
Received 18 January 2026; Received in revised form 26 June 2026; Accepted 28 June 2026
Available online 29 June 2026

non-*Saccharomyces* yeasts has been recently admitted by the Organization of Vine and Wine (OIV) (OIV, 740-2024) requiring ad-hoc investigations on their impact. With regards of YDPs from *S. cerevisiae*, the use of mannoproteins as stabilizing agents was firstly approved in 2004 (OIV, 740-2024). Even if numerous studies have been conducted on YDPs, and several information has been gathered, findings can be sometimes conflicting. This variability may be attributed to multiple experimental factors, including the typology of YDPs, yeast strain, manufacturing process, application dosage and matrix in which these products were employed. Over the years, a few review works were carried out over the use of YDPs during the vinification process, in particular Pozo-Bayón et al. (2009) analyzed the scientific evidences over the employment of inactivated yeast in winemaking, focusing on their employment as alcoholic and malolactic fermentation enhancers, their effect over wine sensory characteristics and over wine safety. Rigou et al. (2021) evidenced the effects of the addition of YDPs on wine aroma, focusing on the effect over the concentration in wine of each type of aromatic compound and over the interaction of YDPs with aromatic compounds and the possible aromatic compounds released by YDPs. However, a complete and more deep review over all the possible implications of the employment of YDPs, considering all the novel studies and scientific evidences is still lacking.

Given the increasing relevance of yeast derivative products (YDPs) in modern winemaking, this review aimed to provide a comprehensive and critical overview of the three main pillars as (i) composition, (ii) mechanisms of action, and (iii) oenological applications. Particular attention was devoted to their multifunctional role throughout the winemaking process, including fermentation management, wine stabilization, protection against oxidative phenomena, and modulation of sensory properties. The review discusses the use of YDPs as nutrient sources and fermentation activators during alcoholic, malolactic, and secondary fermentations, as well as their contribution to tartaric, protein, color, and colloidal stability. Their effects on wine antioxidant capacity, astringency, aromatic expression, and foam-related properties in sparkling wines are also examined. Furthermore, the review highlights the importance of both YDP composition and wine matrix in determining technological effectiveness, emphasizing the complexity of the interactions underlying their performance. Finally, current knowledge gaps and emerging research challenges are discussed to support the development of more targeted and effective applications of YDPs in contemporary oenology.

2. Typologies of yeast derivative products employed in oenology

As mentioned above, different types of YDPs are employed for specific oenological purposes. These include inactivated yeasts, yeast autolysates, yeast protein extracts, yeast hulls, and mannoproteins. A detailed description of each category is provided in this section, as such information is essential for understanding the appropriate application of different YDPs throughout the winemaking process.

2.1. Inactivated yeasts

Inactivated yeasts are yeast cells that have lost their fermentative activity following thermal and/or pH-induced inactivation. In oenology, they are produced by subjecting *Saccharomyces* biomass to heat treatment and/or pH modulation (OIV, 459-2013). This process disrupts the yeast cell wall, increasing the solubility and reducing the molecular weight of intracellular components. Partial autolysis mediated by endogenous hydrolytic enzymes may occur, further enhancing component solubilization; however, the insoluble fraction must represent at least 60% (*w*/w) of dry matter. Regulatory limits also require total nitrogen to remain below 10%, ammonia nitrogen (expressed as N) below 0.5%, and the sum of free and soluble amino acids and small peptides (expressed as glycine equivalents) below 10% of dry matter (OIV, 459-2013).

In winemaking, inactivated yeasts are primarily used as nutritional supplements during yeast rehydration and throughout alcoholic fermentation. In addition, they have been shown to reduce ochratoxin A (OTA) levels during wine maturation. Recent developments have led to the authorization of inactivated yeasts enriched in reduced glutathione (GSH) for use as antioxidant agents in must and wine stabilization (OIV, 603-2018). GSH plays a key role in limiting oxidative stress, thereby preventing premature oxidation and browning. GSH-enriched inactivated yeasts may also supply precursor compounds, such as cysteine and γ-glutamyl-cysteine, potentially enhancing GSH biosynthesis in fermenting yeasts. These products are obtained from *Saccharomyces* and non-*Saccharomyces* biomasses cultivated under controlled conditions to promote intracellular GSH accumulation; exogenous GSH addition is not permitted. Compliance is verified by a γ-glutamyl-cysteine/GSH ratio exceeding 20%, with minimum contents of 1% reduced GSH, 0.3% cysteine, and 1% γ-glutamyl-cysteine (w/w, dry matter) (OIV, 603-2018).

2.2. Yeast autolysates

Yeast autolysates are concentrated hydrolysates obtained from the autolysis of yeast biomass, a process that may be enhanced by thermal treatment and/or pH adjustment; the use of exogenous enzymes is not permitted (OIV, 496-2013). Autolysis involves the enzymatic self-degradation of yeast cellular components, including proteins, nucleic acids, lipids, and polysaccharides. Unlike other yeast-derived products, yeast autolysates undergo no extraction step, thereby retaining both soluble and insoluble fractions. Despite their high water solubility, the soluble fraction of dry matter must remain below 80% in both liquid and dry preparations (OIV, 496-2013).

In winemaking, yeast autolysates are primarily used as nutritional supplements during yeast rehydration and alcoholic fermentation. Regulatory specifications require total nitrogen to remain below 12% of dry matter, ammonia nitrogen below 0.5%, and amino acids and small peptides (expressed as glycine equivalents) to range between 10% and 20% of dry matter (OIV, 496-2013). By supplying readily assimilable nitrogen (RAN) and lipids, yeast autolysates can enhance fermentation performance, yeast viability, and wine aromatic expression (González Marco et al., 2006).

2.3. Yeast protein extract

The oenological use and composition of yeast protein extracts are regulated by several OIV resolutions (OIV, 416-2011; OIV, 417-2011; OIV, 452-2012). These products consist primarily of the cytoplasmic fraction of *Saccharomyces* spp. cells, containing a complex mixture of proteins, peptides, amino acids, ribonucleic acids, metabolites, and low-molecular-weight compounds. The composition and functionality of yeast protein extracts depend on the yeast strain, nutritional conditions, and extraction and drying processes; extraction techniques include physical, enzymatic, and chemical methods.

In winemaking, yeast protein extracts are authorized as fining agents and have demonstrated effectiveness in reducing turbidity, improving clarity, and enhancing colloidal stability (Fernandes et al., 2015; Pozo-Bayón et al., 2009). According to regulatory specifications, these products must contain at least 50% total protein (dry matter), with a minimum of 50% of proteins exceeding 15 kDa, and an amino nitrogen content (expressed as glycine equivalents) between 10% and 20% of dry matter (OIV, 452-2012). Their use is subject to maximum dosages of 60 $g{\cdot}hL^{-1}$ for red wines and 30 $g{\cdot}hL^{-1}$ for musts, white wines, and rosé wines.

2.4. Yeast hulls

Yeast hulls correspond to the yeast cell wall fraction and are commonly obtained as by-products of yeast extract production.

Following autolysis, the insoluble fraction is separated from the soluble extract by centrifugation; alternatively, cell walls may be recovered through mechanical disruption, provided that their surface properties and adsorption capacity are preserved.

The yeast cell wall accounts for approximately 15–30% of the dry weight of *Saccharomyces cerevisiae* and provides structural integrity, morphology, and mechanical and osmotic resistance. It is a rigid structure (110–200 nm thick) mainly composed of β-1,3-glucans (about 50%), β-1,6-glucans (about 10%), mannoproteins (about 40%), and chitin (1–3%), organized into an inner β-glucan-rich network and an outer mannoprotein layer (Ribéreau-Gayon et al., 2006). According to OIV specifications, yeast hull preparations must contain at least 40% carbohydrates, of which 60% must be mannans and glucans, and must be largely insoluble, with a soluble fraction below 10% of dry matter (OIV, 459-2013). Their use in winemaking is limited to a maximum of 40 $g \cdot hL^{-1}$ and is primarily aimed at preventing or correcting stuck fermentations through the adsorption of inhibitory medium- and short-chain fatty acids, such as octanoic and decanoic acids (Soubeyrand et al., 2005).

2.5. Yeast mannoproteins

Yeast mannoproteins form the outer layer of the yeast cell wall, representing approximately 30–50% of cell wall dry weight, which itself represents 20–25% of total yeast cell dry mass (Aguilar-Uscanga & François, 2003). Their molecular weight ranges from 5 to 800 kDa, with most fractions between 50 and 500 kDa (Snyman et al., 2023). Mannoproteins consist predominantly of glycans (85–90%), mainly D-mannose linked by α-1,6, α-1,2, and α-1,3 bonds, with a protein fraction (10–15%) covalently attached to the cell wall glucan network via O- and N-glycosidic linkages (Bicca et al., 2022).

At wine pH, mannoproteins carry a net negative charge, enabling interactions with wine components and adsorption of contaminants such as ochratoxin A (Ringot et al., 2005). They contribute to colloidal stability by limiting tartrate precipitation and protein haze formation (Alcalde-Eon et al., 2014; Li et al., 2023). In addition, mannoproteins have been associated with improved sensory properties, including enhanced mouthfeel, reduced astringency, and increased aromatic persistence (Del Barrio-Galán, Pérez-Magariño and Ortega-Heras, 2011, Del Barrio-Galán, Medel-Marabolí and Peña-Neira, 2015). Nevertheless, their authorized use in winemaking is currently restricted to tartaric and/or protein stabilization (OIV, 674-2022).

The composition and molecular size of mannoproteins depend on yeast species, strain, growth conditions, and extraction methods. Extraction typically involves physical and/or enzymatic processes, with autolytic enzymes influencing mannoprotein structure and size (Bicca et al., 2022).

3. Overall properties of yeast derivatives products

YDPs have been widely used in food industry as flavor and aroma enhancers and as relevant source of nutrients (Otero et al., 2011). In the last decades YDPs have been widely employed in the wine industry not only as a valid substitute of wine aging on yeast lees (Pozo-Bayón et al., 2009; Rigou et al., 2021), but also in other phases of the winemaking process.

Depending on their characteristics and chemical composition, these products can be used in all the phases of the oenological process serving several purposes (Fig. 1). YDPs are claimed to enhance both alcoholic (Feuillat & Guerreau, 1996) and malolactic fermentations (Andújar-Ortiz et al., 2010), preventing the onset of stuck or starving fermentations; they could influence wine colloidal stability and facilitate wine tartaric stabilization (Rigou et al., 2021). YDPs have been largely used and tested for protecting and improving the aromatic, sensory and color characteristics of wines (Iosip et al., 2022; Lambert-Royo et al., 2022; Lubbers et al., 1994; Oyón-Ardoiz et al., 2022). Moreover, their ability to influence the colloidal composition of wines influence also the volatility of the aromatic compounds, and, consequently, the sensory profile of wine (Comuzzo et al., 2012).

It has been demonstrated that YDPs could enhance both alcoholic and malolactic fermentation by supplying assimilable nitrogen, sterols and poly unsaturated fatty acids (PUFA), which are essential to prevent stuck of fermentation. Contemporarily, inactivated yeasts, yeast autolysates and yeast hulls could remove short and middle chain fatty acids being responsible for stuck alcoholic fermentation (González Marco et al., 2006; Soubeyrand et al., 2005). The application of yeast autolysates or inactivated yeasts in winemaking could be related to an increase of antioxidant capacity of wines (Comuzzo et al., 2015). This effect was principally ascribed to the presence of reduced glutathione (GSH), which was detected at relatively high concentrations in commercial inactivated yeasts obtained from high-GSH producing *Saccharomyces* strains, reaching levels up to 9 $mg \cdot g^{-1}$ (Voce et al., 2021). OIV approved in 2018 the use of inactivated yeasts with GSH guaranteed level of minimum 10 $mg \cdot g^{-1}$ (OIV, 603-2018). YDPs can also influence the sensory characteristics as a consequence of the bind between the cell walls and certain aromatic compounds (Lubbers et al., 1994) or the release of aromatic compounds (Comuzzo et al., 2006; Rigou et al., 2021) that are originated from the thermal degradation of sugars, amino acids, proteins and lipids that occur during the manufacturing processes. Certain YDPs, as inactivated yeasts enriched with GSH and yeast autolysates, can influence the wine aroma also through their role of fermentation enhancers, supplementing compounds that prevent the onset of stuck fermentations and the release of off-flavours, as well as are aroma precursors (e.g., amino acids and peptides) (Alfonzo et al., 2021; Gabrielli et al., 2016). YDPs are also a source of polysaccharides which could modulate the colloidal composition of wines and consequently influence the volatility of aromatic compounds (Li et al., 2023).

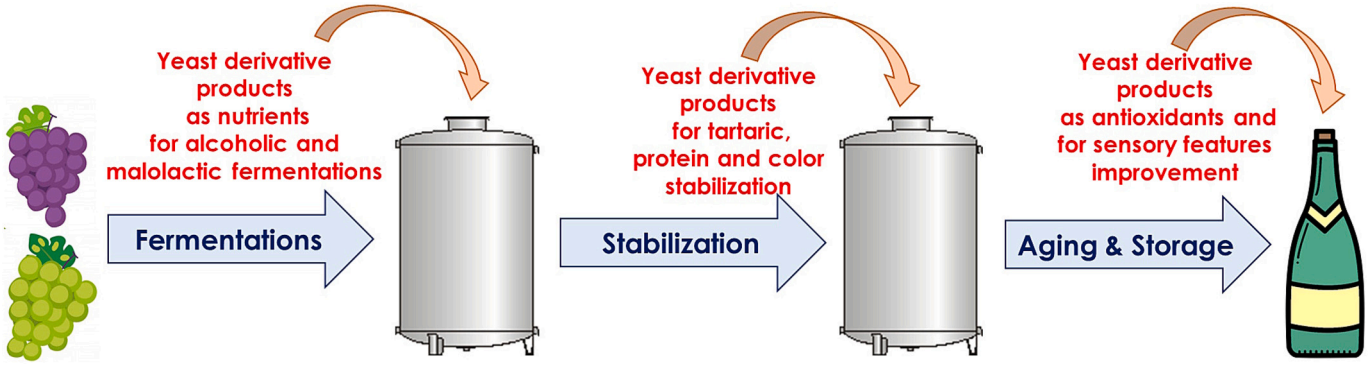

Fig. 1. Use of yeast derivative products in wine production.

Polysaccharides from yeast could also affect the sensory characteristics of wines by forming complexes with proanthocyanidins though reducing the astringency of wine. This is due to the decrease in the number of free proanthocyanidins available to interact with salivary proteins, minimizing the loss of lubrication in mouth (Escot et al., 2001). Besides polysaccharides, several studies demonstrated that mannoproteins released from YDPs may improve several tactile characteristics of wines, such as volume and structure, and they could decrease astringency and bitterness of wines (Del Barrio-Galán, Pérez-Magariño and Ortega-Heras, 2011, Del Barrio-Galán, Cáceres-Mella, Medel-Marabolí and Peña-Neira, 2015). Amino acids, peptides, proteins and also polysaccharides released by YDPs could influence the foamability and the foaming stability of sparkling wines produced with traditional, Martinotti and transfer method (Kemp et al., 2019; Lambert-Royo et al., 2022). Proline-rich YDPs have recently been evaluated as biostimulants for the treatment of both red (*Vitis vinifera* cv. Barbera) (Del Zozzo et al., 2024) and white cultivars (*V. vinifera* cv. Chardonnay) (Tiwari et al., 2025). The results highlighted an improvement in plant physiological performance and suggested the potential to reduce irrigation inputs while maintaining vine productivity and functionality. Furthermore, the application of yeast derivative-based biostimulants promoted the accumulation of hydroxycinnamic acids and stilbenes, phenolic compounds known to contribute to plant defense mechanisms and to inhibit the development of downy mildew (*Plasmopara viticola*) (Puccioni et al., 2025).

4. YDPs as fermentation enhancers

4.1. Use of YDPs as alcoholic fermentation enhancers

The positive effects of YDPs on fermentation performance can be attributed to several mechanisms, including nutrient supplementation (especially nitrogen), the adsorption of anti-fermentative compounds such as medium-chain fatty acids, and the protection of yeast cell membranes mediated by sterols. Feuillat and Guerreau (1996) assessed the performance of yeast autolysates at a dosage of 50 g·hL^{-1} in both nitrogen-deficient (100 mg·L^{-1}) and nitrogen-enriched (300 mg·L^{-1}) media. The authors found that YDP supplementation significantly accelerated sugar consumption and improved yeast viability. Notably, in nitrogen-rich environments, the observed benefits were attributed primarily to the detoxification of inhibitory substances, such as medium-chain fatty acids, rather than to the direct contribution of nitrogen from YDPs. Fermentation stress is further intensified by ethanol accumulation and the production of yeast-derived inhibitory metabolites, including medium-chain fatty acids. In this context, YDP addition has been proposed as an effective strategy to supplement assimilable nitrogen and to detoxify the fermentation medium through the adsorption of short- and medium-chain fatty acids. Sterols, which enhance yeast membrane permeability and integrity, have also been identified as key contributors to the improved fermentation performance observed following YDP addition. González Marco et al. (2006) demonstrated that supplementing Chardonnay must with yeast autolysate (25–100 g·hL^{-1}) increased amino nitrogen uptake during the later stages of fermentation, even under elevated ethanol concentrations. This effect was attributed to the release of long-chain fatty acids (C_{16} and C_{18}) from YDPs, which may enhance membrane transport functions.

However, the effects of YDPs are not consistent across all product types. Dulau et al. (2004) reported that supplementation with yeast protein extract at 30 g·hL^{-1} in synthetic must did not improve fermentation kinetics compared to controls not added with YDPs. It should be considered that the use of synthetic medium can allow to isolate specific properties or mechanisms. However, the well-defined composition, including the presence of essential nutrients (e.g., vitamins, ions, sterols) could lead to the lack of positive influence on fermentation performances. The possible positive results on grape musts could not be excluded. Nonetheless, Xie et al. (2024) found an improved fermentation rates in synthetic juice added with GSH-enriched inactivated yeasts (from 20 to 100 mg·L^{-1}), with the most pronounced effect at 40 mg·L^{-1}, corresponding to the highest viable cell counts. These benefits were attributed to the protective role of GSH against oxidative stress.

The dehydration and subsequent rehydration of active dry yeast (ADY) induce significant biochemical and structural changes that can compromise membrane integrity and cytoplasmic stability. During rehydration, yeast cells may lose up to 30% of intracellular compounds due to increased membrane permeability. In this context, YDPs are widely used to improve ADY rehydration, thereby enhancing fermentation kinetics and reducing fermentation duration. The addition of inactivated yeast at 1.5 g·hL^{-1} during ADY rehydration did show to improve fermentative performance (Soubeyrand et al., 2005). A key mechanism involves the release of yeast cell wall fragments that form micelle-like structures enriched in sterols. These sterols integrate into yeast membranes, acting as bioemulsifiers that reduce surface tension and promote membrane repair. In synthetic must, rehydration with 150 g·L^{-1} of inactivated yeasts provided sterol supplementation equivalent to 40 μg·hL^{-1} of ergosterol, significantly improving fermentation under sterol-limited conditions (Soubeyrand et al., 2005). In addition, polyunsaturated fatty acids released from YDPs during rehydration may protect yeast cells from osmotic stress in high-sugar musts, facilitating metabolic adaptation and potentially reducing volatile acidity, although this effect requires further confirmation (Caridi, 2002).

YDPs also find relevant application during the second fermentation for sparkling wine production. To enhance lees aging, recent studies did investigate the use of different YDPs during this phase. Rodríguez-Nogales et al. (2012) examined the effects of adding β-glucanases (1–3 g·hL^{-1}), yeast autolysates (10–30 g·hL^{-1}), yeast cell walls (10–30 g·hL^{-1}), and mannoproteins (5–30 g·hL^{-1}; added post-disgorging) at tirage. β-Glucanases enzymes, typically produced by *Trichoderma* spp., promote the release of polysaccharides from yeast lees during aging. The use of co-adjuvants was associated with increased pressure during the second fermentation. This effect was attributed to the detoxify properties of yeast autolysates towards short-chain fatty acids and to the release of assimilable nitrogen into the wine, thereby supporting yeast activity.

Given the higher content of nitrogen compounds and lipids in musts intended for red winemaking, it is reasonable to expect that the addition of YDPs could exert a narrow impact on fermentation kinetics compared to musts intended for white winemaking. However, to the best of our knowledge, the most relevant results found in literature comes from white musts or synthetic media and the addition of YPDs in musts from red grape was not investigated in deep.

4.2. Use of yeast derivative products as malolactic fermentation enhancers

The release of different compounds into the wine matrix either stimulating or inhibiting the malolactic fermentation (MLF) can explain the possible enhancement of YDPs towards this process (Pozo-Bayón et al., 2009). *Oenococcus oeni* is capable of efficiently assimilating diverse nitrogen compounds through specialized peptide and protein transport systems. Among these compounds, larger peptides (0.5–10 kDa) appear to promote *O. oeni* growth more effectively than smaller nitrogen sources (lower than 0.5 kDa), although this response is strain dependent (Pozo-Bayón et al., 2009). In addition, several amino acids, including alanine, valine, leucine, methionine, and threonine, have been shown to stimulate *O. oeni* growth (Andújar-Ortiz et al., 2010).

Polysaccharides also exert a significant influence on MLF. Some lactic acid bacteria possess enzymatic activities, such as β-(1 → 3)-glucanase, which enable them to degrade yeast-derived polysaccharides, thereby improving the nutritional quality of the medium (Andújar-Ortiz et al., 2010). Yeast polysaccharides, particularly mannoproteins, can also adsorb short- and medium-chain fatty acids that inhibit LAB

growth. Medium-chain fatty acids, including octanoic, decanoic, and dodecanoic acids, and their esters are potent inhibitors of bacterial activity (Andújar-Ortiz et al., 2010). Lonvaud-Funel et al. (1985) demonstrated that YDPs can enhance MLF by removing fatty acids and other yeast metabolites that are toxic to lactic acid bacteria. In this context, the addition of yeast hulls at 20 g·hL^{-1} promoted *O. oeni* growth and survival, accelerating MLF while reducing acetic acid production. Nonetheless, decanoic acid, which may represent approximately 3.6% of the total fatty acid content in certain YDPs, was specifically implicated in the inhibition of *O. oeni*, potentially limiting the onset or progression of MLF (Andújar-Ortiz et al., 2010). This suggests that YDPs could enhance or, on the contrary, inhibit LAB growth, depending on their lipidic composition. Moreover, the presence of other yeast-derived constituents, such as vitamins and nucleotides, may further modulate MLF (Balmaseda et al., 2021; Terrade & Mira de Orduña, 2009).

Considering the yeast lees, Balmaseda et al. (2021) investigated the effects of lees from different yeast species, including *Saccharomyces* and non-*Saccharomyces* strains, on MLF. While *S. cerevisiae* lees delayed MLF compared with the control, *Torulaspora delbrueckii* lees significantly accelerated the process. In the presence of yeast lees, all three *O. oeni* strains tested exhibited faster L-malic acid consumption, achieving complete MLF in fewer days than the control. These findings highlighted that the impact of yeast lees on MLF is strongly dependent on the specific *O. oeni* strain involved (Balmaseda et al., 2021). These results also suggest the recovery of yeast lees can be a sustainable strategy for ensuring the occurrence of MLF, although its effectiveness remains dependent on yeast and bacterial strain compatibility. Supporting this evidence of yeast lees, Toraño, Martín-García, et al. (2025) and Toraño, Oyón-Ardoiz, et al. (2025) demonstrated that the effect of mannoprotein addition on MLF kinetics is strain-dependent with respect to LAB involved. This variability was attributed to differences in the expression of the α-mannosidase enzyme, which enables the hydrolysis of polysaccharidic chains and, consequently, the assimilation of hexoses by LAB. The same authors further highlighted that specific mannoprotein features, including molecular weight, monosaccharide composition, and protein content, can significantly influence MLF kinetics. Mannoproteins may either accelerate or inhibit the progression of MLF in a LAB strain-related manner.

5. Use of yeast derivative products as antioxidants

Wine aging on yeast lees is widely recognized for its role in maintaining the redox balance of wine by limiting oxidative phenomena, preserving color stability, and enhancing resistance to oxidative degradation through the gradual release of yeast-derived antioxidant compounds (Lubbers et al., 1994). Similarly, YDPs exhibited antioxidant properties, contributing to the preservation of wine freshness by stabilizing reactive quinones on their surface (Iosip et al., 2022). Despite their demonstrated efficacy, the underlying mechanisms remain only partially elucidated, and the specific yeast components responsible have yet to be conclusively identified (De Iseppi et al., 2023).

Among the known antioxidant compounds, GSH, which is present at high concentrations in certain YDPs, is known to play a central role in enhancing oxidative stability by reacting with oxidised phenolic compounds or other oxidation products (Bahut et al., 2020; Iosip et al., 2022). Bahut et al. (2020) showed that GSH-rich inactivated yeasts exhibit significantly relevant radical scavenging activity, underscoring the importance of specific production processes in modulating antioxidant capacity. However, manufacturing conditions, particularly high-temperature treatments, can reduce GSH levels, in part due to its participation in Maillard reactions with reducing sugars, leading to the formation of alternative compounds. Moreover, the weak correlation observed between GSH concentration and radical-scavenging activity (assessed by DPPH assay) suggests that additional components within YDPs contribute synergistically to oxidative stability. This interpretation is supported by the findings of Comuzzo et al. (2015), who reported that yeast autolysates, despite containing lower GSH concentrations than pure GSH, exhibited greater antioxidant activity, indicating the involvement of multiple interacting compounds.

Recent studies further suggest that the antioxidant efficacy of YDPs arises from synergistic interactions between sterols and thiol-containing compounds (De Iseppi et al., 2023). Sterols, which are integral constituents of yeast membranes, are particularly notable for their oxygen consumption capacity (Fornairon-Bonnefond & Salmon, 2003). Civa et al. (2024) hypothesized that inactivated yeasts enriched in ergosterol display enhanced oxygen-scavenging activity, potentially due to the presence of double bonds in the B-ring of ergosterol that confer antioxidant properties. Consistently, Nioi et al. (2022) demonstrated that lipid-enriched YDPs exhibited higher oxygen consumption rates (0.6 mg O_2·day^{-1}·g^{-1}) than YDPs enriched in GSH (0.3 mg O_2·day^{-1}·g^{-1}). These findings suggest that lipids could react with dissolved oxygen, thereby interrupting radical chain reactions and protecting oxidation-sensitive wine components. Consequently, the formation of oxidative off-flavours is reduced, and free sulfur dioxide levels are better preserved. In addition, polysaccharides of YDPs could improve wine antioxidant capacity by protecting polyphenols and in particular anthocyanins from oxidation. Moreover, Yin et al. (2026) observed an increased antioxidant capacity (measured by FRAP assay) after storage by mannoproteins addition at 2, 4 and 6 g·L^{-1} on red grape juice.

The matrix in which these products are applied when aiming to enhance the antioxidant capacity of wines needs be taken into account. It should be noted that studies reporting an increase in antioxidant capacity were carried out on white wines or synthetic wine solutions. It is therefore reasonable to hypothesize that the effects of such additions may be less pronounced and, in some cases, negligible, in red wines being characterized by much higher polyphenol concentrations and, consequently, an greater intrinsic antioxidant capacity.

6. Use of yeast derivative products as stabilizing agents

Prior to bottling, the production of high-quality wine requires effective stabilization to prevent the formation of precipitates or haze in the bottle. Wines that are insufficiently stabilized may develop visible deposits, including not only tartrate salts but also complex polymeric aggregates primarily composed of polyphenols and proteins. Although these precipitates generally do not affect sensory properties, they are commercially unacceptable and, in severe cases, may lead to product recalls. In addition, precipitation phenomena may reduce color intensity through the removal of tannins and anthocyanins involved in polymer formation.

Proteins naturally present in wine can also induce turbidity in white wines, commonly referred to as protein haze. Wine clarity is a fundamental quality parameter, and the appearance of haze, often triggered by temperature fluctuations during transport or storage, is considered unacceptable. To achieve tartaric, protein, and color stabilization, various physical and chemical treatments are available. Traditional clarifying agents, such as bentonite, are widely used; however, bentonite fining can result in losses of aroma, color, and wine volume, ultimately compromising quality (Lomolino & Curioni, 2007). Moreover, some fining agents of animal origin raise concerns related to allergenicity and consumer acceptance (Francisco et al., 2021).

Aging wine on yeast lees prior to filtration and bottling has long been recognized as an effective strategy to improve tartaric stability and reduce haze formation. During lees aging, yeast autolysis releases cellular components, including polysaccharides and proteins, into the wine, which can contribute positively to sensory quality. The stabilizing effects of lees are mainly attributed to mannoproteins derived from the yeast cell wall and to cytoplasmic proteins, both of which modify the colloidal equilibrium of the wine (Francisco et al., 2021).

Nevertheless, while lees contact can enhance wine stability, several studies have shown that yeast cell walls may also adsorb phenolic

compounds, potentially leading to a reduction in color intensity (Mekoue Nguela et al., 2016). Given that approximately 10 m^2 of yeast cell wall surface area is present per litre of fermenting must, the impact of lees contact on red wine color can be substantial (Morata et al., 2003). Prolonged lees aging, particularly when combined with regular bâtonnage, promotes yeast autolysis, increasing mannoprotein release and potentially amplifying their stabilizing effects (Del Barrio-Galán, Medel-Marabolí and Peña-Neira, 2015).

Although lees aging can support wine stabilization and enhance sensory attributes, it also entails several risks. The process is time-consuming, and lees may favour the development of spoilage microorganisms, leading to the formation of off-flavours (Fornairon-Bonnefond et al., 2001). Consequently, in recent decades, considerable effort has been directed towards replacing traditional lees aging with the use of mannoproteins, yeast extracts, and YDPs more broadly. Numerous commercial formulations designed for wine stabilization are now available and are increasingly regarded as promising non-animal fining agents (Francisco et al., 2021). The use of YDPs aims to replicate the benefits of lees aging while minimizing its associated drawbacks.

Extensive research has focused on the stabilizing properties of mannoproteins; however, the mechanisms by which they prevent instability and interact with polyphenols remain only partially understood. The literature reports often contradictory results, likely due to differences in wine matrices, application conditions (e.g., concentration and temperature), and the specific characteristics of the YDPs evaluated. The composition of YDPs varies according to yeast strain and species, growth conditions, and extraction methods (Francisco et al., 2021), leading to diverse functional outcomes. These discrepancies highlight the complex interplay between YDP-related properties and wine matrix composition, suggesting that YDP efficacy is highly context dependent. Snyman et al. (2023) demonstrated that mannoprotein compositional features, such as molecular weight, degree of phosphorylation, and glucose-to-mannose ratio, significantly influence protein stability, tannin aggregation, and color retention, with these parameters being strongly affected by the extraction method. The following sections summarize the main findings concerning the use of YDPs as stabilizing agents.

6.1. Protein stabilization enhancers

Historically, protein instability in bottled wines has been addressed through bentonite fining. However, bentonite can strip wine of aromatic complexity, prompting the exploration of alternative technologies (Lubbers et al., 1994). These include ultrafiltration, pectolytic enzymes, chitosan, charged nanoparticles, and colloidal modification through mannoproteins or yeast-derived protein extracts. It is well established that aging wines on yeast lees contributes to improved protein stability. During yeast autolysis, cell wall components, including mannoproteins and cytoplasmic contents, are released. These components, particularly polysaccharides, reduce the amount of bentonite needed for stabilization. In general, extended lees contact decreases the requirement for bentonite (Comuzzo et al., 2004; Guadalupe et al., 2007; Ribeiro et al., 2014). Dupin et al. (2000) demonstrated that after just 8 weeks on lees, wines exhibit reduced haze-forming potential. The type, concentration, and composition of mannoproteins released depend on the yeast species, strain, and biomass concentration. Mannoproteins are released not only during autolysis but also throughout alcoholic fermentation (Dupin et al., 2000), though the release is slow and entails certain risks. In the 1990s, Waters et al. (1993) isolated a 420 kDa mannoprotein acting as a natural colloid protective against haze formation. Later, Moine-Ledoux & Dubourdieu (1999) identified a 32 kDa glycoprotein, an invertase fragment, also effective in haze prevention. More recently, the stabilizing efficacy was linked to the mannose/glucose ratio within mannoproteins: the higher the ratio, the better the stabilization (Ribeiro et al., 2014). Yeast cell wall polysaccharides form a barrier against haze formation (Gazzola et al., 2012), reducing aggregate size rather than preventing aggregation (Dupin et al., 2000). These polysaccharides interact with proteins to form soluble or insoluble complexes depending on chemical charges and functional groups, explaining why not all colloids are equally effective, and their impact may depend on wine composition. Gazzola et al. (2012) observed that the type of thaumatin-like isomer present in the wine is more important than the type of polyphenols and polysaccharides present in the wine, which show to exploit a synergic effect over haze formation. The authors observed no effect on protein aggregation after adding exogenous polysaccharides at 17 $g{\cdot}hL^{-1}$ in white wine in the absence of wine polyphenols and of yeast derived proteins. In fact, in addition to yeast wall polysaccharides, yeast protein extracts can also exert clarifying effects (Lochbühler et al., 2015; Lomolino & Curioni, 2007). Despite decades of application, YDPs do not always yield positive effects; some studies report no improvement or even increased instability. Comuzzo et al. (2004) noted that the addition of an autolysate obtained through thermal inactivation (0–60 $g{\cdot}hL^{-1}$) in three white wines caused over-finingat high doses. In one wine, 60 $g{\cdot}hL^{-1}$ addition reduced colloid content by 600 $mg{\cdot}L^{-1}$. Protein stability increased immediately after treatment but declined over 10 months, while untreated wines improved. Although the turbidity remained lower in treated wines after aging, these findings suggest the limited durability of YDP effects due to faster colloid evolution and precipitation. The overfining phenomena could be due to the addition of yeast proteins in high quantities, and can contribute to haze formation. Lomolino and Curioni (2007) added mannoproteins to six white wines, noting that stability improvement did not linearly correlate with dose. Instead, the effect followed a parabolic curve, reaching a plateau at about 80–90% haze reduction. These authors proposed that YDPs form particles that compete with wine proteins, inhibiting the formation of large aggregates. In other studies, YDPs demonstrated effective clarifying properties. Lochbühler et al. (2015) compared gelatin, tannins, and yeast extracts (30–70 $g{\cdot}hL^{-1}$), all improving stability with final haze values below 10 NTU. Fernandes et al. (2015) explored the clarifying efficacy of yeast extracts at 10 and 20 $g{\cdot}hL^{-1}$ decreasing the turbidity similarly to gelatin, though thaumatin-like proteins and chitinases were not removed, likely due to the positive charge of YDPs at wine pH. However, the authors attribute this effect to the presence of some mannoprotein residue in the yeast extract preparate. Compared to bentonite, YDP-treated wines yielded 44% less of volume of precipitated, enhanced color brilliance, and showed increased antioxidant capacity.

The efficacy of YDPs in preventing protein haze appears to depend on a complex interplay among wine composition, protein characteristics, and polysaccharide properties. The diversity of wine matrices and YDP formulations therefore hinders the identification of broadly applicable stabilization approaches. Nonetheless, growing evidences support the potential of YDPs as protein stabilization agents. In particular, protein isoforms were shown to play a decisive role in haze formation and to modulate the protective effect of yeast polysaccharides. Furthermore, differences in the molecular weight and structural features of yeast-derived polysaccharides may substantially influence their stabilizing performance, helping to explain the inconsistent results reported among studies.

6.2. Tartaric stabilization enhancers

To prevent crystal formation after bottling, winemakers can employ various stabilization techniques: cold stabilization and contact seeding to promote crystallization, removal of ions via ion exchange and electrodialysis, addition of crystallization inhibitors such as metatartaric acid, Arabic gum, carboxymethylcellulose, and mannoproteins. Among the crystallization inhibitors, metatartaric acid is a partial esterified product of tartaric acid. It forms soluble complexes with calcium and potassium ions, enhancing tartrate solubility. However, it tends to hydrolyze back to tartaric acid in wine, losing its protective capacity and potentially inducing tartaric instability. Hydrolysis rates vary with pH

and temperature, ranging from one week to two years (Lasanta & Gómez-Benítez, 2012).

The stabilizing effect of polysaccharides in wine has been known for decades. A higher polysaccharide concentration could more easily inhibit tartrate precipitation (Gerbaud et al., 1996). Mannoproteins, in particular, are widely used for this purpose. They adsorb tartaric acid and metal ions outside nucleation centers, not preventing but inhibiting or slowing down tartrate precipitation (Cui et al., 2024). Gerbaud et al. (1996) identified highly glycosylated mannoproteins (30–50 kDa) as effective in delaying tartrate salt crystallization. Their stabilizing efficacy is strongly influenced by glycosylation degree and molecular weight, and is also dependent on dosage and tartaric instability of wine (Cui et al., 2024). Lower storage temperatures can reduce stabilizing effect of mannoproteins (Gerbaud et al., 1996). The variability in wine matrices could lead inconsistency in the effectiveness of mannoproteins on tartrate, protein, and color stability. Moreover, an excessive addition can result in overfining and turbidity (Zhai et al., 2025).

Comuzzo et al. (2004) investigated the impact of yeast autolysates at 0, 30, and 60 g·hL^{-1} in three white wines. These authors observed that increased mannoprotein concentrations did not always correlate with reduced tartaric instability. After 10 months, instability increased in all samples added with yeast autolysates and, in certain cases, the conductivity shift resulted even higher in the presence of yeast autolysates. Pellerin et al. (2013) noted that adding mannoproteins and arabinogalactan-proteins at 10 g·hL^{-1} to a Chardonnay wine had only a minor effect on crystallization induction time. Cisterna-Castillo et al. (2024) observed no effect of mannoproteins on stabilization of calcium tartrate. This inconsistence between the results can be ascribable to the different features of both the mannoproteins employed in the studies and the wines especially in terms of susceptibility of tartaric precipitation. Moreover, mannoproteins were found to be the most expensive method of tartaric stabilization, while ion exchange was the least expensive (Lasanta & Gómez-Benítez, 2012). Nonetheless, mannoproteins can offer additional benefits, including protein stabilization, color stabilization, and sensory enhancement.

6.3. *Influence of yeast derivative products on color stabilization*

Numerous studies have examined the effect of mannoprotein addition on wine color, though results are often contradictory or ambiguous. Key findings are summarized in Table 1. The addition of inactivated yeasts to wine has generally resulted in either a decrease in color intensity or no clear effect on color (Del Barrio-Galán, Cáceres-Mella, et al., 2015; Del Barrio-Galán et al., 2019; Del Barrio-Galán, Medel-Marabolí, et al., 2015; González-Royo et al., 2016). This behavior is commonly attributed to the adsorption of coloring matter by the insoluble fractions of inactivated yeasts. However, with increasing degrees of fractionation and autolysis, the observed effects become more variable; yeast autolysates and yeast hulls, for instance, may exert positive effects on color stability (Comuzzo et al., 2005; Del Barrio-Galán et al., 2019; Iosip et al., 2022). Such effects are mainly associated with the release of polysaccharides into the medium, which, through their interactions with anthocyanins and polyphenols, can modulate total anthocyanin concentration, copigmentation phenomena, and consequently color stabilization. The addition of mannoproteins, in particular, may lead to variable outcomes depending on the wine matrix in which they are applied, as highlighted in Table 1. Mannoproteins may behave differently depending on molecular weight, glycosylation, and phosphorylation degree. Oyón-Ardoiz et al. (2022) observed that mannoproteins of 62 and 51 kDa had a greater stabilizing effect on color than those around 337 kDa. Similarly, Poncet-Legrand et al. (2007) found that higher-molecular weight mannoproteins were less efficient in color stabilization. Mannoproteins interact with polyphenols via their glycosidic moieties; greater glycosylation increases potential binding sites. Mannosyl-phosphorylation imparts negative charge to mannoproteins, enhancing electrostatic interactions with positively charged flavylium anthocyanins (Mekoue Nguela, et al., 2023)). Thus, mannoproteins with a greater molecular weight and a more complex structure, in terms of mannosyl-phosphorilation, exhibit stronger interactions with polyphenols (Alcalde-Eon et al., 2019; Mekoue Nguela et al., 2023; Oyón-Ardoiz et al., 2022).

The polyphenolic profile of the wine also influences mannoprotein behavior. Morata et al. (2003) reported that during aging on lees, anthocyanins were adsorbed onto yeast cell walls, particularly by mannoproteins. Acetylated anthocyanins were more readily adsorbed than the glycosylated ones. Lees and mannoproteins preferentially interact with more hydrophobic compounds, although the most polar free anthocyanins were also adsorbed. Interestingly, peonidin and its derivatives were most strongly adsorbed despite their slightly lower hydrophobicity, possibly due to steric hindrance effects. Yin et al. (2026) observed that mannoproteins, through their interactions with anthocyanins, exert a protective effect against oxidative reactions and pigment degradation. In particular, the addition of mannoproteins consistently resulted in a lower decrease in color intensity following oxidative conditions. The authors further reported that mannoproteins preferentially interact with glycosylated forms of delphinidin, malvidin, and petunidin. Recently, the impact of mannoproteins on anthocyanin–flavan-3-ol interactions, and thus on copigmentation, was shown and such interactions depend on the specific flavan-3-ol involved (Alcalde-Eon et al., 2024). The inconsistent findings observed in the various studies carried out can be explained principally through the different wines in which YDPs have been employed and to the different characteristics of the products. In many cases the addition of YDPs led to color decrease of both red and white wines. However, a lower color intensity of white wines can indicate a better protection of the oxidizable phenols. In red wines, the interaction with the matrix is more complex and depends on the polyphenolic profile of the wines. Some studies described mannoproteins as protective colloids that prevented excessive tannin polymerization, thereby avoiding coprecipitation with anthocyanins and color loss (Alcalde-Eon et al., 2014; Escot et al., 2001; Yin et al., 2026). This coprecipitation was also prevented when the cold stabilization was applied (Alcalde-Eon et al., 2014; Alcalde-Eon et al., 2019). In contrast, it was suggested that mannoproteins may form insoluble complexes with anthocyanins and flavan-3-ols, promoting their precipitation (Rodrigues et al., 2012). Rinaldi et al. (2019) observed increased polymeric pigment formation upon mannoprotein addition, whereas other authors reported no effect or even decreased color intensity and stability (Del Barrio-Galán et al., 2019; Guadalupe & Ayestarán, 2008; Rodrigues et al., 2012). Dong et al. (2024) found that the addition of mannoproteins protected anthocyanins from the formation of secondary and tertiary complexes in synthetic wine solutions. The discrepancies among studies may be attributed to differences in both mannoprotein characteristics and the matrices in which they were applied. Rinaldi et al. (2026) reported that mannoproteins with a mannose content exceeding 80% and a molecular weight ranging from 37 to 79 kDa exhibited the most pronounced effect on the copigmentation index, although no significant differences in overall color parameters were observed. In contrast, Dong et al. (2024) demonstrated in red wine that mannoproteins with molecular weights between around 60 and 135 kDa, a high mannans-to-glucans ratio, and approximately 65% protein content can exert a stabilizing effect on anthocyanins.

The maintenance of color is a relevant aspect for white wines as well; indeed, YDPs have been proposed as corrective tools against the browning phenomenon in white wines (Del Barrio-Galán, Pérez-Magariño, Ortega-Heras, Williams & Doco, 2011), a process involving transition metals and polyphenols. Several studies reported that, owing to their antioxidant properties, YDPs (i.e., mannoproteins or yeast autolysates) may partially substitute sulfur dioxide in limiting the color change of white wines (Comuzzo et al., 2015; Del Barrio-Galán, Pérez-Magariño, Ortega-Heras, Williams & Doco, 2011; Ribeiro et al., 2014). In particular, Comuzzo et al. (2015) found absorbance values at 420 nm in young and aged white wine added with yeast autolysates lower than

Table 1
Summary of the findings related to the color stabilization obtained by using yeast-derivatives product.

Typology of YDP	Reference	YDPs added	Wine	Contact/ storage time	Key findings
Inactivated yeasts	Del Barrio-Galán, Cáceres-Mella, Medel-Marabolí and Peña-Neira, 2015	One commercial inactive dry yeast at 30 g·hL^{-1}	Cabernet Sauvignon wine produced with two different commercial active dry yeasts.	Addition after malolactic fermentation. Four months on-lees aging.	No clear effect of the addition of YDPs on color has been found. In many cases color intensity lowered.
	Del Barrio-Galán, Medel-Marabolí and Peña-Neira, 2015	Addition of wine lees, wine lees and wood chips and inactivated yeast at 30 g·hL^{-1}	Syrah red wine.	Addition after malolactic fermentation. Four months aging in tanks.	Lower chroma than control wines; no or very low effect on color intensity with the addition of the inactivated yeast.
	González-Royo et al., 2016	Three commercial inactivated yeasts at 30 g·hL^{-1}	Two synthetic wine solutions, with or without tannin addition and a Cabernet Sauvignon red wine.	15 days aging on lees	-Decrease in color in red wine is lower than in synthetic wine solutions; it is visible in synthetic solution and not visible but significant in red wine. -Slight but significant decrease in total anthocyanins concentrations, difference attributed to the removal of pigments derived from anthocyanins and co-pigments.
	Del Barrio-Galán et al., 2019	One commercial inactivated yeast at 30 g·hL^{-1}	Alcoholic fermentation yeasts, one of them is a high mannoproteins producer	Weekly batonnage on the first month and 3 months bottle aging. Analyses carried out after aging in tanks and in bottle.	Addition of commercial inactivated yeast did not cause color modifications compared to the control wine.
	Voce et al., 2021	Three inactivated yeasts obtained through different treatments (commercial preparation, heat treated and high-pressure homogenization treatment at 53.3 g·hL^{-1}	Chardonnay white wine	Analysis after one and four months.	Wines added with all YDPs showed a higher browning index than wine added with sulfur dioxide, indicating that dioxide is still the most efficient additive in protecting white wine color.
Yeast autolysates	Del Barrio-Galán et al., 2019	One commercial yeast autolysate at 30 g·hL^{-1}	Carménère red wine	Addition after the end of malolactic fermentations. 2 months on aging in tanks	Yeast autolysates improved color stability if coupled with high mannoproteins producer yeast after both tank and bottle aging; significantly lower values of L* and b*, significantly higher value of a* and color intensity.
	Comuzzo et al., 2005	One commercial yeast hull up to 60 g·hL^{-1}	2 red Merlot wines with different maceration period (6 and 10 days).	2 months barrel aging after YDPs addition for the 6 days maceration wine and 5 months for the 10 days maceration wine	YDPs fastened color evolution, more pronounced in wine obtained with shorter maceration. Maximum color intensity and ionization index after 15 days at 45 g·hL^{-1} and after 10 months at 15 g·hL^{-1}.
Yeast hulls	Del Barrio-Galán et al., 2019	One commercial yeast hull at 30 g·hL^{-1}	Carménère red wine produced with 2 different	Addition after the end of malolactic fermentations. 2 months on aging in tanks	Yeast hulls improved color stability if coupled with high mannoproteins producer yeast after both tank and bottle aging;
	Iosip et al., 2022	One commercial yeast hull at 30 g·hL^{-1}	Feteasc㠠neagr㠠red wine	6 months of aging after racking and YDPs addition. Analyses after 3 and 6 months. Control wines are aged six months on fermentation yest lees.	The optical density at 420 nm remained stable during the aging with the addition of yeast hulls. The color intensity increased and the hue remained constant. The use of the commercial YDP resulted in better color stability compared to traditional aging on lees.
Yeast extracts	Iturmendi et al., 2010	Three yeast protein extracts at 8 g·hL^{-1} paired with bentonite at 30 g·hL^{-1}. Y	Seven young Tempranillo wines.	48 h at 20 °C.	Yeast protein extracts with bentonite reduced color intensity less than gelatine and did not modify the hue.
	Fernandes et al., 2015	One yeast extract obtained from selected oenological yeasts at 10 and 20 g·hL^{-1}	Three young white wines from different regions in Portugal.	Addition after (I) alcoholic fermentation and (II) after 5 months long oxidation process. Fining operations lasted 48 h.	The treated samples have been found to be more greenish and less yellowish, more brilliant and less saturated than non-treated samples. Yeast protein extracts protected color of white wines from oxidation.
	Lochbühler et al., 2015	Four commercial yeast protein extracts at 30, 50 and 70 g·hL^{-1}.	Rondo, Bolero and Pinot noir red wine blend and a Syrah red wine.	3 days fining treatment (20 °C).	YDPs caused a slight decrease in color, significant with one yeast protein extract. Slight but not significant increase of

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Table 1 (*continued*)

Typology of YDP	Reference	YDPs added	Wine	Contact/ storage time	Key findings
Mannoproteins	Guadalupe et al., 2007	One commercial mannoprotein at 13.5 g·hL^{-1}.	Tempranillo red wine produced with two different alcoholic fermentation yeasts.	Addition prior alcoholic fermentation. 45 days of oak aging after malolactic fermentation	anthocyanins combined with tannins for one yeast protein extract. Differences in color between wines obtained with the 2 yeasts. Lower color intensity and lower total polyphenol index (TPI) with mannoproteins addition, probably due to precipitation of complexes polyphenols-mannoproteins.
	Guadalupe and Ayestarán, 2008	One commercial mannoprotein at 13.5 g·hL^{-1}	Tempranillo red wine.	Addition prior alcoholic fermentation. 45 days of oak aging.	Wine added with mannoproteins showed lower color intensity; no significant differences were found in monomeric anthocyanidins.
	Rodrigues et al., 2012	Experiment 1: two commercial mannoproteins added at 20 and 40 g·hL^{-1} after malolactic fermentation. Experiment 2: two different commercial mannoproteins added at 30 g·hL^{-1}.	Touriga Nacional, Aragones and Alfrocheiro red wines	-Experiment 1: addition after malolactic fermentation, 21 months bottle aging on 2 wines at 20 °C. -Experiment 2: addition after malolactic fermentation, 60 days at 35 °C.	Wines without mannoproteins maintained slightly higher color intensity. No differences in the content of polymeric pigments. Storage at 35 °C led to higher anthocyanins concentration in wines added with mannoproteins.
	Alcalde-Eon, García-Estévez, Puente, Rivas-Gonzalo and Escribano-Bailón, 2014	Two liquid commercial mannoproteins. Addition of mannoproteins combined with the addition of Pedro Ximénez overripe seeds respectively at 300 mL/hL for the first one and 50 and 125 mL/hL for the second one.	Syrah red wine	Mannoproteins addition after alcoholic fermentations and prior bottle aging. Cold treatment at 4 °C for 7 days to improve wine colloidal instability.	One mannoprotein caused a decrease in anthocyanins and some anthocyanins derivatives; however, it seems able to protect some of the pigments against cold treatment. Both mannoproteins showed a protective effect against the bleaching effect of the pigments.
	Ribeiro et al., 2014	Eleven different commercial mannoproteins added at the concentration suggested by manufacturer.	Young white wine from Douro valley.	7 days at 20 °C before analysis.	Some mannoproteins have a protective effect on white wine color evolution as they decreased the browning potential indicating a faster oxidation of oxidizable phenols.
	Ghanem et al., 2017	One commercial mannoprotein at 10, 25 and 40 g·hL^{-1}	Cabernet red sauvignon wine.	Addition of mannoproteins after the malolactic fermentations. Analyses carried out after 48 h.	Mannoproteins slightly but significantly decreased color intensity and increased the hue of the wine, the results were not correlated with the concentration added.
	Alcalde-Eon et al., 2019	One commercial mannoprotein at 35 g·hL^{-1}	Tempranillo red wines.	Addition prior alcoholic fermentation. Two treatments: - cold treatment (4 °C for 48 h) - ambient temperature for 48 h	Mannoproteins addition increased the hue of the wines and protected the color against cold treatments, it prevented the precipitation of colloidal unstable anthocyanin derivative pigments such as A-type vitisins.
	Rinaldi et al., 2019	Three commercial mannoproteins at 20 g·hL^{-1}	Aglianico and Sangiovese red wines.	Mannoproteins addition after 9 months vinification occurred. 12 months bottle aging.	Mannoproteins favored the formation of polymeric pigments enhancing the color stability of Sangiovese wines. In Aglianico wines, characterized by higher color intensity, no significant modifications of color were observed.
	Rinaldi et al., 2021	Three commercial mannoproteins at 20 g·hL^{-1}	Three Sangiovese red wines obtained with different 12 days of maceration, 27 days of maceration and the pressed fraction.	Mannoproteins addition prior the bottling. 6 months bottle aging.	In extended maceration samples, one commercial mannoprotein improved *b and L* indicating a greater amount of polymeric pigments. In short maceration wines all the treatments improved polymeric pigments concentration. The addition of mannoproteins in wines with a lower ratio between anthocyanins and tannins, such as in extended maceration wines, could improve color stability.
	Yue et al., 2021	One commercial mannoprotein at 10 and 30 g·hL^{-1} prior (I) alcoholic fermentations and (II) bottling.	Cabernet sauvignon red wine	Mannoproteins added (I) prior alcoholic fermentation and (II) before bottling. Bottle aging for 12 months at 20 °C	The addition before fermentation significantly increased the content of certain anthocyanins; during storage the addition of mannoproteins showed a more

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Table 1 (*continued*)

Typology of YDP	Reference	YDPs added	Wine	Contact/ storage time	Key findings
Non specified YDPs	Oyón-Ardoiz, et al., 2022	Four commercial mannoproteins rich extract from *Saccharomyces* and non-*Saccharomyces* at 50 g·hL^{-1}	Tempranillo red wine. 6 months barrel aging.	-Experiment 1: 4 °C for 11 days. -Experiment 2: 22 °C for 4 days.	limited and opposite impact on color components. Decreased a* and L* with the addition during fermentation, opposite effect on color observed with the addition of 30 g·hL^{-1} mannoproteins during storage. Mannoproteins from a specific non-*Saccharomyces* yeast was more effective in stabilizing color, especially in Experiment 1
	Alcalde-Eon, et al., 2024	One commercial mannoprotein at 40 g·hL^{-1}	Different binary synthetic wine solutions containing only malvidin-3-glucoside and different flavan-3-ols.	Synthetic systems kept in darkness at 25 °C for 22 days.	Improved especially vitisin A and B concentration. The copigmentation degree of the solution affected the effect of mannoproteins: (i) for higher copigmentation, the presence of mannoproteins reduced it; (ii) for lower copigmentation, mannoproteins improved it.
	Dong et al., 2024	Three commercial mannoproteins at 1.5 g·L^{-1}.	Cabernet Sauvignon red wine and different synthetic wine solutions.	Addition prior accelerated wine aging (30 °C for 12 days). Synthetic solutions aged for 120 h at room temperature.	Mannoproteins with higher mannose/glucose ratio and lower molecular weight better protected phenolic compounds against degradation and precipitation.
	Liu et al., 2025	Mannoproteins and yeast polysaccharides at 100 g·hL^{-1}	Cabernet sauvignon red wine.	Addition of mannoproteins and polysaccharides prior alcoholic fermentation. 4 months bottle aging.	Addition of mannoproteins could accelerate the decrease of color. A decrease of a* and chroma and an increase of hue was revealed.
	Zhai et al., 2025	Commercial mannoproteins and arabinogalactans at 10, 20 and 40 g·hL^{-1}.	Cabernet Sauvignon, Marselan and Petit Verdot red wines	Addition of polysaccharides prior bottling, 12 months of bottle aging	Higher a* value and lower L* value, mainly attributed to the increased concentration of anthocyanin derivatives. The most notable differences found in the wine with highest anthocyanin concentration and lowest polysaccharide concentration, enhancing color stability during bottle aging.
	Rinaldi et al., 2026	Three commercial mannoproteins at 20 and 40 g·hL^{-1}.	Grenache-Syrah blend and Barbera red wines	Addition one week prior filtration and bottling. Analyses after 1 and 5 months.	Mannoproteins increased copigmentation in both wines, with different magnitude. Mannoproteins generally maintained higher levels of anthocyanins in wine and increased coloring matter stability.
	Yin et al., 2026	One commercial mannoprotein. Thermal stability assessment: addition at 2, 4 and 6 g·L^{-1}. Storage stability assessment: grape juice mixed with 8 g·L^{-1} mannoprotein solution (1:1 *v*/v).	Summer Black garpe juice	Thermal stability: 40, 60 and 80 °C for 4 h. Storage stability: 4 °C and room temperature over 30 days.	Mannoproteins protected anthocyanins from oxidation with heat treatment, maintained higher color intensity, a* and b* coordinates and lower L*. Lower ΔE after storage treatment than untreated trials.
	Del Barrio-Galán, Pérez-Magariño and Ortega-Heras, 2011	Four commercial YDPs; three unsoluble YDPs added at 40 g·hL^{-1};one soluble YDP added at 5 g·hL^{-1}.	Tempranillo red wine	Addition after alcoholic fermentation and after malolactic fermentation. 6 months barrel aging	No significant differences in color after barrel aging
	Del Barrio-Galán, Pérez-Magariño, Ortega-Heras, Williams and Doco, 2011	Three not specified commercial YDPs enriched in polysaccharides; two unsoluble YDPs added at 40 g·hL^{-1};one soluble YDP added at 5 g·hL^{-1}.	Verdejo white wine	Addition after alcoholic fermentation occurred. 60 days on lees aging and 6 months bottle aging.	A little but significative decrease in wine color intensity was found; YDPs were proposed as fining agents for correction of browning in white wines
	Del Barrio-Galán et al., 2012	Six commercial YDPs at 40 g·hL^{-1}.	Tempranillo red wine and Verdejo white wine	Addition after alcoholic fermentation. 8 weeks aging with YDP contact and 3 months bottle aging	Results affected by YDP assayed. In white wines some of the YDPs significantly decreased the absorbance at 420 nm; in red wines YDPs addition increased in some cases the color intensity. No significant differences under the sensory color evaluation viewpoint

the control wine and comparable to those detected in wine added with sulfur dioxide, indicating a preventive effect towards the occurrence of phenol oxidation and, consequently, the browning of wine. Furthermore, Comuzzo et al. (2015) reported a greater susceptibility to browning in wines treated with yeast autolysates. This observation suggests that a lower extent of phenolic oxidation occurred during wine aging, resulting in a larger pool of oxidizable phenolic compounds remaining available at the time of the browning test. These findings indicate that yeast autolysates may exert a protective effect against polyphenol oxidation, thereby contributing to the preservation of white wine phenolic fraction during aging. Ribeiro et al. (2014) observed that mannoproteins could decrease the yellow pigmentation of wines and increased lightness, this effect can be due to the protection of phenols towards oxidation. However, as already mentioned, the effectiveness of YDPs is strongly dependent on the specific product, leading to variable outcomes among different YDP formulations (Del Barrio-Galán et al., 2012). The compound that may play the most relevant role in the oxidative protection provided by YDPs is GSH, as highlighted by Bahut et al. (2020). Nevertheless, several studies have suggested that the decrease of browning could not be solely dependent on GSH concentration (Andújar-Ortiz et al., 2010; Comuzzo et al., 2015; Voce et al., 2021). Other constituents, such as proteins, peptides and lipid fractions, may also contribute to the antioxidant capacity of YDPs (Comuzzo et al., 2015).

The studies available in the literature differ substantially in terms of contact time, storage conditions, YDP formulation, and wine matrix, ranging from synthetic wine solutions to white wines and red wines produced from different grape varieties. Such heterogeneity makes it difficult to draw robust and generalizable conclusions, although several findings highlight the promising potential of YDPs. In particular, the polyphenolic composition of wine, which is strongly influenced by grape variety and vintage, appears to play a key role in determining the effectiveness of YDPs. Their impact may vary according to anthocyanin profiles, tannin composition, and the overall phenolic characteristics of the wine, underscoring the need for tailored YDP formulations designed to achieve specific oenological objectives in particular wine styles. The development of such targeted products and application protocols require large investigations capable of accounting for vintage-related variability and identifying consistent trends across diverse winemaking conditions. Despite these challenges, YDPs represent a valuable tool for addressing some of the emerging issues associated with climate change. Rising temperatures are increasingly leading to a decoupling of technological and phenolic maturity, particularly in warm viticultural regions, resulting in wines characterized by underdeveloped tannin structures and reduced color stability. Under these conditions, the strategic use of YDPs during vinification may contribute to improving phenolic balance, enhancing color stability, and ultimately supporting wine quality.

7. Influence on sensory characteristics

7.1. Influence on wine astringency

It is well-known that the aging of wines on yeast lees can lead to softener wines and a decrease in perceived astringency. The aging on yeast lees can specifically lead to an adsorption of tannins with a higher mDP, leading to a decrease in the total polyphenol index (TPI) and mDP. Polyphenols interact mainly with cell walls; however, they can also interact with cytoplasmic material (Mekoue Nguela et al., 2015). Adsorption occurs mainly due to mannoproteins, but the smaller tannins, especially the more polar ones, can penetrate the pores of the cell wall and interact with the membrane (Mekoue Nguela et al., 2015). Mekoue Nguela and collaborators (2015) also hypothesized that even the larger tannins may be able to penetrate the pores of the cell wall interacting with both the wall and the cytoplasmic material. The use of yeast mannoproteins, yeast hulls, autolysates and inactivated yeasts can represent a suitable opportunity to simulate aging on yeast lees limiting the occurrence of yeast lees-related off flavours (e.g., reduced odors) and ensuring a softer and less astringent wine. Escot et al. (2001) associated the addition of exogenous polysaccharides to wine with a decrease in astringency. The addition of yeast polysaccharides to wine, as those being possible released from YDPs, were associated with a decrease in tannin mDP (González-Royo et al., 2016). Although the underlying mechanisms have not been fully elucidated yet, evidence suggests that yeast polysaccharides may interfere with tannin polymerization reactions, thereby limiting the formation of highly polymerized tannin structures (Rodrigues et al., 2012). The growth of flavan-3-ol polymers can be prevented through the interaction between polysaccharides and polyphenols; this interaction prevents further bonds between flavan-3-ol monomers that also result less reactive towards proteins, increasing their solubility and decreasing their astringency (Guadalupe et al., 2007). Tannins, especially those with higher molecular weight, can be either adsorbed by the insoluble parts of cell walls or interact with the soluble fractions of YDPs, such as peptides and proteins, causing their precipitation (Mekoue Nguela et al., 2016). An additional interaction pathway was hypothesized by Mateus et al. (2004), who reported that polysaccharides can develop a secondary structure in solution, creating hydrophobic pockets capable of encapsulating more complex polyphenols. It should be noted that the adsorption of tannins by polysaccharides, increases only up to a certain limit, beyond which no further polyphenol adsorption occurs. As the polysaccharides concentration is increased, this plateau level rises, allowing excess polyphenols to further interact with both the soluble and insoluble components of YDPs (Mekoue Nguela et al., 2023). However, an excessive addition of YDPs and consequently of polysaccharides to the wine could cause over-collaging, not leading to the desired effects on astringency (Comuzzo et al., 2005). Additionally, Mekoue Nguela et al. (2024) found a great behavior difference among different typologies of YDPs, observing in red wine a significant difference in decrease in high molecular weight pigments (ranged between 19% and 85%) and in tannins precipitation (ranged between 15 and 50%). The lowest decrease was found with the addition of mannoprotein rich-YDPs, indicating that mannoproteins could stabilize the tannins in solution, reducing the active tannin sites for the interaction with salivary proteins. Mannoproteins can have different sizes and compositional characteristics, which explain the different behavior towards the interaction with polyphenols (Rodrigues et al., 2012). In particular, more linear polysaccharides appear to be more effective at stabilizing anthocyanins through direct interactions, whereas more highly branched polysaccharides are better able to mitigate tannin-protein interactions (González-Royo et al., 2016; Manjón et al., 2021). Del Barrio-Galán et al., (2012) observed significant decreases in total polyphenols only with the addition of YDPs that presented polysaccharides with molecular weight between 50 and 400 kDa; however, a significant decrease in the perception of green tannins sensation was observed for each YDP tested. This suggests that, not all the yeast polysaccharides are able to precipitate tannins and certain YDPs do not bind tannins through their insoluble fractions, they can nevertheless modulate the interactions between polyphenols and salivary proteins. The composition of mannoproteins affects the adsorption of polyphenols and consequently the perception of astringency. Galaz-Torres et al. (2026) reported that mannoproteins with an average molecular weight of approximately 43 kDa and a higher polysaccharide content were particularly effective in enhancing wine smoothness, as well as increasing perceptions of warmth and sweetness. The improvement in tannin smoothness was more pronounced in wines exhibiting higher initial astringency, indicating that not only the intrinsic characteristics of mannoproteins, but also the composition of the wine, play a key role in modulating these sensory attributes. Manjón et al. (2020) observed, in a synthetic wine solution, that the mannoproteins with higher proportion of larger polysaccharides (up to 200 kDa), and the less purified mannoproteins reduced the astringency to a greater extent, while the more purified

mannoproteins, composed mainly of mannose, had only a negligible effect on the perception of astringency. Comparable results in term of purification degree were found by Del Barrio-Galán et al. (2012). The possible synergic action between polysaccharides and other soluble and insoluble components of the yeast cells can modulate the perception of astringency. Manjón et al. (2021) observed that mannoproteins with high carbohydrate content could stabilize soluble aggregates with salivary proteins and flavanols, while mannoproteins with higher protein content could precipitate low polymerization degree polyphenols. In both cases non-galloylated flavanols mainly interacted with mannoproteins. The wine, in terms of grape variety, vintage and aging, treated with mannoproteins also plays a role con the effectiveness and consistency in astringency decrease by YDP addition. Mekoue Nguela and collaborators (2024) found that the effects on more aged wines are less evident probably because a relevant part of the large tannins had already precipitated at the time of addition. Del Barrio-Galán, Pérez-Magariño and Ortega-Heras (2011) observed different decreases of both polyphenols and flavonols in two Tempranillo red wines from different vintages, because of the different initial concentration of polyphenols and flavonols; in any case, a decrease in astringency was observed. Rinaldi and collaborators (2019) carried out additions of yeast hulls on two wines from varieties with great differences in polyphenol levels, Aglianico and Sangiovese. A smaller decrease in the concentration of total polyphenols was observed on Sangiovese, which initially presented lower concentrations of total polyphenols than Aglianico. However, in both varieties a decrease in the green tannin sensory characteristic was observed. In a later study, the same authors confirmed these results, observing that a greater decrease in tannins and astringency was observed in wines with a higher tannin content (Rinaldi et al., 2021). The grape variety and the vintage could affect the phenolic composition of wines and thus, the effect that the application of different typologies of YDPs. Mekoue Nguela et al. (2015) evaluated the reactivity of different polyphenolic fractions in synthetic wine and they found inactivated yeasts and yeast autolysates reacted more with grape skin tannins in synthetic wine solution, which had a higher mDP and a higher percentage of galloylation, compared to the other polyphenolic fractions studied. Furthermore, these authors demonstrated yeast protein extracts can create more stable interactions with tannins than purified mannoproteins depending on the protein characteristics on yeast protein extract. All these findings further support that the interactions between yeast cell components and tannins depend on the type of tannins present in the wine matrix. In general, the application of YDPs in winemaking has been generally associated with a reduction in total tannin andpolyphenolconcentrations, a decrease in perceived astringency, and an increase in smoothness and sweetness. However, the magnitude of these effects varies according to the type of wine and the YDP employed, with more pronounced effects on highly polymerized tannins and more limited effects on monomeric flavan-3-ols (Francisco et al., 2021; Ghanem et al., 2017; Guadalupe et al., 2007; Guadalupe & Ayestarán, 2008;Iosip et al., 2022). In contrast, Lochbühler et al. (2015) and Iturmendi et al. (2010) reported no significant effects on either tannin concentration or astringency perception. In another study, a decrease in astringency was observed without a corresponding reduction in tannin concentration (Del Barrio-Galán et al., 2019). Similarly, Rodrigues et al. (2012) described a protective effect of certain YDPs on tannins, despite observing no decrease in proanthocyanidin concentration or mDP. Taken together, these results suggest that specific mannoproteins may protect tannins from precipitation, with this effect being strongly influenced by mannoproteins molecular weight.

7.2. Influence on aromatic characteristics

The addition of YDPs at different stages of winemaking can induce significant changes in the sensory profile of wines, including modifications of mouthfeel as well. It is therefore essential to carefully consider their impact on wine aroma, as these effects may be either beneficial or detrimental to overall wine quality. Numerous studies have investigated the influence of YDPs on aromatic properties; however, the results are often inconsistent, largely due to variations in the wine matrix, the timing of addition, the type of YDP, the dosage applied, and the duration of contact with the wine. Multiple mechanism can occur and affect the interaction YDPs-aromas. Firstly, inactivated yeasts, yeast autolysates and yeast hulls may release volatile compounds into the wine matrix (Pozo-Bayón et al., 2009) and they are capable of adsorbing various aroma-active compounds onto their cell walls and membranes (Lubbers et al., 1994). Inactivated yeasts, yeast autolysates and yeast hulls can also release colloidal substances that alter the volatility of aromatic molecules (Comuzzo et al., 2011). Moreover, they can supply yeasts with amino acids, influencing the pool of aroma precursors (Andújar-Ortiz et al., 2014). They may also adsorb short- and medium-chain fatty acids, improving yeast fermentative performance (Lubbers et al., 1994). Furthermore, inactivated yeasts enriched in GSH can enhance the antioxidant capacity of wines, thus limiting aroma oxidation over time (Gabrielli et al., 2016). Table 2 summarized the most significant findings from recent studies carried out in both wine and synthetic wine over the past decades. A substantial variability of outcomes associated with the addition of YDPs was highlighted from the literature data, reflecting the multiple mechanisms through which YDPs can influence the aromatic properties of wines. The observed effects depend not only on the type of YDP employed, but may also vary within the same category. Indeed, additional factors such as YDP dosage (Comuzzo et al., 2006) and the characteristics of the wine matrix (Comuzzo et al., 2011) play a significant role in determining the final outcome. Nevertheless, a general trend can be identified, whereby the addition of glutathione (GSH)-enriched inactivated yeasts is often associated with an improvement in sensory performance. This effect has been linked to higher concentrations of key aroma compounds, including terpenes, norisoprenoids, and esters, in both white and red wines subjected to different aging conditions. However, Ferrer-Gallego et al. (2017) reported contrasting results, as they did not observe any significant improvement in sensory characteristics following the addition of GSH-enriched inactivated yeasts.

A wide range of volatile compounds were identified in YDPs. Comuzzo et al. (2011) detected up to 160 volatile compounds in yeast autolysates; however, only a limited number of these volatiles were actually released into the wine matrix (Comuzzo et al., 2011). The volatile compounds most frequently found in commercial inactivated yeasts or yeast autolysates preparations were either thermal degradation products of yeast constituents or compounds biosynthesized by yeasts. Such compounds include those derived from the thermal degradation of sugars, amino acids, and lipids. Carboxylic acids in the C_8-C_{16} range, originating from lipid degradation, were detected and, if present in relatively high concentrations, they can contribute to rancid or cheese-like aromas (Comuzzo et al., 2006; Rigou et al., 2021). Linear aldehydes such as pentanal, hexanal, octanal, and nonanal, produced from fatty acid degradation, were also identified, along with branched-chain aldehydes, like 2-methylpropanal and 2,3-methylbutanal, which result from the Strecker degradation of amino acids (Pozo-Bayón et al., 2009). Nitrogen-containing heterocyclic compounds were found at low concentrations; these may arise either from the Strecker degradation of amino acids or from Maillard reactions involving 1,2-dicarbonyl compounds and amino acids. The most abundant of these are 2,3-dimethylpyrazine, 2-ethyl-3,5-dimethylpyrazine, and 2,3,5,6-tetramethylpyrazine (Comuzzo et al., 2006; Pozo-Bayón et al., 2009). These compounds can impart earthy, roasted, or potato-like notes. Pyrroles, which are associated with popcorn-like and bakery aromas, were identified (Rigou et al., 2021). Sulfur-containing compounds, such as di- and trimethyldisulfides, methylthiazole, and benzothiazole, originating from the degradation of sulfur-containing amino acids like methionine, or from Maillard reactions involving cysteine, were detected as well. These molecules are typically associated with off-flavours described as cooked cabbage or rubbery. Comuzzo et al. (2012)

Table 2
Summary of the findings related to the volatile compounds and sensory profile obtained in the presence of yeast-derivatives products.

Typology of YDP	Reference	YDP added	Wine	Contact/ storage time	Key findings
Inactivated yeasts	Rodríguez-Bencomo et al., 2014	<3 kDa fraction of a commercial glutathione enriched inactivated yeast and of a fermentation nutrient inactivated yeast commercial preparation added at 1000 g·hL^{-1}	Synthetic wine solution spiked with single terpene compounds (nerol, β-citronellol, α-terpineol, and linalool) at a concentration of 25 mg·L^{-1}each.	Accelerated oxidation process: 3 weeks at 25 °C.	Aroma compounds. YDPs could prevent the loss of certain terpene compounds such as α-terpineol and linalool, with a decrease of 20% against control treatments with a decrease of around 30% for α-terpineol and around 20–25% with YDP addition against 40–45% decrease of the control sample for linalool.
	Andújar-Ortiz et al., 2014	One commercial GSH enriched inactivated yeast at 20 g·hL^{-1}	Grenache rosè wine	Addition before fermentation. 9 months of aging after fermentation and stabilization.	No sensory analysis performed. Aroma compounds. After 9 months, YDP-enriched wines showed higher concentration of esters in comparison to the control. Increase of linalool in YDP-enriched wines. Fatty acids increased in control wines, while the opposite trend was observed for most of the volatile studied, which diminish during time. Sensory profile. Very similar aromatic profile after 1 month of aging. After 9 months, YDP-enriched treated wines showed higher fruity aromas.
	Del Barrio-Galán, Cáceres-Mella, Medel-Marabolí and Peña-Neira, 2015	One commercial GSH enriched inactive dry yeast at 30 g·hL^{-1}	Cabernet sauvignon red wine produced with two different commercial active dry yeasts.	Addition after malolactic fermentation. 4 months on lees aging.	Aroma compounds. YDPs addition caused an increase of 3-methyl-1-buthanol. YDPs enriched in glutathione furtherly increased the concentration of this alcohol and of 2-hydrossymethylpropanoate, such as other superior alcohols. Sensory profile. Effect of YDPs addition depends on the *S. cerevisiae* strain employed.
	Gabrielli et al., 2016	One commercial glutathione enriched inactivated yeast at 40 g·hL^{-1}, coupled with addition of reduced glutathione depending on the trial.	Sauvignon white wine	Addition prior alcoholic fermentation. Analysis after racking and tartaric stabilization.	Aroma compounds. Addition of YDP increased concentration of esters, some terpenes and thiol compounds. Sensory profile. YDP-enriched wines show highest values of cooked vegetables, tropical, canned tropical, ripe guava and canned pineapple. Lowest values of passion fruit and fresh tropical.
	Ferrer-Gallego et al., 2017	One commercial inactivated yeast enriched with glutathione at 30, 20 and 10 g·hL^{-1}, mixed with chitosan, dmdc, reduced glutathione or oak ellagitannins, depending on the trial.	Tempranillo red wine and Albariño white wine.	Addition during grape reception, at the end of alcoholic fermentation and during bottling. Wines bottled after 4 months the end of fermentation.	Aroma compounds. No significant differences in volatile profile caused by the addition of the YDP in red wine. Sensory profile. Lower olfactory intensity in white wine.
	Del Barrio-Galán et al., 2019	One commercial inactivated yeast at 30 g·hL^{-1}.	Carménère red wine produced with 2 different alcoholic fermentation yeasts, one of them is a high mannoproteins producer	Added at after the end of malolactic fermentation. 2 months on lees aging and 3 months bottle aging	Aroma compounds. Wines treated with inactivated yeasts showed higher concentrations of esters two months after treatment and higher fatty acids 2 months after treatment and after 3 months of bottle aging compared to control wines for the samples fermented with the high mannoproteins producer yeast. Sensory profile. Not assessed
	Alfonzo et al., 2021	Addition of a specific inactivated yeast rich in glutathione at 40 g·hL^{-1}	Catarratto white wine produced with different yeast strains.	Racking after the alcoholic fermentation.	Aroma compounds. YDPs addition caused an increase of 3-methyl-1-buthanol. YDPs enriched in glutathione furtherly increased the concentration of this alcohol and of 2-hydrossymethylpropanoate, such as other superior alcohols. Sensory profile. Effect of YDPs addition depends on the *S. cerevisiae* strain employed.
	Schlögl et al., 2025	One commercial inactivated yeast enriched in GSH at 30 g·100 kg^{-1} of must.	Blaufränkisch grape must.	Addition prior fermentation.	Aroma compounds. Slight protective effects on monoterpenes and norisoprenoids and stabilizing effects over certain acetate esters. Sensory profile. Not assessed
Yeast autolysates	Comuzzo et al., 2006	Two commercial autolysates; addition in Chardonnay wine at 20, 50 and 100 g·hL^{-1}. In the	Chardonnay, Pinot gris, Sauvignon and Traminer white wines.	One overnight permanence on Chardonnay wine before GC-FID and GC–MS analysis. Two weeks bottle	Aroma compounds. Lower dosages increased the fruity and flowery perception, showing higher amounts of esters; higher dosages increased cheese-

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Table 2 (*continued*)

Typology of YDP	Reference	YDP added	Wine	Contact/ storage time	Key findings
		other wines at 15, 30, 45 and 60 g·hL^{-1}.		aging on YDPs before tasting for the other wines.	like and unpleasant odors due to higher amounts of carboxylic acids released. Sensory profile. No significant differences in sensory analysis.
	Comuzzo et al., 2011	One commercial yeast autolysate at 45 g·hL^{-1}	MWS at pH 3 and 4 and white table wine. Aromatic compounds were dissolved in both buffers and in wine.	1 week of contact time.	Aroma compounds. No significative differences of VOCs concentrations in table white wine. Strongly different effects depending on the matrix. Sensory profile. Not assessed
	Comuzzo et al., 2012	Three yeast autolysates obtained by different lysis processes: enzymatic, thermal and mechanical at 20 g·hL^{-1}	Chardonnay white wine	24 h on lees contact.	Aroma compounds. No clear evidence about the release of aromatic compounds in the wine. Sensory profile. Enzymatic autolysate showed the lowest aroma impact, these wine samples were characterized by the lowest olfactory intensity. Thermal autolysate showed the highest values of yeast extract descriptor.
	Del Barrio-Galán et al., 2019	One commercial yeast autolysate at 30 g·hL^{-1}	Carménère red wine produced with 2 different alcoholic fermentation yeasts, one of them is a high mannoproteins producer	Added at after the end of malolactic fermentation. 2 months on lees aging and 3 months bottle aging	Aroma compounds. Higher esters concentration compared to control wines two months after treatment and higher fatty acids after three months of bottle aging for the wines fermented with the high mannoproteins producer yeast. Sensory profile. Not assessed
	Alfonzo et al., 2021	Two commercial yeast autolysates at 40 g·hL^{-1}	Catarratto white wine produced with different yeast strains.	Racking after the alcoholic fermentation.	Aroma compounds. YDPs addition caused an increase of 3-methyl-1-buthanol. Sensory profile. The different commercial yeast autolysates in combination with the yeast strains enhanced different aromatic descriptors, depending on the combination.
	Lubbers et al., 1994	One commercial yeast hulls with and without lipids removed at 1 and 10 g·hL^{-1}	Synthetic wine solution at pH 3.5 spiked with different volatile compounds.	Not specified.	Aroma compounds. All the treated samples showed a decrease in concentration of all the volatile compounds studied. Greatest effect on the most hydrophobic molecules, such as β-ionone. Sensory profile. Not assessed
Yeast hulls	Nieto-Rojo et al., 2014	One commercial yeast hulls at 500 g·hL^{-1}	Synthetic wine with addition of 4-ethylphenol and 4-ethylguaiacol.	Consecutive measurements of 4-ethylphenol and 4-ethylguaicol since the reaching of adsorption equilibrium (up to 150 h).	Aroma compounds. Relevant adsorption of volatile phenols, reaching a maximum of 47% of 4-ethylguaiacol. Sensory profile. Not assessed
	Del Barrio-Galán et al., 2019	One commercial yeast hulls at 30 g·hL^{-1}.	Carménère red wine produced with 2 different alcoholic fermentation yeasts, one of them is a high mannoproteins producer	Added at after the end of malolactic fermentation. 2 months on lees aging and 3 months bottle aging	Aroma compounds. Higher concentrations of esters, higher alcohols, fatty acids and terpenes after three months of bottle aging for the samples fermented with the low mannoprotein producer yeast. Sensory profile. Not assessed
Yeast extracts	Comuzzo et al., 2006	One commercial yeast extract at 20, 50 and 100 g·hL^{-1}. In the other wines at 15, 30, 45 and 60 g·hL^{-1}.	Chardonnay, Pinot gris, Sauvignon and Traminer white wines.	One overnight permanence on Chardonnay wine before GC-FID and GC–MS analysis. Two weeks bottle aging on YDPs before tasting for the other wines.	Aroma compounds. Lower dosages increased the fruity and flowery perception, showing higher amounts of esters; higher dosages increased cheese-like and unpleasant odors, due to the high amount of carboxylic acids released. Strong effect on wine volatile composition due to yeast extract high solubility. Not well suited for aromatic wines. Sensory profile. No significant differences in sensory analysis.
Mannoproteins	Del Barrio-Galán, Pérez-Magariño, Ortega-Heras, Williams and Doco, 2011	Three not specified commercial YDPs enriched in polysaccharides; two insoluble YDPs added at 40 g·hL^{-1}; one soluble YDP added at 5 g·hL^{-1}.	Verdejo white wine	Addition after alcoholic fermentation occurred. 60 days on lees aging and 6 months bottle aging.	Aroma compounds. Possible initial retention of aroma that were released over time. Sensory profile. All the wines showed lower fruity aroma, except wines treated with 1 commercial YDP. After 6 months of aging all the wines showed stronger varietal, fruity, and floral aromas and higher olfactory intensity than the control wines.
	Costa et al., 2018	One commercial mannoprotein at 4 g·hL^{-1}.	Pinot noir, Chardonnay, Riesling and Viognier assembled in proportion: 30%, 30%, 30% and 10%.	Remuage and sampling after the completion of second fermentation.	Aroma compounds. YDP-free wines showed higher concentration of decanoic and dodecanoic acids (fatty and metallic notes). Sensory profile. Treated wines showed

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Table 2 (*continued*)

Typology of YDP	Reference	YDP added	Wine	Contact/ storage time	Key findings
	Liu et al., 2025	One commercial mannoprotein at 100 g·hL^{-1}	Cabernet Sauvignon red wine	Addition prior fermentation. 4 months bottle aging.	higher concentration of esters with fruity aromas. Aroma compounds. Mannoproteins addition led to a small increase of certain esters (ethyl-acetate, ethyl-butyrate and phenylethyl-acetate). Sensory profile. Not assessed
	Rodríguez-Bencomo et al., 2010	One commercial non specified YDP at 30 g·hL^{-1}.	Tempranillo red wine	Addition after alcoholic fermentation. 5 weeks of YDP contact. Samples analyzed after malolactic fermentation and after six months of bottle aging.	Aroma compounds. The differences in volatile compounds found at end of malolactic fermentation between the control wine and the wines treated with YDPs disappeared after 6 months in bottle. Regarding the sensory analysis, no significant differences were found among the different wines studied. Sensory profile. Not assessed
Non specified YDPs	Del Barrio-Galán, Pérez-Magariño and Ortega-Heras, 2011	Four commercial YDPs; three insoluble YDPs added at 40 g·hL^{-1};one soluble YDP added at 5 g·hL^{-1}.	Tempranillo red wine, two different vintages	8 weeks treatments after alcoholic fermentation. Analyses after treatment and after 3 and 6 months of barrel aging.	Aroma compounds. Not assessed. Sensory profile. No significant differences after the treatment. After 6 months wines treated with YDPs had higher fruity aromas than the control wines.
	Del Barrio-Galán et al., 2012	Six commercial YDPs at 40 g·hL^{-1}	Verdejo white wine and Tempranillo red wine	Addition after alcoholic fermentation. 8 weeks aging on YDPs and 3 months bottle aging	Aroma compounds. Not assessed. Sensory profile. No significant differences in the olfactory phase of red wines; treated wines seem to have lower olfactory intensity. Lower but not significant olfactory intensity in white wines also; white wines present lower fruity aroma but higher exotic fruit aroma.

demonstrated that the YDP production technology influence the volatile compounds released by YDPs, in particular, these authors found that lytic treatments result in YDPs with a lower aromatic load, while thermal treatments tend to produce YDPs with more pronounced yeast-like aroma perception.

Besides the high number of volatile compounds found in yeast autolysates, their effects are not limited to aroma release. As mentioned as above, they may also stimulate the formation of aroma compounds when added during alcoholic fermentation and help preserve volatile molecules due to the release of antioxidant compounds, such as GSH. The quantity and nature of released compounds depend on the specific characteristics of the YDP (e.g., type, solubility) as well as the aging conditions (e.g., concentration, duration of contact, matrix composition). Increases in the levels of fatty acids, fatty acid esters, and higher alcohols were observed as a direct result of YDP addition (Comuzzo et al., 2006; Gabrielli et al., 2016). In many cases, an enhanced perception of floral, fruity, herbaceous, or exotic fruit aromas was reported, attributed to the increased formation of thiols and the protection of esters, higher alcohols, and terpenes from oxidative degradation (Comuzzo et al., 2006; Del Barrio-Galán et al., 2012; Iosip et al., 2022; Pérez-Magariño et al., 2015). Inactivated yeasts addition was also associated with an increase in terpene, norisoprenoids, higher alcohols and, some cases, esters concentrations in the finished wine, especially if the products are GSH enriched (Rodríguez-Bencomo et al., 2014; Liu et al., 2025; Schlögl et al., 2025). Comuzzo et al. (2011) reported a more than 30% increase in β-ionone in white wines treated with yeast autolysates; this increase was not solely due to a decrease in oxidative degradation of these compounds due to the presence of GSH. These authors attributed part of the effect to a salting-out phenomenon: monosaccharides released by YDPs may bind water molecules from solvation shells, leading to an increase of the partition coefficient of the aromatic compounds resulting readily available in the gas phase. The same mechanism was proposed to explain increases in ester concentrations, such as ethyl pentanoate and hexyl pentanoate. The concentration of these aroma-contributing molecules evolves over the course of wine aging. This evolution is primarily influenced by the presence of ethanol and oxygen. Ethanol, in particular, promotes esterification of fatty acids; however, these esters may undergo acidic hydrolysis over time. In some cases, YDP addition can slow the hydrolysis of long-chain fatty acid esters (Šuklje et al., 2016). Thus, certain inactivated yeasts, especially those enriched in GSH, could delay esters hydrolysis; in fact, GSH and other sulfur-containing compounds could react with o-quinones produced by the oxidation of caftaric acid and other polyphenol compounds (Šuklje et al., 2016). Andújar-Ortiz et al. (2014) observed higher ester concentrations in rosé wines, obtained by supplementing the must with GSH enriched inactivated yeasts, after nine months of bottle aging. The higher ester concentration was attributed to a higher initial pool of esters, whose production during the alcoholic fermentation was stimulated by the nitrogen compounds released by inactivated yeasts in must. Moreover, the addition of inactivated yeast enriched in GSH, beyond delaying oxidation of aromatic compounds, may also lead to increased concentrations of thiols, such as 3-mercaptohexanol and its acetate ester. This is attributed to the release of cysteine or cysteine-containing peptides into the fermentation medium (Gabrielli et al., 2016). Similar results were obtained by Alfonzo et al. (2021), who reported that GSH-enriched inactivated yeast addition in must led to increased levels of 3-methyl-1-butanol, 2-hydroxypropanoate, and other higher alcohols and esters in white wines.

However, the outcomes of using YDPs in the context of the improvement in sensory properties was not always observed. Del Barrio-Galán et al. (2012) revealed only small effects on aromatic profile for red wines made from must added with yeast autolysates, yeast hulls and mannoproteins in a red wine. Similarly, Rodríguez-Bencomo et al. (2010) did not observe any effect on the sensory profile of wines with the supplementation of a commercial yeast derivative in must. Even the concentration of added YDPs can affect the aromatic quality of the final wine: Comuzzo et al. (2006) found that an addition of 20 g·hL^{-1} in Chardonnay wine enhanced floral aromas, whereas at 50 and 100 g·hL^{-1}, cheese-like and unpleasant notes became more prominent.

Nevertheless, the insoluble fraction could interact with aromatic

compounds already present in wine. Besides the release of odor-active compounds and the direct or indirect modification of the aromatic properties, YDPs can also adsorb a wide range of volatile compounds. They may bind aromatic compounds through their colloidal structures, which may then be removed during clarification, leading to a decrease in overall aroma intensity (Lubbers et al., 1994). In synthetic wine, Lubbers et al. (1994) observed that the most strongly adsorbed compounds by yeast cell walls were those with high hydrophobicity and lipophilicity; for instance, β-ionone decreased up to 70%, and ethyl hexanoate by 44%. Higher alcohols and less lipophilic molecules tend to bind less strongly than esters or norisoprenoids (Comuzzo et al., 2011; Lubbers et al., 1994). The primary interactions involved are hydrophobic interactions and Van der Waals forces. In some cases, only a limited reduction in linalool has been observed (Comuzzo et al., 2011). It is important to consider possible competition among volatile compounds for binding sites. The strength and extent of these interactions also depend on matrix characteristics; binding is stronger at higher pH values, but the magnitude of interaction is greater at lower pH (Comuzzo et al., 2011). Beyond binding desirable aromatic compounds, YDPs can also adsorb off-flavor compounds, such as volatile phenols (e.g., horse sweat or leather descriptors). These molecules can be removed by up to 50% when initially present above their sensory threshold, making YDPs potentially useful in mitigating defects that emerge after alcoholic fermentation, particularly during barrel aging (Pradelles et al., 2008). However, similarly to the aroma depletion, the effectiveness of adsorption depends on the matrix. Nieto-Rojo et al. (2014) reported a removal up to 47% in 4-ethylguaiacol, although the adsorption reached a saturation plateau once YDP binding sites could be fully occupied. Mannoproteins are primarily responsible for volatile phenol binding and interactions with other aroma compounds; the protein fraction plays a crucial role (Li et al., 2023). Nevertheless, Lubbers et al. (1994) found that depletion of lipids from YDPs led to reduced adsorption, especially for highly lipophilic volatiles, suggesting that not only cell walls, but also cell membranes can significantly contribute to volatile binding.

Finally, the purity and the nature of YDPs strongly influence their effects on the aromatic properties of wine. Del Barrio-Galán et al. (2019) assayed an inactivated yeast, a yeast autolysate and a yeast hull on red wines fermented with two different yeast strains; the authors reported that depending on the fermentation yeast employed, the different YDPs typologies could exert the volatile adsorption of some aromatic compound or promote a salting-out effect when applied to the same wine matrix. Interestingly, after six months of aging, all treated wines displayed greater aromatic intensity than the YDP-free control. This finding suggests that initial binding to YDPs protected aroma compounds from degradation, releasing them gradually during aging.

Several studies did explore the impact of YDPs on wine aroma composition (Table 2). The considerable variability among the reported findings underscores the complexity of the mechanisms through which yeast-derived components interact with volatile compounds. The outcome of these interactions appears to be strongly influenced by both the characteristics of the YDPs and the composition of the must or wine matrix, highlighting the matrix-dependent nature of their aromatic effects.

8. Impact of yeast derivative products on foam properties in sparkling wines

Foam properties are key quality indicators in sparkling wines, directly affecting consumer perception and acceptance. Foamability (maximum foam height, HM), foam stability (HS), and effervescence characteristics are influenced by multiple chemical and physical parameters, including the presence of surface-active macromolecules such as proteins, mannoproteins, and polysaccharides (Pérez-Magariño et al., 2015).

Despite the relatively low concentrations of proteins in sparkling wines (4–16 mg/L), they have been identified as the principal compounds contributing to foam formation and stability (Kemp et al., 2019). However, their behavior is not uniform: some proteins are excellent foam formers but poor stabilizers, and vice versa (Martínez-Lapuente et al., 2015). The role of amino acid composition and hydrophobicity need to be taken into account. Proteins with higher hydrophobicity stabilize the inter-bubble films more effectively by anchoring at the gas-liquid interface, forming viscoelastic films. Bentonite fining, which removes proteins, is commonly used for protein stabilization, but significantly reduces foaming properties, underlining the importance of preserving beneficial macromolecules during the preparation of the base wine subjected to refermentation.

Yeast mannoproteins, released during alcoholic fermentation and aging on yeast lees, are among the most effective foam-active compounds due to their amphiphilic nature and high molecular weight (Vincenzi et al., 2014). These glycoproteins could act as a protective skin on the bubbles formed, promoting foam formation and stability. Studies have confirmed that mannoproteins improve foaming properties. Nuñez et al. (2006) isolated and characterized a thermally-extracted yeast cell wall fraction rich in mannoproteins with molecular weights between 10 and 30 kDa and reported that this fraction significantly enhanced both foam height and foam stability in synthetic wine. Moreover, the effect was dose-dependent, meaning that increasing amounts of this extract could lead to progressively higher foam properties. Commercial and experimental yeast autolysates, hulls, and mannoprotein preparations were applied during tirage to improve foam quality (Lambert-Royo et al., 2022). These products showed different contents of mannoproteins, polysaccharides, and proteins and their addition could enhance foamability and foam persistence in sparkling wines produced via traditional bottle fermentation (Lambert-Royo et al., 2022); in long-aged sparkling wines, inactivated yeasts, yeast autolysates and yeast extracts significantly increased the frequency of bubble formation, a parameter linked to effervescence intensity. Autolysates were particularly effective in increasing foam height and stability after 9 and 18 months of aging, with a more dispersive effect after 18 months. However, some of the commercial inactivated yeasts and yeast autolysates negatively influenced the foam stability, indicating a possible different effect depending on the YDP added. While yeast mannoproteins have superior foaming properties, their synergy with grape pathogenesis-related proteins enhances overall foam behavior. Vincenzi et al. (2014) demonstrated that a reconstitution of grape proteins with yeast mannoproteins restored foam in ultrafiltered Prosecco wines, where no foam was measurable in the absence of both grape and yeast proteins and in the presence of only grape proteins. However, the addition of both grape and yeast proteins increased foamability more than the addition of yeast protein fractions alone, thus indicating synergic effects between these protein fractions.

In contrast, Pérez-Magariño et al. (2015) observed that the addition of commercial autolysates during the tirage phase did not significantly improve neither HM or HS in white and rosé sparkling wines. Foam behavior appears to be highly dependent on the wine matrix, grape variety, and the chemical purity and composition of the YDPs, especially their mannoprotein content. In this context, Martínez-Lapuente et al. (2015) reported that grape-derived polysaccharides, specifically arabinogalactan-proteins, showed a higher correlation with HS than yeast mannoproteins. The authors proposed that the protein moiety of glycoproteins plays a key role in foam persistence, whereas mannoproteins may be more important for initial foam formation.

The choice of fermenting yeast strain also plays a key role. Non-*Saccharomyces* yeasts such as *Torulaspora delbrueckii*, when employed for base wine production in subsequent fermentations with *S. cerevisiae*, showed higher autolytic capacity and release of low molecular weight proteins, which could lead to improved foam performance compared to conventional *Saccharomyces cerevisiae* (González-Royo et al., 2017). Sequential inoculation of *T. delbrueckii* and *S. cerevisiae* resulted in sparkling wines with significantly greater HM and protein content than single-strain fermentations (Medina-Trujillo et al., 2017).

9. Limitations and future perspectives

The several studies carried out during the past decades showed that the employment of YDPs can lead to ambiguous results; their effectiveness is highly variable and strongly dependent on product composition, wine matrix, dosage, and timing of application. The knowledge regarding the use of these products has increased markedly in recent years; however, for many of the functions they can perform, their intrinsic characteristics and the application conditions required to achieve specific outcomes in different wines remain poorly defined. Although several mechanisms of action were elucidated, the results of their application are still, in some cases, difficult to predict due to the complexity of interactions between the various soluble and insoluble fractions of YDPs and wine, which is itself a highly complex matrix with extremely variable characteristics. Despite promising applications, the predictability of YDP performance remains limited. This lack of predictability represents a major constraint for their rational use in oenology and underscores the need for a more systematic and mechanistic understanding of their behavior.

YDPs should be regarded not merely as substitutes for aging on yeast lees, but as a flexible tool consistent with the principles of precision and sustainable oenology. A key challenge in the use of YDPs is the identification of specific compositional or functional markers that can predict their suitability for particular oenological applications or for addition to specific types of wines. Such markers would allow winemakers to select the most appropriate YDPs to achieve desired effects on aroma, mouthfeel, stability, or other wine attributes, thereby optimizing product quality and consistency and furtherly implementing the precision oenology. Particular attention should also be devoted to the application of YDPs in low- and no-alcohol wines. These products are often characterized by reduced aroma intensity, lower body and mouthfeel, diminished colloidal stability, and increased susceptibility to oxidation. Moreover, the systematic study of YDPs derived from non-*Saccharomyces* yeasts represents a particularly promising topic. Non-*Saccharomyces* species are known to produce cell wall components, polysaccharides, peptides, lipids, and redox-active compounds with compositional and structural features that can differ from those of *S cerevisiae*. Exploring these differences may lead to the identification of novel markers and functionalities, expanding the current knowledge of YDPs and enabling more tailored and wine-specific applications.

10. Conclusions

YDPs were initially developed and employed as technological alternatives to traditional aging on yeast lees, aiming to reproduce some of the beneficial effects associated with lees contact while offering greater flexibility and process control. Over time, however, their role in winemaking has expanded considerably, and YDPs are now recognized as a diverse and multifunctional class of oenological tools. Their growing relevance stems from their complex composition, which includes polysaccharides, peptides, amino acids, lipids, antioxidants, and other bioactive compounds capable of interacting with multiple wine constituents.

The reviewed evidence highlights that YDPs can influence several key aspects of the winemaking process, including fermentation performance, wine stabilization, oxidation control, color preservation, and sensory quality. However, their technological effects are largely determined by both the characteristics of the YDP employed and the physicochemical properties of the wine matrix. The considerable variability reported among studies indicates that their performance cannot be generalized across wine styles and production conditions, but rather reflects a complex interplay between product composition, wine composition, processing conditions, and target oenological objectives.

Despite this complexity, YDPs have consistently demonstrated their potential to support modern winemaking by providing versatile and sustainable approaches for the modulation of wine quality. Their ability to simultaneously influence multiple technological and sensory parameters distinguishes them from many conventional oenological additives and contributes to their increasing adoption in commercial practice.

Overall, the evolution of YDPs from simple alternatives to aging on yeast lees into multifunctional tools capable of addressing diverse oenological challenges represents one of the most significant developments in this field. Their versatility, combined with the continuous improvement of production technologies and product formulations, positions YDPs as valuable resources for enhancing wine quality and supporting innovation in contemporary winemaking.

CRediT authorship contribution statement

Alessio Altomare: Writing – original draft, Data curation, Conceptualization. **Giulio Staffieri:** Writing – original draft, Data curation. **Maria Manara:** Writing – review & editing. **Daniela Fracassetti:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The doctoral scholarship was co-funded with resources in the frame of D.M. 352. The doctoral scholarship was co-funded by Dal Cin S.p.a.

The authors acknowledge BluWine project funded by the European Union (HORIZON-MSCA-2024-SE-01, Grant Agreement Number 101235144). Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

The authors also acknowledge Supply Chain and District Contracts" 5th call MASAF - PNRR M2C1-I 3.4 - funded by NGEU. Project "White Wine Identity: new horizons for an integrated and sustainable development of the Italian white wine supply chain", CUP B79I21001220001, IRIS ID: PRJ-1058.

Data availability

No data was used for the research described in the article.

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