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Formation, change, and control of Ochratoxin A in wine

Yiding Xie[1], Hui Zhou[1], Yuyan Peng[1], Haiyue Liu[1], Jiaxin Liu[1], Fang Zhou[2], Weidong Huang[1], Jicheng Zhan[1] and Yilin You[1,3*]

[1] *College of Food Science and Nutritional Engineering, China Agricultural University, Beijing 100083, China*
[2] *College of Health Solutions, Arizona State University, Phoenix, AZ 85004, USA*
[3] *College of Food Science and Nutritional Engineering, Beijing Key Laboratory of Viticulture and Enology, China Agricultural University, Beijing 100083, China*
* Corresponding author, E-mail: yilinyou@cau.edu.cn

Abstract

Ochratoxin A (OTA) is a mycotoxin known for its nephrotoxic, hepatotoxic, and immunotoxic effects. The International Agency for Research on Cancer classifies it as a group 2B carcinogen, and it is widely found in wine. This review identifies *Aspergillus carbonarius* as the primary producer of OTA in wine, noting that contamination can occur at any stage of the vinification process. Specifically, OTA levels tend to increase during the pressing and maceration stages, while a reduction in OTA is observed during alcoholic and malolactic fermentation. The concentration of OTA in wine is predominantly influenced by the quality of the grape raw material and the vinification techniques employed. Various physicochemical and biological methods are utilized to mitigate OTA levels in wine, primarily by inhibiting the growth of *Aspergillus carbonarius* and by adsorbing or degrading the toxin itself. This paper examines the impacts of OTA control strategies on the color, organic acids, reducing sugars, antioxidant compounds, and volatile substances present in grape juice or wine. Moving forward, it is recommended that biological control methods be prioritized in efforts to reduce OTA levels in wine, with the goal of detoxifying OTA while preserving the organoleptic qualities of the wine.

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Introduction

Ochratoxins (OTs) are a group of mycotoxins synthesized by *Aspergillus ochraceus*, *Aspergillus carbonarius*, and *Penicillium verrucosum*, among others[1,2]. Ochratoxin A (OTA) is recognized to be the most toxic derivative[3]. OTA is prevalent in food products and can be detected in cereals, nuts, coffee, and wine[4–7]. The structure of OTA is illustrated in Fig. 1. This compound exhibits high solubility in organic solvents, limited solubility in water, and possesses resistance to acidic conditions and elevated temperatures, making it difficult to eliminate once it contaminates food[8]. The toxicity of OTA mainly includes oxidative stress, apoptosis, nephrotoxicity, hepatotoxicity, and immunotoxicity, with potential implications for mutagenesis and carcinogenesis. The primary organs impacted by OTA include the liver, kidneys, immune system, and brain. The International Agency for Research on Cancer categorizes OTA as a Group 2B carcinogen[9–12].

In light of the toxicity of OTA to the human body and its economic repercussions on agricultural products and food supplies, various nations and organizations have regulated the permissible levels of OTA in wine. The International Organisation of Vine and Wine (OIV) has set a maximum allowable concentration of OTA in wine at 2 μg/kg. Similarly, the European Union (EU) has adopted a limit of 2 μg/kg for OTA in wine[13]. Furthermore, the National Food Safety Standards, Limit of Fungal Toxins in Food (GB 2761-2017) specifies that the permissible level of OTA in cereals is capped at 5 μg/kg, in instant coffee at 10 μg/kg, and in wine at 2 μg/kg[14].

In this review, an overview of the formation and influencing factors of OTA in wine will be given, as well as the alterations in OTA levels throughout the vinification. This review will also discuss strategies for controlling *Aspergillus carbonarius* and eliminating OTA, along with the effects of these methods on the quality of grape juice and wine.

Formation and changes of OTA in wine

Formation of OTA in the vineyard

OTA contamination in wine was initially documented by Swiss researchers in 1996[15]. The prevalence of OTA contamination in wine across different countries from 2014 to 2024 is presented in Table 1. The data presented in the table indicate that OTA was identified in wines from the surveyed countries, with certain samples exhibiting concentrations that significantly surpassed the established regulatory limits for OTA[16–21]. Consequently, it is imperative to monitor and regulate the levels of OTA in the production of wine.

The main source of OTA contamination in wine is attributed to the presence of mycotoxins in the grapes[22]. *Aspergillus carbonarius*, *Aspergillus niger*, *Aspergillus welwitschiae*, and *Aspergillus fumigatus* are fungal species capable of producing OTA and have been isolated from grape sources. Among them, *Aspergillus carbonarius* and *Aspergillus niger* are the main responsible fungi for the accumulation of OTA in grapes[23–25].

In comparison to *Aspergillus niger*, the isolation of *Aspergillus carbonarius* from grapes presents greater challenges. However, the majority of research indicates that isolates of *Aspergillus carbonarius* possess a significant capacity for OTA production, albeit the levels of OTA produced by *Aspergillus niger* tend to be relatively low. Research indicates that *Aspergillus niger* strains isolated from Merlot grapes in Brazil exhibit no capacity for OTA production[26]. In contrast, the average OTA production level for *Aspergillus niger* strains sourced from Cyprus is recorded at 23.9 ng/g, whereas *Aspergillus carbonarius* demonstrates a significantly higher OTA production level of 1436.10 ng/g[23].

The growth and OTA production of *Aspergillus carbonarius* and *Aspergillus niger* on grapes are influenced by various factors, including the climatic conditions of the vineyard as well as the presence of pests and diseases. A positive correlation exists between the

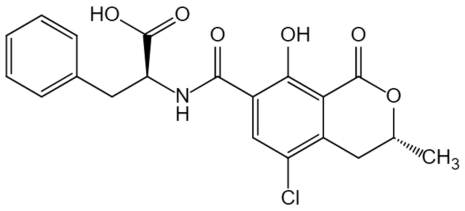

Fig. 1 Chemical structure of OTA.

Table 1. OTA contamination in wine in various countries from 2014 to 2024.

Country	Wine types	Positive/sampling number	Positive detection value (μg/L)	LOD (μg/L)	Ref.
China	–	223/223	< LOD-1.0	0.01	[16]
	–	8/90	0.006–0.126	0.000	[17]
Thailand	Red wine	10/100	0.3-1.7	0.06	[18]
Italy	Red wine	22/41	< LOD-0.270	0.014	[19]
	White wine	5/17	< LOD-0.158	0.012	
Greece	–	10/23	3.4-15.6	1.0	[20]
America	–	35/41	0.3-8.6	0.1	[21]

population of *Aspergillus niger* on grapes and the ambient temperature in the field[25]. *A. carbonarius* is predominantly identified in grapes cultivated in vineyards characterized by elevated temperatures and high humidity levels, whereas its prevalence in soil and atmospheric environments is significantly minimal[27].

Furthermore, *Aspergillus carbonarius* is frequently identified in vineyard soil. *Aspergillus carbonarius*, which is present in the soil surface, can come into contact with grape berries, potentially resulting in its presence on the grapes themselves. When grapes are compromised by pests and diseases, the resultant damage facilitates the attachment of the fungus, allowing it to proliferate and produce OTA, which subsequently contaminates the wine.

Additionally, the development of mycotoxins in grapes is influenced by specific grape varieties[28]. The production of OTA is also related to both the grape variety and the stage of ripeness. Research indicates that grapes exhibiting lower thickness and hardness tend to have elevated levels of OTA, with Chardonnay varieties demonstrating a higher susceptibility to infection by *Aspergillus carbonarius* and subsequent OTA accumulation when compared to Merlot, Cabernet Sauvignon, Tempranillo, and Moscato varieties[29]. *In vitro* studies have shown that Cabernet Sauvignon is one of the grape varieties with a higher incidence and OTA content of *A. carbonarius*[27]. The composition of OTA is affected by physicochemical parameters, including gluconic acid, throughout the maturation process. The synthesis of OTA takes place during the initial phases of grape ripening and can be identified throughout the entire ripening process. The production of OTA by *Aspergillus carbonarius* exhibits a positive correlation with the total acid content of grapes while demonstrating a negative correlation with the levels of reducing sugars and phenolic compounds[30,31].

Changes of OTA in wine

During vinification, the elevation of OTA levels predominantly occurs during the crushing and maceration stages. Following the crushing of grape berries, ochratoxin A is released into the must, which subsequently leads to its incorporation into the final wine product. Furthermore, during the maceration phase of red wine production, the concentration of OTA is observed to rise in correlation with the extended contact time between the grape skins and the juice[32]. Dachery et al.[33] investigated the change of OTA levels throughout the red wine production process and determined that the maceration was the sole associated with an increase in OTA concentration. They observed that the OTA content during maceration was six times greater than that found in the initial grape juice. Due to the absence of maceration involving skin contact during white wine production, OTA levels in white wine are typically lower than those in red wine[34].

The pressing process effectively separates the marc from the must, leading to a reduction in the concentration of OTA. As alcoholic fermentation (AF) progresses, the inoculation of yeast facilitates the metabolism of sugars present in the must, resulting in the production of alcohol, which subsequently inhibits the proliferation of toxigenic fungi. Research indicates that following AF, the levels of OTA in red and white wines decreased by 54% and 35%, respectively[33]. Giacomini et al.[35,36] demonstrated that vinification has the potential to diminish the levels of OTA, with the most significant reduction occurring at the conclusion of AF. This reduction is associated with the activity of peroxidase and the production of glutathione during yeast metabolism. Additionally, a decreasing trend in OTA levels was observed during malolactic fermentation (MLF)[37].

The reduction of OTA during the clarification process may be related to the use of clarifying agents. Bentonite in white wine and yeast cell walls in red wine are the most effective non-carbonaceous clarifiers for the removal of OTA[38], while gelatin clarifiers have been shown to facilitate the removal of up to 58% of OTA from red wine[39]. Overall, the concentration of OTA decreases after the entirety of vinification[32].

In summary, the main factors affecting ochratoxin A levels in wine can be categorized into two parts: grape material and winery vinification (Fig. 2). Investigating the presence of toxin-producing fungi on wine grapes, as well as the variations in OTA levels during vinification, is essential for identifying effective strategies for managing OTA contamination in wine.

Control of OTA in wine

Currently, a substantial body of research has been conducted on the management of OTA in wine, which can be categorized into three primary approaches: physical control, chemical control, and biological control. Physical and chemical control methods, such as high-temperature treatment, ultraviolet light exposure, pulsed light application, irradiation technology, and the use of chemical agents[40], are widely employed in food and feeds, but they may also present certain adverse effects. Studies have indicated that the application of pulsed light in grape juice can effectively diminish the levels of OTA, but the use of pulsed light also has an impact on the aromatic compounds present in the juice[41]. Similarly, the application of chemical reagents can also reduce the levels of OTA; their propensity to generate unpredictable by-products renders them inappropriate for use in food products. Conversely, biological control methods are capable of preserving the nutritional integrity of food and have demonstrated considerable efficacy and specificity in the reduction of OTA. Consequently, biological control has emerged as a prevalent approach for mitigating OTA contamination[40]. The process of formation and alteration of OTA in wine involves biological control strategies that primarily focus on two key areas: the management of fungi that produce OTA and the detoxification of grape juice or wine.

Physical and chemical control methods

The issue of OTA contamination in grapes originates in the vineyard; therefore, it is essential to implement preventive measures at this initial stage. In the context of field management, it is crucial to reduce the contact between grapes and the soil and increase bunch spacing, taking into account the various factors that contribute to the production of OTA. Furthermore, insect pests can inflict damage on the grape skins, thereby facilitating the colonization of

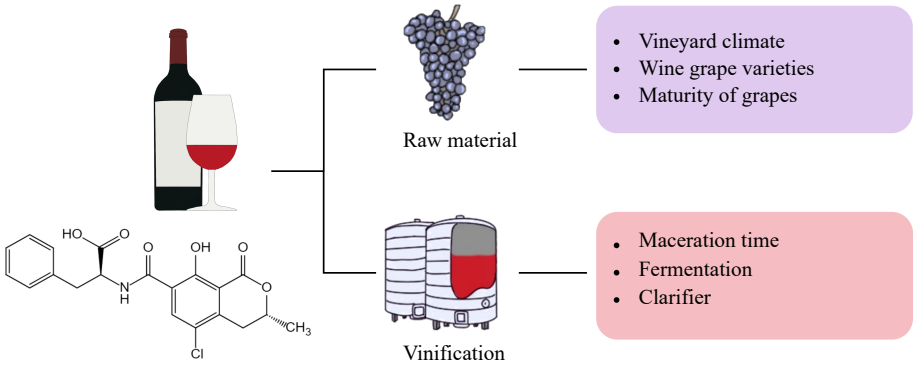

Fig. 2 Factors affecting OTA concentration in wine.

Aspergillus carbonarius. The application of insecticides to manage infestations of *Lobesia botrana* may serve as an effective strategy to mitigate the contamination of grapes with OTA toxins[42]. The utilization of pesticides has also been shown to suppress the growth of *Aspergillus carbonarius*. Specifically, carbendazim and hymexazol are pesticides employed in the management of pests affecting grape cultivation. Studies indicate that these two pesticides are effective in inhibiting the proliferation of *Aspergillus carbonarius* in must. During vinification, the residual levels of these two pesticides diminish over time. Nevertheless, this reduction does not appear to have a substantial impact on the final concentration of OTA in the wine[43]. Research has indicated that the application of electrolyzed oxidized water (EOW) containing 0.6 g/L of active chlorine significantly mitigates the infection of isolated berries by *Aspergillus carbonarius*, achieving a reduction of approximately 87%–92% *in vitro* and over 50% in field trials. Furthermore, this treatment has been shown to decrease the production of OTA. Notably, the use of electrolyzed water results in minimal chlorine residue, positioning it as a viable alternative to conventional fungicides in vineyard management, thereby alleviating concerns associated with chemical residues[44]. Research has indicated that, in addition to pesticides, certain chemical reagents possess the capability to inhibit the growth of *Aspergillus* species. Notably, carvacrol exhibits antifungal properties against various strains, including *Aspergillus carbonarius* and *Aspergillus niger*. When encapsulated in Eudragit® and Chia mucus nanocapsules, carvacrol effectively suppresses *Aspergillus* growth while addressing the challenges associated with the volatility and degradation of monoterpenes. Furthermore, lower concentrations of both encapsulated and unencapsulated carvacrol were employed to inhibit fungal proliferation and ochratoxin production in intact grapes, in contrast to grapes exhibiting surface damage[45].

For wine, physical methods have been demonstrated to effectively reduce the presence of OTA. Numerous studies have demonstrated that ^{60}Co-γ irradiation is an effective method for the degradation of OTA. The degradation rate of OTA in aqueous solutions subjected to ^{60}Co-γ irradiation can achieve up to 90% at an irradiation dose of 4 kGy[46]. The concentration of OTA and the pH level of the solution will affect the degradation of OTA through irradiation. The findings indicate that, at a consistent dose, a lower initial mass concentration of OTA enhances its degradation. The degradation rate of OTA is markedly increased under both neutral and alkaline conditions. Notably, in a solution with a pH of 3.72, OTA can be entirely degraded at a dose of 5 kGy[47]. In addition, a novel method known as high-pressure acidified steaming (HPAS) is governed by the pH level of citric acid and is conducted at a steam temperature corresponding to a pressure of 15 PSI. This technique has been shown to decrease the levels of OTA in peanut samples by 30% to 51%[48].

The application of adsorbents also represents a viable approach for the removal of OTA. The efficacy of OTA reduction in grape juice is influenced by the agent used and the duration of treatment. Specifically, when bentonite, gelatin, and diatomite were utilized at a concentration of 0.75%, a reduction of 50.56% in OTA levels was observed after 3 h of treatment. However, it is important to note that the use of these clarifying agents may also lead to a decrease in the levels of antioxidant-active compounds[49]. Activated carbon has the capacity to remove OTA from both white and red wines, with the efficacy of this removal being influenced by the pore characteristics of the activated carbon utilized[50]. Research has indicated that the adsorption rates of OTA by various conventional clarifying agents in Cabernet Sauvignon red wine, ranked from highest to lowest, are as follows: gelatin (28.59%), chitosan (24.7%), bentonite (22.5%), and polyethylpyrrolidone (PVPP) (7.6%)[51]. It is important to acknowledge that the selection of adsorbents must conform to the permissible categories outlined in national standards.

The ongoing advancements in materials science have led to the utilization of innovative materials for the adsorption of OTA. Among these, novel clay-polymer nanocomposites (CPNs) have demonstrated efficacy in adsorbing OTA from grape juice. By modifying the chemical properties and structural configuration of the polymer, the adsorption capacity of CPNs has been found to be nearly three times greater than that of the commercially available clay montmorillonite (MMT). Furthermore, CPNs exhibit a rapid sedimentation rate, which contributes to a reduced loss of mass and volume in grape juice compared to MMT[52]. CPNs exhibit significant potential for future advancements and applications.

PVPP, a resin composed of N-vinyl-2-pyrrolidinone with ethylene glycol dimethacrylate and triallyl isocyanurate (PVP-DEGMA-TAIC), along with poly acrylamide-co-ethylene glycol-dimethacrylate (PA-EGDMA), has been employed for the removal of OTA from wine. Experimental results showed that in acidic model solutions, both PVP-DEGMA-TAIC and PA-EGDMA polymers were capable of eliminating up to 99.9% of OTA. However, their efficacy in capturing OTA was greatly reduced due to the presence of competing phenolic compounds, such as gallic acid and 4-methylcatechin. In the context of red wine, the PA-EGDMA polymer demonstrated an OTA removal rate exceeding 68.0%. This observation implies that the interaction between OTA and the polymer is likely attributable to van der Waals forces[53]. A nano-MgO-modified diatomite ceramic membrane (MCM) exhibiting a high positive charge has demonstrated efficacy in the removal of OTA from wine, achieving removal rates between 92% and 96%. This process is facilitated by exothermic and physical adsorption mechanisms, specifically through electrostatic interactions[54].

In conclusion, among the physicochemical methods of OTA, insecticides, pesticides, and new reagents have been studied in field

control, while physical methods such as irradiation, high temperature, and high pressures are mostly used for grape raw materials. In addition, the addition of traditional adsorbents for OTA adsorption in wine is a simple and effective means commonly used at present, and new materials also show advantages in removing OTA. However, physicochemical control methods may affect the quality of grapes and lead to chemical residues, and the use of novel adsorbents is also limited by material safety, cost, and reusability.

Control of OTA toxigenic fungi

Aspergillus carbonarius is a fungal species linked to wine production that is known to produce OTA. In the context of biological control, the management of *Aspergillus carbonarius* primarily involves fostering competition within its ecological niche and the secretion of antagonistic compounds[55]. Various bacteria and yeasts from diverse sources have demonstrated the ability to inhibit the growth of *Aspergillus carbonarius*, as outlined in Table 2.

Research indicates that certain fungicides can inhibit the production of OTA in wine. In a study, *Bacillus velezensis* P1, a biocidal agent derived from *Bacillus velezensis*, was co-cultured with *Aspergillus carbonarius* on Chardonnay grapes, resulting in the undetectable growth of *Aspergillus carbonarius*. Furthermore, when the grapes inoculated with *Aspergillus carbonarius* and *B. Velezensis* P1 were processed to produce wine, OTA was not detected[56,57].

Metschnikowia pulcherrima 20C1, *Candida incommunis* 24K2, *Issatchenkia orientalis* 2C2, and 16C2, which have been isolated from the Negroamaro grape, possess the ability to inhibit the growth of *Aspergillus carbonarius* on the surface of grape fruits[58]. In both greenhouse and field settings, strains *Lanchancea thermotolerans* RCKT4 and RCKT5, which were isolated from Argentine wine grapes, have demonstrated the ability to inhibit the growth of *Aspergillus carbonarius*. Furthermore, these strains can reduce the content of OTA by an impressive range of 27% to 100%[59].

Lactobacillus plantarum is among the most prevalent and extensively utilized species within the lactic acid bacteria (LAB) category. *Lactobacillus plantarum* plays a key role in inhibiting fungal growth and facilitating the removal of mycotoxins[60]. *Lactobacillus plantarum* strains T571, 345, 195, and 1645, isolated from feta cheese, fermented cauliflower, black olive, and grape fruits, exhibit inhibitory effects on the growth of *Aspergillus carbonarius* in both MRS medium and grape fruits. This study also showed that these four *Lactobacillus plantarum* strains effectively diminished the levels of OTA by modulating the expression of the *OTAnrps* and *laeA* genes associated with OTA biosynthesis in *Aspergillus carbonarius*[61]. In addition to its role in regulating gene expression to suppress the growth of *Aspergillus carbonarius*, *Lactobacillus plantarum* is also capable of synthesizing various compounds that exhibit antifungal properties against this pathogen. Research has identified several antifungal compounds, including acetic acid, phenyllactic acid, and pyrazines, which have been extracted from the cell-free culture supernatants of *Lactobacillus plantarum* BN16, BN17, LIE3, and LIE4. These compounds demonstrate the potential to inhibit the proliferation of *Aspergillus carbonarius*[62]. Furthermore, the composition of the growth medium influenced the strain's capacity to suppress the proliferation of *Aspergillus carbonarius*. LAB cultivated with malt germ extract as a substitute nitrogen source exhibited a greater inhibitory effect on *Aspergillus carbonarius* Ac089 and a reduction in OTA production in comparison to growth in MRS medium[63].

In conclusion, the inhibition of OTA-producing bacteria can be realized by bacteria, yeast, etc. However, this method is currently implemented solely within laboratory settings. Future research will concentrate on optimizing its efficacy as a spraying agent, establishing the appropriate timing and dosage for application, and translating these findings into practical field applications for prevention and control purposes.

Biological detoxification of OTA

Adsorption detoxification of OTA

Grape pomace is an effective biosorbent for OTA adsorption. It has been shown that only 4% of OTA is dissolved in wine during the vinification of red grapes, while 96% of the OTA is retained in the pomace and lees[64]. Grape pomace, which consists of the pulp and skin of grapes, has demonstrated the ability to adsorb OTA *in vitro* adsorption assay. This adsorption phenomenon may be attributed to polar noncovalent interactions[65]. The re-passage of contaminated grape juice or wine through grape pomace, which exhibited minimal or no initial contamination with OTA, resulted in the removal of up to 65% of OTA within a 24 h period. Furthermore, the pomace demonstrated sustained efficacy in OTA removal after being utilized four times[66].

In the AF and MLF processes, the concentration of OTA is reduced, with yeast and LAB serving a crucial function in the elimination of OTA. The research indicated that *Saccharomyces cerevisiae* primarily adsorbs OTA through its cell wall. When the initial concentration of OTA was set at 1,000 ng/mL, the adsorption rate of OTA reached 41.63% following a 24 h incubation of dry *Saccharomyces cerevisiae* at 30 °C. The adsorption rates for OTA were measured as follows: 57.83% for the cell wall, 55.22% for water-extracted dextran, and 56.37% for commercial dextran. In contrast, the adsorption rate for dextran extracted using alkaline methods was significantly lower at 25.53%, indicating that alkaline pH conditions are not conducive to the adsorption of OTA by dextran[67]. Wine presents an acidic environment that facilitates the adsorption of OTA by glucan present in the cell wall of *Saccharomyces cerevisiae*. Dammak et al.[68]

Table 2. Antifungal microbial resources against *Aspergillus carbonarius*: strain sources, inhibition efficacy, and application potential.

Source	Strains	Evaluation/application	Ref.
Aquatic environments of the Amazon region, Brazil	*Bacillus velezensis* P1	For the first time, it has been observed that *Bacillus* species possess the ability to inhibit the production of *Aspergillus carbonarius* and ochratoxin.	[56,57]
Wine grape negroamaro	*Metschnikowia pulcherrima* 20C1 *Candida incommunis* 24K2 *Issatchenkia orientalis* 2C2 and 16C2	The antagonism of *Issatchenkia orientalis* against *Aspergillus carbonarius* was first demonstrated, potentially attributed to competition for particular growth-limiting resources.	[58]
Argentine wine grape	*Lanchancea thermotolerans* RCKT4 and RCKT5	The antagonistic activity was found in both greenhouse and field settings, resulting in a reduction of OTA levels by 27%–100%.	[59]
Feta cheese	*Lactobacillus plantarum* T571	Regulate the *OTAnrps* and *laeA* genes related to OTA biosynthesis in *Aspergillus carbonarius*.	[61]
Fermented cauliflower	*Lactobacillus plantarum* T345		
Black olive	*Lactobacillus plantarum* T196		
Grape fruit	*Lactobacillus plantarum* T1645		
Tomato	*Lactobacillus plantarum* BN16 and BN17	Produce acetic acid, phenyllactic acid, pyrazines, and other compounds exhibiting antifungal properties.	[62]
Fish intestine	*Lactobacillus plantarum* LIE3 and LIE4		

conducted a study demonstrating that both live and heat-inactivated cells of local *Saccharomyces cerevisiae* SC5, isolated from fresh table grapes, as well as commercial *Saccharomyces cerevisiae* Levulin FB, were effective in reducing the levels of OTA. Notably, the heat-inactivated yeast exhibited superior efficacy, indicating that OTA adsorption occurs via the cell wall. The primary constituents of the cell wall, including polysaccharides, proteins, and lipids, serve as highly accessible sites during the adsorption process and are crucial to the adsorption of OTA. Furthermore, yeast adsorption is influenced by various factors. Wild strains W28 and W46 of *Saccharomyces cerevisiae*, identified from the Uva di Troia grape variety, which is prevalent in southern Italy, also demonstrated a reduction in OTA levels. The effectiveness of adsorption was found to be contingent upon several variables, including time, temperature, sugar concentration, and the presence of diammonium phosphate[69].

LABs are naturally present as part of the indigenous microbiota in fermented foods and beverages. Due to their capacity to eliminate mycotoxins, LAB can serve as biocontrol agents to mitigate mycotoxin concentrations in contaminated food products. The adsorption of LAB to OTA is influenced by the characteristics of the bacterial cell wall, with hydrophobic interactions and electron donor-receptor mechanisms facilitating the binding of mycotoxins to the cell wall[70]. Zheng et al.[71] investigated the impact of various components of *Lactobacillus plantarum* QH06, derived from traditionally fermented pickles, on the reduction of OTA. Their findings indicated that the reduction rates for live cells, dead cells, and cell wall components at a concentration of 100 ng/mL OTA exceeded 82%. Conversely, extracellular metabolites and intracellular enzyme components did not demonstrate a significant reduction effect. The authors hypothesized that *Lactobacillus plantarum* QH06 reduces OTA levels primarily through cell wall adsorption. In addition, it was noted that *Lactobacillus plantarum* QH06 is also effective in decreasing OTA concentrations in grape juice. *Lactobacillus plantarum* strains Lp39, Lp4, and Lp22 have been shown to reduce OTA levels via adsorption on their surface[72]. The Piotrowska's team focused on the adsorption properties of *Lactobacillus plantarum*. Their findings indicated that *Lactobacillus plantarum*, *Lactobacillus brevis*, and *Lactobacillus sanfranciscensis* are capable of reducing the concentration of OTA in both MRS medium and PBS buffer surpassed that of their active counterparts, while the reduction rate of OTA was significantly diminished in bacteria that had undergone cell wall removal. This led to the conclusion that the reduction of OTA is primarily attributed to its binding with the cell wall. The alterations in the cell wall induced by elevated temperatures, specifically protein denaturation and pore formation, resulted in increased permeability of the outer cell wall layer. Furthermore, under treatment with water and 1M HCl, the binding of LAB to OTA was found to be partially reversible. It is posited that OTA is adsorbed onto the surface structure of the cell wall, a process facilitated not only by the hydrophobic characteristics of the cell wall but also by interactions involving electron donor-acceptor dynamics and Lewis acid-base interactions[73].

Besides *Lactobacillus plantarum*, *Lactobacillus rhamnosus* also has demonstrated the capability to adsorb OTA. A study conducted on 71 strains of lactic acid bacteria (LAB) found in traditional fermented pickles from Qinghai Province, China, revealed that *Lactobacillus rhamnosus* Bm01 exhibited the most pronounced effect in reducing OTA levels. The research investigated the removal mechanisms involving intracellular enzymes, cell-free culture supernatants, inactivated cells, and active cell walls. It was hypothesized that *Lactobacillus rhamnosus* Bm01 mitigates OTA concentration primarily through adsorption via its cell wall. Furthermore, the application of *Lactobacillus rhamnosus* Bm01 in grape juice resulted in the complete elimination of OTA at a concentration of 20 ng/mL[74]. Recent research has demonstrated that the biofilm of *Lactobacillus rhamnosus* GG is capable of effectively eliminating mycotoxins within a brief contact period of 1 to 10 min. Furthermore, this biofilm exhibits a substantial impact when applied to red grape juice that has been artificially supplemented with OTA, achieving a reduction rate of 98.3%. These findings suggest that this biofilm could serve as a novel technology for the detoxification of liquid food products[75].

With the development of material technology, the latest research combines LAB with novel materials to enhance the adsorption of OTA. Specifically, the encapsulation of *Lactobacillus plantarum* 299v within a polymeric matrix formed from polyvinyl alcohol (PVA) and alginate has produced the alginate-PVA-LP complex, which has demonstrated the capability to eliminate over 50% of OTA from contaminated wine[76]. *Lactobacillus plantarum* (L-Es) has been shown to markedly enhance the content of sulfhydryl groups through an esterification reaction and can adsorb over 90% of OTA in grape juice. By embedding the prepared L-Es in cellulose nanocrystals (L-Es@CNCs), it is easy to reuse and has excellent biodegradability. The OTA adsorption rate in grape juice samples was significantly improved by 88.28%, with minimal impact on the quality of the juice[77].

The findings from these studies indicate that both yeast and LAB are capable of removing OTA through adsorption. This evidence lays the groundwork for the development of effective biosorbents for OTA that are appropriate for use in wine systems.

Degradation of OTA

OTA that has been removed through adsorption remains in the natural environment, thus rendering its biodegradation a more ecologically advantageous approach. The primary mechanism of OTA biodegradation involves its conversion to the less toxic compound OTα, as illustrated in Fig. 3. The enzymatic detoxification of OTA can be facilitated through hydrolysis, specifically by cleaving the amide bond to yield OTα and L-phenylalanine via the action of an amide hydrolase. Additionally, the hydrolysis of the lactone ring can be accomplished using ochratoxin-lactase[78].

Soil is a rich reservoir of diverse bacterial species, and numerous OTA-degrading bacteria have been identified in vineyard soil. One such strain has demonstrated the ability to degrade OTA into OTα and phenylalanine through the action of carboxypeptidase and other bioactive compounds. *Brevundimonas diminuta* HAU429, isolated from vineyard soil in Henan Province, China, has been shown to degrade OTA to OTα by cleaving peptide bonds via the collaborative function of both intracellular and extracellular enzymes. Genome mining efforts in this study have identified three novel amide hydrolases, designated BT6, BT7, and BT9, which exhibit significant OTA hydrolase activity. Notably, BT7 displayed the highest tolerance to 6% ethanol, retaining 76% of its enzymatic activity under these conditions[79]. *Acinetobacter pittii* AP19, which was isolated from vineyard soil in Yantai, China, was co-cultured with 1 mg/L OTA for a duration of 36 h, resulting in the complete removal of OTA. The degradation of OTA is facilitated by the carboxypeptidase encoded by the *dacC* gene present in this strain, which hydrolyzes amide bonds to yield OTα[80]. The crude enzyme extract derived from *Brevundimonas* sp. ML17, which was isolated from soil, demonstrates the capability to degrade OTA into OTα and phenylalanine. The degradation rate of intracellular substances surpasses that of extracellular substances. Specifically, intracellular components categorized as > 10 kDa, 3–10 kDa, and < 3 kDa exhibited complete degradation of OTA within a 24-h period. This

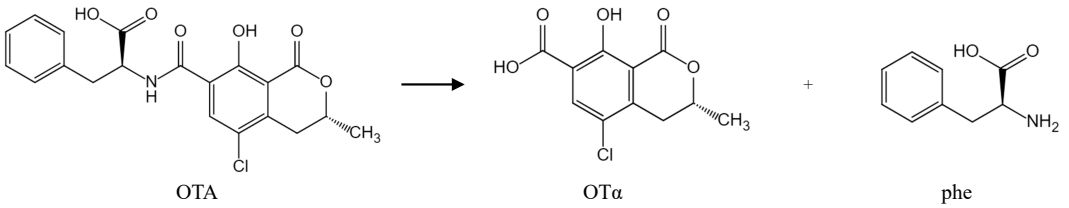

Fig. 3 Degradation of OTA.

phenomenon is hypothesized to result from a synergistic interaction between enzymatic activity and polypeptide components[81]. *Cytobacillus oceanisediminis* CO29, which was isolated from soil samples obtained from various vineyards in Yantai, Shandong Province, China, has been shown the capability to degrade OTA through the action of an intracellular metalloenzyme, resulting in the production of OTα[82]. Additionally, *Lysobacter* sp. CW239, isolated from soil samples contaminated with polycyclic aromatic hydrocarbons, exhibits high efficiency in degrading OTA. Furthermore, a novel gene associated with OTA degradation, designated *cp4*, was successfully cloned from CW239 and subsequently characterized[83].

The cell-free supernatant derived from *Bacillus subtilis* CW14 has demonstrated the capacity to eliminate 97% of 2 μg/mL of OTA within a 24-h period at a temperature of 37 °C. This investigation has identified that both carboxypeptidase and the active peptide present in *Bacillus subtilis* CW14 play significant roles as active agents in the degradation of OTA to OTα[84]. *Stenotrophomonas acidaminiphila* CW117 has been shown to completely degrade 50 μg/L of OTA at 37 °C for 6 h, resulting in the production of OTα. The aminohydrolase encoded by the *ADH3* gene has been isolated as an effective enzyme for OTA degradation. It is noteworthy that enzyme activity is influenced by factors such as temperature, the presence of metal ions, and pH levels[85].

In addition to the aforementioned strains, certain yeast, and LAB possess the capability to degrade OTA. Yang et al.[86] found that *Yarrowia lipolytica* could degrade OTA, with the degradation process being influenced by several factors, including yeast concentration, initial OTA concentration, temperature, and pH. The optimal conditions for OTA degradation were identified as a yeast concentration of 10^8 cells/mL yeast concentration, an OTA concentration of 0.1 μg/mL, a temperature of 28 °C, and a pH of 4. Additionally, *Lactobacillus rhamnosus* JCM 1136T, a kind of LAB isolated from Tempura grape, has been shown to convert OTA into OTα in both tryptone soybean broth medium and wine systems[87]. *Lactobacillus plantarum* CECT 749 and *Pediococcus parvulus* UTAD 473, which were isolated from the MLF of Douro wine, can also degrade OTA to produce degradation product OTα[88,89]. *Pediococcus acidilactici* NJB421 is a kind of LAB that has been isolated from bovine manure and possesses the ability to adsorb and degrade OTA. This strain exhibits notable resistance to high temperatures and acidic conditions. In addition, experimental studies conducted on murine models indicate that NJB421 is safe and non-toxic to mice while also demonstrating the capacity to mitigate OTA-induced damage to the intestines, liver, and kidneys. Additionally, it enhances the antioxidant capacity in these mice[90].

Enzymes derived from various strains have demonstrated the ability to degrade OTA. Research conducted by Orozco-Cortés et al.[78] revealed that bovine trypsin serine protease and *Bacillus subtilis* neutral metalloendopeptidase can effectively detoxify OTA through biotransformation, resulting in its degradation to OTα, with both enzymes exhibiting functionality in acidic environments. This study identified bromelain cysteine protease as capable of reducing OTA levels under acidic conditions, although it was noted that the hydrolysis rate was relatively low. Additional enzymes, including lipase, protease A, carboxypeptidase A (CPA), pancreatic enzymes, carboxypeptidase Y, and peroxidase, have also been shown to possess the capacity to degrade OTA[40].

Nonetheless, certain strains mentioned above are not classified as Generally Recognized as Safe (GRAS) organisms. Therefore, they cannot be directly utilized for the degradation of OTA in food or feed products. A summary of the strains and enzymes that possess the ability to degrade OTA is presented in Table 3.

Effects of OTA removal on wine quality

When employing various techniques for the removal of OTA, it is essential to evaluate their effects on the quality of grape juice or wine. Several prior studies have investigated the quality of grape juice or wine after the removal of OTA.

Clarifying agents have the potential to diminish the levels of antioxidant-active compounds. Specifically, the concentrations of phenolic acids, flavonoids, and other antioxidant-active substances in grape juice subjected to treatment with bentonite, gelatin, and diatomite were found to be decreased. The reduction of phenolic acids, flavonoids, and antioxidant activity were at the lowest level of 23.86%, 7.20%, and 17.27% at the concentrations and clarification times of 0.45%, 0.62%, 0.25%, and 1 h for bentonite, gelatin, and diatomaceous earth, respectively[49]. The application of activated carbon treatment has been shown to diminish the yellow and brown hues in white wine, yielding beneficial outcomes. However, it is important to note that anthocyanins may compete with OTA for the mesopores of activated carbon, which can adversely affect the color characteristics of red wine. The maximum reduction in color intensity observed was 24% of the original color intensity. Therefore, when employing activated carbon for the adsorption of OTA in wine, careful consideration must be given to the selection of an appropriate pore size[50]. The adsorption of polymers has been shown to influence the levels of antioxidant-active compounds, with PVPP and PA-EGDMA resulting in reductions of 35.9% and 13.3% in phenolic compounds, respectively[53]. The nano MgO MCM does not significantly alter the color value of the wine; however, it does lead to a decrease in the content of reducing sugars. Furthermore, the total phenolic content in dry red wine is expected to decline, while an increase in total phenolic content is observed in ice wine. This processing with nano MgO MCM contributes to a reduction in macromolecules and sedimentation in the wine. However, it resulted in a reduction of reducing sugars in dry red and white ice wines by 37.73% and 12.40%, respectively. Additionally, the total phenolic content in red wines experienced a decrease of 0.71%, while ice wines exhibited an increase of 3.30%. Furthermore, the soluble solids content was diminished by 17.39% in red wines and by 6.81% in ice wines[54]. In contrast to other adsorbents, the use of grape pomace derived from the same grape variety as the wine for the adsorption of OTA does not compromise the pertinent quality parameters of the wine ($p < 0.05$). These parameters include color intensity and phenolic composition, specifically trans-resveratrol, quercetin, and total polyphenol content[66].

Table 3. Strains and enzymes capable of degrading OTA.

Strains	Degradation rate	Degradation of active substances	Characteristics of degradation	Ref.
Brevundimonas diminuta HAU429	95% (10 μg/mL, 72 h, 37 °C)	Amide hydrolases BT6, BT7, and BT9	BT6 exhibited the highest level of heat resistance, retaining 38% of its activity following incubation at 70 °C for 10 min. BT7 showed the highest tolerance in the presence of 6% ethanol, maintaining 76% activity.	[79]
Acinetobacter pittii AP19	100% (1 mg/mL, 36 h, 37 °C)	Carboxypeptidase DacC	AP19 is not generally recognized as safe and cannot be used directly in food.	[80]
Brevundimonas sp. ML17	100% (1 μg/mL, 24 h, 37 °C)	Enzymes and peptides	OTA can be degraded to OTα and OTB to OTβ simultaneously. Both intracellular and extracellular components degrade OTA.	[81]
Cytobacillus oceanisediminis CO29	> 50% (1 mg/L, 48 h, 37 °C)	Intracellular metalloenzymes	Coumarin has been used as an alternative substrate for screening OTA degrading bacteria, and *Cytobacillus oceanisediminis* strain with OTA detoxification ability has been reported for the first time.	[82]
Lysobacter sp. CW239	100% (30 μg/L, 24 h, 30 °C)	Carboxypeptidase CP4	The purified recombinant protein rCP4 showed low OTA degradation activity.	[83]
Bacillus subtilis CW14	97% (2 mg/mL, 24 h, 37 °C)	Carboxypeptidase and active peptide segments	Peptides can bind OTA. The removal of OTA from the culture supernatant of strain CW14 may have synergistic effects, including carboxypeptidase degradation and physical adsorption of some small peptides.	[84]
Stenotrophomonas acidaminiphila CW117	100% (50 μg/L, 6 h, 37 °C)	Encoding amide hydrolase ADH3	ADH3 is more inclined than other detoxifying enzymes to form a larger hydrophobic area in the cavity of the catalytic site, which makes OTA easier to enter the catalytic site for hydrolysis. Wide temperature range (0 to 70 °C).	[85]
Yarrowia lipolytica	90% (1 μg/mL, 24 h, 28 °C)	–	HepG2 cells were used to test the toxicity of OTA biodegradation products was lower than OTA, and the degradation efficiency of strain was related to strain concentration, temperature, pH value, and OTA concentration.	[86]
Lactobacillus rhamnosus JCM 1136T	46% (500 μg/L, 48 h, 30 °C)	–	Microbial isolates reduced OTA content in TSB culture medium and wine experimental system.	[87]
Lactobacillus plantarum CECT 749	95% (0.6 μg/mL, 24 h, 37 °C)	–	OTA are degraded by hydrolysis of OTA amide groups and subsequent release of OTα and L-β-Phe portions, and in the presence of LAB, OTA is reduced during gastrointestinal digestion.	[89]
Pediococcus parvulus UTAD 473	100% (1 μg/mL, 7 d, 30 °C)	–	The strain was isolated from Douro wine and could degrade OTA in grape juice. Adsorption did not participate in the elimination of OTA by the strain.	[88]
Pediococcus acidilactici NJB421	49% (2 μg/mL, 48 h, 37 °C)	–	NJB421 has the characteristics of high temperature and acid resistance, and the mouse test shows that NJB421 is safe and harmless to mice.	[90]
–	45.26% (100 μg/L, 0.5 h, 41 °C)	Bovine trypsin serine protease	It was the first attempt to demonstrate that bromelain and trypsin can hydrolyze OTA with low efficiency at acidic pH conditions and that metalloendopeptidase is an effective OTA bioantidote.	[78]
–	7.64% (100 μg/L, 0.5 h, 41 °C)	Neutral metal endopeptidase		
–	100% (20 μg/L, 24 h, 37 °C)	CPA	–	[40]
–	100% (20 μg/L, 24 h, 37 °C)	Lipase	–	
–	75.72% (20 μg/L, 24 h, 37 °C)	Pancreatase	–	

Certain biological methods can influence the levels of antioxidant-active compounds and the coloration of substances. Specifically, the total phenolic content in grape juice subjected to detoxification via a *Lactobacillus rhamnosus* biofilm is markedly reduced compared to that of untreated grape juice. This reduction in antioxidant activity may be attributed to exposure to atmospheric oxygen during the treatment process. To mitigate this issue, it is advisable to conduct the treatment within a closed system in industrial applications[75]. As the adsorption time of L-Es@CNCs was prolonged, significant reductions in the a^* and b^* values of grape juice were observed ($p < 0.05$), while the L^* value exhibited a significant increase ($p < 0.05$). The quality parameters, including Brix content, vitamin C levels, and titratable acidity, did not demonstrate any significant changes. Furthermore, with the increase in adsorption time, the total phenolic content of the grape juice showed a gradual decline, suggesting that certain polyphenolic compounds may interact with L-Es@CNCs, leading to a reduction in polyphenol content[77]. The alginate-PVA-LP complex effectively eliminated OTA without significantly altering the concentration of total phenols; however, a comparison with other quality parameters was not conducted[76].

Biological control mechanisms can significantly influence the volatile compounds present in wine. Wang et al.[40] applied the reported CPA, lipase, and pancreatic enzymes, which are known to degrade OTA into OTα in grape juice and wine, affecting turbidity. The transparency of the wines increased by 9.59% at 3 μ/mL CPA. Pancreatin (16 μ/mL) and lipase (0.057 μ/mL) decreased the light transmission of the wines by 57.44% and 9.64%, respectively. CPA contributes to the enhancement of wine brightness and imparts red and yellow hues, while pancreatic enzymes lead to a darker coloration, producing green and blue tones. Regarding organic acids, pancreatic enzymes were found to reduce the levels of lactic acid, malic acid, and tartaric acid, whereas lipase was responsible for a decrease in tartaric acid levels. CPA exhibited minimal impact on the organic acid composition of the wine. Furthermore, these three enzymes also influenced the volatile compounds. Wine samples subjected to CPA treatment exhibited an elevation in the levels of aldehydes and ketones. In contrast, samples treated with lipase and pancreatin demonstrated a modest reduction in the concentrations of these compounds. The concentrations of lipoic acid and octanol in Chardonnay treated with *Bacillus velezensis* P1 were lower compared to those in the group inoculated with *Aspergillus carbonarius*. The increased levels of volatile terpenes or their derivatives, likely resulting from the glycoside hydrolase activity of the *Bacillus velezensis* strain, enhanced the flavor profile of the white wine[56].

The methods employed for the removal of OTA have significant impacts on the levels of organic acids and antioxidant compounds,

as well as the color and aroma of grape juice and wine, as illustrated in Table 4. A majority of these methods tend to diminish the concentration of antioxidant-active substances, which can negatively affect the quality of grape juice and wine. Furthermore, it is noteworthy that a single method may yield contrasting effects on the coloration of red and white wines. Research on the aromatic components remains relatively limited. Investigating these quality parameters is essential for optimizing the application of OTA removal techniques in the production of wine.

This chapter outlines contemporary strategies for mitigating OTA in wine production (Fig. 4) and their effects on the quality of grape juice and wine. The approaches to OTA removal in wine can be categorized into two main areas: the prevention of the OTA-producing fungus *Aspergillus carbonarius* and the adsorption or degradation of OTA through various physical, chemical, or biological methods. However, these methods have inherent limitations and may negatively impact wine quality. Future research should prioritize biological control strategies that employ yeast or LAB capable of degrading OTA, as these methods have the potential to enhance wine quality while effectively reducing OTA levels.

Conclusions and future perspectives

This paper reviews the formation and factors affecting OTA in wine, how OTA changes during vinification, how to control *Aspergillus carbonarius*, and how to eliminate OTA using biological, chemical, and physical means. It also considers the impact of OTA control on the quality of grape juice and wine. The management of OTA in wine can be categorized into two primary approaches: the prevention of OTA-producing bacteria prior to harvest and the adsorption or degradation of OTA in grape juice or wine following contamination. Each control strategy presents distinct advantages, yet they also possess inherent limitations. Biocontrol methods have garnered significant attention due to their economic viability, environmental sustainability, and high efficacy. However, several challenges remain to be addressed: The mechanisms underlying the inhibition of microbial growth by *Aspergillus carbonarius* are not well understood, and there is a paucity of research conducted at the genetic level concerning this species; the optimal timing for the application of microorganisms that inhibit toxigenic fungi to wine grapes in vineyard settings has yet to be established; there is

Table 4. Effects of different treatments on grape juice or wine.

Treatments	Effects of different treatments on grape juice or wine					Ref.
	Color	Organic acids/ reducing sugars	Antioxidant active substance	Volatile compound	Others	
Bentonite, gelatin and diatomaceous earth	–	–	The contents of phenolic acid and flavonoid were decreased.	–	–	[49]
Activated carbon	Affect	–	The contents of anthocyanins, phenolic acids and catechins decreased.	–	–	[50]
PVPP, PA-EGDMA	–	–	Total phenol content decreased.	–	–	[55]
Nano MgO MCM	No significant effect	Reducing sugars content decreased.	The total phenol content of dry red wine decreased, while that of ice wine increased.	–	Reduce macromolecules and precipitation in wine.	[54]
Grape pomace	No significant effect	–	No significant effect	–	–	[66]
Lactobacillus rhamnosus biofilm	–	–	The content of total phenol in grape juice was significantly lower.	–	–	[75]
L-Es@CNCs	The color of the grape juice is reduced, and the red and yellow components are reduced.	°Brix content and titrable acidity had no significant effect.	The total phenol content of grape juice was reduced.	–	–	[77]
Alginate- PVA- LP complex	–	–	There was no significant effect on total phenol concentration.	–	–	[76]
CPA	Brighter	–	–	Increased esters; alcohol decreases, menthol disappears, and isopropyl alcohol is formed. Decreased acid content; aldehydes and ketones increased.	–	[40]
Pancreatase	Darker	Lactic acid, malic acid, and tartaric acid decreased.	–	The esters increase to produce ethyl palmitate; alcohols decreased; acid increase; aldehydes and ketones decreased.	–	
Lipase	Darker	Tartaric acid drops.	–	The esters increase to produce ethyl palmitate; alcohol decreases, menthol disappears, and isopropyl alcohol is formed. decreased acid content; aldehydes and ketones decreased.	–	
Bacillus velezensis P1	–	–	–	The contents of lipoic acid and octanol are less, while volatile terpenes are increased.	–	[56]

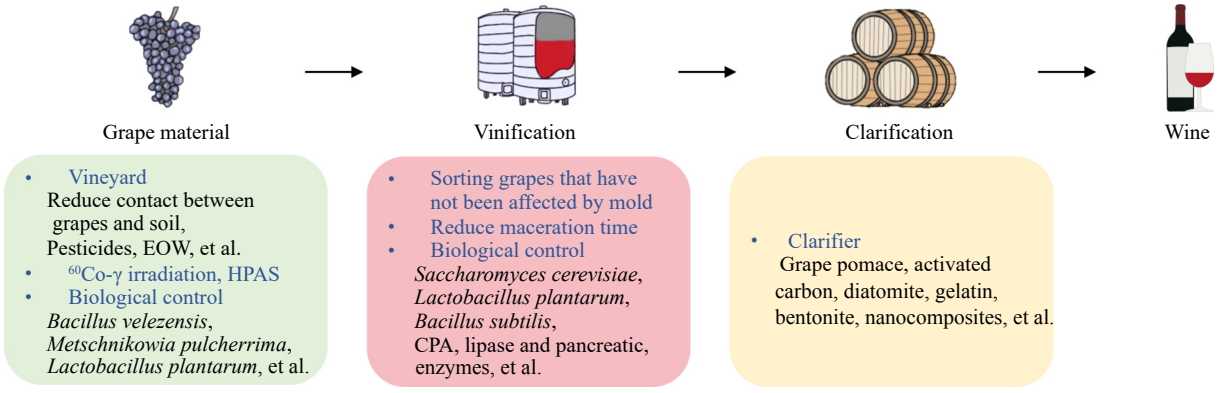

Fig. 4 The controlling strategies to minimize OTA during wine production.

insufficient safety evaluation of microorganisms identified as having OTA detoxification capabilities; the impact of microorganisms or enzymes with OTA detoxification properties on the quality of wine remains unclear, and the practical application of certain microorganisms within grape juice or wine systems poses additional challenges.

Future research should concentrate on elucidating the mechanisms that enhance the detoxification of OTA in wine. It is essential to assess the safety of biological control strategies and the practicality of implementing microbial applications. Additionally, the impact of microorganisms or enzymes on wine quality should be investigated to facilitate OTA detoxification without compromising the overall quality of the wine. Furthermore, advancements in molecular biology techniques may enable the development of enhanced enzymes for OTA detoxification or the transfer of genes encoding enzymes with high OTA degradation capabilities into yeast or LAB commonly utilized in vinification. This approach aims to produce low-OTA wine while simultaneously achieving AF or MLF.

Author contributions

The authors confirm their contribution to the paper as follows: writing - original draft: Xie Y; writing - review and editing: You Y, Zhan J, Huang W, Zhou F; resources: You Y, Zhan J; visualization: Xie Y; supervision: Zhou H, Peng Y, Liu H, Liu J; data curation: Xie Y, Liu H; form analysis: Zhou H; project administration: You Y, Zhan J; funding acquisition: You Y. All authors reviewed the results and approved the final version of the manuscript.

Data availability

All data generated or analyzed during this study are included in this published article.

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Conflict of interest

The authors declare that they have no conflict of interest.

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References

1. Chiotta ML, Fumero MV, Cendoya E, Palazzini JM, Alaniz-Zanon MS, et al. 2020. Toxigenic fungal species and natural occurrence of mycotoxins in crops harvested in Argentina. *Revista Argentina de Microbiología* 52:339–47
2. Dutra-Silva L, Pereira GE, Batista LR, Matteoli FP. 2021. Fungal diversity and occurrence of mycotoxin producing fungi in tropical vineyards. *World Journal of Microbiology and Biotechnology* 37:112
3. Heussner AH, Bingle LEH. 2015. Comparative ochratoxin toxicity: a review of the available data. *Toxins* 7:4253–82
4. Aytekin Sahin G, Aykemat Y, Yildiz AT, Dishan A, Inanc N, et al. 2024. Total aflatoxin and ochratoxin A levels, dietary exposure and cancer risk assessment in dried fruits in Türkiye. *Toxicon* 237:107540
5. Yazdanfar N, Mahmudiono T, Fakhri Y, Mahvi AH, Sadighara P, et al. 2022. Concentration of ochratoxin A in coffee products and probabilistic health risk assessment. *Arabian Journal of Chemistry* 15:104376
6. Zangheri M, Di Nardo F, Calabria D, Marchegiani E, Anfossi L, et al. 2021. Smartphone biosensor for point-of-need chemiluminescence detection of ochratoxin A in wine and coffee. *Analytica Chimica Acta* 1163:338515
7. Zhao Y, Chen W, Fang H, Zhang J, Wu S, et al. 2024. Ratiometric fluorescence immunoassay based on silver nanoclusters and calcein-Ce^{3+} for detecting ochratoxin A. *Talanta* 269:125470
8. El Khoury A, Atoui A. 2010. Ochratoxin A: general overview and actual molecular status. *Toxins* 2:461–93
9. Frangiamone M, Lázaro Á, Cimbalo A, Font G, Manyes L. 2024. *In vitro* and in vivo assessment of AFB1 and OTA toxic effects and the beneficial role of bioactive compounds. *A systematic review. Food Chemistry* 447:138909
10. Khalaf AAA, Elhady MA, Ibrahim MA, Hassanen EI, Abdelrahman RE, et al. 2024. Quercetin protects the liver of broiler chicken against oxidative stress and apoptosis induced by ochratoxin A. *Toxicon* 251:108160
11. Obafemi BA, Adedara IA, Rocha JBT. 2023. Neurotoxicity of ochratoxin A: Molecular mechanisms and neurotherapeutic strategies. *Toxicology* 497–498:153630
12. Stoev SD. 2022. New evidences about the carcinogenic effects of Ochratoxin A and possible prevention by target feed additives. *Toxins* 14:380
13. European Commission. 2007. *Commission Regulation (EC) No 1881/2006 Setting Maximum Levels for Certain Contaminants in Foodstuffs*. https://eur-lex.europa.eu/eli/reg/2006/1881/oj/eng
14. National Health and Family Planning Commission. 2017. *National Food Safety Standards, Limit of Fungal Toxins in Food* (in Chinese). https://sppt.cfsa.net.cn:8086/staticPages/7745B309-65F0-4465-829C-A3E388BAB26C.html
15. Zimmerli B, Dick R. 1996. Ochratoxin A in table wine and grape-juice: occurrence and risk assessment. *Food Additives & Contaminants* 13:655–68
16. Zhong QD, Li GH, Wang DB, Shao Y, Li JG, et al. 2014. Exposure assessment to Ochratoxin A in Chinese wine. *Journal of Agricultural and Food Chemistry* 62:8908–8913
17. Wu T, Gao J, Han B, Deng H, Han X, et al. 2024. Determination of 10 mycotoxins in wine, baijiu, and huangjiu of the Chinese market by liquid

chromatography tandem mass spectrometry and exposure estimation. *Food Chemistry-X* 22:101301
18. Puangkham S, Poapolathep A, Jermnak U, Imsilp K, Tanhan P, et al. 2017. Monitoring and health risk of mycotoxins in imported wines and beers consumed in Thailand. *World Mycotoxin Journal* 10:401–10
19. Campone L, Piccinelli AL, Celano R, Pagano I, Russo M. 2018. Rapid and automated on-line solid phase extraction HPLC–MS/MS with peak focusing for the determination of ochratoxin A in wine samples. *Food Chemistry* 244:128–135
20. Batrinou A, Houhoula D, Papageorgiou E. 2020. Rapid detection of mycotoxins on foods and beverages with enzyme-linked immunosorbent assay. *Quality Assurance and Safety of Crops & Foods* 12:40–49
21. De Jesus CL, Bartley A, Welch AZ, Berry JP. 2018. High incidence and levels of Ochratoxin A in wines sourced from the United States. *Toxins* 10:1
22. Esti M, Benucci I, Liburdi K, Acciaro G. 2012. Monitoring of ochratoxin A fate during alcoholic fermentation of wine-must. *Food Control* 27:53–56
23. Pantelides IS, Aristeidou E, Lazari M, Tsolakidou MD, Tsaltas D, et al. 2017. Biodiversity and ochratoxin A profile of *Aspergillus* section Nigri populations isolated from wine grapes in *Cyprus vineyards*. *Food Microbiology* 67:106–15
24. Welke JE. 2019. Fungal and mycotoxin problems in grape juice and wine industries. *Current Opinion in Food Science* 29:7–13
25. Bellí N, Mitchell D, Marín S, Alegre I, Ramos AJ, et al. 2005. Ochratoxin A-producing fungi in Spanish wine grapes and their relationship with meteorological conditions. *European Journal of Plant Pathology* 113:233–39
26. Nievierowski TH, Veras FF, Silveira RD, Dachery B, Hernandes KC, et al. 2021. Role of partial dehydration in a naturally ventilated room on the mycobiota, ochratoxins, volatile profile and phenolic composition of Merlot grapes intended for wine production. *Food Research International* 141:110145
27. Marques J, Castella G, Bragulat MR, Cabanes FJ. 2025. Diversity of *Aspergillus* section *Nigri* species from vineyards with different agro-climatic conditions in Catalonia, Spain. *International Journal of Food Microbiology* 430:111049
28. Gonçalves A, Palumbo R, Guimarães A, Gkrillas A, Dall'Asta C, et al. 2020. The route of mycotoxins in the grape food chain. *American Journal of Enology and Viticulture* 71:89–104
29. Veras FF, Dachery B, Manfroi V, Welke JE. 2021. Colonization of *Aspergillus carbonarius* and accumulation of ochratoxin A in Vitis vinifera, Vitis labrusca, and hybrid grapes – research on the most promising alternatives for organic viticulture. *Journal of the Science of Food and Agriculture* 101:2414–21
30. Freire L, Guerreiro TM, Caramês ETS, Lopes L, Orlando EA, et al. 2018. Influence of maturation stages in different varieties of wine grapes (*Vitis vinifera*) on the production of Ochratoxin A and its modified forms by *Aspergillus carbonarius* and *Aspergillus niger*. *Journal of Agricultural and Food Chemistry* 66:8824–31
31. Serra R, Mendonça C, Venâncio A. 2006. Ochratoxin A occurrence and formation in Portuguese wine grapes at various stages of maturation. *International Journal of Food Microbiology* 111:S35–S39
32. La Placa L, Tsitsigiannis D, Camardo Leggieri M, Battilani P. 2023. From grapes to wine: impact of the vinification process on Ochratoxin A contamination. *Foods* 12:260
33. Dachery B, Veras FF, Dal Magro L, Manfroi V, Welke JE. 2017. Exposure risk assessment to ochratoxin A through consumption of juice and wine considering the effect of steam extraction time and vinification stages. *Food and Chemical Toxicology* 109:237–44
34. Freire L, Braga PAC, Furtado MM, Delafiori J, Dias-Audibert FL, et al. 2020. From grape to wine: Fate of ochratoxin A during red, rose, and white winemaking process and the presence of ochratoxin derivatives in the final products. *Food Control* 113:107167
35. Giacomini RX, Acosta ER, Cerqueira MBR, Primel EG, Garda-Buffon J. 2023. Alcoholic Fermentation as a Strategy to Mitigate Pesticides and Mycotoxins. *Food and Bioprocess Technology* 16:2315–27
36. Giacomini RX, Barnes Rodrigues Cerqueira M, Primel EG, Garda-Buffon J. 2023. Monitoring of mycotoxins and pesticides in winemaking. *Ciência E Técnica Vitivinícola* 38:10–20
37. Fernandes A, Ratola N, Cerdeira A, Alves A, Venâncio A. 2007. Changes in ochratoxin A concentration during winemaking. *American Journal of Enology and Viticulture* 58:92–96
38. Leong SL, Hocking AD, Pitt JI, Kazi BA, Emmett RW, et al. 2006. Australian research on ochratoxigenic fungi and ochratoxin A. *International Journal of Food Microbiology* 111:S10–S17
39. Lasram S, Mani A, Zaied C, Chebil S, Abid S, et al. 2008. Evolution of ochratoxin A content during red and rose vinification. *Journal of the Science of Food and Agriculture* 88:1696–703
40. Wang S, Cai R, Liu X, Qi L, Wang L, et al. 2023. The detoxification of ochratoxin A in wine and grape juice by different enzymes and evaluation of their effects on the quality. *eFood* 4:e61
41. Wang Z, Cai R, Yang X, Gao Z, Yuan Y, et al. 2021. Changes in aroma components and potential Maillard reaction products during the stir-frying of pork slices. *Food Control* 123:107855
42. Cozzi G, Somma S, Haidukowski M, Logrieco AF. 2013. Ochratoxin A management in vineyards by Lobesia botrana biocontrol. *Toxins* 5:49–59
43. Zhang Y, Wei D, Wu X, Duan T, Xu J, et al. 2023. Occurrence and impact of carbendazim and hymexazol residues on yeast growth and ochratoxin A contamination during wine production. *Journal of the Science of Food and Agriculture* 103:6280–87
44. Magistà D, Cozzi G, Gambacorta L, Logrieco AF, Solfrizzo M, et al. 2021. Studies on the efficacy of electrolysed oxidising water to control *Aspergillus carbonarius* and ochratoxin A contamination on grape. *International Journal of Food Microbiology* 338:108996
45. Tópor A, Veras FF, Cacciatore FA, Silveira RD, Da Silva Malheiros P, et al. 2024. Carvacrol nanocapsules as a new antifungal strategy: Characterization and evaluation against fungi important for grape quality and to control the synthesis of ochratoxins. *International Journal of Food Microbiology* 416:110659
46. Chi L, Ha Y, Wang F, Xue X, Li Y. 2011. Effects of y-irradiation on degradation of Ochratoxin A in aqueous solution. *Journal of Radiation Research and Radiation Processing* 29:61–64
47. Peng C, Zhou L, Li S, An F, Wang L. 2015. Degradation of ochratoxin a irradiated by ^{60}Co-γ rays. *Journal of Chinese Institute of Food Science and Technology* 15:174–79 (in Chinese)
48. Awuchi CG, Nwozo OS, Aja PM, Odongo GA. 2023. High-pressure acidified steaming with varied citric acid dosing can successfully detoxify mycotoxins. *Food Science & Nutrition* 11:2677–85
49. Behfar M, Heshmati A, Mehri F, Khaneghah AM. 2022. Removal of Ochratoxin A from grape juice by clarification: a response surface methodology study. *Foods* 11:1432
50. Cosme F, Inês A, Silva D, Filipe-Ribeiro L, Abrunhosa L, et al. 2020. Elimination of ochratoxin A from white and red wines: Critical characteristics of activated carbons and impact on wine quality. *LWT* 140:110838
51. Zhang J, Cai R, Yue T, Yuan Y, Gao Z, et al. 2022. Assessment of traditional clarifiers on the adsorption of ochratoxin A in Cabernet Sauvignon red wine and their kinetics. *Food Chemistry* 373:131592
52. Alford R, Mishael YG. 2023. Bifunctional clay based sorbent for 'Ochratoxin A' removal and wine fining. *Food Chemistry* 416:135827
53. Carrasco-Sánchez V, Marican A, Vergara-Jaque A, Folch-Cano C, Comer J, et al. 2018. Polymeric substances for the removal of ochratoxin A from red wine followed by computational modeling of the complexes formed. *Food Chemistry* 265:159–64
54. Nan M, Bi Y, Qiang Y, Xue H, Yang L, et al. 2022. Electrostatic adsorption and removal mechanism of ochratoxin A in wine via a positively charged nano-MgO microporous ceramic membrane. *Food Chemistry* 371:131157
55. Punia Bangar S, Sharma N, Bhardwaj A, Phimolsiripol Y. 2022. Lactic acid bacteria: a bio-green preservative against mycotoxins for food safety and shelf-life extension. *Quality Assurance and Safety of Crops & Foods* 14:13–31
56. Nievierowski TH, Veras FF, Silveira RD, Giocastro B, Aloisi I, et al. 2023. A Bacillus-based biofungicide agent prevents ochratoxins occurrence in grapes and impacts the volatile profile throughout the Chardonnay winemaking stages. *International Journal of Food Microbiology* 389:110107

57. Silveira RD, Veras FF, Bach E, Manfroi V, Brandelli A, et al. 2022. *Aspergillus carbonarius*-derived ochratoxins are inhibited by Amazonian *Bacillus* spp. *used as a biocontrol agent in grapes. Food Additives and Contaminants Part A: Chemistry Analysis Control Exposure & Risk Assessment* 39:158–69
58. Bleve G, Grieco F, Cozzi G, Logrieco A, Visconti A. 2006. Isolation of epiphytic yeasts with potential for biocontrol of *Aspergillus carbonarius* and *A. niger on grape*. *International Journal of Food Microbiology* 108:204–209
59. Ponsone ML, Nally MC, Chiotta ML, Combina M, Köhl J, et al. 2016. Evaluation of the effectiveness of potential biocontrol yeasts against black sur rot and ochratoxin A occurring under greenhouse and field grape production conditions. *Biological Control* 103:78–85
60. Li Q, Zeng X, Fu H, Wang X, Guo X, et al. 2023. *Lactiplantibacillus plantarum*: a comprehensive review of its antifungal and anti-mycotoxic effects. *Trends in Food Science & Technology* 136:224–38
61. Iliada KL, Sevasti M, Barbara L, Efstathios ZP. 2018. Control of *Aspergillus carbonarius* in grape berries by *Lactobacillus plantarum*: a phenotypic and gene transcription study. *International Journal of Food Microbiology* 275:56–65
62. Dopazo V, Luz C, Quiles JM, Calpe J, Romano R, et al. 202. Potential application of lactic acid bacteria in the biopreservation of red grape from mycotoxigenic fungi. *Journal of the Science of Food and Agriculture* 102:898–907
63. Domínguez-Gutiérrez GA, Perraud-Gaime I, Escalona-Buendía H, Durand N, Champion-Martínez EI. 2023. Inhibition of *Aspergillus carbonarius* growth and Ochratoxin A production using lactic acid bacteria cultivated in an optimized medium. *International Journal of Food Microbiology* 404:110320
64. Visconti A, Perrone G, Cozzi G, Solfrizzo M. 2008. Managing ochratoxin A risk in the grape-wine food chain. *Food Additives and Contaminants Part A: Chemistry Analysis Control Exposure & Risk Assessment* 25:193–202
65. Avantaggiato G, Greco D, Damascelli A, Solfrizzo M, Visconti A. 2014. Assessment of multi-mycotoxin adsorption efficacy of grape pomace. *Journal of Agricultural and Food Chemistry* 62:497–507
66. Solfrizzo M, Avantaggiato G, Panzarini G, Visconti A. 2010. Removal of ochratoxin A from contaminated red wines by repassage over grape pomaces. *Journal of Agricultural and Food Chemistry* 58:317–23
67. Piotrowska M, Masek A. 2015. *Saccharomyces cerevisiae* cell wall components as tools for Ochratoxin A decontamination. *Toxins* 7:1151–62
68. Dammak I, Alsaiari NS, Fhoula I, Amari A, Hamdi Z, et al. 2022. Comparative evaluation of the capacity of commercial and autochthonous *Saccharomyces cerevisiae* strains to remove Ochratoxin A from natural and synthetic grape juices. *Toxins* 14:465
69. Petruzzi L, Bevilacqua A, Baiano A, Beneduce L, Corbo MR, et al. 2014. *In vitro* removal of ochratoxin A by two strains of *Saccharomyces cerevisiae* and their performances under fermentative and stressing conditions. *Journal of Applied Microbiology* 116:60–70
70. Fuchs R, Peraica M. 2005. Ochratoxin A in human kidney diseases. *Food Additives & Contaminants* 22:53–57
71. Zheng X, Wang S, Tao J, Cao Y, Yang Z. 2022. Scavenging of ochratoxin a by *Lactobacillus plantarum* QH06 and its preliminary application. *Modern Food Science and Technology* 39:270–76
72. Zhao L, Jin H, Zhang R, Zhang Y, Ren H, et al. 2019. Binding of ochratoxin A by three strains of *Lactobacillus plantarum* from fermented dairy products in vitro. *Food Science and Technology* 44:17–23
73. Piotrowska M. 2014. The adsorption of Ochratoxin A by *Lactobacillus* species. *Toxins* 6:2826–39
74. Zheng X, Xia F, Li J, Zheng L, Rao S, et al. 2023. Reduction of ochratoxin A from contaminated food by *Lactobacillus rhamnosus* Bm01. *Food Control* 143:109315
75. Nahle S, El Khoury A, Assaf JC, Louka N, Chokr A, et al. 2022. A promising innovative technique for mycotoxin detoxification from beverages using biofilms of lactic acid bacteria. *Innovative Food Science & Emerging Technologies* 82:103165
76. Castro RI, Laurie VF, Padilla C, Carrasco-Sánchez V. 2022. Removal of Ochratoxin A from red wine using Alginate-PVA-L. plantarum (APLP) complexes: a preliminary study. *Toxins* 14:230
77. Zhao M, Ren H, Yan Z, Ma J, Feng X, et al. 2024. Reusable thiol-modification *Lactobacillus plantarum* embedded in cellulose nanocrystals composite aerogel for efficient removal of Ochratoxin A in grape juice. *Food Chemistry: X* 22:101336
78. Orozco-Cortés PC, Flores-Ortíz CM, Hernández-Portilla LB, Vázquez Medrano J, Rodríguez-Peña ON. 2023. Molecular docking and *in vitro* studies of Ochratoxin A (OTA) biodetoxification testing three endopeptidases. *Molecules* 28:2019
79. Zhang L, Zhang X, Chen X, Zhang W, Zhao L, et al. 2024. Biodegradation of ochratoxin A by *Brevundimonas diminuta* HAU429: Characterized performance, toxicity evaluation and functional enzymes. *Food Research International* 187:114409
80. Yang Y, Zhong W, Wang Y, Yue Z, Zhang C, et al. 2024. Isolation, identification, degradation mechanism and exploration of active enzymes in the ochratoxin A degrading strain *Acinetobacter pittii* AP19. *Journal of Hazardous Materials* 465:133351
81. Peng M, Zhao Z, Liang Z. 2022. Biodegradation of ochratoxin A and ochratoxin B by *Brevundimonas naejangsanensis* isolated from soil. *Food Control* 133:108611
82. Yang Y, Zhong W, Liu Z, Xue X, Gao Q, et al. 2023. Isolation and identification of a *Cytobacillus oceanisediminis* strain with ochratoxin A detoxification ability. *Food Control* 151:109797
83. Wei W, Qian Y, Wu Y, Chen Y, Peng C, et a. 2020. Detoxification of ochratoxin A by *Lysobacter* sp. CW239 and characteristics of a novel degrading gene carboxypeptidase cp4. *Environmental Pollution* 258:113677
84. Hu HN, Jia X, Wang YP, Xiong L, Peng MX. 2019. Detoxification of ochratoxin a by an expressed carboxypeptidase and some isolated peptides from *Bacillus subtilis* CW14. *Toxicon* 158:S67
85. Luo H, Wang G, Chen N, Fang Z, Xiao Y, et al. 2022. A superefficient Ochratoxin A hydrolase with promising potential for industrial applications. *Applied and Environmental Microbiology* 88:e196421
86. Yang Q, Wang J, Zhang H, Li C, Zhang X. 2016. Ochratoxin A is degraded by *Yarrowia lipolytica* and generates non-toxic degradation products. *World Mycotoxin Journal* 9:269–78
87. Luz Mínguez C, Ruvira Garrigues MA, López Ocaña L, Aznar Novella R, Mañes Vinuesa J, et al. 2020. Transformation of Ochratoxin A by microorganisms isolated from tempranillo grapes in wine systems. *American Journal of Enology and Viticulture* 71:167–74
88. Abrunhosa L, Inês A, Rodrigues AI, Guimarães A, Pereira VL, et al. 2014. Biodegradation of ochratoxin A by *Pediococcus parvulus* isolated from Douro wines. *International Journal of Food Microbiology* 188:45–52
89. Luz C, Ferrer J, Mañes J, Meca G. 2018. Toxicity reduction of ochratoxin A by lactic acid bacteria. *Food and Chemical Toxicology* 112:60–66
90. Tang J, Yin L, Zhao Z, Ge L, Hou L, et al. 2023. Isolation, identification and safety evaluation of OTA-detoxification strain *Pediococcus acidilactici* NJB421 and its effects on OTA-induced toxicity in mice. *Food and Chemical Toxicology* 172:113604