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BIOTECHNOLOGICAL POTENTIAL OF LACTIC ACID BACTERIA FOR MYCOTOXIN REDUCTION IN FERMENTED MILK

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Abstract:
Mycotoxin contamination, particularly aflatoxin M1 (AFM1), represents a serious food safety concern in milk and fermented dairy products. AFM1 originates from contaminated feed and exhibits high stability during technological processing, which makes its removal challenging. In recent years, lactic acid bacteria (LAB) have been recognized as promising biotechnological agents for reducing mycotoxin levels. Their activity is primarily associated with adsorption to cell wall structures, strain-dependent bioadsorption, possible enzymatic transformation, and indirect inhibition of toxin-producing molds. The effectiveness of these mechanisms is influenced by several factors, including bacterial strain, environmental conditions, and food matrix composition. However, the reversibility of toxin binding remains a major limitation. Overall, LAB-based approaches offer a promising strategy for improving the safety of fermented dairy products, although further research is required to optimize their application under real processing conditions.

Keywords: *Lactic acid bacteria; fermented milk; aflatoxin M1; mycotoxins; detoxification; food safety*

Introduction

Mycotoxins are toxic secondary metabolites produced by various fungal species and represent a significant threat to food safety and public health [1]. They are typically low-molecular-weight compounds characterized by high chemical stability and resistance to conventional food processing methods, which makes their elimination from food matrices particularly difficult [1]. The most important mycotoxin-producing genera include *Aspergillus, Penicillium, Fusarium*, and *Alternaria*, while the most

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frequently detected toxins are aflatoxins, ochratoxin A, fumonisins, and deoxynivalenol [1].

Although mycotoxins are mainly associated with plant-based products, they may also be transferred into foods of animal origin, particularly milk, through contaminated feed [1]. Among them, aflatoxin M1 (AFM1), a hydroxylated metabolite of aflatoxin B1, is of particular concern due to its persistence during milk processing [2,3].

Traditional physical and chemical detoxification methods are often insufficient or may negatively affect the nutritional quality of food products [4]. For this reason, biological approaches have gained increasing attention as more sustainable alternatives, enabling mycotoxin reduction while preserving food quality [4,5].

In this context, lactic acid bacteria (LAB) have emerged as effective biological agents capable of reducing mycotoxin levels through multiple mechanisms, including adsorption, bioadsorption, and biotransformation [4–6]. The efficiency of these processes depends on various factors such as strain selection, pH, temperature, and medium composition [5]. Numerous studies have also demonstrated the potential of LAB to reduce AFM1 levels in milk and fermented dairy products [7,8].

The aim of this paper is to review the biotechnological potential of lactic acid bacteria in mycotoxin detoxification, with particular emphasis on their mechanisms of action and application in fermented dairy systems.

1. Occurrence of Mycotoxins in Milk and Fermented Dairy Products

The presence of mycotoxins in milk is primarily linked to contaminated animal feed, where aflatoxin B1 is metabolized in the animal organism into aflatoxin M1 (AFM1), which is subsequently excreted into milk [2,3]. The extent of this carry-over process depends on the level of feed contamination as well as physiological characteristics of the animal [3].

AFM1 is considered the most relevant mycotoxin in milk due to its toxicity and frequent detection [2]. It is highly stable and only partially reduced during pasteurization, sterilization, or fermentation processes [2,7]. Although fermentation may contribute to a certain decrease in AFM1 levels, complete removal is not achievable [7,8].

Due to associated health risks, regulatory limits have been established. In Serbia, the maximum permitted concentration of AFM1 in milk is 0.25 μg/kg, whereas European Union regulations prescribe a significantly lower limit of 0.05 μg/kg [9,10].

2. Mechanisms of Mycotoxin Detoxification by Lactic Acid Bacteria

Lactic acid bacteria (LAB) are capable of reducing mycotoxin levels through several mechanisms, including adsorption, bioadsorption, biotransformation, and inhibition of toxigenic fungal growth [4–6]. The effectiveness of these mechanisms is strongly influenced by the bacterial strain, environmental conditions, and the type of mycotoxin involved [4,5].

2.1 Adsorption of Mycotoxins on the Cell Wall

Adsorption represents the most extensively studied mechanism of mycotoxin removal by LAB. It involves the binding of toxin molecules to bacterial cell wall components such as peptidoglycan, polysaccharides, and teichoic acids [4]. These interactions are predominantly non-covalent, including hydrophobic interactions, hydrogen bonding, and van der Waals forces [5].

The efficiency of adsorption is influenced by the physicochemical properties of both the bacterial surface and the surrounding environment, including pH and temperature [5]. However, a major drawback of this mechanism is its reversibility, as bound mycotoxins may be released under certain conditions, particularly within the gastrointestinal tract [4].

2.2 Bioadsorption and Strain-Specific Differences

Bioadsorption refers to more specific interactions between mycotoxins and bacterial cell surfaces, which are often strain-dependent. Different LAB strains exhibit varying binding capacities, highlighting the importance of strain selection [6]. Factors such as cell wall composition, surface hydrophobicity, and the presence of specific functional groups play a crucial role in this process [5]. Species such as *Lactobacillus rhamnosus* and *L. plantarum* have demonstrated particularly strong binding abilities toward aflatoxins [6].

2.3 Biotransformation and Biodegradation

Biotransformation represents a potentially highly effective detoxification mechanism, as it involves the chemical modification of mycotoxins into less toxic or non-toxic products. This process includes enzymatic reactions that can lead to the degradation of mycotoxins [4].

However, although there is evidence suggesting that LAB can transform certain mycotoxins, including aflatoxins, this mechanism is still insufficiently explored [5]. A particular challenge is the assessment of the toxicity of the resulting products, which is essential for confirming the safety of this approach [5].

2.4 Inhibition of the Growth of Toxigenic Molds

LAB can also contribute indirectly to mycotoxin reduction by inhibiting the growth of toxin-producing molds. This effect is associated with the production of organic acids, bacteriocins, and other antimicrobial metabolites [6]. Additionally, the decrease in pH during fermentation creates unfavorable conditions for mold growth and mycotoxin production [4].

2.5 Critical Analysis of Detoxification Mechanisms

Although numerous studies indicate the effectiveness of LAB in reducing mycotoxin content, it is important to make a clear distinction between temporary binding and actual detoxification[4-6]. Adsorption, as the dominant mechanism, does not necessarily result in the permanent removal of mycotoxins, but may represent only a temporary reduction in their bioavailability [4].

On the other hand, biotransformation has the potential to provide permanent detoxification, but it requires further research to determine its effectiveness and safety [5]. Therefore, the development of reliable biotechnological solutions requires a detailed understanding of the mechanisms involved and their validation in real food systems [4-5].

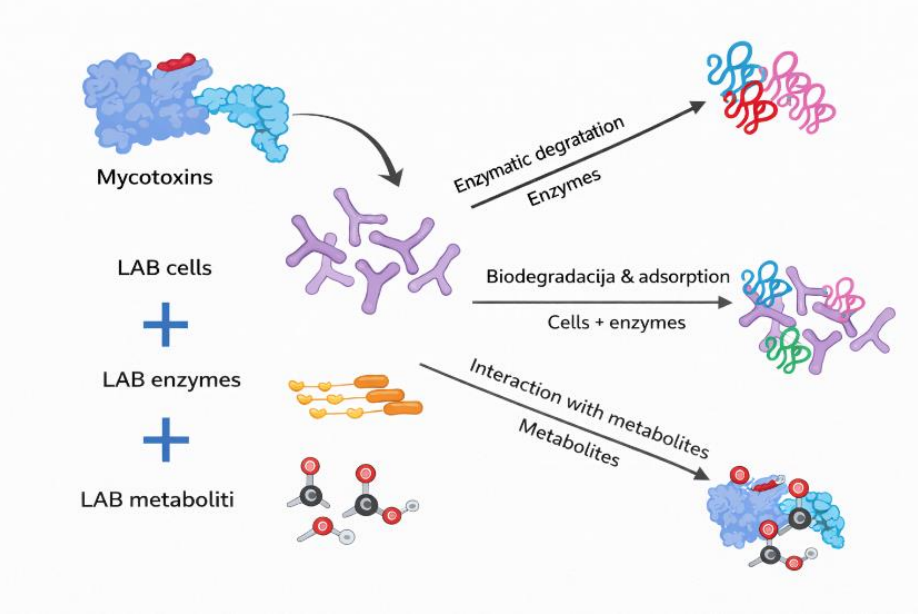
The main mechanisms of mycotoxin detoxification by lactic acid bacteria, together with their characteristics and representative microorganisms, are presented in Table 1 [4–6].

Table 1: *Mechanisms of Mycotoxin Detoxification by Lactic Acid Bacteria*

Mechanism	*Description*	*Key factors*	*Advantages*	*Limitations*	*Microorganisms*
Adsorption	Binding of mycotoxins to cell wall components (peptidoglycan, polysaccharides, teichoic acids)	pH, temperature, cell surface properties	Fast and simple process	Reversible binding	*Lactobacillus rhamnosus, L. casei[4,5]*
Bioadsorption	Strain-specific interactions between mycotoxins and bacterial surface	Cell wall structure, hydrophobicity	Higher selectivity	Strain-dependent	*Lactiplantibacillus plantarum, L. rhamnosus [5,6]*
Biotransformation	Enzymatic degradation of mycotoxins into less toxic products	Enzymatic activity, environmental conditions	Potential permanent detoxification	Insufficiently studied	*L. plantarum, L. fermentum [4,5]*
Inhibition of fungi	Reduction of fungal growth and mycotoxin production	pH, LAB metabolites	Preventive effect	Does not remove existing toxins	*L. plantarum, L. brevis[4,6]*

Source: Author's own work based on references [4–6].

The mechanisms of mycotoxin detoxification by lactic acid bacteria are summarized in Table 1 [4–6], while their interrelationship and modes of action are schematically illustrated in Picture 1. As can be observed, the detoxification process is not the result of a single mechanism, but rather the synergistic action of adsorption, enzymatic biodegradation, and interactions with microbial metabolites. This complexity further highlights the need for a detailed understanding of these mechanisms in order to optimize their application in real food systems.



Picture 1. *Schematic representation of mycotoxin detoxification mechanisms by lactic acid bacteria(Source: Adapted from [1])*

3. Factors Affecting the Efficiency of Mycotoxin Detoxification by Lactic Acid Bacteria

The efficiency of mycotoxin detoxification by lactic acid bacteria (LAB) depends on numerous interrelated factors, including the characteristics of the bacterial strain, environmental conditions, and the properties of the food matrix [4,5].

One of the most important factors is the selection of the bacterial strain, since different LAB strains show significant differences in their ability to bind and transform mycotoxins. These differences are primarily related to the structure of the cell wall and the surface properties of the bacteria [4].

The pH of the medium plays a key role in the detoxification process, as it affects the stability of mycotoxins, as well as the surface charge of bacterial cells and their ability to interact with toxins. Lower pH values, typical of fermented products, may increase adsorption efficiency, but at the same time may also affect the stability of the bound complexes [5].

Temperature and contact time also significantly influence detoxification efficiency. An increase in temperature and a longer interaction time

between bacteria and mycotoxins may enhance the degree of removal, but excessive prolongation of the process may lead to the desorption of bound toxins [5].

The composition of the food matrix is another important factor, because proteins, fats, and other milk constituents may affect the availability of mycotoxins and their interaction with bacteria. For example, the presence of casein may affect the availability of mycotoxins and their interaction with bacteria [4,5].

Finally, the concentration of bacterial cells and the initial concentration of mycotoxins directly affect the binding capacity and overall process efficiency. A higher bacterial concentration usually leads to a greater degree of mycotoxin removal, but this relationship is not always linear [4].

Given the complexity of these factors, the optimization of the detoxification process requires a systematic approach and the adjustment of conditions to the specific food system [4,5].

4. Conclusion

Mycotoxins, particularly aflatoxin M1, represent a major concern in milk and fermented dairy products due to their stability and toxicity. Lactic acid bacteria show considerable potential for reducing mycotoxin levels through adsorption, biotransformation, and inhibition of mold growth. However, the predominance of reversible adsorption limits long-term effectiveness.

The overall efficiency of these processes depends on both bacterial and environmental factors, emphasizing the need for optimization. Future research should focus on a deeper understanding of detoxification mechanisms and their validation under real processing conditions to enable practical application.

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