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REVIEW ON BIO-DETOXIFICATION OF AFLATOXINS BASED ON LACTIC ACID BACTERIA: MECHANISM AND APPLICATIONS

Hajar Zolfaghari[1], *Arezou khezerlou*[1], *Seyed Alireza Banihashemi*[1], *Milad Tavassoli*[1], *Ali Ehsani*[*2]

Address(es):
[1] Student research committee, Department of Food Science and Technology, Faculty of Nutrition and food science, Tabriz University of Medical Sciences, Tabriz, Iran.
[2] Professor, Department of Food Science and Technology, Faculty of Nutrition and food science, Tabriz University of medical sciences, Tabriz, Iran.

*Corresponding author: ehsani@tbzmed.ac.ir

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ABSTRACT

Access to healthy food, without any undesirable contamination, is one of fundamental human right. Some of mycotoxins, especially aflatoxins (AFs), contamination feed and food that cause problems such as acute damage liver, irritation, and cancer of the liver and teratogenic complications. Among the physical, chemical and biological methods used to prevent the production, reduction, elimination and deactivation of AF in contaminated food, biological methods have been considered, due to maximum efficiency, low cost, eco-friendly and non-degradation of nutritional quality. The protective effect of lactic acid bacteria as probiotic microorganisms against mutagenic factors, such as polycyclic amines, N-nitrosamine compounds, and mycotoxins has been proven. Therefore, in addition to the beneficial properties using these probiotic bacteria with the ability to remove AF can help to enhance food safety. Although some naturally-occurring bacteria in the intestine can be attached to harmful components such as toxins and prevent them from binding to the intestinal layer, but probiotics have the potential to inactivate toxins through surface binding, due to high adhesion properties in their cell wall proteins. Polysaccharides and peptidoglycans in the cell wall are two of the main ingredients for decomposition, bonding and binding of AFs to lactic acid bacteria. Therefore, this review examines the economic and health impacts of AF contamination in foods. Further, this review discusses how lactic acid bacteria are able to detoxify common food AFs.

Keywords: Aflatoxin; Cell wall; Detoxification; Lactic acid bacteria

INTRODUCTION

Access to healthy food, without any undesirable contamination, is one of fundamental human right **(Ayala and Meier., 2017; Muhialdin *et al*., 2020).** Scientific studies show that in recent decades a number of contaminants, especially mycotoxins, have been spread from the environment to natural resources and food and feed. Mycotoxins have bad effects on human health and cause diseases such as cancer. This is one of the main concerns of developing countries **(Alshannaq and Yu., 2017)**. Aflatoxins (AFs) are the most dangerous among mycotoxins. Today, many methods (including physical, chemical and biological) are used to detoxify and decontaminate AFs from food and feed **(Sipos *et al*., 2021)**. Physical and chemical methods in the industry are not being used due to the high cost and effects on the texture and taste and the reduction of nutritional value **(Deng *et al*., 2019; Jard *et al*., 2011)**. Most researchers have identified biological methods as the best way to decontaminate AF. These methods due to the use of effective microbial species with the ability of reducing AF easily to maximize efficacy, minimize cost, compatibility with the environment and not to reduce nutrition value have been considered **(Marshall *et al*., 2020)**. Most lactic acid bacteria (LAB), especially lactobacillus and *Bifidobacterium* species, are probiotic microorganisms that have the ability to detoxify AFs **(Liu *et al*., 2020)**. According to the World Health Organization, probiotics are living microorganisms that provide health benefits to their host, if they consumed as much as needed. These living microorganisms help to maintain the balance of the digestive tract of mammals and their functional properties include Immune modulation, reducing serum cholesterol, gastrointestinal tract infections, cancer risk, skin sensitization, food allergy in children, urinary tract infections and the risk of chronic and travel diarrhea **(Aureli *et al*., 2011; Oelschlaeger., 2010)**. There are also reports of the protective effect of probiotic LABs against chemical mutagenic agents such as AFs, multi-ring amines, N-nitrosamine compounds and benzopyrene. Therefore, using these probiotic bacteria with the AFs removing the ability, also can help to increase food safety along with their beneficial properties **(Afshar *et al*., 2020; Ondiek *et al*., 2022)**. In the next sections of this paper, overview of Mycotoxins, AFs and the beneficial properties of probiotics, cell wall structure of lactic acid bacteria as the most common probiotics, and their potential applications to eliminate AF have been investigated.

MYCOTOXINS

Mycotoxinogenic fungi play an undeniable role in reducing food safety through the production of mycotoxins. These natural carcinogens (mycotoxins) are present in human diets due to the contamination of raw materials or the production of toxic substances during the processing or storage of food **(Yang *et al*., 2020)**. Mycotoxins are toxic secondary metabolites of low molecular weight, which do not have antigenic properties alone and therefore cannot stimulate the host immune system **(Santos *et al*., 2019)**. The importance of mycotoxins is due to their toxicity, carcinogenic, teratogenic, mutagenic, acute and long-term suppressive effects **(Bakırdere *et al*., 2012)**. Specifically, they are common in tropical and sub-tropical countries and infect about 25% of human food and animal feed **(Monda and Alakonya, 2016)**. Their prevalence may be by using toxic food or contaminated plant and animal products. Six groups of mycotoxins, including AFs, fumonisin, ochratoxin, patulin, *tricotesen*, and zearalenone, are often seen in various food systems **(Huffman *et al*., 2010)**. The studies of the effect of microorganisms on mycotoxins have been begun decades ago. The surface binding of some microorganisms to various mycotoxins including AFs, ochratoxin and zearalenone has been reported. Many studies have been conducted to remove mycotoxins by lactic acid bacteria. The ability of LABs to remove mycotoxins greatly depends on the environmental conditions, type, composition of the amino acid and the peptidoglycan structure **(Agriopoulou *et al*., 2020)**. The connection of ochratoxin and zearalenone is attributed to cell wall glucans. Hence, it can be concluded that the removal of mycotoxins from different matrices by living and non-living cells depends on their strain and species, and each strain and species behave in a different way **(García-Béjar *et al*., 2021; Vartiainen *et al*., 2020)**.

Aflatoxins

AFs are a group of carcinogenic mycotoxins that cause acute or chronic poisoning and liver cancer in humans and animals. They also cause a lot of economic losses in the industry due to contamination of food and animal feed **(Vartiainen *et al*., 2020)**. These toxins are secondary metabolites of some *Aspergillus* species, especially *Aspergillus flavus* and *Aspergillus parasiticus* and mainly found before harvesting or during storage in cereals, especially rice, corn, wheat, barley, sorghum, almonds, peanuts, Brazilian nuts, pistachios and oilseeds such as cottonseed **(Liu *et al*., 2020)**. The production of this toxin can be affected by several factors, including water activity (aw), temperature, light, oxygen

concentrations, pH, nutrients, storage time, mechanical/thermal damage, and competitive growth of other microorganisms. Among them, aw and temperature, the two key environmental factors during storage, have a strong impact on both fungal growth and secondary metabolite production. Also, mold growth is strongly influenced by humidity. The optimal growth temperatures for Aspergillus range from 28–40 °C with and aw 0.94–0.99, but the fungi can survive temperatures of 12–48 °C. Both *A. flavus* and *A. parasiticus* can grow over the pH range of 2.1 to 11.2, with an optimum between pH 3.5 and 8 **(Lv *et al*., 2019)**. More than 20 types of AFs are known, of which Aflatoxin B1 (AFB1), Aflatoxin B1 (AFB2), Aflatoxin G1 (AFG1), Aflatoxin G1 (AFG2), Aflatoxin M1 (AFM1), and Aflatoxin M1 (AFM2) are biologically common **(Miklós *et al*., 2020)**. which their structure is shown in Figure 1. Among AFs, AFB1 and AFB2 are the most important and type B1 is known as the most toxic AF. The liver is the main target organ for AF, although the tumor may also occur in other organs, such as the lung, kidney, and colon **(Long *et al*., 2016)**. *Aspergillus Flavus* is known to produce AFB, while *Aspergillus Parasiticus* produces both AFB and G through numerous biochemical processes. Hydroxylation of AFB1 leads to the formation of AFM1. Receive and direct absorption of AFB1 by animal's produces and stores AFM1 in milk **(Patyal *et al*., 2020)**. AFM1 is resistant to pasteurization and sterilization. The European Union and the International Codex have set the maximum level of 0.5 mg/L for AFM1 in milk, milk powder and other processed products **(Fashandi *et al*., 2018)**. Chemical and physical methods may be subject to limitations in the areas of biological safety, the loss of quality and nutritional value, the limitations on the efficiency, effectiveness and cost of equipment. A variety of chemical methods are used in the food and feed industry to remove or reduce mycotoxin content, such as oxidation, alkalization, acidification, reduction, and ammoniation. The use of hundreds of chemicals, such as ammonia, calcium hydroxide monoethylamine, sodium hydroxide, ozone, chlorine, and calcium hydroxide, has shown promise in reducing mycotoxin levels in foods. It is possible to partially destroy mycotoxins by using chemical methods, such as oxidation and alkalization, but some nutrients are also destroyed **(Jard *et al*., 2011; Karlovsky *et al*., 2016)**.

The safety and harmless of lactic acid bacteria and Bifidobacteria as probiotics provide a good opportunity for application in biological reduction of AF in food **(Lyagin and Efremenko, 2019)**. The ability and stability of microorganisms in binding toxins are very important for evaluating the ability of strains to reduce the biological effects of AFs. The release of toxin during transition through the stomach may result in harmful health effects. This limitation is reversible and its stability depends on the strain, formation conditions and method used to determine the stability **(Ahlberg *et al*., 2015)**.

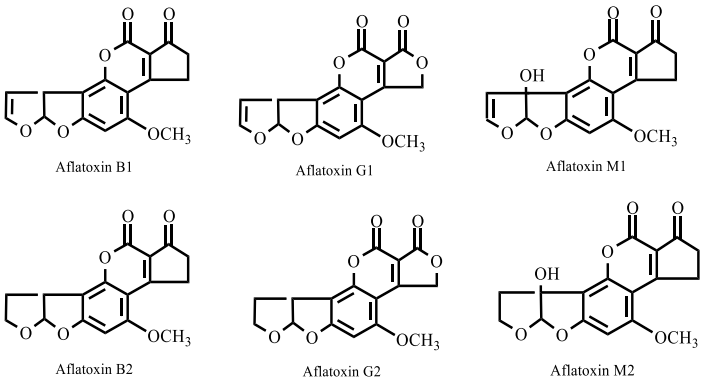

Figure 1 The structure of common Aflatoxins

PROBIOTIC BACTERIA

Probiotic is derived from the Greek word "for living". They are known as living organisms, which can have beneficial effects on the host by improving the balance of the microbial flora of the gut if used sufficiently **(Kouhi *et al*., 2022)**. Probiotics are living organisms that confer health benefits on the host when administered in an adequate amount. Typically, they are available as either food products (fermentable or non-fermentable) or dietary supplements (capsule, tablet, or powder). A growing awareness among consumers is leading to an increase in consumption of probiotics. Probiotics are an innovative and inexpensive invention in society that can improve the health of people. Due to the accumulation of toxic substances during digestion, the presence of bad microorganisms causes many diseases and illnesses in the human body. During this time, the immune system begins to deteriorate **(Fashandi *et al*., 2018)**. Probiotics in higher doses are an alternative method to treating such problems instead of taking antibiotics. Probiotics can be formulated in various products, especially foods, medicines and dietary supplements. This group of bacteria plays an important role in inhibiting infections in different parts of the body, especially the mouth, gastrointestinal and genitourinary tract **(Picard *et al*., 2005)**. Among probiotics, Lactobacillus species and Bifidobacterium species are most used, but *Saccharomyces cerevisiae* and some Bacillus species are also used as probiotics. Therefore, it can be said that lactic acid bacteria, especially lactobacillus and Bifidobacterium, are the most important probiotic bacteria that are completely safe and non-pathogenic to humans. In order to provide health benefits, the end product population of viable bacteria must be greater than 10^7 CFU/mL. These probiotics can prevent the absorption of AFs in the gastrointestinal tract by binding to AFs in foods **(Guarner *et al*., 2012)**.

Lactic acid bacteria and bifidobacteria

Lactic acid bacteria are Gram-positive, non-spore forming and catalase-negative bacteria and they mainly produce lactic acid by fermentation of carbohydrates. For the first time, they were isolated from milk and widely used as starting cultures in dairy, meat, vegetable and cereal industries **(Valenzuela *et al*., 2019)**. They are mainly divided into four genera, such as Lactobacillus, *Lactococcus*, *Leuconostoc*, and *Pediococcus*. The term lactic acid bacteria are used for different species of Bifidobacterium, although they have unique carbohydrate fermentation pathways and have no physiological relationship **(Hernandez-Mendoza *et al*., 2011)**.

Lactobacillus species have strong antimicrobial activity against many pathogen microorganisms. Also, *Enterococcus faecium* is one of the lactic acid bacteria found in nature and some processed dairy products **(Bartkiene *et al*., 2020)**. Lactic acid bacteria naturally exist in mucous membranes and skin of the human and animal's body. They have been widely used in fortified foods, due to their beneficial health effects and preservative properties. Most of their useful properties relate to the binding capacity and adhesion to the intestinal mucosa or epithelial cells. They also protect food from toxic substances and produce some antagonistic compounds that are capable of controlling pathogenic bacteria and spoilage **(Alp and Kuleaşan, 2019; Mirlohi *et al*., 2008)**. Due to their efficiency, low cost, and nature-friendly properties, biological decontamination procedures are rapidly becoming an encouraging alternative to chemical methods. There is a significant efficacy of LAB for eradicating mycotoxins irreversibly, without leaving any toxic residues. In different food products such as dairy products, they can be used as starter cultures in fermentation processes **(Sevim *et al*., 2019)**. It is possible to enjoy the benefits of LAB through consumption of probiotic-related food products. Most commonly, LABs preserve materials by producing organic acids, competing for nutrients, and ultimately releasing antimicrobials. As well as reducing and inactivating toxins, some antifungal metabolites released by LABs also suppress fungal growth. Metabolites such as phenolic compounds, fatty acids, hydrogen peroxide, and proteinaceous compounds are present in the body. Fermented dairy products are highly dependent on this fermentation procedure that controls the contamination of the product by pathogens by producing lactic acid from lactose. Two mechanisms are involved in mycotoxins' detoxification from food by the LAB. It is possible to detoxify food by LAB by using the viable cells of the microbes or by using the enzymes produced by some LAB strains **(Muhialdin *et al*., 2020).** Microorganisms, including fungi, have been a source of food spoilage for an extended period of time **(Varga and Tóth, 2005).** A number of bioactive metabolites produced by LAB limit the growth of fungi and prevent the formation of mycotoxins in food. The bioactive compounds contained in LAB include acids, hydrogen peroxide, carbon dioxide, phenyllactic acid, and low molecular weight peptides. The LAB produces a number of proteolytic enzymes capable of hydrolyzing proteins. These enzymes include cell-wall bound proteinases, which break down proteins into polypeptides, peptide transporters that carry peptides into cells, and intracellular peptidases which degrade them into amino acids. As a result of LAB proteolytic enzymes, mycotoxins in food are detoxified most effectively **(Alberts *et al*., 2009)**.

Generally, the antimicrobial activity of LAB can be explained by three mechanisms such as organic acid function, competition for nutrients and the production of antagonistic compounds **(Chen *et al*., 2019)**. Antifungal metabolites of lactic acid bacteria include sugary catabolites (such as organic acids, acetic acid, and formic acid), oxygenated catabolites (such as hydrogen peroxide), and protein compounds (such as low molecular weight peptides, hydroxylic fatty acids, and phenolic compounds) **(Servin, 2004).**

Antifungal activity of LAB is affected by some processing parameters including temperature, incubation time, pH and nutritional factors **(Dalié *et al*., 2010)**. Using a combination of certain strains of probiotic bacteria may be more effective than using a single strain, however, it may reduce the toxin removal capacity **(Liu *et al*., 2019).** Therefore, to remove a single compound, an efficient strain and to remove several compounds, a mixture of the best strains is used **(Khorshidian *et al*., 2020)**.

Cell wall of acidic lactic acid bacteria

The LAB has a peptidoglycan matrix, which forms the main constituent of the cell wall structure. Teichoic Acid, Lipoteichoic Acid, protein layers, and neutral polysaccharides are the other constituents of the cell wall that have different functions **(Niderkorn *et al*., 2009)**. Adhesion and biding to macromolecules are the function of the fiber network in Teichoic Acid and polysaccharides such as cell wall polysaccharides and exopolysaccharides. Cell wall polysaccharides of lactic acid bacteria are one of the most commonly used polysaccharides with a wide variety in the compounds containing rhamnose **(Chapot-Chartier and Kulakauskas, 2014)**. Exopolysaccharides are either transmitted to the extracellular medium or attached to a surface to form a capsular polysaccharide **(Liu *et al*., 2019)**. Some genera of Lactic acid bacteria, including Lactobacillus,

Enterococcus and Streptococcus, as well as the genera used in the dairy industry, such as Bifidobacteria and Propionic bacteria, produce exopolysaccharides as glucose, galactose, rhamnose, mannose, N-acetylglucosamine and N-acetyl galactosamine. Peptidoglycan in LAB is composed of N-acetylglucosamine and N-acetylmuramic acid disaccharide polymers that are arranged side by side with beta-1, 4 glycosylated bonds and these chains are bonded by transverse pentapeptide bridges **(Sánchez *et al*., 2006)**. The peptidoglycan disaccharide units have three different modes. Acetyl groups may be broken down in both N-acetyl-glucosamine disaccharides and N-acetyl muramic acid **(DeMeester *et al*., 2019)**. An extra acetyl group is added to the oxygen number 6 of N-acetyl-muramic acid and the position of carbon-6 of N-acetylmuramic acid is replaced by teichoic acid. The peptide segment consists of 3 amino acids that are linked to muramic acid. The amino acids of the penta-peptide bridge in N-acetyl-muramic acid usually contain one of the two compounds, L-alanine, D-glutamine, Diaminopimelic acid, or L-alanine, D-glutamine, and L-Lysine. Although at least five different subtypes have been identified for peptidoglycans **(Delcour *et al*., 1999)**. A di-peptide residue from D-alanine is directly or via a bridge attached to this peptide. The amino acid D-alanine in some lactic acid bacteria that are resistant to vancomycin, such as *Enterococcus faecium*, *Pediococcus Pentosaceus*, *Lactobacillus plantarum* and *Lactobacillus casei* replace the d-lactate in penta peptide bridge, but in the bacteria *Enterococcus faecium*, *Pediococcus Pentosaceus*, *Lactobacillus plantarum*, *Lactobacillus casei* and *Enterococcus Gallinarum*, *D*-serine is replaced **(Barbieri *et al*., 2019)**.

Teichoic acids are anionic polymers in the cell wall that covalently bond to the peptidoglycan layer and are the cause of the serological difference is the presence of several gram-positive bacteria **(Brown *et al*., 2013)**. Teichoic acids are composed of glycerol phosphate or ribitol phosphate polymers and carbohydrates that are bonded to each other by a phosphodiester bond. The composition of the structural unit in *Lactobacillus plantarum* has been reported as glycerol phosphate-n-acetyl manozamin with glycosylated beta-1 and 4 grafts **(Seltmann and Holst, 2013)**. The lipoteichoic acid is structurally similar to teichoic acids, but they attach to the cytoplasmic membrane glycolipid, instead of peptidoglycans. Generally, the glycolipid consists of diacylglycerol bonded to *di-, or disaccharide* units **(Hynönen and Palva, 2013)**. Frequently it has been recognized that lipoteichoic acid is poly (glycerol phosphate) LAB that is almost similar to the poly (glycerol phosphate) teichoic acids, which differ only in the chirality of glycerol. Similar to teichoic acids, the lipoteichoic acid also have glycerol and di-alanine, which are replaced by hydroxyl groups in glycerol. It has been reported that many LAB of the genus Lactobacillus produce s-layer protein. These proteins are noncovalent and have a size of 25-50 KDa **(Silhavy *et al*., 2010).**

LAB that cannot produce s-layer proteins has a negative surface charge at neutral pH. Despite the fundamental nature of the surface layer protein, it is reported that surface charge on the surface layer which produced by Lactobacillus also have been reported negative **(Ventura *et al*., 2002)**.A hypothesis for this mechanism may be the involvement of positive-charge regions in surface-layer proteins on binding to peptidoglycans. Injury or destruction in the cell wall of the bacteria in Comparison to a completely healthy and without attachment sites can reveal unattended connection sites and may allow the attachment of AF to the cell wall and plasma membrane compounds **(Macek *et al*., 2019; Smit *et al*., 2001)**. The use of acidic and heat treatments is likely to disrupt the integrated structural form, and thus allow AF to be incorporated into intracellular compounds. This mechanism was identified during the use of antibody to analyze AFB1 in acid-treated bacteria that prevents antibody entry, because the size of the antibody molecule is large and could not cross the cell wall of the bacterium and bind to the AFB1 molecule in the inner wall. According to a study by **Haskard *et al*. (2001b)**, *Lactobacillus rhamnosus* was exposed to enzymatic treatment and its effect on the binding of AFB1 was investigated. The results showed that there was no evidence of exopolysaccharide involvement, but cell wall proteins, calcium ions and magnesium ions played a decisive role in this regard. Adsorption to surface components of different nature has been reported as the major mechanism for binding, mycotoxins. Figure 2 shows the cell wall structure in LAB and proposed processes involved in the interaction with AFs.

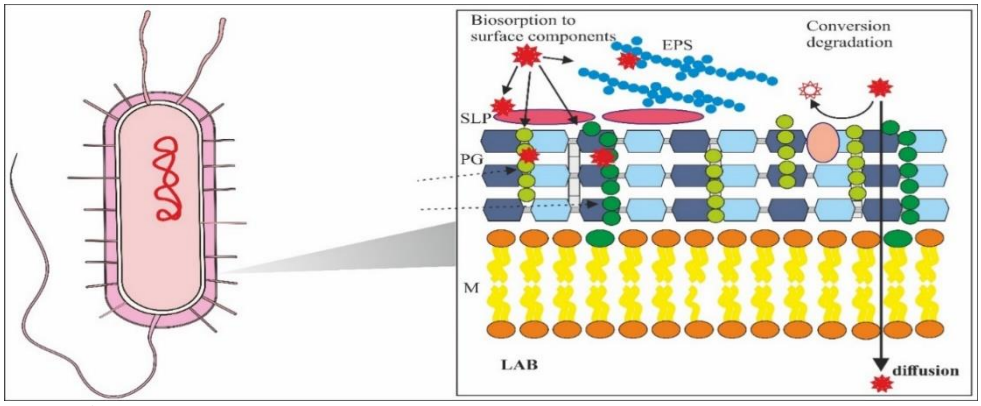

Figure 2 Schematic representation of the cell wall structure in LAB and proposed processes involved in the interaction with AFs. Adsorption to surface components of different nature has been reported as the major mechanism for binding, mycotoxins. EPS, exopolysaccharides; SLP, S-layer proteins; PG, peptidoglycan; TA, teichoic acids; LTA, lipoteichoic acids; M, cytoplasmic membrane.

The function of lactic acid bacteria in aflatoxin detoxification

According to previous studies, microorganisms such as *Saccharomyces cerevisiae*, *Flavobacterium* and *Lactobacillus* species, including *Lactobacillus acidophilus* and *Lactobacillus rhamnosus*, and other subtypes, could decompose and bind AFs through their cell walls **(Shetty and Jespersen, 2006)**. Injury or destruction in the cell wall of the bacteria in Comparison to a completely healthy and without attachment sites can reveal unattended connection sites and may allow the attachment of AF to the cell wall and plasma membrane compounds **(Gao *et al*., 2021; Haskard *et al*., 2001b)**. According to previous studies, polysaccharides and peptidoglycans in the cell wall are two main elements in LAB, and both of these compounds are strongly affected by acidic and heat treatment in order to effectively interact with mutagens **(Sezer *et al*., 2013)**. Heat causes the denaturation of protein or formation of maillard reaction products between polysaccharides and proteins or peptides. Also, acid can break glycosidic bonds in polysaccharides, and release monomer, which later turns into aldehyde and then breaks down peptide bonds and releases amino acids. Although the peptidoglycan layer is quite thick in these microorganisms, but in this case there may be a reduction in thickness and transverse joints in it **(El-Nezami *et al*., 1998; Gao *et al*., 2021)**. It is noted that AFB1, connects to the superficial compounds of LAB. Destruction of these specific compounds of the cell wall, such as carbohydrates and proteins, reduces AFB1 bonding by *Lactobacillus rhamnosus* GG, and it is stated that these compounds are important for the binding of AFB1. According to a study by Haskard, El-Nezami, Kankaanpää, Salminen, and Ahokas (2001a), the bacterium *Lactobacillus rhamnosus* was exposed to enzymatic treatment and its effect on binding of AFB1 was investigated and the results showed that there was no evidence of exopolysaccharides involvement, but the proteins in the cell wall, calcium and magnesium ions play a decisive role in this regard **(Fochesato *et al*., 2019; Haskard *et al*., 2001a)**. It is likely that the use of acid and heat treatment eliminate the structural integrity and there for AF could bond to intracellular compounds. This mechanism was identified during the use of antibodies to analyze AFB1 in acid-treated bacteria, which prevented the entry of antibodies, because the size of the antibody molecule is large and does not have the ability to cross the cell wall of the bacterium and connect to the AFB1 molecule in the inner wall **(Ahlberg *et al*., 2015).** Some of the different types of LAB and Bifidobacteria have been investigated for the removing AFB1 from aqueous buffer solution, in vitro, and it has been said that their elimination is by binding of bacteria to toxic compounds and is not related to bacterial metabolism **(Haskard *et al*., 2001b; Hernandez-Mendoza *et al*., 2009)**. Table 1 lists the LAB that can remove AFs. **Muaz *et al*. (2021)** investigated the in vitro ability of *L. rhamnosus*, *L. lactis ssp. lactis* and one *L. lactis ssp. cremoris* at 10^{10} cells/mL to bind to AFM1 in skimmed milk, and showed higher binding capacities by 81.4, 56.8, and 50.8%, respectively. This binding is due cell wall isolates and exopolysaccharide compounds. **Liew *et al*. (2018)** studied the ability of *L. casei Shirota* (live cell, heat-treated, and cell wall compounds) to bind AFB1, the binding capacity of *L. casei Shirota* was dependent on concentration of AFB1.They found that live cells had maximum binding capacity (98%). In vivo studies, *L. casei Shirota* neutralized toxicity of AFB1 on body weight and intestine by binding process. **Chlebicz and Śliżewska (2020)** performed in vitro study on the binding properties of AFB1 by 12 strains of lactic acid bacteria, which its concentration was decreased on average by 60% after 24 h incubation. **Ben Salah-Abbes *et al*. (2020)** have investigated the ability of *L. paracasei* BEJ01 to bind AFM1 in vitro and have revealed this strain was very effective for eliminating AFM1 with more than 95% of the toxin with concentration of 100 µg/ml.

Table 1 The ability of lactic acid bacteria to reduction of Aflatoxins.

Microorganism	Method	Incubation of medium	Aflatoxin	Reduction (%)	Reference
L. rhamnosus and *L. lactis* *Saccharomyces cerevisiae*	HPLC	Frescal cheese	M1	94 % 100 %	**(Gonçalves *et al*., 2020)**
L. acidophilus (ATCC 4356) *L. casei* (ATCC 39392)	HPLC	Human gastrointestinal tract	B1	13.86–70%	**(Tajik and Sayadi, 2020)**
L. fermentum *L. delbrueckii subsp. lactis*	HPLC	Almond butter	B1 G1 B1 G1	50% 58% 58% 70%	**(Hashemi and Amiri, 2020)**
Bifidobacterium longum *L. mesenteroides* *L. rhamnosus*	TLC	-	G1	28% after 24 h at 37 °C 27.1% and 56% after 24h and 72 h at 37 °C 56.8 after 72 h at 37 °C	**(Danial *et al*., 2021)**
L. acidophilus PTCC 1643 *L. rhamnosus* PTCC 1637	HPLC	Yogurt	B1	64.56 to 96.58%	**(Mosallaie *et al.*, 2020)**
L. reuteri *L. rhamnosus*	-	Sarshir	M1	72.72%	**(Bagher Hashemi and Amiri, 2021)**
L. helveticus	ELISA	Wheat bran	B1	88.6%.	**(Zhang *et al*., 2021)**
Lb. plantarum MNC 21 *Lactococcus lactis* MNC 24	ELISA	fermented sorghum-millet beverages	B1	19.3–69.4 %	**(Byakika *et al*., 2019)**
L. plantarum CRD7 *L. rhamnosus CRD9* *L. plantarum CM63* *L. plantarum BM71* *L .plantarum HIF81*	ELISA	In vitro Digestion Model	M1	52.84 ± 3.34% 44.09 ± 5.86% 32.61 ± 3.13% 37.5 ± 3.5% 48.26 ± 4.53%	**(Panwar *et al*., 2019)**
L. rhamnosus yoba 2012 *Streptococcus thermophilus C106*	HPLC	Kwete	B1, B2, G1, G2	17% 83%	**(Wacoo *et al*., 2019)**
Lactobacillus sp. bacteria (12 strains) *S. cerevisiae* yeast (6 strains)	HPLC	-	B1	60% by *Lactobacillus* 65% by yeast	**(Chlebicz and Śliżewska, 2019)**
L. reuteri, *L. plantarum,* *L. pentosus,* *L. rhamnosus* *L. paracasei* *Saccharomyces cerevisiae*	HPLC ELISA	-	B1	liver from 8.9 to 3.7 kidneys from 11.8 to 5.9 µg/kg	**(Śliżewska *et al*., 2019)**
L. plantarum ATCC 10697 *B. animalis ATCC 27672,* *B. bifidum ATCC 35914)*	ELISA	Commercial probiotic yoghurts	M1	54.0 ± 1.95% 49.5 ± 2.00% 50.4 ± 1.98%	**(Sevim *et al*., 2019)**
L. rhamnosus	HPLC	-	M1	60.74%	**(Assaf *et al*., 2019)**
L. rhamnosus	ELISA	Fermented dairy products	*AFs*	76% -81.6% at MRS medium and AIF	**(Alrabadi *et al*., 2018)**
L. acidophilus (EMCC 1324) *Bifidobacterium bifidum (EMCC 1334)* *kluyveromyces lactis CBS 2359 Saccharomyce cerevisiae ATCC 64712)*	HPLC /FLD	Coctile	B1, B2, G1, G2	8.17% - 6h 36.12% - 12h 44.75% - 24h 64.72% - 48h 93.21% - 72h	**(Hamad *et al*., 2018)**
Bacillus subtilis, *L. casein* *Candida utilis*	ELISA	-	B1	26.06 ± 2.52 38.83 ± 4.24 21.08 ± 0.12	**(Huang *et al*., 2018)**
L. brevis *L. paracasei*	HPLC	Traditional Egyptian dairy products	B1	90.4 - 96.31% 84.65 - 90.12%	**(Gomaa *et al*., 2018)**
L. Plantarum *L. acidophilus* *Bifidobacterium bifidum* *Kluyveromyces lactis* *Saccharomyces cerevisiae*	HPLC	Yoghurt	M1	80.56% - 12 h 86.64% - 24 h 88.60% - 48 h 90.88% - 72 h	**(Abdelmotilib *et al*., 2018)**
Bifidobacterium BB-12 *L. acidophilus* DSM 20242	ELISA	-	B1	8.24% 23.70%	**(Florina *et al*., 2018)**
L. acidophilus ATCC 4356	HPLC	Gastrointestinal simulated medium Sterilized milk	B1	70±0.022% at sterilized milk	**(Sayadi and Tajik, 2018)**
L. acidophilus *L. plantarum* *streptococcus thermophilus* *L. rhamnosus*	HPLC	MRS broth media and whole milk	B1	80% reduction in milk 85% reduction 65.7% 44.4%	**(Marrez *et al*., 2018)**
L. plantarum CIDCA 83114	-	Poultry feed	B1	20%	**(Moretti *et al*., 2018)**
LAB species in milk	ELISA	Traditional Fermented Milk	M1	57.33 and 54.04%	**(Shigute and Washe, 2018)**

HPLC: High-performance liquid chromatography; TLC: Thin layer chromatography; ELISA: Enzyme-linked immunosorbent assay.

Attaching of LAB to AF is fast (more than 1 minute) and reversible **(Bueno *et al*., 2007)**. Pre-treatment of LAB with heat or acid increases the AF decontamination, while treatment with some of the main compounds such as sodium hydroxide, sodium carbonate and isopropanol have a negative effect on this connection. The total AFB1 molecules, which can be connected to a live bacteria is estimated to be more than 107 molecules **(Gonçalves *et al*., 2020)**. More over AFB1, these bacteria also bind to other AFs, such as B2a, G1, G2, M1, M2, B2, as well as other mycotoxins, but not as much as AFB1**(Bueno *et al*., 2007; Salminen *et al*., 2010)**. It has been confirmed that the addition of metal ions, for example, sodium chloride and calcium chloride, and a wide range of pH (from 2.5 to 8.5), did not significantly

affect the binding of AFB1, which means that electrostatic interactions and hydrogen bonding do not play an important role in bonding **(Vázquez-Durán *et al*., 2021)**.

CONCLUSION

Biological control methods based on LAB provide a promising approach to controlling the growth of mycotoxins in the food chain and hence reduce the health risks of fungal toxins. Many studies have shown different efficacy of LAB from a variety of matrices in the removal of mycotoxins (especially AF). Mainly, the detoxification relies on the binding of mycotoxin to the lactic acid bacteria and inactivation by antifungal products such as acetic acid. Most likely, it is related to the cell wall components (mainly peptidoglycan and exopolysaccharides) of LAB. In addition, studies have shown that treatment of cells with acid and heat can detoxify them. Therefore, removal and reduction can be demonstrated by the connection of toxin to the bacterial cell wall. However, the exact mechanism for bonding AF to probiotics is not known, but studies have shown that AF binding is a reversible reaction which occur in the surface of the bacteria and it includes interactions with carbohydrates, peptidoglycans and to some extent the protein structure. It seems that AF binding extremely related to strain, matrix, temperature, and pH and incubation time. There for, most probably, specific strains LAB is required against fungal contamination in different applications. Especially, strains of Lactobacillus genus have been studied and according to reports, potentially could reduce the risks of AFs hazards associated with food matrix and contaminated Animal feed. But still further research is needed to identify the potential species LAB from traditional fermented products, which produced in different parts of the world and testing their functionality in different matrices. The optimum conditions for mycotoxin detoxification and the mechanisms involved in mycotoxin degradation still require further research. There is a need to determine the diversity and suitability of LAB for different food applications based on their detoxification activity. It is important for future studies to combine LAB strains with different detoxification mechanisms in order to further enhance the efficiency of mycotoxin degradation.

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