Ability of Different Treatments of \textit{Saccharomyces cerevisiae} to Surface Bind Aflatoxin M\textsubscript{1} in Yoghurt

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\textbf{ABSTRACT}

Microbial detoxification is considered as one of the most common methods used for the elimination of aflatoxins. Reports indicate that \textit{S. cerevisiae} can be effective in removing aflatoxins through the adsorption of aflatoxins to their cell wall. In the current research, the ability of \textit{S. cerevisiae} (viable, acid-, heat- and ultrasound-treated yeasts) to bind aflatoxin M\textsubscript{1} was assessed in yoghurt. To this end, firstly, recombinant milk containing 12\% solids, non-fat skimmed milk powder was prepared. Next, the samples were spiked by aflatoxin M\textsubscript{1} using different concentrations (100, 500 and 750 pg mL\textsuperscript{-1}). When the starter bacteria were added to the milk, the treated yeasts were added as well. The concentration of aflatoxin M\textsubscript{1} residue in the supernatant of the yoghurt samples after different storage times (1, 7, 14 and 21 days) was measured using the ELISA method. The results showed that all treatments containing viable, acid-, heat-, ultrasound-treated yeast and starter bacteria were able to adsorb aflatoxin M\textsubscript{1}, and the ability of the treated yeast was significant as compared with the control ($P<0.05$). Among the treated yeasts, the ability of the acid-treated yeasts was higher in toxin binding. Overall, it can be concluded that using \textit{S. cerevisiae} for the biological adsorption of aflatoxin M\textsubscript{1} is effective in fermented dairy products.

\textbf{Keywords:} Biological adsorption, Cell wall, Fermentation, Mannan, Yeast.

\textbf{INTRODUCTION}

Some fungi produce toxic secondary metabolites which can cause acute toxic, mutagenic, teratogenic and carcinogenic effects. Aflatoxins are dangerous mycotoxins that are present in feed and food and are produced by species of Aspergillus, but Aspergillus \textit{flavus}, Aspergillus \textit{parasiticus} and \textit{Aspergillus nomius} are of most concern (Kusumaningtyas \textit{et al.}, 2006; Mohamadi and Alizadeh, 2010).

Aflatoxins may directly enter the human body by swallowing contaminated products or indirectly by consuming derived foods from primary contaminated materials, such as milk and dairy products from contaminated livestock. Aflatoxin B\textsubscript{1} is the most toxic mycotoxin, having harmful hepatotoxic, mutagenic, and carcinogenic effects on livestock. When aflatoxin B\textsubscript{1} in contaminated feed is ingested by livestock, it can be bio-transformed in the liver into aflatoxin M\textsubscript{1}, a hydroxylated metabolite which is excreted in milk, tissues, and biological fluids of animals (Masoero \textit{et al.}, 2009).

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Taking into account the health risks associated with human and livestock exposure to dietary aflatoxin levels, multiple efforts have been made for the complete removal or reduction of aflatoxin content in food products. Different methods have been used for reducing the amount of aflatoxin; for example, physical, chemical, and microbiological methods. According to the researches, microbiological method is an attractive alternative to control or reduce aflatoxin in foodstuffs (Alberts, et al., 2009). *S. cerevisiae* is the most effective microorganism for binding aflatoxin B$_1$ in Phosphate Buffer Saline (PBS) (Phillips et al., 1995; Sarimehmetoglu and Kuplulu, 2004; Shetty and Jespersen, 2006) and aflatoxins (B$_1$, B$_2$, G$_1$ and G$_2$) in PBS and cereals extracts (Hegazy et al., 2011), although Corassin et al. (2013) reported the capability of *S. cerevisiae* to bind aflatoxin M$_1$ in UHT skim milk.

The cell wall of *S. cerevisiae* represents about 30% (w/w) of total weight of the cell and is a bi-layered structure, the structural part of which is made up of $\beta$-1,3-glucan and $\beta$-1,6-glucan. The majority of the cell wall proteins (mannoproteins) are covalently linked to $\beta$-1,3-glucans through $\beta$-1,6-glucan chains. In addition, the cell wall is a highly dynamic structure responding quickly to changes in the environmental stresses. Based on chemical composition and physical nature of the *S. cerevisiae* cell wall, it is reasonable to think that the cell surface presents innumerable sites for the physical adsorption of molecules. Yeast cells can adsorb different molecules as complexes on their cell wall surface, such as toxins and metal ions. According to certain research, it is confirmed that removal of mycotoxins by cell wall binding is more relevant to covalent binding. Moreover, non-alive cells do not lose their ability to attract (Shetty and Jespersen, 2006). The mannan components of cell wall play a major role in aflatoxin linkage to *S. cerevisiae* (Devegowda et al., 1996).

Fermentation of food has been used as a method of preservation for centuries, and Lactic Acid Bacteria (LAB) and yeast, especially *S. cerevisiae*, are reported to reduce mold growth and aflatoxin production (Mokoena et al., 2006). LAB and *S. cerevisiae*, due to their GRAS status and use as probiotics, are of particular interest for reducing the bioavailability of aflatoxin M$_1$ in fermented dairy products. Also, there is no previous report on the use of *S. cerevisiae* for decontamination of yoghurt containing aflatoxin M$_1$. Therefore, this study was carried out to evaluate the potential of *S. cerevisiae* (viable, acid-, heat- and ultrasound-treated) to remove aflatoxin M$_1$ from yoghurt, when added with the yoghurt starters to yoghurt prepared from milk spiked with aflatoxin M$_1$, and the degradation of aflatoxin M$_1$ in yoghurt during storage time.

**MATERIALS AND METHODS**

**Preparation of Aflatoxin M$_1$ Solutions**

Aflatoxin M$_1$ was suspended in benzene-acetonitrile (97:3, V/V) to obtain an aflatoxin M$_1$ stock solution concentration of 1 µg mL$^{-1}$. The true concentration of this stock solution was calculated using a Beer-Lambert curve and an absorption measurement at 348 nm. The stock solution was solubilized at appropriate amounts of methanol after benzene-acetonitrile evaporation by heating in a water bath (70°C for five to 10 minutes) in order to obtain aflatoxin M$_1$ solutions with appropriate concentrations (Zinedine et al., 2005).

**Activation and Preparation of the Yeast Suspension**

*S. cerevisiae*, (PTCC 5177), was obtained from the Iranian Research Organization for Science and Technology (IROST), the Persian-type culture collection. The strain was grown on a Yeast Mould Broth (YMB; Difco) and incubated for 24 hours at 26°C. The cells were harvested by centrifugation at
3,400×g for 10 minutes, washed twice with phosphate-buffered saline (PBS, pH 6), and the spinning of the cells at 3,400×g for 10 minutes each time. The turbidity of suspension must be standardized to match that of a 7 McFarland standard (corresponds to approximately 2.1×10⁹ CFU mL⁻¹) (Peltonen et al., 2001; Shetty et al., 2007; Rahaie et al., 2010). The 7 McFarland standard solutions were prepared by mixing 93 mL sulfuric acid 1% and 7 mL barium chloride 1.175%. (Martin and Palomino, 2009).

Yeast Treatment with Ultrasound, Heat and Acid

The activated yeast were re-suspended in 10 mL PBS and autoclaved at 121°C for 15 minutes (Shahin, 2007), or incubated at 37°C in 2M HCl solution for one hour with mild shaking (Peltonen et al., 2001; Rahaie et al., 2010), or sonicate in ultrasonic bath for 15 minutes (50°C, 25 MHZ and 50% power) (Limaye and Coakley, 1998). After treatment, cells were centrifuged at 3400×g for 10 minutes and washed twice with PBS.

Contamination of Reconstituted Milk with Aflatoxin M₁ and Yoghurt Production

Reconstituted milk containing 12% total solids (non-fat) was prepared from skimmed milk powder. Some portions were contaminated with standard working solutions of aflatoxin M₁ at three different concentrations (100, 500, and 750 pg mL⁻¹) and a portion was noted as the control samples. After milk contamination, the samples were pasteurized at 90°C for 5 minutes and then cooled to 42°C. The samples were inoculated with starter cultures and the treated yeast cells were added. After mixing, homogenous samples were poured into sterile plates and incubated. After reaching pH 4.5, the samples were transferred to 4°C and stored for three weeks (Sarimehmetoglu and Kuplulu, 2004). The yoghurt samples were centrifuged to evaluate the residual aflatoxin in supernatant after 1, 7, 14, and 21 days.

Analysis of Aflatoxin M₁ by ELISA

The quantitative analysis of aflatoxin M₁ in the yoghurt samples was performed by competitive enzyme immunoassay using the RIDASCREEN Aflatoxin M₁ 30/15 (Art. No. R1111, R-Bio pharm, Darmstadt, Germany) test kit. One-hundred microliters of standard solutions and the prepared samples were added into separate microliter wells and incubated for 60 minutes at room temperature (22-25°C) in the dark. The liquid was then poured out and the wells were washed with a washing buffer (250 µL) twice. In the next stage, 100 µL of the diluted enzyme conjugate was added to the wells, mixed gently by shaking the plate manually, and incubated for 15 minutes at room temperature in the dark. The wells were again washed twice with a washing buffer. Afterwards, 100 µL of substrate/chromogen was added, mixed gently, and incubated in the dark at room temperature for 15 minutes. Finally, 100 µL of the stop reagent (1N H₂SO₄) was added into the wells and the absorbance was measured at k= 450 nm in an ELISA plate reader (ELx800, Bio-Tek Instruments, USA) (El-kest et al., 2015).

Statistical Analysis

The data were analyzed using a completely randomized design. The three factors were: aflatoxin concentration at three levels (100, 500, and 750 pg mL⁻¹); yeast type at four levels (viable, acid-, heat- and ultrasound-treated); and storage time at four levels (1, 7, 14, and 21 days). Statistical analyses were performed by a DUNCAN test and ANOVA with repeated measures, using the SPSS software package program.
RESULTS AND DISCUSSION

Table 1 shows that the effect of treatment type, initial concentration of toxin, and storage time on the percentage of aflatoxin $M_1$ bound in yoghurt were significant ($P<0.05$). The highest amounts of aflatoxin $M_1$ adsorption were related to acid- (76.46%), heat- (76.39%), ultrasound- (75.99%), and viable yeast (74.20%) treatments, respectively. Similar results were obtained by Rahaie et al. (2010) who showed that the cell treatment under acid condition had the highest adsorption ability of the aflatoxin among the three yeast treatment types (viable yeast, acid, and heat treatment).

Comparing viable and unviable yeast cells (treated with heat, acid, and ultrasound), it was shown that unviable cells had a greater capacity for aflatoxin binding and, consequently, toxin reduction. Our results were not in agreement with Hegazy et al. (2011) who found that non-viable yeast had a higher adsorption capacity.

Table 1. The mean (±SD) of aflatoxin $M_1$ bound (%) by $S. cerevisiae$ (viable and treated with ultrasound, heat or acid) in yoghurt contaminated with aflatoxin $M_1$ during storage times.*

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Initial concentration</th>
<th>Time</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>500</td>
<td>750</td>
</tr>
<tr>
<td>Control</td>
<td>$90.3*0.4$</td>
<td>$89.5*0.3$</td>
<td>$89.5*0.3$</td>
</tr>
<tr>
<td>Viable</td>
<td>$47.9*8.0$</td>
<td>$84.9*0.2$</td>
<td>$89.8*0.1$</td>
</tr>
<tr>
<td>Acid</td>
<td>$54.3*1.1$</td>
<td>$85.1*0.1$</td>
<td>$90.0*0.3$</td>
</tr>
<tr>
<td>Heat</td>
<td>$54.2*15.8$</td>
<td>$85.1*0.6$</td>
<td>$89.9*0.6$</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>$53.3*6.8$</td>
<td>$84.9*0.1$</td>
<td>$89.9*0.1$</td>
</tr>
</tbody>
</table>

*Different superscript with capital letter (A-D) or lowercase letter (a-b) within a row or column, respectively significances at $P<0.05$. 

**P** values of $<0.05$ were considered to be significant.
low binding effect. Aflatoxin binding appears to be a physical phenomenon with non-viable and physically altered cells binding significantly higher levels of toxin than their viable counterparts. Similar results were reported by Rahaie et al. (2010) and Shetty et al. (2007). In addition, there will be innumerable physico-chemical changes taking place in the cell wall during the heat treatment resulting in exposing more binding sites. The nature of cell wall components involved in mycotoxin binding is still not clear and carbohydrate rich mannoproteins or glucans may be the likely candidates involved in the binding. Raju and Devegowda (2000) attributed the aflatoxin binding by yeast cell walls to mannan oligosaccharides. However, systematic studies with the intact cells and isolated cell walls are still needed to understand the chemistry of binding.

The results revealed that the initial concentration of aflatoxin M$_1$ had a significant effect ($P<0.05$) on the amount of aflatoxin M$_1$ bounded by the control, viable, acid-, heat-, and ultrasound-treated yeasts, while there were no statistically differences between treatments at each initial concentration of toxin ($P>0.05$) (Table 1). The highest percentage of toxin removal was related to acid-treated yeast and the control samples at 750 and 100 pg mL$^{-1}$ of initial concentration of toxin, respectively. The results of this study are in agreement with El-Nezami et al. (1998), Hassanin (1994), Lee et al. (2003), Pranoto et al. (2007), and Sarimehmetoglu and Kuplulu (2004). Mycotoxin binding was dependent on its solution concentration and was always linear at low level of aflatoxin B$_1$ and showed the transition to a plateau with higher toxin concentrations. The amount of toxin removed increased with increasing aflatoxin B$_1$ concentration, but the percentage removed decreased with increasing toxin concentration, because the saturation started (Lee et al., 2003).

According to Figure 1 (b-e), a similar rising trend of removal toxin is observed by an increase in initial concentration of the toxin from 100 to 750 pg mL$^{-1}$, in viable, acid-, heat- and ultrasound-treated yeast, while there is no regular trend during storage times of yoghurt.
Figure 1. The interaction effect of initial concentration of toxin and storage time on aflatoxin M₁ bound: (a) Control; b: Viable; c: Acid; d: Heat, and e: Ultrasound at three replicates.
The results indicate that although removal of the toxin at 500 and 750 pg mL\(^{-1}\) increased, this increment was not significant for viable yeast (P< 0.05). A significant reduction in aflatoxin M\(_1\) bound was observed at an initial concentration of 100 pg mL\(^{-1}\) at seven day of storage compared to the previous and succeeding days of storage (P> 0.05). In total, this toxin concentration had significant differences compared to the other concentrations during storage (P< 0.05) (Figure 1-b). *S. cerevisiae*, in its viable and untreated form, could bind more than 89% of aflatoxin M\(_1\) at its initial concentration of 750 pg mL\(^{-1}\). However, the toxin binding was about 84% for the contaminated samples, containing 500 pg mL\(^{-1}\) and, with a reduction of the initial concentration to 100 pg mL\(^{-1}\), the aflatoxin binding decreased to about 47%. These results were similar to those obtained by Kusumaningtyas et al. (2006) and Shetty et al. (2007). They concluded that the absolute amounts of aflatoxin B\(_1\) that were bound increased steadily with increasing aflatoxin B\(_1\) concentrations.

As Figure 1-c shows the highest amount of aflatoxin was removed from the supernatant of acid-treated yeast after seven days of storage and removal of the toxin was 66.36, 85.11, and 90.27% at 100, 500, and 750 pg mL\(^{-1}\) toxin concentrations, respectively. However, these differences during storage time were significant only at the lowest toxin concentration (P< 0.05). The highest removal percentage was obtained after seven days storage of the yoghurt samples containing acid-treated yeasts. The reason could be related to a chemical change in the bacteria cell wall structure due to an increase in acidity during storage. Pranoto et al. (2007) reported that at low pH (≤ 5), amount of bound aflatoxin by bacteria was higher than at pH 6 and 7. Besides affecting aflatoxin, pH also affected lactic acid bacteria itself. Haskard et al. (2001) reported that acid treatment could affect components of cell wall like polysaccharide and peptidoglycan. Acid could destroy cell wall of bacteria, thereby causing aflatoxin B\(_1\) to be easily bound by constituents of sitoplasmic membrane. Furthermore, it makes aflatoxin B\(_1\) to be bound rapidly at lower pH.

As shown in Figure 1-d, the highest and lowest removal percentages are related to 750 and 100 pg mL\(^{-1}\) concentrations for the heat-treated yeast, respectively; however, no significant differences were observed between the 500 and 750 pg mL\(^{-1}\) concentrations (P> 0.05). According to the results obtained, the toxin binding by the heat-treated yeast increased after 21 days of yoghurt storage, although no significant increase was observed until 14 days (P> 0.05) (Figure 1-d). Bejaoui et al. (2004), Corassin et al. (2012), El-Nezami et al. (1998), Rahaie et al. (2010), Sahebghalam et al. (2013), Shetty et al. (2006), and Shetty et al. (2007) found that the amounts of toxin removed by heat-treated yeast depend on initial toxin concentrations.

Figure 1e shows the interaction effect of the initial toxin concentration and yoghurt storage time on the amount of bounded aflatoxin M\(_1\) for ultrasound-treated yeast. Although according to the results, an increase in the removal of toxin from the supernatant was observed at 500 and 750 pg mL\(^{-1}\) initial concentrations; this increment was not significant (P> 0.05). At the lowest toxin concentration, a significant difference was observed during storage time. The highest percentage of toxin removal for the ultrasound-treated yeast was related to the highest level of aflatoxin, which was 750 pg mL\(^{-1}\). Furthermore, the results illustrated that an increase in the initial concentration of the toxin from 100 to 750 pg mL\(^{-1}\) caused a significant increase in toxin binding for the ultrasound-treated yeast (P< 0.05). For these yeasts, the highest toxin binding percentage was obtained in the first days of storage, and a significant decrease was observed for the bounded aflatoxin M\(_1\) after 14 days of yoghurt storage (P<0.05).

**CONCLUSIONS**

There are no previous studies to evaluate the effect of *S. cerevisiae* on removal of aflatoxin M\(_1\) in yoghurt. Although low levels
of aflatoxin M<sub>1</sub> in yoghurt can be achieved by prevention through controlling contamination levels of aflatoxin B<sub>1</sub> in feed, our results indicate that viable and nonviable cells of <i>S. cerevisiae</i> may be useful for significantly removing aflatoxin M<sub>1</sub> from yoghurt containing up to 750 pg mL<sup>-1</sup>. Viable, acid-, heat- and ultrasound-treated <i>S. cerevisiae</i> cells have a high efficiency to bind aflatoxin M<sub>1</sub> in yoghurt. Therefore, the methods of aflatoxin removal employing <i>S. cerevisiae</i>, mainly those strains that are already currently used in food products, have a potential application for reducing the levels of aflatoxin M<sub>1</sub> in yoghurt and other fermented foods at the household and industrial level. However, aiming the commercial application in the dairy industry, further studies are needed to investigate the mechanisms involved in the removal process of the toxin by <i>S. cerevisiae</i> and the factors that affect the stability of the toxin sequestration such as the concentration of yeast, strains of yeast, acidity, and type of starter culture.

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جذب سطحی آفلاتوکسین M1 توسط مخمر ساکارولیس مس رویزیه در ماست

ج. کاراژیان، م. مهربان سنگ آتش، ر. کاراژیان، ا. مهرزاد، و. ا. حیفی

چکیده

تکسین‌دازی میکروبی یکی از روش‌های حذف آفلاتوکسین‌ها از جمله آفلاتوکسین‌ها محسوب می‌شود. گزارش‌های نشان داده‌اند که مخمر ساکارولیس مس رویزیه از طریق جذب سطحی آفلاتوکسین‌ها به‌درباره سلول‌های خود می‌تواند در حذف آن مؤثر باشد. در این تحقیق توانایی مخمر ساکارولیس مس رویزیه به شکلی که در مایع تیمارشده با آن در دمای 30° و ظرفیت مایع 150، 300 و 500 میلی لیتر تیمارشده با آن، در حذف آن مورد بررسی قرار گرفت. نتایج نشان داد که نسبت به مخمر بخصوص آن که در ظرفیت مایع 150 میلی لیتر حذف شد. تکنیک تیمارشده با آن به‌دنبال تیمارشده با اسید، تیمارشده با اولتراسون و تیمارشده با اسید و اولتراسون در حذف آن مؤثر بود.

کلید واژه‌های مهم: آفلاتوکسین مایع تیمارشده با اسید، تیمارشده با اولتراسون، میکروبی‌یکی