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Review

Bioremediation of heavy metals in food industry: Application of *Saccharomyces cerevisiae*

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ABSTRACT

Heavy metals are natural elements in the Earth's crust that can enter human food through industrial or agricultural processing, in the form of fertilizers and pesticides. These elements are not biodegradable. Some heavy metals are known as pollutants and are toxic, and their bioaccumulation in plant and animal tissues can cause undesirable effects for humans; therefore, their amount in water and food should always be under control. The aim of this study is to investigate the conditions for the bioremediation of heavy metals in foods. Various physical, chemical, and biological methods have been used to reduce the heavy metal content in the environment. During the last decades, bioremediation methods using plants and microorganisms have created interest to researchers for their advantages such as being more specific and environmentally friendly. The main pollutant elements in foods and beverages are lead, cadmium, arsenic, and mercury, which have their own permissible limits. Among the microorganisms that are capable of bioremediation of heavy metals, *Saccharomyces cerevisiae* is an interesting choice for its special characteristics and being safe for humans, which make it quite common and useful in the food industry. Its mass production as the byproduct of the fermentation industry and the low cost of culture media are the other advantages. The ability of this yeast to remove an individual separated element has also been widely investigated. In countries with high heavy metal pollution in wheat, the use of *S. cerevisiae* is a native solution for overcoming the problem of solution.
This article summarizes the main conditions for heavy metal absorption by *S. cerevisiae*.

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1. Introduction

Presently, industrialization in the world is growing increasingly, which can affect the quality of the water, food, feed, and weather [1]. Various industries such as chemical, food, textile, and metallurgy release high amounts of waste including toxic substances to the environment. Pesticides and chemical fertilizers in agriculture and vehicles for transportation discharge large quantities of pollutants containing heavy metals into the atmosphere [2].

Food safety is considerably threatened by heavy metal pollution. Several studies have also proved the accumulation of heavy metals in water [3,4,5,6], rice [7,8], vegetables [9,10,11], and fish [12]. Accumulation of heavy metals in human organs and tissues has caused some diseases such as kidney, cardiovascular system, and nervous system disorders [1,2].

Many strategies have been used thus far for solving the problem of heavy metal pollution in the environment. Applying the bioremediation methods for decreasing the amount of heavy metals in the environment has attracted increasing attention. Among all the methods, the use of living organisms to absorb pollutants and remove heavy metals from the environment is quite interesting. Plants; fungi; and microorganisms such as yeasts, bacteria, algae, and cyanobacteria are usually used for the bioremediation of heavy metals. Microorganisms are the most acceptable ones because they are easier to work with [13,14,15].

The main advantage of using microorganisms to remove toxic elements is their safety in human aspects. One of these microorganisms is the bakery yeast (*Saccharomyces cerevisiae*), which is widely used in the food industry [16,17].

Comparing the results of using different biomaterials revealed that *S. cerevisiae* is a unique biomaterial in metal biosorption despite its mediocre capacity [18]. The advantages of using *S. cerevisiae* for the biosorption of heavy metals are easy cultivation in a large scale, easy growth by nonfermentation methods, use of cheap media, easy manipulation at the molecular level, and also high biomass production [16]. As a by-product of the fermentation industry in a large quantity, *S. cerevisiae* is extensively used in beverage and food production [19].

Several studies have shown the ability of *S. cerevisiae* to remove toxic metals, recover precious metals, and clean up radioactive elements from aqueous solutions. Some studies have proved the removal of lead (Pb) [20], cadmium (Cd) [21], zinc (Zn) [22], mercury (Hg) [23], nickel (Ni) [24], arsenic (As) [25], chromium (Cr) [26], gold (Au) [27], platinum (Pt) [28], and uranium (U) [29] by *S. cerevisiae*. This microorganism is surprisingly able to individualize different metal species on the basis of their toxicity, such as Se (IV) and Se (VI), Sb (III), and Sb (V), as well as the organic and inorganic Hg [30,31,32]. The use of this yeast to remove heavy metals from foodstuff is a valuable and promising cost-effective biotechnology. *S. cerevisiae* is generally considered to be safe for human consumption [33]. Heavy metals may enter in different stages of the food chain, and among all, Pb, Cd, As, and Hg have harmful effects on human health [34]. The permissible limit of these contaminants in most foods is very low, usually less than 0.5 mg/kg [35]. Most of the studies are conducted on the absorption of high concentrations of heavy metals by *S. cerevisiae,* which is not much important in food safety [17,18,36,37]. Therefore, the use of this biotechnology to remove the lower concentrations of heavy metals in food still needs more research. On the other hand, most of the studies have been conducted on removing an individual element in synthetic media, whereas various elements are naturally together in foods and beverages and may have synergistic or inhibiting effects on one another.

The metal biosorption mechanism occurs through a complicated process. Some of the important conditions for the absorption of metals by this microorganism are being mentioned.

2. Main conditions for absorption by *S. cerevisiae*

2.1. Metal ion concentration

Results are available on the biosorption of Zn [22], Ni [24], Cu [38], Cd and Hg [39], Pb [40], Cr [41], and As [42] by *S. cerevisiae.* The removing capacity of this yeast was observed in 0.2-0.3 ppm concentrations of As [43]. The lowest absorbed concentration of Mg by the yeast was 0.8 ppm [44]. The biosorptive capacity for Cu^{2+} has been studied, and the results showed the following decreasing order [45]:

S. cerevisiae > *Kluyveromyces marxianus* > *Candida* sp. > *Schizosaccharomyces pombe*

S. cerevisiae treated with hot alkali was also capable of removing various heavy metal cations such as Fe^{3+}, Cr^{3+}, Fe^{2+}, Cu^{2+}, Ni^{2+}, Hg^{2+}, Pb^{2+}, Cd^{2+}, and Ag^{+} [39].

2.2. Temperature

Temperature seems to be one of the most important parameters in the bioremediation of heavy metals [46]. In the range of 15–40°C, the highest biosorption capacity of Pb, Ni, and Cr ions by *S. cerevisiae* was observed at 25°C [16,45]. Investigation of the effect of different temperatures (35, 45, and 55°C) on the growth rate of *S. cerevisiae* showed that the growth increased with an increase in the temperature and reached to the maximum level at 55°C [25]. Pb and Ni uptake was reported to occur at 25 to 40°C [24]. Hg removal by a genetically engineered bacterium, *Deinococcus geothermalis,* has been reported to occur at high temperatures [46].

2.3. pH

pH is considered to be the other most important factor in biosorption processes. It influences the competition of metallic ions and the activity of the biomass functional groups [39]. The biosorption of metal cations increase with an increase in the pH; however, in high alkali medium, sedimentation of metal complexes occur [16]. The optimum pH for the absorption of different elements is different, for example, the optimum pH for Cu removal by *S. cerevisiae* is pH 5, whereas for U, it is pH 4–5 [45,46,47]. The results showed that the maximum bioremediation of heavy metals by this yeast occurs in pH >5 [36,48]. The solution pH affects the amount of ionized groups in the yeast cell wall. At low pH, an increase in the protonation in yeast cell wall ligands causes a decrease in the adsorption of metals [18]. The maximum biosorption of As takes place in pH 6 because of the reaction between the yeast cell wall amino acids and As ions [25].

2.4. Inoculation rate

In different studies, 0.1 to 1.5 mg/L of *S. cerevisiae* has been inoculated to the medium containing different metal ions [36,48]. Usually, the uptake of elements is reversely related to the inoculation rate, and the absorption of heavy metals increase with a decrease in the yeast inoculation rate; this is because the metal ions enter into the cell depending on their concentrations after filling the absorption sites on the cell wall completely [49].

2.5. Glucose treatment

Glucose is a suitable source of energy for the yeasts and increases their bioremediation capacity. Treatment of *S. cerevisiae* cells with glucose enhanced the amount of heavy metal (Cd, Cr, Cu, Zn, and Ni) removal from the electroplating effluents [49]. The yeast obtained from the fermentation industry contains saccharides such as glucose, sucrose, and fructose, which are considered to be inexpensive and effective sources in removing pollutant elements. Glucose treatment of yeast cells facilitates an adequate energy supply, which helps the cells to accumulate substantially more metals from the solution [36,48].

2.6. Treatment with organic solvents

Treatment of yeast cells with some organic solvents represented an increase in metal uptake. Tetrahydrofuran, acetone, acetonitrile, dimethylsulfoxide, and ethanol were used as organic solvents to treat the yeast cells [36]. The organic solvents are thought to break the yeast membrane and expose cryptic binding sites so that the possibility of binding elements further would increase [50]. Organic solvents affect the permeability of yeast cell walls and also reduce the positive charge of the cationic site of the cell walls and therefore increase metal uptake [51].

2.7. Competing ions

Some research results showed that anions and cations affect the metal accumulation [11]. In fact, the biosorption of metal ions is decreased by other ions present in the solution [37]. It has been observed that biosorption of metal ions by *S. cerevisiae* is selective and competitive. *S. cerevisiae* has higher affinity to some metal ions than the other metal ions. The competitive results of the biosorption of metals by *S. cerevisiae* are in the following order:

Hg > Zn > Pb > Cd > Co > Ni > Cu

Table 1 shows the comparative results of the biosorption of toxic metals by *S. cerevisiae.* Light metal ions such as Na^+, K^+, and Ca^{2+}, which are present in industrial wastewater, have little effect on the biosorption of heavy metals by *S. cerevisiae*, thus indicating that the affinity of this yeast for light metal ions is less than that for heavy metal ions [16]. The biosorption capacity decreased in the presence of sulfate, chloride, phosphate, and carbonate, as well as ethylenediaminetetraacetate (EDTA), because of their ability to form complex with the metal ions [52].

The bioremediation of toxic metals such as Cd [20], Hg [23], Pb and Ni [24], Cu [38], and Zn and Co [53] has also been studied. The biosorption of manganese from groundwater by *S. cerevisiae* has also been studied [54]. Manganese may enter the surface water, groundwater, and soil and cause contamination [55,56,57,58]. Eleven living and dead forms of *S. cerevisiae* yeast strains have been monitored for the bioaccumulation and biosorption of manganese from aqueous solution [59]. The live form of *S. cerevisiae* F-25 has been observed to be highly biosorbent for Mn^{2+} (22.5 mg of Mn^{2+} was biosorbed). The optimum conditions for the highest Mn^{2+} biosorption by *S. cerevisiae* F-25 were 4.8 mg Mn^{2+}/l for 30 min at pH 7 at 30°C [37,60]. The bioremediation of As from water using *S. cerevisiae* has been evaluated. The yeast was grown in YEPD medium, and the As synthetic solution was prepared in the concentration of 1.5 mg/l. The maximum removal of As (90.46%) was observed in pH 6 at 55°C. The use of *S. cerevisiae* is highly efficient for As removal from the contaminated water [25,61,62]. Another research was carried out on As biosorption by *S. cerevisiae*. The maximum biosorption capacity was 62.908 μg/g at 35°C and pH = 5 at biosorbent dosage of 5 g/l. The reaction was endothermic and spontaneous [33,63]. *S. cerevisiae* has been also used for Ni removal [64]. The bioremediation process was 12 g of dry weight/l of yeast cells at 45°C and pH 6, and the results showed 89% of Ni removal. The use of the cells of *S. cerevisiae* is considered to be an alternative method for Ni removal from industrial electroplating wastewater [18,65]. *S. cerevisiae* has been used for the biosorption of copper from the aqueous solution. This yeast was immobilized on the surface of chitosan-coated magnetic nanoparticles (SICCM) and used as a magnetic adsorbent for Cu [29]. The optimal pH for Cu absorption was pH 4.5. At this pH, the negative charge density on the biomass surface increased, which in turn caused more metal adsorption sites and therefore more adsorption [38,54,66]. The highest removal efficiency of 96.8% was obtained after 1 hour, which was noticeably higher than that for other Cu adsorbents. Therefore, SICCM can be a modern alternative to conventional adsorbents for the removal of heavy metals from wastewater [67]. The effect of *S. cerevisiae* on the biosorption of Cd, Cu, Pb, and Zn has been studied in another project [68,69]. The optimum pH was pH 5. Treatment of yeast cells with 10–20 mM glucose increased the uptake of all metals. THF showed the highest and DMSO represented the lowest capacity as organic solvents in metal uptake by the yeast cells [70]. By increasing the biomass, the metal uptake was increased because of an increase in the binding sites of the biomass [71]. Zn uptake was more sensitive to enhancing the biomass than other metals [22,72]. Two strains of *S. cerevisiae*, ATCC 834 and ATCC 24858, were compared in terms of Cd uptake. The specific surface area of ATCC 834 was larger than that of ATCC 24858. The outer mannan layer of ATCC 24858 cells was thinner than that of ATCC 834. The larger specific surface layer and the thicker mannan layer caused larger Cd uptake capacity on the ATCC 834 strain. The optimum temperature was at 30°C, and by increasing the pH from 7 to 9.5, the Cd biosorption was increased [73,74]. In another study, the capacity of eight different yeast species was compared in terms of Cd absorption [75,76,77]. The results showed that *S. cerevisiae* was the most sensitive strain for metal uptake and had the highest accumulation of Cd ions in the cell walls and intracellular compartments (cell and cytosol). Therefore, *S. cerevisiae* is a suitable yeast for metal absorption [78,79,80].

Table 1
Comparison of toxic metals that were biosorped by *S. cerevisiae* at 25°C.

Toxic metals	Uptake capacity (mg/g)[a]	Optimal pH	References
Hg	55.76	5.4	[23]
Zn	30.27	5.5	[53]
Pb	24	5.8	[24]
Cd	20.91	5.8	[20]
Co	14.50	5.2	[53]
Ni	13.50	5.2	[24]
Cu	4.45	5.5	[38]

[a] mg metal/g of dry weight biomass.

3. Conclusion

Heavy metal pollution has turned into one of the most serious environmental problems in recent years. The last decade studies have made a better understanding of metal biosorption by using biosorbents.

The findings of this study revealed the capability of *S. cerevisiae* in removing heavy metals from foodstuffs. It is an effective and inexpensive biosorbent and has good sorption characteristics for several heavy metals. Decreasing the nutrients present in the media does not actually affect the growth of *S. cerevisiae*.

The removal of Pb, Cd, As, and Hg, the four toxic elements in the food industry, by *S. cerevisiae* has been studied previously. The gap in research is the permissible concentrations of these elements and considering them in the bioremediation of heavy metals in foodstuffs.

This study can be optimized and applied in various food and drink industries to reduce and remove heavy metals in foodstuffs. This study can be optimized and applied in various food and drink industries to reduce and remove heavy metals in foodstuffs. Particularly, it can be concluded and recommended that in countries with high heavy metal pollution in wheat, the use of *S. cerevisiae* as sourdough or other forms in food matrix (e.g., bread) can be an easy native solution for overcoming the problem of their accumulation in the human body.

Conflict of interest

The authors confirm that the content in this article has no conflicts of interest.

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