The biosorption capacity of *Saccharomyces cerevisiae* for Cadmium in Milk

Ramona Massoud 1, Kianoush Khosravi-Darani 2,* Anoosheh Sharifan 3, GholamHassan Asadi 3 and Habibollah Younesi 4

1 Department of Food Science and Technology, Standard Organization, Tehran, Iran.
2 Research Department of Food Technology, National Nutrition and Food Technology Research Institute, Faculty of Nutrition Sciences and Food Technology, Shahid Beheshti University of Medical Sciences, P.O. Box: 19395-4741, Tehran, Iran.
3 Department of Food Science and Technology, Science and Research branch, Islamic Azad University, Tehran, Iran.
4 Department of Environment Science, Faculty of Natural resources and Marine Sciences, Tarbiat Modares University, Mazandaran, Noor, Iran
* Correspondence: kiankh@yahoo.com & k.khosravi@sbum.ac.ir; Tel.: +98-21-22086348

**Abstract:** This study aimed to evaluate the capacity of *Saccharomyces cerevisiae* for Cadmium absorption in Milk. Nowadays one of the most serious problems of the industrialized world is heavy metals pollution. Applying microorganisms as a novel biotechnology is so useful especially in foodstuffs. Among the biosorbents used for heavy metals’ removal, *Saccharomyces cerevisiae* has got an increasing attention due to its popularity in food industry. In this regard, the effects of some important factors such as the initial metal concentration, biomass concentration and contact time on the biosorption capacity of *Saccharomyces cerevisiae* were studied. The biosorption was analyzed by the inductively coupled plasma mass spectrometer (ICP-MS). The maximum Cd removal (70%) was at 80 µg/L of Cd concentration in milk samples containing 30×10^8 CFU *Saccharomyces cerevisiae* at the end of storage time (the 4th day). There were no significant differences in sensory and physicochemical properties of milk samples during storage (p < 0.05). The isotherm studies followed by two popular models; Langmuir and Freundlich and the results showed a better fit to the Langmuir isotherm. Altogether, the results of this study demonstrated that the approach of using this valuable yeast, could be applied for foods’ detoxification and producing healthier foodstuffs.

**Keywords:** *Saccharomyces cerevisiae*; biosorption; milk; ICP-MS; isotherm; sensory evaluation

1. Introduction

Toxic metal contamination is a serious environmental problem all around the world due to the fast development of industries such as fuel, pesticides and mining. Their wastes discharge metals into the environment directly or indirectly [1, 2]. These toxic metals can enter to the food chain and then into our bodies [3]. Cadmium (Cd) is one of the high toxic metals in this regard [4]. Milk is a valuable food source for humans and animals. It has nearly all essential nutrients for growth [5]. According to World Health Organization (WHO), the maximal allowed concentration values for Cd in milk is less than 10 µg/L [6].

Some reports have shown Cd contamination of milk around the world and unfortunately in some places it is more than the permissible level: Turkey [7], China [8], Iraq [9] and Iran [10, 11].

Common techniques for heavy metals removal from aqueous solution like ion exchange, chemical precipitation, membrane technologies, electrochemical treatment and using activated carbon which are expensive and also not effective for using in foodstuffs [12, 13].
Biosorption as a green technology, is the process of metal binding from aqueous solution to the surface of microorganism. The mechanism occurred through the absorption of metal ions to functional groups which is on the cell wall of the biomass [12]. It is a cheap, eco-friendly and fast technique [14]. Biosorption is process that the heavy metals trap into the cell wall's active site [12]. The heavy metal’s removal takes place through various mechanisms. The functional groups of the cell wall of S. cerevisiae such as hydroxyl and carboxyl, are responsible for the biosorption technique. They are the main agents for metals to be attached during the mechanism. Moreover, the heavy metals intracellular accumulation occurs in the cell wall and metals are able to attach to the cell molecules [14-16].

In biosorption method various microorganisms like yeasts, bacteria, algae and fungi are applied. They possess some advantages such as being cheap and practical for foodstuffs [15, 16].

The unique yeast “Saccharomyces cerevisiae” is commonly used in bakery and brewery industries. It is an economic available biosorbent [17]. There are some studies about using this yeast for heavy metals biosorption [18-22].

Our study aims to evaluate the capacity of S. cerevisiae for Cd absorption in Milk. So, the effects of three main factors; initial metal concentration, biomass concentration and contact time on the biosorption capacity of S. cerevisiae were studied. These factors were chosen through the previous studies of heavy metals bioremoval [20-23] and also based on the results of our research team. This technique would be useful in case of emergency in food and beverage industry.

2. Materials and Methods

2.1. Preparation of the biomass

The S. cerevisiae (PTCC-5020) was purchased from the Science Research and Technology Department, Tehran, Iran. Glucose, yeast extract, (NH₄)₂SO₄, KH₂PO₄, MgSO₄ and KH₂PO₄ were combined as the yeast culture medium and then autoclaved at 121°C for 20 min. The medium was inoculated with S. cerevisiae after cooling followed by 20 h shaking at 70 rpm and then incubated at 30°C. The biomass colonies were counted and the mean of 30×10⁶ CFU/mL was obtained through the dilution method; the seed culture (1 mL) was diluted in a ratio of 1:10 with NaCl with serial dilutions (10 times). Then the dilution (1 mL) was added to the nutrient agar medium by pour plate method and incubated for 72 h at 30°C for 72 h [24].

2.2. Chemicals

All chemicals were provided from Merck company (Germany) and Cd standard solution from Accu Trace company (USA). All the containers were acid-washed by HNO₃ (15% v/v) overnight and then rinsed with distilled water.

2.3. Sample Preparation

Each sample was prepared of milk (50 mL) with levels of S. cerevisiae (10×10⁸ to 50×10⁸ CFU/mL) and different initial Cd concentration (40, 50, 60, 70, 80 μg/L) and stored in fridge for 4 days. Then the effect of 3 variables; initial metal concentration (40-80 μg/L), biomass concentration (10 - 50×10⁸ CFU/mL) and contact time (1-4 days), on the biosorption capacity of S. cerevisiae were studied.

2.4. Physicochemical Analysis

The pH, acidity and density of milk samples were determined according to AOAC methods [24]. The pH value of milk samples was evaluated with a pH meter (Metrom, Switzerland) at room temperature. The titratable acidity was determined by titration method; milk sample (10 ml) was titrated by NaOH solution (0.1 N) and adding phenolphthalein as an indicator. The Lactodensimeter (Alla, France) was used to measure the density of milk samples [24].
2.5. Sensory Analysis

The sensory analysis was evaluated during storage time (1st to 4th day) by 10 trained panelists [25]. Milk samples were analyzed for consistency, color, odor and overall acceptability. The samples were scored in a 9-point hedonic scale. The scores were from 1 (extremely dislike) to 9 (extremely like). Mean values (± SD) were calculated from the panelists scores of each sample.

2.6. Central Composite Design (CCD)

The 3 variables; initial Cd concentration, *S. cerevisiae* biomass and contact time, having significant effects on Cd removal. In this study, CCD was used to find the optimal conditions of Cd biosorption with the experimental factors levels as shown in the Table 1.

| Main Variable                  | Range and level |
|--------------------------------|-----------------|
| *S. cerevisiae* biomass dosage | − α (−1.6)      |
| (× 10⁸ CFU)                    | −1              |
|                               | 0               |
|                               | +1              |
|                               | +α (+1.6)       |
| Initial Cd concentration (μg/L)| 40              |
| Contact time (day)            | 0               |
|                               | 1               |
|                               | 2               |
|                               | 3               |
|                               | 4               |

2.7. ICP-MS Analysis

The inductively coupled plasma mass spectrometer (ICP-MS, England) applied in this study, with a standard torch, a cross flow nebulizer and a quartz spray chamber. It was tuned before each experiment started. All the samples were put in microwave 1200W (Milestone Micro oven) to be digested with segmented rotor MPR-600 [26].

2.8. Removal Evaluation

The milk sample containing *S. cerevisiae* and Cd were digested in the microwave and then centrifuged (at 2000×g) for 15 min. The supernatant was injected to the ICP-MS for Cd residual determination. measured by using the ICP-MS. All the trials were repeated triple. The Cd removal efficiency (%) was calculated by Eq. (1) [27]:

\[
\text{%Removal} = 100\left(\text{C}_i - \text{C}_f\right) / \text{C}_i \tag{1}
\]

where \( \text{Co} (\mu g/L) \): is the initial Cd concentration in solution; \( \text{Ci} (\mu g/L) \): is the final Cd concentration in solution.

2.9. Absorption Isotherm

The biosorption isotherm were evaluated by adding the biosorbent (*S. cerevisiae*) to the milk samples with initial Cd concentrations (20 - 100 μg/L). After biosorption, the remained Cd was determined by ICP-MS. The biosorption experiments were repeated three times.

2.10. Statistical Analysis

The statistical analysis was done by MINITAB statistical software (version 14). The statistics data was provided by analysis of variance (ANOVA). The data are presented as the mean value ± SD during storage days. The P-values below 0.05 were statistically significant.

3. Results

3.1. The effect of initial metal concentration
The effect of initial Cd concentration (40, 50, 60, 70, 80 μg/L) on the bioremoval efficiency was investigated (Figure 1a). The results showed that by increasing the Cd concentrations, the absorption improved. The highest Cd removal (70%) was observed at the initial metal concentration of 80 μg/L.

3.2. The effect of contact time

In this study, the Cd biosorption was evaluated during the contact times from 1 to 4 days. Figure 1(b) shows that Cd removal by S. cerevisiae increased as the time passed. As it shows the maximum removal of Cd was occurred in the 4th day. By increasing time up to 8 days, the yeast count was enhanced as the removal was nearly constant. Table 2 shows the yeast count and the bioremoval levels during 8 days of storage.

Table 2. The bioremoval level of Cd in milk samples during storage.

| Storage Time (day) | 1       | 4       | 8       |
|--------------------|---------|---------|---------|
| S. cerevisiae biomass (CFU/mL) | $10^8$  | $10^8$  | $10^9$  |
| Total count (CFU/mL)      | $10^{12}$ | $10^{12}$ | $10^{13}$ |
| Cd bioremoval (%)         | 45.51<sup>a</sup> | 70.10<sup>b</sup> | 70.21<sup>b</sup> |

Different letters are significantly different ($p < 0.05$).

3.3. The effect of biomass concentration

As shown in Figures 1 (a and b), by increasing S. cerevisiae biomass concentration from 10 up to 50×$10^8$ CFU/mL, the removal efficiency enhanced. The optimum level of S. cerevisiae biomass concentration was 30×$10^8$ CFU with the highest removal amount of 70%.

3.4. Physicochemical evaluation

There was a slight reduction in pH values and a rise in titratable acidity of the milk samples. Also the density level was nearly constant. However, the differences were not significant in the milk samples ($p>0.05$) (Table 2).

3.5. Sensory evaluation

Table 3 also represents the results of sensory analysis during the storage of milk samples. There were no significant differences in consistency, smell and color of these milk samples during time.
intervals with control samples (p < 0.05). Also the overall acceptance of milk samples had no significant difference through storage period (p < 0.05).

Table 3. Physicochemical and sensory properties of milk samples during storage.

| S. cerevisiae biomass concentration (CFU/mL) | Control 10 × 108 | 50 × 108 |
|--------------------------------------------|------------------|----------|
| Storage time (day)                         | 1                | 4        | 1        | 4        | 1        | 4        |
|                                            | Physicochemical properties |           |          |          |          |          |
| pH                                         | 6.7±0.01a        | 6.67±0.05a | 6.78±0.01a | 6.67±0.07a | 6.80±0.07a | 6.71±0.07a |
| Acidity (% lactic acid)                    | 0.14±0.01a       | 0.15±0.05a | 0.14±0.07a | 0.15±0.07a | 0.14±0.07a | 0.16±0.07a |
| Density (g/cm3)                            | 1.01±0.01a       | 1.01±0.05a | 1.02±0.01a | 1.03±0.05a | 1.02±0.07a | 1.02±0.05a |
| Sensory property                           | Color            | 7.99±0.07a | 7.97±0.05a | 7.97±0.07a | 7.90±0.05a | 7.85±0.05a |
|                                            | Smell            | 7.99±0.05a | 7.96±0.05a | 7.95±0.05a | 7.66±0.05a | 7.95±0.07a | 7.52±0.05a |
|                                            | Consistency      | 7.98±0.05a | 7.98±0.07a | 7.97±0.05a | 7.94±0.07a | 7.90±0.05a | 7.88±0.05a |
|                                            | Overall acceptance| 7.98±0.07a | 7.95±0.05a | 7.98±0.07a | 7.95±0.05a | 7.98±0.07a | 7.90±0.07a |

Different letters are significantly different (p < 0.05).

3.6. Isotherm studies

The capacity of S. cerevisiae biomass concentration (10⁸ CFU/mL) for Cd biosorption was determined at Cd initial concentrations (20, 40, 60, 80 and 100 μg/L) via two popular biosorption isotherms; Langmuir and Freundlich models. The regression coefficient (R²) represent the better isotherm model for Cd biosorption by S. cerevisiae.

The Langmuir equation is as the Eq. (2) [28]:

\[
\frac{C_e}{Q_e} = \frac{1}{K L Q_{max}} + \frac{C_e}{Q_{max}}
\]

Eq. (2)

Where Qe (µg/L) is the Cd amount in absorbing process, Ce (µg/L) is the Cd equilibrium concentration in milk, Qmax (µg/L) is the maximum Cd absorption level. KL (L/µg) is the Langmuir constant. The Freundlich equation is as is following the Eq. (3) [29]:

\[
\ln Q_e = \ln K_f + \frac{1}{n} \ln C_e
\]

Eq. (3)

Where n and Kf are the Freundlich constants. The Langmuir and Freundlich parameters are shown in Table 4.

Table 4. Langmuir and Freundlich isotherm parameters for Cd removal.

| Cd initial concentration (µg/L) | Langmuir model† | Freundlich model§ |
|--------------------------------|-----------------|-------------------|
| Ce                            | Qe              | Ce/Qe             | Ln Qe | Ln Ce |
| 20                            | 13.4            | 6.6               | 2.033 | 1.887 | 2.595 |
| 40                            | 23.2            | 16.8              | 1.381 | 2.821 | 3.144 |
| 60                            | 27              | 33                | 0.818 | 3.256 | 3.269 |
| 80                            | 28              | 51                | 0.522 | 3.889 | 3.263 |
| 100                           | 28              | 70                | 0.389 | 4.254 | 3.321 |

†R² for Langmuir model was obtained 0.9186
§ R² for Freundlich model was obtained 0.8587

As Table 3 shows, both correlation coefficients were high in Langmuir and Freundlich isotherm models. By the comparison of calculated R² values, it was revealed that the Langmuir isotherm model showed better fit than Freundlich model.
4. Discussion

As shown in figure 1 (a and b) by rising the biomass concentration up to 30 × 10^6 CFU, the absorption rate increased. The yeast of S. cerevisiae has a high biosorption affinity for heavy metals [30, 31]. This trend is due to the carboxyl, hydroxyl and amino groups of the cell wall as the main responsible for the heavy metals’ absorption [32-34]. As the amount of metal ions increased, their absorption to the surface of the S. cerevisiae increases so, the higher biosorption would be observed [21, 35 and 36]. By enhancing the S. cerevisiae biomass concentrations, the biosorption increases that is because of the more available binding sites for metal ions and therefore more binding combinations [37].

Also by increasing Cd concentration from 40 to 100 µg/L, the biosorption yield increased (Figure 1a). Similar to our studies’ results; Hadiani et al. [21] reported that Cd removal by S. cerevisiae increased with rising the Cd level (25 to 80 µg/L). Ghorbani et al. [38] observed the Cd bioremoval by S. cerevisiae (2.13 g/L) at the concentration of 26.46 mg/L. Also Peng et al. [39] showed that Cu absorption by S. cerevisiae increased by increasing the metal from 40 to 120 mg/L. As shown in Figure 1(b), Cd absorption enhanced by rising contact time from 1- 4 day. With time passing, more Cd ions would attach to S. cerevisiae receptor sites in the surface [40]. The findings of this study is in accordance with Hadiani et al. [21] observed the increasing Mercury biosorption by S. cerevisiae from 24- 48 h and Hatami Fard and Mehrnia [35] reported more mercury absorption during 4 days. Like the above studies, in this study, the highest Cd removal efficiency (70%) was observed at the Cd concentration of 80 µg/L and the biomass of 30 × 10^6 CFU in the 4th day of storage. Prolongation of the experiment is recommended to evaluate more removal of heavy metal in longer exposure. Also, it should be taken into account that in the case of spoilage of milk with bacterial cells, or high initial microbial loading of milk the rate of bio-decontamination could be quite different with this report.

Also Table 3 shows that the absorption increased by increasing the initial concentration of Cd, as more initial concentration prepared more contact sites for absorbent and Cd [35]. Comparing both R^2 values in Langmuir and Freundlich isotherm models, it shows that Langmuir model has a better fit, which confirms that Langmuir equation is correct for monolayer absorption on surface with similar sites. The higher R^2 in Langmuir model confirm the Cd absorption by S. cerevisiae in our study obey this model.

5. Conclusions

In this study, three important variables; Cd and biomass concentration and the contact time for Cd bioremoval by S. cerevisiae were evaluated. Our findings showed the highest level of Cd biosorption (70%) observed in the S. cerevisiae concentration of 30 × 10^6 CFU and Cd amount of 80 µg/L in the 4th day. The ability of S. cerevisiae had been studied in high levels (ppm) of Cd and other heavy metals in effluents not in foodstuffs. This study shows the ability of this valuable yeast for Cd remediation in very low concentrations (ppb) from milk with no changes in physiochemical and sensorial acceptability. S. cerevisiae is a desirable and eco-friendly biosorbent for toxic metals bioremediation from food and water resources. These findings open the window for evaluating the capacity of heavy metals’ binding by S. cerevisiae in milk. There is a need for more studies in this field to reduce the toxic effects of the heavy metals in food and drinks.

**Author Contributions:** Conceptualization, R.M., K.K.D.; Software, A.Z.; Formal Analysis, R.M. and A.Z.; Writing-Original Draft Preparation, R.M.; Writing-Review & Editing, K.K.D., A.S. and G.I.A.; Supervision, K.K.D. and A.S.; All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received financial support of Shahid Beheshti University of Medical Sciences for grant Number 22408.

**Acknowledgments:** We are grateful to the National Nutrition and Food Technology Research Institute (NNFTRI) of Iran for supporting this study. Also we like to thank Dr. Younesi for his kind assistance.

**Conflicts of Interest:** The authors declare no conflict of interest.

**References**
1. Weldeslassi, T.; Balwant, H.; Oves, M. Chemical Contaminants in Soil. Air and Aquatic Ecosystem. *Mod. Age Environ. Prob. Rem.* **2017**, *25*, 1-22.

2. Doležalová Weissmanová, H.D.; Mihoˇcová, S.; Chovanec, P.; Pavlovský, J. Potential Ecological Risk and Human Health Risk Assessment of Heavy Metal Pollution in Industrial Affected Soils by Coal Mining and Metallurgy in Ostrava. *Czech Republic Int. J. Environ. Res.* **2019**, *16*, 4495; doi:10.3390/ijerph16224495

3. Kanwal, R.; Fiz, F.; Iqra, W.; Muhammad, S.; Hamid, A. Prevalence of exposure of heavy metals and their impact on health consequences. *J. Cell. Biochem.* **2019**, *119*, 157-184.

4. Ostroumov, S.A.; Tropin, I.V.; Kiryushin, A.V. Removal of Cadmium and Other Toxic Metals from Water: Thermophiles and New Biotechnologies. *Rus J. Gen. Chem.* **2018**, *88*, 2962–2966. DOI: 10.1134/S1070363218130224.

5. Burim, N.; Ametaj. Introducing Dairy: A Transdisciplinary Journal to Advance Understanding of Dairy Nutrition, Health and Productivity, Welfare and Well-Being as Well as Milk Synthesis-Composition and Health Effects of Its Products. *Dairy* **2018**, *1*, 1–5; doi:10.3390/dairy1010001

6. WHO (World Health Organization), International Standards for Drinking Water, 5th ed., 2010, Geneva.

7. Ayar, A.; Sert, D.; Akın, N. The trace metal levels in milk and dairy products consumed in middle Anatolia-Turkey. *Environ. Monitor. Assess.* **2015**, *152*(1),1-12.

8. Qin, L.; Wang, X.; Li, W.; Tong, X.; Tong, W. The minerals and heavy metals in cow's milk in China *Japan J. Health Sci.* **2009**, *55*(2), 300-305.

9. Alani, M.S.; Al-Azzawi, M.N. Assessment of Lead Cadmium and Copper concentrations in Raw Milk Collected from different location in Iraq. *Iraq J Sci* **2016**, *56*(1), 350-355.

10. Nejatolah, M.; Mehrjo, F.; Sheykhi, A.; Bineshpour, M. Lead Concentrations in Raw Cows' Milk from Fars Province of Iran. *Americ J Food Nut* **2014**, *2*(5), 92-94.

11. Najarnezhad, V.; Akbarabadi, M. Heavy metals in raw cow and ewe milk from north-east Iran. *Food Add. Contamin.* **2013**, *12*, 2-6.

12. Katarzyna, C.; Marcin M. Green analytical methods of metals determination in biosorption studies. *Trends Anal. Chem.* **2019**, *116*, 254-265.

13. Jianlong, W.; Can C. Biosorption of heavy metals by Saccharomyces cerevisiae: A review. *Biotechnol. Adv.* **2006**, *24*, 427 – 451.

14. Gupta, V.K.; Nayak. A.; Agarwal, S. Bioadsorbents for remediation of heavy metals: current status and their future prospects. *Environ. Eng. Res.* **2015**, *20*, 001-018. https://doi.org/ 10. 4491/ eer. 2015.018.

15. Massoud, R.; Hadiani, M.R.; Khosravi Darani, K. Bioremediation of heavy metals in food industry Application of Saccharomyces cerevisiae. *Electron J. Biotechnol.* **2019**, *37*, 56–60. https://doi.org/ 10.1016/j.ejbt.2018.11.003

16. Wang, J.L.; Chen, C. Biosorption of heavy metals by Saccharomyces cerevisiae a review. *Biotechnol Adv.* **2006**, *24*, 427–451. https://doi.org/10.1016/j.biotechadv.2006.03.001
17. Jéssica, M.; Nascimentoa, D.; Oliveirab, Andrea, J.D.; Rizzoc, C.L.; Selma G.F. Leite. Biosorption Cu (II) by the yeast Saccharomyces cerevisiae. Biotechnology Reports 2018, 20, 31-35.

18. Salimi, M.; Mahzounieh, M. Saccharomyces cerevisiae on Mo and Cd removal. J. Med Microbiol Infect Dis. 2015, 3 (2), 18-22.

19. Amirnia, S.; Ray, M.B.; Margaritis, A. Heavy metals removal from aqueous solutions using Saccharomyces cerevisiae in a novel continuous bioreactor–biosorption system. Chem Eng J. 2015, 264, 863-872. https://doi.org/10.1016/j.cej.2014.12.016

20. Infante, C.; Arco, D.; Angulo, E. Removal of lead mercury and nickel using the yeast Saccharomyces cerevisiae. Rev MVZ Cordoba. 2014, 19, 4141–4149.

21. Hadiani, M.R.; Khosravi-Darani, K.; Rahimifard, N.; Younesi, H. Assessment of Mercury biosorption by Saccharomyces Cerevisiae Response surface methodology for optimization of low Hg (II) concentrations. J. Environ Chem Eng. 2018, 6, 4980–4987. https://doi.org/ 10.1016/ j. jece.2018.07.034

22. Amirnia, S.; Ray, M.B.; Margaritis, A. Heavy metals removal from aqueous solutions using Saccharomyces cerevisiae in a novel continuous bioreactor-biosorption system, Chem. Eng. J. 2015, 264, 863–872. doi:http://dx.doi.org/ 10.1016/j.cej.2014.12.016.

23. Massoud, R.; Khosravi-Darani, K.; Sharifan, A.; Asadi, G.H. Lead Bioremoval from Milk by Saccharomyces cerevisiae. Biocat Agri Biotechnol. 2019, 22, 11-20. https,//doi.org/ 10.1016/ Journal bcab.2019.101437

24. AOAC, Official Methods of Analysis. Association of official analytical chemists, Washington, DC 2005.

25. ISO 22935-2:2009 (IDF 99-2:2009). Milk and milk products - Sensory analysis - Part 2: Recommended methods for sensory evaluation. 2009.

26. Khan, N.; Jeong, S.; Hwang, M.; Kim, J.; Choi, S.H.; Yeong, E.; Yeon Choi, J.; Park, K.S.; Kim, K.S. Analysis of minor and trace elements in milk and yogurts by inductively coupled plasma-mass sperometry (ICP-MS). Food Chem 2014,147, 220–224.

27. Gok sungur, Y.; Uren, S.; Guvenc, U. Biosorption of cadmium and lead ions by ethanol treated waste baker’s yeast biomass. Bioresour. Technol. 2005, 96, 103–109.

28. Langmuir, I. The adsorption of gases on plane surfaces of glass, mica and platinum. J. Am. Chem. Soc. 1918, 40(9), 1361–1403.

29. Freundlich, H. M. F. The adsorption in solutions. Chemistry 2000, 57, 385-470.

30. Zheng, X.; Wang, X.; Shen, Y.; Lu, X.; Wang, T. Biosorption and biomineralization of uranium (VI) by Saccharomyces cerevisiae -Crystal formation of chernikovite. Chemosphere 2017, 175, 161-169.

31. Hlihor, R.M.; Diaconu, M.; Fertu, D.; Chelaru, C.; Sandu, I.; Tavares, T. Bioremediation of Cr (VI) polluted wastewaters by sorption on heat inactivated Saccharomyces cerevisiae biomass. Int. J. Environ. Res 2013,7, 581–594.
32. Fadel, M.; Hassanein, N.M.; Elshafei, M.; Mostafa, A.H.; Ahmed, M.; Khater, H.M. Biosorption of manganese from groundwater by biomass of Saccharomyces cerevisiae. HBRC J. 2017, 13, 106–113.

33. Gohari, M.; Hosseini, S.; Sharifnia, S.; Khatami, M. Enhancement of metal ion adsorption capacity of Saccharomyces cerevisiae's cells by using disruption method. J. Tai. Ins. Chem. Eng. 2013, 44, 637–645.

34. Parvathi, K.; Nagendran, R.; Biosorption of chromium from effluent generated in chrome electroplating unit using Saccharomyces cerevisiae. Sep. Sci. Technol. 2007, 42, 625–638.

35. Hatami Fard, G.; Mehrnia, M.R. Investigation of mercury removal by Micro-Algae dynamic membrane bioreactor from simulated waste water. J. Environ. Chem. Eng. 2016, 10, 25-33. http://dx.doi.org/10.1016/j.jece.

36. Saber-Samandari, S.; Gazi, M. Removal of mercury (II) from aqueous solution using chitosan-graft-Polyacrylamide Semi-IPN hydrogels. Sep. Sci. Technol. 2013, 48, 1382–1390.

37. Prasanna Kumar, Y.; King, P.; Prasad, V.S. Adsorption of zinc from aqueous solution using marine green algae -Ulva fasciata sp. Chem. Eng. J. 2007, 129, 161–166.

38. Ghorbani, F.; Younesi, H.; Ghasempouri, S.M.; Zinatizadeh, A.A.; Amini, M.; Daneshi, A. Application of Response Surface Methodology for Optimization of Cadmium Biosorption in an Aqueous Solution by Saccharomyces cerevisiae. Chem. Eng. J. 2008, 145, 267–275.

39. Peng, Q.; Liu, Y.; Zeng, G.; Xu, W.; Yang, C.; Zhang, J. 2010. Biosorption of Copper (II) by Immobilizing Saccharomyces cerevisiae on the Surface of Chitosan-Coated Magnetic Nanoparticle from Aqueous Solution. J. Hazard. Mat. 2010, 177, 676-82. 0.1016/j.j hazmat. 2009.12.084.

40. Amini, A.; Younesi, H. Biosorption of Cd (II), Ni (II) and Pb (II) from Aqueous Solution by Dried Biomass of Aspergillus niger, Application of Response Surface Methodology to the Optimization of Process Parameters. Clean Soil Air Water J. 2009, 37, 776-786.