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Trace enrichment of metal ions in aquatic environments by *Saccharomyces cerevisiae*

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Abstract

Sorption properties of baker's yeast cells, characterised as *Saccharomyces cerevisiae* were evaluated for trace enrichment of metal ions: Cd^{2+}, Cr^{3+}, Cr^{6+}, Cu^{2+}, Pb^{2+} and Zn^{2+} from aqueous environments. Metal concentration was determined by flame atomic absorption spectrometry (FAAS). Parameters affecting metal uptake such as solution pH, incubation time, amount of yeast biomass and effect of glucose concentration (energy source) were optimised. Further studies were carried out to evaluate the effects on metal uptake after treating yeast with glucose as well as with an organic solvent. The results showed that trace enrichment of the metals under study with yeast, depends upon the amount of yeast biomass, pH and incubation time. Treatment of yeast cells with 10–20 mM glucose concentration enhanced metal uptake with exception to Cr^{6+}, whose metal enrichment capacity decreased at glucose concentration of 60 mM. Of the investigated organic solvents THF and DMSO showed the highest and lowest capacity, respectively, to enhance metal uptake by yeast cells. Trace enrichment of metal ions from stream water, dam water, treated wastewater from a sewage plant and wastewater from an electroplating plant achieved enrichment factors (EF) varying from 1 to 98, without pre-treatment of the sample. pH adjustment further enhanced the EF for all samples. The results from these studies demonstrate that yeast is a viable trace metal enrichment media that can be used freely suspended in solution to achieve very high EF in aquatic environments.

Keywords: Flame atomic absorption spectrometry; Trace metal enrichment; Baker's yeast cells; *Saccharomyces cerevisiae*; Aquatic environments

1. Introduction

Metal analysis continues to be a challenge for analytical chemists due to the contribution of metal ions into the effluent by mining, metal, textile and petroleum industries [1]. There is always a possibility that metals will be taken up by plants such that they end up in the human food chain. Metal speciation studies have shown that various oxidation states of metals are toxic to humans and also that they are associated with several types of diseases [2–6]. In order to facilitate the analysis of metal ions in aquatic environments, analytical methodologies that address aspects of sampling, sample clean-up and analyte enrichment are necessary. If possible, such methodologies should be simple, robust and inexpensive as well as address limitations associated with collecting samples from remote sampling sites.

Harnessing nature's processes has always been shown to be the most effective approach, because of the inherent selectivity, specificity and sensitivity. Analytical chemistry has already benefited significantly from enzymes in the development of biosensing devices [7]. Recently, there has been a trend towards the use of micro-organisms to recover metals from industrial wastewater [8–11]. Biological substrates [9], including the baker's yeast, *Saccharomyces cerevisiae* has been shown to have good sorption characteristics for several heavy metals [10]. Because of the abundance of yeast as a by-product of fermentation processes [10–18] and its ability to selectively differentiate metal species according to toxicity [13,14]. It appears a favourable candidate to explore for enrichment of metal ions in aquatic environments.

The authors are aware of the various studies of the application of yeast for bioremediation [2–12]. However, it's potential for metal bioaccumulation can be further adopted for trace enrichment of metal ions in analytical chemistry. Such an application can have a significant role in cases whereby the metal being detected is low (1–100 $\mu g\,ml^{-1}$). Then, yeast

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can be used to enrich the metal ion being detected hence increasing the concentration to detectable level. Recent efforts to employ yeast biomass for trace metal enrichment have included immobilisation on various types of support media [19]. Such strategies, although effective, would mean that once the yeast sorption properties are no longer desirable, then one would have to go through the tedious immobilisation process. The present studies evaluate the possibility to employ freely suspended yeast in solution for the trace enrichment of metal ions in industrial wastewater, dam water, water from an electroplating plant and processed wastewater from a sewage plant. The results indicate that *S. cerevisiae* is a good candidate for trace enrichment of metal ions in aquatic environments.

2. Experimental

2.1. Reagents

Stock solutions of 1000 μg ml^{-1} Cd, Cr, Cu, Pb and Zn were obtained from Saarchem (Muldersdrift, RSA). Standard solutions were prepared by diluting the stock solutions to appropriate volumes. $CuCl_2$, $PbCl_2$, $CrCl_3{\cdot}6H_2O$, $ZnCl_2$, $Na_2CrO_4{\cdot}4H_2O$, KCl, NaCl, $CaCl_2$, $MgCl_2{\cdot}6H_2O$, NaOH and HCl were obtained from Saarchem (Muldersdrift, RSA) while $CdCl_2{\cdot}2.5H_2O$ was from Acros Organics (NJ, USA). Tetrahydrofuran, acetonitrile, acetone, ethanol, dimethylsulphoxide were obtained from Rochelle Chemicals (Johannesburg, RSA). D-Glucose was obtained from Sigma (St. Louis, MO, USA). All standard solutions were daily freshly prepared using ultra-pure water from a Millipore-Q system supplied by Millipore (Bedford, MA, USA). The yeast biomass by Anchor Yeast Inc. (Johannesburg, RSA) was purchased from the local grocery shop.

2.2. Instrumentation

Two Varian models, SpectrAA-10 and SpectrAA-220 FS flame atomic absorption spectrometers from Varian (Sidney, Australia), were used in the determination of metals in standard solutions and in the yeast supernatants during sorption studies. Instrumental parameters for metal determination were those provided by the manufacturer. All pH measurements were carried out with a HANNA digital pH meter, HANNA Instruments (Arvore-Vila do Conte, Portugal). The yeast suspensions were incubated in a Labcon (Maraisburg, RSA) model WBE-SPL 25 water bath with a shaking platform. A Heraeus SEPATECH (Osterode, Germany) model Labofuge 200 was used to centrifuge yeast suspensions.

2.3. Sorption studies

For all experiments the concentrations of metal ions were 5 mM and were made by dissolving their chloride salts in ultra pure water. Chloride salts of the metals were used to facilitate ion exchange between the yeast cells and metal solution hence improving metal binding to the yeast cells. The pH of the metal solutions was optimised in the pH range 5.0–6.5. 0.1 M NaOH or HCl solution was used to adjust the pH of the metal solutions to a constant pH value prior to incubation with yeast. The optimum pH was used for subsequent studies.

2.4. Adsorption and desorption of metal ions

For adsorption, 400 mg of yeast biomass (dry mass) was weighed into individual centrifuge tubes. To the tubes were added 5 ml of a 5 mM metal solution and 5 ml of buffer solution for pH adjustment. The resulting suspension was incubated at 25 °C for 30 min in a water bath with shaking at 150 rpm. For desorption, the yeast paste was dislodged and homogenised with the remaining 5 ml of the supernatant to make a suspension. The pH of the mixture was lowered to pH 2. The suspension was then incubated at 25 °C for 30 min in a water bath with shaking at 150 rpm. This was followed by centrifugation at 5000 × *g* for 5 min. 5 ml of supernatant were separated from the yeast paste and diluted to 50 ml with ultra-pure water. The metal concentration was then determined by FAAS. For any subsequent experiments to optimise metal uptake, this sorption procedure was repeated.

2.5. Evaluation of the effect of various parameters on uptake of metal ions

2.5.1. Amount of yeast biomass

These investigations were carried out for Zn and Pb at their optimum sorption pH in the range 0.2–1.0 g.

2.5.2. Incubation time

In order to establish optimum incubation times for enrichment of Zn and Pb, experiments were carried for incubation times ranging from 30 to 120 min. For all the experiments 400 mg of yeast was used at the optimum sorption pH of the metal ions.

2.5.3. Effect of glucose on uptake of Cu, Cd, Cr(III), Cr(VI), Zn and Pb

400 mg of yeast were treated in 10, 20, 30, 40, 50 and 60 mM glucose solutions. The solutions were added to the yeast cells and the resulting suspension was left to incubate at room temperature for 40 min. The resultant suspension was centrifuged at 4500 × *g* for 10 min. The supernatant was discarded and the remaining yeast pellets were washed with ultra-pure water to remove excess glucose. The yeast was then suspended in 5 ml of the metal solution and the optimum sorption pH of each metal solution was maintained by addition of 5 ml of buffer solution. The yeast was then incubated for 4 h at 25 °C with gentle shaking at 100 rpm. Metal uptake was determined after 4 h. Control experiments were conducted using untreated yeast that was washed in a buffer solution.

2.5.4. Effect of organic solvents on the uptake of Cu, Cd, Cr(III), Cr(VI), Zn and Pb

Tetrahydrofuran, acetonitrile, acetone, ethanol and dimethylsulphoxide were used to treat yeast cells. 400 mg of yeast biomass was suspended in 5 ml of the organic solvents with gentle shaking at 25 °C for 24 h prior to sorption of the metal ions. The organic solvents were decanted and evaporated off by air. To the dry yeast, 5 ml of buffer solution were added followed by 5 ml metal solution. The yeast cells were incubated for 1 h at 25 °C with shaking at 150 rpm.

2.5.5. Effect of glucose on uptake of Cu after incubation in THF and DMSO

For these experiments, the same procedures as discussed in previous sections were used. Glucose treatment of the yeast was effected after pre-treatment with an organic solvent.

2.5.6. Evaluation of pH dependence of Cu uptake after treatment with organic solvents

For these experiments, the same procedures as discussed in previous sections were used. pH dependence or response of the yeast was effected after pre-treatment with an organic solvent.

3. Results and discussion

If yeast biomass is to be employed as trace enrichment media for metal ions in aquatic environments, the effect of physical and chemical parameters needs to be established. It is preferable that yeast should achieve enrichment and sample clean-up without any further treatment of the sample or biomass. The results presented from our studies attempt to address some of these important requirements. Evaluation of the ability to enrich metal ions is expressed by the enrichment factor (EF) or percent uptake is defined as in Eq. (1) and Eq. (2).

$$\text{Uptake}\ (\%) = \frac{C_{\text{des}} - C_{\text{ads}}}{C_{\text{std}}} \quad (1)$$

$$\text{EF} = \frac{C_{\text{yeast}}}{C_{\text{sample}}} \quad (2)$$

where C_{des} and C_{ads}, are the concentrations of metal ions (μg ml^{-1}) in the supernatant after desorption and adsorption, C_{std} is the concentration of the standard solution, C_{yeast} and C_{sample} are the concentrations of metals sorbed in yeast and sample solution, respectively.

3.1. Optimisation of the pH for metal ion uptake

These studies were carried out for Pb, Zn, Cr(III), Cr(VI), Cd and Cu as indicated by the results in Fig. 1. Metal uptake by yeast showed a dependency on pH owing to competition between the metal cation and the proton [20]. All metals studied exhibited a pH optimum greater than pH 5. The uptake of Cd and Zn by yeast increased with pH up to pH 5.8. Such a trend confirms that at low pH, the affinity for the binding site on yeast, by the proton is much greater than that of the metal ion ($H^+ \gg M^{2+}$) as compared to at higher pH where $M^{2+} \gg H^+$. However, as pH increases beyond pH 5.8, it appears that other physiological factors may affect the

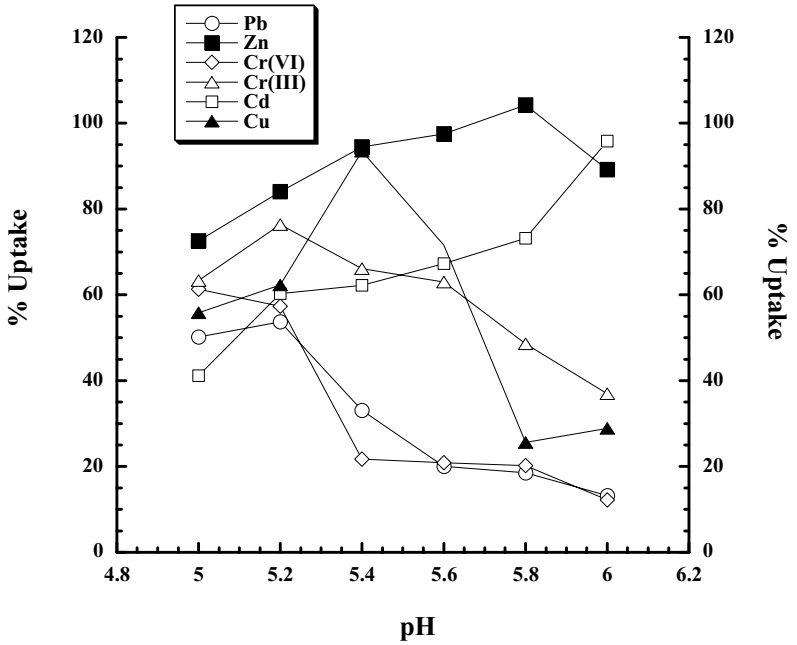

Fig. 1. Effect of pH on uptake of Cd^{2+}, Cr^{3+}, Cr^{6+}, Cu^{2+}, Pb^{2+} and Zn^{2+} by *S. cerevisiae*. The yeast biomass used was 400 mg, for an incubation time of 30 min at 25 °C. Data are expressed as the mean and the S.D. < 2 for $n = 3$.

metal uptake as the enrichment factor decreases. The uptake of Cr(III) and Pb does not seem to benefit from a further increase in pH. Enrichment factors for both metals increased up to pH 5.2 (optimum pH), and subsequently decreased as the pH was increased.

The uptake of Cr(VI) by yeast decreased with an increase in pH in the investigated range of pH 5–6. This trend was in agreement with previously reported Cr(VI) uptake by yeast that showed a maximum at pH 2.5 [21]. Previous studies have suggested that hexavalent chromium either as CrO_4^{2-} or $Cr_2O_7^{2-}$ is converted to Cr(III) by yeasts [21,24]. Because of the low rate of uptake of Cr(III) at high pH, the measured uptake of total Cr is still very low. Furthermore, since pH can affect the charge on the yeast surface the pH trend shown for uptake of Cr(VI) suggests a different mechanism for the sorption processes [22]. This is because Cr(VI) ions are anionic and could be electrostatically bonded to unprotonated carboxyl oxygen and sulphate, therefore the interaction of these ions with microbial cells is primarily electrostatic in nature [24]. The pH dependency of metal sorption is best described by isotherms as reported for Cd^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, $Pb^{2+}$and Zn^{2+} [23]. Huang et al. used modified isotherms to show that the pH dependency of metal adsorption was a competitive process that is inhibited by H^+ [23].

The different pH binding profiles for the heavy metal ions could be due to their chemical interactions with the yeast cells and are associated with the isoelectric point of the cell [24]. Heavy metals have a strong affinity for proteins of the cell wall. At pH values above the isoelectric point, there is a net negative charge on the cells and the ionic state of ligands such as carboxyl, phosphate and amino groups found within the cell walls and membranes will be such as to promote reactions with metal cations. As the pH is lowered, however the overall surface charge on the cells becomes positive, which will inhibit the approach of positively charged metal cations [24]. At the isoelectric point the cell surface becomes uncharged as the metal ions have precipitated on the cell walls and membrane forming insoluble micro-precipitates. Hence, at isoelectric point pH, the lowest solubility of metal ions is observed as metal ions are not released into solution. This situation is favourable for the adsorption of metal ions [25].

3.2. Evaluation of metal uptake dependence on yeast biomass and incubation time

Owing to the high and low uptake of Zn and Pb respectively, during pH optimisation studies, they were chosen for further experiments to evaluate the effect of biomass and incubation time. Fig. 2 shows an increase in metal uptake as the biomass was increased. As expected (see Fig. 1), the uptake of Zn was much more sensitive to increase in biomass compared to that of Pb (see Fig. 2). The increase in metal uptake with biomass confirms the increase in binding sites for both metal ions.

Fig. 2 shows that the uptake of Zn reached a maximum after 60 min, compared to 90 min for Pb. These data probably indicate that low uptake values reflect a sluggish adsorption process and vice versa for higher uptake values. It has already been demonstrated that Pb ions can bind on the surface adsorption sites prior to penetrating into the inner cellular parts of the yeast [26]. The presumed complex formed in the inner cell structure is much stronger such that the complexed Pb may not be available during the desorption process [26], hence lower uptake compared to Zn. For all metals, it is preferable that the adsorption process on the membrane takes places over a short period of time to avoid

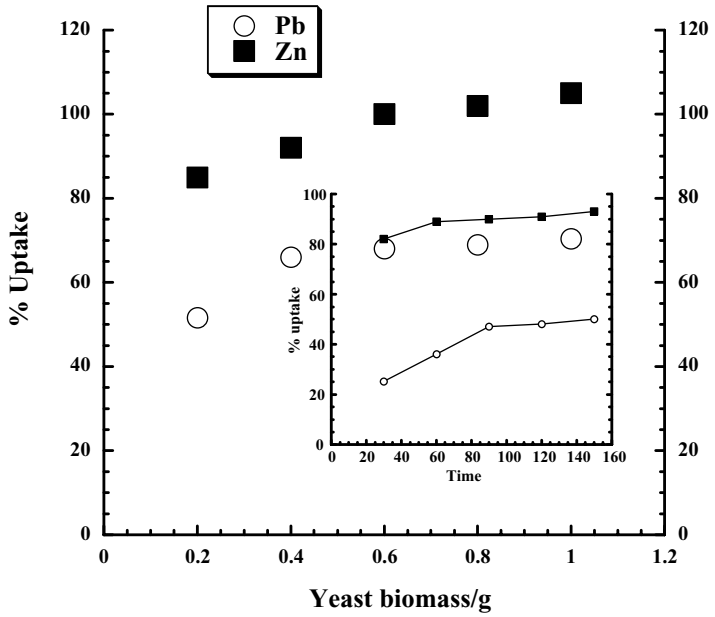

Fig. 2. Effect of biomass and time on uptake of $Pb^{2+}$and Zn^{2+} by *S. cerevisiae* at 25 °C. Data are expressed as the mean and the S.D. < 1 for $n = 3$.

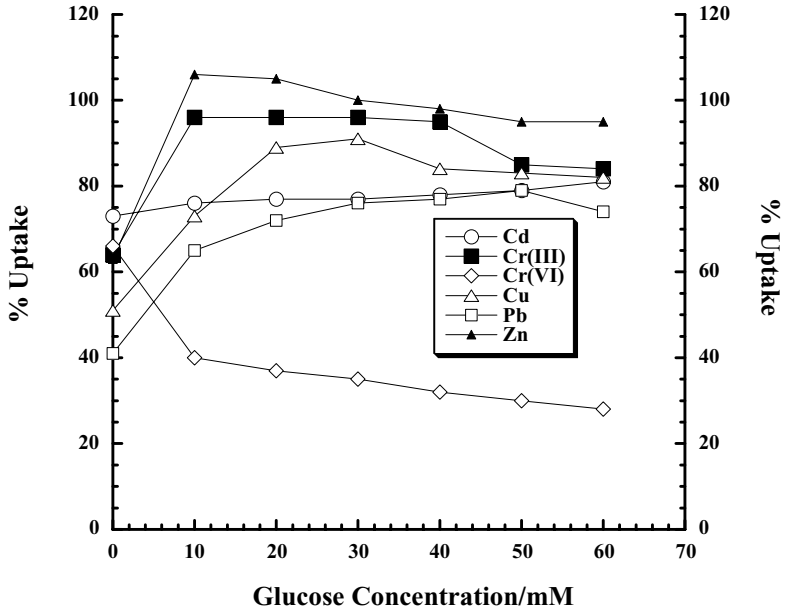

Fig. 3. Effect of glucose concentration on uptake of Cd^{2+}, Cr^{3+}, Cr^{6+}, Cu^{2+}, Pb^{2+} and Zn^{2+} by *S. cerevisiae*. The yeast biomass used was 400 mg, for an incubation time of 4 h at 25 °C. Data are expressed as the mean and the S.D. < 3 for $n = 3$.

internalisation of the metal ions which would result in lower desorption and enrichment of metal ions [27].

3.3. Effect of glucose on trace enrichment of metal ions by baker's yeast

Since metal uptake by yeast is moderated by several factors including the chemical and physical properties of the metal [28], physiology of the cell [29] and the solution pH [30], the effect of glucose on uptake was evaluated. Stoll and Duncan demonstrated that treatment of yeast cells with glucose resulted in an increase in removal of Pb, Cu, Cd, Ni and Zn, from electroplating effluents [31]. As shown in Fig. 3, all metals except Cr(VI), benefited from glucose treatment. The data shows that concentrations of 10–20 mM glucose resulted in a 30–40% increase in the metal uptake by yeast. The trend exhibited by Cr(VI) might suggest that the mechanism of uptake is not similar to those of the other metals as the uptake decreased by almost 50% following a treatment of yeast by 60 mM glucose. Such a poor uptake of Cr(VI) may be associated with toxicity and osmotic stress [32] related processes where the available glucose is utilised in metabolic reactions to yield carbon dioxide and ethanol.

However, the results show a high uptake of Cr(III). Trivalent chromium plays an important role in the maintenance of normal carbohydrate metabolism in mammals and yeasts [32]. The role of Cr^{3+} ions in the metabolism of mammals is connected with the glucose tolerance factor (GTF) [33]. This is a cationic Cr^{3+} complex of lower molecular weight consisting of Cr^{3+}, nicotinic acid, and the amino acids glycine, glutamic acid and cysteine [33]. It is also believed that its biological role in yeast cells is mainly connected with carbohydrate metabolisms [34]. Hence, such a high uptake of Cr(III) in the presence of glucose might be due to the requirements of Cr(III) as GTF for carbohydrate metabolism by yeast cells. Because it is generally expected that metal ions that are required for cellular processes are strongly bound such that they would not be available for desorption, the high uptake values experienced for Cr(III) are very welcome given its role as a GTF. Also, given the fact

Table 1
Effect of organic solvents on uptake of Cd^{2+}, Cr^{3+}, Cr^{6+}, Cu^{2+}, Pb^{2+} and Zn^{2+} by *S. cerevisiae*[a]

Organic solvent	Percentage metal uptake after treatment with organic solvent					
	Cd	Cu	Cr(III)	Cr(VI)	Pb	Zn
Control	65.3 (0.60)	50.7 (0.22)	55.3 (1.21)	49.0 (1.17)	50.2 (1.94)	47.6 (1.80)
DMSO	48.4 (1.27)	23.2 (3.32)	42.4 (0.91)	62.3 (0.76)	13.2 (0.45)	33.7 (0.14)
THF	72.6 (3.11)	90.8 (3.40)	59.9 (1.36)	49.6 (1.42)	53.7 (1.97)	82.3 (1.30)
Acetone	72.1 (2.00)	80.2 (2.16)	45.8 (1.30)	49.2 (1.40)	33.1 (0.57)	52.4 (1.59)
Ethanol	67.1 (1.61)	76.5 (2.12)	46.6 (0.90)	54.9 (1.54)	18.5 (1.76)	37.6 (0.28)
Acetonitrile	72.7 (0.42)	64.8 (1.11)	44.5 (1.30)	48.4 (1.25)	20.0 (1.12)	48.5 (0.61)

[a] Data are expressed as the mean and the numbers in brackets represent the S.D. for $n = 3$. The yeast biomass used was 400 mg, for an incubation time of 1 h at 25 °C.

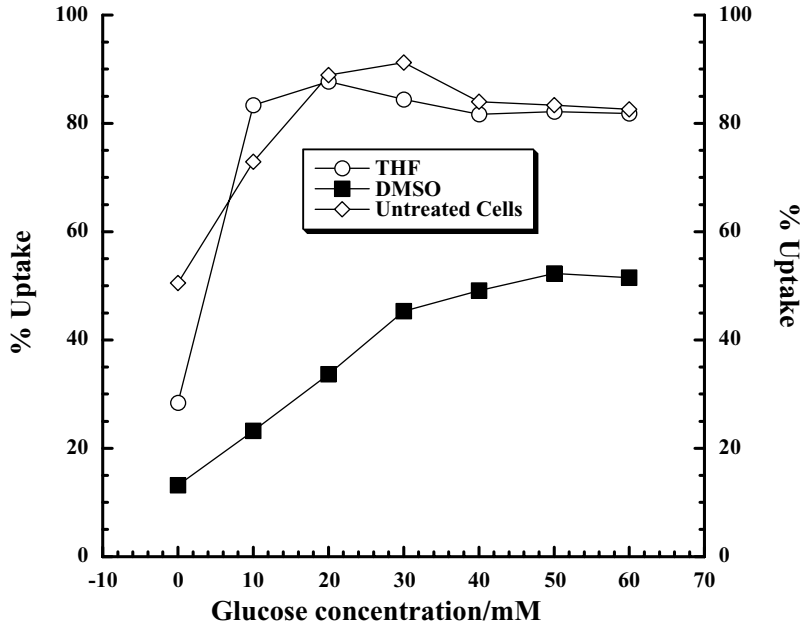

Fig. 4. Effect of glucose concentration on yeast cells treated with organic solvents in uptake of Cu^{2+} by *S. cerevisiae*. The yeast biomass used was 400 mg, for an incubation time of 4 h at 25 °C. Data are expressed as the mean and the S.D. < 2 for $n = 3$.

that the spent yeast biomass is associated with fermentation processes that already have some energy source (glucose, sucrose), the observed trend is encouraging for trace metal enrichment by yeast.

3.4. Effect of organic solvent on metal uptake by yeast

As shown in Table 1, the effect of treating yeast with various organic solvents was evaluated for Cd, Cu, Cr(III), Cr(VI), Pb and Zn. Treatment of yeast with THF, acetone and acetonitrile enhanced metal uptake equally for Cd. Cu uptake also increased significantly when yeast was treated by acetone, ethanol and THF. Treatment of yeast with THF gave the best uptake for Cu and the highest observed for all metals. There was no significant increase in metal uptake for Cr(III) and Pb after treatment of the yeast. DMSO and THF were the only organic solvents that improved uptake for Cr(VI) and Zn, respectively. The increase in metal

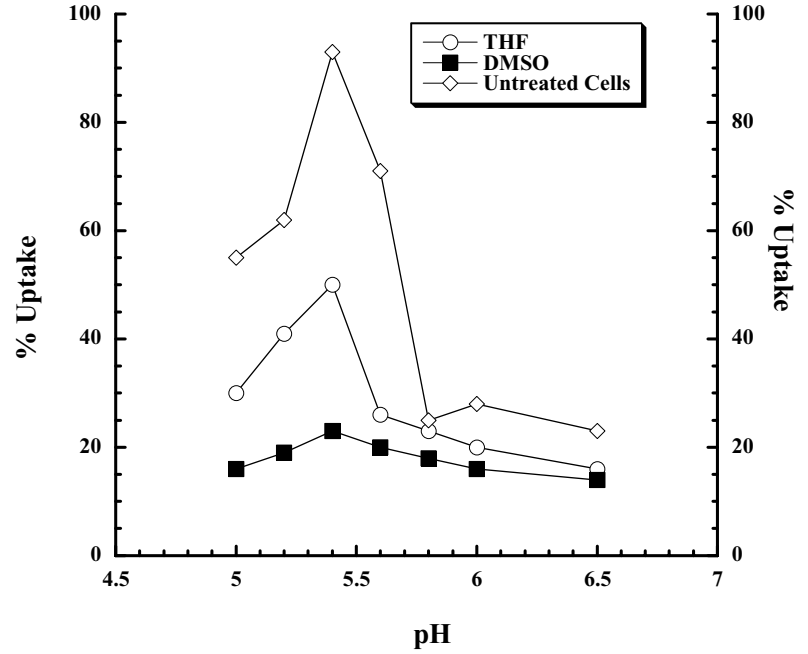

Fig. 5. Effect of organic solvents on yeast cells response to pH on uptake of Cu^{2+}. by *S. cerevisiae*. The yeast biomass used was 400 mg, for an incubation time of 1 h at 25 °C. Data are expressed as the mean and the S.D. < 2 for $n = 3$.

uptake after treatment of yeast with an organic solvent is in agreement with previous reports. Formaldehyde and benzaldehyde were reported to have increased the uptake of metals by yeast [35]. The organic solvent is supposed to expose latent binding sites through disruption and permeabilisation of membranes [36,37]. An organic solvent can also be used to break membrane crypticity barriers and reveal hidden enzymatic activity [36]. It also decreases the positive charge of the cationic sites on the cell walls and hence increases metal uptake [38]. Electron donating groups of the organic solvents are also likely to facilitate the adsorption process through electrostatic bonding between metal cations and functional groups on the cell surface [35].

3.5. Effect of glucose on yeast treated with organic solvents

Since metal uptake by yeast is associated with two mechanisms that either depend upon the cell physiology [29] and metabolism [19] or pure adsorption on the cell membrane [27], it was deemed necessary to evaluate the effect of organic solvents on the yeast cells. The metabolic pathway of uptake is the least preferred mechanism as it results in lower uptake values due to internalisation of the metal ions. Studies were carried out using THF and DMSO as they had shown the highest and lowest effect on metal uptake, respectively. As shown in Fig. 4, yeast treated with THF and subsequently treated with glucose exhibits a profile similar to that by untreated yeast cells. However, the rate of response for cells treated with DMSO was not as sensitive to the initial concentration of glucose as observed for THF. From these studies it can be assumed that the treatment of yeast cells with organic solvents is most likely to disrupt the yeast membrane such that any metal uptake might only be metabolic driven, hence low values are achieved.

3.6. Effect of organic solvent on yeast response to pH change

It was postulated that if indeed the organic solvents resulted in the death or rupture of the yeast cell walls, then it would be expected that metal uptake would not show a dependency on pH similar to that by fresh cells. Fig. 5 shows the pH profile for cells treated with THF and DMSO. It is evident from the profile that the cells treated with DMSO do not respond to a pH change as much as those treated with THF. However, some studies have shown that dead yeast cells (heat-treated cells) show an uptake that responds to changes in pH [39,40]. The observed trend in the case of DMSO probably suggests that treatment of yeast with this solvent results in binding of metal ions through covalent interaction rather than ionic bonding that is facilitated by ion exchange mechanisms. Hence, a change in pH would not impact on the covalently bound metal ions.

Table 2
Enrichment factors for Cr^{3+}, Cu^{2+}, Pb^{2+} and Zn^{2+} in water samples after enrichment by *S. cerevisiae*[a]

Sample type and pH	Cu			Pb			Zn			Cr		
	Direct analysis ($\mu g\,ml^{-1}$)	EF 1	EF 2 (pH 5.40)	Direct analysis ($\mu g\,ml^{-1}$)	EF 1	EF 2 (pH 5.2)	Direct analysis ($\mu g\,ml^{-1}$)	EF 1	EF 2 (pH 5.8)	Direct analysis ($\mu g\,ml^{-1}$)	EF 1	EF 2 (pH 5.2)
Stream water (pH 7.26)	0.006 (0.002)	6	8	0.051 (0.005)	1	4	0.029 (0.001)	54	75	0.090 (0.008)	1	2
Dam water (pH 7.89)	0.002 (0.001)	10	23	0.056 (0.004)	1	4	0.026 (0.000)	80	84	0.030 (0.006)	1	2
Treated wastewater (pH 9.36)	0.004 (0.001)	7	11	0.060 (0.007)	1	2	0.021 (0.002)	98	100	0.027 (0.000)	1	2
Metal effluent (pH 5.60)	0.076 (0.03)	3	3	0.194 (0.006)	1	2	0.434 (0.050)	3	6	2.008 (0.060)	1	1

[a] Data for enrichment factors after enrichment by *S. cerevisiae* with and without the pH adjustment of the water samples. The yeast biomass used was 400 mg, for an incubation time of 1 h at 25 °C. Data are expressed as the mean and the numbers in brackets represent the S.D. for $n = 3$.

3.7. Analysis of metal ions from wastewater after enrichment with untreated yeast cells

Although treatment of yeast cells with glucose and organic solvents showed an increase in metal uptake for some metals, analysis of the real wastewater samples was carried out using untreated yeast. It is generally preferred that analytical methodologies should be inexpensive and wherever possible avoid use of organic solvents as they are regarded as environmentally unfriendly. Therefore, analysis was carried out with and without pH adjustment of the sample. As shown in Table 2, enrichment factors (EF) varied from 1 to 98 when the samples were analysed without pH adjustment (EF 1). For the detected metals, the lowest and highest EF were achieved for Cr and Zn, respectively. Cd was not detected in all samples, with or without pH adjustment.

Adjusting the pH significantly enhanced the metal uptake as shown by the increased EF for all metals (EF 2). The dam water and treated wastewater samples seemed to benefit most from pH adjustment.

4. Conclusion

The studies have clearly demonstrated that yeast, is an important biomass that can be employed for trace enrichment of metal ions in aquatic environments. Analysis for Cu, Cr, Pb and Zn in different types of wastewater showed that enrichment factors of 100 could be achieved for metals such as Zn. Glucose treatment of yeast cells facilitates a provision of an adequate energy supply enabling cells to accumulate substantially more of the metals from solution. In light of this observation, spent yeast from fermentation industries which has saccharides such as glucose, fructose, sucrose can have a positive impact in trace enrichment of metals and also because it is readily available and cheap. These factors make spent yeast biomass ideal for trace enrichment of metal ions. The present study has demonstrated that freely suspended yeast cells can retain their ability to accumulate a broad range of metals to varying degrees under a wide range of external conditions which makes them more suitable for environmental analysis. Further work on sorption properties of other yeast strains individually or as more than one yeast strain is necessary. This can enhance the use of yeast strains in trace enrichment of metal ions by identifying which yeast strains are better accumulators of metal(s). Competition between yeast strains as a mixture could enhance metal uptake. Having a hybrid yeast strain can have a positive impact on metal uptake. The use of freely suspended yeast in solution can eliminate the sampling of water samples for metal analysis. This is usually carried out by bottling of the water sample followed by transportation to the laboratory for analysis.

Acknowledgements

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