Biolife
AN INTERNATIONAL QUARTERLY JOURNAL OF BIOLOGY & LIFE SCIENCES
3(1):77-106
ISSN (online): 2320-4257
www.biolifejournal.com
BIOLIFE REVIEW ARTICLE

Mycoremediation: utilization of fungi for reclamation of heavy metals at their optimum remediation conditions

Archana[1]* and A. K. Jaitly[2]

[1-2]*Microbiology lab, Department of plant science, MJP Rohilkhand University Bareilly, 243006*

E-mail: archana.4208@gmail.com, jaitly1958@gmail.com

ABSTRACT

Contamination of environment by heavy metals has become a major concern worldwide. Role of conventional methods in remediating heavy metals have become ineffective and costly. Conventional methods can remove only up to certain minimum level. Therefore, the bioremediation is cost effective, efficient and environmentally friendly alternative of removing heavy metals. The ubiquitous presence of fungi has allowed acclimation to most types of wastes. During the last decade, fungi have been used in the treatment of a wide variety of wastes, wastewaters and the role of fungi in the bioremediation of various hazardous and toxic compounds in soils and sediments has been established. The properties of fungi to absorb and accumulate heavy metals give potential for cheap alternative method of heavy metal removal from soil and waste water. Therefore, the purpose of this review is to discuss about the heavy metal removal from contaminated natural resources and aqueous solutions by fungi of different groups as Zygomycotina, Ascomycotina, Basidiomycotina and Deuteromycotina with their optimum conditions (pH, temperature, contact time, physical and chemical pretreatments etc.). In this review we found, species of Aspergillus, Penicillium, Trichoderma, Saccharomyces, Mucor, Rhizopus and Pleurotus represent best remediation agents for different heavy metals.

Key words: Heavy metals; mycoremediation; biosrption; bioaccumulation

INTRODUCTION

Contamination of natural resources especially soil and water by heavy metals has become a major concern worldwide. Role of conventional methods in remediating heavy metals has become ineffective and costly. Conventional methods can remove only up to certain minimum level. Therefore, the bioremediation is cost effective, efficient and environmentally friendly alternative of removing heavy metals. Microorganisms play a significant role in bioremediation of heavy metal contaminated soil and wastewater. Mycoremediation is a form of bioremediation using fungi to degrade or sequester contaminants in the environment. Fungi are present in aquatic sediments, terrestrial habitats and water surfaces and play a significant role in natural remediation of heavy metals (Dugal and Gangawane, 2012).

The complex structure of microorganisms implies that there are many ways for the metal to be taken up by the microbial cell. The biosorption mechanisms are various and are not fully understood. They may be classified according to various criteria. According to the dependence on the cell's metabolism, biosorption mechanisms can be divided into: (1) metabolism dependent and (2) non-metabolism dependent. According to the location where the metal removed from solution is found, biosorption can be classified as: (1) Extra cellular accumulation/ precipitation (2) Cell surface sorption/precipitation and (3) Intracellular accumulation. Transport of the

metal across the cell membrane yields intracellular accumulation, which is dependent on the cell's metabolism. This means that this kind of biosorption may take place only with viable cells. It is often associated with an active defense system of the microorganism, which reacts in the presence of toxic metal. During non-metabolism dependent biosorption, metal uptake is by physico-chemical interaction between the metal and the functional groups present on the microbial cell surface. This is based on physical adsorption, ion exchange and chemical sorption, which is not dependent on the cells' metabolism. This type of biosorption, i.e., non-metabolism dependent is relatively rapid and can be reversible (Pagnanelli et al., 2002)

The process of bioremediation mainly depends on microorganisms which enzymatically attack the pollutants and convert them to harmless products. As bioremediation can be effective only where environmental conditions permit microbial growth and activity, its application often involves the manipulation of environmental parameters to allow microbial growth and degradation to proceed at a faster rate.

Fungal biomass proves to be advantageous in having a high percentage of cell wall materials which offers excellent metal binding properties (Mann, 1990; Luef et al., 1991; Muraleedharan et al., 1991). Fungal cell walls can act as a cation exchanger due to their negative charge originating from the presence of different functional groups, e.g. carboxylic, phosphate, amine or sulfhydryl, in different wall components (hemicelluloses, pectin, lignin, etc.) (Fomina et al., 2007). Cell walls of fungi are rich in polysaccharides and glycoproteins such as glucans, chitin, mannans and phospho-mannans. These polymers provide abundant sources of metal binding ligands (Farkas, 1980). Metals and their compounds can interact with fungi in various ways depending on the type of metal, organism and environment (Aung and Ting, 2005). Moreover the use of fungal biomasses as biosorption materials is very convenient because of their inexpensive production methods based on simple fermentation techniques (Maurya et al., 2006). Fungi can also serve as an economical and constant supply of biomass for biosorption of heavy metals and they can also be grown using inexpensive media and unsophisticated fermentation techniques. Therefore, the cost of a biosorbent will be significantly lowered as compared to the cost of the conventional adsorbent. Furthermore, fungi play fundamental roles in the natural environment especially regarding decomposition, transformation and nutrient cycling.

The properties of fungi to absorb and accumulate heavy metals give potential for cheap alternative method of heavy metal removal from soil and waste water. Therefore, the aim of this review is to discuss about the heavy metal removal from contaminated sources and aqueous solutions by fungi of different groups.

Heavy metal remediation by fungi of Zygomycotina:

The fungi included in this group are terrestrial and are mainly found in soil and dung. There are various examples of fungi of Zygomycotina those have been used for heavy metal removal. These are (Table 1):

Circinella

Circinella sp. was employed as a biosorbent for removal of Ni from aqueous solutions. The effect of several parameters, such as biosorbent dosage, contact time, initial concentration of metals, pH and temperature, on biosorption process was evaluated. The results of the biosorption of Ni on Circinella sp. showed that temperature and initial concentration of metal ion greatly influenced the uptake capacity of the biosorbent. The biosorption capacity increased with an increase both in temperature up to 40ºC and in the concentration of the metal ions up to 3.0 mM (Alpat et al., 2010).

Cunninghamella

Table 1 Heavy metal remediation by the different fungi of group Zygomycotina with optimum conditions.

Fungi	Heavy metal	Initial concentration of metal	Metal uptake by biomass with optimum conditions	References
Circinella sp.	Ni	_	18.66 mg/g	Alpat *et al.,* 2010
			pH 6	
Cunnigmella	Pb	_	45 mg/g	El-Morsy El-Sayed, 2004
echinulata			pH 4, 15 min CT, 200 mg/l BC	
	Cu	_	20 mg/g	El-Morsy El-Sayed, 2004
			pH 5, 15 min CT, 200 mg/l BC	
	Cu	50mg/l	20%	Shoaib *et al.,* 2012
	Ni	50mg/l	20%	Shoaib *et al.,* 2012
	Zn	_	18.8 mg/g	El-Morsy El-Sayed, 2004
			pH 5, 15 min CT, 200 mg/l BC	
Mucor hiemalis	Cd	10-50 mg/l	85.47 mg/g	Srivastava and Hasan, 2011
			pH 6, 35 min CT, 25°C Tem	
	Cr	50 mg/l	4.3 mg/g	Pillichshammer *et al*., 1995
			pH 1, 30°C Tem, 1000 min CT	
	Cr	_	22 mg/g	Ebner *et al*., 2002
			pH 5, 25°C Tem, 30 min CT	
Mucor rouxii	Pb	10 mg/l	53.75 mg/g	Yan and Viraraghvan, 2003
			pH 6, NaoH PRT	
	Pb	100 mg/l	90%	Majumdar *et al*., 2010
			pH 5-6, 30°C Tem	
	Pb	10 mg/l	17.13 mg/g	Yan and Viraraghvan, 2000
			Live biomass, pH 5, 15 hrs CT	
			pH 6, NaoH PRT	
	Cd	10 mg/l	6.94 mg/g	Yan and Viraraghvan, 2000
			Live biomass, pH 5, 15 hrs CT	
	Ni	10 mg/l	20.49 mg/g	Yan and Viraraghvan, 2003
			pH 6, NaoH PRT	
	Ni	10 mg/l	5.24 mg/g	Yan and Viraraghvan, 2000
			Live biomass, pH 5, 15 hrs CT	
	Zn	10 mg/l	53.85 mg/g	Yan and Viraraghvan, 2003
			pH 6, NaoH PRT	
	Zn	10 mg/l	4.89 mg/g	Yan and Viraraghvan, 2000
			Live biomass, pH 5, 15 hrs CT	

Mucor sp.	Cu	3 mM	94.6 mg/g	Tahir, 2012
	Cu	90 mg/l	38 mg/g	Khan *et al*., 1998
Rhizopus	Pb	1 µg/mg	154.41± 11.64 µg/g	Pal *et al*., 2010
arrhizus			28°±2°C Tem, 5 days IP	
	Pb	10-600 mg/l	55.6 mg/g	Fourest and Roux, 1992
			pH 5-7, 3-5 hrs ET	
	Pb	150 mg/l	68.8 mg/g	Sag *et al*., 1995
			pH 5, 25°C Tem	
	Pb	300 mg/l	50 mg/g	Volesky, 1992
			pH 3.5, 26°C Tem	
	Cr	0-100 mg/l	8.40 mg/g/min	Prakasham *et al*., 1998
			pH 1-2, 35°C Tem, 60 min CT	
	Cr	5-15 mg/l	70%	Shoaib *et al.,* 2012
	Cd	10-600 mg/l	26.8 mg/g	Fourest and Roux, 1992
			pH 6-7, 3-5 hrs ET	
	Cd	10-400 mg/l	25 mg/g	Volesky, 1992
			pH 3.5, 26°C Tem	
	Cu	_	9.5 mg/g	Gadd *et al*., 1988
			pH 5.5, 25°C Tem	
	Ni	10-600 mg/l	18.7 mg/g	Fourest and Roux, 1992
			pH 6-7, 3-5 hrs ET	
	Ni	300 mg/l	46.67%	Shoaib *et al.,* 2012
	Zn	10-600 mg/l	13.5 mg/g	Fourest and Roux, 1992
			pH 6-7, 3-5 hrs ET	
Rhizopus cohnii	Cd	_	40.5 mg/g	Luo *et al*. 2010
			pH > 2	
Rhizopus	Cr	100 mg/l	80%	Bai and Abraham, 2001
nigricans			pH 2, 4 hrs CT	
	Cr	_	47 mg/g	Volesky and Holan, 1995
	Pb	_	13-105 mg/g	Volesky and Holan, 1995
	Zn	5-200 mg/l	14 mg/g	Volesky, 1992
Rhizopus oryzae	Cu	5 mg/l	2.3 mg/l	El-Gendy *et al*., 2011
			pH 6±0.1, 30°C Tem, 3 hrs CT	
	Cd	3.5 mg/l	1.7 mg/l	El-Gendy *et al*., 2011
			pH 6±0.1, 30°C Tem, 3 hrs CT	
Rhizopus sp.	Cu	3 mM	98.8 mg/g	Tahir, 2012
	Cd	6 mM	2.72 mg/g	Zafar *et al*., 2006
			25°C Tem, 4 hrs CT	
	Cd	6 mM	8.21 mg/g	Ahmad *et al*., 2005b
			pH 4.5, 18 hrs CT, 5 N NaoH PRT	

*Tem=Temperature, CT=Contact time, BC=Biomass concentration, PRT=Pretreatment, ET=Equilibrium time, CT= Incubation period, -- = not identified

Cunninghamella echinulata was chosen for biosorption studies by El Morsy-El Sayed (2004). They found that free and immobilized biomass of C. echinulata sequestered ions from polluted water in the decreasing sequence of Pb > Cu > Zn. The effects of biomass concentration, pH and time of contact were also investigated. The level of ion uptake rose with increasing biomass concentration and with increasing pH up to 4 in the case of Pb and 5 in the case of Cu and Zn. Maximum uptake for all metals was achieved after 15 min. Results revealed a marked increase in uptake of all tested metals by the alkali-treated, alginate-immobilized biomass over free biomass. Treatment of C. echinulata biomass with NaOH improved biosorbent capacity about 25-30 %, as did immobilization with alginate.

Mucor

Live and dead biomass of Mucor rouxii has been found to uptake heavy metals from aqueous solution. Live biomass had high biosorption capacity for Pb followed by Ni, Cd and Zn. The dead biomass adsorbed metal ions

in the order of Zn>Pb>Ni>Cd. At pH 4.0 little biosorption occurred and almost no biosorption was observed at pH 2.0 (except for nickel). A sharp increase in biosorption capacity took place in the pH range of 4.0–5.0. Above pH 5.0, biosorption of lead was found to be relatively constant; biosorption of cadmium and nickel still increased but to a lesser extent (Yan and Viraraghavan, 2003). Other species as M. hiemalis was investigated for biosorption of Cr by their whole cells and isolated cell walls. A fast initial sorption of Cr on the cell wall was found, reaching 80% of the calculated maximum load after 30 min contact time. From the Langmuir-fitted biosorption isotherms theoretical maximum biosorption capacities of 132 and 22 mg Cr/g dry weight were calculated for cell wall and whole cells, respectively. The composition of isolated cell walls was studied. The major components were chitosan (32%) and chitin (11%) (Ebner et al., 2002). In another study M. hiemalis was studied for the removal of cadmium from aqueous solution in a batch system. Effects of various parameters such as pH, biomass dosage, contact time, and initial metal concentrations were also investigated (Srivastava and Hasan, 2011).

Rhizopus

Rhizopus sp. was tested for their metal biosorption potential for Cr and Cd in vitro. Biosorption experiments were conducted with initial metal concentrations of 2, 4, 6 and 8 mM with a contact time of 4 h and wet fungal biomass (1-5 g) at 25^{o}C. Maximum biosorption of Cr and Cd ions was found at 6 mM initial metal concentration (Zafer et al., 2007). Similarly another strain of this fungal species, Rhizopus (RSH 9) was selected for the biosorption potential for Cr and Cd and biosorption results were varied with respect to initial concentration of heavy metals and other factors like temperature and pH (Ahmad et al., 2005b). A Lead tolerant strain, R. arrhizus (M1) was investigated for accumulation of Pb in the mycelia in comparison to wild type strains. Accumulation of Pb in cell wall of M1 strain was more than wild type strain. Optimum incubation period and temperature were also evaluated in this study. The results indicated that the cell surface functional groups of the fungus might act as ligands for metal sequestration resulting in removal of the metals from the aqueous culture media (Pal et al., 2010). R. cohnii was used as an efficient biosorbent for removing cadmium from wastewater. The sorption conditions, such as pH, the dose of biomass and the initial concentration of cadmium were also examined. The uptake of cadmium was higher in weak acid condition than in strong acid condition. Nearly no sorption of cadmium occurred when the pH value was lower than 2.0 (Luo et al., 2010).

Heavy metal remediation by fungi of group Ascomycotina:

Fungi of this group occur in a wide range of habitats: in soil, dung, marine and fresh waters. This group of fungi mainly encompasses filamentous fungi and yeasts. There are various examples of fungi of Ascomycotina those show

excellent bioremediation capacity for different metals. These are (Table 2):

Aspergillus

Aspergillus sp. was evaluated as a metal resistant species for bioaccumulations of Cr and Ni and was characterized to assess its applicability for heavy metal removal from industrial wastewaters. The optimum pH and temperature conditions for both the growth and heavy metal removal were also determined. The observed effect of pH was attributable mainly to organism-specific physiology because in all the tested cases the cellular growth positively correlated with heavy metal removal (Congeevaram et al., 2007). Ahmad et al., 2005b were conducted an experiment in which NaOH pretreated dead biomass of Aspergillus (ASH 1) was selected for the biosorption potential of Cr and Cd. Bioadsorption of Cd and Cr was influenced by initial metal concentration (2-8 mM), nature of organism and other factors like temperature, pH, contact time and agitation rate. Similarly in the study of Zafer et al., (2007) Aspergillus sp. was tested for their metal biosorption potential for Cr and Cd in vitro with initial metal concentrations of 2, 4, 6 and 8 mM with a contact time of 4 h and wet fungal biomass (1-5 g) at 25^{o} C. Maximum biosorption of Cr and Cd ions was found at 6 mM initial metal concentration. As well as in a study conducted by Ramasamy et al., (2012) it was found that Aspergillus sp. has the potential to be used as biosorbent for Cd ions removal from contaminated wastewater. The optimal parameters for removal of Cd such as metal concentration, pH, temperature and time were studied. In the controlled conditions it was demonstrated that the maximum of 88% Cd was removed from aqueous solution by Aspergillus sp. at an optimum pH 4 and temperature 30°C.

In batch mode, NaOH pretreated A. niger biomass was investigated for cadmium biosorption. The effect of three independent variables, initial pH of solution (1.3–8.7), biomass dosage (0.1–7.5 g/l) and initial cadmium ion concentration (0.5–37.5 mg/l) on the biosorption process was determined (Amini et al., 2009). In another experiment, A. niger was tested for their Cr, Ni and Cd biosorption potential using alkali treated, dried and powdered mycelium and found to adsorbed metal from single and multimetal solutions in the order of Ni > Cd > Cr (Ahmad et al., 2005a). *A. niger* (Ni27) isolates has observed to maximum uptake of Ni at intial metal concentration of 50 ppm (Joshi et al., 2011). Besides a cadmium tolerant strain A. niger (AB10) was studied for distribution of accumulated Cd in the mycelia in comparison to wild type strains and accumulated maximum amount of cadmium after optimum incubation period and temperature in a synthetic medium. Accumulated cadmium in the cell wall fractions of cadmium tolerant A. niger was more than the wild type strain. Cytosolic fraction contained the next highest load of metal. The results indicated contribution of the surface property of the fungus in metal bioaccumulation. Involvement of the cellular metabolism during metal bioaccumulation and distribution in the sub-cellular compartments was substantiated by the use of some metabolic inhibitors during growth in presence of metals (Pal et al., 2010). Moreover A. niger has found to tolerate and accumulate toxic metals namely Ni, Zn, Cd, Pb, Cr and Cu from synthetic medium and Paper mill effluent with maximum accumulation of Pb followed by Zn > Cu > Cr > Ni at 100 mg/l of metal solution, whereas metal accumulation from 250 and 500 mg/l of metal solution was found in following order: Pb > Cu > Zn and Pb > Cu respectively (Thippeswamy et al., 2012b). Furthermore, It was investigated for their potential abilities to accumulate arsenic from salt medium and found to uptake 64.20±18.60 nmol/mg As from the medium (Adeyemi, 2009).

A. fumigatus was found to be suitable biosorbent for Pb ions, especially when the metal content in the aqueous solution was in the concentration of 100 mg/l. Factors as pH, temperature, time and ionic concentration showed significant effects on lead biosorption on A. fumigatus. A significant differential expression of some polypeptides was seen in lead trained fungi than the untrained. This was probably attributed due to a higher degree of functional diversity among the fungi (Ramasamy et al., 2011). A. terreus

has been found to uptake Pb excellently at initial metal concentration of 50 ppm (Joshi et al., 2011). A. versicolor biomass subjected to dimethyl sulfoxide had maximum Pb biosorption capacity of 30.6 mg g-1 at pH 5.5 and contact time of 180 min (Cabuk et al., 2005).

A. nidulans isolated from arsenic-contaminated soil, had the potential to remove arsenic from soil. The isolated resistant strain showed resistance up to 500 ppm and the mean weight was found to be 1.309 g. The effect of different concentrations of nutrient sources such as carbon as dextrose nitrogen as yeast extract and phosphate as K2HPO4 on improvement of the remediation of arsenic-contaminated soil was also studied. The effect of ionic strength on A. nidulans was optimized by NaCl at 0.12–0.30% (Maheshwari and Murugesan, 2009). A. ustus has been investigated to biosorb Zn and Cu from waste water. At the 50% concentration A. ustus was absorbed the high amount of Zn ion (Chandrakar et al., 2012). A. flavus was evaluated for absorption of Zn and Cu from municipal waste water with high removal rate of Cu than Zn (Chandrakar et al., 2012), moreover it has found to tolerate and accumulate toxic metals namely Ni, Zn, Cd, Pb, and Cu from synthetic medium and Paper mill effluent with maximum accumulation of Pb followed by Zn, Cu, Ni (Thippeswamy et al., 2012a).

Candida

Candida sp. effectively biosorbed Cu, Fe and Zn ions from industrial effluent. Iron removal was highest by Candida sp. biomass followed by copper and the zinc. Time was found an important factor because if time even the untreated Candida sp. biomass absorbed about 80% of all the metal ions in the effluent. The NaOH treated Candida sp. biomass had the highest amount absorbed followed by overnight oven treated than the untreated biomass as against the control (Anaemene, 2012). Akhtar et al. (2008) were used C. tropicalis as biosorbent to remove zirconium (Zr) from dilute aqueous solutions. The process was found to be highly dependent on initial pH and concentration of metal solution. At optimized experimental parameters, the maximum zirconium biosorption capacity of Candida tropicalis was 179 mg Zr g−1 dry weight of biosorbent.

Gliocladium

Gliocladium viride was found to be highly copper tolerant fungus isolated from electroplating tanning effluent and was exposed to Cu metal ions up to 3mM to study metal tolerance. Whole mycelium and cell wall component were analyzed for Cu biosorption and it was found that cell wall components are responsible for Cu biosorption. Amino groups were found to be abundant in the cell wall of Gliocladium sp. These examinations indicated the involvement of amines in metal uptake. This finding also indicate direct relationship between level of metal resistance and biosorption capacity (Tahir, 2012).

Neurospora

The sorption of Pb and Cu ions from aqueous solutions by raw and pretreated Neurospora crassa fungal biomass was investigated in the batch mode. The influence of solution pH, equilibrium time and initial metal ion concentration using dried N. crassa cells as well as pretreatment on the sorption capacity of the biomass at optimum conditions were studied. These studies indicated that biosorption capacity of biomass decreased with increasing the competing metal ion concentration (Ismail et al., 2005).

Penicillium

Penicilium sp. was tested for their Cr, Ni and Cd biosorption potential using alkali treated, dried and powdered mycelium and was found to adsorbed metals from single and multi-metal solutions in the order of Cr > Cd > Ni (Ahmad et al., 2005a). A strain of this fungus Penicillium (MRF-1) was found as best lead resistant fungus. Effects of pH, temperature and contact time on adsorption of Pb by this strain was studied and it was observed that sorption gradually increased with pH from 2.0 to 5.0 and then stabilized at pH 6.0 and also increased with increasing temperature. The maximum removal of Pb by biosorbent was observed after two hours of exposure between the metal ion and the

Table.2. Heavy metal remediation by the different fungi of group *Ascomycotina* with optimum conditions.

Fungi	Heavy metal	Initial concentration of metal	Metal uptake by biomass with optimum conditions	References
Aspergillus	Zn	0.45 mg/l	0.40 mg/l	Chandrakar *et al.,* 2012
flavus			5 days IP	
	Zn	100 mg/l	49%	Thippeswamy *et al.,* 2012a
	Cu	100 mg/l	45%	Thippeswamy *et al*., 2012a
	Cu	300 mg/l	23%	Shoaib *et al.,* 2012
	Cu	0.6625 mg/l	0.62 mg/l	Chandrakar *et al.,* 2012
			5 days IP	
	Ni	100 mg/l	25%	Thippeswamy *et al*., 2012a
	Ni	50-100 mg/l	16%	Shoaib *et al.,* 2012
	Pb	100 mg/l	75%	Thippeswamy *et al.,* 2012a
Aspergillus	Cr	5 mg/l	97%	Prasenjit and Sumathi,
foetidus			pH 7, 92 hrs CT	2005
Aspergillus	Cu	25 mM	72%	Rao *et al.,* 2005
fumigatus	Cd	25 mM	61%	Rao *et al.,* 2005
	Co	25 mM	49%	Rao *et al.,* 2005
	Ni	25 mM	37%	Rao *et al.,* 2005
	Pb	100 ppm	85.25%	Ramasamy, 2011
			pH4, 30^{o}C Tem	
Aspergillus	Cu	5 mg/l	3.1 mg/l	El-Gendy *et al.,* 2011
luchuensis			pH 6±0.1, 30^{o}C Tem, 3 hrs CT	
	Cd	3.5 mg/l	1.3 mg/l	El-Gendy *et al.,* 2011
			pH 6±0.1, 30^{o}C Tem, 3 hrs CT	
Aspergillus	As	500 mg/l	84.35%	Maheshwari and Murugesan,
nidulans			pH 4, 35^{o}C Tem, After 11 days	2009
Aspergillus	Cd	4 µg/ml	243.20±18.17 µg/g	Pal *et al.,* 2010
niger			8 days IP, 28^{o}±2^{o}C Tem	
	Cd	_	26.72 mg/g	Junior *et al.,* 2003
			pH 5, 6 hrs IP	
	Cd	30 mg/l	10.14 mg/g	Amini *et al.,* 2009
			pH 5.96, 1440 min CT	
	Cd	4 mM	19.4 mg/g	Ahmad *et al.,* 2005a
			25^{o}C Tem, 18 hrs CT	
	Cd	50-250 µg/ml	0.01-0.303 mg/g	Kumar *et al.,* 2011
			30-35^{o}C±2^{o}C Tem, 48 hrs CT	
	Pb	100 mg/l	82%	Thippeswamy *et al.,* 2012a
	Pb	1000 mg/l	209.33 mg/g	Faryal *et al.,* 2007

			pH 9.5, 28°C Tem	
	Zn	100 mg/l	40%	Thippeswamy *et al.,* 2012a
	Zn	50-250 µg/ml	3.399-6.783 mg/g	Kumar *et al.*, 2011
			30-35°C±2°C Tem, 48 hrs CT	
	Cu	100 mg/l	34%	Thippeswamy *et al.*, 2012a
	Cu	50 mg/l	36%	Shoaib *et al.,* 2012
			pH 4.5, 25°C Tem, 3 hrs CT	
	Cu	0.5 mM	7.22 mg/g	Rao *et al.,* 1993
			pH 5, 41 g/l BC	
	Cu	100 mg/l	4 mg/g	Venkobacher, 1990
	Ni	100 mg/l	20%	Thippeswamy *et al.,* 2012a
	Ni	50 ppm	0.55 mg/g	Joshi *et al.,* 2011
	Ni	50-100 mg/l	20%	Shoaib *et al.,* 2012
			pH 4.5, 25°C Tem, 3 hrs CT	
	Ni	4 mM	25.05 mg/g	Ahmad *et al.,* 2005a
			25°C Tem, 18 hrs CT	
	Cr	100 mg/l	41%	Thippeswamy *et al.,* 2012a
	Cr	4 mM	18.05 mg/g	Ahmad *et al.,* 2005a
			25°C Tem, 18 hrs CT	
	Cr	35 mg/l	51%	Shoaib *et al.,* 2012
			pH 4.5, 25°C Tem, 3 hrs CT	
	As	0.40%	64.20±18.60 nmol/mg	Adeyemi, 2009
Aspergillus	Cr	20 ppm	94.10%	Seshikala and Charya,
ochraceous			pH 3-7	2012
Aspergillus	Cr	240 mg/l	97%	Nasseri *et al.,* 2002
oryzae			pH 5, 30°C Tem	
	Cd	_	7.22 mg/g	Rao *et al.,* 1993
Aspergillus sp.	Cd	100 mg/l	88%	Kumar *et al.,* 2011
			pH 4, 30°C Tem, 24 hrs IP	
	Cd	150 mg/l	57 mg/g	Khan *et al.,* 1998
			25°C Tem, 3 hrs CT	
	Cd	6 mM	2.72 mg/g	Zafar *et al.,* 2006
			25°C Tem, 4 hrs CT	
	Cd	4 mM	6 mg/g	Ahmad *et al.,* 2005b
			pH 4.5, 18 hrs CT, 0.5 N NaoH PRT	
	Cr	100 mg/l	92%	Congeevaram *et al.,* 2007
			pH 5, 35°C Tem, 18 hrs IP	
	Cr	0-500 mg/l	34.8 mg/g	Sen and Dastidar, 2007
			pH 2, 30°C Tem, 36 hrs CT	
	Cr	50-500 mg/l	10-27.5 mg/g	Sen and Dastidar, 2010
			pH 2, 30°C Tem, 2 hrs CT	
	Pb	150 mg/l	42 mg/g	Khan *et al.,* 1998

			25°C Tem, 3 hrs CT	
	Zn	150 mg/l	67 mg/g	Khan *et al.,* 1998
			25°C Tem, 3 hrs CT	
	Cu	3 mM	254.7 mg/g	Tahir, 2012
			pH 3, 30°C Tem, 24 hrs IP	
Aspergillus	Pb	50 ppm	59.67 mg/g	Joshi *et al.,* 2011
terrus	Cu	50 mg/l	21%	Shoaib *et al.,* 2012
	Cu	22.57 mg/l	7.77 mg/g	Varshney *et al.,* 2010
			pH 4, 27°C Tem	
	Ni	100 mg/l	21%	Shoaib *et al.,* 2012
	Cr	20 ppm	94.30%	Seshikala and Charya,
				2012
Aspergillus	Cu	5 mg/l	2.5 mg/l	El-Gendy *et al*., 2011
tubingensis			pH 6±0.1, 30°C Tem, 3 hrs CT	
	Cd	3.5 mg/l	0.9 mg/l	El-Gendy *et al*., 2011
			pH 6±0.1, 30°C Tem, 3 hrs CT	
Aspergillus	Zn	0.45 mg/l	0.42 mg/l	Chandrakar *et al*., 2012
ustus			5 days IP	
	Cu	0.6625 mg/l	0.62 mg/l	Chandrakar *et al*., 2012
			5 days IP	
Aspergillus	Pb	100 mg/l	30.6 mg/g	Cabuk *et al.,* 2004
versicolor			pH 5.5, 180 min CT,	
			DMSO (Dimethyl sulphoxide) PRT	
Ascohyta betae	Cr	20 ppm	85%	Seshikala and Charya, 2012
			pH 3-7	
Candida sp.	Cu	0.082 ppm	0.079 ppm	Anaemene, 2012
			2 hrs CT, 0.5 N NaoH PRT	
	Zn	0.075 ppm	0.074 ppm	Anaemene, 2012
			2 hrs CT, 0.5 N NaoH PRT	
	Fe	0.091 ppm	0.088 ppm	Anaemene, 2012
			2 hrs CT, 0.5 N NaoH PRT	
Candida	Zr	1 g/l	179 mg/g	Akhtar *et al*., 2008
tropicalis			pH 3.5, 28±2°C Tem, 24 hrs CT	
Candida utilis	Cr	50 µm	90%	Pattanapipitpaisal *et al.,* 2001
Cladosporium	Cu	1-320 mg/l	25.4 mg/g	Gadd and de Rome, 1988
resinae			pH 5.5, 25°C Tem	
Cladosporium sp.	Zn	0.45 mg/l	0.44 mg/l	Chandrakar *et al.* 2012
			5 days IP	
	Cu	0.6625 mg/l	0.66 mg/l	Chandrakar *et al.,* 2012
			5 days IP	

	Cu	90 mg/l	37 mg/g	Khan *et al.,* 1998
Curvularia	Cu	5 mg/l	1.04 mg/l	El-Gendy *et al.,* 2011
lunata			pH 6±0.1, 30°C Tem, 3 hrs CT	
	Cd	3.5 mg/l	1 mg/l	El-Gendy *et al*., 2011
			pH 6±0.1, 30°C Tem, 3 hrs CT	
	Cr	20 ppm	58%	Seshikala and Charya,
			pH 3-7	2012
Dactylosporium	Cr	20 ppm	74%	Seshikala and Charya,
sp.			pH 3-7	2012
Drechslera	Cu	5 mg/l	4.18 mg/l	El-Gendy *et al.,* 2011
hawaiiensis			pH 6±0.1, 30°C Tem, 3 hrs CT	
	Cd	3.5 mg/l	0.9 mg/l	El-Gendy *et al.,* 2011
			pH 6±0.1, 30°C Tem, 3 hrs CT	
Drechslera	Cr	20 ppm	74%	Seshikala and Charya, 2012
rostrata			pH 3-7	
Gliocladium sp.	Cu	3 mM	474.5 mg/g	Tahir, 2012
			pH 3, 30°C Tem, 24 hrs IP	
Metarrhizium	Pb	100 mg/l	23.3 mg/g	Cabuk *et al.,* 2004
anisopliae			pH 5.5, 180 min CT, autoclave PRT	
Monacrosporium	Cu	5 mg/l	3.5 mg/l	El-Gendy *et al.,* 2011
elegans			pH 6±0.1, 30°C Tem, 3 hrs CT	
	Cd	3.5 mg/l	1.6 mg/l	El-Gendy *et al.,* 2011
			pH 6±0.1, 30°C Tem, 3 hrs CT	
Neurospora	Pb	200 mg/l	49.06 mg/g	Ismail *et al.,* 2005
crassa			pH 4, 15 min ET, Detergent treated	
	Cu	200 mg/l	12.28 mg/g	Ismail *et al.,* 2005
			pH 4, 15 min ET, Detergent treated	
Penicillium	Cd	_	102.7 mg/g	Say *et al.,* 2003
canescens			pH 5	
	Pb	_	213.2 mg/g	Say *et al.,* 2003
			pH 5	
	As	_	26.4 mg/g	Say *et al.,* 2003
			pH 5	
	Hg	_	54.8 mg/g	Say *et al.,* 2003
Penicillium	Cr	_	27.2 mg/g	Tan and Cheng, 2003
chrysogenum	Ni	_	19.2 mg/g	Tan and Cheng, 2003
	Cu	_	13 mg/g	Skowronski *et al.,* 2001
			pH 6, 21°C Tem	
	U	_	70 mg/g	Tsezos and Volesky, 1981
			pH 4-5, 23°C Tem	

	Th	_	142 mg/g	Tsezos and Volesky, 1981
			pH 4-5, 23°C Tem	
	Zn	_	24.5 mg/g	Tan and Cheng, 2003
	Zn	_	6.5 mg/g	Niu *et al.,* 1993
			pH 4-5	
	Zn	_	13 mg/g	Skowronski *et al.,* 2001
			pH, 21°C Tem	
	Pb	_	96 mg/g	Skowronski *et al.,* 2001
			pH 6, 21°C Tem	
	Cd	_	11 mg/g	Niu *et al.,* 1993
			pH 4-5	
	Cd	_	21.5 mg/g	Skowronski *et al.,* 2001
Penicillium	Cu	15 mg/l	50 mg/g	Ianis *et al.,* 2006
cyclopium			pH 4.5	
Penicillium	Cd	0.1-3 mM	83%	Levinskaite, 2001
decumbens	Ni	0.1-3 mM	29.40%	Levinskaite, 2001
	Cr	0.1-3 mM	77.80%	Levinskaite, 2001
Penicillium	Cd	10-50 mg/l	3.5 mg/g	Galun *et al.,* 1987
digitatum			pH 5.5, 25°C Tem	
	Cu	10-50 mg/l	3 mg/g	Galun *et al.,* 1987
			pH 5.5, 25°C Tem	
	Pb	10-50 mg/l	5.5 mg/g	Galun *et al.,* 1987
			pH 5.5, 25°C Tem	
Penicillium	Cu	5 mg/l	1.4 mg/l	El-Gendy *et al.,* 2011
duclauxi	Cd	3.5 mg/l	1.5 mg/l	El-Gendy *et al.,* 2011
Penicillium	Cu	5 mg/l	4.27 mg/l	El-Gendy *et al.,* 2011
lilacium	Cd	3.5 mg/l	1.1 mg/l	El-Gendy *et al.,* 2011
Penicillium	Cr	25 ppm	94.10%	Seshikala and Charya,
notatum				2012
Penicillium	Cr	_	36.5 mg/g	Say *et al.,* 2003
pupurogenum			pH 6, 20°C Tem	
Penicillium	Cd	200 mg/l	52.50 mg/g	Fan *et al.,* 2008
simplicissimum			pH 5, 28°C Tem	
	Zn	250 mg/l	65.60 mg/g	Fan *et al.,* 2008
			pH 5, 28°C Tem	
	Pb	250 mg/l	76.90 mg/g	Fan *et al.,* 2008
			pH 5, 28°C Tem	
Penicillium sp.	Cr	4 mM	18.05 mg/g	Ahmad *et al.,* 2005a
			25°C Tem, 18 hrs CT	
	Cd	4 mM	19.4 mg/g	Ahmad *et al.,* 2005a
			25°C Tem, 18 hrs CT	
	Cd	120 mg/l	58 mg/g	Khan *et al.,* 1998

			25°C Tem, 3 hrs CT	
	Cd	350 mg/l	95%	Dugal and Gangawane, 2012
			pH 6, 37°C Tem, 96 hrs IP	
	Ni	4mM	25.05 mg/g	Ahmad *et al.,* 2005a
			25°C Tem, 18 hrs CT	
	Ni	150 mg/l	62 mg/g	Khan *et al.,* 1998
			25°C Tem, 3 hrs CT	
	Zn	150 mg/l	70 mg/g	Khan *et al.,* 1998
			25°C Tem, 3 hrs CT	
	Cu	3mM	254.7 mg/g	Tahir, 2012
			pH 3, 30°C Tem, 24 hrs IP	
	Pb	0.15 g/l	72.5 mg/g	Velmurugan *et al.,* 2010
			pH 6-10, 20-60°C Tem	
Penicillium	Zn	_	0.2 mg/g	Townsley and Ross, 1985
spinulosum	Cu	_	0.4-2 mg/g	Townsley and Ross, 1985
Penicillium	Pb	100 mg/l	23.3 mg/g	Cabuk *et al.,* 2004
verrucosum			pH 5.5, 180 min CT,	
			autoclaved PRT	
Pestalotiopsis	Cu	5 mg/l	4.01 mg/l	El-Gendy *et al.,* 2011
clavispora	Cd	3.5 mg/l	1.1 mg/l	El-Gendy *et al.,* 2011
Pyrenocheta	Cr	20 ppm	71.50%	Seshikala and Charya,
cajani			pH 3-7	2012
Saccharomyces	Cd	2000 mg/l	52%	Thippeswamy *et al.,* 2012b
cerevisae	Cd	30 ppm	79%	Damodaran *et al.,* 2011
			pH 5.5, 30 days IP,	
			1.5 % glucose, 6.5 LPM aeartion	
	Cd	5.6 mg/l	1 mg/g	Huang *et al.,* 1990
			pH 5, 25°C Tem	
	Ni	2000 mg/l	43%	Thippeswamy *et al.,* 2012b
	Ni	50 mg/l	0.468 mg/g	Mihova and Godjevargova,
			48 hrs CT	2001
	Pb	2000 mg/l	45%	Thippeswamy *et al.,* 2012b
	Pb	5 ppm	82%	Damodaran *et al.,* 2011
			pH 5.5, 30 days IP,	
			1.5 % glucose, 6.5 LPM aeartion	
	Pb	50 mg/l	1.146 mg/g	Mihova and Godjevargova,
			48 hrs CT	2001
	Cr	2000 mg/l	41%	Thippeswamy *et al.,* 2012b
	Cr	0-100 mg/l	4.30 mg/g/min	Prakasham *et al.,* 1998
			pH 1-2, 35°C Tem, 60 min CT	
	Zn	2000 mg/l	38%	Thippeswamy *et al.,* 2012b
	Zn	5-200 mg/l	17 mg/g	Volesky, 1992

	Cu	2000 mg/l	37%	Thippeswamy *et al.,* 2012b
	Cu	50 mg/l	0.246 mg/g	Mihova and Godjevargova,
			48 hrs CT	2001
	Cu	3.2 mg/l	0.8 mg/g	Huang *et al.,* 1990
			pH 4, 25°C Tem	
Sarcinella sp.	Zn	0.45 mg/l	0.43 mg/l	Chandrakar *et al.,* 2012
			5 days IP	
	Cu	0.6625 mg/l	0.58 mg/l	Chandrakar *et al.,* 2012
			5 days IP	
Talaromyces	Cu	600 ppm	52%	Romero *et al.,* 2006
helicus			pH 5	
Trichoderma	Zn	500 mg/l	18.1 mg/g	Yazdani *et al.,* 2010
atroviride				
Trichoderma	Cu	50-500 mg/l	24%	Shoaib *et al.,* 2012
harzianum	Ni	50 mg/l	46%	Shoaib *et al.,* 2012
	Ni	50 mg/l	90.20%	Sarkar *et al.,* 2010
			pH 4-5, 30°C Tem, 7 days IP	
	Cr	5 mg/l	76%	Shoaib *et al.,* 2012
Trichoderma	Cr	50 ppm	0.55 mg/g	Joshi *et al.*, 2011
longbrachiatum				
Trichoderma sp.	Cu	90 mg/l	43 mg/g	Khan *et al.,* 1998
			25°C Tem, 3 hrs CT	
	Pb	150 mg/l	60 mg/g	Khan *et al.,* 1998
			25°C Tem, 3 hrs CT	
	Cr	100 ppm	97.39%	Vankar and Bajpai,
			pH 5.5	2007
Trichoderma	Pb	10 mg/l	90%	Prasad *et al.,* 2013
virde			pH 6, 30°C Tem, 90 min CT	
	Ni	0.1-3 mM	58.20%	Levinskaite, 2001
	Cd	0.1-3 mM	94.40%	Levinskaite, 2001
	Cd	50 ppm	16.25 mg/g	Joshi *et al.,* 2011
	Cr	0.1-3 mM	81.90%	Levinskaite, 2001
	Cr	20 ppm	67%	Seshikala and Charya,
				2012
	Cr	175 mg/l	4.66 mg /g	Hala and Eman, 2009
			pH 6, 45 min CT, 3.7 mg/l BC	
Trichosporon	Cr	1 mM	24.08%	Bajgai *et al.,* 2011
cutaneum			120 min IP	
Verticillium	Cu	5 mg/l	1.7 mg/l	El-Gendy *et al.,* 2011
fungicola	Cd	3.5 mg/l	1.2 mg/l	El-Gendy *et al.,* 2011

*Tem=Temperature, CT=Contact time, BC=Biomass concentration, PRT=Pretreatment, ET=Equilibrium time, IP= Incubation period, -- = not identified

fungal biomass, and the equilibrium of metal removal was reached after 3 hours in all concentrations (Velmurugan et al., 2010). A cadmium resistant Penicillium sp. was obtained by carrying out successive enrichments from soil samples and screening for resistance to other heavy metals showed significant tolerance to zinc, lead, nickel and copper. The fungal culture demonstrated resistance to 1.4 mg/ml cadmium. Optimum pH, temperature and growth conditions for the isolate were determined. Study of growth pattern of this culture revealed a low specific growth rate, with an extended lag period in the presence of cadmium. The isolate was found to remove 67%, 84%, and 95% of cadmium from solution after 48, 72 and 96 hours respectively. The order of resistance to heavy metal concentration was Zn > Pb > Cd > Cu = Hg > Ni > Cr (Dugal and Gangawane, 2012).

P. chrysogenum has been studied for biosorption of Cd, Zn and Pb from aqueous solution with high capacity of Pb removal over Cd and Zn (Niu et al., 1993; Skowronski et al., 2001). In the same way the biosorption potential of P. simplicissimum to remove Cd, Zn and Pb from aqueous solutions was reported by Fan et al. (2008) and it was found that initial pH significantly influenced Cd, Zn and Pb uptake. The sorption capacities of metal ions increased as temperature increased, but decreased with increased in biomass dose. The maximum removal capacity was higher for Pb followed by Zn and Cd. P. canescence was investigated to be able for remove the Cd, Pb, Hg and As ions from aqueous solutions by biosorption. The binding of heavy metal ions to P. canescence was pH-dependent and it showed preference to binding Pb over Cd, Hg and As ions (Say et al., 2003). Live cells of P. cyclopium has been studied for Cu biosorption and it was strongly dependent on pH, time, biomass and Cu ion concentrations in the solutions. The biosorption process was rapid, and in the first five minutes up to 75% of total Cu ions were deposited in the P. cyclopium surface (Ianis et al., 2006).

P. purpurogenum was reported to bind high amounts of Chromium which was clearly dependent on pH and sorption capacity increased with increasing the pH. Time was also found as an important factor because adsorption capacity increased with time during the first four hours and then levels off toward the equilibrium (Say et al., 2004). Likewise, P. notatum was also found as good absorbent for high chromium concentrations and was found to adsorb about 94% Cr at 20 ppm concentration of Cr (Seshikala and Charya, 2012). Other species of Penicillium as P. lilacinum was found to remove Cu (85.4%) brilliantly and cadmium in relatively less amount (31.43 %) from aqueous solutions (El-Gendy et al., 2011). P. decumbens (102 ML) showed highest accumulation rate for Cd followed by Cr and Ni from soil and in response to Cd it was more sensitive as compared to its reaction towards Ni and Cr (Levinskaite, 2001) and P. verrucosum biomass subjected to autoclave pretreatment has maximum biosorption capacity for Pb was 23.3 mg/g at pH 5.5 and contact time was 180 min (Cabuk et al., 2005).

Saccharomyces

Damodaran et al. (2011) revealed that S. cerevisiae has good potential of accumulating Pb and Cd from metal contaminated soil. The parameters affecting the biosorption of heavy metals; such as time, carbon source, aeration, metal concentration and biomass concentrations have been investigated. The time taken for maximum sorption of Pb and Cd was 30 days for soil containing 100 and 300 ppm of Pb and Cd respectively. A better growth of S. cerevisiae is observed in soil samples, which is continuously aerated at 6.5 LPM and soil pH is maintained at 5.5. The availability of glucose as carbon source found to facilitate the bioaccumulation process indirectly by increasing the biomass. An optimum concentration of 1.5 % glucose was found to support the biosorption to a maximum level. The effect of Cu concentration on sorption and growth of this strain was studied and it was found that the biomass concentration decreased with the increase of Cu concentration. Cuprous

ions with concentration of 50 mg/l exert a weak inhibiting effect and with concentrations higher than 250 mg/l the period of cells adaptation was longer and its growth was slower (Mihova and Godjevargova 2001). Toxic metals Cu, Zn, Ni, Cr, Cd and Pb have also been efficiently removed by S. cerevisiae in both aqueous medium and effluent. Obtained results show high Cd accumulation followed by Pb, Ni, Cr, Zn and Cu in aqueous medium. The efficiency of heavy metals accumulation in Saccharomyces sp. decreased with increase in metal concentration due to saturation of biosorbent. Saccharomyces sp. accumulated high cadmium and lead among all treated metals due to presence of cysteine rich metallothionein. This protein shows higher affinity towards Cd and Pb as compared with other metals. Outer mannan layer on the cell wall contribute heavy metals accumulation by Saccharomyces. Result also indicate that metal removal capability in Saccharomyces sp. increased with decrease in their biomass. The low biomass of Saccharomyces sp. causes high surface area-to-volume ratio and holds maximum heavy metals in both soluble and particular forms. Low biomass also leads to exhaustion of heavy metal ions in the medium and cause increased interaction of metals with active binding sites of the cell surface (Thippeswamy et al., 2012b).

Talaromyces

Talaromyces helicus, an efficient strain was trained with high copper levels, and became co tolerant to cobalt, lead and cadmium when was cultured in their presence. The copper adaptation was the result of physiological mechanisms, and the activated biochemical processes conferred resistance to Cu as well as to other heavy metals. Interestingly, metals combinations were less toxic than single ones, and co tolerance development indicated that the cellular mechanisms that conferred resistance were non-specific, so the micobiota isolated from co-contaminated environments often exhibited resistance to more than one ions. These results emphasized the detoxification abilities of T. helicus and the adaptation to heavy metals compounds (Romero et al., 2006).

Trichoderma

Biosorption of the chromium ion onto the cell surface of Trichoderma fungal species in aerobic condition was investigated. Batch experiments were conducted with various initial concentrations of chromium ions to obtain the sorption capacity. The results of FT-IR analysis suggested that the chromium binding sites on the fungal cell surface were most likely carboxyl and amine groups. Best results for sorption were obtained at 5.5–5.8 pH, at low or high pH values, Cr uptake was significantly reduced (Vankar and Bajpai, 2007). T. longibrachiatum has also been reported to maximum uptake (0.55 mg/g) of Cr at initial metal concentration of 50 ppm (Joshi et al., 2011). T. viride has been found to maximum uptake (16.25 mg/g) of Cd at initial metal concentration of 50 ppm (Joshi et al., 2011) and found as suitable adsorbent for the removal of Pb from effluents. The adsorption was strongly dependent on pH and contact time (Prasad et al., 2013). It was also found to accumulate highest amount of Ni, Cr and Cd from soil and showed highest resistance to all these metals (Levinskaite, 2001).

Siddiquee et al. (2013) have determined the resistance levels of different concentrations of heavy metals (Pb, Ni, Zn and Cu) using three different species of this fungus namely T. aureoviride, T. harzianum, and T. virens. The accumulation and uptake capacity was determined by the maximum removal of Pb, Cu, and Ni by a T. harzianum in liquid medium when compared to other fungi. The metal removal occurred at a concentration of 500 mg/L and was 13.48 g/g for Pb, 3.1254 g/g for Cu and 0.8351 g/g for Ni. For Zn, the highest tolerance and uptake capacity of metal was recorded at 3.1789 g/g by T. virens. Dry biomass of T. harzianum, T. virens, and T. aureo-viride decreased with increasing initial concentrations of heavy metals (Ni, Zn, Pb, and Cu) for 7 days at room temperature conditions of 28°C ± 2°C. In another study it was found that T. harzianum had tolerance capacity to different nickel concentrations. It was noticed that T. harzianum was moderately tolerant up to 60 mg/L of Ni, where the inhibition of mycelial

growth was 33.3 %. Further increase in Ni concentration decreased the growth and total inhibition was observed at 200 mg/L. Moreover, the chromium biosorption ability of T. harzianum was tested in vitro. The metal residues were analyzed at different day's interval (4, 5, 6, 7 and 8 days) and effect of different pH and temperature on metal removal was also investigated (Sarkar et al., 2010).

Trichosporon

The adsorption data obtained from the experiments conducted by Bajgai et al. (2012) have showed the applicability of Trichosporon cutaneum (R57) in the remediation of heavy metals particularly Cr from solution. The removal efficiency of this strain increases with decrease in the concentration of metal ions present in the solution up to certain minimum level; it removes 20.89% Cr from 1 mM of ions in the culture medium while only 14.01% from 10 mM of Cr ions in 30 minutes. Removal efficiency also increases with the contact time between the metal ions and fungal biomass in lower concentrations.

Heavy metal remediation by fungi of group Basidiomycotina:

Most Basidiomycota are found in terrestrial habitats, a few are marine. This group comprises macro-fungi. There are various examples of fungi of Basidiomycotina those have been used for heavy metal removal. They are as follows (Table 3):

Agaricus

Agaricus biosporus has been found to accumulate heavy metals from soil in decreasing sequence of Zn > Mn > Cu > Ni > Pb > Cd (Ita et al., 2008). Nagy et al. (2013) have conducted an experiment in which biosorption of Cd ions from aqueous solutions onto immobilized fruit bodies of cultivated A. biosporus was investigated in batch system. The bisosorption of Cd ions was carried out at different concentrations ranging from 45 to 265 mg/l. The operating parameters, initial metal ion concentration, contact time and pH were considered to describe the biosorption efficiency on the removal of Cd ions. The adsorption capacity increases with an increase of metal concentration, pH up to 5.6–5.8 favored the biosorption process and a contact time between 90 and 120 min was necessary to reach the equilibrium. The adsorption capacity was found to increase with the increase of initial concentration but a decrease in the removal efficiency was observed.

Lactarius

The ability of cultivated wild Lactarius piperatus for Cd biosorption from aqueous solution was investigated in batch conditions. The bisosorption of Cd ions was carried out at different concentrations ranging from 45 to 265 mg/l. The operating parameters, initial metal ion concentration, contact time and pH were considered to describe the biosorption efficiency on the removal of Cd ions (Nagy et al., 2013).

Phanerochaete

The adsorption capacity of wasted solids that contained dead fungal biomass of Phanerochaete chrysosporium was studied to remove cadmium, copper, zinc and iron from synthetic water and leachate. The effects of biomass dosage, contact time, pH and agitation speed were also observed for optimal adsorption (Mamun et al., 2011). This fungal species has also been used by Mihova and Godjevargova (2001) for decontamination of waste waters containing Cu ions. The sorption of Cu by this fungal strain was proved to be a fast process. Up to 75% of the Cu content were absorbed during the first 6 hours. The effect of the type of metal on the sorption process was studied and the following order of sorption was observed: Pb > Ni > Cu.

Pleurotus

Biosorption of copper by Pleurotus spent mushroom compost has been investigated. Parameters including, initial pH, contact time, initial copper concentration and temperatures were examined in batch mode (Tay et al., 2010). In addition, P. sapidus has been reported to accumulate heavy metals from soil in decreasing sequence of Zn > Cu > Mn > Pb > Ni > Cd, while P. ostreatus has reported to accumulate

Table-3. Heavy metal remediation by the different fungi of group Basidiomycota with optimum conditions.

Fungi	Heavy metal	Initial concentration of metal	Metal uptake by biomass with optimum conditions	References
Agaricus biosporous	Ni	14.31 µg/g	2.87 µg/g	Ita *et al.,* 2008
	Cu	66.57 µg/g	23.18 µg/g	Ita *et al.,* 2008
	Cu	_	13.5 µg/g	Sesli and Tuzen, 1999
	Pb	26.55 µg/g	1.33 µg/g	Ita *et al.,* 2008
	Pb	_	0.28 µg/g	Sesli and Tuzen, 1999
	Mn	_	3.61 µg/g	Sesli and Tuzen, 1999
	Mn	82.31 µg/g	40.01 µg/g	Ita *et al.,* 2008
	Cd	8.34 µg/g	0.83 µg/g	Ita *et al.,* 2008
	Cd	_	89.50%	Nagy *et al*., 2013
			pH 5.6-5.8, 296 K Tem,	
			90-120 min CT	
	Cd	_	0.74 µg/g	Sesli and Tuzen, 1999
	Zn	213.53 µg/g	50.22 µg/g	Ita *et al.,* 2008
	Zn	_	22.5 µg/g	Sesli and Tuzen, 1999
	Hg	_	0.03 µg/g	Sesli and Tuzen, 1999
	Fe	_	31.3 µg/g	Sesli and Tuzen, 1999
Agaricus bitorquis	Cu	796.19 mg/l	93.53%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Zn	729.69 mg/l	98.02%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Fe	401.71 mg/l	88.92%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Cd	1226.34 mg/l	98.97%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Pb	1251.21 mg/l	88.76%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Ni	493.84 mg/l	97.22%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
Armillariella mellea	Ni	14.31 µg/g	0.64 µg/g	Ita *et al.,* 2008
	Cu	66.57 µg/g	30.18 µg/g	Ita *et al.,* 2008

	Pb	26.55 µg/g	1.42 µg/g	Ita *et al.,* 2008
	Mn	82.31 µg/g	41.11 µg/g	Ita *et al.,* 2008
	Cd	8.34 µg/g	0.49 µg/g	Ita *et al.,* 2008
	Zn	213.53 µg/g	82.47 µg/g	Ita *et al.,* 2008
Calocybe indica	Cr	_	55%	Kuzhali, 2012
	Zn	_	37.90%	Kuzhali, 2012
	Ni	_	49.10%	Kuzhali, 2012
Ganoderma lucidum	Cu	0.2-2 mM	0.383 mM/g	Muraleedharan *et al.,* 1995
			pH 4, 3 hrs CT	
	Cu	5-50 mg/l	24 mg/g	Venkobacher, 1990
			pH 5	
Lactarius piperatus	Cd	_	95.73%	Nagy *et al.,* 2013
			pH 5.6-5.8, 296 K Tem,	
			90-120 min CT	
Lentinus edodes	Cd	20-1000 mg/l	58 mg/g	Chen *et al.,* 2005
			pH 6.95	
	Pb	20-1000 mg/l	82.48 mg/g	Chen *et al.,* 2005
			pH 6.04	
	Cr	20-1000 mg/l	12.61 mg/g	Chen *et al.,* 2005
			pH 4.82	
Phanerochaete	Cu	50 mg/l	0.348 mg/g	Mihova and Godjevargova, 2001
chysosporium	Cu	4.77 mg/l	41.29%	Mamun *et al.,* 2011
			pH 5, 5 hrs CT	
	Ni	50 mg/l	0.398 mg/g	Mihova and Godjevargova, 2001
	Pb	50 mg/l	1.144 mg/g	Mihova and Godjevargova, 2001
	Cd	0.295 mg/l	28.81%	Mamun *et al.,* 2011
			pH 5, 18 hrs CT	
	Zn	1.985 mg/l	58.94%	Mamun *et al.,* 2011
			pH 5, 5 hrs CT	
	Fe	4.67 mg/l	52.03%	Mamun *et al.,* 2011
			pH 5, 5 hrs CT	
Pleurotus florida	Cr	_	88.50%	Kuzhali, 2012
	Zn	_	68.40%	Kuzhali, 2012
	Ni	_	58.80%	Kuzhali, 2012
	Pb	10 mg/l	100%	Prasad *et al.,* 2013
			pH 7, 30^{o}C Tem, 60 min CT	
Pleurotus floridianus	Cu	796.19 mg/l	93.53%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Zn	729.69 mg/l	98.02%	Lamrood and Ralegankar, 2013

			pH6, 32°C Tem, 180 min CT	
	Fe	401.71 mg/l	85.02%	Lamrood and Ralegankar, 2013
			pH6, 32°C Tem, 180 min CT	
	Cd	1226.34 mg/l	98.93%	Lamrood and Ralegankar, 2013
			pH6, 32°C Tem, 180 min CT	
	Pb	1251.21 mg/l	98.14%	Lamrood and Ralegankar, 2013
			pH6, 32°C Tem, 180 min CT	
	Ni	493.84 mg/l	97.22%	Lamrood and Ralegankar, 2013
			pH6, 32°C Tem, 180 min CT	
Pleurotus ostreatus	Ni	14.31 µg/g	1.03 µg/g	Ita *et al.,* 2008
	Ni	_	20.40 mg/g	Javaid *et al.,* 2011
			pH 4.5-5, 150 min ET	
	Cu	66.57 µg/g	57.45 µg/g	Ita *et al.,* 2008
	Cu	_	8.06 mg/g	
			pH 4.5-5, 150 min ET	Javaid *et al.,* 2011
	Cu	_	5 mg/kg	Tuzen *et al.,* 1998
	Cu	_	13.6 mg/kg	Demirbas, 2001
	Cu	_	45.20%	Arbanah *et al.,* 2012
			pH 6, 25°C Tem	
	Cu	50 mg/l	4.6 mg/g	Tay *et al.,* 2010
			pH 5.5, 10 min CT	
	Pb	26.55 µg/g	0.78 µg/g	Ita *et al.,* 2008
	Pb	_	0.11 mg/kg	Tuzen *et al.,* 1998
	Pb	_	3.24 mg/kg	Demirbas, 2001
	Mn	82.31 µg/g	45.98 µg/g	Ita *et al.,* 2008
	Mn	_	10.3 mg/kg	Tuzen *et al.,* 1998
	Mn	_	6.27 mg/kg	Demirbas, 2001
	Cr	_	10.75 mg/g	Javaid *et al.,* 2011
			pH 2.5, 150 min CT	
	Cr	_	12.47%	Arbanah *et al.,* 2012
			pH 5, 25°C Tem	
	Cd	8.34 µg/g	0.54 µg/g	Ita *et al.,* 2008
		_	0.55 mg/kg	Tuzen *et al.,* 1998
	Cd	_	1.18 mg/kg	Demirbas, 2001
	Cd	10 mg/l	85%	Talib, 2013
			pH 6, 26±1°C Tem, 10 min CT	
	Zn	213.53 µg/g	52.23 µg/g	Ita *et al.,* 2008
	Zn	_	3.22 mg/g	Javaid *et al.,* 2011

			pH 4.5-5, 150 min ET	
	Zn	_	19.3 mg/kg	Tuzen *et al.,* 1998
	Zn	_	29.8 mg/kg	Demirbas, 2001
	Zn	_	5.04%	Arbanah *et al.,* 2012
			pH 5, 25^{o}C Tem	
	Fe	_	48.6 mg/kg	Tuzen *et al.,* 1998
	Fe	_	86.1 mg/kg	Demirbas, 2001
	Fe	_	80.52%	Arbanah *et al.,* 2012
			pH 6, 25^{o}C Tem	
	Hg	_	0.31 mg/kg	Tuzen *et al*., 1998
	Hg	_	0.42 mg/kg	Demirbas, 2001
Pleurotus sajorcaju	Hg	0.150-3 mmol/dm-3	0.660±0.019 mmol/g	Arica *et al.,* 2003
	Pb	_	7 mg/kg	Mitra, 1994
	Pb	1251.21 mg/l	94.73%	Lamrood and Ralegankar, 2013
	Cd	_	33 µg/g	Mitra, 1994
	Cu	796.19 mg/l	93.50%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Zn	729.69 mg/l	98.00%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Fe	401.71 mg/l	88.15%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Cd	1226.34 mg/l	98.94%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Pb	1251.21 mg/l	94.73%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Ni	493.84 mg/l	97.22%	Lamrood and Ralegankar, 2013
			pH6, 32^{o}C Tem, 180 min CT	
Pleurotus sapidus	Ni	14.31 µg/g	0.52 µg/g	Ita *et al.,* 2008
	Cu	66.57 µg/g	24.66 µg/g	Ita *et al.,* 2008
	Pb	26.55 µg/g	0.55 µg/g	Ita *et al.,* 2008
	Mn	82.31 µg/g	22.56 µg/g	Ita *et al.,* 2008
	Cd	8.34 µg/g	0.41 µg/g	Ita *et al.,* 2008
	Zn	213.53 µg/g	60.45 µg/g	Ita *et al.,* 2008
Polyporus frondosis	Ni	14.31 µg/g	20.98 µg/g	Ita *et al.,* 2008
	Cu	66.57 µg/g	22.56 µg/g	Ita *et al.,* 2008
	Pb	26.55 µg/g	1.42 µg/g	Ita *et al.,* 2008

	Mn	82.31 µg/g	20.54 µg/g	Ita *et al.,* 2008
	Cd	8.34 µg/g	0.61 µg/g	Ita *et al.,* 2008
	Zn	213.53 µg/g	42.34 µg/g	Ita *et al.,* 2008
Polyporus sulphureus	Ni	14.31 µg/g	1.78 µg/g	Ita *et al.,* 2008
	Cu	66.57 µg/g	46.77 µg/g	Ita *et al.,* 2008
	Pb	26.55 µg/g	0.91 µg/g	Ita *et al.,* 2008
	Mn	82.31 µg/g	34.88 µg/g	Ita *et al.,* 2008
	Cd	8.34 µg/g	0.52 µg/g	Ita *et al.,* 2008
	Zn	213.53 µg/g	38.12 µg/g	Ita *et al.,* 2008
Rhizoctonia solani	Cr	25 ppm	94.10%	Seshikala and Charya, 2012
Serpula himantioides	As	0.40%	112.80±28.80 mmol/mg	Adeyemi, 2009
Volvariella diplasia	Cu	796.19 mg/l	93.59%	Lamrood and Raleganker, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Cd	1226.34 mg/l	98.90%	Lamrood and Raleganker, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Pb	1251.21 mg/l	98.18%	Lamrood and Raleganker, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Ni	493.84 mg/l	96.92%	Lamrood and Raleganker, 2013
			pH6, 32^{o}C Tem, 180 min CT	
Volvariella volvacea	Cu	796.19 mg/l	93.59%	Lamrood and Raleganker, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Zn	729.69 mg/l	98.02%	Lamrood and Raleganker, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Fe	401.71 mg/l	84.92%	Lamrood and Raleganker, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Cd	1226.34 mg/l	98.91%	Lamrood and Raleganker, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Pb	1251.21 mg/l	98.69%	Lamrood and Raleganker, 2013
			pH6, 32^{o}C Tem, 180 min CT	
	Ni	493.84 mg/l	96.94%	Lamrood and Raleganker, 2013
			pH6, 32^{o}C Tem, 180 min CT	

*Tem=Temperature, CT=Contact time, ET=Equilibrium time, -- = not identified

these metal in decreasing order of Cu > Zn > Mn > Ni > Pb > Cd (Ita et al., 2008). As well as adsorption potential of P. ostreatus was explored to remove copper, nickel, zinc and chromium from water. Different operational parameters such as the effect of pH, biomass dose, equilibrium time, stirring intensity, temperature and initial metal ion concentrations were studied (Javaid et al., 2011). In another experiment P. ostreatus employed as biosorbent for metals removal with the highest removal efficiency of Fe followed by Cu, Cr and Zn. The results obtained shows that pH, temperature and contact time plays an important role in biosorption capacity of the fungus (Arbanah et al., 2012). Furthermore, it was found to remove Cd excessively from wastewater at optimum conditions of initial pH 6, 10 minutes contact time, 10 mg/l cadmium concentration in 50 ml solution and at room temperature (Talib, 2013).

Mycelial biomass of cultivated P. florida, has been evaluated for biosorption of heavy metals such as Cr, Zn and Ni from tannery effluent. It showed the maximum biosorption for Cr than Zn and Ni (Kuzhali et al., 2012) and in another study biomass of this fungal species was studied for adsorption of Pb from effluents. The optimum conditions of pH and contact time for biosorption were also determined (Prasad et al., 2013). Furthermore, P. sajur-caju mycelia immobilized in Ca-alginate beads was used for the removal of mercuric ions from aqueous solutions. The sorption of Hg ions by alginate beads and both immobilized live and heat-killed fungal mycelia of P. sajur-caju was studied in the concentration range of 0.150–3.00 mmol dm−3. The biosorption of Hg increased as the initial concentration of Hg ions increased in the medium. Biosorption capacities for live and heat-killed P. sajur-caju were 0.450 ± 0.014 mmol Hg/g and 0.660 ± 0.019 mmol Hg/g respectively. Biosorption equilibrium was established in about 1 h and maximum adsorption was observed between pH 4.0 and 6.0 (Arica et al., 2003).

Polyporus

According to Ita et al. (2008) Polyporus frondosis revealed maximum bioaccumulation of Zn followed by Cu, Mn, Pb, Ni and Cd from soil, while P. sulphureus had the ability to accumulate these metals in decreasing sequence of Cu > Zn > Mn > Ni > Pb > Cd.

Trametes

Trametes versicolor was investigated for their potential abilities to accumulate arsenic from an agar environment consisting of non-buffered mineral salts media amended with 0.2, 0.4, 0.6 and 0.8% (w/v) arsenopyrite (FeAsS). Growth rates, dry weights and arsenic accumulation by the fungi as well as the pH of the growth media were all assessed during this study. T. versicolor was showed higher accumulation of As at 0.4% arsenopyrite and least at 0.6% (Adeyemi, 2009). Immobilization of this fungus with Ca-alginate found effective in removal of mercuric ions from aqueous solutions. The sorption of Hg ions by alginate beads and both immobilized live and heat-killed fungal mycelia of T. versicolor was studied in the concentration range of 0.150–3.00 mmol dm−3. Maximum biosorption capacities for alginate beads were 0.144 ± 0.005 mmol Hg/g; for immobilized live and heat-killed fungal mycelia of T. versicolor were 0.171 ± 0.007 mmol Hg/g and 0.383 ± 0.012 mmol Hg/g respectively. Maximum adsorption was observed between pH 4.0 and 6.0 and equilibrium was established in about 1 h (Arica et al., 2003).

Heavy metal remediation by fungi of group Deuteromycotina:

The vast majority of these organisms are terrestrial, although a good number have been reported from marine and fresh water habitats. Following fungi of Deuteromycotina had been shown as biosorbents for heavy metals remediation (Table 4):

Alternaria

Alternaria alternata has found to accumulate Cd, Cr and Ni from soil and exhibited highest resistance to Chromate and sensitive to nickel (Levinskaite, 2001) and in another experiment it showed less absorption of Cr (40%) with 114 mg dry weight at 25 ppm chromium concentration (Seshikala and Charya, 2012).

Table-4. Heavy metal remediation by the different fungi of group Deuteromycotina with optimum conditions.

Fungi	Heavy metal	Initial concentration of metal	Metal uptake by biomass with optimum conditions	References
Alternaria alternata	Cd	0.1-3 mM	86.90%	Levinskaite, 2001
	Cr	0.1-3 mM	67.80%	Levinskaite, 2001
	Cr	20 ppm	70.50%	Seshikala and Charya, 2012
	Ni	0.1-3 mM	43.60%	Levinskaite, 2001
	Ni	50 mg/l	20%	Shoaib *et al.,* 2012
	Cu	50-100 mg/l	20%	Shoaib *et al.,* 2012
Fusarium oxysporum	Cr	100 ppm	90%	Amatussalam *et al.,* 2011
			pH 5.8, 120 hrs CT	
	Cr	20 ppm	95%	Seshikala and Charya, 2012
			pH 3-7	
Fusarium solani	Cr	500 mg/l	60 mg/g	Sen and Dastidar, 2011
			pH 4, 30^{o}C Tem, 24 hrs CT	
	Zn	500 mg/l	60 mg/g	Sen, 2013
			pH 6, 2 hrs ET	
	Ni	500 mg/l	54.5 mg/g	Sen, 2013
Fusarium sp.	Zn	0.45 mg/l	0.45 mg/l	Chandrakar *et al*., 2012
			5 days IP	
	Cu	0.6625 mg/l	0.60 mg/l	Chandrakar *et al.,* 2012
			5 days IP	

*CT= Contact time, ET= Equilibrium time, Tem=Temperature, IP= Incubation period

Fusarium

Fusarium sp. has been investigated to biosorb Zn and Cu from waste water with maximum biosorption of Cu (Chandrakar et al., 2012). The potential of the resting cells of the F. solani has been evaluated for Cr removal from aqueous solution. The effects of pH, initial Cr concentration, biomass concentration and age of the culture on Cr removal from aqueous solutions were studied using synthetic Cr solution in batch bioreactors (Sen and Dastidar, 2011). Besides, in the study of Amatussalam et al. (2011) maximum efficiency of Fusarium oxysporum for Cr removal was up to 90%, achieved at the end of 5th day incubation (120 min contact time) for 100 and 200 ppm concentration of Cr with pH ranging from 5.8 and 5.6 respectively. Furthermore, nonliving cells of Fusarium solani has been used for biosorption of zinc and nickel from wastewaters. The specific metal removal increased with increase in initial metal ion concentration up to 500 mg/l for both zinc and nickel (Sen, 2013).

DISCUSSION

This review highlighted the abilities of certain fungi for remediation of heavy metals. Present review indicated that heavy metal remediation is effective by fungi of Ascomycotina followed by

Basidiomycotina, Zygomycotina and Deuteromycotina. Among Ascomycotina species of Aspergillus were found more effective followed by species of Penicillium, Trichoderma and Saccharomyces. Besides, species of Mucor and Rhizopus represent best bioremediator among Zygomycotina species of Pleurotus among Basidiomycotina and species of Fusarium among Deuteromycotina.

As we have known from the above examples, fungi has found higher ability to remove high concentrations of heavy metals, however, an optimization of pH, temperature, Carbon sources, physical and chemical pretreatments is very important to obtain a good output of heavy metal biosorption as fungal biosorption principally depends on parameters such as pH, temperature, metal ion concentration, biomass concentration, physical and chemical pretreatments of biomass and presence of various legends in solution. Higher amounts of metal ions concentration in wastewater increased the contact probability between these ions and active binding sites on the surface of the biosorbent and subsequently enhanced the metal removal. The pH of the biosorption medium affects the solubility of the metal ions and the ionization state of the functional groups. Fungal surfaces have a negative charge in the pH range of 2-6 (Congeevaram et al., 2007).

The proton concentration is high at lower pH (<2) and heavy metal biosorption decreases due to the positive charge density on metal binding sites. The negative charge density on the cell surface increases with increasing pH due to deprotonation of the metal binding sites. The metal ions then compete more effectively for available binding sites, which increase biosorption (Kapoor et al., 1999). Decrease in biosorption at higher pH (>6) is due to the formation of soluble hydroxylated complexes of the metal ions and their competition with hydroxyl ions for active sites. Beyond pH 8.0, precipitations of the ions as hydroxides occur (Vimala and Das, 2009; Venkanna Lunavath and Estari Mamidala, 2013). In this review pH 2-7 is found effective in bioremediation by the fungi of Zygomycotina, pH 3-9.5 by the fungi of Ascomycotina, pH 4-6 by the fungi of Basidiomycotina and pH 3-7 by the fungi of Deuteromycotina. The temperature of the adsorption medium could be important for energy dependent mechanisms in metal removal by microorganisms. Temperature is known to affect the stability of the cell wall, its configuration and can also cause ionization of chemical moieties. These factors may simultaneously affect the binding sites on isolated fungal species causing reduction in heavy metal removal. Energy-independent mechanisms are less likely to be affected by temperature since the processes responsible for removal are largely physiochemical in nature (Gulay et al., 2003; Repudi Lalitha and Estari Mamidala, 2013). Here we have found 25-35^{o} C temperature is suitable for best bioremediation by the fungi of all these above mentioned groups. By increasing biomass concentration, may result in more biosorbent surface area and more available adsorption sites. These sites remain unsaturated during biosorption process so equilibrium uptake decreases by increasing biomass concentration (Schnepf et al., 1998). Physical and chemical pretreatments of biomass may increase the metal sorption capacity of fungi. As the biosorption process involves cell surface sequestration, the modification of cell wall can greatly alter the binding of metal ions. A number of methods have been employed for cell wall modification of microbial cells in order to enhance the metal binding capacity of biomass and to elucidate the mechanism of biosorption. The physical treatments include heating/boiling, freezing/thawing, drying and lyophilization. The various chemical treatments used for biomass modification include washing the biomass with detergents, cross-linking with organic solvents, and alkali or acid treatment. The pretreatments could modify the surface characteristics/groups either by removing or masking the groups or by exposing more metal binding sites (Vieira and Volesky, 2000; Runa Rashmi, 2014). Thus removed cells would offer a larger available surface area and expose the

intracellular components and more surface binding sites because of the destruction of the cell membranes (Errasquin and Vazquez, 2003).

Further studies should be accompanied by those fungi which have least knowledge for sorption/accumulation abilities of heavy metals for more and more application of fungi in the field of bioremediation as use of fungi is cost effective than other conventional biosorbents, their cell wall components show outstanding metal binding properties and fungi also play fundamental roles in the natural environment especially regarding decomposition, transformation and nutrient cycling. More information on biosorption is required to determine the best combination of metals, biomass types and optimum conditions. Moreover, further detailed studies should be conducted in order to clarify the causes of enhancement or decrease in adsorption capacity for fungal biomasses.

REFERENCES

1. Adeyemi, A.O. 2009. Bioaccumulation of Arsenic by Fungi. Am. J. Environ. Sci. 5: 364-370.
2. Ahmad, I., Ansari, I. and Aqil, F. 2005a. Biosorption of Ni, Cr and Cd by metal tolerant Aspergillus niger and Penicillium sp. using single and multi-metal solution. Indian J. Exp. Biol. 44: 73-76.
3. Ahmad, I., Zafar, S. and Ahmad, F. 2005b. Heavy metal biosorption potential of Aspergillus and Rhizopus sp. isolated from wastewater treated soil. J. Appl. Sci. Environ. Manage. 9: 123-126.
4. Akhtar, K., Akhtar, M.W. and Khalid, A.M. 2008. Removal and recovery of Zirconium from its aqueous solution by Candida tropicalis. J. Hazard. Mater. 156: 108–117.
5. Alpat, S., Alpat-Kilinc, S., Bilge H.C., Ozbayrak, O. and İhsan, Y. 2010. Effects of biosorption parameter: kinetics, isotherm and thermodynamics for Ni (II) biosorption from aqueous solution by Circinella sp. Electron. J. Biotechnol. 13: 1-12.
6. Amatussalam, A., Abubacker, M.N. and Rajendran, R.B. 2011. In situ Carica papaya stem matrix and Fusarium oxysporum (NCBT-156) mediated bioremediation of chromium. Indian J Exp. Biol. 49: 925-31.
7. Amini, M., Younesi, H. and Bahramifar, N. 2009. Statistical modeling and optimization of the cadmium biosorption process in an aqueous solution using Aspergillus niger. Colloids Surf. A: Physicochem. Eng. Aspects. 337: 67–73.
8. Anaemene, I.A. 2012. The Use of Candida sp in the Biosorption of Heavy Metals from Industrial Effluent. Eur. J. Exp. Biol. 2: 484-488.
9. Arbanah, M., Miradatul, N.M.R. and Halim, K.H. 2012. Biosorption of Cr(III), Fe(II), Cu(II), Zn(II) Ions from Liquid Laboratory Chemical Waste by Pleurotus ostreatus. Int. J. Biotechnol. Wellness Ind. 1: 152-162.
10. Arıca, M.Y., Arpa, Ç., Kaya. B., Bektaş, S. Denizli, A. and Genç, O. 2003. Comparative biosorption of mercuric ions from aquatic systems by immobilized live and heat-inactivated Trametes versicolor and Pleurotus sajur-caju. Biores. Technol. 89: 145–154.
11. Aung, K.M.M. and Ting, Y.P. 2005. Bioleaching of spent fluid catalytic cracking catalyst using Aspergillus niger. J. Biotechnol. 116: 159–170.
12. Bai, R.S. and Abraham, T.E. 2001. Biosorption of Cr (VI) from aqueous solution by Rhizopus nigricans. Biores. Technol. 79: 73–81.
13. Bajgai, R.C., Georgieva, N. and Lazarova, N. 2012. Bioremediation of chromium ions with filamentous yeast Trichosporon cutaneum R57. J. Biol. Earth Sci. 2: 70-75.
14. Cabuk, A., Ilhan, S., Filik, C. and Caliskan, F. 2005. Pb2+ Biosorption by pretreated fungal biomass. Turk J. Biol. 29: 23-28.
15. Chandrakar, V., Verma, P. and Jamaluddin 2012. Removal of cu and zn by fungi in municipal sewage water. Int. J. Adv. Biotechnol. Res. 2: 787-790.
16. Chen, G.Q., Zeng, G.M., Xiang, T.U., Huang, G.H. and Chen, Y.N. 2005. A novel biosorbent: Characterization of the spent mushroom compost and its application for removal of heavy metals. J. Environ. sci. 17: 756-760.
17. Congeevaram, S., Dhanarani, S., Park, J., Dexilin, M. and Thamaraiselvi, K. 2007. Biosorption of chromium and nickel by heavy metal resistant fungal and bacterial isolates. J. Hazard. Mater. 146: 270–277.
18. Damodaran, D., Gummadi, S. and RajMohan, B. 2011. Bioremediation of soil by removing heavy metals using Saccharomyces cerevisiae. 2nd International Conference on Environmental

Science and Technology IPCBEE vol.6 IACSIT Press, Singapore.
19. Demirbas, A. 2001. Concentration of 21 metals in 18 species of mushrooms growing in the east Black Sea Region. Food Chem. 75: 453-457.
20. Dugal, S. and Gangawane, M. 2012. Metal tolerance and potential of Penicillium species for use in mycoremediation. J. Chem. Pharm. Res. 4: 2362-2366.
21. Ebner, C., Pümpel, T. and Gamper, M. 2002. Biosorption of Cr (III) by the cell wall of Mucor hiemalis. Eur. J. Miner. Proc. Environ. Prot. 2: 168-178.
22. El-Gendy, M.M.A., Hassanein, N.M., El-Hay I.H., El-Baky, A. and Doaa, H. 2011. Evaluation of some fungal endophytes of plant potentiality as low-cost adsorbents for heavy metals uptake from aqueous solution. Aust. J. Basic Appl. Sci. 5: 466-473.
23. El Morsy El Sayed 2004. Cunninghamella echinulata a new biosorbent of metal ions from polluted water in Egypt. Mycologia. 96: 1183–1189.
24. Errasquin, E.L. and Vazquez, C. 2003. Tolerance and uptake of heavy metals by Trichoderma atroviride isolated from sludge. Chemosphere. 50: 137-143.
25. Fan, T., Liu, Y., Feng, B., Zeng, G., Yang, C., Zhou, M., Zhou, H., Tan, Z. and Wang, X. 2008. Biosorption of cadmium (II), zinc (II) and lead (II) by Penicillium simplicissimum: Isotherms, kinetics and thermodynamics. J. Hazard. Mater. 160: 655-661.
26. Farkas, V. 1980. Biosynthesis of cell wall of fungi. Microbiol. Rev. 44: 117-141.
27. Faryal, R., Sultan, A., Tahir, F., Ahmed, S. and Hameed, A. 2007. Biosorption of lead by indigenous fungal strains. Pak. J. Bot. 39: 615-622.
28. Fomina, M., Charnock, J., Bowen, A.D. and Gadd, G.M. 2007. X-ray absorption spectroscopy (XAS) of toxic metal mineral transformations by fungi. Environ. Microbiol. 9: 308-321.
29. Fourest, E. and Roux, J.C. 1992. Heavy metal biosorption by fungal mycelial by-products: mechanisms and influence of pH. Appl. Microbiol. Biotechnol. 37: 399–403.
30. Gadd, G.M. and de Rome, L. 1988. Biosorption of copper by fungal melanine. Appl. Microbiol. Biotechnol. 29: 610-617.
31. Gadd, G.M., White, C. and de Rome, L. 1988. Heavy metal and radionuclide uptake by fungi and yeasts; in Biohydrometallurgy (eds) PR Norris and DP Kelly: proceedings of the 7th international symposium, Kew, surrey, UK. 421-435.
32. Galun, M., Galun, E., Siegel, B.Z., Keller, P., Lehr, H. and Siegel, S.M. 1987. Removal of metal ions from aqueous solutions by Penicillium biomass: kinetic and uptake parameters. Water Air Soil Pollut. 33: 359-371.
33. Gulay, B., Sema, B. and Yakup, A.M. 2003. Biosorption of heavy metal ions on immobilized white-rot fungus Trametes versicolor. J. Hazard. Mater. 101: 285–300.
34. Hala, Y.E.K. and Eman, M.E.T. 2009. Optimization of batch process parameters by response surface methodology for mycoremediation of chrome-vi by a chromium resistant strain of marine Trichoderma Viride. Am. Eurasian J. Agric. & Environ. Sci. 5: 676-681.
35. Huang, C.P., Huang, C.P. and Morehart, A.L. 1990. Removal of copper (II) from dilute aqueous solutions by Saccharomyces cerevisiae. Water Res. 24: 433-439.
36. Ianis, M., Tsekova, K. and Vasileva, S. 2006. Copper biosorption by Penicillium cyclopium: equilibrium and modelling study. Biotech. Bioeng. 20: 195-201.
37. Ismail, K., Akar, T. and Tunali, S. 2005. biosorption of Pb and Cu from aqueous solution by pretreated biomass of Neurospora crassa. Proc. Biochem. 40: 3550-3558.
38. Ita, B.N., Ebong, G.A., Essien, J.P. and Eduok, S.I. 2008. Bioaccumulation potential of heavy metals in edible fungal sporocarps from the Niger Delta region of Nigeria Pakistan. J. Nutr. 7: 93-97.
39. Javaid, A., Bajwa, R., Shafique, U. and Anwar, J. 2011. Removal of heavy metals by adsorption on Pleurotus ostreatus. Biomass Bioenerg. 35: 1675–1682.
40. Joshi, P.K., Swarup, A., Maheshwari, S., Kumar, R. and Singh, N. 2011. Bioremediation of heavy metals in liquid media through fungi isolated from contaminated sources. Indian J. microbial. 51: 482-487.
41. Junior, L.M.B., Macedo, G.R., Duarte, M.M.L., Silva, E.P. and Lobato, A.K.C.L. 2003. Biosorption of cadmium using the fungus Aspergillus niger. Braz. J. Chem. Eng. 20: 229-239.
42. Kapoor, A., Viraraghavan, T. and Cullimore, D.R. 1999. Removal of heavy metals using the fungus Aspergillus niger. Biores. Technol. 70: 95–104.

43. Khan et al. 1998. Investigation of fungi as biosorbents for removal of metal ions from waste water. WISA Biennial conference, 1998, Cape Town.
44. Kita, G. and Skobewski, P. 2010 Biosorption of heavy metals-modern and cheap method of polluted waste water treatment. Food Chem. Biotechnol. 74: 99-105.
45. Kumar, A., Bisht, B.S. and Joshi, V.D. 2011. Zinc and Cadmium removal by acclimated Aspergilus niger: Trained fungus for biosorption. Int. J. Environ. Sci. Res. 1: 27-30.
46. Kuzhali, S.S., Manikandan, N. and Kumuthakalavalli, R. 2012. Biosorption of heavy metals from tannery effluent by using macrofungi. Elixir Pollut. 47: 9005-9006.
47. Lamrood, P.Y. and Ralegankar, S.D. 2013. Biosorption of Cu, Zn Fe, Cd, Pb and Ni by non-treated biomass of some edible mushrooms. Asian J. Exp. Biol. Sci. 4: 190-195.
48. Levinskaite, L. 2001. Simultaneous effect of Ni, Cd and Cr on soil micromycetes. Biologija. 13-15.
49. Luef, E., Prey, T. and Hubicek, C.P. 1991. Biosorption of zinc by fungal mycelial wastes. Appl Microbiol Biotechnol. 34: 688–692.
50. Luo, J.M., Xiao, X. and Luo, S.L. 2010. Biosorption of cadmium (II) from aqueous solutions by industrial fungus Rhizopus cohnii. Trans. Nonferrous Met. Soc. China. 20: 1104–1111.
51. Maheswari, S. and Murugesan, A.G. 2009. Remediation of arsenic in soil by Aspergillus nidulans isolated from an arsenic-contaminated site. Environ. Technol. 30: 921–926.
52. Majumdar SS, Das SK, Chakravarty R, Saha T, Bandyopadhyay TS and Guha AK 2010 A study on lead adsorption by Mucor rouxii biomass. Desalination. 251: 96–102.
53. Mamun, A.A., Alam, Z., Nik, A.N. and Shah, S.R. 2011. Adsorption of heavy metal from landfill leachate by wasted biosolids. Afr. J. Biotechnol. 10: 18869-1888.
54. Mann, H. 1990. Removal and recovery of heavy metals by biosorption; in Biosorption of heavy metals (ed) Volesky (Boca Raton: CRC press) pp 93-137.
55. Maurya, N.S., Mittal, A.K., Peter, C. and Elmar, R. 2006. Biosorption of dyes using dead macro fungi: Effect of dye structure, ionic strength and pH. Biores. Technol. 97: 512-521.
56. Mihova, S. and Godjevargova, T. 2001. Biosorption of Heavy metals from aqueous solutions. J. Int. Res. pub. Issue 1.
57. Mitra, A.K. 1994. Studies on the uptake of heavy metal pollutants by edible mushrooms and its effect on their growth, productivity and mammalian systems, Phd thesis, University of Calcutta.
58. Muraleedharan. T.R., Iyengar, L. and Venkobachar, C. 1991. Biosorption: an attractive alternative for metal removal and recovery. Curr. Sci. 61: 379-385.
59. Muraleedharan, T.R., Iyengar, L., and Venkobachar, C. 1995. Screening of tropical wood-rotting mushrooms for copper biosorption. Appl. Environ. Microbiol. 61: 3507–3508.
60. Nagy, B., Maicaneanu, A., Indolean, C., Manzatu, C., Silaghi-Dumitrescu, L. and Majdik, C. 2013. Comparative study of Cd(II) biosorption on cultivated Agaricus bisporus and wild Lactarius piperatus based biocomposites: Linear and nonlinear equilibrium modelling and kinetics. J. Taiwan Inst. Chem. Eng. 1-9.
61. Nasseri, S., Mazaheri, A.M., Noori, S.M., Rostami, K.H., Shariat, M. and Nadafi, K. 2002. Chromium removal from tanning effluent using biomass of Aspergillus oryzae. Pak. J. Biol. Sci. 5: 1056–1059.
62. Niu, H., Xu, X.S., Wang, J.H. and Volesky, B. 1993. Removal of lead from aqueous solutions by Penicillium biomass. Biotechnol. Bioeng. 42: 785-787.
63. Nourbakhsh, M., Sag, Y., Ozer, D., Aksu, Z., Kutsal, T. and Caglar, A. 1994. A comparative study of various biosorbents for removal of chromium (IV) ions from industrial waste waters. Proc. Biochem. 29: 1-5.
64. Pagnanelli, F., Toro, L. and Veglio, F. 2002. Olive mill solid residues as heavy metal sorbent material: a preliminary study. Waste Manag. 22: 901–907.
65. Pal, T.K., Bhattacharyya, S. and Basumajumdar, A. 2010. cellular distribution of bioaccumulated toxic heavy metals in Aspergillus niger and Rhizopus arrhizus. Int. J. Pharma. Bio. Sci. 1: 1-6.
66. Pattanapipitpaisal, P., Brown, N.L. and Macaskie, L.E. 2001. Chromate reduction by Microbacterium liquefaciens immobilized in polyvinyl alcohol. Biotechnol. Lett. 23: 41-43.
67. Pillichshammer, M., Pumpel, T., Poder, R., Eller, K., Klima, J. and Schinner, F. 1995. Biosorption of chromium to fungi. Biometals. 8: 117-121.
68. Prakasham, R.S., Merrie, S., Sheela, J., Saswathi, N. and Ramakrishna, S.V. 1998. Biosorption of chromium (VI) by free and

immobilized Rhizopus arrhizus. Environ. pollut. 104: 421-427.
69. Prasad, A.S., Varatharaju, G., Anushri, C. and Dhivyasree, S. 2013. Biosorption of Lead by Pleurotus florida and Trichoderma viride. Brit. Biotechnol. J. 3: 66-78.
70. Prasenjit, B. and Sumathi, S. 2005. Uptake of chromium by Aspergillus foetidus. J. Mater. Cycles Waste Manage. 7: 88–92.
71. Ramasamy, R.K., Congeevaram, S. and Thamaraiselvi, K. 2011. Evaluation of isolated fungal strain from e-waste recycling facility for effective sorption of toxic heavy metal pb (II) ions and fungal protein molecular characterization- a mycoremediation approach. Asian J. Exp. Biol. Sci. 2: 342-247.
72. Ramasamy, R.K., Lee, J.T. and Cho, J.Y. 2012. Toxic cadmium ions removal by isolated fungal strain from e-waste recycling facility. J. Environ. Appl. Biores. 1: 1-4.
73. Rao, C.R.N., Iyengar, L. and Venkobachar, C. 1993. Sorption of Copper from aqueous phase by waste biomass. J. Environ. Eng. 119: 369-377.
74. Rao, K.R., Rashmi, K., Latha, J.N.L. and Maruthi, M.P. 2005. Bioremediation of toxic metal ions using biomass of Aspergillus fumigatus from fermentative waste. Indian J. Biotechnol. 4: 139-143.
75. Repudi Lalitha, Estari Mamidala and Rajeshwa. 2013. Invitro antimicrobial and antioxidant activity of *Acmella paniculata* plant extracts, Vol-4, Issue-1. Jan-Mar-2013. 132-135.
76. Romero, M.C., Reinoso, E.H., Urrutia, M.I. and Kiernan, A.M. 2006. Biosorption of heavy metals by Talaromyces helicus: a trained fungus for copper and biphenyl detoxification. Electron. J. Biotechnol. 9: 221-226.
77. Runa Rashmi and Maheshwar Prasad Trivedi. Assessing the morphological characters for taxonomic significance among intraspecific variations of *Catharanthus roseus*. Biolife 2014;2(4); 1002-1007.
78. Sag, Y., Ozer, D. and Kutsal, T. 1995. A comparative study of the biosorption of Lead (II) ions to Z. ramigera and R. arrhizus. Proc. Biochem. 30: 169–174.
79. Sarkar, S., Satheshkumar, A., Jayanthi, R. and Premkumar, R. 2010. Biosorption of Nickel by live biomass of Trichoderma harzianum. Res. J. Agr. Sci. 1: 69-74.
80. Say, R., Yilmaz, N. and Denizli, A. 2003. Removal of heavy metal ions using the fungus Penicillium canescens. Adsorpt. Sci. Technol. 21: 643-650.
81. Say, R., Yilmaz, N. and Denizli, A. 2004. Removal of chromium (VI) ions from synthetic solutions by the fungus Penicillium purpurogenum. Eng. Life Sci. 4: 276-280.
82. Schnepf, E., Crickmore, N., Rie, J.V., Lereclus, D., Baum, J., Feitelson, J., Zeigler, D.R. and Dean, D.H. 1998. Bacillus thuringiensis and its pesticidal crystal proteins. Microbiol. Mol. Biol. Rev. 62: 775–806.
83. Sen, M. 2013. Biosorption of zinc and nickel from wastewaters using nonliving cells of Fusarium solani. Int. J. Chem. Tech. Appl. 2: 63-70.
84. Sen, M. and Dastidar, M.G. 2007. Biosorption of Cr (VI) by resting cells of Aspergillus sp. Iran. J. Environ. Health Sci. Eng. 4: 9-12.
85. Sen, M. and Dastidar, M.G. 2010. Adsorption desorption studies on Cr (VI) using nonliving fungal biomass. Asian J. chem. 22: 2331-2338.
86. Sen, M. and Dastidar, M.G. 2011. Biosorption of Cr (VI) by resting cells of Fusarium solani. Iran. J. Environ. Health. Sci. Eng. 8: 153-158.
87. Seshikala, D. and Charya, M.A.S. 2012. Effect of pH on Chromium biosorption. Int. J. Pharma. Bio.Sci. 2: 298-302.
88. Sesli, E. and Tuzen, M. 1999. Levels of trace elements in the fruiting bodies of macrofungi growing in the East Black Sea region of Turkey. Food Chem. 65: 453-460.
89. Shoaib, A., Aslam, N. and Aslam, N. 2012. Myco and Phyto Remediation of Heavy metals from aqueous solution. Onl. J. Sci. Technol. 2: 35-40.
90. Siddiquee, S., Salleh, N.A., Sujjat, A., Saili, N.S. and Naher, L. 2013. Tolerance and biosorption capacity of Zn2+, Pb2+, Ni3+ and Cu2+ by filamentous fungi (Trichoderma harzianum, T. aureoviride and T. virens). Adv. Biosci. Biotechnol. 4: 570-583.
91. Skowronski, T., Pirszel, J. and Pawlik-Skwronska, B. 2001. Heavy metal removal by the waste biomass of Penicillium chrysogenum. Water Pollut. Res. J. Can. 36: 793-803.
92. Srivastava, P. and Hasan, S.H. 2011. Biomass of Mucor heimalis for the biosorption of Cd from aqueous sollutions: Equilibrium and kinetic studies. Biores. 6: 3656-3675.
93. Tahir, A. 2012. Resistant fungal biodiversity of electroplating effulent and their metal tolerance index (ed) D Sebayang, ISBN: 978-953-51-0471-1, Available from: http://www.intechopen.com

94. Talib, S.A. 2013. Fungal Pleurotus Ostreatus biosorbent for Cadmium (II) removal in industrial waste water. J. Life Sci. Technol. 1: 65-68.
95. Tan, T. and Cheng, P. 2003. Biosorption of metal ions with Penicillium chrysogenum. Appl. Biochem. Biotechnol. 104: 119-128.
96. Tay, C.C., Redzwan, G., Liew, H.H., Yong, S.K., Surif, S. and Talib, S.A. 2010. Copper (II) Biosorption Characteristic of Pleurotus Spent Mushroom Compost. International conference on science and social research, Kuala Lumpur, Malaysia, Varma, Heidelberg, Germany, Springer-Verlag.
97. Thippeswamy, B., Shivkumar, C.K. and Krishnappa, M. 2012a. Bioaccumulation potential of Aspergillus niger and Aspergillus flavus for removal of heavy metals from paper mill effluent. J. Environ. Biol. 33: 1063-1068.
98. Thippeswamy, B., Shivakumar, C.K. and Krishnappa, M. 2012b. Accumulation potency of heavy metals by saccharomyces sp. indigenous to paper mill effluent. J. Environ. Res. Dev. 6: 439-445.
99. Townsley, C.C. and Ross, I.S. 1985. Copper uptake by Penicillium spinulosum. Microbes. 44: 125-134.
100. Tsezos, M. and Volesky, B. 1981. Biosorption of uranium and thorium. Biotechnol Bioeng. 23: 583–604.
101. Tuzen, M., Ozdemir, M. and Demirbas, A. 1998. Study of heavy metals in some cultivated and uncultivated mushrooms of Turkish origin. Food Chem. 63: 247-251.
102. Vankar, P.S. and Bajpai, D. 2007. Phyto-remediation of chrome-VI of tannery effluent by Trichoderma species. Presented at the conference on Desalination and the Environment. Sponsored by the European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort, Halkidiki, Greece. pp 22–25.
103. Varshney, R., Bhadauria, S. and Gaur, M.S. 2010. Biosorption of Copper (II) from electroplat¬ing wastewaters by Aspergillus terreus and its kinetics studies. Water. 2: 142-151.
104. Velmurugan, N., Hwang, G., Muthuswamy, S.K., Choi, T.K., Kui-Jae, L., Byung-Taek, O. and Yang-Soo, L. 2010. Isolation, identification, Pb (II) biosorption isotherms and kinetics of a lead adsorbing Penicillium sp. MRF-1 from South Korean mine soil. J. Environ. Sci. 22: 1049–1056.
105. Venkanna Lunavath and Estari Mamidala, 2013. Preliminary phytochemical screening and antibacterial studies of the leaves of *Eclipta alba* International journal of pharma and bio sciences, 4(3):380-384.
106. Venkobacher, C. 1990. Metal removal by waste biomass to upgrade wastewater treatment plants. Water Sci. Technol. 22: 319–320.
107. Vieira, R.H.S.F. and Volesky, B. 2000. Biosorption: a solution to pollution? Int. Microbiol. 3 17-24.
108. Vimala, R. and Das, N. 2009. Biosorption of cadmium (II) and lead (II) from aqueous solutions using mushrooms: A comparative study. J. Hazard. Mater. 168 376-382.
109. Volesky, B. 1992 Removal of heavy metals by biosorption in harnessing biotechnology for the 21st century (eds) MR Ladisch and A Bose, American chemical society, Washington, DC.
110. Volsesky, B. and Holan, Z.R. 1995. Biosrption of heavy metals: Review. Biotechnol Prog. 11 235-250.
111. Yan, G. and Viraraghavan, T. 2000. Effect of pretreatment on the bioadsorption of heavy metals on Mucor rouxii. Water SA. 26 119-123.
112. Yan, G. and Viraraghavan, T. 2003. Heavy-metal removal from aqueous solution by fungus Mucor rouxii. Water Res. 37 4486–4496.
113. Yazdani, M., Yap, C.K., Abdullah, F. and Tan, S.G. 2010. An in vitro Study on the adsorption, absorption and uptake capacity of Zn by the bioremediator Trichoderma atroviride. Environ. Asia. 3 53-59.
114. Zafar, S., Aqil, F. and Ahmad, I. 2007. Metal tolerance and biosorption potential of filamentous fungi isolated from metal contaminated agricultural soil. Biores. Technol. 98 2557–2561.

*****