# Biosorption and adsorption of some heavy metals by *Fusarium* sp. F6c isolate as affected by gamma irradiation and agricultural wastes

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**ABSTRACT**: Various industries produce and discharge wastes containing different heavy metals into the environment. Biosorption as a biological method for removal of heavy metals from industrial and sewage wastewater has attracted the attention of researchers due to its unique properties compared to physical and chemical methods. The purpose of this study is to investigate the fungal biosorption of different heavy metals (lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), cobalt (Co), and chromium (Cr)) from wastewater. Through the current work, eight fungal isolates have been isolated from wastewater and investigated for their ability to grow in and uptake of different heavy metals. The most potent fungal isolate F6c was identified as *Fusarium* sp. based on morphological and physiological characterization. The strain F6c has been investigated for its ability to grow at 100 ppm of both $PbCl_2$ and $CdCl_2$. Evaluation of the effect of γ-irradiation on Pb and Cd uptake showed that the biosorption was improved at 1 kGy but gradually suppressed at higher doses. Use of different agricultural wastes including rice bran, rice straw, wheat straw, maize wastes, and bagasse in combination with gamma irradiation improved both $PbCl_2$ and $CdCl_2$ uptake by F6c. Biosorption and adsorption techniques using the irradiation of *Fusarium* strain F6c could be a potential alternative to conventional methods in terms of availability of materials, cost-effectiveness as biosorbent for removal of high concentration metals from wastewater and industrial effluents.

**KEYWORDS**: adsorption, biosorption, *Fusarium* sp., heavy metals, mycoremediation, wastewater

## INTRODUCTION

Heavy metals are emitted into the environment by sewage and waste materials from various resources such as metal plating, paint industry, metallurgy, released oil ingredients in the soil, combustion of fossil fuels, mining, ore washing, pesticides, colored materials, batteries, natural erosion of rocks and so on [1].

Although some metals are essential to the biological functions of plants and animals but at elevated levels, they interfere with metabolic reactions in systems of organisms. Toxic heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), chromium (Cr), zinc (Zn), nickel (Ni), and arsenic (As), which are not useful to plants, are capable of reducing plant growth due to the reduction of photosynthetic activities, plant mineral nutrition, and activity of essential enzymes [2]. Heavy metals could accu-

mulate in agricultural soils and get into the food chain, thereby becoming a major threat to food security and health risks to living organisms [3]. The toxic effects of these compounds particularly on intervention in cellular enzymatic systems are able to impose their biological effects at the cellular level and cause severe detrimental effects on gastrointestinal, respiratory and nervous organs and tend to cause cell necrosis in the exposed organs [4]. Heavy metals are cytotoxic at low concentrations and could lead to cancers in humans [5]. Their existence also shows adverse effects on flora, fauna and leads to groundwater contamination through leaching. They reduce the performance and product quality in agriculture and are dangerous for public health and other living organisms [6].

Conventional and physical methods for metal removal are expensive and not effective in areas with low metal toxicity. It is important to note that

the overall treatment cost of metal-contaminated water varies, depending on the process employed and the local conditions. In general, the technical applicability, plant simplicity and cost-effectiveness are the key factors in selecting the most suitable treatment for inorganic effluent. Bioremediation is an eco-friendly and efficient method of reclaiming environments contaminated with heavy metals by making use of the inherent biological mechanisms of microorganisms and plants to eradicate hazardous contaminants [7]. In bioremediation process, the microorganisms use contaminants as a source of nutrients and energy and convert them into soluble substances [8]. In this method, there is the possibility of removing one or more pollutants from environment, with a low cost, and remaining products have no detrimental effects on the ecosystem of contaminated sites [9].

Selection of biomass for using in bioremediation is very important; it should be abundant in the environment and adapted to environmental conditions [10]. The use of microorganisms such as algae, fungi, bacteria, and yeasts that can absorb heavy metals has been well considered in bioremediation of heavy metal polluted media [11]. In this way, microorganisms immobile metal ions by means of linking them with their cell walls [12]. Many contaminants have been remediated by fungi [13]. Some researchers achieved the removal of Cd, Ni, and Pb using fungi with efficiency of 94.5% for Cd, 79.8% for Ni, and 99.7% for Pb [14]. Others achieved 90% removal efficiency of nickel with 0.1 milligrams of fungal biomass of *Aspergillus niger* [15]. Also in another study, 0.7 g/l of fungal biomass of *A. niger* showed 84% removal of Cd [16]. Recent report showed that *Fusarium solani* KUSF204, a nonpathogenic saprophytic soil fungus, could tolerate different concentrations of a wide variety of heavy metals with the potential to produce phytohormones adequately. The *Fusarium* species is also peculiar in the sense that it produced an iron chelator called siderophore which negatively influences the microbial populations [17].

Therefore, this work aimed to isolate heavy metal resistance fungi and study the biosorption and adsorption process using the native and γ-irradiated fungus.

## MATERIALS AND METHODS

### Samples

Three wastewater samples were collected from different localities of drainage water in Bhnabai village, Zagazig, Egypt, in sterilized containers. These samples were brought to laboratory and kept at 4 °C for further processing.

### Preparation of agro-industrial wastes

Agricultural wastes (wheat bran, rice bran, rice straw and maize wastes) were collected from different localities in Egypt. Sugar cane industry bagasse was also used. All these wastes were sun dried, ground and used in this work for bio-treatment of wastewater.

### Preparation of media

Four media were prepared. Medium a contains the following (g/l): yeast extract 10, agar 20, and wastewater 1 l; medium b (Czapek Dox medium) has the following composition (g/l): sucrose 30, sodium nitrate 3, dipotassium phosphate 1, magnesium sulphate 0.5, potassium chloride 0.5, ferrous sulphate 0.01, and distilled water 1 l [18] with the final pH adjusted to $7.3 \pm 0.2$; medium c (modified Czapek Dox medium) contains the previous composition as medium b but using wastewater instead of distilled water; medium d contains the following composition (g/l): industrial waste (bagasse) 50, yeast extract 20, agar 20, and wastewater 1 l.

### Isolation and purification of heavy metal-resistant fungi

Heavy metal-resistant fungi were isolated from wastewater samples using the previous media a, b, c, and d by using spread plate method. The plates were incubated at 27 °C for 4–7 days. Plates were examined and different isolates were further purified by repeated single colony isolation. The fungal isolates were identified using cultural morphology and cellular techniques. The purification of heavy metal-resistant fungi was carried out according to the agar streak technique [19]. Cultural morphology to determine the colony color, shape, and texture was studied on PDA medium [20]. Eight fungal isolates, coded as F1a, F2b, F3b, F4b, F5c, F6c, F7c, and F8d according to isolated medium, have been screened, grown and preserved on modified Czapek Dox agar (medium c).

### Effect of heavy metals on growth of tested fungal isolates

Eight tested fungi were grown and examined on Czapek Dox agar (medium b) amended with four heavy metals (zinc chloride, cadmium chloride,

mercuric chloride, and lead chloride) at three concentrations of 50, 100, and 200 ppm. The capability of tested fungi to grow against heavy metals at different concentrations in solid condition was determined.

### Screening for heavy metal-resistant fungi

Eight fungal isolates were grown on Czapek Dox broth medium with wastewater instead of distilled water (medium c) at 30 °C for 7 days. The most promising heavy metal-resistant fungal isolates were subjected to screening for the ability in biosorption of metals such as Pb, Cd, Cu, Co, Fe, and Cr, then screened again for growth at high concentrations of $CdCl_2$ and $PbCl_2$. All the experiments were measured using inductively coupled plasma-optical emission spectrometer (ICP-OES optical emission, Teledyne-Leeman, USA) in The Central Laboratory for Elemental and Isotopic Analysis and XRF in Hot Laboratory, Nuclear Research Center, Atomic Energy Authority, Egypt.

### Identification of the most potent fungal isolate

For macroscopic characterization of the mycelium, colony morphology, color, texture, shape, diameter, appearance, and pigmentation of the colony, etc., was observed and recorded. Microscopic identification was carried out with the slide culture technique, of which the fungi was cultured on thin PDA on glass slides (spore bearing fruiting body, spore size, growth rate hyphae, septation in mycelium, presence of specific reproductive structures, shape, and structure of conidia and presence of sterile mycelium were observed). Staining was performed using Lactophenol cotton blue (LPCB) stain. Then, the slide was observed under a light microscope. The spores, hyphae, and conidiophore arrangement were observed and recorded.

### Impact of different concentrations of cadmium chloride, lead chloride separately or combined on growth of *Fusarium* sp. F6c

The most promising fungal isolate *Fusarium* sp. F6c was inoculated on Czapek Dox agar (medium b) amended with lead chloride and cadmium chloride separately or combined at different concentrations (25, 50, 100, 250, 500, and 1000 ppm). The strain was inoculated using disc on the middle of the plate, incubated for 7 days and then the growth zone was measured.

### Effect of different doses of γ-radiation on growth, cadmium and lead uptake of *Fusarium* sp. F6c

*Fusarium* sp. F6c was inoculated on 100 ml broth medium c in a shaking incubator at 30 °C, pH 6 and 180 rpm and subjected to γ-radiation at doses 0.5, 1, 2, 3, 5, 10, and 20 kGy from Cobalt-60 gamma source with dose rate of 695.02 Gy/h at the Nuclear Research Center, Atomic Energy Authority, Egypt, and then incubated for 7 days at 30 °C. The irradiated mixtures were tested for Pb and Cd uptake and compared with non-irradiated control.

### Effect of agro-industrial wastes alone or combined with irradiation on cadmium and lead uptake of *Fusarium* sp. F6

Ten grams of agro-industrial wastes mentioned previously were added separately to 100 ml wastewater, inoculated with the strain F6c irradiated with 1 kGy, and then incubated for 7 days. Estimation of cadmium and lead uptake was performed and compared with the non-irradiated control.

### Estimation of lead and cadmium in filtrate and mycelium of *Fusarium* sp. F6c

Fungal biomass was removed after incubation period (36 h) from supplemented broth Czapek Dox (medium b) with or without cadmium and lead at concentration of 100 ppm. The cell-free supernatant was passed through filter paper (Whatman no. 42) and centrifuged at 1500 rpm for 5 min. The debris was discarded and the upper homogeneous layer without fungal particles was collected [21]. All experiments were conducted in three replicates. The supernatant filtrate was determined for lead and cadmium concentration using prodigy, high dispersion ICP, USA mode b. The fungal biomass was collected, washed, dried, and crushed to powder in a mortar and then used for adsorption estimation. Dry cell weight was gravimetrically estimated and separately determined for lead and cadmium uptake using X-ray fluorescence spectrometer model JSX-3222 analyzer.

### Statistical analysis

Independent variables are pH of the solution, different concentrations of heavy metals and various strains of *Fusarium* sp. The dependent variable is the removal efficiency of heavy metals in each of the solution. The obtained data were analyzed using PASW (SPSS 18) software. For testing of normality and distribution of data, the Kolmogorov-Smirnov

test with 95% confidence level was used. Two-way analysis of variance (ANOVA) was used for comparing of the means of obtained results [22].

## RESULTS

### Isolation and screening of fungal isolates

Eight isolates were able to grow in various concentrations (50–200 ppm) of different heavy metals as shown in Table 1. All eight heavy metal-resistant fungal isolates exhibited the good growth at 50, 100, and 200 ppm of zinc chloride, cadmium chloride and lead chloride but did not grow in mercuric chloride at 200 ppm.

For further screening, eight different morphological fungal isolates were obtained from the wastewater samples using media supplemented with different heavy metals (lead, cadmium, copper, cobalt, and chromium; zinc was omitted from this experiment due to its very low concentration in wastewater samples). F1a fungal isolate was grown on medium a; F2b, F3b, F4b, fungi isolates on medium b; F5c, F6c, F7c isolates on medium c, and F8d fungal isolate on medium d. The biosorption of different heavy metal uptake by the isolated fungal species was investigated (Table 2). The eight heavy metal-resistant fungi growing on experimental wastewater were capable of decreasing all heavy metals tested. The presence of high metal-absorption activity is an indicator of the most promising fungal isolate; the highest ability in heavy metal absorption especially was observed with Pb, Cd, and Cr. We did not choose Cr for further study because initial concentration of this metal in wastewater samples was not so high compared to Pb and Cd.

Isolates F6c and F7c exhibited heavy metal resistant and showed better growth on cadmium chloride and lead chloride and therefore were chosen for further study for absorption of heavy metals from wastewater. All fungal isolates were tolerant to all tested heavy metals at 50, 100 ppm. However, only fungal isolate F6c could tolerate all heavy metal concentrations at 50, 100, and 200 ppm, exhibited the highest growth rate and consequently was selected for identification and further studies.

### Morphological and physiological identification of F6c

The most promising fungal isolate F6c was identified as *Fusarium* sp. according to the macroscopic and microscopic features (Fig. 1).
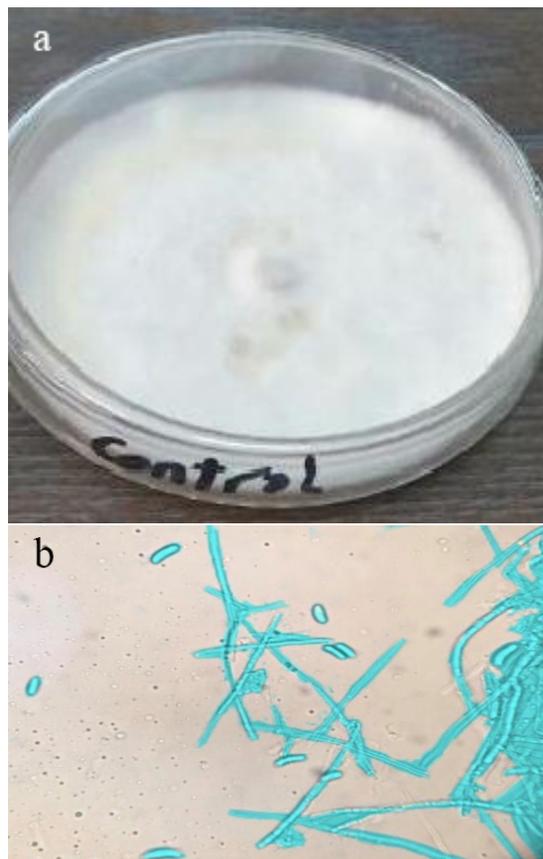


**Fig. 1** Macroscopic image of (a) *Fusarium* sp. F6c; (b) *Fusarium* sp. F6c stained spores and mycelium under light microscope with magnification power of $10 \times 40$.

### Impact of different concentrations of cadmium chloride, lead chloride separately or combined on growth of *Fusarium* sp. F6c

It is well known that exposure of water and sediment to heavy metals can produce considerable modification of their microbial populations, reducing their activity and their number. *Fusarium* sp. F6c exhibited decreased growth with increasing cadmium concentration from 25–1000 ppm where the growth zone decreased from 8.5 to 2.5 cm (Fig. 2). While the growth of tested isolate was not affected by increasing lead concentration from 25–1000 ppm since stable growth at 9.0 cm was observed (Fig. S1). Maximum biosorption was recorded for cadmium chloride with lead chloride at low concentration of 25 ppm and decreased gradually with the concentrations of 50, 100, 250, and 500 ppm while no growth was recorded at 1000 ppm with cadmium chloride and mixture of cadmium and lead chloride (Fig. S2). Colony

**Table 1** Effect of different concentrations (ppm) of $ZnCl_2$, $CdCl_2$, $HgCl_2$, and $Pb\,Cl_2$ on growth of tested fungi.

| Fungal isolate | $ZnCl_2$ | | | $CdCl_2$ | | | $HgCl_2$ | | | $PbCl_2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 100 | 200 | 50 | 100 | 200 | 50 | 100 | 200 | 50 | 100 | 200 |
| F1b | +++ | +++ | ++ | +++ | +++ | ++ | + | + | − | +++ | +++ | +++ |
| F2b | +++ | +++ | ++ | ++ | ++ | ++ | + | + | − | +++ | +++ | +++ |
| F3b | +++ | +++ | ++ | ++ | + | +++ | + | + | − | +++ | +++ | +++ |
| F4b | +++ | +++ | ++ | ++ | + | +++ | + | + | − | +++ | ++ | ++ |
| F5c | +++ | +++ | +++ | ++ | ++ | + | + | + | − | +++ | ++ | ++ |
| F6c | +++ | +++ | +++ | +++ | +++ | +++ | ++ | ++ | + | +++ | +++ | +++ |
| F7c | +++ | +++ | +++ | ++ | ++ | + | ++ | + | − | +++ | ++ | ++ |
| F8d | +++ | +++ | ++ | ++ | ++ | + | + | + | − | +++ | ++ | ++ |

− no growth, + weak, ++ good, and +++ very good.

**Table 2** Heavy metal uptake (%) from wastewater by fungal isolates.

| Fungal isolate | Pb | Cd | Cu | Co | Cr |
|---|---|---|---|---|---|
| F1b | 67.45 | 81.13 | 35.29 | 55.37 | 84.45 |
| F2b | 74.53 | 68.21 | 55.88 | 46.28 | 87.82 |
| F3b | 15.09 | 84.77 | 50.00 | 47.93 | 77.73 |
| F4b | 16.04 | 81.79 | 44.12 | 46.28 | 86.97 |
| F5c | 28.30 | 95.03 | 55.88 | 47.11 | 81.93 |
| F6c | 83.96 | 93.38 | 23.53 | 59.50 | 84.03 |
| F7c | 15.09 | 93.38 | 23.53 | 59.50 | 94.54 |
| F8d | 35.38 | 37.08 | 11.76 | 70.24 | 62.18 |

**Table 3** Effect of different concentrations of cadmium chloride, lead chloride and cadmium chloride with lead chloride metals on growth of *Fusarium* sp. F6c.

| Heavy metal (ppm) | Cadmium chloride | Lead chloride | Cadmium & lead chloride |
|---|---|---|---|
| 25 | $8.50 \pm 0.05$ | $9.0 \pm 0.01$ | $7.72 \pm 0.05$ |
| 50 | $7.70 \pm 0.02$ | $9.0 \pm 0.01$ | $7.70 \pm 0.02$ |
| 100 | $7.50 \pm 0.05$ | $9.0 \pm 0.01$ | $7.20 \pm 0.04$ |
| 250 | $3.30 \pm 0.10$ | $9.0 \pm 0.02$ | $5.90 \pm 0.03$ |
| 500 | $2.50 \pm 0.10$ | $9.0 \pm 0.01$ | $4.80 \pm 0.02$ |
| 1000 | NG | $9.0 \pm 0.02$ | NG |
| Control | – | $9.0 \pm 0.00$ | – |

The data expressed as diameter of growth zone in petri dish (cm $\pm$ SD) from three independent experiments; NG = no growth; Control = no heavy metal.

**Table 4** Effect of various doses of γ-radiation on growth, Cd and Pb uptake by *Fusarium* sp. F6c.

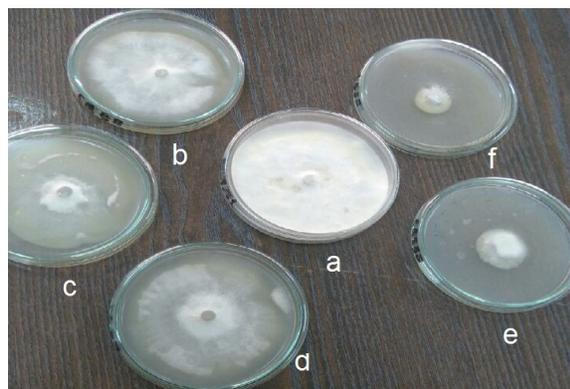| Dose (kGy) | Dry weight (g/50 ml) | Cadmium uptake (%) | Lead uptake (%) |
|---|---|---|---|
| None | $0.44 \pm 0.001$ | 95.36 | 51.80 |
| 0.5 | $0.33 \pm 0.001$ | 96.36 | 78.42 |
| 1 | $0.42 \pm 0.001$ | 96.69 | 82.01 |
| 2 | $0.53 \pm 0.001$ | 95.70 | 58.27 |
| 3 | $0.46 \pm 0.001$ | 92.38 | 50.36 |
| 5 | $0.44 \pm 0.001$ | 95.36 | 38.84 |
| 10 | $0.06 \pm 0.001$ | 15.89 | 12.95 |
| 20 | $0.02 \pm 0.001$ | 7.62 | 2.88 |



**Fig. 2** Effect of different concentrations of cadmium chloride on growth of *Fusarium* sp. F6c: (a) control, (b) 25 ppm, (c) 50 ppm, (d) 100 ppm, (e) 250 ppm, (f) 500 ppm.

**Effect of different doses of γ-radiation on growth, cadmium and lead uptake of F6c**

The effect of different doses of gamma radiation on adsorption of heavy metals (Table 4) showed that the dose 1 kGy especially improved lead adsorption compared to the non-irradiated control. On the other hand, the increase in the dose of radiation

growth of *Fusarium* sp. F6c was inhibited at higher concentration of heavy metals while lower concentration of heavy metals either inhibited or had no effect on colony growth (Table 3). The data are expressed as diameter of growth zone in cm $\pm$ SD from three independent experiments.

**Table 5** Effect of agro-industrial wastes combined with γ irradiation (1 kGy) on cadmium and lead uptake from wastewater by *Fusarium* sp. F6c.

| Agro-industrial waste | Cadmium uptake (%) | | Lead uptake (%) | |
|---|---|---|---|---|
| | Non-irr. | Irr. | Non-irr. | Irr. |
| Rice bran | 99.97 | ND | 98.35 | ND |
| Rice straw | ND | ND | 97.27 | 94.17 |
| Wheat straw | 99.93 | ND | ND | 94.60 |
| Bagasse | 98.54 | 97.78 | 97.63 | ND |
| Maize waste | ND | 99.97 | 98.92 | 98.42 |
| None (no biomass) | – | 96.69 | – | 82.01 |

Irr. = irradiated; ND = not determined.

**Table 6** Estimation of lead and cadmium concentrations in the filtrate and mycelium of *Fusarium* sp. F6c.

| Heavy metal | Dry weight (g/100 ml) | Concentration (ppm) | |
|---|---|---|---|
| | | Filtrate | Mycelium |
| Pb (100 ppm) | 0.45 ± 0.03 | 0.17 ± 0.05 | 99.8 ± 0.01 |
| Cd (100 ppm) | 0.36 ± 0.01 | 0.17 ± 0.05 | 99.8 ± 0.01 |
| Control | 0.43 ± 0.03 | 0.00 | 0.00 |

Control = no metal ion.

resulted in gradual decrease in heavy metal adsorption up to 20 kGy. Increase of γ-radiation over 20 kGy inhibited the uptake of the organism.

### Effect of different agro-industrial wastes combined with irradiation on cadmium and lead uptake from wastewater by F6c

Properties of adsorbent, pH, concentration of adsorbent, and the presence of co-ions in solution affect the biosorption of metal ions from aqueous solutions. In this study, attempts were made to increase heavy metal uptake by *Fusarium* sp. F6c using different agro-industrial wastes with 1 kGy of γ radiation dose as the best gamma irradiation dose (Table 5). It was shown that exposing agro-industrial wastes to irradiation (1 kGy) gave nearly the same results as the non-exposing condition. This result implied that agro-industrial wastes could be used for biosorption of metal in replace of radiation.

### Estimation of lead and cadmium in filtrate and F6c mycelium

Attempt was made to study the mechanism of *Fusarium* sp. F6c on the biosorption of two tested heavy metals (cadmium chloride and lead chloride). Measurement of the quantity of the two tested heavy metals in the filtrate (extracellular) using ICP and in mycelium (intracellular) using XRF was carried out. The results exhibited that fungus mycelium can harvest great amount [99.8 ppm] of Cd and Pb,

leaving the filtrate with slight amount of less than 0.2 ppm (Table 6).

### DISCUSSION

Fungal enzymes degrade the heavy metals by incorporating them in their metabolic pathways and immobilizing them. Eight fungal isolates, namely F1a, F2b, F3b, F4b, F5c, F6c, F7c, and F8d, were grown in different concentrations (50–200 ppm) of zinc, cadmium, mercuric, and lead chloride (Table 1). All eight heavy metal-resistant fungal isolates exhibited the good growth at 50, 100, and 200 ppm of zinc chloride, cadmium chloride and lead chloride but did not grow in mercuric chloride at 200 ppm. Also, for further screening, all isolates growing on experimental wastewater were capable of decreasing five heavy metals (Table 2). In this respect, various metal resistant-fungi belonging to genera *Aspergillus*, *Penicillium*, *Alternaria*, *Geotrichum*, *Fusarium*, *Rhizopus*, *Monilia*, and *Trichoderma* were isolated from wastewater treated soil [23]. Other research groups had screened 36 microbes including fungi and yeast for their resistance to heavy metals [24]. We found eight filamentous fungal isolates that showed resistance to heavy metals including Pb, Cd, Cu, Co, and Cr. However, many researchers demonstrated tolerance of heavy metals (Cr and Pb) by *Fusarium* spp. [25], while others [26] studied the level of tolerance of fungi against lead and selenium. *Fusarium* reached a maximum diameter in 4 days; the colonies grown on amended PDA showed inhibited growth on the 7th day of incubation. However, microorganisms isolated from contaminated sites were more tolerant than those from the control sites [27]. Microorganisms including fungi and bacteria have been reported to extract heavy metals from wastewater through bioaccumulation and biosorption. Attempts were made to isolate bacteria and fungi from sites contaminated with heavy metals for higher tolerance to be used in the removal of metals from wastewater.

In this work, the fungal isolate F6c, the most potent strain, was identified as *Fusarium* sp. by its physiological and morphological characters. *Fusarium* is a filamentous fungus found ubiquitously in soil and decaying plant materials, where it acts as a decomposer. *F. solani* isolates could leach and uptake Cu and Zn from insoluble Cu phosphate-containing and Zn phosphate-containing media [28]. *Fusarium* spp. was reported to show metal resistance to six heavy metals: Cu, Cr, Pb, Cd, Sb, and Ni [29]. Another study [30] on *F. molini-*

*forme* concluded that the fungus was a good indicator for consumption of contaminants, e.g. contaminated soils and hydrocarbon molecules. In addition to that, *F. solani* was able to bioaccumulate heavy metals in soil samples [28].

Data illustrated in Table 3 indicated the decrease of growth of *Fusarium* sp. F6c with increase in cadmium concentrations from 25–1000 ppm where the growth diameter significantly decreased. However, the growth of this fungus was not affected by increasing lead concentrations from 25–1000 ppm. Reduction in growth of fungi in the presence of higher concentrations of heavy metals may be due to an increase in length of the initial (lag) phase. The fungal isolate might respond to these heavy metals by several processes, including transport across the cell membrane, biosorption to the cell walls and entrapment in extracellular capsules, precipitation, complexation and oxidation-reduction reactions [31]. This proves the possible utilization of selected fungal isolate as a nature's original recyclers that not only functioned under a broad spectrum of conditions like pH, temperature, etc., but also found economically feasible due to the cheap raw supplies that can be utilized as biosorbents [32].

Effect of different doses of radiation on adsorption of heavy metals (Table 4) showed that the dose 1 kGy improved Cd and Pb adsorption compared to the non-irradiated control. On the other hand, the increase in the dose of radiation resulted in gradual decrease in Cd and Pb adsorption up to 20 kGy. Increase of γ-radiation over 20 kGy inhibited the organism. In this regard, gamma rays are short wave high-energy electromagnetic radiations capable of ionizing other atoms [33]. Gamma radiation has also been reported to increase the level of activity of many enzymes at low levels [34]. At higher levels of γ-radiation, the enzyme(s) responsible for reduction of heavy metal is disrupted and subsequently, heavy metal adsorption is reduced. On the other hand, some studies reported that γ-radiation is able to produce amino acids by breaking down of proteins [35]. High level of radiation causes DNA damage.

The results in Table 5 clarified that all different agro-industrial wastes incubated with the strain F6c could be used for bio-absorption of cadmium and lead metal ions (gave nearly the same result) with or without 1 kGy γ irradiation dose. Using agro-industrial waste or biomass instead of radiation is suggested. Fungal mycelium could harvest great amount [99.8 ppm] of heavy metals (Table 6). The differences between the sampled sites regarding their richness on microbial isolates appear to be closely linked to the degree of heavy metal pollution. Generally, pollution of soil and water by heavy metals may lead to a decrease in microbial diversity. The sources of pollutant as well as long period of exposure are also the important factors regulating the stress and fungal adaptation [36].

In the present study, the *Fusarium* sp. F6c showed tolerance to investigated heavy metals. The process of biosorption is dependent on factors including fungal species, biosorbent size, metal concentration and ionic composition. Fungi constitute a high proportion of the microbial biomass in water and soil. Being widespread in soil, their large surface to volume ratio and high metabolic activity, fungi can contribute significantly to heavy metal dynamics in soil [37]. Fungi have been proven more efficient and economical for removal of toxic metals from dilute aqueous solution because of their filamentous morphology and high percentage of cell walls [38].

## CONCLUSION

Many aquatic environments face metal concentrations that exceed water criteria designed to protect the environment, animals and humans. Every essential element is toxic if taken in excess and there is a safe window for essential dose between deficiency and toxicity. Biological absorption is an effective technology for the optimal removal of heavy metals. In this process, adsorption and desorption rates are very high. Simplicity of the operation makes this technique the good way to remove toxic materials from the environment. *Fusarium* sp. F6c is the terricolous fungi that showed the absorption ability of heavy metals from aqueous solutions. One of the advantages of absorption by fungi is high-speed absorption. Based on the results of this work, it could be more economical and more preferable to use biosorption method to remove heavy metals in wastewater than other conventional methods as it minimizes chemical and biological sludges with the possibility of metal and biosorbent recovery.

### Appendix A. Supplementary data

Supplementary data associated with this article can be found at http://dx.doi.org/10.2306/scienceasia1513-1874.2020.008.

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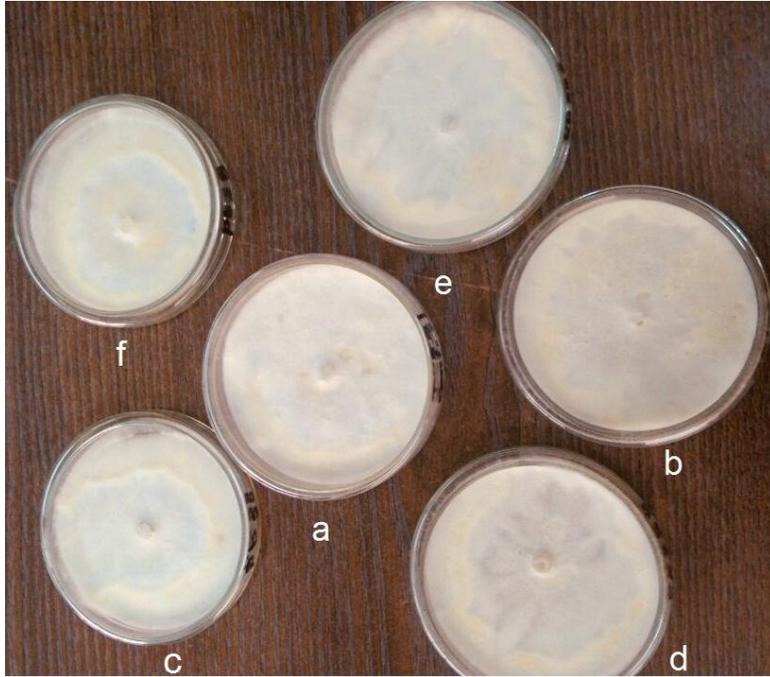**Appendix A. Supplementary data**



**Fig. S1** Effect of different concentrations of lead chloride on growth of *Fusarium* sp. F6c.
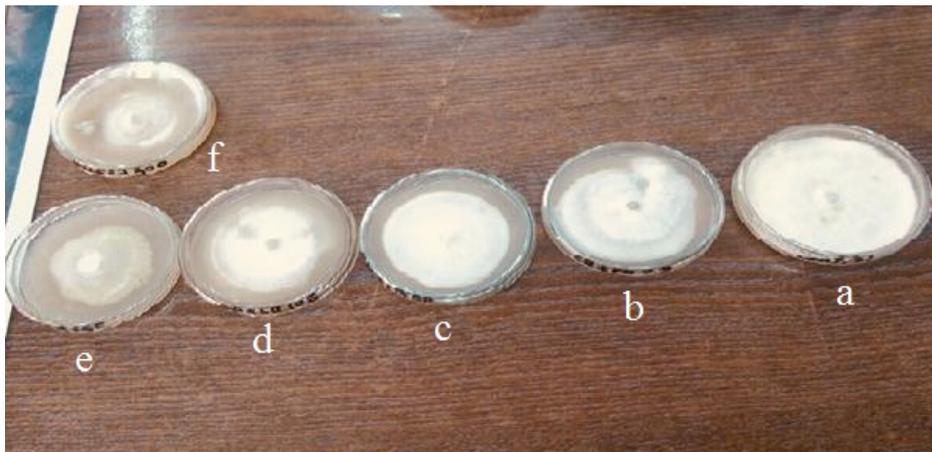


**Fig. S2** Effect of different concentrations of cadmium chloride combined with lead chloride on growth of *Fusarium* sp. F6c.