

LIGNOCELLULOSE-RICH SPENT MUSHROOM COMPOST FOR BIOSORPTION OF HEAVY METALS FROM EFFLUENT SAMPLES

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Lignocellulose-rich spent mushroom compost (SMC) has been found to contain various functional groups that can be used for biosorption. Effluent samples collected from common effluent treatment plants (CETPs), *i.e.* Ludhiana Electroplaters Association (L-CETP) and Punjab Small Industries and Export Corporation (PSIEC) Leather Complex, Jalandhar (J-CETP), were analyzed for different waste water quality parameters, such as Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and heavy metal profile. Chromium was the dominant heavy metal in both samples, with a concentration of 226.62 ppm in L-CETP and 1.83 ppm in J-CETP. Spent compost of different cultivated mushrooms was analysed for its use in chromium biosorption by varying physicochemical parameters. Maximum removal of Cr was obtained at an initial metal concentration (Ci) of 50 mg/L, pH 6 and temperature of 25 °C. Experimental results were well fitted to the Langmuir and Freundlich isotherms. Fourier transform infrared (FT-IR) spectra showed a shift in peaks, indicating the functional groups involved in biosorption of chromium.

Keywords: biosorption, chromium, FT-IR, isotherms, CETP

INTRODUCTION

Rapid industrialization has resulted in the discharge of various organic contaminants into the environment, which affect ecosystems and human health. Heavy metals are considered to be more persistent than organic contaminants, such as pesticides or petroleum by-products, and are non-biodegradable.¹⁻² These metals can become mobile in the soil, depending on the soil pH, and can leach to underground water reservoirs.³⁻⁴ The entry of heavy metals in the food chain can give rise to vital challenges threatening our ecosystems and human life, thus their removal from effluents is imperative, but it demands expensive clean-up procedures. Usually, heavy metals repress several essential enzymatic processes. Metals are associated with oxidation of proteins, by attaching themselves to the amino-acid residues present in these enzymes, as well as with inhibition of cell division and DNA damage. Heavy metals, such as mercury, silver and cadmium, can lead to toxic effects in organisms, when ingested even in trace amounts, and their maximum permissible limit in effluent discharge is 0.001 ppm, 0.1 ppm and 0.01 ppm, respectively.⁵ Considering the harmful effects of heavy metals on animals and human health, serious efforts need to be made for *in-situ* degradation of these recalcitrants.

In recent years, bioremediation has emerged as a cost-effective and eco-friendly method for transforming harmful, recalcitrant contaminants into environment-friendly and remedial by-products by the action of varied microbiological treatments. This process involves two approaches: biosorption and bioaccumulation. Biosorption involves the use of cheap biomaterials and allows treating large volumes of wastewater, whereas bioaccumulation consists in removing heavy metals by the living cells of microorganisms, as they have better selectivity. Spent mushroom compost (SMC) is an unconventional biosorbent for heavy metals, such as cadmium, lead and chromium, due to the presence of hydroxyl, phosphoryl and phenolic functional groups on the outer side of the SMC.⁶ The utilisation of a spent mushroom substrate for heavy metal uptake combines the biosorption of heavy metals by the spent compost and the bioaccumulation of these recalcitrants by the impregnated fungal mycelium.⁷ The present study was conducted to explore the application of spent compost in effluent bioremediation and to contribute to finding an effective low-cost biosorbent.

EXPERIMENTAL

Characterization of common effluent samples

Effluent samples were collected from common effluent treatment plants located in Ludhiana and Jalandhar. After filtration through Whatmann filter paper No. 1, they were analysed in terms of various physico-chemical quality indicators, such as pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), total hardness, dissolved oxygen (DO), biological oxygen demand (BOD5) and chemical oxygen demand (COD), as per standard methods.⁸ The metal profile of the effluent samples was estimated using Inductively Coupled Argon Plasma Atomic Emission Spectroscopy (ICAP-AES).

Standardisation of process parameters for biosorption of total chromium

Spent mushroom compost of *Agaricus bisporus*, *Pleurotus florida*, *Calocybe indica* and *Volvariella volvacea*, received from the Mushroom Research Complex, Punjab Agricultural University, Ludhiana, was dried in an oven at 60 °C and ground to obtain a powder with particle size of 0.3-0.7 mm. Batch experiments were carried out in Erlenmeyer flasks to study the effect of various operating parameters, such as initial heavy metal concentration, pH and temperature, on biosorption of total chromium.

Standard curve of chromium

A stock solution of Cr (VI) was prepared by dissolving 2.83 g of $K_2Cr_2O_7$ in 1000 mL of distilled water. From this stock solution, 50, 100, 200, 300, 400 and 500 ppm solutions were prepared by using distilled water, and 0.2 mL of concentrated sulphuric acid was added to test tubes. The concentration of total Cr ionic species was measured by a UV visible double beam spectrophotometer at 440 nm⁹. The standard curve was plotted using metal concentration expressed in ppm and optical density at 440 nm (Fig. 1).

Effect of pH, temperature and initial metal concentration on biosorption

The initial pH of the potassium dichromate solution was varied in the range of 2-10 (adjusted by addition of 0.1 N HCl and NaOH). 2 g of spent mushroom compost of different white rot fungi was added to the 50 ppm solution, under shaking at 250 rpm. The flasks were incubated at 25 °C for 2 h. Another set of flasks was prepared by using 50 ppm Cr concentration, with an optimized pH, and incubated at different temperatures (15, 25, 35 and 45 °C) under shaking at 250 rpm.

Similarly, to optimize the substrate concentration, adsorption was studied in flasks by varying initial metal concentration, at the selected optimum pH and optimum temperature for each spent mushroom compost. The flasks were shaken at 250 rpm for 2 h. The filtrate was collected and samples were analyzed for Cr removal.

Adsorption isotherm

The equilibrium of biosorption of heavy metals was modeled using adsorption isotherms. The Langmuir and Freundlich isotherms were applied to describe the adsorption equilibrium. The Langmuir adsorption isotherm is a nonlinear sorption model, which suggests that the uptake occurs on a heterogeneous surface by monolayer sorption without interaction between adsorbed molecules. In addition, it also assumes uniform energies of adsorption onto the surface.¹⁰ The linearized form of this model is the following:

$$C_e/q_e = C_e/q_{max} + 1/bq_{max} \quad (1)$$

where C_e is the metal concentration at equilibrium, q_e – the equilibrium metal biosorption uptake, q_{max} – the maximum metal biosorption rate and b – Langmuir constant. The values of q_{max} and b were calculated from the slope and intercept of the graph.

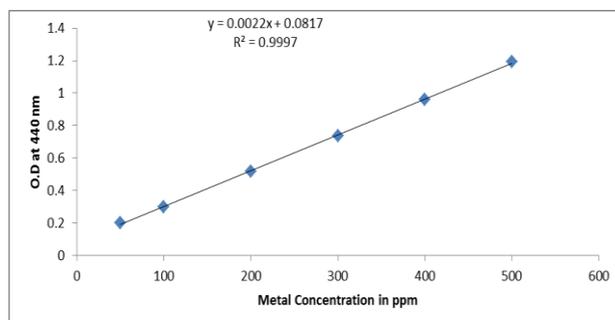


Figure 1: Standard curve for chromium estimation

The Freundlich isotherm is a nonlinear adsorption model, which proposes monolayer sorption with heterogeneous distribution of active sites, accompanied by interactions between adsorbed molecules. The logarithmic form of this isotherm is:

$$\log q_e = \log K_f + 1/n \log C_e \quad (2)$$

where q_e and C_e are the same as in Eq. (1), K_f – Freundlich constant, indicating adsorption capacity and n – empirical constant. The values of K_f and n were calculated from the intercept and slope of the graph, respectively.

FTIR analysis

FTIR analysis provides an insight into the adsorption process. The functional groups, involved in the adsorption process were determined by analyzing the peaks obtained. Differences in the peaks of the spent mushroom substrate before and after adsorption can be investigated by Fourier transform infrared spectroscopy. Metal binding was indicated by the shift in the ratio of the peaks related to protonated and dissociated carboxyl groups. These peaks reveal the important groups involved in the adsorption process.¹¹

Fourier transform infrared (FT-IR) spectroscopy (Model Thermo Nicolet, 6700 USA) was carried for *Agaricus bisporus* SMC to identify the characteristic functional groups participating in the biosorption of metal ions.

RESULTS AND DISCUSSION

Characterization of effluent samples from CETPs

The sample collected from L-CETP was found to have an acidic pH value (2.3) because electroplating effluents are generated from washing, rinsing and batch dumps that contain soluble forms of various metal ions, such as brass, nickel, cadmium, zinc, copper *etc.* On the other hand, the sample from J-CETP was found to possess alkaline pH (8.64), as it caters the needs of tannery industry. Alkaline pH is related to the use of lime pelt during tanning (Table 1). The colour of the electroplating industry effluent was green due to the presence of a high amount of nickel, iron and zinc, whereas the colour of the tannery effluent was deep brown due to the presence of tannic compounds and other impurities. A very high EC value was observed in the L-CETP sample due to the presence of a high level of salts of various metals in the effluent. Similarly, in the J-CETP sample, the EC value was 1061 mS/cm, which was mainly due to the addition of a significant amount of sodium and chromium salts during the pickling and chrome tanning. The hardness of both effluent samples was very high (779.29 mg equivalent CaCO_3/L and 982.55 mg equivalent CaCO_3/L) because of a high concentration of multivalent cations in water. Total solids were high in J-CETP (964.8 mg/L), as shown by the more pronounced turbidity, as compared to that of the L-CETP sample (640.7 mg/L). The values of total dissolved solids were observed to be high in the sample from J-CETP (756.9 mg/L), as compared to L-CETP (594.4 mg/L), which was mainly due to the presence of insoluble and soluble organic compounds.

In L-CETP, DO was very low (4.39 mg O_2/L) due to high concentration of pollutants and BOD values were also observed to be low – of 13.2 mg O_2/L , indicating the water sample had a high load of heavy metals rather than other organic pollutants. An abnormally low pH (2.30) in the effluent sample can result in a significant decrease in the rate of removal of organic compounds from the effluent by reducing microbial activity, which can be responsible for a significantly low BOD value. On the other hand, sample 2 had a high value of DO (9.20 mg O_2/L), indicating that the water sample had an indigenous microflora. BOD values were observed to be high (71.0 mg/L) due to a high amount of organic matter from various chemicals used during the processing of hides and skins. It has been reported that a significant part of the chemicals used in the tanning process are not actually absorbed in the process and discharged into the environment. The L-CETP sample had high COD values (320 mg O_2/L), indicating the presence of biologically resistant organic materials, whereas J-CETP was found to have a value of 240 mg O_2/L , which was within the limits prescribed by the Central Pollution Control Board (CPCB) (*i.e.* 250 mg O_2/L).

Table 1
Physicochemical and heavy metal profile of the effluent samples

| Parameters* | L-CETP | J-CETP | Permissible limits as per CPCB |
|--|----------------------|------------|--------------------------------|
| pH | 2.3±0.2 | 8.64±0.1 | 6.0-9.0 |
| Colour | Green | Deep brown | Clear |
| Temperature (°C) | 24.8±0.2 | 26.9±0.1 | 40.0 |
| EC (µS/cm) | 1849±3.3 | 1061±1.4 | 2500 |
| Total hardness (mg CaCO ₃ /L) | 779.29±0.2 | 982.55±0.1 | 200-500 |
| Total solids (TS) (mg/L) | 640.7±0.4 | 964.8±0.1 | 100 |
| Total dissolved solids (TDS) (mg/L) | 594.4±0.2 | 756.9±0.2 | 500 |
| DO (mg O ₂ /L) | 4.39±1.5 | 9.20±1.6 | - |
| BOD (mg O ₂ /L) | 13.2±2.1 | 71.5±1.6 | 30 |
| COD (mg O ₂ /L) | 320±0.2 | 240±0.3 | 250 |
| Metals | L-CETP | J-CETP | Permissible limit as per CPCB |
| | Concentration (ppm)* | | |
| Arsenic (As) | 0.06 | 0.06 | 0.2 |
| Boron (B) | 10.05 | 5.65 | - |
| Calcium (Ca) | 49.15 | 38.88 | - |
| Cadmium (Cd) | 0.02 | 0.32 | 2.0 |
| Chromium (Cr) | 226.62 | 1.83 | 0.1 |
| Cobalt (Co) | 0.14 | 0.01 | 3.0 |
| Copper (Cu) | 7.07 | 0.56 | 5.0 |
| Iron (Fe) | 2189.67 | 20.34 | 3.0 |
| Magnesium (Mg) | 159.44 | 215.33 | - |
| Manganese (Mn) | 26.38 | 0.10 | 2.0 |
| Nickel (Ni) | 28.12 | 0.10 | 3.0 |
| Phosphorus (P) | 158 | 4.09 | - |
| Lead (Pb) | 0.77 | 0.39 | 0.1 |
| Zinc (Zn) | 20.03 | 4.43 | 5.0 |

*Data represent mean of triplicate observations

The metal profile of the effluent samples was determined by using Inductively Coupled Argon Plasma-Atomic Emission Spectroscopy (ICAP-AES). The results showed that, in the L-CETP effluent, among the major heavy metals of environmental concern, total Cr was found to be the dominant heavy metal contaminant with a concentration of 226.62 ppm, followed by nickel (28.12 ppm), lead (0.77 ppm) and cadmium (0.02 ppm). Sample 2 (J-CETP) was found to have a much lower concentration of these heavy metals of environmental concern, as compared to L-CETP, whereby the concentration of total Cr was 1.83 ppm, followed by lead (0.39 ppm) and nickel (0.10 ppm). As shown in Table 1, the permissible limit given by CPCB for the discharge of effluent is 0.1 ppm for Cr, 3.0 ppm for Ni and 0.1 ppm for Pb, indicating that the wastewater coming from both industries needs to be treated before its discharge into water bodies.

Earlier studies¹²⁻¹³ also reported that the pH of an electroplating industry effluent was 3, with COD and BOD values of 240 mg O₂/L and 8.08 mg O₂/L, respectively. The values of pH, temperature, EC, TDS, TSS, BOD and COD of electroplating industry effluents has been reported to be 2.5, 25, 1680 mS/cm, 360 mg/L, 675 mg/L, 101 mg O₂/L and 371 mg O₂/L, respectively. Similarly, for tannery effluents – the pH, colour, EC, TS, TDS, COD and BOD were reported as: about 7.08, brown, 9070, 6867.3, 492, 2749.8 and 1099.2, respectively.¹⁴ The heavy metal profile of the tannery effluent indicated that the concentration of chromium (total) was 106.51 mg/L, with hexavalent chromium – 3.67 mg/L, trivalent chromium – 102.84 mg/L, nickel – 21.70 mg/L, copper – 2.78 mg/L, zinc – 9.20 mg/L and cadmium – 0.35 mg/L.¹⁵ Another study has also shown the presence of heavy metals in a tannery effluent, in which the concentrations of cadmium, lead, nickel, copper and zinc were 11.2 mg/L, 6.6 mg/L, 2.3 mg/L, 2.4 mg/L and 3.3 mg/L, respectively.¹⁶ In 2015, the metal species profile of an electroplating industry effluent indicated the concentration of calcium, magnesium, sodium, potassium and nickel ions to be of 273 mg/L, 255 mg/L, 98 mg/L, 43 mg/L and 126 mg/L, respectively.¹⁷

Biosorption is a process that is influenced by various operating parameters, such as pH, temperature and initial metal concentration. Thus, for maximum biosorption of heavy metals, all these parameters were standardized.

Influence of pH

The effect of pH on Cr biosorption by the spent mushroom compost of *Agaricus bisporus*, *Pleurotus florida*, *Calocybe indica* and *Volvariella volvacea* was studied over a pH range of 2-10, with continuous agitation at 250 rpm. It was observed that biosorption was high at acidic pH for all the four selected white rot fungi. This could have been due to high solubility of the metals in the pH range of 4-6. For the SMC of *Agaricus bisporus*, the pH of 4.0 was found to show maximum removal (%) of total chromium, while for the SMC of *Pleurotus florida*, *Calocybe indica* and *Volvariella volvacea*, the optimum pH value was 6.0 (Fig. 2).

It has been illustrated that the optimum pH for biosorption by spent mushroom compost of *Agaricus bisporus*¹⁸ was 1.0. Meanwhile, another study reported that the optimum pH for biosorption of Cr (VI) by *Pleurotus mutilis*¹⁹ was around 5.4. Similarly, for Pb, it has been reported that the optimum pH for biosorption of Pb by *Pleurotus florida*²⁰ was 7.0. The optimum pH for the removal of Pb by *Calocybe indica*¹⁶ was reported to be 5.0.

Influence of temperature

The adsorption on spent mushroom compost was studied in the temperature range of 15-45 °C. The maximum percent removal of Cr was achieved at a temperature of 25 °C for *Agaricus bisporus* spent compost (60.63%), *Pleurotus florida* spent compost (72.45%) and *Calocybe indica* spent compost (66.09 %), whereas *Volvariella volvacea* spent compost showed 32.45% removal at 35 °C (Fig. 2). An increase in temperature in the suitable range increases the rate of adsorbate diffusion across the external boundary layer.

Earlier studies reported that the optimum temperature for biosorption by the spent mushroom compost of *Agaricus bisporus* and *Pleurotus mutilis* was 20 °C.¹⁸⁻¹⁹ A temperature of 28 ± 2 °C has been found to be optimum for *Calocybe indica* for the removal of lead from aqueous solutions.¹⁶

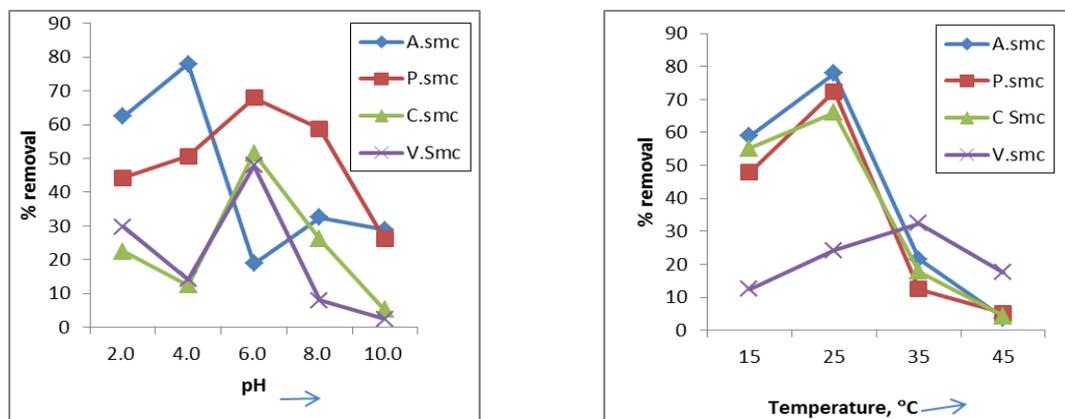


Figure 2: Influence of pH and temperature on biosorption of total Cr with SMC as adsorbent. Note: A.smc – *Agaricus bisporus* based spent mushroom compost (SMC), P.smc – *Pleurotus florida* based SMC, C.smc – *Calocybe indica* based SMC, V.smc – *Volvariella volvacea* based SMC

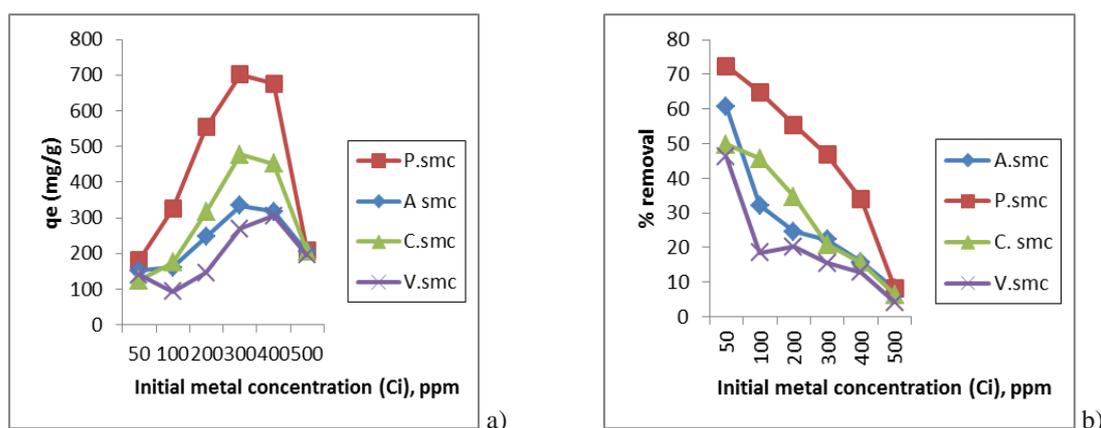


Figure 3: Influence of initial metal concentration on (a) sorption capacity and (b) removal of total Cr with SMC as adsorbent at optimized pH and temperature. Note: A.smc – *Agaricus bisporus* based SMC at pH 4.0 and temperature 25 °C, P.smc – *Pleurotus florida* based SMC at pH 6.0 and temperature 25 °C, C.smc – *Calocybe indica* based SMC at pH 6.0 and temperature 25 °C, V.smc – *Volvariella volvacea* based SMC at pH 6.0 and temperature 35 °C

Influence of initial concentration of metal ions

The initial metal concentration in the solution influences the equilibrium uptake of total Cr. It was seen that increasing the initial metal concentration increases the sorption capacity, which was mainly due to the equilibrium process. A higher initial metal concentration provided an increased driving force necessary to overcome all mass transfer resistance of metal ions between the aqueous and the solid phases, resulting in higher probability of collision between metal surfaces, which results in a higher metal uptake. As illustrated in Figure 3a, the effect of varying initial metal concentration on the sorption capacity of all the selected spent mushroom compost types was studied. It was seen that with increasing initial metal concentration, after 300 ppm, a decline in sorption capacity was observed and the biosorbent showed a trend of saturation at high concentrations.

As illustrated in Figure 3b, the effect of varying initial metal concentration on the percent removal was studied for all the selected spent mushroom compost types. The concentration of 50 ppm showed the maximum removal of Cr for *Pleurotus florida* SMC (72.45%), followed by *Agaricus bisporus* SMC (60.63%), *Calocybe indica* SMC (49.72%) and *Volvariella volvacea* SMC (46.09%).

In earlier studies, the optimum initial metal concentration for biosorption by the spent mushroom compost of *Agaricus bisporus* and *Pleurotus mutilis* was recorded to be 100 ppm.¹⁸⁻¹⁹ Also, an initial metal concentration of 10 mg/L has been reported to be optimum for the removal of lead by *Calocybe indica* from aqueous solutions.¹⁶

Adsorption isotherms

The equilibrium of biosorption of heavy metals was modeled using adsorption isotherms. The Langmuir and Freundlich isotherms were applied to describe the adsorption equilibrium. The linearized plots of C_e/q_e versus C_e are illustrated in Figure 4, and the Langmuir parameters were calculated from the slope and intercept of the graph. Further analysis of the Langmuir isotherm model was made by finding the value of R_L , the variation in the range of 0-1 indicates a favourable adsorption process. The value of $R_L = 1$ indicates that the adsorption is linear and if $R_L = 0$, it is irreversible.²¹ The value of R_L was 0.66, 0.50, 0.01 and 0.60 for *A. bisporus*, *P. florida*, *C. indica* and *V. volvacea* based SMC, indicating favourable adsorption for all the selected biosorbents of white rot fungi.

It has been reported the values of R^2 , q_{max} and b to be 0.99, 8.00 mg/g and 0.07 for *Agaricus bisporus* as adsorbent, and 0.916, 23.25 and 1.13 using *Pleurotus mutilis* as biosorbent.¹⁸⁻¹⁹ For biosorption of lead using *Pleurotus florida* as adsorbent, the values of R^2 , q_{max} and b have been reported to be 0.967, 12.19 mg/g and 0.058, respectively.²⁰ Vimala and Das (2009) reported the values of R^2 , q_{max} and b to be 0.9972, 24.09, 0.04, respectively, for biosorption of cadmium by *Calocybe indica* from aqueous solutions.¹⁶

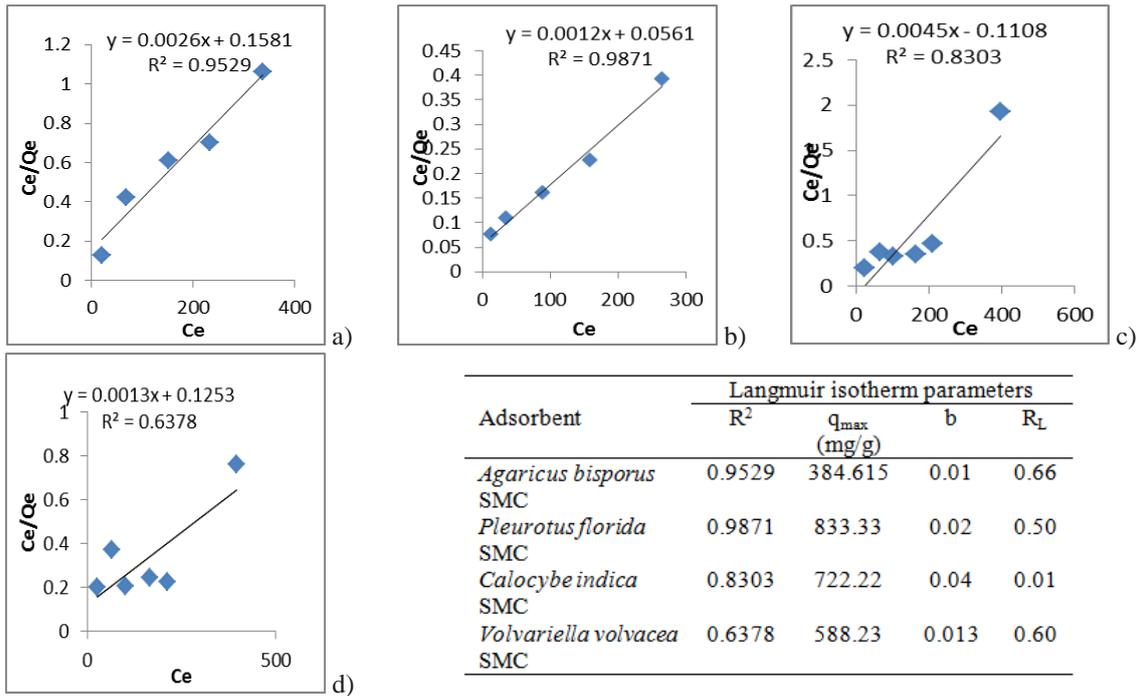


Figure 4: Langmuir isotherms and isotherm parameters for (a) *Agaricus bisporus*, (b) *Pleurotus florida*, (c) *Calocybe indica* and (d) *Volvariella volvacea* as biosorbents

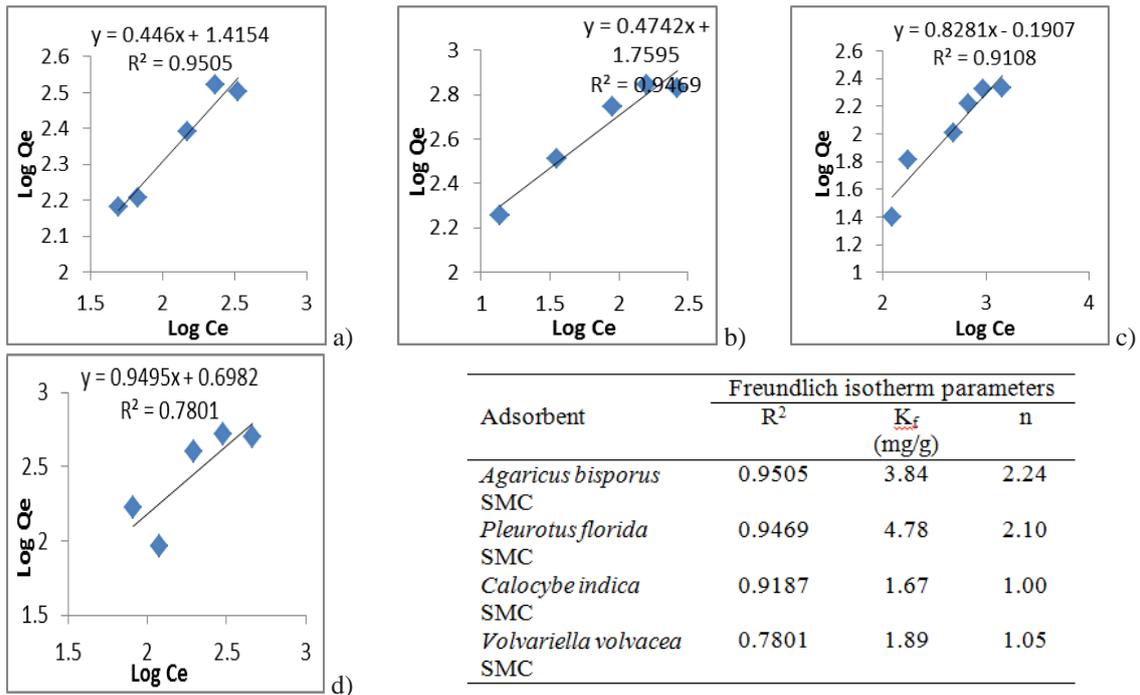


Figure 5: Freundlich isotherms and isotherm parameters for (a) *Agaricus bisporus*, (b) *Pleurotus florida*, (c) *Calocybe indica* and (d) *Volvariella volvacea* as biosorbents

The linearized plot of $\log C_e$ versus $\log q_e$ is given in Figure 5 and the estimated Freundlich isotherm parameters for the biosorption of Cr at an optimum temperature and pH are also mentioned, which were calculated from the graphical plot. The value of $1/n$ in the range of 1.0-10.0 indicates a favorable adsorption process.²² The findings illustrated the favorable adsorption process for all the selected biosorbents.

The values of K_f , R^2 and n were found to be 1.79 mg/g, 0.97 and 0.32, respectively, with *Agaricus bisporus* spent compost as biosorbent, and 1.29 mg/g, 0.88, 1.32, respectively, with *Pleurotus mutilus* as adsorbent.¹⁸⁻¹⁹ Using *Pleurotus florida* as adsorbent, the values of K_f , R^2 and n were shown to be

0.954, 0.906 and 1.61, respectively, for biosorption of lead.²⁰ Meanwhile, using *Calocybe indica* as biosorbent of cadmium from aqueous solutions, the values of K_f , R^2 and n were reported to be 0.9498, 2.27 and 1.99, respectively.¹⁶ Here, K_f is an indicator of the adsorption capacity, a higher K_f value indicates better adsorption capacity of the spent compost. Whereas n is a measure of the intensity of adsorption, a higher $1/n$ value indicates more favorable adsorption. Generally, $n < 1$ is required for favorable adsorption. A value of n higher than 1 indicates that the intensity of adsorption is very low.

FTIR analysis

The FT-IR spectra of the *Agaricus bisporus* compost mainly consist of two regions. The FT-IR spectra before and after adsorption are shown in Figures 6 and 7, while Table 2 presents the band assignment for functional groups before and after adsorption. The first region lies in the wavenumber range of 1500-4000 cm^{-1} and represents the functional group region, indicating the presence of specific functional groups at different wavenumbers. Thus, a peak at 3400 cm^{-1} indicates the presence of the N-H group. Another peak in the region of 2800-3000 cm^{-1} indicates the CH group, while that in the range of 2400-3000 cm^{-1} indicates the presence of the OH group. The absence of bands in the region of 2100-2200 cm^{-1} indicates the absence of $\text{C}\equiv\text{N}$ and $\text{C}\equiv\text{C}$ bonds, whereas the presence of a number of bands in the region of 1600-1800 cm^{-1} indicates the presence of $\text{C}=\text{O}$ bonds, which can be associated with complex ring deformation. The second region lies within the wavenumber range of 500-1500 cm^{-1} and is called as the fingerprint region, which indicates multiple bond deformation. The characteristic bands in the range of 1027-1048 cm^{-1} are indicative of the presence of complex polysaccharides. The multiple peaks at 3200-3500 cm^{-1} indicate O-H bond stretching vibrations.

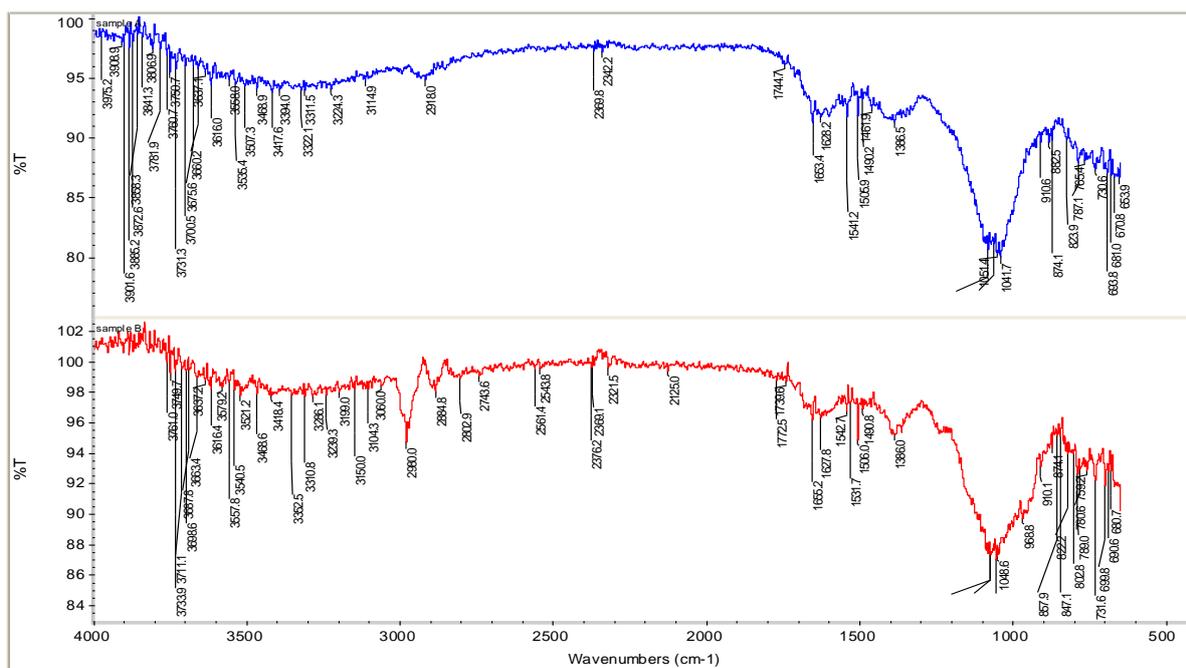


Figure 6: FT-IR spectra of *Agaricus bisporus* SMC (a) before biosorption and (b) after biosorption of sample 1 (L-CETP)

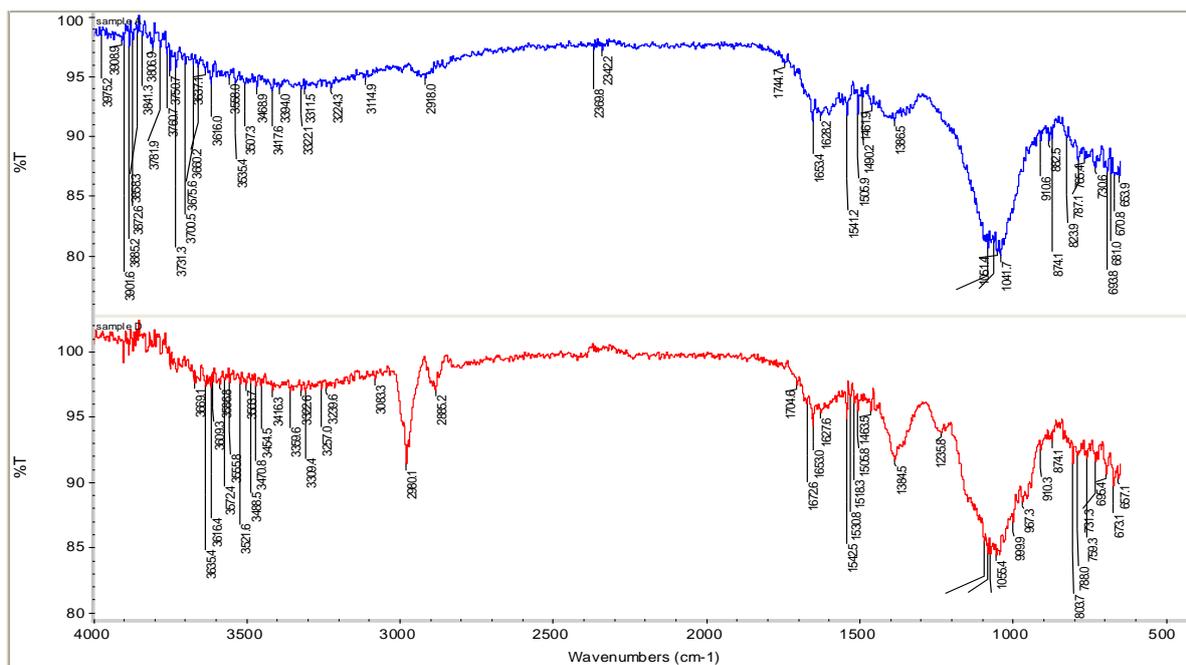


Figure 7: FT-IR spectra of *Agaricus bisporus* SMC (a) before biosorption and (b) after biosorption of sample 2 (J-CETP)

Table 2
FT-IR spectra of spent mushroom compost before and after adsorption

| IR peak | Adsorption bands (cm ⁻¹) | | | Inference |
|---------|--------------------------------------|------------------|-------------|--|
| | Before adsorption | After adsorption | Differences | |
| 1 | 2918 | 2884.8 | -33.2 | Stretching of CH and CH ₂ group |
| 2 | 1041 | 1048 | +7 | Differences in polysaccharides |
| 3 | 1744.7 | 1739.6 | -5.1 | Masking of protonated carboxyl group |
| 4 | 2342.2 | 2321.5 | +20.7 | Carboxylic group O-H bond stretch |

In comparison with the control sample A, showing the peak at 1744.7 cm⁻¹, the treated sample (1) exhibited the peak at 1739.6 cm⁻¹. This peak corresponds to the presence of ketones, quinones and carboxylic acid esters. A similar shift was seen at the position 2918 cm⁻¹, which was present in the control sample A, but shifted to 2980 cm⁻¹ in the treated sample, indicating the stretching of C-H and CH₂ group. The characteristic peak at 1506.9 cm⁻¹ in the control and 1506.0 cm⁻¹ in the treated sample indicates the presence of lignin. The presence of the peak at 1653.4 cm⁻¹ in the control sample and at 1655.2 cm⁻¹ in the treated sample indicated the presence of the CO₂ stretch of the carboxylic group and aliphatic alkanes. Similar variations have also been observed while comparing the control sample with sample (2).

A comparison of the adsorption capacity of SMC of different fungi (*A. bisporus*, *P. florida*, *C. indica* and *V. volvacea*) indicated maximum adsorption achieved by *P. florida* based SMC, showing a q_{max} value of 833.33 mg/g (Fig. 4) and a K_f value of 4.78 (Fig. 5). This can be related to the high lignolytic ability of *P. florida*, as compared to the other fungal genera used here. Higher lignolytic activity resulted in the creation of more voids for binding of the metal. The *P. florida* based SMC, therefore, can be used as an environmentally friendly effective and low-cost adsorbent.

CONCLUSION

Based on the results obtained in the present study, it can be suggested that spent mushroom compost can be considered as a cost-effective biosorbent for removing heavy metals from aqueous media. The high q_{max} and K_f values of the SMC revealed its great potential as an adsorbent of heavy metals. Thus, the spent mushroom compost has a great potential to be developed into a green remediation technology due to its high uptake capacity, the possibility to reuse the biosorbent and

recover the metals from it. More in-depth studies are required to be done to further explore the potential of spent mushroom compost for possible heavy metal bioremediation of effluent wastewater.

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