Academic Sciences International Journal of Pharmacy and Pharmaceutical Sciences

ISSN- 0975-1491 Vol 5, Issue 3, 2013

Research Article

BIOSORPTIVE REMOVAL OF LINDANE USING PRETREATED DRIED YEAST *CINTRACTIA SORGHI* VITJZN02 – EQUILIBRIUM AND KINETIC STUDIES

JASEETHA ABDUL SALAM AND NILANJANA DAS *

Environmental Biotechnology Division, School of Biosciences and Technology, VIT University, Vellore-632014, Tamil Nadu, India.
Email: nilanjana00@lycos.com

Received: 22 May 2013, Revised and Accepted: 26 Jun 2013

ABSTRACT

Objective: Lindane is an organochlorine pesticide used for pharmaceutical and agricultural purposes. The aim of the present study was to investigate the biosorption of lindane from aqueous solutions using pretreated dried biomass of anamorphous yeast, *Cintractia sorghi* VITJzN02 isolated from contaminated soil.

Methods: The characteristics of surface modified yeast biomass during lindane biosorption were investigated by batch equilibrium studies, FTIR and SEM analysis.

Results: Among the various pretreated chemicals tested for surface modifications, citric acid showed the best result for enhanced uptake of lindane. Lindane biosorption was most favoured at acidic pH and sorption equilibrium was attained in 330 min with an initial lindane concentration 500 mg/l. Modified biomass were found to have 3-4 folds higher biosorption yield compared to dried natural biomass. Adsorption isotherms were best fitted to the Langmuir model showing monolayer sorption capacity 100 mg/g. Four kinetic models viz. pseudo-first-order, pseudo-second-order, intra-particle diffusion and Elovich were employed to explain the sorption mechanism. The kinetic data were found to follow the pseudo first order kinetic model suggesting that adsorption process was controlled by physisorption. The intra-particle diffusion plots being non linear over whole time range indicated that intra particle diffusion was not the only rate limiting step for biosorption of lindane.

Conclusions: Biosorption of lindane by pretreated biomass of yeast *Cintractia sorghi* VITJzN02 is governed by physisorption and monolayer adsorption pattern. Based on the results, it may be concluded that biosorbent prepared from yeast *Cintractia sorghi* VITJzN02 can serve as potential adsorbent for the removal of lindane from aqueous solutions.

Keywords: Biosorption; Equilibrium; Kinetics; Langmuir; SEM; Yeast.

INTRODUCTION

Lindane or γ-hexachlorocyclohexane (γ-HCH, erroneously known as Benzene hexachloride) was used as a broad spectrum organochlorine insecticide to control phytophagous and soil inhabiting insects since the 1940s [1]. It is one of the most widely detected organochlorine compounds in environmental samples including air, surface water, soil, and living organisms. The use of lindane as a pharmaceutical in three medical products (a lotion and two shampoos) was approved by US FDA for the treatment of lice and scabies [2]. Pesticide residues are known to cause serious health effects [3]. Lindane is reported to have an adverse effect on human health, due to impact on central nervous, endocrine, immune, and reproductive systems [4]. For these reasons, the US-EPA has recommended lindane concentration in drinking waters not to exceed 200 ppt [5]. It has become extremely important to find an eco-friendly option to remediate lindane polluted environment and thereby preserve the health of the deteriorating environment.

Biosorption has emerged as an efficient, cost-effective and environmental friendly technique alternative to the conventional techniques for remediation of heavy metals and various organic pollutants [6]. The use of non-living biomaterials as sorbent have the advantage of not requiring utmost care and maintenance as well as being useful in remediating areas with high level contamination [7]. There are few reports on natural microbial species including bacteria and fungi which are capable of removing lindane by biosorption showing low uptake capacity [8-9]. As sorption mainly takes place on the biomass surface, increasing or activating the binding sites on the surface by pretreatment would be an effective approach for enhancing the biosorption capacity [10]. Pretreatment aids in stabilizing the biosorbents and keeping the reactive sites intact [11].

The organic acid pretreatment may introduce the additional functional group in biomass which may enhance the sorption capacities of the treated biomass [12]. A variety of different chemicals have been used for the pretreatment of biosorbent to enhance the uptake of lindane [9,13]. However, no report is available regarding the use of dried yeast cell pretreated with organic acids as biosorbent for the removal of lindane. Therefore, the present study aims (1) to explore the utility of dried biomass obtained from a novel soil yeast *Cintractia sorghi* VITJzN02 in the removal of lindane, (2) to study the effect of pretreatments on uptake of lindane by the sorbent (3) to evaluate the lindane biosorption kinetics and equilibrium on native and pretreated dried yeast biomass and (4) to elucidate the biosorption mechanism using FTIR and SEM analysis.

MATERIALS AND METHODS

Preparation of biosorbent from the yeast

The yeast used in the present study was isolated from contaminated soil of maize cultivation fields located at Katpadi, Tamil Nadu (India). The yeast was identified at the molecular level by 18S rDNA, ITS regions and D1/D2 domains. Subsequently it was named as Cintractia sorghi VITJzN02 using a BLAST similarity search in the database available on the NCBI website. The yeast was maintained on yeast extract peptone dextrose agar slants at 4 °C and periodically subcultured. For the mass preparation of biosorbent, 48 h pre-grown cultures were centrifuged at 10,000 X g for 10 min and harvested. The cells were washed twice with phosphate buffer and dried to a constant weight at 95 °C for 45 mins. The obtained dried biomass was ground to fine powder using a grinder and sieved to a constant size (100–125 µm). This biosorbent was designated as native biomass.

Preparation of lindane solutions

Lindane used in this study was of commercial quality (99% purity, Sigma Aldrich, USA; MW- 290.8; MF $C_6H_6Cl_6$) and used without further purification. Pesticide stock solution (1000 mg/l) was prepared by dissolving accurately weighed quantity of the chemical in methanol (SRL, India). Different concentrations of lindane were prepared by diluting the stock solution with suitable volume of double distilled water. The initial solution pH was adjusted using 0.1 (N) HCl and 0.1 (N) NaOH solutions.

Pretreatment of native biomass

Powdered native biomass was mixed with various concentrations of pretreatment chemicals *viz* ethylenediamine tetra acetic acid (EDTA), citric acid, phosphoric acid and succinic acid in a ratio of 5.0

g biomass to 50 ml of the respective chemical solution and stirred for 2 h at room temperature (25 ± 2 °C). The acid/biomass suspension was dehydrated at 60 °C for 24 h in a hot air oven. The oven temperature was then raised to the desired temperature (60–140 °C) for various reaction times (0.5–4 h). The surface modified biomass were removed and allowed to cool, and then washed several times with distilled water until the pH of the distilled water became constant. The washed biomass was finally dried in an oven at 60 °C for 24 h and preserved in a desiccator as the pretreated biosorbent for future use.

Equilibrium sorption experiments

A batch-equilibrium technique was employed to determine the sorption of lindane onto native and citric acid treated biomass. The influence of pH (1.0-10.0), biosorbent dosage (1-9 g/l), initial lindane concentration (100-700 mg/l), and contact time (30-420 min) was evaluated during the present study. All experiments were conducted in 250 ml Erlenmeyer flasks with 100 ml working volume, containing a concentration of 50 mg/l of lindane. 1g of biosorbent was added to the flasks and was agitated at a constant speed of 140 rpm for 12 h in rotating shaker. Samples were collected from the flasks at predetermined time intervals for analyzing the residual pesticide concentration in the solution. The amount of lindane adsorbed per unit adsorbent (mg lindane per g dried biomass) was calculated using the following equation:

$$Q_{eq} = \frac{C_0 - C_{eq}}{M} X V \quad (1)$$

The percent removal (%) of pesticide was calculated using the following equation:

$$Removal\ efficiency\ (\%) = \frac{C_0 - C_{eq}}{C_0} X\ 100 \quad (2)$$

where, Q_{eq} is the equilibrium uptake, C_0 and C_{eq} are the concentration of lindane initially and at equilibrium respectively. M (g) is the mass of the biosorbent and V is the volume of the working solution of lindane (ml). In order to ensure the reproducibility of results, all the biosorption experiments were performed in triplicate and the results are presented as means of the replicates along with standard deviation (represented as error bars).

FT-IR analysis

Infrared spectra of native biosorbent and lindane loaded biosorbent were obtained using a Fourier transform infrared spectrometer (IR affinity-1 FT-IR spectrophotometer, Shimadzu). The sample was prepared as a KBr disc and examined to identify the functional groups responsible for the biosorption over the range 500–4000 cm^{-1}.

SEM analysis

Scanning electron microscopy (SEM) was used to study the surface morphology of the biosorbent as well as to confirm lindane adsorption onto the biosorbent. SEM studies were conducted at the Central Instrumentation Facility, Pondicherry University. A Hitachi Model S-3400N scanning electron microscope was used in this study. Dehydrated samples were fixed on to microscopic slides and coated with a thin layer of gold to make the sample conductive.

GC analysis

In order to analyze the residual lindane present in the experimental flasks after reaching equilibrium, the samples were taken and centrifuged for liquid–solid separation. Lindane was extracted twice from the supernatant by adding an equal volume of hexane: acetone solution (1:1) and finally once with an equal volume of ethyl acetate. The solvent was removed under vacuum by rotary evaporation and the residue was redissolved in ethyl acetate prior to analysis. The appropriately diluted supernatant was used to analyze the residual lindane concentration using gas chromatography (GC, NUCON 5765 model) equipped with a split-split less injection port. The injector temperature was maintained at 230 °C; oven temperature at 240 °C; detector temperature at 280 °C. The samples (1.0µl) were injected via a split-less injection. Nitrogen was used as a carrier gas at a flow rate of 34.4 ml/min.

RESULTS AND DISCUSSION

In the present study, anamorphous yeast belonging to the soil Basidiomycota family had been isolated from the agricultural fields of maize plants. The strain named as VITJzN02 was found to utilize lindane as a sole source of carbon and energy in mineral medium. Figure 1 shows the phylogenetic relation of the yeast *Cintractia sorghi* VITJzN02 with the other closely related species. The dried biomass of the yeast, *C. sorghi* VITJzN02 was used as a potential biosorbent for removal of medium-high concentrations of lindane from aqueous solutions.

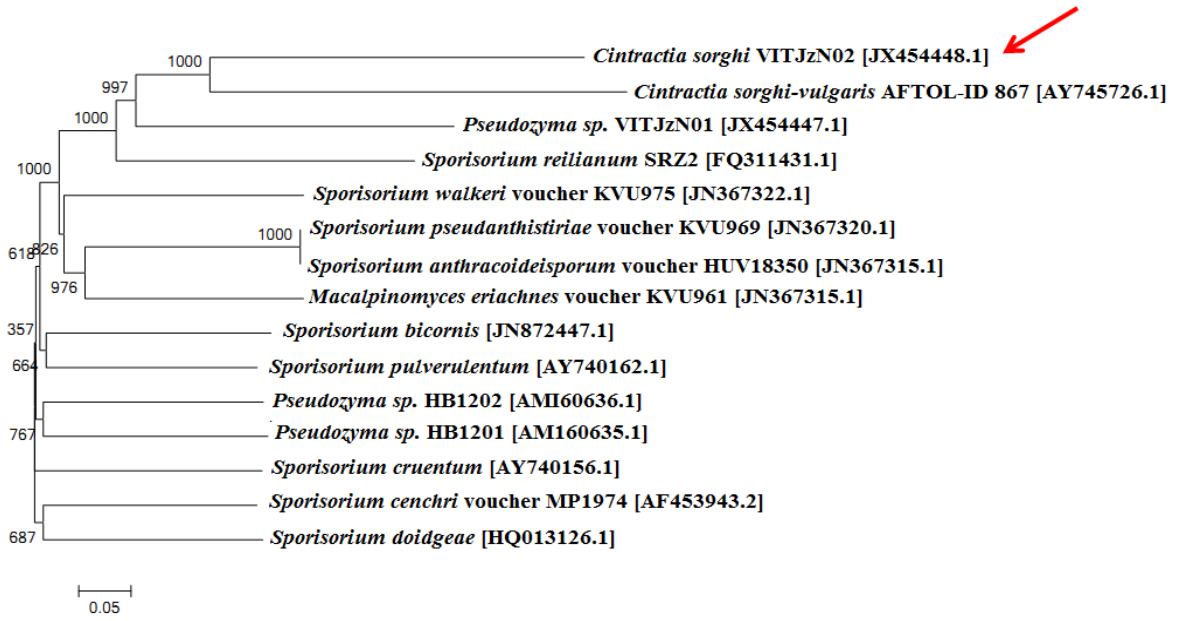

Fig. 1: Phylogenetic tree constructed from the 18S rDNA sequence of *C. sorghi* VITJzN02 (GenBank accession no. JX454448) and related organisms using NCBI BLAST N analysis and neighbor-joining algorithm from the alignment (CLUSTAL X) of 2317 nucleotides using the MEGA 5.1 software.

Effect of initial pH on the sorption of lindane on to the native biosorbent

The initial solution pH has been recognized as one of the most important parameters affecting any sorption process. pH influences the biosorption process by affecting the surface charge of adsorbent, degree of ionization and speciation of the adsorbate [14]. In the present study, biosorption capacity of native yeast biomass for lindane was highest at pH 3.0. Increase in pH above 3.0 resulted in decreased lindane uptake (Figure 2A). The acidic pH of 3.0 was used for further studies. Lindane has a weak negative charge with the spatial arrangement of Cl^- atom around it. As a charged species, the degree of its sorption onto the biosorbent surface is primarily influenced by the surface charge on the biosorbent, which in turn is influenced by the solution pH. At acidic pH, the protonation of surface functional groups on the biosorbent takes place, and thereby enhances the approach of negatively charged pesticide molecule to the surface of the biosorbent resulting in increased biosorption.

Effect of biosorbent concentration on the removal efficiency of lindane

Concentration of the biosorbent is an important parameter influencing sorption process since it determines the sorption capacity of a biosorbent for a given initial concentration of the adsorbate at the operating conditions. Figure 2B shows the lindane removal efficiency versus different biosorbent concentration in the range of 1.0–9.0 g/l. It is observed that the percentage of pesticide removal increases with increase of biosorbent dosage. The biosorption efficiency was increased from 72.08 to 95.93% when the biosorbent concentration was increased from 1-5.0 g/l. Further, an increase in the biosorbent concentration did not have any significant increase in biosorption efficiency, due to the saturation of all the binding sites available for lindane on the native biomass surface. A similar tendency has been reported for the adsorption of lindane by fly ash baggase and powdered activated carbon prepared from apricot stone [13,15]. The optimum biosorbent dosage was taken as 5.0 g/l for the successive experiments.

Effect of initial lindane concentration on the uptake capacity of native biosorbent

The influence of initial pesticide concentration in equilibrium adsorption capacity of lindane by native yeast biosorbent is presented in Figure 2C. The adsorption capacity increases with increase in initial pesticide concentration. This is due to increasing the concentration gradient which acts as an increasing driving force to overcome all mass transfer resistances of the lindane molecules between the aqueous and solid phase, leading to an increasing equilibrium sorption until sorbent saturation is achieved [16]. Similar results have been reported for sorption of lindane from aqueous solution onto chemically modified apricot stone [13].

Effect of contact time on lindane uptake

In order to determine the biosorption equilibrium time for lindane, the contact time was varied from 30 to 420 min and the results are shown in Figure 2D. As depicted in Figure, lindane shows a fast rate of biosorption during the first 150 min of the pesticide–sorbent contact. The fast biosorption rate is due to the large amount of surface area available for biosorption of the pesticide molecules. At higher contact time the rate of biosorption decreases, gradually leading to equilibrium. This decline is due to decrease in the total biosorbent surface area and less available binding sites [17]. The equilibrium time for maximum uptake is 360 min. After this equilibrium period, the amount of pesticide adsorbed does not show a time-dependent change. Similar results have been reported by other workers for biosorption of lindane on other low-cost biosorbents [8,9,13,18].

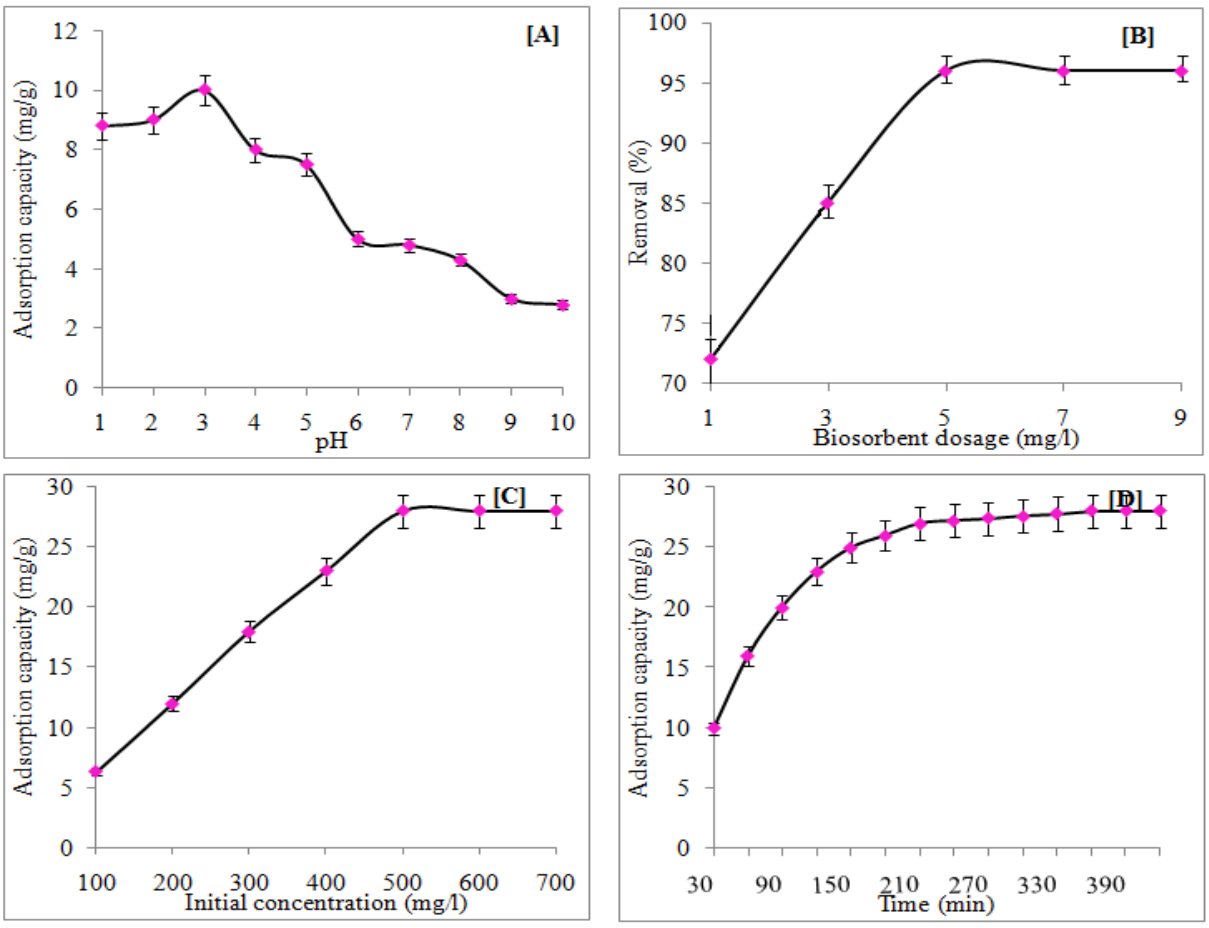

Fig. 2: Effect of operating parameters on the biosorption of lindane onto dried yeast biomass

Effect of pretreatment on the uptake of lindane by *Cintractia sorghi* biomass

In order to increase the protonization of the surface of the native yeast biomass, it was pretreated with various organic acids for enhanced lindane uptake. Figure 3 shows the effect of various pretreatments on the biosorption of lindane onto native biosorbent. Maximum uptake was obtained with the pretreatment with citric acid (95 mg/g). Citric acid treated *C. sorghi* had enhanced lindane uptake capacity of about 3-4 folds higher than the native yeast biomass. The citric acid treated *C. sorghi* biomass was used for isotherm and kinetic experiments in comparison with the native yeast biosorbent.

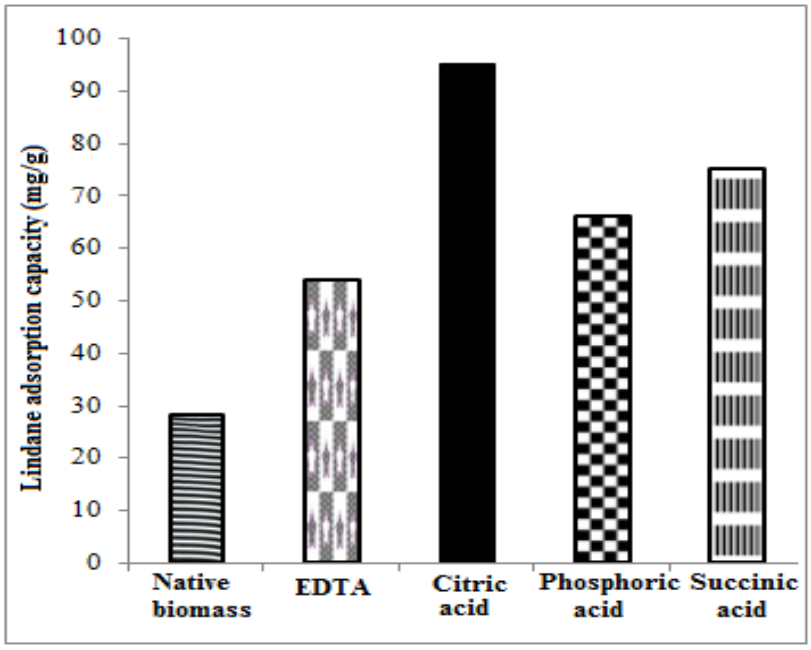

Fig. 3: Comparison of lindane adsorption capacities for various pretreated yeast biomass.

Characterization of *C. sorghi* biomass

For a more detailed understanding on the intensity and nature of the functional groups on the biomass surface, the FT-IR spectra of the native and lindane treated biomass were analyzed in the frequency range from 500 to 4000 cm^{-1} and are shown in Figure 4A and 4B respectively. As seen in Fig. 4A, the shift in the sharp peak at 3441.01 to broad peak around 3481.51 cm^{-1} can be ascribed to the hydrogen-bonded –OH vibration of the chitin and the mannan structure of the yeast cell wall. The other peaks found to have involvement in the lindane adsorption were at 2922.16, 1631.78, 1400.32 and 582.2 cm^{-1} due to the presence of $>CH_2$ vibrations, C=C stretch in primary amines and N-H bond, teritiary –OH stretch in carboxylic acid and S-S disulfide stretches in amino acids respectively. Thus, the FT-IR results established the presence of hydroxyl, amine and sulfide groups on the native sorbent surface. Thus, these groups on the surface of the yeast play an important role in the affixing of lindane onto the biomass surface. In addition, SEM analyses were also done to confirm the adsorption of lindane onto native and pretreated biomass of *C.sorghi* VITJzN02. Figure. 5 shows the SEM images of native biosorbent (Figure 5A), biosorbent pretreated with citric acid (Figure 5B), and lindane adsorbed onto surface of the pretreated biosorbent (Figure 5C). The surface morphology of the native biosorbent supports a smooth appearance. The porous and irregular surface structure of the biosorbent after pretreatment could be clearly observed in the SEM image. The sizes of pores were indicative of the expected biosorption of the lindane molecules onto the surface of the biosorbent. As seen in Figure 5C, after lindane adsorption, there were shrinkage and distortion on the surface of the biosorbent and lindane was uniformly adsorbed throughout, suggesting a monolayer adsorption pattern. Similar results were reported by other workers [8,9].

Biosorption isotherms of lindane on native and pretreated yeast biomass

To evaluate the maximum biosorption potential of native and citric acid treated biosorbent, isotherm experiments were performed by varying the initial concentration of lindane in the range of 50–700 mg/l with a constant biosorbent dosage of 5g/l at pH 3. In the present study, the Langmuir, Freundlich, Temkin isotherm and Dubinin–Radushkevich (D–R) models were used to describe the equilibrium biosorption data of lindane onto native and pretreated biomass [19-22]. The equilibrium constants of the isotherm models were calculated from the linearized form of the isotherm equations as follows:

$$Langmuir: \frac{1}{Qe} = \frac{1}{C_{eq} K_L Q_{max}} + \frac{1}{Q_{max}} \quad (3)$$

$$Freundlich: \log Q_{eq} = \log K_F + \frac{1}{n} \log C_{eq} \quad (4)$$

$$Temkin: Q_{eq} = B_T \ln A_T + B_T \ln C_{eq} \quad (5)$$

$$Dubinin - Radushkevich\ (D-R): \ln Q_{eq} = \ln Q_{max} - K_D \varepsilon^2 \quad (6)$$

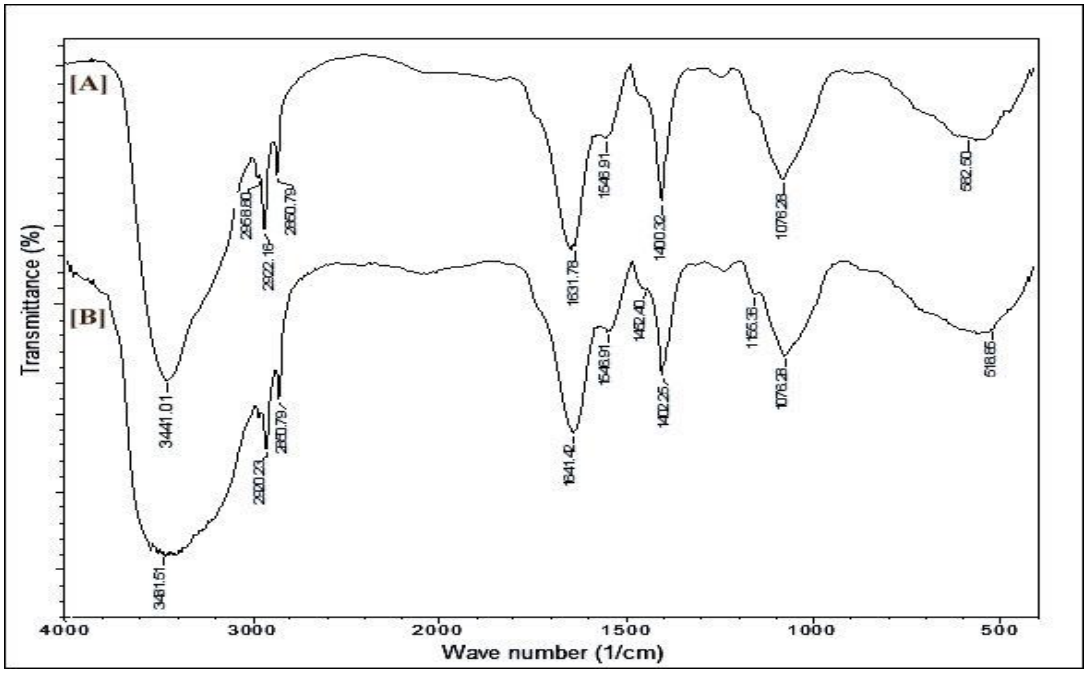

Fig. 4: FTIR spectra of dried *C.sorghi* VITJzN02 before and after adsorption of lindane

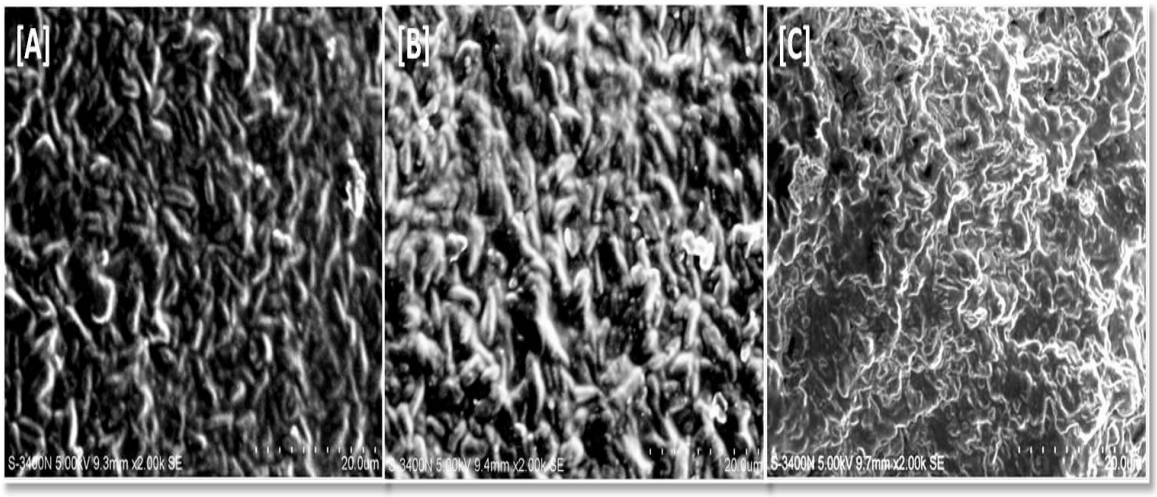

Fig. 5: SEM micrograph of the dried yeast *C. sorghi* VITJzN02 [A] Native biosorbent [B] citric acid treated biosorbent before the adsorption of lindane [C] citric acid treated biosorbent after lindane adsorption

Table 1: Isotherm constants for sorption of lindane on native and pretreated dried biomass of *Cintractia sorghi* VITJzN02

Isotherm	Native	Citric acid treated
Langmuir		
Q_{max} (mg g^{-1})	50	100
K_L (l g^{-1})	0.014	1.43
R^2	0.978	0.993
Freundlich		
K_F (mg g^{-1})	21.92	31.19
N	40	2.71
R^2	0.978	0.952
Tempkin		
A_T	1.38	18.54
B_T	5.3	14.29
b_T	459.62	170.46
R^2	0.901	0.980
Dubinin-Radushkevich		
Q_{max} (mg g^{-1})	28	65
K_D	2 X 10^{-5}	5 X10^{-8}
E (KJ mol^{-1})	0.158	3.162
R^2	0.981	0.896

The parameters and correlation coefficients obtained from the plots of Langmuir ($1/Q_{eq}$ versus $1/C_{eq}$), Freundlich (log Q_{eq} versus log C_{eq}), Temkin (Q_{eq} versus ln C_{eq}) and D–R (ln Q_{eq} versus ε^2) (figures not shown) for native and pretreated biosorbents are listed in Table 1. Comparatively, citric acid modified biomass performed well compared to the raw biomass. The experimental results indicate that sorption of lindane onto both native and pretreated biomass of *Cintractia sorghi* VITJzN02 follows the Langmuir model. The excellent fit of the experimental data to the Langmuir isotherm confirmed that 1) the biosorption process is a mono-layer adsorption type, 2) sorption of each molecule has equal activation energy and 3) that sorbate-sorbate interaction is negligible. As implied from Freundlich isotherm model, the value of N is greater than one in case of both the adsorbents indicating a favourable adsorption process. The D–R isotherm model constant gives an idea about the mean free energy E (kJ/mol) of biosorption per mole of the adsorbate which in turn can give information about the type of sorption mechanism. E can be calculated using the relationship:

$$E = \frac{1}{\sqrt{2K_D}} \quad (7)$$

If the magnitude of E is between 8 and 16 kJ/mol, the sorption process is supposed to proceed via chemisorption, while for values of E <8 kJ/mol, the sorption process is of physical nature [23]. The value of E for both adsorbents was >8 kJ/mol, indicating that the biosorption process of lindane by the native and the pretreated adsorbent is a physisorption process. Our results were in concordance with the previous reports on lindane biosorption by other adsorbents describing the process to be a physical adsorption process [8,9,13,15,18].

Kinetics of biosorption

The knowledge of the kinetics of any biosorption process is crucial in order to be able to design industrial scale separation processes. Therefore, the pseudo-first-order, pseudo-second-order [24,25] and intra-particle diffusion and Elovich kinetic models [23] were used to study the biosorption process of lindane on to native and surface modified biomass.

Table 2: Kinetic parameters of lindane sorption on native and citric acid treated dried biomass of *Cintractia sorghi* VITJzN02

Kinetic Model	Parameters	Native	Citric acid treated
Pseudo-first order	Q_e(mg g^{-1}) exp	28	95
	K_1 (min^{-1})	0.020	0.012
	Q_e (mg g^{-1}) cal	26	105.68
	R^2	0.989	0.995
Pseudo-second order	K_2 (g mg^{-1} min^{-1})	1.08 X10^{-3}	1.19 X10^{-4}
	Q_e(mg g^{-1}) cal	31.25	125
	R^2	0.981	0.986
Intra-particle diffusion	K_{int} (mg g^{-1} $min^{1/2}$)	0.768	6.053
	C	15.75	9.051
	R^2	0.874	0.920
Elovich	α (mg $g^{-1}min^{-1}$)	11.66	4
	β (g mg^{-1})	0.235	0.039
	R^2	0.959	0.900

Pseudo-first-order equation can be expressed in linear form as:

$$\log (Q_{eq} - Q_t) = \log Q_{eq} - \frac{K_1}{2.3030} t \quad (8)$$

where, Q_{eq} is equilibrium uptake, Q_t is the uptake at time t and K_1 is the biosorption rate constant for pseudo-first-order reaction. The sorption rate constants and the theoretical values of Q_{eq} calculated from the slope and intercept of the linear plot log (Q_{eq} - Q_t) versus t are summarized in Table 2 with the corresponding correlation coefficients. The kinetic data showed excellent fit to the pseudo-first-order equation for both the biosorbents studied. From Table 2, it is evident that the calculated Q_{eq} values agree with experimental Q_{eq} values well, and also, the correlation coefficients for the pseudo-first-order kinetic plot are higher (R^2 ~0.99).

Pseudo-second-order equation for biosorption in linearized form is as follows:

$$\frac{t}{Q_t} = \frac{1}{K_2 {Q_{eq}}^2} + \frac{t}{Q_t} \quad (9)$$

where, Q_{eq} is the amount of pesticide sorbed at equilibrium, Q_t is the amount of pesticide sorbed at any time t and K_2 is the pseudo-second-order reaction rate constant for sorption. The values for the pseudo-second order reaction parameters were calculated from the linear plot t/Q_t versus t and presented in Table 2.

The intra-particle diffusion model was also used to study the kinetic behaviour of lindane adsorption on native and pretreated biomass. The intra-particle model can be given as:

$$Q_t = K_{int}\, t^{1/2} + C \quad (10)$$

Where, C is the intercept and related to the thickness of the boundary layer and K_{int} is the intra-particle diffusion rate constant. The parameters of the intra-particle diffusion model, was calculated from the linear plot Q_t versus $t^{1/2}$. The intra-particle diffusion is a kinetic model that is related to the transfer of lindane from its aqueous media to the pores of sorbent. According to Eq. (10), the plot should be a straight line when the biosorption mechanism follows the intra-particle diffusion process. However, if the data shows multi-linear plots, then the process is governed by two or more steps. The intra-particle diffusion is not only the rate limiting mechanism involved in the biosorption of lindane onto the biosorbents studied as suggested from the kinetic plot (not shown) and the values presented in the Table 2. The regression value, R^2 is also less than 0.99.

The Elovich kinetic equation is used to describe the kinetics of a chemisorption mechanism on heterogeneous adsorbent surfaces. It is expressed as:

$$Q_t = \frac{1}{\beta} \ln(\alpha\beta) + \frac{1}{\beta} \ln t \quad (11)$$

where, α and β are known as the Elovich coefficients. α represents the initial sorption rate and β is related to the extent of surface coverage and activation energy for chemisorptions process. The coefficients of Elovich model were calculated from the linear plot of Q_t versus ln t. The results from kinetic models shows that experimental data fitted well to the pseudo-first-order kinetic model with the calculated uptake value, Q_{eq} equals 26 mg/g and 105.68 mg/g, rate constant, K_1 equals 0.020 per min and 0.012 per min and a regression value, R^2 value of 0.989 and 0.995 for native and citric acid treated *C. sorghi* biomass respectively. Thus, it can be concluded that the adsorption of lindane on to native and pretreated biosorbent is controlled by physisorption.

Comparison of pretreated *C. sorghi* VITJzN02 biomass with the other biosorbents

Table 3 summarizes the comparison of the maximum lindane uptake capacities of various sorbents including citric acid treated biomass. Citric acid treated *C. sorghi* biomass showed the higher sorption capacity of lindane than most of the other reported biosorbents. The high sorption capacity could be due to the porous and the irregular nature of the surface of pretreated biomass. Moreover, as the surface of *C. sorghi* is protonated and positively charged upon pretreatment, the increasing electrostatic attraction between negatively charged lindane molecules and positively charged biosorbent resulted increased adsorption of lindane. The ease of bulk production of the *C. sorghi* VITJzN02 biomass and single step pretreated of the biomass from the yeast enabled it to be used as potential biosorbent for removal of lindane residues from the aqueous environment effectively.

Table 3: Comparison of the lindane biosorption capacity of citric acid treated *C. sorghi* VITJzN02 with other reported adsorbents

Sorbent	Q_{max} (mg g^{-1})	Reference
R. arehizus	3.622 mg/l	[8]
Pretreated *E.coli*	4 mg/l	[9]
Pretreated Powdered activated carbon	1.5 mg/l	[13]
Fly ash baggase	2 µg/g	[15]
Compost soil	48.42±1.8 mg/g	[18]
Granular activated carbon	487±72 mg/g	[26]
Pine bark	3.17 mg/g	[27]
Pretreated *C. sorghi*	100 mg/g	Present study

CONCLUSIONS

C. sorghi VITJzN02 biomass can serve as good adsorbent for the removal of organochlorine pesticide, lindane from aqueous environment. The process follows the Langmuir isotherm model for monolayer adsorption. Hydrophobic interactions and weak Van der Waals forces are mainly responsible for this adsorption process. Citric acid pretreated yeast biomass can be used for the enhanced removal of lindane from wastewater.

ACKNOWLEDGMENTS

The authors thank VIT University, Vellore for providing the Laboratory facilities to carry out research in a fruitful manner.

REFERENCES

1. Vizcaíno Martínez MP, Pistocchi A. A GIS model-based assessment of the environmental distribution of γ-hexachlorocyclohexane in European soils and waters. Environ Pollut 2010;158 :3017-3027.
2. FDA. The Electronic Orange Book. U.S. Food and Drug Administration. http://www.fda.gov/cder/ob/default.htm 2009.
3. Bais SK, Chandewar AV. Comparative evaluation of endosulfan content in triphala churna marketed in yavatmal district of India by HPLC method. Int J Pharm Pharm Sci 2011; 3 Suppl 3:35-40.
4. McManus SL, Coxon CE, Richards KG, Danaher M. Quantitative solid phase microextraction - gas chromatography mass spectrometry analysis of the pesticides lindane, heptachlor and two heptachlor transformation products in groundwater. J Chromatogr A 2013;1284 :1-7.
5. EPA United States environment protection authority. Available online: http://water.epa.gov/drink/contaminants/basic information/lindane.cfm#four 2012.
6. Wu J, Yu HQ. Biosorption of 2, 4-dichlorophenol by immobilized white-rot fungus *Phanerochaete chrysosporium* from aqueous solutions. Bioresour Technol 2007;98 :253-259.
7. Manzoor Q, Raziya N, Munawar I, Rashid S, Tariq MA Organic acids pretreatment effect on *Rosa bourbonia* phyto-biomass for removal of Pb (II) and Cu (II) from aqueous media. Bioresour Technol 2013;132 :446-452.
8. Tsezos M, Bell JP Comparison of the biosorption and desorption of hazardous organic pollutants by live and dead biomass. Water Res 1989;23 :561-568.
9. Ju YH, Chen TC, Liu JC A study on the biosorption of lindane. Colloids Surf B Biointerfaces 1997;9 :187-196.
10. Mao J, Won SW, Vijayaraghavan K, Yun YS Surface modification of *Corynebacterium glutamicum* for enhanced Reactive Red 4 biosorption. Bioresour Technol 2009;100 :1463-1466.
11. Abdallah MAM. The potential of different bio adsorbents for removing phenol from its aqueous solution. Environ Monit Assess 2012: 1-9.
12. Wong KK, Lee CK, Low KS, Haron MJ. Removal of Cu and Pb by tartaric acid modified rice husk from aqueous solutions. Chemosphere 2003;50 :23-28.
13. Hassan AM, Abed El-Moteleb M, Ismael AM. Removal of lindane and malathion from wastewater by activated carbon prepared from apricot stone. Ass Univ Bull Environ Res 2009;12 :1-8.
14. Yao Z-Y, Qi J-H, Wang L-H. Equilibrium, kinetic and thermodynamic studies on the biosorption of Cu (II) onto chestnut shell. J Hazard Mater 2010;174 :137-143.
15. Gupta VK, Jain CK, Ali I, Chandra S, Agarwal S. Removal of lindane and malathion from wastewater using bagasse fly ash—a sugar industry waste. Water Res 2002;36 :2483-2490.
16. Baek MH, Ijagbemi CO, Kim DS. Removal of Malachite Green from aqueous solution using degreased coffee bean. J Hazard Mater 2010;176 :820-828.
17. Saha P, Chowdhury S, Gupta S, Kumar I. Insight into adsorption equilibrium, kinetics and thermodynamics of Malachite Green onto clayey soil of Indian origin. Chem Eng J 2010;165 :874-882.
18. Rama Krishna K, Philip L. Adsorption and desorption characteristics of lindane, carbofuran and methyl parathion on various Indian soils. J Hazard Mater 2008;160 :559-567.
19. Langmuir I. The constitution and fundamental properties of solids and liquids. J Am Chem Soc 1916;38 :2221–2295.
20. Freundlich HMF. Over the adsorption in solution. J Phys Chem 1906;57 :385-470.
21. Temkin M, Pyzhev V. Kinetics of ammonia synthesis on promoted iron catalysis. Acta Physiochim URSS 1940;12 :385-470.
22. Dubinin MM. The potential theory of adsorption of gases and vapors for adsorbents with energetically non-uniform surface. Chem Rev 1960;60 :235–266.
23. Chowdhury S, Chakraborty S, Saha P. Biosorption of Basic Green 4 from aqueous solution by *Ananas comosus* (pineapple) leaf powder. Colloids Surf B Biointerfaces 2011;84 :520-527.
24. Lagergren S. About the theory of so-called adsorption of soluble substances. K Sven Vetenskapsakad Handl 1898;24 :1-39.
25. Ho YS, McKay G. The sorption of lead (II) ions on peat. Water Res 1999;33 :578-584.
26. Sotelo JL, Ovejero G, Delgado JA, Martinez I. Adsorption of lindane from water onto GAC: effect of carbon loading on kinetic behaviour. Chem Eng J 2002;87 :111-120.
27. Ratola N, Botelho C, Alves A. The use of pine bark as a natural adsorbent for persistent organic pollutants–study of lindane and heptachlor adsorption. J Chem Technol Biotechnol 2003;78 :347-351.