

# Biosorption properties of *Morus alba* L. for Cd (II) ions removal from aqueous solutions

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**Abstract** The abundantly available industrial waste product *Morus alba* L. pomace (MAP) is one of the cost-effective biosorbent for removal of metal ions from aqueous solutions. Hence, in the present study, we aimed to test the ability of MAP to remove Cd(II) ions through batch biosorption process. Firstly, MAP was characterized using several techniques, and then the influence of various experimental parameters such as initial pH of the aqueous solution, initial Cd(II) concentration, contact time, MAP concentration, and temperature were evaluated upon the biosorption process. It was found that the maximum uptake of Cd(II) ions occurred at initial pH 6.0 and optimum contact time was observed as 60 min. Cd(II) ions adsorption on MAP analyzed by the Langmuir and Freundlich isotherm models and the maximum monolayer biosorption capacity of MAP was found to be 21.69 mg g<sup>-1</sup> by using the Langmuir isotherm model. The

pseudo-first-order, pseudo-second-order, Elovich, and intraparticle diffusion models were employed to describe the biosorption kinetics. In order to investigate the thermodynamic properties of the biosorption process, the changes in the Gibbs free energy ( $\Delta G$ ), enthalpy ( $\Delta H$ ), and entropy ( $\Delta S$ ) were also evaluated and it has been concluded that the process was feasible, spontaneous, and endothermic in the temperature range of 5–40 °C.

**Keywords** Biosorption · Removal · *Morus alba* L. pomace · Cadmium · Kinetics · Thermodynamics

## Introduction

High industrial activity is a sine qua non for a healthy economy, but this comes with a price; one of which is heavy metal pollution. Most of the industrial processes including milling, textile, metal plating, stabilizers, battery manufacturing, metallurgical alloying, and mining operations discharge heavy metals into the environment, namely rivers, lakes, streams, and groundwater. In addition to the toxic and other harmful effects to the living organisms in water, heavy metals can also enter the food chain and may affect human health as well (Akar et al. 2009; Bhat et al. 2008; Ozdes et al. 2011; Forstner and Wittman 1981).

Cadmium is one of the most common toxic metals that take place in various industrial processes. The half-life of cadmium is in the range of 10–30 years.

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The accumulation of cadmium in human body affects kidney, bones, and causes acute and chronic metabolic disorders, such as itai-itai disease, renal dysfunction, lung damage, emphysema, hepatic injury, hypertension and testicular atrophy, and teratogenic effects (Verougstraete et al. 2002; Megateli et al. 2009). According to the World Health Organization (WHO) recommendation, the maximum permissible limit for Cd(II) ions in drinking water is as low as  $5 \mu\text{gL}^{-1}$  (WHO 1993). Because of its high toxicity, the Cd(II) levels in drinking water and wastewater should be reduced to below the maximum permissible concentration (ATSDR 1999).

Since the heavy metals may be valuable resources for some other industrial applications, their recovery from the pollutants and recycling of them would be a significant contribution. In addition, strict environmental regulations obligate industries to choose cleaner production methods. As a result of these restrictions, development of non-polluting, cost-effective, and efficient treatment techniques for metal rich wastes has been an attractive field of research (Nagpal et al. 2011).

Biosorption is a recently raising and attractive technology which is based on the process of sorption of a dissolved substance using a biomaterial. It has been shown that this technique has a strong potential for removal of heavy metals from aqueous solutions as well as recovery of precious metals (Guillen-Jimenez et al. 2009; Rehman and Anjum 2011).

Several methods such as chemical precipitation, ion-exchange, reverse osmosis, filtration, electrochemical treatments, solvent extraction, membrane processes, and adsorption have been developed for removal of organic and inorganic pollutants from aqueous environment (Chong and Volesky 1995; Elouear et al. 2009; Ozcan et al. 2005; Aci et al. 2008). The adsorption processes have proven many advantages over the conventional methods. The main advantages of this technique are the recyclability of the sorbents, relatively low operating cost, high selectivity for the metal of interest, removal of heavy metals from effluent disregarding their toxicity, shorter processing time, and no production of secondary toxic agents (Ahluwalia and Goyal 2007; Liu et al. 2007). Various plant-derived materials including orange peel (Li et al. 2008), mushrooms (Vimala and Das 2009), eucalyptus bark (Ghodbane et al. 2008), and papaya wood (Asma et al. 2005) have been evaluated for their biosorption capability in removal of Cd(II) ions from aqueous solutions.

The aim of this study is to explore the biosorption efficiency of *Morus alba* L. pomace (MAP) in biosorbing of Cd(II) ions. The conditions affecting the biosorption process such as initial solution pH, contact time, MAP dosage, initial Cd(II) concentration, and temperature were investigated. The Langmuir and Freundlich models were used to determine the equilibrium isotherms. The kinetics and thermodynamic parameters were also determined to describe the biosorption process of Cd(II) ions onto MAP.

## Materials and methods

### Preparation and characterization of MAP

The plant of *M. alba* L. is a common tree in East Black Sea Region of Turkey. The *M. alba* L. pomace can be processed as animal feed and undergoes aerobic or anaerobic digestion to produce compost or energy. It was used as a biosorbent without any previous physical or chemical pretreatment for the biosorption of Cd(II) ions. It was supplied from Doga Pestil Kome Factory in Gumushane, Turkey. This factory processes 60 tons of *M. alba* L. annually and 12 tons of MAP remains as an industrial waste product. This industrial waste was washed with deionized water to remove dust, surface impurities and soluble materials. Then it was dried in an oven (Nüve FN 400) at  $40^\circ\text{C}$  for 4 days. The dried waste was grounded to a fine powder in a grinding mill and sieved to get size fraction of  $<150 \mu\text{m}$ , and stored in a desiccator to be used in all biosorption experiments.

The surface acidic functional groups containing oxygen were determined according to Boehm titration (Boehm 2002). The other characterization parameters such as self pH value of the MAP, pH of zero charge ( $\text{pH}_{\text{pzc}}$ ), and moisture content were determined using standard methods (APHA 1985) and the results were given in Table 1.

### Biosorption experiments

A batch technique was performed for the biosorption of Cd(II) ions onto MAP. Stock solution of the Cd(II) ions was prepared as  $5,000 \text{ mgL}^{-1}$  from  $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$  by dissolving appropriate amount of it in distilled/deionized water. For biosorption tests, 10 mL of Cd(II) solutions in the concentration range of  $50\text{--}1,000 \text{ mgL}^{-1}$  at initial pH 6.0 (which was adjusted with 0.1 N HCl or

**Table 1** Characteristics of MAP

pH	5.85
pH <sub>pzc</sub>	5.60
Moisture content (%)	7.06
Surface functional groups (mmol g <sup>-1</sup> )	
Carboxylic	0.52
Phenolic	1.04
Lactonic	0.17
Total acidic value	1.73

0.1 N NaOH at the beginning of the experiments) was added into the polyethylene centrifuge tubes. Then 50 mg of MAP (5.0 gL<sup>-1</sup> suspension) was transferred into the solutions, and then the mixture was shaken on a mechanical shaker (Edmund Bühler GmbH) at 400 rpm. After reaching the equilibrium (60 min), the suspension was centrifuged at 3,000 rpm for 10 min, and the concentration of the dilute phase was analyzed for the Cd (II) concentration using a flame atomic absorption spectrometer, FAAS (Perkin Elmer AAnalyst-400). The amount of the biosorbed Cd(II) ions by the MAP was calculated using the following equation:

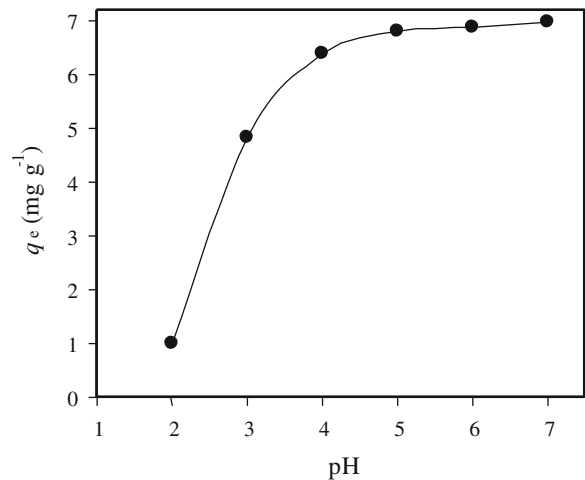
$$q_e = \frac{(C_o - C_e)V}{m_s} \quad (1)$$

where C<sub>o</sub> (mgL<sup>-1</sup>) is the initial concentration of Cd(II) solution, C<sub>e</sub> (mgL<sup>-1</sup>) is the equilibrium concentration of Cd(II) in aqueous solution, V (L) is the volume of the solution, m<sub>s</sub> (g) is the mass of the MAP, and q<sub>e</sub> (mg g<sup>-1</sup>) is the calculated Cd(II) biosorption amount onto 1.0 g of MAP.

## Results and discussion

### Effect of initial pH

Since the pH of the aqueous media is one of the most important parameters affecting the biosorption process, the effects of initial pH on the biosorption of Cd(II) ions onto MAP were evaluated by changing the initial pH values over a range of 2.0–7.0. The experiments were conducted with initial Cd(II) concentration of 50 mgL<sup>-1</sup> and MAP concentration of 5.0 gL<sup>-1</sup>. The biosorption amount of Cd(II) ions increased with the increase in initial pH from 2.0 to 7.0 (Fig. 1). The pH<sub>PZC</sub> of any adsorbent is a very important characteristic that determines the pH at which the surface has net electrical



**Fig. 1** Effect of initial pH on Cd(II) biosorption onto MAP (initial Cd(II) concentration, 50 mgL<sup>-1</sup>; biosorbent concentration, 5.0 gL<sup>-1</sup>)

neutrality (Khan and Wahab 2007). The effects of initial pH can be explained by considering the surface charge of MAP at different pH values. The surface of MAP is negatively charged when pH value is higher than pH<sub>PZC</sub>, whereas when pH value is lower than pH<sub>PZC</sub>, the surface charge of MAP becomes positive. Because of the pH<sub>PZC</sub> value of MAP was found to be 5.60, the Cd(II) ions can bind easily to the surface of MAP at pH values higher than 5.60. At lower pH values, the Cd(II) removal was inhibited, possibly due to the competition with the hydronium ions for metal binding sites on the surface of the MAP. As the pH increasing, more negatively charged and deprotonated MAP surface become available thus facilitating greater Cd(II) biosorption. As a result, the optimum initial pH for Cd(II) biosorption onto MAP was found to be 6.0.

### Effect of contact time and biosorption kinetics

In order to evaluate the effect of contact time on the biosorption of Cd(II) ions onto MAP, a solution of initial Cd(II) concentration of 50 mgL<sup>-1</sup> and MAP suspension of 5.0 gL<sup>-1</sup> was used within the contact time range of 1–360 min. At the initial phase of the biosorption process, since the active biosorption sites were more available and the metal ions could interact easily with these sites, the rate of uptake of Cd(II) ions was high for the first 10 min of the contact time. After this initial phase, the uptake continued at a slower rate and finally the equilibrium was reached through the saturation of the biosorption sites in 60 min. Therefore, the following

biosorption experiments were carried out for a contact time of 60 min (Fig. 2(a)). The mechanism of the biosorption process was estimated by applying the pseudo-first-order, pseudo-second-order, Elovich and intraparticle diffusion models to the experimental data.

The pseudo-first-order equation can be written as follows (Lagergren 1898):

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (2)$$

The pseudo-second-order model is in the following form (Ho and McKay 1999):

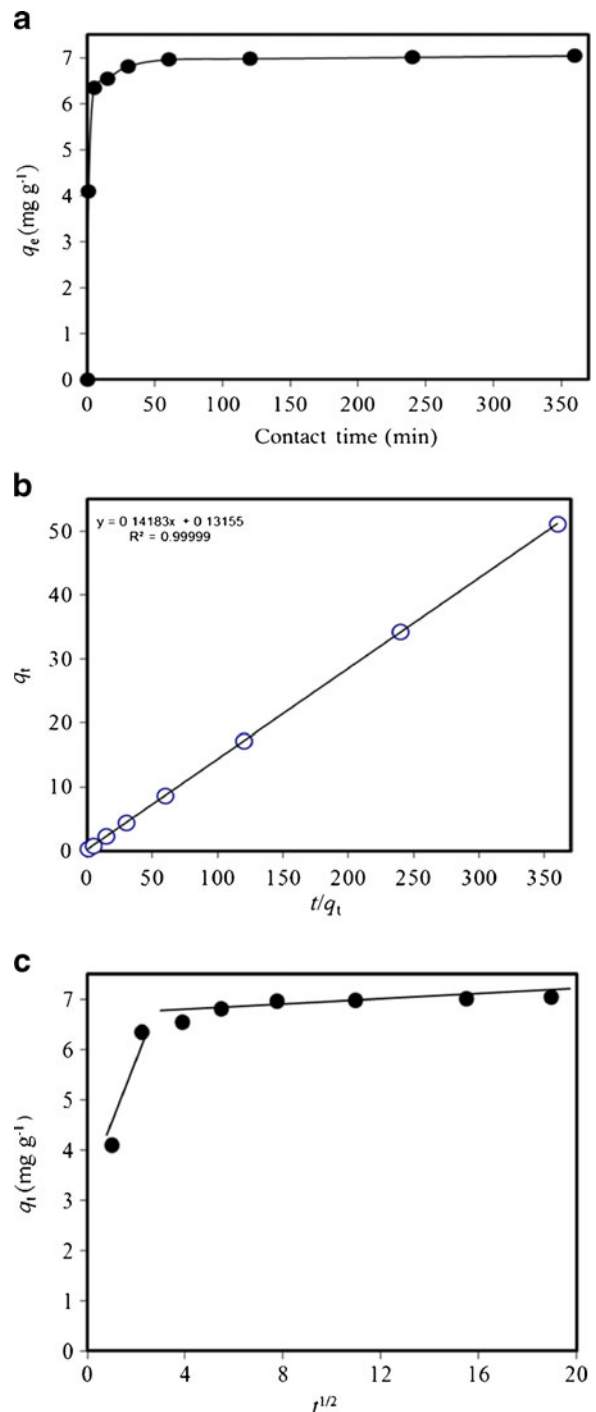
$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (3)$$

The Elovich equation is given as follows (Cheung et al. 2001):

$$q_t = (1/\beta) \ln(\alpha\beta) + (1/\beta) \ln t \quad (4)$$

where  $q_e$  ( $\text{mg g}^{-1}$ ) and  $q_t$  ( $\text{mg g}^{-1}$ ) are the amounts of the metal ions biosorbed on the biosorbate at equilibrium and at any time  $t$ , respectively,  $k_1$  ( $\text{min}^{-1}$ ) is the rate constant of the first order equation,  $k_2$  ( $\text{g mg}^{-1} \text{min}^{-1}$ ) is the rate constant of the second-order equation,  $\alpha$  ( $\text{mg g}^{-1} \text{min}^{-1}$ ) is the initial sorption rate, and  $\beta$  ( $\text{g mg}^{-1}$ ) is related to the extent of surface coverage and activation energy for chemisorption.

The pseudo-first-order model constants,  $k_1$  and  $q_e$ , can be obtained from the slope and intercept of the linear plot of  $\ln(q_e - q_t)$  versus  $t$ , respectively. The value of  $q_e$  ( $q_{e \text{ cal}}$ ), calculated by applying the model, is not in a good agreement with the experimental value of  $q_e$  ( $q_{e \text{ exp}}$ ). The Elovich model constants,  $\alpha$  and  $\beta$ , were also calculated from the intercept and slope of the plot of  $q_t$  versus  $\ln(t)$ , respectively. The lower values of the correlation coefficients lead to a conclusion that the pseudo-first-order and Elovich models are not suitable for modeling the biosorption of Cd(II) ions onto MAP (Table 2). As in the previous models, the pseudo-second-order kinetic model constants,  $k_2$  and  $q_e$ , were determined from the intercept and slope of the plot of  $t/q_t$  versus  $t$  (Fig. 2(b)), respectively, and the calculated values were presented in Table 2 along with the corresponding correlation coefficient. It can be easily seen that the  $q_e$  value, calculated from the model as described above, and the experimental value of it are very close to each other. The correlation coefficient value obtained from the pseudo-second-order kinetic model seems to be relatively high. Therefore, it can be easily claimed beyond any speculation



**Fig. 2** a Effect of contact time on Cd(II) uptake by MAP (initial Cd(II) concentration,  $50 \text{ mg L}^{-1}$ ; biosorbent concentration,  $5.0 \text{ g L}^{-1}$ ; initial pH 6.0). b Pseudo-second-order kinetic model

that the pseudo-second-order adsorption mechanism is predominant for the biosorption of Cd(II) ions onto MAP.

**Table 2** Parameters of pseudo-first-order, pseudo-second-order, Elovich, and intraparticle diffusion models

Pseudo-first-order kinetic model				Pseudo-second-order kinetic model			
$q_e \text{ exp (mg g}^{-1}\text{)}$	$k_1 \text{ (min}^{-1}\text{)}$	$q_{\text{ecal}} \text{ (mg g}^{-1}\text{)}$	$R^2$	$k_2 \text{ (g mg}^{-1}\text{ min}^{-1}\text{)}$	$q_{\text{e cal}} \text{ (mg g}^{-1}\text{)}$	$R^2$	
7.04	-0.0182	1.03	0.6367	0.153	7.05	0.9999	
Intraparticle diffusion model				Elovich model			
$k_{\text{id,1}} \text{ (mg g}^{-1}\text{ min}^{-1/2}\text{)}$	$R^2$	$k_{\text{id,2}}$	$R^2$	$C$	$\beta \text{ (g mg}^{-1}\text{)}$	$\alpha \text{ (mg g}^{-1}\text{ min}^{-1}\text{)}$	$R^2$
1.331	0.9999	0.026	0.7949	5.68	0.422	$1.4 \times 10^5$	0.7223

The intraparticle diffusion model equation is expressed as (Weber Jr and Morriss 1963);

$$q_t = k_{\text{id}}t^{1/2} + c \tag{5}$$

where  $q_t$  (mg g<sup>-1</sup>) is the amount of sorption at time  $t$  (min) and  $k_{\text{id}}$  (mg g<sup>-1</sup> min<sup>-1/2</sup>) is the rate constant of intraparticle diffusion model. The biosorption process usually occurs in three stages, which are film diffusion, intraparticle or pore diffusion, and sorption onto interior sites. Thus, the plot of  $q_t$  versus  $t^{1/2}$  may present multilinearity. In most cases, the sorption of a biosorbate onto interior sites of a biosorbent occurs rapidly, and therefore, the sorption process is controlled by film diffusion or pore diffusion, depending on the rate of each stage. Two distinct phases were observed in the intraparticle mass transfer curve of Cd(II) biosorption (Fig. 2(c)). In the first phase, Cd(II) ions diffuse into the external surface of MAP and the intraparticle diffusion of Cd (II) ions into the pores of MAP occurs in the second phase. The rate constants of the first ( $k_{\text{id,1}}$ ) and the second phase ( $k_{\text{id,2}}$ ) can be obtained from the slope of the plot of  $q_t$  versus  $t^{1/2}$ . The obtained results were given in Table 2. Since the value of  $k_{\text{id,2}}$  is smaller than  $k_{\text{id,1}}$ , it can be concluded that the intraparticle diffusion occurs slower than the film diffusion. Therefore, it can be claimed that the rate of the intraparticle diffusion is the limiting factor for Cd(II) biosorption process. However, the line corresponding to the intraparticle diffusion phase does not pass through the origin, and hence the Cd(II) biosorption onto MAP can be considered as a complex process, where both intraparticle diffusion and surface sorption contribute to the rate-limiting step (Masamune and Smith 2004).

Effect of initial Cd(II) concentration and biosorption isotherms

The effects of initial Cd(II) concentration on the biosorption process were evaluated by using the solutions in which the initial Cd(II) concentration changes in the

range of 50–1,000 mgL<sup>-1</sup> at initial pH 6.0. The availability of the active biosorption sites on the biosorbent surface and the ability of these sites to bind metal ions are the important factors which may be effective on the metal uptake efficiency at different initial metal ion concentrations. As the initial Cd(II) concentration was increased from 50 to 1,000 mgL<sup>-1</sup>, the equilibrium concentration increased from 6.8 to 21.2 mgg<sup>-1</sup> due to the increased driving force of the Cd(II) ions towards to the active biosorption sites, whereas the biosorption percentage decreased from 76.3 % to 11.4 % due to the saturation of the available biosorption sites on the biosorbent surface which prevents further Cd(II) ions binding (Fig. 3(a); Reddad et al. 2002). The possible biosorption mechanisms of Cd(II) ions onto MAP were evaluated in terms of Langmuir and Freundlich isotherm models.

The Langmuir isotherm model in linear form is (Langmuir 1918);

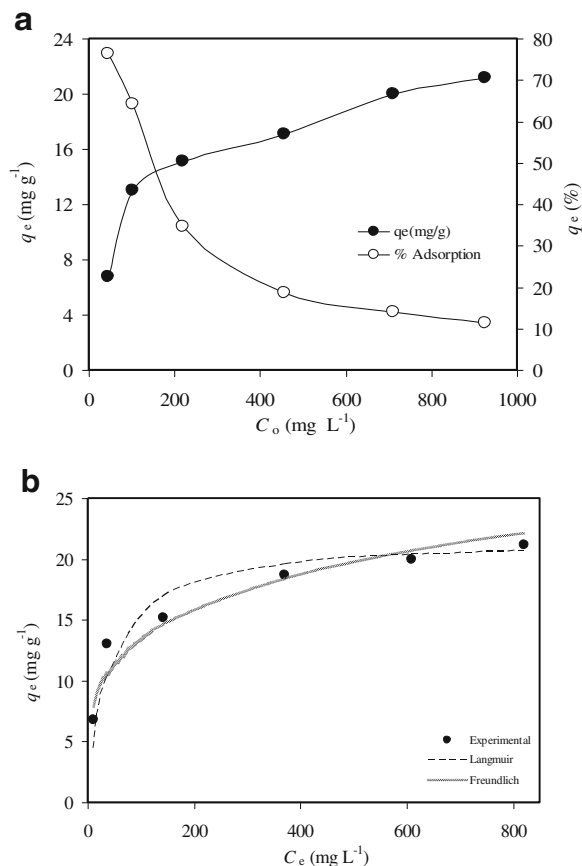
$$\frac{C_e}{q_e} = \frac{C_e}{q_{\text{max}}} + \frac{1}{bq_{\text{max}}} \tag{6}$$

where  $q_e$  (mg g<sup>-1</sup>) is the amount of the metal ions biosorbed per unit mass of biosorbent,  $C_e$  (mgL<sup>-1</sup>) is the equilibrium metal ion concentration in aqueous solution,  $q_{\text{max}}$  (mg g<sup>-1</sup>) and  $b$  (Lmg<sup>-1</sup>) are the Langmuir constants related to the biosorption capacity and free energy or net enthalpy of biosorption, respectively. The linear plot of  $C_e/q_e$  versus  $C_e$  shows that sorption obeys the Langmuir model and the constants  $q_{\text{max}}$  and  $b$  are evaluated from slope and intercept of the linear plot, respectively. According to the Langmuir isotherm model, the maximum monolayer biosorption capacity of MAP for Cd(II) was found to be 21.69 mgg<sup>-1</sup>.

The Freundlich isotherm model in linear form is (Freundlich 1906);

$$\ln q_e = \ln K_f + \frac{1}{n} \ln C_e \tag{7}$$

where  $K_f$  is a constant related to the sorption capacity (mg g<sup>-1</sup>) and  $1/n$  is an empirical parameter related to



**Fig. 3** **a** Effect of initial Cd(II) concentration on Cd(II) biosorption onto MAP (initial pH 6.0; biosorbent concentration, 5.0 gL<sup>-1</sup>; contact time, 60 min). **b** Comparison of equilibrium isotherms between the experimental and theoretical data for Cd(II) uptake

the sorption intensity. The value of  $n$  varies with the heterogeneity of the sorbent and gives an idea for the favorability of the sorption process. The value of  $n$  should be less than 10 and higher than unity for favorable sorption conditions. The Freundlich constants  $K_f$  and  $1/n$  can be determined from the intercept and slope of the linear plot of  $\ln q_e$  versus  $\ln C_e$ , respectively. According to the Freundlich isotherm model,  $n$  value was found to be 4.21 which implies that the adsorption process is favorable under the studied experimental conditions.

The equilibrium data obtained from the biosorption of Cd(II) ions onto MAP were fitted to the Langmuir and Freundlich isotherm models (Fig. 3(b)). All of the isotherm constants and correlation coefficients were calculated from the linear equations of the models and the results were displayed in Table 3. Comparison of

the correlation coefficient values obtained from the models leads to a conclusion that the experimental data are fitted well to Langmuir isotherm model which reflects the homogeneous distribution of the active biosorption sites on the surface of the MAP.

#### Effect of temperature and thermodynamics of biosorption

The effect of temperature on the biosorption amount of Cd(II) ions was tested by conducting the experiments in the temperature range of 5–40°C. In these experiments, the initial Cd(II) concentration and MAP suspension were kept at 50 mgL<sup>-1</sup> and 5.0 gL<sup>-1</sup>, respectively. It was concluded that the biosorption of Cd(II) ions onto MAP was endothermic, since the biosorption capacity of Cd(II) ions increased from 6.3 (73.2 % removal) to 6.9 mgg<sup>-1</sup> (80.0 % removal) with the increase in temperature from 5 °C to 40 °C (Fig. 4). The following two reasons may be attributed to this observation: either the number of active biosorption sites on the MAP surface increased or the mobility of Cd(II) cations increased with the increase in temperature (Briand et al. 2000).

The thermodynamic parameters including Gibbs free energy ( $\Delta G$ ), enthalpy ( $\Delta H$ ), and entropy ( $\Delta S$ ) changes were calculated using the following equations (Smith and Van Ness 1987);

$$\Delta G = -RT \ln(K_d) \quad (8)$$

where  $R$  is the universal gas constant (8.314 Jmol<sup>-1</sup> K<sup>-1</sup>),  $T$  is the temperature (K), and  $K_d$  is the distribution coefficient. The  $K_d$  value is calculated using following equation;

$$K_d = q_e/C_e \quad (9)$$

**Table 3** Langmuir and Freundlich isotherm parameters for the biosorption of Cd(II) onto MAP

Langmuir isotherm model	
$q_{max}$ (mgg <sup>-1</sup> )	21.69
$b$ (Lmg <sup>-1</sup> )	0.025
$R^2$	0.9964
Freundlich isotherm model	
$K_f$ (mgg <sup>-1</sup> )	4.52
$n$	4.21
$R^2$	0.9213

**Table 4** Thermodynamic parameters of Cd(II) biosorption onto MAP at different temperatures

Thermodynamics parameters			
$T$ (°C)	$\Delta G$ (kJmol <sup>-1</sup> )	$\Delta S$ (Jmol <sup>-1</sup> K <sup>-1</sup> ) <sup>a</sup>	$\Delta H$ (kJmol <sup>-1</sup> ) <sup>a</sup>
5	-2.32	36.09	7.59
25	-2.91		
35	-3.28		
40	-3.59		

<sup>a</sup>Measured between 278 and 313 K

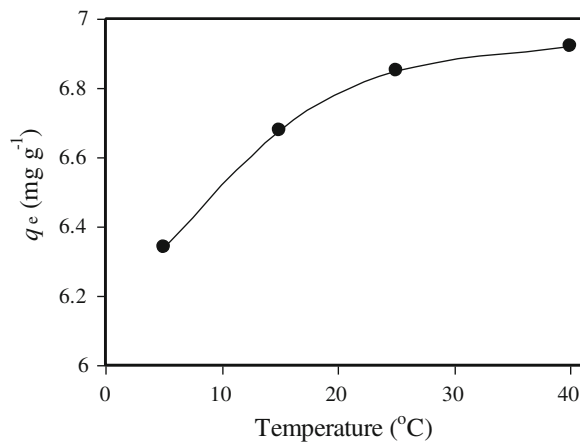
where  $q_e$  (mgL<sup>-1</sup>) and  $C_e$  (mgL<sup>-1</sup>) are the equilibrium concentration of Cd(II) ions biosorbed onto MAP and remained in the solution, respectively. The enthalpy ( $\Delta H$ ) and entropy ( $\Delta S$ ) changes of the process were estimated from the following equation:

$$\Delta G = \Delta H - T\Delta S \tag{10}$$

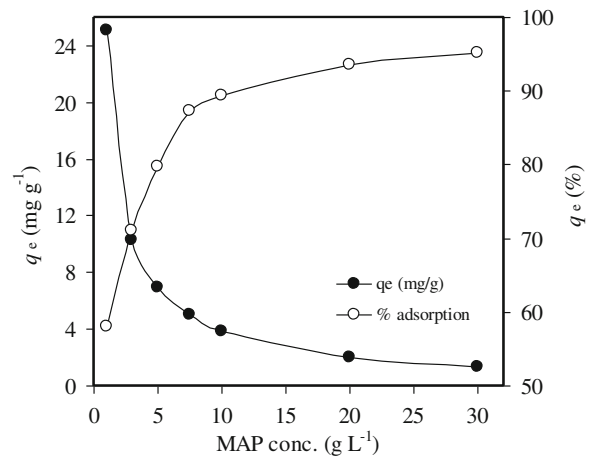
This equation can be written as;

$$\ln K_d = \frac{\Delta S}{R} - \frac{\Delta H}{RT} \tag{11}$$

The slope and intercept of the plot of  $\ln(K_d)$  versus  $1/T$  was used to estimate the  $\Delta H$  and  $\Delta S$  values, respectively. Equation (8) was utilized to determine the  $\Delta G$  values within the temperature range of 5–40 °C. The present biosorption process was feasible and spontaneous in nature as indicated by the negative  $\Delta G$  values (Table 4). The endothermic nature of the biosorption process of Cd(II), as was pointed out earlier, was clearly indicated by the positive value of



**Fig. 4** Effect of temperature on Cd(II) uptake (initial Cd(II) concentration, 50 mgL<sup>-1</sup>; biosorbent concentration, 5.0 gL<sup>-1</sup>; initial pH 6.0; contact time, 60 min)



**Fig. 5** Effect of MAP concentration on Cd(II) uptake (initial Cd(II) concentration, 50 mg L<sup>-1</sup>; initial pH 6.0; contact time, 60 min)

$\Delta H$ . In addition, the randomness of the solid/solution interface during the biosorption of Cd(II) ions onto MAP increased as indicated by the positive  $\Delta S$  value.

#### Effect of MAP concentration

The effects of MAP concentration on the removal of Cd(II) ions were investigated with a series of experiments in which the MAP concentrations were varied in the range of 1–30 gL<sup>-1</sup>. In these experiments, the contact time, initial Cd(II) concentration, and initial pH value of the aqueous solution were kept as 60 min, 50 mgL<sup>-1</sup>, and 6.0, respectively. The influence of the MAP concentration on the removal of Cd(II) was displayed in Fig. 5. The results pointed out that the percentage biosorption amount of Cd(II) ions increased with the increase in MAP concentration. This observation could be explained by the increase in active biosorption sites on the MAP surface, and therefore making penetration of the Cd(II) ions into the sorption sites easier. However, there is an inverse ratio between the adsorbent dosage and the amount of adsorbate uptaken by the sorbent such that the Cd(II) ions biosorbed per unit mass of the MAP ( $q_e$ ) decreased with increasing the MAP concentration because of the aggregation of the biosorbent particles (Ozer et al. 2012; Walker and Weatherley 2001).

#### Conclusions

The removal of Cd(II) ions with a batch biosorption process from an aqueous solutions by utilization of *M.*

*alba* L. pomace (MAP), which was an agricultural byproduct, has been examined. The study is important from environmental point of view because it provides an economically viable means to recycle of an unused resource which presents serious disposal problems. The MAP was used without any previous activation treatment which decreased the biosorption costs. The efficiency of the MAP in removing of Cd(II) ions was tested with respect to equilibrium, kinetics and thermodynamics parameters. The kinetics of Cd(II) biosorption onto MAP surfaces was followed by the pseudo-second-order model. The best results for the equilibrium were obtained with the Langmuir isotherm model and the monolayer biosorption capacity of MAP was found to be 21.69 mg g<sup>-1</sup> by using the Langmuir isotherm model. The investigation carried out on thermodynamic parameters indicated that the biosorption of Cd(II) ions onto MAP was feasible, spontaneous, and endothermic in nature. Taking into account of the findings of this study, it can be concluded that the natural MAP can be used as an effective, economical and easily available biosorbent in removal of Cd(II) ions from aqueous solutions by using the present biosorption process.

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