Original Article

Antioxidant activity and characterization of fruit peels and its application as a low-cost biosorbent for removal of lead ions Pb(II)

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ABSTRACT

A study performed in 2011 found that about 30% of the total quantity worldwide of food waste was fruit peels. The fruit peel wastes are very beneficial because of their phytochemical products and heavy metal adsorbent activity. Eleven samples of fruit peel wastes of some massively consumed local fruits were characterized for total phenolic and flavonoid content, and antioxidant capacity and evaluated as adsorbents to remove Pb(II) ions from aqueous solutions under different conditions of pH, contact time, adsorbent dose, and initial metal ion concentration. From a comparison study, it was found that the most efficient samples were apple and watermelon peels. The maximum adsorption capacities (qmax) for apple and watermelon peels were 52.36 and 76.34 mg/g, respectively, indicating that watermelon peels were more efficient. Comparative studies between the two peels revealed that the free energy E-value was 12.59 and 13.099 kJ/mol, respectively. Fourier transform infrared spectroscopy (FTIR) analysis revealed that hydroxyl and carboxyl groups were responsible for metal adsorption. The results concluded that apple and watermelon peels had a reasonable biosorption capability to remove lead ions from aqueous solutions.

KEYWORDS: biosorption, fruit peels, phytochemical compounds, heavy metals.

INTRODUCTION

Fruits and vegetables are highly consumed due to their micronutrients, dietary fibers and are thus considered as an important component of a healthy diet that plays a sophisticated role in the prevention of various diseases [1]. According to FAO (Food and Agriculture Organization), about 1.3 billion tonnes of food are wasted globally each year [2]. A study done in 2011 found that about 30% of the total quantity worldwide of food waste was fruit peels [3]. Fruit peel is one of the waste products that affect the environmental balance [4]. It was found that fruit peels are rich in carbohydrates, alkaloids, and phenolic compounds [3]. Thus they show antioxidant [5, 6], anti-inflammatory [7], antifungal, and antimicrobial [8] activities.

The rapid and continuous growth of industrial activities has resulted in a high risk of contamination of the environment. Heavy metal pollutants are of concern due to their nondegradability and potential toxicity to human health and the environment, even at very low concentrations [9]. Metals including Pb, Hg, Zn, As, Cd, Cu, and Ni are considered to be toxic substances. These metal ions are discharged from many industries [10, 11]. The Agency of Toxic Substances and Diseases Registry considers lead Pb(II) to be one of the primary hazardous pollutants [12]. Statistia [13] revealed that around 11.5 million metric tonnes of lead were consumed worldwide in 2020.

Several approaches are available for the removal of metals, including the membrane separation process,

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electrochemical precipitation, emulsion protraction, ion exchange, preconcentration, fertilization, and adsorption [14-16]. Along with these procedures, adsorption is considered the one of the most userfriendly mechanisms for metal removal and seems to be highly versatile and efficient if combined with compatible regeneration steps. Recently, enormous attention has been focused on the use of bio-based raw materials and their by-products as biosorbents for heavy metal removal since they possess hydroxyl, carboxyl, and other groups over their surfaces [17, 18]. Heavy metals such as Pb(II) show higher affinity towards fruit peels due to their surface properties (rough and porous), and high acidic sites and high varieties of functional groups make them suitable as adsorbents [4].

This study investigates the various uses of fruit peel wastes. The fruit peels serve as a rich source of phytochemical compounds and as a low-cost adsorbent for Pb(II) removal from wastewater. Therefore, the purpose of the present study is to evaluate the phytochemical efficiency of the selected fruit peels and the total phenolic and flavonoid contents, in addition to, antioxidant potential using DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity. After chemical extraction, the remaining plant material (marc) will be tested for its adsorption ability. Different adsorption models are used to find the fruit peels that are most effective in Pb(II) adsorption.

MATERIALS AND METHODS

Preparation of the bioadsorbants

Some of the common kitchen bio-wastes produced in large amounts each year including, apple (Malus domestica), pumpkin (Cucurbita moschata), banana (Musa acuminata), orange (Citrus aurantium), hernak (Physalis philadelphica), prickly pear (Opuntia ficus-indica), watermelon (Citrullus lanatus), mango (Mangifera indica), soursop (Annona cherimola), muskmelon (Cucumis melo) and papaya (Carica papaya) peels were collected after its edible part was consumed. The peels were washed under tap water several times followed by distilled water, then cut into small pieces, dried in a convection oven at 60 °C, then crushed, sieved to constant particle size, and stored in desiccators for further use. For estimating the total phenolic content, total flavonoid contents, and antioxidant

capacity, 50 g of each peel were peel type was extracted separately with 70% methanol in a beaker, with stirring at room temperature, and then filtered. The filtrates were evaporated using a rota-vapor to obtain the methanolic dry extract.

Determination of total phenolic content (TPC)

Total phenolic content was determined according to the Folin-Ciocalteu method [19]. An aliquot (150 µl) of 100 µg/ml of each type of fruit peel methanol extract was separately added to 0.5 ml of distilled water and 125 µl of the Folin-Ciocalteu reagent. The mixture was then shaken and allowed to stand for 6 min, before adding 1.25 ml of Na₂CO₃ (7%). The solution was then adjusted with distilled water to reach a final volume of 3 ml, mixed thoroughly, and then held in darkness for 90 min at ambient temperature. After incubation, the absorbance was measured at 760 nm. The TPC was determined in triplicate, and gallic acid (Sigma-Aldrich Chemicals Co., St. Louis, MO, USA) was used as a standard (from 50 to 250 mg/L) to produce the calibration curve. The results were expressed as gallic acid equivalents mg/g of dry plant weight.

Determination of total flavonoid content

The total flavonoid content (TFC) was determined using a colorimetric assay [20] based on the formation of a flavonoid–aluminum complex which has maximum UV (Ultra Violet light) absorption at 510 nm and using quercetin (Sigma–Aldrich Chemicals Co., St. Louis, MO, USA) as a standard for a calibration curve. 1 ml of the diluted sample (each extract, separately) was mixed with 1 ml of 2% aluminum chloride methanolic solution. After incubation at room temperature for 15 min, absorbance was measured. Results were taken in triplicate (the mean was used) and expressed as quercetin equivalents mg/g of dry plant weight.

DPPH radical scavenging activity

The free radical scavenging activity (RSA) of all extracts against DPPH was determined as described by Amari [21]. One mL of different concentrations of the samples was added to 0.25 mL of methanolic solution of DPPH (0.2 mmol/l) and allowed to react in darkness for 30 min. The absorbance was then read against a blank at 517 nm. Trolox was used as a reference. The assay

was carried out in triplicate and the percentage of inhibition was calculated using the following formula:

$$RSA\% = \frac{Blank_{(abs)} - Sample_{(abs)}}{Blank_{(abs)}} \times 100$$

Lead ion solution

Analytical grade Pb(NO3)2 (Merck) was used in the preparation of standard stock solution (1000 mg/L). The synthetic solution was then prepared by diluting this stock solution with deionized water.

Batch sorption experiments

Adsorption experiments for lead ions were performed at room temperature $(25.0 \pm 2 \text{ °C})$ in a batch-wise manner to study the effect of different parameters like contact time, pH value, sorbent dosages, and initial ion concentration of Pb(II). A comparison of metal uptake capacities of various peels was performed by using 0.5 g of each peel with the synthetic solution of Pb(II) ions with an initial concentration of 12 mg/L at a pH value of 5.5 ± 0.1 in a mechanical shaker at 150 rpm for 2 h. At this pH value, there would be little competition between metal ions and protons compared to lower pH values, which leads to high metal uptake. After agitation, the synthetic solution containing Pb(II) was filtered through a Whatman filter paper (No. 41) and the concentration of Pb(II) was determined in the filtrate to calculate the percentage of Pb(II) removal and the sorption capacity using the following equation [22].

Removal (%) =
$$[(C0 - Cf)/C0] \times 100$$
 (1)

where C0 and Cf are the initial and equilibrium concentration (mg/L) of Pb(II) ions in solution, respectively.

Kinetic and isotherm studies

The sorbent dosage was varied from 1-10 g/L using a fixed volume of 100 ml of 12 mg/L of Pb(II) solution. The sorption isotherms were measured by varying the initial Pb(II) concentration at the equilibration time and keeping the sorbent mass constant. Different sorption models described by Volesky [23] were used for comparison with experimental data. The kinetic studies were carried out by conducting batch sorption experiments with an initial Pb(II) concentration of 12 mg/L at different periods (15, 30, 60, 90, 120 min). Various models were evaluated to describe sorption kinetics. The rate of adsorption of Pb(II) on peels was measured by studying pseudo-first-order, pseudo-second-order, and intra-particle diffusion kinetics of adsorption.

Pseudo-first-order kinetic model

The kinetic data was achieved using the Lagergren first-order model [24, 25] which is the earliest known description of the adsorption rate based on the adsorption capacity. The integral form of the pseudo-first-order model is generally expressed as follows:

$$\log (qe - q) = \log qe - (k1, ads / 2.303) \times t$$
 (2)

where qe (meq/g) and q are the amounts of adsorbed metal ions on the adsorbent at the equilibrium and at any time t, respectively; and k1, ads is the Lagergren rate constant of the firstorder sorption (min -1). The model is based on the assumption that the rate is proportional to the number of free sites. If the pseudo-first-order kinetics is applicable, a plot of log (qe - q) versus t should provide a linear relationship from which k1, ads, and predicted qe can be determined from the slope and intercept of the plot, respectively. The rate variation should be proportional to the first power of the concentration for strict surface adsorption.

Pseudo-second order model

The pseudo-second-order model is based on the assumption that biosorption follows a secondorder mechanism, where the rate of sorption is proportional to the square of the number of unoccupied sites. This model has been widely applied to several metal/sorbent sorption systems [26, 27]. The linearized form of the equation is expressed as

$$t / qt = 1 / (k2, ads \times qe 2) + t / qe$$
 (3)

where k^2 , ads is the rate constant of pseudo-second-order sorption (g·mg⁻¹·min-1).

Intra-particle diffusion model

Diffusion mechanisms during the lead ion removal process cannot be identified with pseudo-first-order and/or pseudo-second-order models. Therefore, the intra-particle diffusion equation (4) has been applied to explain the process of removal that occurred on a porous sorbent of the adsorbents [28].

$$qt = ki t 0.5 + Ci \tag{4}$$

where *q*t is the removal amount of Pb(II) ions by the sorbent at time *t*, *k*i is the intra-particle diffusion rate constant (mg·g⁻¹·min^{-1/2}) that indicates improvement in the rate of uptake and Ci is the intercept of the line and contributes to intraparticle diffusion parameter which changes with the boundary layer thickness.

Isotherm modeling

Three different isotherms equations were selected for analysis in this study, which are the Langmuir, Freundlich, and Dubinin-Radushkevich (DKR) isotherms [29].

Equilibrium sorption experiments were performed for two types of peels (that showed the highest adsorption) at the optimum condition (time and dosage) of each adsorbent. Sorbent of 0.2 gm for both apple and watermelon peels were exposed to Pb(II) solution with an initial concentration of 25-400 mg/L at pH 5.0 - 5.5. Due to their simplicity, the Langmuir and Freundlich equations are the most widely used models to describe the relationship between equilibrium metal uptake (qe) and final concentrations (Ce) at equilibrium.

The Langmuir isotherm relationship is given as:

$$qe = (K \times qmax \times Ce) / (1 + K Ce)$$
(5)

where K (L/mg) is the equilibrium adsorption constant which is related to the affinity of the binding sites and qmax (mg/g) is the maximum amount of metal ion per unit mass of biosorbent when all binding sites are occupied. The Langmuir parameters can be determined from a linearized form of Eq (6) (by plotting Ce/qe versus Ce), represented by:

$$\operatorname{Ce} / q \operatorname{e} = 1 / (k \times q \operatorname{max}) + \operatorname{Ce} / q \operatorname{max}$$
(6)

The Freundlich equation is given by:

$$q\mathbf{e} = k\mathbf{f} \times \mathbf{C}\mathbf{e}\mathbf{1} / n \tag{7}$$

where kf and n are the Freundlich constants and are related to the adsorption capacity of the biosorbent and the adsorption intensity. To simplify the determination of kf and 1/n, Eq. 7 can be linearized in a logarithmic form which allows the determination of the unknown parameters by plotting $\log qe$ versus $\log Ce$:

$$\log q e = \log k f + 1 / n \times \log C e$$
(8)

The choice between Langmuir and Freundlich isotherms depends mainly on the nature of equilibrium data. In many equilibrium studies, the metal uptake data attains a plateau which corresponds to the Langmuir model (qmax).

Langmuir and Freundlich isotherms do not give any idea about sorption mechanism. The Dubinin– Kaganer–Radushkevich isotherm (DKR isotherm) is an analog of Langmuir type but it is more general because it does not assume a homogeneous surface or constant sorption potential [30]. The linearized DKR isotherm equation can be written as shown in the following equation:

$$\ln q e = \ln X m - \beta \epsilon 2 \tag{9}$$

where qe is the number of metal ions adsorbed per unit weight of adsorbent (mol/g), Xm is the maximum sorption capacity, b is the activity coefficient related to mean sorption energy, and ε is the Polanyi potential, which is equal to:

$$\varepsilon = RT \ln \left(1 + 1/Ce \right) \tag{10}$$

where *R* is the gas constant $(kJ \cdot mol^{-1} \cdot k^{-1})$ and *T* is the temperature (K). The saturation limit Xm may represent the total specific micropore volume of the sorbent. The sorption potential is independent of the temperature but varies according to the nature of sorbent and sorbate [31]. The slope of the plot of ln *q*e versus $\epsilon 2$ gives *b* (mol² kJ⁻²) and the intercept yields the sorption capacity, Xm (mol/g). The sorption space in the vicinity of a solid surface is characterized by a series of equipotential surfaces having the same sorption potential. The sorption energy can also be worked out using Eq. (11):

$$\mathbf{E} = 1 / \sqrt{-2\beta} \tag{11}$$

RESULTS

Characterization of peels

Total phenolic and total flavonoid contents (TPC, TFC), antioxidant activity (RSA%), percentage of lead removal (R%), and the sorption capacity of Pb(II) (Q mg/g) for the peels were examined and presented in Table 1. The TPC of both soursop

No.	Type of peel	TPC (mg GAE/g DW)	TFC (mg QE/g DW)	RSA%	R%	Q mg/g
1	Apple	$0.151 \pm 0.003*$	$0.106 \pm 0.001 *$	28	93.4	1.94 ± 0.01
2	Pumpkin	$0.282 \pm 0.003*$	$0.223 \pm 0.001 *$	48	80.3	1.56 ± 0.01
3	Banana	$0.192 \pm 0.001 *$	$0.152 \pm 0.003 *$	32	74.3	1.72 ± 0.01
4	Orange	$0.235 \pm 0.001 *$	$0.183 \pm 0.002*$	45	81.9	1.88 ± 0.04
5	Hernak	$0.176 \pm 0.002*$	$0.130 \pm 0.002*$	30	89.5	1.56 ± 0.02
6	Prickly pear	$0.151 \pm 0.003*$	$0.181 \pm 0.001 *$	33	74.3	1.66 ± 0.02
7	Watermelon	$0.221 \pm 0.001 *$	$0.068 \pm 0.001 *$	45	98.0	2.04 ± 0.01
8	Mango	$0.549 \pm 0.001 *$	$0.294 \pm 0.001 *$	88	68.6	1.44 ± 0.02
9	Soursop	$0.709 \pm 0.001 *$	$0.452 \pm 0.002 *$	87	74.3	1.56 ± 0.01
10	Muskmelon	$0.213 \pm 0.003*$	$0.288 \pm 0.001*$	50	86.7	1.82 ± 0.01
11	Papaya	$0.299 \pm 0.003 *$	$0.181 \pm 0.003*$	60	84.8	1.78 ± 0.01

Table 1. Total phenolic content (TPC), total flavonoid content (TFC), antioxidant activity (RSA%) and comparison of the percentage removal (R%) and the sorption capacity of Pb(II) (Q mg/g) for different peels using 12 mg Pb/L at pH 5.5 ± 0.1 for 2 hours.

*Results are mean values of three readings \pm standard deviation.

and mango, as estimated by the Folin-Ciocalteau reagent method regarding the standard curve gave the highest value of 0.709 and 0.549 mg GAE/g DW, respectively. TFC of soursop was the highest (0.452 mg QE/g DW) and that of watermelon was the lowest (0.068 mg QE/g DW). The antioxidant activity analyzed using DPPH radical scavenging showed that mango and soursop gave the highest value (88 and 87%, respectively) and apple gave the lowest activity (28%); notice that the other fruit peels showed approximate results. Comparing the adsorption capacity of the sorbents revealed that the Pb(II) removal by apple and watermelon peels at a dose of 0.5 g/L was most efficient and reached 93.8 and 98.0% respectively, attributed to 1.94 and 2.04 sorption capacity (Q mg/g) which reflects their extreme activities for removal of the metal ion contaminants (Table 1).

Kinetic modeling

It is essential to study the contact time between the adsorbents and lead ion solution for the determination of the equilibrium time. Results revealed that the removal of Pb(II) by apple and watermelon peels at a dose of 0.5 g/L was very fast with an efficiency that reached 93.8 and 98.0%, respectively within 15 min which reflects their extreme activities for removal of the metal ion contaminants. The reaction equilibrium was achieved within 90 min. for both apple and watermelon. Therefore, further experiments were carried out on apples and watermelon. Increasing the contact time from 90 to 120 min. was not associated with a significant increase in the removal efficiency. Thus, the contact time of 90 min was chosen to carry out the study.

In Table 2 it was observed that the first-order model failed to represent the actual value of qe of adsorbed Pb(II) since the experimental values of qe (0.0215 and 0.022 meq/g) were higher than the fitted value (0.0049 and 0.0047 meq/g) for apple and watermelon, respectively. This underestimation of the count of binding sites is likely because qe was specified from the yintercept (t = 0). This intercept is hardly affected by the low metal uptake, which is normally much lower than the uptake at equilibrium. This is considered as a common disadvantage of applying a linearized first-order model, where the firstorder adsorption reaction of Pb(II) onto the two peels is not suitable to characterize the whole process even when the correlation coefficient R2 is relatively high.

The linearized second-order plot of t/qt against t according to Eq. (3) showed straight lines for

Adsorbent	Pse	eudo-first o	rder kineti	Pseudo-second order kinetics			
type	q _e Exp. (meq/g)	q _e (meq/g)	k_1 (min ⁻¹)	\mathbf{R}^2	$q_{\rm e}$ (meq/g)	k_2 (g mg ⁻¹ min ⁻¹)	\mathbf{R}^2
Apple	0.02156	0.0049	0.0012	0.9767	0.02184	41	0.999
Watermelon	0.0224	0.0047	0.0781	0.9662	0.0229	33.84	0.999

Table 2. Characteristics of kinetic models for the removal of Pb(II) ions using apple and watermelon peels.



Figure 1. Intra-particle diffusion model for lead ion removal using 5 g/L of apple and watermelon peels at pH 5 - 5.5 and 25 ± 0.2 °C.

Pb(II) which enable the determination of the second-order rate constants (k2, ads) and qe from the slope and the y-intercept (Table 2). Calculated qe values which were very close to the experimental data are considered as a primary sign of the suitability of the second-order kinetic model. Notice that the R2 values for this model were 0.999 for the Pb(II) adsorption onto the two peels tested. The reaction of a divalent metal ion M binding to two free binding sites B can be explained using theoretical considerations (29, 30) described by the following expressions:

 $M + 2 B \longleftarrow B2M$ r = k [M] [B] 2

The eminent fit of this model showed that a 1:2 binding stoichiometry applies, where one divalent metal binds to two monovalent binding sites.

Figure 1 shows that the intra-particle diffusion of Pb(II) within the adsorbents occurred in two stages. The linear step corresponds to fast uptake by the adsorbents. The line in the initial stage doesn't pass through the origin and this means that the uptake is dominated by film diffusion for the intra-particle diffusion process. In the second stage, the

speedup of uptake by the sorbent reflects the nonconsecutive diffusion of the sorbate molecules within the sorbent.

Impact of adsorbent dosage

The impact of absorbent dose on Pb(II) removal is given in Figure 2. The amount of sorbents applied was changed from 1 to 10 gm/L (0.1 - 1g/100 ml), with agitation time 90 min and 12 mg/L as an initial Pb(II) concentration and at fixed temp. 25.0 \pm 2 °C and pH 5.0-5.5. The results revealed that the percentage of Pb(II) removal got higher with the rise in the adsorbent dose from 0.1 to 0.2 g for apple and watermelon peels. This may be a result of the elevation in the number of active sites ready for adsorption of metal [32] but the number remained almost unchanged when the adsorbent dosage was more than 0.2 g. This conclusion was expected because, for a fixed incipient solute concentration, an increasing amount of adsorbent provides greater adsorption sites (or surface area) where the concentration of both the surface metal ions and the solution of metal ions come to equilibrium with each other [33].



Figure 2. Removal of lead ions using different doses of apple and watermelon peels at an initial concentration of lead ions of 12 mg/L, pH 5.0 - 5.5 and 25 ± 0.2 °C.

Table 3. Parameter summary of isotherm models for Pb(II) ion adsorption on apple and watermelon peels.

Adsorbent	Langmuir model			Freundlich model			Dubinin–Kaganer–Radushkevich (DKR)			
	K L/mg	q _{max} (mg/g)	R ²	Kf	п	R ²	X _m (mol/g)	$\frac{\beta}{(\mathrm{mol}^2\mathrm{kJ}^{-2})}$	E (KJ/mol)	R ²
Apple	53.22	52.36	0.999	14.10	3.70	0.832	8.8x 10-4	-0.3024x 10-8	12.86	0.935
Watermelon	76.34	28.83	0.998	16.68	3.04	0.843	1.08x 10- 3	-0.2914x 10-8	13.099	0.898

Langmuir, Freundlich and DKR isotherm models

Adsorption isotherm study is essential and plays a fundamental part in the maximal capacity determination of adsorbents. For the adaption of the applied system, an appropriate model reproducing the experimental results obtained is presented in Table 3. In general, the Langmuir equation applies to adsorption isotherm studies on totally identical surfaces where interactions between adsorbed molecules are trivial and the Freundlich equation applies in the case of aqeous samples. The correlation factor is higher than 0.97 for the Langmuir model, which indicates a perfect representation of the experimental results upon using the Langmuir isotherms.

Dubinin–Kaganer–Radushkevich isotherms (DKR isotherms)

DKR parameters are calculated from the line slope and listed in Table 3. Results show that the

E values (kJ/mol) are 12.86 for apple and 13.099 for watermelon. These E positive values indicate that the sorption process is endothermic and in favor of higher solution temperature [34]. The E value ranged between 8-16 kJ/mol indicated that the sorption process onto two types of peels is an ion exchange [35].

FTIR analysis

It is fundamental to identify the functional groups (binding sites) of the adsorbent biomass implicated in the adsorption process. FTIR spectroscopy (Jasco FTIR-300E Model) was used to identify these groups present in apple and watermelon peels and to record the changes before and after the adsorption. The FTIR spectra of apple peel are shown in Figure 3a. The broadband in the 3500-3240 cm⁻¹ range corresponds to the O-H bond stretch of alcohols and that in the 3400-2400 cm⁻¹ range to O-H bond vibration of carboxylic acids. Sharp peaks at 2920 cm⁻¹



Figure 3. FTIR of apple peels (1) and watermelon peels (7) before and after adsorption of lead ions.

and 1730 cm⁻¹ correspond to C-H and C=O stretch, respectively. Stretching of C=C bond in aromatic rings gave absorption in the range of 1600-1585 and 1500-1400 cm⁻¹. FTIR of watermelon peels (Figure 3b) displayed a broad peak at around 3400 cm⁻¹ which corresponds to -OH stretching of carboxylic acids (pectin), peaks at 2918 cm⁻¹ are attributed to C-H of methyl and methoxy groups, and those at 1735 cm⁻¹ correspond to C=O stretching. The FTIR spectra of the two studied peels showed slight peak shifts after lead ion sorption. These shifts may be attributed to changes associated with hydroxylate and carboxylate ions suggesting the potential of these groups in lead ion uptake [36, 37].

DISCUSSION

Nowadays, providing safe drinking water is one of the main challenges that are faced by every nation on earth. Several methods have been advocated to remove toxic effluents from wastewater. Recently, adsorption, a biotechnological innovation process, has been considered as one of the most popular techniques for water cleaning due to its simplicity and convenience of having a wide range of applications in wastewater treatment in addition to being a cost-efficient and excellent tool for the removal of heavy metals from aqueous solutions [38]. It uses bio-based raw materials to bind contaminants *via* physio-chemical mechanisms [39].

Global concerns regarding the use of biological solid waste have necessitated the evaluation of fruit and vegetable wastes as potential bioremediation agents. The use of a load of abandoned parts of fruits and vegetables as an inexpensive and effective nonconventional biosorbent alternative to the costly conventional methods has been considered for the removal of heavy metals due to their good uptake, low cost and rapid kinetics. These agricultural wastes have basic chemical constituents that comprise different functional groups such as hydroxyl, amino, and carboxyl groups on their surfaces thus achieving the potential to bind ions and molecules [40].

This work aimed to use the fruit peels for their phenolic and flavonoid contents, in addition to their antioxidant activity and their potential as adsorbents to remove lead ions from aqueous solutions. This study used locally available fruit peel wastes collected for the treatment of polluted wastewater for a greener environment. Thus, the peels of some fruits that contain a variety of phenolic compounds were chosen, including apple [41], pumpkin [42], banana [43], orange [44], hernak [45], prickly pear [46], watermelon [47], mango [48], soursop [49], muskmelon [50] and papaya [51].

Results revealed that the fruit peels studied showed characteristic adsorbability to lead ions. Experimental studies have shown that chelation, adsorption, and ion exchange are important mechanisms for binding lead ions to the sorbents [52]. Carboxylic groups are mainly responsible for metal binding predominantly in an ion-exchange mechanism [53] or complexation or a combination of both [54]. In this study, apple and especially, watermelon peels which are mainly domestic biowaste produced in huge masses each year showed a remarkable rate of lead ion adsorption as it consists of pectin, citrulline, proteins, and carotenoids [55]. Pectin-rich plant materials have a higher ability for metal binding due to α -(1-4) linked Dgalacturonic acid which has a large number of carboxyl groups [56]. Lead ions among other metals have the affinity for cation-binding to pectin due to the interaction of divalent cations with pectin chains [57, 58].

CONCLUSION

Apple and watermelon peels could be employed as sorbent materials for heavy metal removal from industrial wastewater. Reutilization of watermelon peel as an adsorbent for lead ion removal may lessen the issue of toxic effluent disposal and subsequently increase economic profit to many industries. The use of fruit peel wastes for adsorption is in a nascent stage and requires further assessment.

CONFLICT OF INTEREST STATEMENT

No potential conflict of interest is reported by the author(s).

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