



Biosorption study of some heavy metals from its aqueous solutions by plant residue: 1-Adsorption equilibrium reaction

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Abstract

Some plant residues (Sidr leaves - Bamber leaves - Palm sap) were used to study their efficiency in the bioabsorption of several heavy metal ions (iron, zinc, and manganese) from solutions contaminated with heavy elements through studying some physicochemical properties and thermal equilibrium reactions in which the thermal equilibrium equation (Langmuir-Frondlage) was tested in the linear form. It was observed that the percentage of heavy elements (iron, zinc, and manganese) adsorption on the surfaces of plant residue particles (Sidr leaves, Bamber leaves, and Palm sap) increased with the decrease in the sizes of these particles, as the percentage of adsorption ranged from less than 100 and 100-200 and 200-300 microns. The highest adsorption percentage was (90.05, 89.61, 89.57, 90.15, 9.68, 89.29, 90.20, 90.06), 89.87) % of manganese ions on the surfaces of plant residues (Sidr leaves, Bamber leaves, and palm carob) respectively. There was an increase in the adsorbed amount with the increase in the initial concentration added to all elements (iron, zinc, and manganese) and all plant residues (Sidr leaves, Bamber leaves and palm carob), and the highest adsorbed amount was recorded at 52649.62 $\mu\text{g g}^{-1}$ of manganese on palm carob at the initial concentration of 400 $\mu\text{g ml}^{-1}$. Most of the elements took the following sequence in increasing adsorption on the surfaces of the adsorption sites: manganese > zinc > iron for all plant residues under study. A decrease was observed in the adsorbed amount of the studied elements per unit mass, as the weight of 1 gram of Sidr leaves gave the lowest adsorbed amount of iron and manganese, amounting to 3081.174 and 4550.667 $\mu\text{g g}^{-1}$ respectively. The Langmuir equation in its various forms gave the best description of the adsorbed amount through the values of the coefficient of determination R².

Keywords: Biosorption, Heavy metals, Plant residue, 1-Adsorption equilibrium reaction

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Introduction

Water resources in Iraq suffer from various types of pollution. This problem has two aspects: quantitative, meaning scarcity and lack of fresh water reaching Iraq, which has begun to decrease due to the control of the upstream countries, which increases the risk of water pollution in Iraq. The second aspect is qualitative, which results from human misuse of water and dumping of industrial, agricultural, and household waste into it (Al-Shammari and Al-Kanani, 2012).

Water pollution with heavy metals is one of the main and serious problems for the environment. The matter has become more complicated due to the growth of various industries and technologies and the toxins and chemical wastes that result from them, in addition to the great expansion in pesticide use and sewage and industrial water discharge. All of these activities will pollute water sources, especially surface water, groundwater, drain water, and wells, by mixing this polluted water with natural water with various types of pollutants, including toxic heavy metals (Al-Qasir, 2012).

The use of heavy elements in many industries such as the battery industry, fertilizers, various electronic industries, metal plating, and others has led to the pollution of the water discharged from these industries with many heavy elements and at concentrations that are consistent with the type of industry (Adelekan and Abegunde, 2011).

The pollution of the aquatic environment with heavy elements has become one of the major problems of importance in all countries of the world

due to their toxic effects. The danger of heavy elements such as lead, cadmium, nickel, copper, manganese, zinc, cobalt, chromium, and others comes from their toxicity and negative effects even at low concentrations. They represent dangerous environmental pollutants because they are not soluble in water enter the body through food or contaminated water do not dissolve within the tissues of living organisms and are transmitted through the food chain to humans, causing damage over time (Wahab and Al-Zubaidi, 2012; Al-Qaseer, 2012).

There are several treatments and methods described to get rid of heavy elements polluting the environment, and the best of these methods are adsorption and ion exchange, as adsorption is one of the important techniques for removing heavy elements from the environment (Cutierre and Moteno, 2008).

Rowell, 2006 concluded that there are many methods for removing pollutants from water, such as ion exchange, reverse osmosis, adsorption on activated carbon, and sand filters. He also showed the possibility of using plant residues, which are low-cost and available in large quantities, to remove mineral ions from polluted water (Giraldo-Gutiérrez and Moreno-Piraján, 2008; Yassen and Fakher, 2016).

Dry plant residues can remove some heavy elements from polluted solutions due to their high capacity to adsorb pollutants such as heavy elements. These plant residues include jujube, palm fronds, bamber, eucalyptus, palm fronds, rice husks, and other plant residues. They are considered the most low-cost option for filtration. They are materials used as a

good filter to remove pollutants from water, especially sewage, industrial water, and groundwater, due to their high adsorption capacity, availability in large quantities, and low cost (Dai, *et al.*, 2018; Al-Eid *et al.*, 2022).

The scarcity of fresh water and the high degree of pollution in well water in the southern regions of Iraq, especially in Basra Governorate, and its use in irrigating crops and the increasing demand for water for agricultural purposes under the dry and semi-dry conditions of the country's climate, this study aimed to achieve the following objectives: i. Study the absorption characteristics of Bamber, sidr, and palm kernel leaves for iron, zinc, and manganese ions, including the sizes of particles, initial concentration, and weight of plant residues ii. Test the thermal desorption equations of Incomer and Freindage in describing the equilibrium data.

Materials and Methods

1. Preparation of Plant Remains for the Study

1. Plant remains samples (Sidr leaves, Bamber leaves, and palm kernel) were collected and air dried for 15 days
2. Plant remains were washed with distilled water and then dried at 50 °C
3. Plant remains were ground and passed through sieves of different diameters, ranging from (less than 100, 100-200, 200-300) microns.

2. Preparation of Salt Solutions for Heavy Elements

Standard solutions for the studied elements (iron, zinc, manganese) were prepared by taking weights of the salts of

these elements with an initial concentration equal to 1000 μgml^{-1} by dissolving them in distilled water, then they were kept in tightly sealed plastic containers and stored in a refrigerator at a temperature of 250 until the laboratory experiments began.

3. Laboratory Experiments

Study the effect of the sizes of plant residue particles on the adsorbed amount

After passing through a series of μ sieves (less than 100, 100-200, 200-300) microns.

1. Weigh 0.2 gm of plant residues and then put them in plastic containers with a capacity of 100 ml.
2. Solutions of the studied heavy elements were prepared at a concentration of 40 g $\text{ml}^{-1}\mu$
3. Add 40 mL of each solution to the containers containing the plant residues and shake the samples in the mechanical shaker at a speed of 2000 rpm for an hour, then filter the samples through the filter paper. The concentration of heavy elements in the filtrate was estimated using the atomic absorption device. The amount of the element absorbed was calculated using the following equation:

$$X = \frac{(C_o - C_e) * V}{m} \quad \text{---(1)}$$

Where:

X: Adsorbed amount in $\mu\text{g gm}^{-1}$

C_o: Initial concentration g $\text{ml}^{-1}\mu$

C_e: Final concentration $\mu\text{g ml}^{-1}$

V: Volume mL

m: Weight of plant residue g

Study of the difference in initial concentration in the adsorption reaction

1. Take a weight of 0.2 g of plant residues (Sidr leaves, Bamber leaves, and palm carob)
2. Different concentrations of the studied heavy elements solutions were prepared according to the following concentrations (50, 100, 200, 400) gml-1 μ .
3. Add 40 ml of each solution of the studied elements to the boxes containing the plant residues
4. The samples were shaken in the mechanical shaker at a speed of 2000 rpm for one hour, and then the samples were filtered through filter paper.
5. Estimate the concentration of heavy elements in the filtrate using an atomic absorption device. Calculate the amount of the element absorbed as stated in paragraph (3-1) of Table 1.

Table 1: Thermal equilibrium equations studied.

Vocabulary (Constants)	Intersection of coordinates	Linear formulas	Equations	
$K_f = \exp(\text{intercept})$ $1/n = (\text{slope})$	$\ln q_e$ VS $\ln C_e$	$\ln q_e = \ln k_f + n^{-1} \ln C_e$	$q_e = K_f C_e^{1/n}$	Freundlich
$q_m = (\text{intercept})^{-1}$ $K_L = \text{intercept/slope}$	$\frac{C_e}{q_e}$ VS C_e	Type(I) $\left(\frac{C_e}{q_e}\right)$ $= \left(\frac{1}{q_m K_L C_e}\right) + \left(\frac{C_e}{q_m}\right)$		
$q_m = (\text{slope})^{-1}$ $K_f = \text{slope/intercept}$	$\frac{1}{q_e}$ VS $1/C_e$	Type(II) $\left(\frac{1}{q_e}\right)$ $= \left(\frac{1}{q_m K_L C_e}\right) + \left(\frac{1}{q_m}\right)$		
$q_e = -$ (intercept/slope) $K_f = -\text{slope}$	q_e VS q_e/C_e	Type(III) q_e $= q_m - \left(\frac{1}{K_L}\right) q_e/C_e$	$q_e = (q_m k_L C_e) / (1 + K_L C_e)$	Langmuir
$q_m = \text{intercept}$ $K_f = -(\text{slope})^{-1}$	$\frac{q_e}{C_e}$ VS q_e	Type(IV) $\left(\frac{q_e}{C_e}\right) = K_L q_m - K_L q_e$		

Symbols:

q_m : adsorption capacity $\mu\text{g g}^{-1}$

k_L : Langmuir constant $\text{ml } \mu\text{g}^{-1}$

$1/n$: S Freundlich

K_f : Freundlich constant freundlich ml g^{-1}

K_T : Constant enable temkin

D : Dubinin-Radushkevich constant $\text{mol}^2 \text{KJ}^{-2}$

BRP: Redlich-Peterson constant $[(L \mu\text{g}^{-1})]^\wedge\text{g}$

ARP: $L \mu\text{g}^{-1}$ Redlich-peterson constant

Results and Discussion

Effect Of Particle Sizes on the Adsorption of Heavy Elements

The results of Table 2 showed an increase in the percentage of adsorption of heavy elements (iron, zinc and manganese), as the percentage of adsorption on the surfaces of plant residue particles (sidr leaves, bamber leaves and palm carob) increased with the decrease in the sizes of these particles, as the percentage of adsorption ranged between 86.98-87.19 and 88.60-88.67 and 89.57-90.05% for iron, zinc and manganese elements for

sidr leaves, respectively, and between 86.84-87.57 and 88.11-88.78 and 89.29-90.15% for iron, zinc and manganese elements for bamber leaves, respectively, and 97.68-98.71 and 88.56-88.75 and 89.87-90.20% for iron, zinc and manganese elements for palm carob, respectively. The results in Table 2 show that the highest percentage of adsorption in all plant residues was at particle sizes with diameters less than 100 microns, while the lowest percentages of removal were at diameters between 200-300 microns, as the adsorption rate depends on the size of the adsorbent particles. The smaller the particle size, the larger the surface area, and thus the higher the adsorption rate (Valdés *et al.*, 2021). This is because the smaller the size of the particles and particles, the greater the adsorption efficiency due to the increase in the surface area available for adsorption with a decrease in the size of

the particles and the availability of opportunities for contact and association with heavy elements (Somsesta, Sricharoenchaikul and Aht-Ong, 2020; Yassin *et al.*, 2017).

When arranging plant remains according to their ability to adsorb heavy elements represented by iron and manganese, we find that they have taken the following order: - Palm kernels < Bamber leaves < Sidr leaves, while the results show that

Plant remains took the following sequence in the adsorption of zinc: bamber leaves < palm fronds < sidr leaves. This may be due to the internal structure of plant remains, as if these particles have a porous structure, which means an increase in the number of pores, they create an internal surface area that may have a greater role in adsorption (Malamis and Katsou, 2013).

Table 2: Percentage of removal of heavy elements studied by plant residues used with different particle sizes (microns).

Plant Residues	Diameter (Micron)	Heavy metals		
		Fe	Zn	Mn
Sider	100	87.19	88.67	90.05
	100-200	87.08	88.67	89.61
	200-300	86.98	88.67	89.57
Bamber	100	87.57	88.67	90.15
	100-200	87.38	88.67	89.68
	200-300	86.84	88.67	89.29
Palm grove	100	98.71	88.67	90.20
	100-200	98.08	88.67	90.06
	200-300	97.68	88.67	89.87

Effect of initial concentration of heavy elements on the adsorbed amount 4.2

The results shown in Tables 3, 4, and 5 showed the role of the initial concentration of the studied element ions in the adsorption efficiency on the surfaces of plant residues by increasing the adsorbed amount on the surfaces of

plant residues, as the adsorbed amount increased with the increase in the initial concentration added for all elements (iron, zinc, and manganese) and all plant residues (sidr leaves, bamber leaves, and palm carob). The highest adsorbed amount was 52649.62 micrograms g⁻¹ of manganese on palm carob at the initial

concentration of 400 micrograms ml⁻¹, while the lowest adsorbed amount was 4418.36 micrograms g⁻¹ of manganese on the surfaces of sidr leaves at the initial concentration of 50 micrograms ml⁻¹. The plant residues differed in the adsorbed amount of elements in addition to the difference between the elements in the amount of adsorption, as the plant residues took the following sequence in increasing the amount of adsorption of elements Palm kernel > Bamber leaves > Sidr leaves and the elements mostly took the following sequence in increasing adsorption on the surfaces of the adsorption sites: manganese > zinc > iron for all the plant residues under study. The adsorbed amount of palm kernel, Bamber leaves and sidr leaves ranged from (8457.08-52649.62), (6301.53-45682.77) and (4418.36-30432.71) $\mu\text{g g}^{-1}$ respectively, regardless of the adsorbed element. This may be attributed to the difference in the physical and chemical properties of the studied plant residues, as palm kernel contains organic cellulose

compounds such as lignin and hemicellulose, which act as absorption agents, in addition to containing minerals such as potassium, calcium, and magnesium, which can interact with some heavy elements. These results are consistent with what was reached by (Hossain and Ngo, 2012; Aziz and Hamzah, 2013). As for Bamber leaves, they have silica within their composition, which works to remove heavy elements from aqueous solutions (Zhang and Zheng, 2012). Sidr leaves are considered one of the effective methods for removing Heavy elements from water because they contain a group of chemicals that restore water balance and reduce heavy elements effectively (Anastopoulos, Ahmed and Hummadi, 2022; Godiya and Ruotolo, 2023). While the adsorbed amount of the studied elements (manganese, zinc, and iron) ranged (from 4418.36-52649.62) and (4973.63 -45341.37) and (6301.53-10881.90) $\mu\text{g g}^{-1}$ respectively, regardless of the type of plant residues.

Table 3: The adsorbed amount of the studied elements ($\mu\text{g g}^{-1}$) on the surfaces of Sidr leaves according to the different initial concentrations ($\mu\text{g ml}^{-1}$).

Concentration ($\mu\text{g ml}^{-1}$)	Iron	Zinc	Manganese
50	6622.47	5145.66	4418.36
100	7950.80	10177.00	8976.56
200	8180.15	20669.53	10392.77
400	9541.55	30432.71	20897.82

Table 4: Adsorbed amount of the studied elements ($\mu\text{g g}^{-1}$) on the surfaces of the leaves of the pamper plant according to the initial concentration ($\mu\text{g ml}^{-1}$).

Concentration ($\mu\text{g ml}^{-1}$)	Iron	Zinc	Manganese
50	6301.53	4973.65	6535.08
100	7801.00	8619.72	12361.37
200	8445.85	16847.29	25641.98
400	10142.15	30625.61	45682.77

Table 5: Adsorbed amount of the studied elements ($\mu\text{g g}^{-1}$) on the surfaces of palm kernels depending on the initial concentration ($\mu\text{g ml}^{-1}$).

Concentration ($\mu\text{g ml}^{-1}$)	Iron	Zinc	Manganese
50	8457.08	7247.47	8221.95
100	8793.40	11734.82	15912.384
200	9904.95	23341.56	25367.22
400	10881.90	45341.37	52649.62

Effect of Plant Residue Weight on the Amount of Heavy Metals Adsorbed

The level of addition of plant residues is an important factor in the adsorption process because it expresses the adsorption capacity of the adsorbent materials at the initial concentration of the element in the experimental conditions. We note from the results of Table 5 and 6 that there was a decrease in the adsorbed amount of the studied elements per unit mass, as the weight of 1 g of Sidr leaves gave the lowest adsorbed amount of iron and manganese, which amounted to 3081.174 and 4550.667 $\mu\text{g g}^{-1}$, respectively, while the same weight (1 g) gave the highest adsorbed amount of zinc, which amounted to 7052.597 $\mu\text{g g}^{-1}$. The weight of 1 g of Bamber leaves gave the lowest adsorbed amount, which amounted to 3830.743 and 4493.333 $\mu\text{g g}^{-1}$ of iron and manganese, respectively, while the weight of 0.2 g gave the lowest

adsorbed amount of zinc, which amounted to 4812.105 $\mu\text{g g}^{-1}$, while Palm kernel gave the highest adsorbed amount at 0.2 gm weight, reaching 6888.190 and 7171.545 $\mu\text{g g}^{-1}$ for iron and manganese elements, respectively, while it gave the lowest adsorbed amount for zinc at the same weight (0.2 gm), which reached 4767.125 $\mu\text{g g}^{-1}$. This gives the impression that the adsorbed amount of heavy elements is not proportional to the added level of plant residues (adsorbent material), as doubling the addition of the added level is not accompanied by a double increase in the binding adsorption sites. It is believed that there are two reasons for the decrease in the adsorbed amount of heavy elements, the first is related to the lack of complete saturation of the adsorption sites, and the second is related to the aggregation of particles, which leads to a decrease in the total surface area and an increase in the length of the diffusion path (Malamis and Katsou, 2013).

Table 6: Adsorbed amount of the studied elements ($\mu\text{g g}^{-1}$) on the surfaces of plant residues according to the added weight (g).

Plant Remains	Weights (g)	العناصر المدروسة		
		Fe	Zn	Mn
Sidr	0.2	6854.155	4765.325	7189.780
	0.4	3630.397	7010.390	4232.000
	0.8	3288.428	7044.805	4512.000
	1	3081.174	7052.597	4330.667
Bumper	0.2	7369.215	4812.105	7220.395
	0.4	7264.249	5450.667	5450.667
	0.8	6445.596	7197.403	4914.667
	1	3830.743	7236.364	4493.333
Palm grove	0.2	6888.190	4767.125	7171.545
	0.4	3810.017	7046.104	4402.667
	0.8	3336.788	7075.325	4350.667
	1	3132.988	7090.909	4293.333

Plant residues can be effectively utilized for the biosorption of heavy metals for treating (cleaning) contaminated water sources. The high capacity for uptake of metals at the levels observed in this study indicates that these

types of materials may be utilized in filtration systems or constructed wetlands in watershed cleaning. Plant residue biosorbents are inexpensive, biodegradable materials that could be used for environmental remediation on a

larger scale. Therefore, biosorption with plant residues represents a sustainable green option for reducing heavy metal pollution in aquatic environments.

Equilibrium Equations for Thermal Isotropy

Linear Equations

Knowing the relationship between the adsorbent and the adsorbent, which is known as thermal adsorption, is essential for experimental work. Linear equations are often used to obtain the best description of the thermal isotropy equilibrium. The most important equations were chosen to describe the data status of the heavy elements adsorbed on the surfaces of the studied plant residues, which have two constants such as the Langmuir and Freundlich equation. The data calculated from the interaction of heavy elements represented by iron, manganese and zinc with plant residues (leaves of the lotus, the pod and the palm kernel) were applied. Through the (Least square) method, the equations for thermal isotropy can be found. After subjecting the existing data to the description of these equations and calculating the coefficient of determination (R^2), the results showed that these studied equations, through the coefficient of determination R^2 , all succeeded in describing the nature of the interaction as shown in the results of Table 7, but they differed among themselves in giving the best description of the data through the relationship between the quantity The actual and calculated adsorption and the success of the studied linear equations in describing

the interactions of heavy elements on the surfaces of plant residues means the association of elements on the adsorption sites present in the plant residues, which may include all the adsorption methods described by these equations, but with varying proportions of these sites and associations on each surface (Al-Jassim, 2023).

The results showed that the Langmuir equation in the linear form (Langmuir III) for iron adsorption on the surfaces of Sidr leaves gave the best description of the nature of adsorption compared to other equations Table (7) as R^2 reached the highest value of 0.9980, followed by the Langmuir I equation in representing the data for iron adsorption on the surface of Sidr leaves.

When studying the adsorption of heavy elements (iron, zinc and manganese) on the surfaces of the pamper leaves through the linear formula of the equations, the Langmuir III equation gave the best description of the zinc element, Table (7), which gave R^2 values of 0.9970. In general, it can be said that the three linear equations gave a good and close description of the adsorption of iron on the surfaces of the pamper leaves, while the Langmuir II equation obtained the best description of the binding of the zinc element to the adsorption sites on the surfaces of the pamper leaves. The best expression of the adsorption reaction of the manganese element was achieved through the description of the Langmuir II equation on the surfaces of the pamper leaves, which gave R^2 values of 0.9980.

Table 7: Values of the coefficient (R2) for the adsorption equations for thermal isotropy in the linear formula for the studied elements on the surfaces of Sidr leaves, Bamber leaves, and date palm carob.

Palm grove			pamper leaves			Sidr leaves		
R2	The equation	The element	R2	الصيغ الخطية المعادلة	The element	R2	The equation	The element
0.9977	Langmuir I	Fe	0.9930	Langmuir I	Fe	0.9948	Langmuir I	Fe
0.9515	Langmuir II		0.8752	Langmuir II		0.8439	Langmuir II	
0.9980	Langmuir III		0.9970	Langmuir III		0.9980	Langmuir III	
0.5043	Langmuir IV		0.8226	Langmuir IV		0.8121	Langmuir IV	
0.9515	Freundlich		0.8752	Freundlich		0.8439	Freundlich	
0.5045	Langmuir I	Zn	0.8385	Langmuir I	Zn	0.8562	Langmuir I	Zn
0.9704	Langmuir II		0.9918	Langmuir II		0.9968	Langmuir II	
0.4316	Langmuir III		0.7649	Langmuir III		0.6452	Langmuir III	
0.4316	Langmuir IV		0.7649	Langmuir IV		0.6452	Langmuir IV	
0.9089	Freundlich		0.9139	Freundlich		0.9140	Freundlich	
0.6240	Langmuir I	Mn	0.7774	Langmuir I	Mn	0.7140	Langmuir I	Mn
0.9929	Langmuir II		0.9980	Langmuir II		0.9554	Langmuir II	
0.6622	Langmuir III		0.7560	Langmuir III		0.7110	Langmuir III	
0.5975	Langmuir IV		0.7602	Langmuir IV		0.6926	Langmuir IV	
0.9868	Freundlich		0.9964	Freundlich		0.9341	Freundlich	

When the equations were subjected to the linear form to describe the adsorption of heavy elements on the plant residue sites represented by palm kernels, the Langmuir III equation was distinguished in giving the best description of the iron element through the high values of the coefficient of determination R^2 (Table 7), while the Langmuir II equation was the best in describing the reaction of the zinc element on the surfaces of palm kernels. Also, the Langmuir II equation had succeeded in clarifying the nature of manganese adsorption, which gave values of the coefficient of determination R^2 of 0.9929, respectively. Through these results, we note that the adsorption equations for thermal symmetry differed in their ability to describe the adsorption

reaction of heavy elements represented by iron, zinc and manganese on the surfaces of plant residues used in the study. Therefore, it can be said that the surfaces of plant residues contain different adsorption sites that differ in containing the binding site according to their composition and the nature of the binding (physical and chemical) as well as the nature of the presence of binding sites on the surfaces or in the gaps in addition to the difference in the type of ion of the adsorbed element (Yassin, Omran and Hassan, 2017). These results are consistent with what (Al-Jassim, 2023) reached, which attributed the reason for the success of the thermal adsorption equations used represented by Langmuir with its four hypotheses and

the Freundlich equation in describing adsorption on the surfaces of plant residues to the fact that the adsorption reaction that occurs between heavy elements and plant residues under study contained more than one type of binding due to the difference in the nature of the sites and the composition of the adsorbent materials and the difference in heavy elements and thus the difference in affinity between the sites and heavy elements. Thus, different bonds were formed from them in the form of a layer. Of the ions, which were represented by the description of the Langmuir equation for the interaction, which took the largest part of the connection, and there were other connections that included heterogeneous sites and overlapping energy and in more than one layer, in which the Freundlich equation succeeded in describing them.

Using more of these cheap, sustainable materials can lower our reliance on chemical adsorbents and energy-intensive treatments. Using sustainable materials for environmental pollution control advances the principles of a circular economy and sustainable remediation.

Conclusions

The particles with diameters less than 100 microns of plant residues (Sidr leaves, Bamber leaves, and palm carob) achieved the highest percentage of adsorption of the studied heavy elements (iron, zinc, and manganese). The plant residues took the following order according to their ability to adsorb heavy elements represented by iron and manganese: Palm carob < Bamber leaves < Sidr leaves. While the results show that the plant

residues took the following sequence in the adsorption of zinc: Bamber leaves < Palm carob < Sidr leaves. The adsorbed amount also increased with the increase in the initial concentration added to all elements and to all plant residues. The plant residues differed in the amount of elements adsorbed in addition to the difference between the elements in the amount of adsorption, as the plant residues took the following sequence in increasing the amount of adsorption of the elements: Palm carob > Bamber leaves > Sidr leaves. Most of the elements took the following sequence in increasing adsorption on the surfaces of the adsorption sites: Manganese > Zinc > Iron for all plant residues under study. The amount of absorbed elements differed according to the weight of the plant residues, as the amount of absorbed heavy elements was not proportional to the added level of plant residues (the adsorbent), as doubling the addition of the added level was not accompanied by a double increase in the binding adsorption sites. The Langmuir thermal equilibrium equation was also superior in providing the best description of the thermal adsorption of the studied data compared to the Freundlich equation for most of the heavy elements and plant residues studied. Compared to filtration and chemical-based methods, biosorption using plant residues has distinct advantages: it is inexpensive, less polluting, and removes metals efficiently even at low concentrations. In addition, the materials are reusable, making the method even more sustainable and applicable in developing countries.

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