Chapter

Potential Use of Agro/Food Wastes as Biosorbents in the Removal of Heavy Metals

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Abstract

The production of large quantities of agro/food wastes from food processing industries and the release of pollutants in the form of heavy metals from various metallurgical industries are the grave problems of the society as well as serious threats to the environment. It is estimated that approximately one–third of all food that is produced goes to waste, meaning thereby that nearly 1.3 billion tonnes of agro/food wastes are generated per year. This readily available and large amount waste can be utilized for the removal of toxic metals obtained from metallurgical industries by converting it into the adsorbents. For example, mango peel showed adsorption capacity of 68.92 mg/g in removing cadmium II ions. Similarly, coconut waste showed a higher adsorption capacity of 285 and 263 mg/g in removing cadmium and lead ion, respectively. Biosorption and bioaccumulation are recommended as novel, efficient, eco-friendly, and less costly alternative technologies over the conventional methods such as ion exchange, chemical precipitation, and membrane filtration, etc. for the removal of toxic metal ions. Because of the presence of metal-binding functional groups, the industrial by-products, agro-wastes and microbial biomass are considered as the potential biosorbents. Thus they can be used for the removal of toxic metal ions. This chapter highlights the available information and methods on utilizing the agro/food waste for the eradication of toxic and heavy metal ions. Furthermore, this chapter also focuses on the sorption mechanisms of different adsorbents as well as their adsorbing capacities.

Keywords: agro/food wastes, heavy metals, adsorption, biosorption, wastewater

1. Introduction

The generation of large quantities of agro/food wastes by various means of food processing industries and the release of high amount of heavy metals into the environment through various industrial activities such as refining ores, metal plating, fertilizer industries, batteries, mining, and tanneries, etc. are very serious increasing problems of the society as well as they are grave threats to the environment [1–3]. It is estimated that worldwide, around 39% of food is wasted in the food manufacturing industries and this is expected to rise to about 126 million tonnes by 2020 if proper prevention polices are not put in place [2, 4]. Similarly in India a large amount of agro/food wastes are generated every year. Nearby about 20% of the produced fruits and vegetables are wasted because, India is the second largest producer of fruits, vegetables, groundnut, sugarcane, rice, wheat and cotton.

As the production increased, it also increased the percentage of wastes generated from them [5, 6]. This readily available, cheap, and large amount of waste could be utilized for the removal of heavy metals from the effluents as bioadsorbents either in their natural form or in modified form. So the idea of utilization of agro/food wastes for the removal of heavy metals can suppress both the aforementioned problems to a great extent. Some of the industries such as paper, electroplating, metallurgy, textiles, batteries, metal plating, dyes, pesticides, and fertilizers, etc. are the major contributors of heavy metals into the wastewater [7]. These industries directly or indirectly discharge the heavy metals into the environment, especially in developing countries. The discharge of heavy metals like mercury (Hg), iron (Fe), chromium (Cr), lead (Pb), nickel (Ni), cadmium (Cd), cobalt (Co), zinc (Zn), copper (Cu), arsenic (As) etc. from industries is hazardous to humans [8]. These heavy and toxic metals are a serious concern and are threats to environment due to their toxicity, persistence in nature, and bio-accumulation tendency [9]. Several reputed and standard organizations have set the limits for the release of toxic metals into the water streams. But the addition of heavy metals into the aquatic stream at a higher concentration is increasing day by day by the various industrial activities, thus it increases the human health hazards and environmental pollution. Two tragedies namely, Minamata and Itai-Itai (Jintsu River) occurred in Japan because of the contamination of methyl-mercury and cadmium in aquatic streams [3, 10].

In the past several years various conventional techniques have been used for the eradication of toxic metal ions such as ultrafiltration, reverse osmosis, oxidation, ion exchange, chemical precipitation, reduction, and electrodialysis [11]. But these conventional methods are mainly associated with certain limitations, such as they produce large amount of sludge, are less efficient, are sensitive in operating conditions and are of costly disposal [12]. Thus, the use of agro/food wastes material and by-products of fruits and vegetables such peel, pomace and seeds as a bioadsorbents for the eradication of toxic metals is an emerging and potentially alternative method and in the recent years this method has gained much attention. This technique has several advantages over the conventional method such as low cost, high efficiency, produces less sludge, and regenerates biosorbents [13]. Various types of agro/food waste materials such as sugarcane bagasse, wheat bran, rice bran, rice husk, orange peels, coffee beans, hazelnut shells, groundnut shells, wheat husk, waste tea leaves, maize corn cob, apple peels, banana peels, coconut shells, sugar beet pulp, soybean hulls, cotton stalks etc. have been tried by several researchers for the eradication of heavy metals [14–16]. The agro/food waste materials, especially those containing cellulose, show a high biosorption capacity. Their components such as lignin, hemicellulose, starch, lipids, proteins, hydrocarbons and other functional groups expedite metal complexation that helps in the removal of heavy metals [17]. Because of the several advantages that are associated with the agricultural waste as mentioned above it seems to be a viable option for the removal of heavy metals. These readily available, low cost, promising agro/food waste materials can be effectively utilized for the eradication of various toxic metal ions either in their natural form or after some modifications [18].

2. Conventional methods for the eradication of toxic metal ions

Several conventional methods are readily available for the removal of heavy metal ions present in effluents that come from different sources. These conventional methods can be classified as physical, chemical, and biological [19]. In the past several years, various industries were extensively using physical and chemical methods, but nowadays, they do not prefer these traditional methods due to several reasons associated with them such as high cost and disposal problems. Membrane filtration, gravity concentration, adsorption, flotation, mechanical screening, and magnetic separation are some of the physical methods. Membrane filtration can be further classified as electrodialysis, reverse osmosis, ultrafiltration, and nanofiltration. In comparison to membrane filtration and adsorption, adsorption has been considered the appropriate and effective method for the removal of heavy metals because most of the times membrane separation is associated with several problems such as fouling. Chemical methods include electrochemical processes, coagulation, electro kinetic coagulation, irradiation, and electroflotation [20]. These chemical methods are efficient for removing the heavy metals from the effluent but they are very expensive and commercially unattractive. Like physical methods, these chemical methods are also associated with several limitations such as; they require high energy and high consumption of chemical reagents. Several studies have reported that both the physical and chemical methods are not much effective and economical towards the removal of heavy metals especially when the metals are present in low concentration [21, 22]. Some of the researchers have also used metal and metal oxide nanoparticles for water decontamination and purification [23]. Biological methods or bio removal is one of the alternative methods which can effectively reduce the concentration of heavy metals to environmentally tolerable levels at a reasonable cost [24]. In the past several years a large number of studies were conducted for the eradication of toxic metal ions from the waste water by utilizing the various products and by-products of plants [18, 25, 26]. They have also confirmed the efficacy of agricultural products or by-products as sorbents for the removal of metals. Further, they have recommended that this process is a good and efficient alternative for the removal of heavy metal but only if the adsorbents are inexpensive and do not require any pre-treatment before the application. Besides the several advantages of biological method, various other authors have also highlighted its drawbacks such as, it requires large area and has less design flexibility and lesser modes of operation. Further, it has also been recommended that this process is not favourable for the handling of large amount of effluent [27]. In order to overcome the drawbacks associated with the above mentioned techniques, several researchers have recommended the biosorption method as an economical and environmental friendly method. Biosorption is not only a method for the eradication of heavy metals but it is also an example of the potential use of bio waste (agro/food waste). Formation of adsorbent by using agro/food waste is a cheap, economical, environmental friendly, and simple to design method and moreover it does not produce any toxic and dangerous material [18].

3. Biosorption and its classification

It is a process that utilizes the biological material or components as adsorbents for the eradication of toxic metal and non-metal ions, and small particulates from the wastewater, which come from numerous industries such as ore refining, metallurgic, fertilizer, paper, batteries, etc. The biological materials that are used as adsorbents in the process of biosorption are called as biosorbents. They can be classified as natural, biological, and waste oriented as shown in **Figure 1**. Some of the natural adsorbents that are having the good properties of an adsorbent are clay, zeolite, and siliceous material and they are easily available in the ecosystem [28]. Most of the biological adsorbents emanate from microorganisms which include bacteria, fungi, algae, and yeast [20]. Other than these, some of the biological adsorbents obtained from biological sources such as chitin and chitosan, peat, and

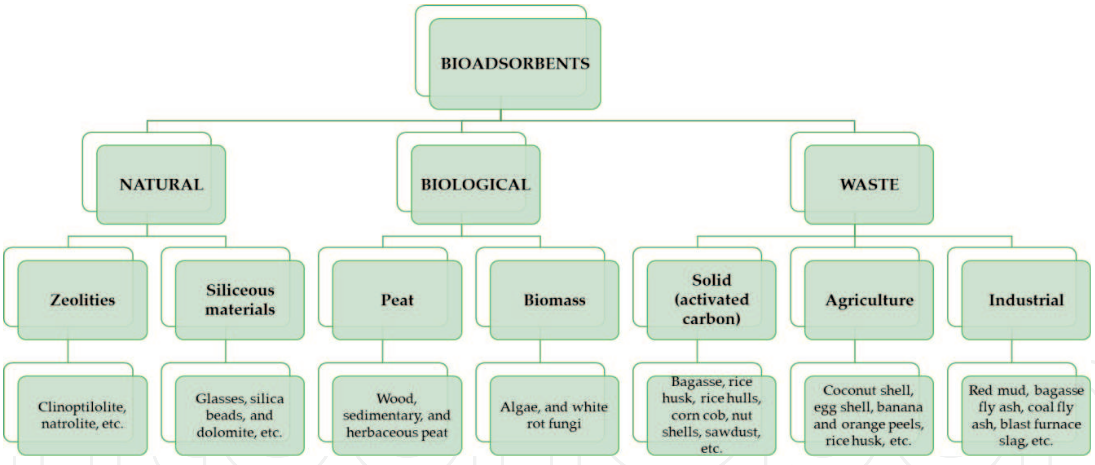

Figure 1.
Classification of bioadsorbents and their examples.

biomass. Waste oriented adsorbents include, bagasse, nutshells, sawdust, sugar beet pulp, bamboo and cassava peel, rice husk, orange and banana peels, egg shell, corn stack, etc. to name a few that come from solid waste, agricultural waste, waste from fruits and vegetables peels, and industrial waste [28]. Some of the examples of natural, biological and waste oriented bioadsorbents are indicated in **Figure 1**.

4. Biosorbents from agro and food waste

Agricultural waste, pulp, peels and seeds of fruits and vegetables are the discarded waste material and due to its several properties it may have a wide range of application in the removal of heavy metal ions. Generally, the agricultural waste having cellulose shows a high metal biosorption capacity. The ingredients of agricultural waste such as proteins, lipids, lignin, hemicelluloses, starch, hydrocarbons, and functional groups facilitate metal complexation which helps in the removal of heavy metals [29]. Several studies reveal [20, 26, 30] that this low cost, readily available, renewable, efficient, and eco-friendly waste material seems to be a feasible option for the removal of toxic metal ions. In the past several years, research has been carried out for the eradication of toxic metal ions using several bioadsorbents that come from agro and food waste such as wheat bran, rice bran, coconut shells, wheat husk, rice husk, saw dust of various plant, maize corn cob, arjun nuts, black gram husk, sugar cane bagasse, coffee beans, apple peels, banana peels, orange peels, sugar beet pulp, and grapes stalks etc. [12, 14, 18, 28, 31]. They have been used either in their natural form or after some modification (may be physical or chemical).

5. Biosorption mechanisms

The mechanism of biosorption is a complex process which involves the binding of sorbate onto the biosorbent [17]. Various materials that are found natural including agricultural wastes can be used as biosorbents which involve the binding of metal ions by several mechanisms including chelation, complexation, ion exchange, chemisorption, reduction, precipitation, and adsorption on the surface and pores [32, 33]. **Figure 2** shows the different mechanisms involved in the biosorption phenomenon. Bisorbents especially made from agro and food waste contain several compounds

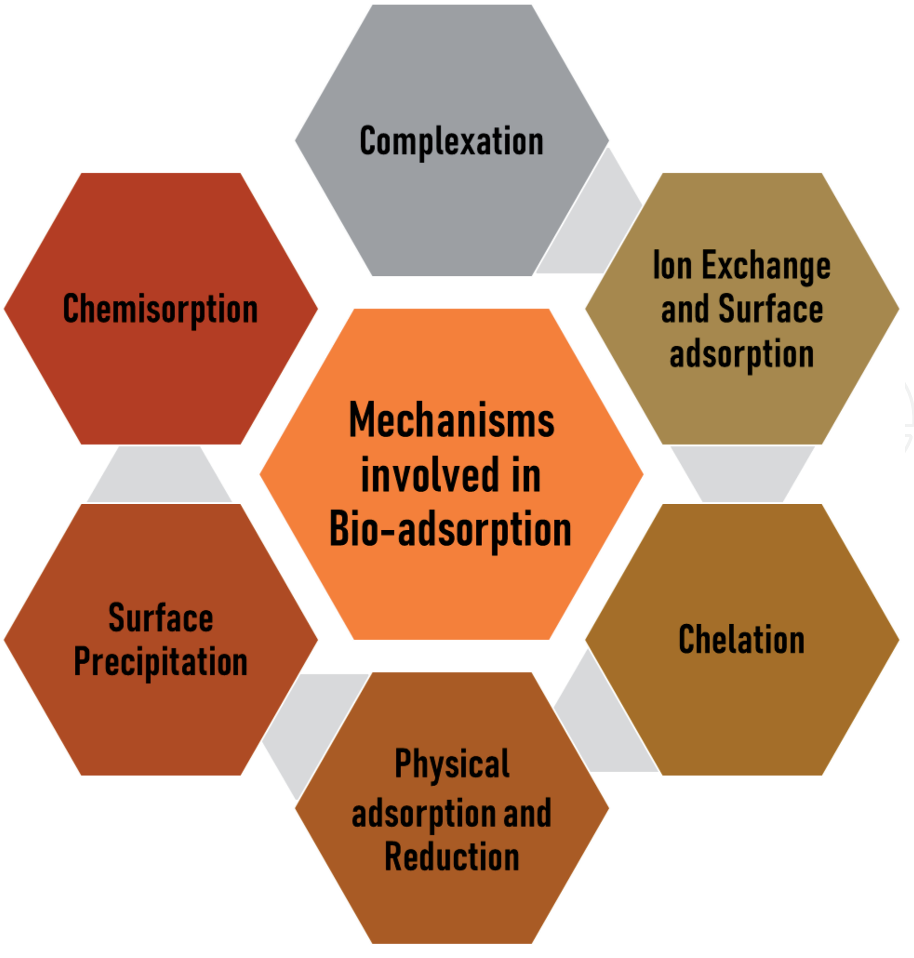

Figure 2.
Various mechanisms involved in bioadsorption process.

such as starches, cellulose, simple sugar, hemicellulose, lignin, proteins, hydrocarbons and various functional groups such as carbonyl, amine, amide, sulfonate, carbonyl, phenolic, carboxyl groups, alcohols, and esters that can attract and isolate the metal ions. In the past several years many researchers have confirmed the presence of the aforementioned functional groups in the biosorbents and furthermore, they have also reported their complexation with heavy metals during the biosorption process [34, 35]. Some of the factors that help in controlling and characterizing the mechanism of biosorption are given in **Figure 3**.

5.1 Chelation

It is a mechanism in which an organic complex agent (chelate) binds the metal ions at more than one place at a time in order to form a ring structure. The molecules on an organic compound that form these types of coordination are called as ligands and the ligands—metal association is referred as coordination complex [36]. An increase in the coordination complexes on mineral surfaces weakens the bond of the metal or cation to the crystal lattice resulting in the dissolution. Chelates form several binding with the metal ion at more than one place as compared to the complexes, therefore, chelates are more stable. In the past several years various studies have reported the application of this mechanism for the eradication of toxic metal ions from the waste water that was obtained from different sources [17]. For example, in one study, for the eradication of Cd (II) from the wastewater rice straw has been used successfully as a potential biosorbent [37].

Figure 3.
Factor affecting the mechanism of bioadsorption.

5.2 Complexation

It is a process in which two or more species are associated and they form a complex. When the complexes of metal ions and the ligands are formed in such a way that the single metal atom enjoys the central position then it is called a mononuclear complexes. When more than one metal ion is present in the centre they form a polynuclear complex [38]. During the formation of polynuclear complexes, on the basis of number of binding ligands involved the metal atom may hold a positive, negative, or neutral charge. Several studies have confirmed that the formation of complexes by the mononuclear ligands is more desirable than polynuclear ligands because the latter contains multiple ligands results multiple species binding.

5.3 Chemisorption

Chemical adsorption is also known as chemisorption. It is a process of adsorption which involves a chemical reaction between the surface and the adsorbate. Mainly, it occurs when the adsorbate and adsorbent are attracted via a chemical bond or due to the chemical forces of attraction [39]. During the process of chemisorption only a single layer of adsorbate on adsorbent is formed and this process has high enthalpy of adsorption. With a rise in temperature, the rate of the process of chemisorption first increases and then decreases.

5.4 Ion exchange

This process also plays a vital role in adsorption. During the biosorption process it exchanges the binary metal ions with the counter ions present on the surface of the biosorbent. Various systems that are readily available for the purification of water, work on the ion exchange mechanism. The process of ion exchange generally takes place either by cation or anion exchange. Amino groups are one of the good examples of anion exchangers while carboxyl groups represent the cation exchangers [28]. Several studies have reported the ion exchange mechanism of biosorption using various agro/food waste such as watermelon rind, rice straw etc. for the eradication of toxic metal ions such as chromium, Cu (II), Zn (II), Pb (II), and cadmium [17, 40].

5.5 Surface precipitation

It is a process in which the metal ions present in the aqueous solution form precipitates with the functional groups that are present on the surface of the microbial cells due to which the metal ions remain intact with the microbial cell. Organic and inorganic metal precipitates are generally formed during the process of adsorption. Use of microbial cells forms the organic metal precipitates, that occur due to the excretion of extracellular polymeric substances. In several other cases, insoluble inorganic metal precipitates are also formed. Several studies have reported the involvement of surface precipitation mechanism using the husk of green tomato, soybean meal, and watermelon rind for the eradication of Cu (II), Cu (III), Pb (II), Zn (II), Fe and Mn [41, 42].

5.6 Reduction

Reduction is also an important mechanism of adsorption that plays a vital role in the biosorption of various heavy metals such as gold and palladium. During the process of reduction the metal connects with the functional group, gets reduced, and undergoes the growth of crystals. The metal that is reduced binds the biosorbent at various places. The eradication of numerous heavy metals such as chromium, gold, palladium etc. can be done easily by the process of reduction. For example, by using the process of biosorption, removal of Cr (VI) can be done easily by reducing it into Cr (III) from the aqueous solution [17].

6. Involvement of functional groups in adsorption process

Several types of functional groups are generally involved in the process of adsorption namely, hydroxyl, amino and carboxyl groups [43]. These groups play an influential role in the metal adsorption process. The heavy metals are more efficiently absorbed by the phenolic, lactonic, and oxygen functional groups as compared to the other groups. During the formation of adsorbent the temperature and high degree carbonization majorly affects the mechanism of these functional groups but the other factors such as porosity, surface area, increase in pH, etc. do not alter the mechanism of these groups [28]. Several authors have confirmed the potential role of functional groups in the adsorption process by using the FTIR (Fourier Transform Infrared Spectroscopy) [44]. Low temperature pyrolysis retains the functional groups inside the sample whereas, an increase in temperature during the pyrolysis may lead to the loss of the functional group. For example, when the wood and grass feedstock biomass is heated below 100–200°C then its FTIR spectra shows no prominent change in their functional groups [45]. Some of the external parameters such as pH change the complexity of functional groups when they undergo certain mechanisms. The carboxyl group works efficiently in the adsorption process at the pH range 3–4. Beyond this pH the carboxyl group of biosorbent forms a complex with the positively charged metals after deprotonation. Several authors [17, 33, 35] have observed the changes in the functional groups of adsorbent before and after the adsorption of metals. Various interactions such as complexation, precipitation, cation exchange, electrostatic interaction and chemical reduction have an intrinsic effect to make the process of eradication of heavy metal successful. The functional groups like hydroxyl (-OH) and carboxylate (-COOH) available on the surface of bio char have strong interaction with heavy metals [28].

7. Role of agro/food waste as biosorbents for the eradication of toxic metal ions

Utilization of agro and food waste as biosorbents for the eradication of toxic metal ions from the wastewater and aqueous streams is a promising and innovative technology [35]. In the past several years, this promising technology has gained more attention because these waste materials have shown a higher efficacy towards the removal of heavy metals and the other reasons include low cost, and easy availability. The efficacy of agro/food waste depends upon its phsico-chemical nature, capacity of adsorption and affinity. A lot of research has already been carried out for the removal of heavy metals such as arsenic, lead, mercury, cadmium, chromium, nickel, cobalt, etc. by using various types of biosorbents namely rice husk, wheat bran, peels of apple and banana, etc. [14, 46–48]. They have used biosorbents either in the natural form or in modified form by thermal and chemical treatment to increase their sorption capacities.

7.1 Removal of cadmium

Cadmium metal and its ions are the most severe pollutants because they are highly soluble in water as compared to the other toxic metal ions. Therefore, they are easily mobile in soil and have a higher tendency to bioaccumulate. Some of the basic sources that produce cadmium into the environment include solid waste, sewage irrigation, plastics, application of fertilizer, mining, plating on steel, etc. [49]. If the human body is exposed to cadmium for a long time it may result in severe diseases such as bone damage, kidney and lung cancer [50]. Rice husk, rice bran, wheat bran, black gram husk, rice polish, fig leaves, jack fruit, and orange peels, are some of the waste materials that have shown the excellent efficiency towards the removal of Cd. Several studies have been tried using these materials for the eradication of Cd either in their natural form or in the modified form. In addition, potato peels, olive branches, Musa paradisiacal peels, and coconut waste have also been extensively used for the removal of Cd. The adsorption capacity of coconut waste for the removal of Cd (II) was found to be 285.70 mg/g while, the adsorption capacities of other material such as potato peels, olive branches, and Musa paradisiacal peels, were found to be 125, 38.17, 10.0 mg/g, respectively [15]. Therefore, coconut waste has shown the highest adsorption capacity as compared to the potato peels, olive branches, and Musa paradisiacal peels. Some of the waste materials have shown higher adsorption capacity when they were used at acidic pH namely, fig leaves, medlar peels, beans, and jack fruits [51, 52]. Some of the research work that has already been done for the removal of Cd using various agricultural wastes is presented in **Table 1**.

7.2 Removal of Chromium

Chromium is a naturally occurring heavy metal found in the earth's crust. It can be released into the environment either through the natural process or by manmade industrial activities. Industrial activities include wood preservation, tanning, textile manufacturing, pigments, paints, and dyes manufacturing. Chromium is generally found in a number of oxidation states but Cr (III), and Cr (VI) are the largest threat to the environment [42, 84]. In the last two decades, a lot of researches have been done by using various agricultural wastes such as orange, lemon and banana peels, soybean and rice hulls, hazelnut and peanut shells for the removal of chromium metals and ions from different types of wastewater [26, 85]. These waste materials have shown significant chromium removal efficiency as shown in **Table 1**. Other than these waste materials, neem leaves powder, cactus leaves, coconut shell fiber, and pine needles have also shown a promising efficiency in the range 90–100% for the removal of chromium at optimum pH [71]. Wheat brans have showed the highest adsorption capacity for Cr (VI) at 310.58 mg/g whereas, rice bran is a lesser effective adsorbent for the removal of Cr with only up to 50% efficiency [86]. Saw dust, bagasse, rice husk, and mustard oil cake have also been tried by numerous researchers for the removal of chromium and they have reported significant efficiencies in literature [85].

7.3 Removal of nickel

The removal of nickel is also of great interest due to its high toxicity and its presence in various types of industrial wastewater and effluents. Nickel may enter into the environment by natural and industrial sources. Some of the industrial sources include batteries, coloured ceramics, nickel plating, power plants and trash incinerators [87]. Nickel and its compounds have no taste and odour. Various types of agricultural waste materials such as saw dust of maple, hazelnut and groundnut shell, and waste tea leaves, etc. have been used for the removal of nickel from the effluents either in natural or modified form. These waste materials have shown a very promising and significant efficacy for the removal of nickel. For example, the bagasse of sugarcane showed more than 80% removal efficiency in its natural form for nickel [88]. Similarly, other agro and food wastes such as corncobs, soybeans, cotton seeds, and coir fibers have also been tried by various researchers for the eradication of nickel in their modified form [78, 83]. *Acacia leucocephala*bark has shown the highest adsorption capacity for nickel at 294.10 mg/g and *Cassia fistula* biomass in its natural form has shown the removal efficiency of 99–100% for nickel [15, 73].

7.4 Removal of lead

Various activities such as finishing of tools, steel and cable reclamation, manufacturing of plastics, formation of cathode ray tubes, ceramics and soldering are the major sources of lead discharge into the environment [89]. Large exposure of lead results in various harmful biological effects and it strongly binds itself with the particles of oil, sediments, and sewage sludge due to which its removal has gained much attention. Various types of agro/food waste materials have been used for the removal of lead such as orange peel, chitosan, rice husk, walnut shells, peanut, lemon grass *(Cymbopogoncitratus)*, groundnut (*Arachishypogaea)*,

Heavy Metal Ion	Agro/Food Waste	Efficiency	References
Cd (II)	Wheat bran	>82%	[16]
	Bagasse	90–95%	[53]
	Green coconut shell powder	98%	[54]
	Rice bran	>80%	[55]
	Black gram husk	99%	[56]
	Rice husk	80–97%	[57]
	Papaya wood	98%	[58]
	Wheat bran	87.15%	[59]
	Rice polish	>90%	[59]
	Bagasse fly ash	90%	[60]
Pb (II)	Rice bran	>80%	[55]
	Waste tea leaves	92%	[12]
	Apple residue waste	Nearly 80%	[61]
	Orizasativa husk	98%	[62]
	Black gram husk	Nearly 93%	[63]
	Maple saw dust	80–90%	[64]
	Saw dust of rubber wood	85%	[35]
	Activated carbon of peanut shells	Nearly 75%	[65]
Cr (III)	Oat biomass	>80%	[66]
	Jatropha oil cake, maize corn cob and sugarcane bagasse,	Up to 97%	[9]
Cr (VI)	Wheat bran	>82%	[16]
	Raw rice bran	40–50%	[67]
	Rubber wood saw dust	60–70%	[68]
	Beech saw dust	100%	[69]
	Coconut shell fibers	>80%	[70]
	Neem leaf powder	>96%	[71]
	Bagasse fly ash	96–98%	[72]
Ni (II)	Sugarcane bagasse	>80%	[9]
	Casia fistula biomass	100%	[73]
	Saw dust of oak	70–90%	[74]
	black gram husk	Nearly 93%	[63]
	Tea waste	86%	[75]
	Maple saw dust	75%	[76]
	Waste tea leaves	92%	[12]
	Mustard oil cake	Nearly 94%	[77]
	Defatted rice bran	57%	[78]
Cu (II)	Mango saw dust	60%	[79]
	Wheat shell	99%	[80]
As (III)	Charred saw dust	80%	[81]
	Rice hush	Nearly 71%	[82]

Heavy Metal Ion	Agro/Food Waste	Efficiency	References
Zn (II)	Coir fiber	>70%	[83]
	Black gram husk	Near about 93%	[63]
	Defatted rice bran	87%	[78]
	Rice bran	>80%	[55]
	Bagasse	Near about 95%	[53]
	Papaya wood	67%	[58]

Table 1.
Performance of several agricultural wastes for the removal of toxic metal ions.

Toxic Metal Ions	Agro/Food Waste	Adsorption Capacity (mg/g)	References
Cr (VI)	Almond shell	3.40	[85]
	Banana peel	131.56	[14]
	Walnut shell	1.33, 8.01	[85]
	Hazelnut shell	8.28	[85]
	Coconut waste (puresorbe)	285.70	[30]
	Nut shell	1.47	[92]
	Pea waste	21.2	[93]
	Saw dust	10.01, 16.05	[20]
	Pinusroxburghii bark	4.15	[94]
	Groundnut husk	7.0	[95]
	Bael fruit	17.27	[96]
	Wheat bran (Chemically modified)	93.00	[16]
	Wheat bran	310.58	[28]
	Groundnut husk (Ag coated)	11.40	[95]
	Wheat straw (Chemically modified)	322.58	[97]
	Wheat straw	21.34	[97]
Cd (II)	Rice husk	73.96	[98]
	Banana peel	35.52, 5.71	[99, 100]
	Rice husk (H_3PO_4 treated)	102.00	[47]
	Wheat bran	22.78, 21.00, 15.82	[101, 102]
	Wheat bran (Ultrasonic treated)	51.58	[102]
	Wheat straw	39.22, 21.00,14.56, 11.60	[103, 104]
	Wheat straw (Urea treated)	4.25	[103]
	Orange peel	47.60	[105]
	Mango peel	68.92	[106]
	Tea waste	11.29	[35]
	Rice husk (Alkali treated)	125.94	[98]
	Orange peel (chemically modified)	136.05	[105]
	Raw coffee powder	15.65	[35]

Toxic Metal Ions	Agro/Food Waste	Adsorption Capacity (mg/g)	References
Cu (II)	Wheat bran	8.34	[80]
	Rice husk (acid treated)	29.00	[89]
	Orange peel	50.94	[105]
	Peanut hull pellet	12.00	[107]
	Sago husk ash	12.40	[108]
	Orange peel (chemically modified)	70.67	[105]
	Potato peel ($ZnCl_2$ treated)	74.00	[109]
	Peanut hull	21.25	[110]
	Mango peel	46.09	[106]
	Chestnut shell	12.56	[111]
Ni (II)	Mango peel	39.75	[106]
	Guava seed	18.05	[112]
	Pomegranate peel	52.00	[113]
	Orange peel	158.00	[114]
	Tea waste	73.00	[12]
Pb (II)	Wheat bran (chemically modified)	62.00	[16]
	Hazelnut shell	28.18	[91]
	Mango peel	99.05	[105]
	Coconut (coir pith waste)	263.00	[90]
	Rice husk (acid treated)	108.00	[89]
	Wheat bran	87.00	[115]
	Chitosan	8.30	[91]
	Banana peel	2.18	[100]
Zn (II)	*Cicerarientinum*seed	20.00	[116]
	Wheat bran	16.40	[48]
	Mango peel	28.21	[106]
	Tea waste	8.90	[117]

Table 2.
Biosorption capacities of different agricultural waste and plant products for the eradication of toxic metal ions.

and coir pith waste of coconut [15, 89]. The absorption capacity of coir pith waste of coconut and chitosan is found to be 263.0 mg/g and 8.3 mg/g respectively as shown in **Table 2** [90, 91]. Biosorption capacities of various other agro/food wastes against the removal of toxic heavy metal ions are presented in **Table 2**.

8. Conclusions

The existing physical and chemical methods for the removal of heavy metals have severe limitations such as they require various chemicals, are energy intensive, costly to operate, produce large quantities of sludge whose disposal is a big problem etc. Therefore, there is a need of some alternative method which can attractively remove the toxic metal ions in the best possible way. In this regard biosorption is an attractive alternative method to remove the toxic metal ions effectively from the effluents that are generated from various industrial activities. This method has proven itself to be efficient and environmental friendly. It solves the problems of the health and environmental hazards of heavy metals in our ecosystem and the utilization of huge quantities of agro/food waste. The use of agricultural wastes as bioadsorbent is recommended because of their sustainability, easy availability, low cost, and high affinity towards the removal of heavy metals. Numerous studies have recommended the use of several agro and food wastes such as wheat bran, coconut shell, rice bran, wheat husk, and rice husk, etc. either in their natural form or after some modification for the removal of chromium, cadmium, cobalt, nickel, lead, etc. In literature very few details are available regarding the modification and regeneration of biosorbents, about the pore size distribution of adsorbent, recovery of metal ions, and molecular size of metal ions. Thus, a lot of work is still required to be done in this direction in the coming days for the effective transformation of agro/food waste into the biosorbents.

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