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Review

Maize plant (*Zea mays*) as a source of potential adsorbents: A review

*Moyo M and Okonkwo OJ

Department of Environmental, Water, and Earth Sciences, Tshwane University of Technology, Private Bag X680, Arcadia, Pretoria 0001, South Africa.

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Maize plant *(Zea mays)*, provides one of the most staple food in most countries. In recent times, the non-edible parts of the maize plant have attracted much interest as a source of potential low cost adsorbents. These non-edible parts are currently discarded as wastes in most developing countries. This article provides a selective overview of past and present scenario of biosorption process carried out using maize plant adsorbents such as maize tassel, maize cob and husk, leaves and maize stalk which have demonstrated an amazing ability in the sorption and recovery of heavy metals from simulated aqueous, non-aqueous solutions and waste-water from industries. Various factors are considered when choosing a sorbent to be adopted at large scale and these are availability, cost, renewability and sorption capacity. Factors that affect the biosorbent such as pH, initial concentration, agitation rate, sorbent dosage and temperature were discussed. Future perspectives related to the use of these biosorbents in making electrochemical sensors have been suggested.

Key words: biosorption, maize tassel, maize cob, maize leaves, maize stalk, recovery, heavy metals

INTRODUCTION

Rapid urbanization and industrialization of the world has been leading to accumulation of vast number of contaminants in our environment. Heavy metals hold a superlative position in that list and are responsible of contaminating soil, air and water in many parts of the world (Nriagu, 1988; Bontidean et al., 2004; Verman and Singh, 2005; Liu et al., 2007). The treatment of these polluted sources, for example, wastewater involves recuperative techniques such as solvent extraction, adsorption, filtration, precipitation, ion exchange, biological treatment and destructive techniques such as ozonation and oxidation for the removal of pollutants from gaseous and liquid phases (Karbassi et al., 1994; Lakatos et al., 2002; Doyurum and Celik, 2006; Muruthan et al., 2006). However, there are a number of challenges to be addressed in order to fulfill the applications of these methods. Some of the challenges such as incomplete metal removal, high reagent requirements, high regeneration cost, intraparticle resistance in adsorption process and poor mechanical strength of adsorbents have been highlighted (Aravindhan et al., 2009; Kumar, 2009). Given these disadvantages, efforts have now been geared towards introducing low cost biomaterials that can serve as alternatives for the biosorption of environmental pollutants.

Coresponding author E-mail: moyom@msu.ac.zw Tel.: +27-83-984-7553.

Biosorption process and its advantages

Biosorption is a bioremediation technique of removing toxic metal ions or metalloid species, compounds and particulate substances particularly from industrial effluents by biological material (Ting and Sun, 2000; Riordan et al., 2001; Diniz and Volesky, 2005, Volesky, 2007). Das et al. (2008) further asserts that the process involves a solid phase (sorbent or biosorbent; biological material) and a liquid phase (solvent, normally water) containing a dissolved species to be sorbed (sorbate, metals ions). Sorption of heavy metals on the surface of the biomaterials occur through different functional groups such amino, carboxylic, hydroxyl, phenolic, ester, sulfhydryl and phosphate (Wang and Chen, 2009). This is further supported by Zvinowanda et al. (2009), who characterized maize tassel and found out that it contains functional groups such as -OH, NH_2, C=O, C=C, -COOH and phenolic groups. The sorption process continues till equilibrium is established between the amount of solid-bound sorbate species and its portion remaining in the solution. The distribution between the solid and liquid phase is determined by the degree of sorbent affinity for the sorbate. The foremost advantages of biosorption technology over conventional treatment include low cost, high efficiency of metal removal from dilute solution, minimization of chemical and/or biological sludge, no additional nutrient requirement, regeneration of biosorbents and the possibility of metal recovery (Gadd, 1993; Kratochvil and Volesky, 1998).

Classification of biosorbents

Some potential biomaterials, which have emerged as eco-friendly, effective, low cost and with high metal-binding capacity have been identified in part. Among those biosorbents, are marine green algae e.g., *Chlorellan vulgas* (Aksu and Kutsal, 1991), *Sargassum sp.* (Antunes et al., 2003; Cossich et al., 2004), *Eclonia* (Park et al., 2006), *Spirogyra* (Gupta et al., 2001), *Lyngbya putealis* (Kiran et al., 2006); bacteria e.g., *Pseudomona sp.* (Addour et al., 1991); *Saprophyticus* (Ilhan et al., 2004); fungi e.g., *Rhizopus arrhizus* (Preetha et al., 2005); *Aspergillus* (Kapoor et al., 1995; Kapoor and Viraraghavan, 1999); yeast e.g., S. cerevisae (Bakkaloglu et al., 1998) and agricultural by-products such as rice husk (Wong et al., 2003), wheat bran (Ozer and Ozer, 2004). During recent decade, maize plant as a source of potential adsorbents such as leaves (Babarinde et al., 2006; Babarinde et al., 2008; Kamsonlian, 2011), stalks (García-Rosales and Colín-Cruz , 2010), cobs and husks (Igwe et al., 2005; Abia and Igwe, 2005; Akporhonor et al., 2007; Igwe and Abia, 2007; Opeolu et al., 2009) and tassels (Zvinowanda et al., 2009; Dadzie et al., 2011) has attracted significant attention for the removal of heavy metals. The following section of this review focuses on the advantages of maize plant as a source of adsorbents, physicochemical characterization of maize plant adsorbents and discussion of optimum parameters required for metal removal from aqueous and non-aqueous solutions by maize plant derived adsorbents.

ADVANTAGES OF MAIZE PLANT AS A SOURCE OF BIOSORBENTS IN METAL BIOSORPTION

Maize is a versatile cereal crop that is grown widely throughout the world in a range of agro-ecological environments. Maize is a fast growing, vigorous and tall (2 – 3 m) cereal crop having broad (5 – 10 cm), long (50 – 100 cm) leaves. Maize forms from 16 to 22 leaves per plant (Wuana and Okieimen, 2010). Tassel, the male inflorescence of the maize plant forms at the top of the stem and provides the pollen for fertilizing the "ear" (also known as a cob). Maize usually forms a single ear (or cob). Cobs are usually 15 to 39 cm long. Generally, maize plant is the most important cereal crop in sub-Saharan Africa (SSA) and an important staple food for more than 1.2 billion people in SSA and Latin America (IITA, 2010). Most parts of the maize plant including tassel has no value after fertilization and farmers involved in seed production usually cut off the tassel after pollination period. The leaves and stalk after harvesting are usually cut into pieces to make manure or left to decay on the ground. Waste management in most developing countries have often recommended the use of the maize residues for animal feeds (Oseni and Ekperisin, 2007), power generation (Patel and Kumar, 2010) and anaerobic production of biogas (Eze and Osike, 2012). Maize plant adsorbents are generally regarded as safe and can be easily accepted by the public when applied practically, hence there is a need to make better use of the different adsorbents in environmental management for removal of heavy metals.

PHYSICOCHEMICAL CHARACTERIZATION OF MAIZE PLANT ADSORBENTS

Few researchers have characterized the physicochemical of the maize plant derived adsorbents. Zvinowanda et al. (2009) used the Brunauer-Emmett-Teller (BET) isotherm to experimentally model N_2 adsorption data (up to a relative pressure of 0.30); the results indicated that the powdered tassel was mesoporous with a BET specific surface area of 2.52 m^2/g, for the 150-300 µm fraction. Laser diffraction pattern analysis yielded particle size distributions of varied fractions. The Scanning Electron Microscopy (SEM) of the tassel showed that the tassel was flattish, with very minimal porosity whilst the leaves powder revealed a highly porous structure (Kamsonlian et al., 2011). Generally, the Fourier Transformation Infrared Spectrometry (FTIR) displayed functional groups such as aliphatic ethers, aliphatic primary amines, primary aliphatic alcohols, carboxylic acids, alkenes and phenolic groups on the surface of tassel and leaves (Zvinowanda et al., 2008; Kamsonlian et al et al., 2011). These were believed to act as metal-binding sites for cationic species during sorption analysis.

UTILIZATION OF MAIZE PLANT ADSORBENTS FOR SORPTION OF HEAVY METAL IONS

Maize cob and husk

Raw, modified maize cob and husk powder has been used to model the removal of heavy metal ions from aqueous solution (Table 1). In their study involving agricultural waste by-products, Igwe and Abia (2003) have shown that maize cob and husk can be used as adsorbents for the removal of Cd (II), Pd (II) and Zn (II) ions from aqueous solutions. Sorption data for the metal ions fitted the Freundlich isotherm model. In another study, Igwe and Abia (2005) reported on the sorption kinetics and intraparticulate diffusivities of Cd, Pb and Zn ions on maize cob. The fractional attainment of equilibrium followed the order Zn^{2+}, Pb^{2+} ion and then lastly Cd^{2+} ion. The mechanism of sorption has been deduced to be particle diffusion controlled. The rate coefficients for particle diffusion were 0.07 min^{-1} for Zn^{2+}, 0.053 min^{-1} for Pb^{2+} and 0.081 min^{-1} for Cd^{2+}.

The possibility of modifying an adsorbent has attracted much interest among many researchers. Igwe et al. (2005) reported on the competitive adsorption of Zn (II), Cd (II) and Pb (II) ions from aqueous and non- aqueous solution by maize cob and husk. Before modification, the maximum adsorption occurred at 495.9 mg/g for Zn^{2+} ion, 456.7 mg/g for Pb^{2+} ion and 493.7 mg/g for Cd^{2+} ion. Adsorption efficiency of each metal ion was influenced by factors such as the presence of other metal ions, presence of non-aqueous solvent and modification by carboxymethylation. Igwe and Abia (2007) reported a study based on equilibrium sorption isotherm studies of Cd (II), Pb (II) and Zn (II) ions detoxification from waste-water using unmodified and EDTA-modified maize husk. The prepared maize husk was found to have an excellent adsorption capacity for metal ions. The adsorption capacity of maize husk after modification with ethylenediamine tetra acetic acid (EDTA) was increased due to the chelating ability of (EDTA). The sorption data fitness obtained followed the order of the Dubinin-Radushkevich isotherm, the Freundlich isotherm and then the Langmiur isotherm. Igwe and Abia (2007) also demonstrated that modified and unmodified maize cob could be used to remove Co (II), Fe (II) and Cu (II) ions from waste water and also the mechanism of sorption was established.

In another study, chemically modified maize cobs were explored to remove metal ions (Akporhonor and Egwaikhide, 2007). Maize cob carbon was prepared by pyrolysis at 300 and 400°C for 35 min, steeping in saturated ammonium chloride before sorption studies. Sorption data for the metal ions obeyed the Langmuir isotherm with accumulation following the order $Zn^{2+} > Ni^{2+} > Cd^{2+}$ in terms of binding capacities. These results suggested the formation of homogenous monolayer of the heavy metals on the surface of the activated carbon and indicated that the binding of the heavy metals may be caused by interaction with functional groups present on the absorbent. This experimental work demonstrated that carbonized maize cobs were found to be good adsorbents for heavy metal ions.

Recently, maize cobs were used as an adsorbent in order to evaluate their potential for the removal of lead in aqueous solutions and effluents from battery and paint industries (Opeolu et al., 2009). The sorption data obtained fitted the Freundlich model. Adsorption removal of the Pb^{2+} by maize cob from battery effluent was 99.99% while it was 47.38% for Dowex. Results from the paint effluents were 66.16 and 27.83% for maize and Dowex respectively. The authors concluded that maize cob has the potential to remove Pb^{2+} from aqueous solutions and industrial effluents and the results implied that maize cobs may also decontaminate waste-waters containing other divalent metal ions.

Maize leaves and stalks

Utilization of raw dried maize leaves powder and cut pieces as solid phase sorbents for metals have been explored by many researchers (Table 2). Babarinde et al. (2006) studied the viability of using maize leaves as adsorbent for the removal of lead ions from dilute aqueous solution. The authors demonstrated that metal ion concentration has an effect on adsorption capacity showing that biomass adsorbed the lead ions from solution. The amount of adsorbed Pb (II) ions increased with the increase in initial metal ion concentration. Sorption data for the metal ion obeyed both the Freundlich and the Langmuir isotherms. In another study, Babarinde et al. (2008) showed that the biomass from maize leaves can provide a cheap and effective method for removal of Zn (II) from aqueous solution. The adsorption isotherms fitted well into both the Freundlich and Langmuir isotherms. The removal of Cd (II) from dilute aqueous solution using maize wrapper as a biosorbent was reported (Babarinde et al., 2008).

Recently, powdered maize leaves biomass have been used for the removal of As (III) ion from aqueous solution utilizing the biosorption process (Kamsonlian et al., 2011).The authors deduced that the mechanism of adsorption involved functional groups such as aliphatic ethers, aliphatic primary amines and primary aliphatic alcohols present on the surface of maize leaves biomass. The Freundlich isotherm was better fitted with the experimental data. A kinetics and thermodynamics study on the adsorption of As (III) was demonstrated. The adsorption kinetics data were well fitted by the pseudo-second-order rate model with high regression coefficients (R^2 =0.997). The negative value of Gibbs free energy (ΔG^0) represented the feasibility and spontaneous nature of biosorption onto the surface of maize leaves. The positive sign for change in enthalpy (ΔH^0) and entropy (ΔS^0) indicated that As (III) ion biosorption was endothermic.

Maize stalk, on the other hand has also been used for sorption of heavy metals such as Pb (II) from aqueous solution. The Freundlich model was found to describe the sorption energetics of Pb (II) by maize stalk sponge (García-Rosales and Colín-Cruz, 2010). The kinetics of Pb (II) sorption onto maize biosorbent were described by the pseudo-second-order equation (R^2=0.9998). The results obtained showed that maize stalk sponge was a

Table 1. Properties of dried, powdered maize cobs and husks used to study removal of metal ions from aqueous and non-aqueous solutions.

Mode of sorbent	Experimental conditions	Sorption capacity/binding capacity	Isotherm obeyed	Application of sorbent	Remark	Reference
Maize cob and husk	2 g adsorbent, initial concentration 1000 mg/L Cd(II), Pb(II) and Zn(II), pH 7.5, shaking time 10 min.	Unmodified cob and husk Zn^{2+} (495.9 mg/g), Pb^{2+} (456.7 mg/g), Cd^{2+} (493.7 mg/g).	-	Aqueous and non-aqueous solutions.	Amount of adsorbed metal ions was decreased as a result of modifying the adsorbent in aqueous solution, the presence of non-aqueous solution decreased the amount of metal adsorbed but an increase in the concentration of non-aqueous did not have an appreciable effect on the amount adsorbed.	Igwe et al. (2005)
Maize cob	2 g dosage, 2 000 mg/L, contact time 10 min.	Zn^{2+} (71%), Cd^{2+} (32%), Pb^{2+} (30%).		Aqueous solutions.	A plot of ln(1-α) against time showed straight lines indicating that sorption process for Zn^{2+}, Cd^{2+}, Pb^{2+} ion is particle diffusion controlled.	Abia and Igwe (2005)
Maize cob-derived activated carbon	1 g carbonised dosage, carbon pH 6-8, shaking time 60 min, initial concentration 2-60 mmol/L.	At 400°C (Zn^{2+} 0.368, Ni^{2+} 0.136; Cd^{2+} 0.110); at 300°C (Zn^{2+} 0.214; Ni^{2+} 0.124; Cd2+, 0.101).	Langmuir isotherm	Synthetic laboratory solutions.	Increase in temperature of carbonisation increases the amount of metal ions absorbed.	Akporhonor and Egwaikhide (2007)
Modified and unmodified maize husk	2 g dosage, contact 1 hr, pH 7.5, concentration 2 000 mg-1 000 mg/L.	Zn (II) > Pb (II) > Cd (II).	Dubinin-Radushkevich isotherm.	Wastewater.	Modification by EDTA enhanced the adsorption process, sorption was found to be a physiosorption process.	Igwe and Abia (2007)
Raw maize cob, Dowex	0.4 g dosage, 30 min-3.0 hr sorption time, pH 2-8, 20-600 mg/L Pb^{2+}, agitation 150 rpm.	Pb^{2+} (99.99%), Dowex (47.38%) in battery effluent, Pb^{2+} (66.16%), Dowenex (27.83%) in paint effluent	Freundlich Isotherm.	Battery effluents, Paint effluents.	Enhanced adsorption with increasing pH from 2 to 8, initial metal concentration tends to have no effect on maize cob adsorption of Pb^{2+} which is consistent with other sorbents such as cassava, and yeast.	Opeolu et al. (2009)

α is the fractional attainment of equilibrium

Table 2. Batch studies of metal ions using dried leaves.

State of maize leaf biosorbent	Batch optimum conditions	Maximum removal capacity	Analysis method	Remark	Reference
Dried cut pieces	0.5 g, pH 3, contact time 30 mins.	Pb (II) (95-100%).	Atomic absorption spectrophotometer.	Adsorption capacity of maize leaves found to be comparable to that of brown marine algae and *Aspergillus niger*.	Babarinde et al. (2006)
Dried cut pieces	0.5 g sorbent, pH range 4-7, contact 40 mins, initial concentration 100 mg/L, temperature 27 °C.	Zn (II) 94-96%.	Atomic absorption spectrophotometer.	Biosorption capacity of maize leaves increased with pH, contact time and initial concentration.	Babarinde et al. (2008)
Grounded leaf powder	1 g dosage, pH 8, contact time 4 hrs, agitation rate 180 rpm, temperature 40°C.	As (III) (84.98%).	Silver diethyl diethocarbamate (SDDC) method using spectrophotometer.	As (III) ion sorption was found to be highly pH dependent, uptake of As (III) ion increases rapidly with the lapse of time and increase in temperature induces positive impact on removal of As (III) ion from aqueous solution.	Kamsonlian et al. (2011)

useful biomaterial for Pb (II) sorption and biosorption capacity was pH dependant.

Maize tassel

Maize tassels, which were dried in an oven at 105°C for 24 h to expel any moisture present were fractionated into different particles sizes and used to model the removal of metals from different environments (Table 3). The first study on the removal of Pb(II) metal from aqueous solution by means of maize tassel powder as a solid phase sorbent for metals was reported (Okonkwo et al., 2006). The best adsorption (with respect to pH) was obtained from neutral pH 7, with percentage adsorptions of approximately 80% for Pb (II). Zvinowanda et al. (2009) also showed that adsorption of both chromium (VI) and cadmium (II) using maize tassel powder was highly pH dependant. In a similar study utilizing the maize tassel, Zvinowanda et al. (2009) reported the removal of Pb (II) from simulated solutions and finally in borehole water contaminated with mine wastewater. The Freundlich model was found to describe the sorption energetics of Pb (II) on tassel more fully than the Langmuir. The adsorption process could be well described by both the Langmuir and the Freundlich isotherms with R^2 values of 0.957 and 0.972 respectively. The recovery of copper from synthetic industrial wastewater using maize tassel, an agricultural waste material was reported (Sekhula et al., 2010). Dadzie et al. (2011) also gave a short communication on the use of tassel for the remove mercury, arsenic, manganese and lead from contaminated water.

Recently, Zvinowanda et al. (2010) demonstrated the possibility of using maize tassel to adsorb and recover heavy metals using Pb (II) sample solutions. The stripping process was carried out with either sodium citrate or nitric acid and proved to be viable. These concepts of metal desorption and recovery is an important consideration for large scale industrial uses. Das et al. (2010) has reported that the desorption process requires proper selection of stripping solutions, which is a function of the biosorbent and mechanism of biosorption. The economic application of a given biosorbent is governed not only by biosorptive capacity but also by a variety of factors such the ease of its generation or, reuse. All these considerations should be taken into account when dealing with recovery of metals. In summary, maize tassel has been compared with other adsorbents in the recovery of metals (Table 4). The use of maize tassel as the low cost adsorbent in recovery of heavy metal ions has been found to comparable with other adsorbents listed in Table 4.

Table 3. Batch sorption of metal ions using maize tassel powder.

Optimum conditions	Removal capacity/concentration	application	Remark	Reference
pH 1, pH 4, 200 ppm.	Recovery of 29.5-33.9 % at pH 1, 56.7-73.2 % at pH 4.	Synthetic industrial wastewater.	Recovery of copper by tassel is pH dependent.	Sekhula et al. (2010)
1 g adsorbent, pH 7.00-7.20, temperature 25°C.	Pb (II) (333.3mg/g).	Simulated and Borehole water contaminated with mine wastewater.	The uptake of metals from environmental samples dependent on pH, ionic strength, competing species, the following were recovered from wastewater Se (100%), Sr (5.41-59.0%), U (100%), V (46.1-100%).	Zvinowanda et al, 2009
pH 2, 25°C, 1 h for Cr (VI), pH 5-6, 25°C, 1 h for Cd (II).	Cr (VI) (79.1%), Cd (II) (88%)	Simulated samples.	Removal of chromium from aqueous solutions strongly depended on pH of the solution, adsorbent mass, initial chromium concentration, contact time, adsorption of cadmium strongly influenced by pH of solution.	Zvinowanda et al. 2009
20 g tassel, time 0-60 minutes, 2 mg/l simulated sample containing As, Mn, Lead, Hg.	Arsenic (0.001 mg/L), Manganese (0.005 mg/L), Lead(0.203 mg/L) and Mercury 0.020 mg/L in simulated samples, Arsenic (0.0005 mg/L), Manganese (0.0021 mg/L), Lead (0.050 mg/L),and Mercury (0.0025 mg/L) in groundwater.	Simulated samples and contaminated groundwater.	Maize tassel had adsorption capabilities for arsenic, manganese, lead, mercury and adsorption dependent on time.	Dadzie et al. (2011)

Comparison of the different adsorbents derived from the maize plant and other adsorbents

The performance of the maize plant derived adsorbents for sorption of heavy metals is compared with other biomass sorbents in Table 5. From Table 5, it can be observed that maize plant adsorbents such as maize cobs and husks gave the highest Langmuir monolayer adsorption constants (495.9 mg g^{-1} Zn^{2+}; 456.7 mg g^{-1} Pb^{2+}; 493.7 mg g^{-1} Cd^{2+}) for the different metals ions followed by maize tassels with 333.3 mg g^{-1} (Pb^{2+}). Bio-adsorbents such as algae waste gave values ranging from 227-243 mg g^{-1} (Pb^{2+}) whilst natural materials (zeolite) gave a value of 200.54 mg g^{-1} (Pb). Activation was also found to have a significant effect on adsorption capacity of rice husk carbon giving a value of 112.43 mg g^{-1} (Cu^{2+}). Industrial wastes for example coal fly ash was found to have a low adsorption capacity constant (0.401 mg g^{-1} Co). This comparison shows that the maize plant adsorbents had high sorption capacities for heavy metal ions as compared to other adsorbents; hence their continued use in environment management is encouraged.

CONCLUSIONS AND FUTURE PERSPECTIVES

The use of maize plant adsorbents for metal biosorption has been reviewed. The different adsorbents showed excellent adsorption abilities for several metals studied.

The biosorption process has been found to be

Table 4. Desorption and recovery of selected metal ions using different sorbents.

Adsorbent	Stripping solution	Desorption/conditions	Recovery	Application	Advantages and disadvantages	Reference
Cassia angustifolia bark	acid, base.	Cu^{+2} (78.52%), Cd^{+2} (96.78 %), Pb^{+2} (76.64 %). At pH 1.	-	Waste waters.	The process is rapid and the biosorbent can be regenerated, the process is pH dependant.	Mulgund et al. (2011)
aquatic fern, *Azolla filiculoides*.	HNO_3, HCl, EDTA, CH_3COOH	-	>80% Ni (EDTA), <80%, (CH_3COOH, HCl), 50-60% (HNO_3).	Polluted waters.	The high recovery percentage of Ni ions by EDTA allows the recycling of ions from the biomass in industry.	Ahmady-Asbchin et al. (2011)
Sargassum	NaOH	97.8% Au (III).	91.4%.	Dilute solutions.	Rapid process, gold from dilute solutions can be recovered through green processes in ionic, nanocrystalline, or metallic form as desired by the end-consumer using *Sargassum* biomass as biomaterial.	Sathishkumar et al. (2010)
Immobilized *Mentha arvensis* distillation waste (IMADW) biomass	HC*l*	90% Cu(II), Zn(II)	-	Aqueous solutions.	Biomass cannot be re-used.	Hanif et al. (2009)
Maize tassel	0.5-50 M Nitric acid, 0.01-0.2 M sodium citrate	98%	Pb (II) 57-74, 57-67 % respectively.	Aqueous solutions.	Tassel can be regenerated.	Zvinowanda et al. (2010)
Biomass with mixture of chlorophyte algae with caducipholic plants.	HCl, $NaHCO_3$.	80% (Pb, Cd, Cu) first 5 min with HCl, first 30 min with NaHCO3.	In the first cycles, HCl ranged between 63 - 100%, $NaHCO_3$ ranged between 1-77%.	Industrial effluents.	Desorption process was fast and the amount depended on the stripping solution.	Lezcano et al. (2011)

significantly affected by parameters such as pH, adsorbent dosage and, contact time. Considering the easiness of cultivation of the plant, easy preparation of the adsorbents and environmental disposal problems in some developing countries, biosorption offers an attractive application of the biosorbents obtained from the maize plant. However, since commercialization is still far from being realized, efforts are now geared towards the

Table 5: Overview summary of selected studies on metal sorption by adsorbents.

Adsorbent	Metal	R (%)	Qe (mg g^{-1})	Reference
Bioadsorbents: Algae waste	Cu^{2+}, Pb^{2+};	-	85-94, 227-243;	Feng and Aldrich. (2004)
Rhizopus oryzae	Cu^{2+}		52-91	Fu et al. (2012.)
Agricultural solid waste:Cocoa shells	Pb, Cr, Cd, Cu, Ni, Al	95(Pb)	6.2 (Pb)	Meunier et al. (2003)
Maize tassels	Cd, Cr^{2+}, Pb	88, 79.1	333.3 (Pb)	Zvinowanda et al, (2009)
Maize leaves	As^{3+}	84.98	85.6	Kamsonlian et al. (2011)
Maize stalk sponge	Pb^{2+}		80	García-Rosales and Colín-Cruz (2010)
Maize cobs and husks	Zn^{2+}, Pb^{2+}, Cd^{2+}		495.9, 456.7, 493.7.	Igwe et al. (2005)
Rice Straw	Cu^{2+}		74.70	Buasri et al. (2012)
Natural materials: zeolite	Pb	-	200.54	Kleinubing et al. (2008)
Activated carbon: *Tridax procumbens* (Asteraceae)	Pb, Cd;	95, 98;	2.90, 2.88	Singanan (2011),
Rice husk activated carbon	Cu^{2+}	-	112.43	Khan et al. (2011)
Miscellaneous type of biosorbents: Tea waste	Ni	98	1.07	Aikpokpodion et al. (2010)
Industrial wastes:				
Coal fly ash	Co	-	0.401	Musapatika et al.(2010)
Bagasse Fly Ash	Cd, Zn		6.19, 7.03	Srivastava et al.(2006)

%: R is the removal percent; Qe is the Langmuir monolayer adsorption constant

use of the adsorbents derived from the maize plant in removing organophosphates from aqueous solutions and in biosensing on electrodes. Maize tassels, leaves, stalks and husks which have shown potential for trace metal removal, could also be used as electron mediators and immobilization matrix in biosensor development design as witnessed by the presence of functional groups such as $-NH_2$, $-C=O$ and $-COOH$ from FT-IR studies. These materials can be blended with sol-gel or nanomaterials to enhance the physicochemical properties so that efficient electron transfer between the electrode and enzyme is improved. It is believed that the merits of biomaterial based sensors will bring dramatic changes in future sensor technology and environmental cleanliness.

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