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Phytoremediation of Effluents Contaminated with Heavy Metals by Floating Aquatic Macrophytes Species

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Abstract

The progress of urbanization and technologies led to the rise of anthropogenic activities, which consequently have high production of pollutants, affecting ecosystems, including aquatic biomes. One of the contaminating forms that cause environmental impact is heavy metals, which are produced in large quantities by inappropriate disposal of batteries, residential, industrial, agricultural and mining waste. Such components generate bioaccumulative effects, classifying them as dangerous elements that must be removed from environment. However, in species such as plants, this bioaccumulative effect can be exploited, aiming a biotechnological and bioengineering application to remove metals, called phytoremediation, employing floating aquatic macrophytes, which have high potential due to their properties retaining contaminants. Results obtained were conclusive for adaptation of *Eichhornia crassipes* and *Salvinia auriculata* as better phytoremediation agents, respectively, while *Lemna minor* and *Pistia stratiotes* fit better in biomonitoring, which have resistance to certain concentrations of metal when related to Cd, Hg, Zn, Ni and Pb.

Keywords: environmental bioengineering, biotechnology, phytoremediation, water, heavy metals, floating aquatic macrophytes

1. Introduction

In contemporary society, the great amount of harmful elements produced that come to nature has contributed greatly to environmental degradation, such aggressions to the environment are due to several factors, mainly by the pollutants and substances that affect the planet and its spheres (atmosphere, lithosphere, hydrosphere), as well as affect the biosphere, which participates in these different levels and aggregates all life and its different ecological niches. Therefore, it is necessary to find alternatives of reduction and even exclusion of these pollutants that affect our planet in a devastating way [1, 2].

Since the harmful damages to the environment from human activities were discovered, we look for sources and methods that can maintain sustainability, thinking about ecologically sustainable projects, making biodegradable products, looking for options to reduce pollutants and contaminants, other substitutions for extraction of material resources aimed at less damaging the ecosystem, creating environmental

remediation mechanisms, among many other extraordinary ideas that have been carefully studied and applied successfully, but which in most cases can not completely reverse what has already been destroyed [1].

Many techniques have been applied obeying the principle of sustainability, achieved through the use of the reasoning of distinct areas of knowledge, which, through the same purpose, manage to create products, methods and innovations that lead to some environmental benefit. An area of extreme importance that contributes greatly to the development of this type of clean technology so necessary for the environment is Biotechnology, in which the knowledge of biological systems, organisms and their products are used for the insertion in processes that can generate high impact in the society [3], including by implementing biotechnological processes that can reduce contaminants or even improve environmental issues on a large scale.

When dealing with techniques that aim at direct environmental improvement, bioremediation is one of the most effective biotechnological alternatives to combat pollutants, especially when dealing with larger cases, such as in the case of an oil spill. Such technique consists in the removal or transformation of toxic elements by living organisms that when associated with a medium confer some characteristic that holds the aggressor, making it impossible for this element in its harmful form to still be in dispersion or contact with other biological and natural resources [4, 5].

“Brazil has a privileged situation in relation to water availability (...) the idea of abundance served for a long time as a support to the culture of wasted water available, and then acquired low value as a resource (...)” [6], due to the excessive water loss not only from Brazil, but worldwide, the minimum measures that can be implemented are those of environmental remediation, following the sustainable reasoning.

Plants used in the phytoremediation technique can be used in the terrestrial environment to remove organic or inorganic pollutants such as: toxic metals, chlorinated solvents, petroleum hydrocarbons, polychlorinated biphenyls and even radionuclides [7], as well as several species are used in the aquatic environment [8], where one of the genera that can be manipulated are the aquatic macrophytes, which has presented great expectations related to the remediation, providing numerous benefits in the extraction mainly when they deal with its bioaccumulative principles of heavy metals [9] in the media contaminated, which will be more exploited in this work, since they have functions that can be used for the restoration of water resources.

In this context, the objective of this work was a review for the evaluation of phytoremediating properties of aquatic macrophytes against heavy metals, such as: Cd, Hg, Zn, Ni and Pb according to the bioaccumulative capacity of four species of macrophytes. These metals were chosen because of their toxic properties or their ability to contaminate the environment, and they are present among pollutants with higher indices in wastewater and high metal toxicity [8, 9], while the selected plants were the most prominent in scientific articles.

2. Methodology

This research was carried out through a collection of information with the comparative function of studying and discussing the potential of phytoremediation of some species of floating aquatic macrophytes, made through the cross - linking of data from scientific articles from sources such as PubMed and Scielo, academic papers of high relevance and journals of impact, in order to cover in a global way the state of the art of this study.

3. Hydric contaminants and heavy metals

The intense urbanization and increase of anthropogenic activities, coupled with the surplus population growth, have contributed to the scarcity of primary natural resources, extinction of species, among innumerable damages caused by urban and industrial pollution that can be cited, such as the increase in the incidence of diseases of the nervous system, often caused by heavy metals from vehicles, mining, metallurgy and electroplating; the increase in particulate matter related to the increase in the rate of respiratory diseases, besides neoplasias that may arise from several origins, among these there are already hypotheses of some harmful pollutants and others already proven that are still used in our daily life [1], as an example the nickel, an element in great abundance used in metal alloys, electroplating, composition of batteries among other products, being related to episodes of contact dermatitis and indications of carcinogenicity according to the increase of its concentration [9].

Heavy metals are inorganic compounds, some even considered as essential micronutrients for the metabolism of plants and other living beings, but when in high concentrations (varying according to the referred compound) can generate toxic effects on organisms, it is important to note that these effects may vary according to circumstances such as the organism tolerance, pH, presence of other ions that interfere with bioavailability, among other issues that may interfere with the result of contact with the element [10, 11]. With this toxicity, adverse effects are caused in plant physiology and metabolism, interacting mainly with their enzymes; since the plants are the organisms that theoretically have direct contact with these elements, thus they carry forward the damages of the bioaccumulation. These compounds can be captured by plants when they come in contact with soil or water that is contaminated with waste, emphasizing the industrial and agricultural [12], the latter cited is widely used to exemplify the accumulation of these materials in the food chain. The response of plants to contact with heavy metals depends on the concentration and exposure to them, presenting some phytotoxicity traits as reduced growth, especially the root system is more affected, chlorosis and leaf necrosis followed by traces of senescence and abscission, which changes lead to lower nutrient uptake and interfere with the biomass acquired [13].

4. Environmental biotechnology and bioengineering

Biotechnology is situated, due to its range of possibilities, among one of the main tendencies to the vision of the future, always with a look ahead of the possible methods to improve the quality of life, besides using resources in a less aggressive way. Aiming at the progression of mankind and at the same time environmental preservation, several biotechnological routes were created, as examples are much cited fields of food production, energy generation, prevention of environmental pollution and remediation areas [4].

Bioengineering is widely used in the environmental aspect aiming at the maintenance of resources, commonly present in soil erosion recovery processes along riverbanks [14], but can also be applied to water bodies, aiming at reestablishment with interventions designed from problems such as discharge of domestic, industrial and agricultural effluents and diffuse pollution, making possible an improvement in the water body in question and consequently of the biota that inhabits it [15].

Among these processes were created “phytotechnologies,” alternative methods of remediation with plant utilization, aiming at the cleaning or stabilization of contaminants, this being an important function, which becomes more effective

when implemented with other mechanisms and primary remediation techniques, promoting their decontamination capacities together [16].

There are also different techniques associated with measures to promote phytoremediative capacities that have promising results, such as the use of rhizobacteria associated with plants and transgenic practices adopted to overcome their absorptive or resistance to toxicity [17]. The application of phytoremediation is acceptable because it is a green technology, making phytoremediation a very useful technique in environment-related biotechnology, combining the characteristics of plant species for gradual decontamination.

5. Vegetable resistance to metals

Plants to acquire resistance to heavy metals have several mechanisms, often varying the tolerant characteristics of the plant to different metals, in order to prevent these harmful components from reaching their tissues and cells, interacting in metabolic processes and leading to signals toxicity, although not completely elucidated, some part of the mechanisms is known. Among the effects that counteract the damages of heavy metals are mentioned: in the *E. camaldulensis* species when exposed to $45 \mu\text{mol/L}^{-1}$ cadmium there is increase of carotenoids (related to the tolerance to oxidative stress), and there is also an increase in the thickness of the epidermis and root endoderm according to the increased doses of the metal and the decrease in the thickness of the mesophyll and leaf limb related to the decrease of the photosynthetic capacity [7].

Oxidative stress is the toxic effects generated in plants through free radicals or reactive oxygen species (ROS) such as hydroxyls, superoxide anions, hydrogen peroxides [18] and may cause changes in proteins, DNA and membrane lipid peroxidation, which will interfere in the chlorophyll production inhibiting the production of α -aminolevulinic acid, in addition to demonstrating that the plants exposed to cadmium had lower water potential than the control group [7].

Reactive oxygen species are constantly produced in plants, this condition can be stimulated when in contact with a situation of homeostatic imbalance, as is the case of the presence of heavy metals, however the vegetables have an antioxidant defense system, to reduce the harmful effects the cells are among the antioxidant metabolites: ascorbate, glutathione, β -carotene, α -tocopherol that sequester or promote the degradation of ROS [19]. One of the main mechanisms related to this resistance being studied are phytochelatins.

5.1 Phytochelatins

Also called PCs (Phytochelatins), polypeptides are composed, most often by glutamic acid, glycine, and with a large amount of cysteine, and the presence of other amino acids may occur. Synthesized from glutathione (GSH) in steps catalyzed by the enzyme PC synthase, the increase of PC synthesis occurs by the contact of the plant with metal ions, inducing the enzyme PC synthase to exert greater activity [20].

There is greater involvement of research involving Cu, Zn, Ni, As and especially when it comes to cadmium, there is an increased expression related to PC, both in angiosperms, gymnosperms and pteridophytes and even bryophytes, PC are the main products associated with resistance because they act as metallic chelants, so the plants that have PCs in greater quantity may acquire greater resistance to the contaminated environment. On the other hand the functions of phytochelatins in the absence of heavy metals are not elucidated, although there are hypotheses of the participation of PCs in processes metabolic enzymes that lack metals [21]. Other non-plant organisms have PC biosynthesis, such as yeasts, algae and nematodes [22].

It is worth emphasizing that the metals that can be complexed by the phytochelatins are not all, being more effectively chelating Cadmium (by the incorporation of sulfides and formation of a cadmium sulfide coated with phytochelatins), Pb, Ag and Hg being the last three verified the formation of complexes with phytochelatins *in vitro*; Cd and Cu showed the formation of complexes with PC *in vivo*. The mechanism of metal tolerance attributed to PCs is due, in the presence of the metal, to the induction of the enzyme Phytochelatin synthase, which uses glutathione as a substrate for PC formation, after which the ion is transported and isolated in vacuoles, where they form complexes together to sulfides or organic acids [21, 22]. In addition, like the PC's, the amino acid cysteine that contains the sulfur in its structure is present in other clusters also called metallothioneins, which have in common a sequence of tripeptides, two of which are cysteine and a variant, having their binding capacity due to the sulfhydryl group present, with affinity for several metallic ions such as Zn, Hg, Cd, Cu, among others, for transport, storage and protection functions against metals and free radicals [23].

5.2 Distinct mechanisms of metal resistance in plants

There are some mechanisms different from the PCs that make the plant acquire more tolerance, as it is the case of the increase in the thickness of the wall root tissue, being the endoderm and exoderme root one of the main tissues to retain metals, association with microorganisms like fungi in the root region (mycorrhizae), can also secrete root exudates, compounds such as organic acids that complex the metal cations reducing the extracellular activity of these, are capable of suppressing the transport system, thus reducing its absorption, heat shock proteins (HSP) that have already been associated with protection of the plasma membrane, complexation or chelation by ligands pointed out in researches such as phytochelatin, metallothionein and organic acids that reduce the activity of the metal in the cytosol, which when ligated with the same are transported to vacuoles and stored, all these are mechanisms of immobilization, exclusion, repair of damages or complex, and have not been well elucidated yet, so they may have other relations and functions between them [18]. Due to these attributes a plant can become a good species for the phytoremediation technique.

6. Phytoremediation

Plants are organisms that maintain a good part of the ecosystem due to their beneficial properties to the means in which they are: phytodegradation, phyto-stimulation, volatilization, phytoprocessing, rhizofiltration, and also serve as a base to cover the area of environmental remediation, called phytoremediation. Their properties range from natural bioindicators to organisms that can be applied to a bioremediative technique; having several functions to remove contaminants, for these reasons, it has been proven that studies are still needed to identify species capable of acting more effectively [8, 24].

Among the main elements that can be remedied by plants are petroleum hydrocarbons, agrochemicals, explosives, chlorinated solvents and industrial byproducts, organic or even inorganic substances [25]. The focus of this chapter is related to heavy metals, which fit the last category mentioned and can also be related to the activities of mining [26], causing long-term toxic effects to those who eventually come into contact with them.

Phytoremediation mechanisms are widely used in the environment contaminated by principles of bioaccumulation, occurring commonly in soil, however, are not only limited to this site, due to the variety of species in the flora, such as the

extraction of pollutants from the aquatic environment by aquatic macrophytes, which according to the definition of phytoremediative capacities, those that have greater resistance to the toxicity of the environment, have great capacity of biomass generation in a shorter interval of time, becoming great options for gradual decontamination of the environment, having substantial action in the case of effluents containing metals [8, 27].

The phytoremediative features that give the plant favorable conditions for its use, according to [8] are: high growth, high biomass production, vigor and resistance to toxicity, in which the macrophytes fit perfectly. Of the many benefits that can be cited from the use of plants included in these aquatic macrophytes, [28] states that “Remedial potential in various environments may under certain circumstances be a good alternative to habitat decontamination methods” the possibility of exploring the theme in a way that demonstrates the important collaborations of this application for the survival of a water ecosystem and its benefits to a contaminated environment, mainly exalting the relation of its efficiency in the extraction of heavy metals, always evaluating its advantages of removal, efficacy, selectivity and cost of the process.

Thus the phytoremediative process is due to an excellent biotechnological technique capable of overcoming in terms of expenses and sustainability, since it aims at improvements with the minimum impact to nature [27].

6.1 Aquatic macrophytes

Among the aquatic plants are the macrophytes, their group encompasses several aquatic plants that are generally divided by their classification of life form, being categorized in: free floating, submerged rooted, rooted with floating and emerging leaves [29]. It also shows that in the neotropical countries, Brazil is among one of the largest producers of scientific content related to macrophytes, solidifying the interest of the use and knowledge of these species that has great ecological importance. Studies have shown that the richness of the species of floating aquatic macrophytes comes from the morphoclimatic characteristics, through the relation between the hydrological characteristics and the diversity patterns of these plants [30]. The regions where they have predominance are, respectively, wetlands (wastewater treatment areas), lakes-ponds, and also river-streams; there are other ecosystems where they are found as the case of the marine environment, however they do not present population as expressive as the first three cited previously [29].

Some macrophytes may be considered “weeds,” due to their resistance and exponential vegetative growth characteristics, which on the one hand become important factors that affect the biomass control of the species treated as pests. The *Eichhornia*, *Salvinia*, and *Pistia* genera, when exposed to pesticides that are often effective to other plants, do not demonstrate such toxicity in some types of superweeds, these resistance attributes that make them good organisms for the environmental remediation technique [31].

6.2 Free floating aquatic macrophytes

Macrophytes may be associated with phosphorus and nitrogen concentrations in water, and their development is generally favored by high temperatures. When they are classified as floating they have characteristics such as high primary productivity, commonly found in waters with moderate current velocity, and are limited by the oscillation of the water level, since this can lead to death of the plant population of these species. Within this classification of floating macrophytes are some species, such as: *Eichhornia crassipes*, *Pistia stratiotes*, *Salvinia auriculata* and *Lemna minor* [32].

6.2.1 *Eichhornia crassipes*

The species *E. crassipes*, known as “aguapé” or “water hyacinth,” is a floating aquatic macrophyte, native to South America and belongs to the family Pontederiaceae [31], highly tolerant to polluted environments and effective for extracting nutrients and metals such as Cd, Pb and Hg. Research has shown that for elements such as Hg, it has great absorption properties, with only the characteristic of chlorosis in the plant when exposed, without drastically affecting its growth over a long period with a certain quantity of mercury, counting on this attribute even in the remediation of water with high levels of K and NO_3^- [33]. Also, it was demonstrated the ability of this species to absorb many other elements such as Cd, Cu, Ni, Pb, Zn, with copper being the most absorbed in the root region, presenting a high value bioconcentration factor; for lead, when presented at low concentrations demonstrates large accumulation at roots, not finding values as high for the other metals in this study [34]. In another comparative study between cadmium values absorbed by Aguapé and *Salvinia*, the Aguapé was more tolerant to the metal, and the author associated this resistance with the higher production of thiol compounds by *Eichhornia crassipes* [35]. In another comparative research between *E. crassipes*, *P. stratiotes* and *S. molesta*, Aguapé has an advantage over the characteristics of phytoremediation of effluents due to its large biomass production capacity and the accumulation of several elements at the same time, increasing its biomass by 4.5× in only 30 days in the quoted experiment [36, 37].

The absorption capacity of Zn(II) and Cd(II) measured in the biomass (stem and leaf) of this macrophyte is respectively 9.3 and 12.4 mg.g^{-1} , as maximum capacity of metal in the plant [9]. As results of metal absorption this species succeeded in the bioaccumulation of the metals evidencing greater percentage of removal respectively of Zn, Pb and Cu [38].

6.2.2 *Pistia stratiotes*

The species *P. stratiotes*, commonly known as “water lettuce”, considered as a pest because of its resistance and replication capacity, even by the characteristic of regrowth [31]. It belongs to the Araceae family, monocot, commonly distributed in tropical and subtropical countries, it is demonstrated that it is a good accumulator of Copper (Cu), although other elements can also be captured by it [39].

Studies have demonstrated bioaccumulation values at distinct points of the Guarapiranga reservoir localized in SP/Brazil, for different macrophytes. The values of bioaccumulation between two macrophytes in three different sites of the same reservoir were evaluated, being high values in the *E. crassipes* of the As, Co, Cu, Mn, Ni elements, as well as the accumulation of this species, including the element Zn, which has significant difference between the values of *Pistia stratiotes*. Although *Pistia*, at different collection sites, it was able to obtain results similar to or even slightly larger than that of the Aguapé for Cu, Pb and Ni elements [40]. The accumulation value for Zinc is also highlighted in another study in which at the end of the third stage of the experiment Zn values were almost zero from an initial solution with 0.01 mg.L^{-1} , indicating that it may also be employed in remediation [41].

6.2.3 *Salvinia auriculata*

This species of macrophyte in the family Salviniaceae is a plant in which each individual has three hairy verticillate leaves, being two floating, has high capacity of absorption of many elements as the other plants, however studies have shown the response of potential bioindicator of this species to cadmium, because even at a

solution concentration of $10 \mu\text{mol.L}^{-1}$, it presents very great toxicity, consequently leading to oxidative stress, foliar necrosis and death. These results state that the possibility of *Salvinia auriculata* remediation of Cd is not as effective, leading to a possible ecological indicator for this species, since the accumulation data presented are not high due to its sensitivity when exposed to metal [42]. In another study it is also proposed that when the amounts of zinc in the water are above the amount allowed by the legislation, 5 mg.L^{-1} this species already shows signs of toxicity, a result that is biased toward its use in biomonitoring (reaction bioindicator) of contaminated sites, whereas for Pb it is considered to be a good accumulator mainly in the submerged part of the plant. This absorption occurs through the plasma membrane and presented a better accumulated value in the concentration of 5 mg.L^{-1} in the solution, and although it decreased its biomass, their clonal reproduction was not completely lost [43]. In a comparative study of this species with two more of the same family, *S. molesta* and *S. natans*, the results obtained indicate that the bioaccumulation values of *S. auriculata* are not the largest compared to these two species for the metals Cd, Hg, Pb, Ni and Zn, often meeting as intermediary between them, although their employability in phytoremediation is still possible [44].

6.2.4 *Lemna minor*

Also known as “duckweed”, has a cumulative capacity, in a study carried out by [45], makes a comparison with the *Azolla filiculoides*, obtaining results of good Mn accumulation by *Lemna*, although higher concentration of other metals in *Azolla*, and concluded that both plants are candidates for phytoremediation of contaminated and wastewater. Another study demonstrated that in addition to wastewater treatment the macrophyte can be used for aquatic toxicity tests, taking into account its sensitivity to heavy metals and herbicides, as well as the possibility of being used as animal feed (pigs, poultry, cattle, among others) provided that do not contains any toxic substances included [46].

In an experiment done by [47] the efficiency of Hg removal is tested by comparing the species *E. crassipes* and *Lemna minor*, proving a higher uptake by the first, both with indications of morphological changes due to toxicity, and although the rapid reproduction of *Lemna minor*, the one with the most resistance is *E. crassipes*. According to [48], when compared to other plant species *Lemna minor* is not the first desirable one to be chosen, since its performance does not support peaks of contaminant concentration and grows well in places with low concentration pollution although these are also of risk because its bioaccumulation is great, it would be ideal to use it for attributions such as polishing the water after pretreatment or even using its sensitivity characteristics for biomonitoring. Another comparison is made between *P. stratiotes*, *L. minor* and *Spirodela intermedia*, where they obtained excellent absorption values, especially *P. stratiotes*, although the *L. minor* species did not survive at the end of the experiment, the theory proposed by the author due to vegetal cover in the water layer that prevents the increase of oxygen dissolved in the recipient, leading to the death of individuals [49]. Research indicates that there is the capacity of using this plant also to increase the oxygenation of deep waters, called phytodepuration [50].

6.3 Phytoremediation mechanism

The remedial capacity of a plant is directly linked to its absorptive and cumulative potential of metals, with the help of proteins from the plants themselves acting as chelators, thus being able to isolate these substances in vacuoles with the intention of reducing toxicity to the organism itself [12]. Through phytochelatin that

acts as chelator and also of other proteins, the metals join to this protein and form complexes, being able to be transported to vacuoles, as a form of defense for the compound does not attack the vegetable organism [51].

According to the remediation mechanisms provided by the plants, the characteristics of phytoextraction, phytodegradation, phytostabilization, phytostimulation, phytovolatilization, phytotransformation and rhizofiltration are included [52].

6.3.1 Phytoextraction

Absorption of contaminant, with transport and storage at a particular plant site (roots, leaves, stems), it is also indicated that heavy metals hyperaccumulating plants are commonly used in this technique, and phytoextraction becomes effective only if the plants are removed before and during the degradation process, soils contaminated by Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn and the radionuclides of Sr, Cs, Pu and U (unstable chemical elements that emit radiation) can be remedied by this technique [53, 54].

6.3.2 Phytodegradation

Due to the mechanisms of the plant, some products are degraded by the metabolism processes and are usually organic, but there are some inorganic compounds that can also be degraded, among them: TNT (Trinitrotoluene), DDT (DichloroDiphenylTrichloroethane), TCE (Trichlorethylene), HCB (Hexachlorobenzene) and PCB's (Polychlorinated Biphenyls) [54].

6.3.3 Phytostabilization

When it is not possible the degradation of the contaminating element, precipitation of this component occurs in the rhizospheric region, between the root and the soil, applicable mainly when it comes to metals like Cd, Cr, Cu, Hg, Pb and Zn, so it is necessary tolerant plants for adequate stabilization [54].

6.3.4 Phytostimulation

The plant in the rhizosphere region produces substances that accelerate the degradation of the organic component, in addition to stimulating the proliferation and development of microorganisms such as bacteria and fungi, which may help in the process of uptake and degradation of contaminants, one of the main compounds remedied in these petroleum hydrocarbons [52].

6.3.5 Phytovolatilization

Process occurred to contaminants that may be volatilized after metabolization or biodegradation in the rhizosphere. It is also mentioned in a study that some compounds can be released by the direct action of the plant through the surface of the leaves, and that still they can be contaminants, being able to accumulate also in fruits and in the stem, among the inorganic components that can be volatilized are Se and Hg, although the use of this technique is still questionable for some authors [54].

6.3.6 Phytotransformation

The contaminant product is biotransformed, that is, converted to the less harmful substance, a feature that is very useful for the remediation of organic compounds, and this process can be understood as the metabolization of the pollutant in less toxic forms by the plant itself [52].

6.3.7 Rhizofiltration

When the phytoextraction is applied in a hydroponic medium, it has the name of rhizofiltration, it consists of the adsorption of the contaminants through the combination of the extraction and stabilization, is suitable for the removal of Pb, Cd, Cu, Ni, Zn, as well as some radionuclides [54].

6.4 Phytoremediative applications

As some of the many examples of decontamination made by plants, it can be demonstrated [55], where in a contaminated environment (Arroio de Santa Barbara, Rio Grande do Sul, Brazil) species of macrophytes of the families Asteraceae, Araliaceae, Poaceae, Araceae and Alismataceae were collected, including *Pistia stratiotes*. In this study, the concentration of bioconcentrated metals in these plants was measured. The obtained values proved that the remediation is effective because of its bioconcentration and resistance to the contaminants, and the metals studied and accumulated in this study were Zn, Cr, Pb, Ni and Mn.

A study by [56] suggested the technique of decontamination by plants and applied in wetlands with 20 L of effluent received by the Mussuré Creek, Paraíba, Brazil, to verify the efficacy of phytoremediation of three species. Divergent genus and species of plants have been studied, as *Lemna sp.*, *Pistia stratiotes*, and *Eichhornia crassipes*, obtaining results such as color reduction, turbidity, biochemical oxygen demand (BOD), being efficient for treatment of domestic effluent, besides being a simple and low cost system.

Other contaminant removal applications can be described, such as those cited in [57], Indian mustard becomes effective in the removal of Cd, Cr, Cu, Ni, Pb and Zn; the sunflower that has accumulating property (in hydroponic means) of Pb, U and even Cs-137 and Sr-90 that are radioactive isotopes demonstrating a wide phytoremediative capacity of several different species.

In parallel, some authors cite different methodologies, through transgenic plants, such as the CYP2B6 gene insertion of the human cytochrome P450, inducing the tolerance of the rice plant, and when compared to a control group, conferred resistance to herbicides, reaching the result that the plant can effectively remove contaminants such as Metolachlor, a member of the chloroacetanilide herbicide family. This proposed editing of genes to extend resistant attributes of plants has been well discussed in articles for biotechnological purposes [58].

6.5 Phytoremediation advantages by floating aquatic macrophytes

Phytoremediation is of great value when compared to other methods of environmental decontamination because its variety of contaminants that can be captured from the environment is very broad, including metals, radionuclides, various categories of organic pollutants, functioning as an efficient ecologically acceptable method with very low cost, although the remediation characteristics are dependent on the concentration of pollutants that generate toxicity to the plants that will come into contact, logically varying species, type of pollutant and environmental characteristics, so it is necessary in these cases to use other methods of direct decontamination [59].

This method is among one of the biotechnological techniques available for environmental decontamination, although it is more used in tropical climate countries, its application in Brazil also has a wide expectation due to the vast flora and temperature suitable for the development of the plant specimens, which consequently facilitates success when adopting the phytoremediation technique. As a mean of mitigating the situation of water bodies contamination, there are already

studies proving the efficacy and relevance of the phytoremediative process of floating aquatic macrophytes, their applications if well studied should lead to a gradual decontamination of the environment, as long as their characteristics are analyzed before to apply them *in situ*. According to the studied macrophytes, one of the most outstanding in the literature was the *Eichhornia crassipes* species, which has resistance attributes, including to pesticides [31], their replication rate and accumulation are favorable for the metals analyzed [38, 40], however it is necessary to emphasize that the other species may still be appropriate for the environmental remediation functions, since it is noted that the values of bioaccumulation, absorption and tolerance to metals have divergences in each experiment. Such plants are effective in the capture of heavy metals in the aquatic environment, and may even serve as biosensors, such as the species *S. auriculata* [41] and *L. minor* [46, 48] that are more suitable for this task or for the polishing of the water, according to the morphological characteristics presented when in contact with potential contaminants. The four species (*Eichhornia crassipes*, *Pistia stratiotes*, *Salvinia auriculata* and *Lemna minor*) are of great value in the aspect of contaminant removal [38, 41, 44, 45] because they facilitate the post-capture process of metals, where floating macrophytes take advantage over the rooted ones and contribute to the process of plant removal, consequently the extraction of the metals from the medium is facilitated.

There are some difficulties encountered in the application of the technique such as: time to obtain the results not immediate, doubt about the correct techniques of plant fate post treatment still existing and not be completely profitable for patenting as has been shown by [7], on the other hand, there are advantages of this method like the public acceptance and its attractiveness, the possibility of being applied in preventive methods, or even allied with other types of remediation, such as its excellent polishing capacity in already functioning water treatment systems, besides its economical characteristic satisfactory.

Although it is considered to be a green and ecologically acceptable technology, special care should be taken, such as the need for research and technological development, to verify pre and post-harvest phases of biomass from the site being treated, such as: the best species to remediate certain contaminants, to be aware of the route and transformation of the contaminants in the body of the vegetable, to destine to the biomass in suitable places. All these requirements are required for detailed strategies to achieve results as expected to avoid transferring contamination to other receptor bodies [7]. Many methods are used for decontamination; however, the use of vegetable mass for such a function has a great advantage over costs.

7. Destinations of plant biomass after treatment

After remediation of the contaminated effluent or body of water, the biomass incorporates the metals and retains them, that is, it still has the bioaccumulated heavy metals that need to be removed from the contact with the medium and can be submitted to manual processes or even mechanics for the withdrawal of the vegetal specimens, reaching the stage of isolation of the vegetal mass, thus avoiding a new dispersion of the contaminants post extraction. However a final disposal is required, often subjecting it to harmful environments such as the deposit of these contaminants in landfill and incineration; the latter technique is mentioned as a proposal to reduce the volume of plants and to generate energy by means of heat, also contributing to the removal of metals [8]. However, research suggests the incorporation of the biomass used in the treatment of ceramic blocks, proposing an efficient method of transformation of the products obtained, promoting a new environmentally acceptable use, without generating more contaminants and dispensing with incineration

[26], also studies affirm that the incorporation of the vegetal components in the ceramic sector is possible because the clay favors in the inertization of the as a way of preserving natural resources and avoiding further degradation of the environment. In the same work are mentioned researches of incorporation of macrophytes used after the technique of phytoremediation with large amounts of copper and chromium, proving in both the viability of inclusion of a percentage of the biomass in the clay leading to the consequent inertization of metals [60].

Measures such as the use of biomass in boilers, furnaces and for electric power generation, as well as the production of biogas in biodigesters, are proposed to avoid the final disposal of these macrophytes as solid residue, however, when used after the phytoremediation method, all caution is required to remove toxic components and avoid recontamination [60]. Although the phytoremediative method is a great technique and low cost, it has some contradictory factors that cause doubt in the application, one of them is the relation of the correct disposition of the contaminated material.

The elaboration of this work stems from the need to improve the study of phytoremediative capacities of certain species of aquatic macrophytes, especially those of the floating type (not rooted), due to the benefits brought to their processes of decontamination or removal of heavy metals, this is a subject which can be more explored and there is a certain lack in the technical-scientific scope related to this topic. With the present work, the characteristics of these macrophytes can be praised with in-depth study, relating their respective adaptations that lead to methods that may be less aggressive to treat water contaminated with metallic ions of the environment. The choice of the theme is also related to the diversity of the flora of aquatic macrophytes in the Brazilian region and the ideal temperature for growth, cited by several authors [30, 61, 62], among many other researchers who reaffirm the vast flora existing in Brazil, which including, is being increasingly investigated for phytoremediative aspects, due to the conditions of the numerous pollutants generated. Since the final disposal is considered one of the crucial procedures for phytoremediation, and seen that if not applied correctly can lead to a rebound contamination, there is a need for emphasize final destination processes in forward researches, suggesting an improvement of the phytoremediative technique if the appropriate destination is taken, reaching in that way the original idea of decontaminating phytotechnologies, amplifying percentages of removal [60].

8. Conclusions

Among the four species of floating aquatic macrophytes with phytoremediation potential cited in this study, *Eichhornia crassipes* stands out due to the number of studies and data available and a great capacity of biosorption and mass production combined with resistance to contaminants, although this species has great values of accumulation in relation to the others, it is unlikely to affirm that it would be the best alternative in all situations, questions of environmental temperature, pH, bio-availability, and mainly time of extraction related to metals and their interactions, biological oscillations that cause variations between each scientific experiment and that should not be disregarded, require more study to adapt more concrete values of absorption to each species. The potential uses of water hyacinth have been cited in studies such as their ability to remove radionuclides, wastewater from a wide range of sources (industrial, petrochemical, metallurgic, agriculture, pharmaceutical and personal care products waste, herbicides, even Polycyclic Aromatic Hydrocarbons can be included, recognized by your higher efficiency for being a hyperaccumulator, that can reduce turbidity by 92,5%, Cd by 97,5%, Ni 95,1% and Hg 99,9%, results acquired in researches depending of the concentrations of metal in water [63].

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Conflict of interest

The authors, Cleide Barbieri de Souza and Gabriel Rodrigues Silva, declare that there is no conflict of interest that might constitute an impediment to the publication of this research work.

Notes/thanks/other declarations

Nothing to declare.

Appendices and nomenclature

Ag	silver
As	arsenic
BOD	biochemical oxygen demand
Cd	cadmium
Co	cobalt
Cr	chromium
Cs	cesium
Cu	copper
DDT	dichlorodiphenyltrichloroethane
DNA	deoxyribonucleic acid
GSH	glutathione
HCB	hexachlorobenzene
Hg	mercury
HSP	heat shock proteins
K	potassium
Mn	manganese
Mo	molybdenum
Ni	nickel
NO ₃	nitrate
Pb	lead
PC	phytochelatin
PCB	biphenyl polychlorinated
Pu	plutonium
ROS	reactive oxygen species
Se	selenium
Sr	strontium
TCE	trichlorethylene
TNT	trinitrotoluene
U	uranium
Zn	zinc

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