REVISTA CONTRIBUCIONES A LAS CIENCIAS SOCIALES

The use of attenuators in Amazonian forest species under heavy metal stress: a literature review

O uso de atenuadores em espécies florestais da Amazônia sob estresse de metais pesados: uma revisão da literatura

El uso de atenuadores en especies forestales amazónicas sometidas a estrés por metales pesados: una revisión bibliográfica

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ABSTRACT
Anthropogenic activities such as industrial and mining activities have caused biotic and abiotic stress in plants through contamination by heavy metals deposited in the environment. Some of these are toxic to the plant in any concentration. Phytoremediation and its techniques then emerged as a measure capable of reducing heavy metal contamination. In addition to phytoremediation techniques, research shows the use of growth regulators to act as attenuators and mitigators of stress caused by heavy metals in plants. Thus, the objective of this bibliography was to gather information on contamination by heavy metals in Amazonian forest species, and to outline possible pathways and mechanisms capable of reducing this problem, enabling the use of specific species that can carry out phytoremediation of the soil, making contaminated and unproductive areas into productive ones and capable of being used in forest restoration programs and recovery of degraded areas. Understanding and studies on phytoremediation and its techniques have been deepened. However, it is necessary to increasingly understand the behavior of different species in the presence of heavy metals in the soil.

Keywords: toxicity, stress, growth regulators.

RESUMO
As atividades antropogênicas, como as industriais e de mineração, causaram estresse biótico e abiótico nas plantas por meio da contaminação por metais pesados depositados no ambiente. Alguns deles são tóxicos para as plantas em qualquer concentração. A fitorremediação e suas técnicas surgiram então como uma medida capaz de reduzir a contaminação por metais pesados. Além das técnicas de fitorremediação, pesquisas mostram o uso de reguladores de crescimento para atuar como atenuadores e mitigadores do estresse causado por metais pesados nas plantas. Assim, o objetivo desta bibliografia foi reunir informações sobre a contaminação por metais pesados em espécies florestais amazônicas e traçar possíveis caminhos e mecanismos capazes de reduzir esse problema, possibilitando a utilização de espécies específicas que possam realizar a fitorremediação do solo, tornando áreas contaminadas e improdutivas em produtivas e passíveis de serem utilizadas em programas de restauração florestal e recuperação de áreas degradadas. O

entendimento e os estudos sobre a fitorremediação e suas técnicas têm se aprofundado. No entanto, é necessário entender cada vez mais o comportamento de diferentes espécies na presença de metais pesados no solo.

Palavras-chave: toxicidade, estresse, reguladores de crescimento.

RESUMEN

Las actividades antropogénicas, como las industriales y mineras, han causado estrés biótico y abiótico a las plantas a través de la contaminación por metales pesados depositados en el medio ambiente. Algunos de estos metales son tóxicos para las plantas en cualquier concentración. La fitorremediación y sus técnicas surgieron entonces como una medida capaz de reducir la contaminación por metales pesados. Además de las técnicas de fitorremediación, la investigación muestra el uso de reguladores del crecimiento para actuar como atenuantes y mitigadores del estrés causado por los metales pesados en las plantas. Así, el objetivo de esta bibliografía fue reunir informaciones sobre la contaminación por metales pesados en especies forestales amazónicas y delinear posibles caminos y mecanismos capaces de reducir este problema, posibilitando el uso de especies específicas que puedan realizar fitorremediación de suelos, transformando áreas contaminadas e improductivas en productivas, utilizables en programas de restauración forestal y recuperación de áreas degradadas. El conocimiento y los estudios sobre la fitorremediación y sus técnicas se han profundizado. Sin embargo, es necesario comprender cada vez mejor el comportamiento de las distintas especies en presencia de metales pesados en el suelo.

Palabras clave: toxicidad, estrés, reguladores del crecimiento.

1 INTRODUCTION

In nature, plants are constantly threatened by biotic and abiotic stresses. Heavy metals such as Fe, Mn, Cu, Ci, Zn and Cd accumulate for a long time in soils through anthropogenic activities, such as industrial waste, fertilizer applications, metal smelting and sewage disposal (Aydinalp and Marinova, 2009). These activities cause metals to leach into groundwater or accumulate on the soil surface. Therefore, metals such as cadmium present in pesticides have no beneficial role and become toxic if their concentration exceeds a certain limit.

Plants are natural bioaccumulators, that is, they extract and concentrate various heavy metals from soil and water that may or may not be necessary for their adequate growth (Ozturk and Turkan 1993; Aksoy and Ozturk 1996, 1997; Aksoy et al. 2000; Ali and Aboul-Enein 2002). The rate of accumulation and tolerance of plants to heavy metals varies from species to species, with some becoming toxic at a faster rate. Plants facing heavy metal toxicity have visible symptoms such as stunted growth, chlorosis, root browning, decline, and death (Ozturk et al. 2008, 2015b).

Thus, phytoremediation is a type of bioremediation that uses plants to reduce the toxic effects of heavy metals in the environment (Ashraf et al., 2019). As an emerging alternative technology to conventional remediation approaches, phytoremediation offers the advantage of being economically and ecologically sustainable (Emenike et al., 2018; Li et al., 2020; Hasan et al., 2019). Among the phytoremediation technologies applicable to soils contaminated with heavy metals, two of the most used are phytoextraction and phytostabilization (Yan et al., 2020). In phytoextraction, fast-growing plants that tolerate high concentrations of metals in their aerial tissues are used. In phytostabilization, plants are used that have a strong ability to reduce the mobility of metals in the rhizosphere or roots (Favas et al., 2014; Wei et al., 2021).

Plant growth regulators play a vital role in regulating signal transduction and cross-talk with other metabolites in plants, which result in the enhancement of plant processes and tolerance directly or indirectly of different environmental stresses (Wani et al. 2016; Ahmad et al. al. 2018; Rhaman et al. 2021). Growth regulators such as auxins, cytokinins, gibberellins, abscisic acid (ABA), ethylene and salicylic acid have been extensively studied in regulating plant growth as well as mitigating abiotic stress.

Recently, it has been proven that 5-aminolevulinic acid (ALA) is a potential plant growth regulator, playing an important role in certain metabolic processes, promoting growth and stress tolerance abilities, in addition to increasing yield through improved fixation. of CO_2 and N_2 assimilation (Maruyama-Nakashita et al. 2010; Naeem et al. 2010). Recently, ALA was reported to function as a scavenger of reactive oxygen species (ROS) in plants.

Therefore, it is important to know species capable of carrying out phytoremediation techniques, and which can thus be indicated as potential species for programs to recover degraded areas. As well as knowing possible attenuators and mitigators of stress caused by heavy metals in plants.

2 OBJECTIVE

The objective of this bibliographical survey is to gather information about contamination by heavy metals in Amazonian forest species, and to outline possible pathways and mechanisms capable of reducing this problem, enabling the use of suitable species that can perform soil phytoremediation, making areas contaminated and unproductive into productive and capable of being used in forest restoration programs and recovery of degraded areas.

Furthermore, we seek to explore the most important characteristics of phytohormones and growth regulators, as well as existing heavy metals and Amazonian forest species, with the aim of seeking potential solutions and effective strategies to combat existing contamination, which appears to be an impediment to the success of forestry production in Amazonian regions.

This review aims to fill gaps in current knowledge about attenuators capable of mitigating plant stress due to heavy metal contamination, bringing together a series of information found in several separate studies, thus offering a more comprehensive view of the causes, origins and possible strategic approaches to prevention. Understanding the behavior of Amazonian forest species and which regulators or attenuators respond most efficiently is fundamental and crucial to improving and accelerating the diagnosis of contaminated areas, bringing effective approaches and treatments.

3 MATERIAL AND METHODS

The study was carried out through a bibiographical survey, consulting books, repositories and articles indexed in the main research bases, such as: *Google Scholar*, *Web of Science*, *Scielo*, *Scopus*, *Wiley Online Library* and *PubMed*. To locate articles, the following terms were used, both in Portuguese and English: attenuators; abiotic stresses; heavy metals; aminolevulinic; cadmium; heavy metals in plants; phytoremediation; forest restoration and reforestation.

This review is integrative and of a qualitative exploratory nature, addressing an important topic that has been the focus of discussion in recent years. Original articles written in both Portuguese and English and indexed in the last decade were included, filtering the search for articles published between 2012 and 2023, thus seeking updated references that serve as a basis for future work and studies.

Through a bibliographical survey and in order to form a better understanding of the consequences and consequences of contamination by heavy metals in forest species native to the Amazon region, in addition to presenting possible mitigators that aim to mitigate the problem, this article was subdivided into topics: Summary; Summary; Introduction; Goal; Methodology; Results and Discussion (Heavy metals in the environment; Effects of heavy metals on plants; Forest species and the presence of heavy metals; Plant growth regulators; Biochar; 5-

aminolevulinic acid; Relationship between heavy metals and stress attenuators); Conclusion; References.

4 RESULTS AND DISCUSSION

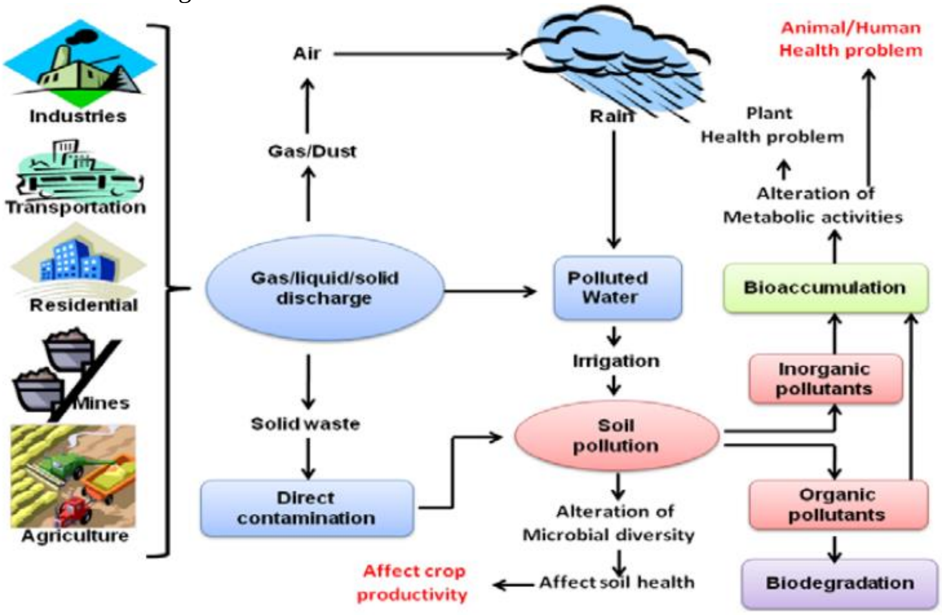
4.1 HEAVY METALS IN THE ENVIRONMENT

Heavy metals are those elements that have a specific weight greater than 5g cm^3 (Leonard et al. 2004). Metals that are at least 5 times denser than water are also defined as heavy metals (ASTDR, 2000). Heavy metals can be essential metals (Mo, Mn Cu, Ni, Fe, Zn) or non-essential metals (Cd, Ni, As, Hg, Pb).

Many heavy metals are essential for plants, as they act as cofactors, activate the enzymatic reaction and have ductility, conductivity and provide cationic stability (Stohs & Bagchi, 1995). However, these metals present in concentrations greater than necessary show toxicity. Deficiencies of essential heavy metals affect human health and agricultural yields. Non-essential metals present toxicity even at low concentrations, as they do not metabolize into other intermediate compounds and do not decompose in the environment.

Due to industrial, domestic, agricultural, medicinal, technological application or natural events such as rock weathering, heavy metals are released into the ecosystem. According to Carvalho et al. (2008), metals arising from environmental contamination are deposited in the soil, mainly in the agricultural or arable layer, often present in the soil solution and available to plants, becoming a source of risk and route of exposure to contamination for the population.

Figure 1. Source of metal contamination and toxic effects.



Source: Oves et al., 2012.

4.2 EFFECTS OF HEAVY METALS ON PLANTS

It is well documented that the presence of heavy metals in soil, water or plants significantly impairs crop growth and yield. The presence of metals causes stunted plant growth, wilting of crowns and degradation of Chlorophyll content, which results in decreased photosynthetic rate and therefore plant death (Prasad and Strzałka 1999; Zhang et al. 2010). Therefore, it is important to know the characteristics and particularities of each metal, and in what form and concentrations they can affect the functioning of the plant.

Some heavy metals (Fe, Cu and Zn) are essential for plants and animals (Wintz, 2002) their availability in the environment varies, and metals such as Cu, Zn, Fe, Mn, Mo, Ni and Co are essential micronutrients (Reeves & Baker, 2000) whose Excess absorption by the plant results in toxic effects (Monni, 2000).

The heavy metals available for absorption by plants are those present as soluble components in the soil solution or those solubilized by root exudates (Blaylock & Huang, 2000). Plants require certain heavy metals for their growth and maintenance, excessive amounts of these metals can become toxic to plants and the ability of plants to accumulate essential metals also allows them to acquire other non-essential metals (Djingova & Kuleff, 2000). As metals cannot be decomposed, when concentrations in the plant exceed optimal levels, they negatively affect the plant, both directly and indirectly, and some of the direct toxic effects caused by high metal concentrations include inhibition of cytoplasmic enzymes and damage to structural cells due to oxidative stress (Assche & Clijsters, 1990; Jadia & Fulekar, 1999).

The negative influence of heavy metals on the growth and activities of soil microorganisms also indirectly affects plant growth. The reduction in the number of beneficial microorganisms in the soil due to the high concentration of metals can lead to decreased decomposition of organic matter, leading to lower soil fertility. Enzymatic activities are very useful for plant metabolism, which is hampered by the interference of heavy metals in the activities of soil microorganisms. These toxic effects (direct and indirect) lead to a decrease in plant growth, which ultimately results in plant death (Schaller & Diez, 1991).

Thus, the effect of heavy metal toxicity on plant growth and development differs depending on the specific heavy metal for this process.

4.3 FOREST SPECIES AND THE PRESENCE OF HEAVY METALS

According to Nori et al. (2009), plant species differ widely in their ability to accumulate heavy metals. Many authors have concluded that metal concentrations in plants growing in the same soil vary between species and even between genotypes of the same species (Kabata-Pendias, 2001; Hamon et al., 1997).

Some of the mechanisms that may be responsible for differences between plant species in metal concentrations have been identified. These mechanisms include differences in: 1) root architecture; 2) water use efficiency; 3) rhizosphere chemistry; 4) expression and affinity of root surface transport proteins for metals; 5) metal loading in the xylem and translocation within the plant (Hamon et al., 2003). Furthermore, the age and growth stage of the plant can affect the concentration of metals in plants (Elekes, 2014).

4.4 PLANT GROWTH REGULATORS

Various strategies have been adopted to alleviate heavy metal toxicity in plants; however, modulation of plant growth regulator by physiological or molecular processes has been a major goal in plant research. Among the main regulators, plant hormones [auxins, gibberellins (gibberellic acid, GA), cytokinins (CKs), abscisic acid (ABA), ethylene, jasmonic acid (JA), nitric oxide and brassinosteroids play significant roles mainly in developmental processes of plants and have been extensively researched.

The crucial roles that regulators play in the adaptation and survival of plants growing under different metals/metalloids including Cd are known (Arasimowicz-Jelonek et al. 2011; Masood et al. 2012; Piotrowska-Niczyporuk et al. 2012; Khan and Khan 2014). Furthermore, the role of regulators such as auxins and gibberellic acid in phytoextraction have also been reported (Bulak et al. 2014).

There are growth regulators that are currently gaining ground in research experiments, such as Biochar and 5-aminolevulinic acid:

4.5 *BIOCHAR*

Biochar is an organic substance with stable properties, a complex structure and substantial carbon and is formed by pyrolysis and carbonization of biomass materials at 300–700°C under oxygen-free or hypoxic conditions (Antal and Grønli 2003). The inherent characteristics of biochar, such as high carbon content, large specific surface area, rich pore structure, and stable physicochemical properties, provide an important structural basis for improving soil texture (Ahmed et al. 2016; Li et al. 2017; Lévesque et al. 2020; Mohan et al. 2014).

Numerous studies have demonstrated that biochar plays an important role in nutrient cycling in soil ecosystems (Esfandbod et al. 2017; Knowles et al. 2011) and improving soil fertility (Huang et al. 2013). Furthermore, biochar plays an active role in the process of biological nitrogen fixation in soil (Ogawa and Okimori 2010; Quilliam et al. 2013) and can regulate microbial activity (Lehmann et al. 2011).

4.6 5 *AMINOLEVULINIC ACID (5-ALA)*

5-aminolevulinic acid (ALA) is a plant growth regulator that is present in all plants and has a variety of biological activities. ALA is a key precursor in the biosynthesis of porphyrins such as chlorophyll, heme and cytochrome (An & Qi, 2016; Ali et al., 2015). Previous studies indicated that ALA was involved in several important physiological processes, promoting primary root elongation (An et al., 2019), including promoting seed germination (Wang et al., 2015), promoting biomass accumulation plant (Nunkaew et al., 2014), improving photosynthesis (Wang et al., 2004; Wang et al., 2018), contributing to the inhibition of ABA-induced stomatal closure (An et al. 2016). Notably, ALA is crucial for plant response to abiotic stress (Wu et al. 2019).

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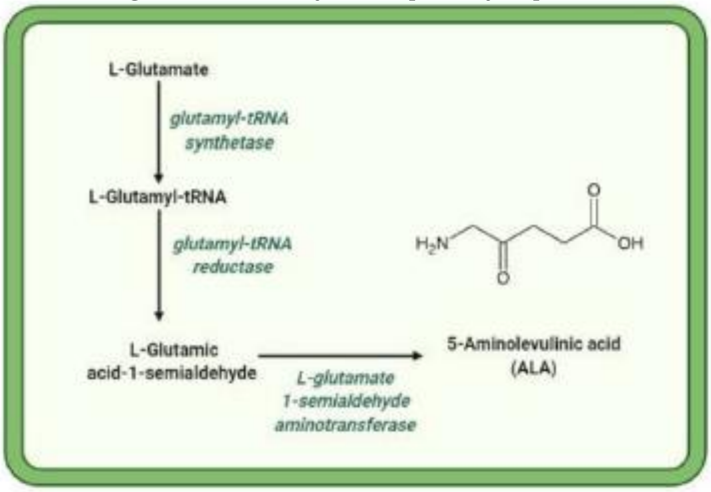
Previous studies demonstrated that pre-spraying ALA on leaves improved plant tolerance to various abiotic stresses, such as cold stress (Balestrasse et al., 2010), waterlogging, heat stress (Zhang et al., 2012), salinity (Naeem., 2012) and stress due to water deficit (Liu et al., 2011).

Figure 2. ALA biosynthesis pathway in plants.



Source: Authors

5 CONCLUSION

The toxicity of heavy metals caused by their accumulation in the soil can be removed using hyperaccumulator plants through phytoremediation, a process effectively used to treat soils polluted by heavy metals.

Plants employ different mechanisms in the remediation of soils polluted by heavy metals and phytoextraction is the most common phytoremediation method used to treat soils polluted by heavy metals, which guarantees complete removal of the pollutant.

The understanding and studies on phytoremediation and its techniques have deepened. However, it is necessary to increasingly understand the behavior of different species in the presence of heavy metals in the soil.

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