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Indian Knowledge System for Sustainable Mitigation of Heavy Metal Effects in Plants

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Abstract

Heavy metal contamination presents a major threat to agricultural productivity and ecosystem health, negatively impacting plant growth, physiology, and metabolism. Traditional Indian knowledge systems, including Ayurveda, indigenous farming methods, and environmentally conscious practices, offer effective solutions for tackling heavy metal contamination in plants. These systems emphasize sustainable techniques such as using native plants for phytoremediation, organic fertilizers like cow dung and neem-based products, and eco-friendly farming practices. These combined methods promote plant health, enhance soil fertility, and contribute to long-term agricultural sustainability. By integrating these traditional approaches with modern scientific methods, we can develop effective strategies to reduce the harmful effects of heavy metals on plants.

Keywords: Heavy metals, Panchagavya, Biochar, Phytoremediation, Sustainability.

Introduction:

The pollution caused by heavy metals has become a global issue, disturbing the environment and posing serious threats to human health. The main causes of the increase in heavy metal pollution are rapid urbanization and industrialization. The increasing population, industrial revolution, and economic globalization have exponentially increased the diversity of contaminants [7]. Anthropogenic activities have drastically affected the geochemical cycle of heavy metals. Some of these metals viz., iron (Fe), cobalt (Co), manganese (Mn), copper (Cu), and zinc (Zn) are essential for human body in low concentrations however metals such as mercury and lead have no known beneficial effect [18]. Among the heavy metals arsenic (As), mercury (Hg), chromium (Cr), lead (Pb), and cadmium (Cd) are of most concern as these are non-threshold toxins which are reported to be present in higher concentration in the aquatic, terrestrial and aerial system [17]. Heavy metals have various detrimental effects on plants, affecting their growth, development, and survival. These effects vary depending on the type of heavy metal, concentration, and the plant species involved. Heavy metals, such as arsenic, cadmium, mercury, and lead, at high concentrations, negatively affect plant health by causing toxicity, nutrient imbalances, and impairing photosynthesis. They induce oxidative stress, alter water absorption, and reduce reproduction. Additionally, plants accumulate heavy metals, which enter the food chain, posing ecological and health risks. Overall, heavy metal contamination disrupts plant growth, development, and survival.

Reduction or removal of toxic heavy metals has become a challenging task. Indian Knowledge Systems (IKS) have gained attention for their sustainable approaches to mitigating heavy metal toxicity in plants, ensuring environmental protection and food security. This aligns with the global push toward sustainable agricultural practices that maintain ecological integrity.

Traditional Indian Practices for Soil and Crop Management:

Indian Knowledge Systems have long been integral to sustainable agricultural practices in India. These ancient methods, rooted in the understanding of nature and the environment, offer a holistic approach to agriculture, focusing on maintaining ecological balance, enhancing soil health, and ensuring food security. These systems encourage the use of locally available, natural resources, reducing reliance on synthetic fertilizers, pesticides, and soil contaminants. Some important traditional practices are-

1. Use of Panchagavya:

In traditional Indian agriculture, Panchagavya (a concoction of cow dung, cow urine, milk, curd, and ghee) is used to improve plant growth, reduce the uptake of heavy metals from the soil, and activate antioxidant defence mechanisms. This provides a potential phytoremediation strategy in contaminated environments. The application of Panchagavya to soil has been shown to reduce the absorption of heavy metals such as lead (Pb) and cadmium (Cd) by plants. This may be because the Panchagavya forms complexes with organic substances that bind to the metal ions and prevent the roots from absorbing them. In plants, Panchagavya has been shown to boost the production of antioxidant enzymes including superoxide dismutase (SOD) and peroxidase (POD), which can reduce the oxidative stress caused by heavy metal toxicity. It can slightly reduce the soil's pH, potentially enhancing the availability of certain essential micronutrients and lowering the solubility of some heavy metals. Panchagavya can improve plant growth parameters such as shoot and root biomass, chlorophyll content, and overall yield by reducing the harmful effects of heavy metals on plant physiology. [13 & 22].

2. Biochar Application:

Biochar (charcoal derived from biomass such as agricultural residues, forestry waste, and other biodegradable materials) has been traditionally used to improve soil fertility and reduce heavy metal uptake by plants. It not only enhances soil fertility but also offers a viable means for carbon sequestration, thereby addressing global warming concerns. Indigenous communities across the world, particularly in the Amazon Basin, have long used similar materials to enrich the soil. Known as “terra preta” or “black earth,” these ancient soils were highly fertile due to the application of charcoal and organic waste. In India, traditional farming practices have also included the use of ash and organic carbon to enhance soil productivity. Biochar adsorbs heavy metals and prevents leaching into the root zone [23]. The biochar amalgamation with heavy metal-polluted soil may improve pH, fertility and water-holding capacity, minimize the mobility of pollutants, and encourage revegetation [9]. Phytoremediation of mine sludge soil with biochar obtained from residues of orchard prune and organic manure at four distinct concentration levels (0, 1, 5, and 10%) demonstrated substantial benefits of biochar in revegetating plant species in metal and metalloid contaminated soils. Also, the bioavailability of Zn, Cd, and Pb reduced proportionally as the biochar content increased [5].

3. Use of Plant Extracts:

Plant extracts play a crucial role in mitigating the adverse effects of metal toxicity on plants by enhancing the plant’s natural defence mechanisms and detoxification processes. Through its bioactive constituents, the plant extract appeared to promote overall plant health, leading to improved growth and productivity under heavy metal stress conditions.

Neem (Azadirachta indica): Leaves and seed extracts of Neem contain antioxidants that protect plants from oxidative damage caused by heavy metals. Neem leaf powder, known for its porous structure and active compounds, has the potential to efficiently adsorb toxic heavy metals from water sources. Neem leaf powder (NLP) has very good potential for utilization as an adsorbent for Cd (II) from aqueous medium

[20]. Dyes and heavy metals which are present in waste water are removed using neem leaves by adsorption [1]. It has been reported that Neem leaf serves as a potential alternative adsorbent to remove copper and zinc ions from aqueous solution [14].

Tulsi (Ocimum sanctum): Tulsi leaves have been used to enhance plant immunity and reduce oxidative stress in plants exposed to heavy metals. Tulsi is also having good efficiency for removal of metal ions such as lead, cadmium, chromium, iron, copper and zinc. Various combination of Tulsi leaves with Methi leaves, Lemon leaves, Calotropis procera and Custard Apple leaves also exhibit appreciable removal efficiency for metal ions such as copper and zinc [3].

Tamarind (Tamarindus indica): Tamarind is traditionally used in agriculture as a foliar spray to detoxify heavy metal stress in crops. The extract from tamarind fruit contains compounds like polyphenols, flavonoids, and organic acids, which help bind heavy metals such as arsenic, cadmium, and lead, reducing their harmful effects on plants. Additionally, its antioxidant properties combat oxidative stress, supporting plant health. This natural, sustainable practice aligns with eco-friendly farming methods by improving soil health and reducing the need for chemical detoxification [24].

Amla (Phyllanthus emblica): Amla (Indian gooseberry), rich in antioxidants like vitamin C and polyphenols, is used in agriculture to protect plants from oxidative stress caused by heavy metals. The antioxidants in Amla extract neutralize free radicals, reducing damage to plant cells and tissues. It also helps bind toxic metals like cadmium, lead, and arsenic, preventing their uptake by plants. By reducing oxidative stress, Amla supports overall plant health, improves growth, and boosts crop yields, making it a natural and sustainable solution for managing heavy metal toxicity in agriculture [21].

4. Phytoremediation Using Indigenous Plants:

Phytoremediation is an environmentally friendly method that uses plants to clean up soil, water, and air pollutants. Indigenous plants are especially effective in this process because they are naturally adapted to local conditions, requiring less maintenance and promoting biodiversity. These plants can absorb, degrade, stabilize, or transform contaminants like heavy metals and organic pollutants through various mechanisms like uptake, rhizodegradation, and phytovolatilization. Indian plants like Indian mustard (Brassica juncea), Willows (Salix spp.), Sunflowers (Helianthus spp.) and Vetiver (Chrysopogon zizanioides) are used in traditional farming to absorb heavy metals, such as lead and arsenic, from contaminated soils. "Moringa (Moringa oleifera)" is known for its hyperaccumulative properties and has traditionally been used to purify water and detoxify soil [30].

5. Ayurveda and Metal Detoxification:

Ayurveda describes several ancient plants with detoxifying properties that may assist in the removal of heavy metals from the body or environment. These plants, such as Ashwagandha (Withania somnifera), Brahmi (Bacopa monnieri), Coriander (Coriandrum sativum), Guduchi (Tinospora cordifolia), Guggulu (Commiphora wightii), Neem (Azadirachta indica), Shatavari (Asparagus racemosus), Tulsi (Ocimum sanctum), Turmeric (Curcuma longa), and Triphala (Amla, Bibhitaki, and Haritaki), have long been used for their purifying effects. They also play a role in phytoremediation efforts to detoxify metal contaminated soil. Incorporating these plants into detox protocols, whether for individual well-being or environmental healing, offers a holistic method rooted in centuries of traditional wisdom [27].

Shilajit (Aphaltum), a natural resin used in Ayurvedic medicine, is believed to aid in metal detoxification due to its content of fulvic acid. Its chelation properties help bind heavy metals like lead and mercury, making them easier to remove. Shilajit improves soil health by enhancing microbial activity and supporting bioremediation, where natural processes help degrade or absorb contaminants. It also aids in phytoremediation, enhancing plant absorption of metals [4].

6. Organic Manures and Compost:

Indian farmers have traditionally used composted manure and vermicompost as natural fertilizers to enrich soil health and enhance crop productivity. These organic materials are particularly rich in humic acids and fulvic acids, which are organic compounds formed during the decomposition of plant and animal matter. Humic acids and fulvic acids play a crucial role in soil chemistry, especially when it comes to detoxifying the soil from harmful pollutants like heavy metals. These acids have the ability to chelate, or bind, heavy metals such as lead, cadmium, arsenic, and mercury. By forming stable complexes with these metals, humic and fulvic acids reduce the bioavailability of the metals, which means they are less likely to be absorbed by plants, thus preventing them from entering the food chain and posing health risks to humans and animals. These organic inputs enhance soil microbiota, which further helps in heavy metal immobilization [25].

7. Soil Microbiota and Mycorrhizal Fungi:

The soil microbiota and mycorrhizal fungi play an essential role in mitigating heavy metal contamination in soils. Traditional Indian farming practices emphasize the role of beneficial microorganisms like Rhizobacteria and mycorrhizal fungi to improve plant nutrient uptake and heavy metal immobilization. Mycorrhizal fungi form symbiotic relationships with plant roots, improve phosphorus uptake and reduce metal toxicity. By using various bioremediation strategies, such as biosorption, chelation, and immobilization, these organisms contribute to reducing metal bioavailability, improving soil health, and promoting plant growth in contaminated environments. Their symbiotic relationship with plants enhances the ability of crops to thrive in polluted soils, contributing to sustainable farming practices and environmental restoration efforts [32].

8. Vrikshayurveda (Ancient Indian Agricultural Text):

Vrikshayurveda, an ancient Indian text on plant science, highlights several natural methods to enhance soil health and strengthen plant resistance to stress, including heavy metal contamination. The key recommendations from Vrikshayurveda include:

Application of Cow Urine: Cow urine serves as a natural chelator, promoting improved soil microbial activity and aiding in soil detoxification.

Bio-Extracts from Leaves: Extracts from leaves of plants such as banana, neem, and tulsi are used for their ability to cleanse the soil and reduce heavy metal toxicity.

Use of Ash: Wood ash is used for neutralizing soil acidity and helping to immobilize heavy metals, making them less available to plants.

These traditional methods offer sustainable approaches for improving soil quality and supporting plant growth in contaminated environments [10].

9. Bioremediation with Indigenous Bacteria:

Indian farmers have long relied on certain soil microbes, such as Pseudomonas and Rhizobium species, for their beneficial effects on plants. These microbes play an important role in improving soil health and promoting plant growth. Indigenous Indian bacteria, including Pseudomonas and Rhizobium species, have shown the ability to bioaccumulate heavy metals [6 & 26]. Through processes like nitrogen fixation (in Rhizobium) and phosphate solubilization (in Pseudomonas), they promote plant growth by improving nutrient availability [11]. These bacterial strains are also capable of detoxifying toxic metals such as cadmium and lead through enzymatic processes, reducing their harmful effects on plants and soil health

[15 & 28]. These microbes not only enhance agricultural yields but also contribute to environmental well-being by helping to mitigate soil pollution.

10. Siddha and Unani Contributions:

The Siddha system, a traditional form of medicine practiced in South India, utilizes a holistic approach to health that encompasses not only human well-being but also environmental health, particularly soil and plant management. Siddha practices involve using plant and mineral combinations to detoxify the soil, enhance plant immunity, and promote stress tolerance. Soil health is improved through natural management methods, and foliar sprays made from herbal extracts boost plant resistance to diseases, pests, and environmental stresses.

The Unani system, originating from Greek and Islamic medicine, also integrates soil management techniques that focus on reducing toxicity and promoting healthy plant growth. Unani practices emphasize composting organic materials and using sulphur containing herbs to reduce heavy metal toxicity in the soil. These herbs help neutralize harmful metals like lead and cadmium, improving soil quality and promoting healthier plant growth [2 & 31].

Both systems emphasize environmentally friendly farming techniques that enhance soil fertility, reduce contamination, and support sustainable agriculture.

11. Sustainable Crop Rotation Practices:

Traditional Indian agricultural systems promote crop rotation as an effective strategy to reduce heavy metal accumulation in the soil. The practice of crop rotation with legumes and green manure crops improves soil health, reduces the bioavailability of harmful metals like arsenic, mercury, chromium, cadmium and lead, and enhances soil organic matter. The inclusion of legumes helps limit metal absorption, while green manure crops increase organic matter, enriching the soil and boosting fertility. In the long run, crop rotation supports sustainable farming by maintaining soil quality, enhancing plant growth, and reducing soil contamination [29].

12. Use of Traditional Salt Compounds:

Saindhava Lavana (rock salt) is traditionally used in Indian villages to improve soil health. When applied in small amounts, it enhances soil structure by increasing aeration and water retention, particularly in compacted soils. It helps bind heavy metals such as arsenic, chromium, cadmium, and lead reducing their bioavailability and preventing plant uptake, thereby reducing plant toxicity. The salt also promotes better water retention, supports soil fertility by providing trace minerals, and increases microbial activity for natural soil detoxification. This sustainable practice improves crop growth and soil health while minimizing the need for synthetic chemicals, supporting environmentally friendly farming [12].

13. Biodynamic Farming Methods:

Biodynamic farming is a holistic agricultural approach that integrates traditional Indian practices with spiritual and ecological principles. It focuses on enhancing soil health, promoting biodiversity, and maintaining ecological balance. A key aspect of biodynamic farming is its use of lunar cycles to guide planting, sowing, and harvesting, believing that the positions of the moon can influence plant growth and soil vitality. A key component of this approach is the use of Jeevamrut, a fermented liquid manure made from cow dung, cow urine, jaggery, and pulse flour. Jeevamrut boosts microbial activity, improving soil fertility, and helps reduce heavy metal stress by making toxic metals less available to plants. It also enhances soil structure, nutrient content, and moisture retention, supporting sustainable, eco-friendly farming practices [8 &16].

14. Integration of Spiritual Practices:

Many Indian farmers integrate spiritual practices into their agricultural methods, such as applying sacred ash or holy water to fields. While these rituals are spiritually significant, they also offer practical benefits for soil health. Sacred ash adds essential minerals like potassium, calcium, and magnesium to the soil, improving fertility. Holy water from sacred rivers may introduce beneficial microbes that enhance nutrient availability and promote soil health. These practices also help in detoxifying soils contaminated with heavy metals by reducing their bioavailability, supporting sustainable farming while maintaining cultural traditions [19].

Case Studies of Indigenous Knowledge Systems (IKS) Application:

Recent studies have validated many traditional Indian practices for their effectiveness in mitigating heavy metal toxicity. For example:

- **Punjab Agricultural University Research (2019): Panchagavya Application in Rice Cultivation:** Punjab Agricultural University (PAU) conducted research to explore the potential of Panchagavya. The study observed that cadmium levels in rice were reduced by 30% when treated with Panchagavya. It is suggested that Panchagavya may influence the bioavailability of cadmium, making it less accessible to plants or enhancing the plant's ability to detoxify the metal.
- **Tamil Nadu Agricultural University (TNAU) Study (2018): Neem Leaf Extract for Reducing Lead Uptake in Brinjal:** The study found that Neem leaf extract significantly reduced the uptake of lead by 20% in brinjal. The active compounds in Neem, such as azadirachtin, may work by acting as chelators, binding to the lead ions in the soil and preventing them from being absorbed by the plant roots.
- **ICAR, New Delhi (2021): Phytoremediation Using Vetiver for Arsenic Contaminated Fields:** The study revealed that Vetiver, with its deep rooting system, was capable of absorbing and accumulating high levels of arsenic from contaminated soil. The plant's roots have been shown to trap and sequester arsenic in their tissues, preventing it from entering the food chain through crop uptake.

Conclusion:

One of the most pressing challenges in modern agriculture is heavy metal toxicity, which poses significant risks to both human health and the environment. However, Indian Knowledge Systems (IKS) presents promising solutions for mitigating these risks, as evidenced by several studies, including the use of Panchagavya, neem leaf extract, and vetiver for phytoremediation. Despite the promising potential of IKS, there are several challenges to its wider adoption:

Lack of Awareness: Many farmers are either unaware of the benefits of IKS or are skeptical about its effectiveness compared to modern chemical inputs.

Scientific Validation: Although traditional practices have been used for centuries, there is still a need for robust scientific evidence to validate and measure their effectiveness in modern agricultural settings.

Policy and Institutional Support: There is limited policy support for integrating IKS with modern agricultural practices. The lack of government incentives and regulatory frameworks may hinder the widespread adoption of these practices.

To overcome these challenges, future research is crucial to document, test, and validate the efficacy of traditional practices. Additionally, policy support should aim at creating an enabling environment for sustainable agricultural practices that integrate both traditional knowledge and modern science. This includes funding for field trials, knowledge-sharing platforms, and community-based training programs to empower farmers with the tools they need to implement IKS effectively.

In conclusion, Indian Knowledge Systems offer valuable, sustainable, and holistic solutions to the growing problem of heavy metal toxicity in agriculture. By integrating these time-tested practices with modern scientific research, we can enhance the resilience of farming systems, improve food safety, and promote environmental sustainability.

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