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Original Article

Applicability Of Microgreens To Mitigate Bioaccumulation Of Heavy Metals And Environmental Toxicants

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ABSTRACT

The prevalence of environmental pollution has resulted in widespread human exposure to heavy metals and toxic xenobiotics through food, water, air and consumer products. Persistent toxicants such as lead(Pb), mercury(Hg), Cadmium (Cd), Arsenic(As), Pesticides, endocrine-disrupting chemicals (EDCs)and industrial pollutants undergo bioaccumulation leading to oxidative stress, chronic inflammation, endocrine dysfunction, neurotoxicity and carcinogenesis. Bioaccumulation is the process by which a harmful material progressively accumulates in a living organism when the rate of absorption exceeds the rate of metabolism and excretion. People are searching for new trends of food which they can fulfill their healthy lifestyles by combating against bioaccumulation of heavy metals and environmental toxins. Microgreens are young edible seedlings of vegetables, herbs and cereals harvested at the cotyledon to first true leaf stage emerged as a trending functional food. The objective of the study is to evaluate the applicability of microgreens to mitigate bioaccumulation of heavy metals and environmental toxicants. Literature has been collected from authentic texts, previous research evidences, journals and authentic web sites. Microgreens are rich with antioxidants, vitamins, minerals, higher amounts of phytonutrients and minerals as Calcium, Magnesium, Iron, Manganese and Zinc. Microgreens are beneficial to protect the body from many disease conditions as heart diseases, alzheimer's disease, diabetes, cancer, chronic kidney diseases and lead for healthy bones, eyes and boosting immunity of people which is work as a solution against bioaccumulation of toxins in the body.

Keywords: bio- accumulation, environment toxins, heavy metals, microgreens, toxins.

INTRODUCTION

Environmental pollution became one of the significance threat to global health in the 21st century.[1] International environmental monitoring agencies have informed that millions of individuals chronically exposed to heavy metals and toxic environments through contaminated food, drinking water, occupational exposure, household products, pharmaceuticals, cosmetics and atmospheric pollution.[2] Besides that, many acute toxic agents and heavy metals are persistent due to environmental stability and they accumulate within biological tissues over prolong periods. [3]

Heavy metals, including Lead, Mercury, Cadmium, Arsenic, Chromium and Nickel has no physiological role in the human body and can cause toxic effects even at relatively low concentrations.[4] Further, modern populations are increasingly exposed to endocrine-disrupting chemicals, pesticides, herbicides, plastic and industrial pollutants. Continuous exposure leads to cumulative toxic and distraction of physiological homeostasis.[5]

Bioaccumulation refers to the progressive accumulation of toxic substances in living organisms through direct exposure or food chain magnification. It will lead to adverse health effects in humans and ecosystems.[6] Heavy metals like cadmium (Cd), lead (Pb), arsenic (As), and contaminants such as microplastics persist in agricultural soils due to industrial emissions, wastewater irrigation, and improper waste disposal, contributing to their accumulation in staple crops and edible vegetables. [7] This has raised concerns over food safety and public health worldwide.[8] Modern strategies to address this problem involve both pre-harvest interventions and dietary choices that limit toxin intake while boosting nutrient density.[9]

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Microgreens are young shoots of vegetables and herbs harvested typically 7–21 days after germination.[10] They have gained attention for their superior nutrient density, particularly in vitamins, minerals, and antioxidants, compared to mature plant tissues. Their cultivation under controlled conditions may also reduce the risk of contaminant uptake.[11] Given the limitations of pharmacological detoxification approaches and the growing emphasis on preventive medicine, dietary interventions have attracted considerable scientific attention. Among emerging functional foods, microgreens have gained recognition due to their extraordinary nutrient density and abundance of biologically active compounds. The present review explores the scientific rationale supporting the application of microgreens as a dietary strategy for mitigating heavy metal bioaccumulation and environmental toxicant-induced health effects.

MATERIALS AND METHODS

Literature has been collected from authentic texts, previous research evidence, journals published in PubMed., PubMed Central and Google Scholar, and authentic websites. This structured search covered both traditional and modern research evidence.

1. Heavy metals and environmental toxicants

Environmental toxicants and heavy metals are persistent pollutants that come from both natural and man-made processes, including mining, industrialization, the burning of fossil fuels, agriculture, the dumping of electronic waste, and urbanization. Due to their non-biodegradability, environmental persistence, and potential to build up in biological tissues over time, heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), and nickel (Ni) are particularly concerning. Contaminated food, drinking water, air pollution, occupational exposure, medications, cosmetics, and consumer goods are some of the ways that these toxicants enter the human body.[12]

Reactive oxygen species (ROS), oxidative stress, mitochondrial dysfunction, DNA damage, inflammation, apoptosis, and disruption of cellular signaling pathways are the main mechanisms by which heavy metals cause toxicity. Neurotoxicity, nephrotoxicity, hepatotoxicity, cardiovascular illnesses, reproductive abnormalities, immunological dysfunction, endocrine disruption, and carcinogenesis have all been associated with chronic exposure.[13] Additionally, heavy metals can interact with environmental toxicants such microplastics, pesticides, endocrine-disrupting chemicals (EDCs), and persistent organic pollutants (POPs) in a way that increases their bioavailability and toxicological consequences.[14]

Heavy metals and Environmental toxicants	Sources	Health impacts
Pb	Lead-based paints Industrial emissions Battery manufacturing Contaminated water system Electronic waste	Neuro development impairment Cognitive dysfunction Nephrotoxicity Hypertension Reproductive toxicity
Hg	Industrial Discharge Dental amalgam Fish consumption Coal combustion	Neurotoxicity Immunotoxicity Renal damage Development abnormalities
Cd	Cigarette smoke	Renal dysfunction

	Fertilizers Industrial waste Contaminated crops	Oxidative stress Carcinogens
As	Groundwater Contamination Mining activities Industrial emission	Skin disorders Hepatotoxicity Cardiovascular diseases Various cancers
Microplastics	Plastic packaging Bottled water Food containers Cosmetics Synthetic textiles	Oxidative stress Inflammation Gut dysbiosis Endocrine disruptions
Pesticides	Agricultural sprays Food residues Household pest control products	Neurotoxicity Endocrine disruptions Reproductive disorders Developmental abnormalities Carcinogenicity
Endocrine Distrpting Chemicals(EDCs)	Plastics, Cosmetics, Food packaging, Personal care products	Hormonal imbalance Infertility Obesity Thyroid dysfunction Metabolic syndrome Developmental abnormalities
Persistent Orgnaic Pollutants (POPs)	Industrial chemicals Pesticides Contaminated food chains	Immunotoxicity Carcinigenecity Endocrine distruptions Reproductive and developmental toxicity[16]

Table 1 Sources and health impacts of heavy metals and environmental toxicants [15], [16]

Bioaccumulation in Conventional Crops and Food Safety Risks

One of the main causes of risking safety in food is, bioaccumulation of heavy metals and associated toxins found in agricultural products. For example, research has shown that leafy vegetables irrigated with contaminated water accumulate considerable amounts of Ni, Pb, Co, and Cd, which pose serious health concerns to humans because of their mobility and permanence in edible tissues. [17]

The process by which plants gradually acquire and retain environmental toxins, such as synthetic pesticides and heavy metals in their edible tissues is faster than they can remove or break them down, is known as bioaccumulation in conventional crops. The main ways that these contaminants enter the food chain in traditional agriculture are through the overuse of chemical fertilizers, contaminated irrigation water, and persistent pesticides that stay in the soil.[18]

Because of their great stability, these chemicals remain unchanged as they move up the food chain, a process called biomagnification that results in a significant increase in the concentration of poisons by the time they reach human consumers.

Food safety is seriously threatened by this contamination since long-term dietary exposure to these accumulating toxins. This can damage essential human cellular functions, long-term health problems, such as renal damage, neurological disorders, and an increased risk of cancer. Developmental delays and immune system damage are also more common in susceptible groups, particularly in young children and pregnant women.

To control these ubiquitous risks, international agencies such as the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) establish and strictly enforce Maximum Permissible Limits (MPLs) to monitor and limit dangerous residues in commercial food supply.[19]

2. Plant profile, characteristics and nutritional significance of microgreens

2.1 Morphology

Microgreens are soft immature greens made from vegetable and plant seeds that have two completely developed cotyledon leaves with or without the appearance of a rudimentary pair of first true leaves. Microgreens typically reach a height of 13.3 inches and are harvested in 7–14 days after germination [11], depending on the species.

2.2 Cultivation and propagation

Microgreens are relatively easy to grow on a small scale and if sunlight is available, they can thrive indoors. They are produced in a variety of environments as open air, protected environment, indoor and growing systems. Containerized productions adaptable both to micro scale urban and large scale commercial operations. Peat and peat based media are the most commonly used. Microgreens can grow either in soil or hydroponically, but sunlight is essential. They are usually grown in greenhouses in growing flats containing potting mixes, peat-based mixes, hydroponic growth medium, or even with recycled textile fiber mats [11] [20]

Microgreens are ideally suited for indoor production and controlled environmental agriculture (CEA) [21] .This will be helpful due to population growth, shrinking arable land, and the need for ensuring food security [22] The short time to harvest for microgreens and high market values makes them important CEA crops

2.3 Harvesting

Most species are harvested at the appearance of the first true leaves with cotyledons which are fully expanded, still turgid,retaining their typical colour and seedling having a height of 5cm-10cm. Harvest is performed by cutting the seedlings manually or mechanically few millimeters above the growing media surface.[23]

2.4 Common microgreens

Family	Commonly grown microgreens
Alliaceae	chives, scallions, shallots, onions, garlic Amaranthaceae spinach, amaranth, beets, swiss chard, orach, and magenta spreen
Apiaceae	celery, cilantro, chervil, fennel, parsley, carrot, and dill
Asteraceae	lettuce, endive, sunflower, garland chrysanthemum, shungiku, tagetes (marigold)
Brassicaceae	mustards, cabbages, broccoli, cauliflower, radishes, tatsoi, wasabi, arugula, cresses, kohlrabi, mizuna, turnip, savoy, kale, komatsuna, pak choi, kogane, collard, nasturtium, brussel sprouts, rapini, rutabaga
Cucurbitaceae	cucumber
Fabaceae	sweet pea, alfalfa, fenugreek, adzuki, fava
Lamiaceae	mint, basil, chia, and lemon
Oxalidaceae	wood sorrels, clover
Poaceae	corn, lemongrass
Portulacaceae	claytonia, purslane

Table 2 - Common Microgreens[11] , [24]

2.5 Nutrient Profile

Many studies were conducted to analyze the nutritional values of different types of microgreens. Research studies have shown that microgreens are containing potassium, iron, zinc, magnesium and copper. And they are rich with antioxidents, vitamins, minerals than the same quantity of mature greens. [20]

In fact, comparing microgreens to mature greens that they are containing wider variety of polyphenols and other antioxidents than their mature counterparts.

Microgreens have been shown to give larger amounts of phytonutrients (ascorbic acid, -tocopherol,-carotene, and phylloquinone) and minerals (Mg, Ca Fe,Mn, , Zn,Se, and Mo) when compared to other foods. Furthermore, because microgreens are typically taken uncooked, they can meet the needs of so-called "raw foodists."[20], [25]

Ascorbic acid, carotenoids, phylloquinone, and tocopherols were found in the highest amounts in red cabbage, cilantro, garnet amaranth, and green daikon radish microgreens, with levels considerably higher in microgreens compared to data base values for mature vegetable counterparts. (2012, Xiao et al.)

Mature leaves of pea and lupin had higher carotenoid concentrations than pea and lupin microgreens. (Klopsch et al. 2018)

Over the course of the 16-day growing period, the carotenoid content of wheat and barley microgreens increased. (Niroula et al. 2019)

Polyphenols were discovered in five Brassica microgreen cultivars, including several highly glycosylated and acylated quercetin, kaempferol, cyanadin aglycones, and complicated hydroxycinnamic and benzoic acids among them. Microgreens had more complex polyphenol profiles and a wider diversity of polyphenols than mature plant counterparts, according to the researchers.

Brassica microgreens are high in the macroelements K and Ca, as well as the microelements Fe and Zn, according to Brassicaceae (Xiao et al 2016).

Ascorbic acid, phylloquinone, carotenoids, tocopherols, glucosinolates, and polyphenols were shown to be moderate to excellent sources in Brassicaceae microgreens (Xiao et al. 2019).

Cauliflower, rapini, red radish, China rose radish, and ruby radish microgreens were found to have the greatest contents of total ascorbic acid, phylloquinone, total tocopherols, total glucosinolates respectively.

The DPPH radical scavenging capacity of ruby radish microgreens was also the highest.

Microgreen lettuce (Latuca sativa var. capitata; 2 week old) showed higher mineral content than mature lettuce (Ca, Mg, Fe, Mn, Zn, Se, and Mo).

Purple basil had the highest levels of ascorbic acid, while green basil and coriander had the highest levels of betacarotene and total polyphenols.

VITAMIN CONTENTS IN MICROGREENS

Microgreens	**Vit.C**	**Vit.E**	**Vit.K**
Garnet amaranth	131.6	17.1	4.1
Opal basil	90.8	24.0	3.2
Red beet	46.4	34.5	2.0
Red cabbage	147.0	24.1	2.8
Cilantro	40.6	53.0	2.5
Peppercress	57.2	41.2	2.4
Pea tendrils	50.5	35.0	3.1
Green radish	70.7	87.4	1.9
Arugula	45.8	19.1	1.6
Celery	45.8	18.7	2.2
Popcorn shoots	31.8	7.8	0.9
Golden pea tendrils	25.1	4.9	0.7

Table 3- Vitamin contents of microgreens [25]

	mg/100g of fresh product				
Microgreens	**NO_3^-**	**Na^+**	**K+**	**Ca^{2+}**	**P**
Argula	305	8.8	301	116	13.2
Green basil	429	11.9	299	107	13.2
Red basil	462	8.3	230	105	14.0
Brassica raab	355	9.8	255	114	18.4

Broccoli	267	8.4	167	126	20.1
Red cabbage	368	8.2	256	126	32.6
Mizuna	400	6.6	383	96	17.0

Table 4- Nitrate and mineral contents [25]

Ascorbic Acid.

Total ascorbic acid (TAA) and free ascorbic acid (FAA) were determined spectrophoto metrically according to the procedure previously reported by Hodges et al.12. Among samples tested, red cabbage and garnet amaranth microgreens had the highest TAA contents, followed by China rose radish, opal basil and opal radish.[25]

Phylloquinone.

Phylloquinone also known as Vitamin K_1 is required for blood coagulation and is most abundant in photosynthetic tissues of dark green vegetables, such as spinach, kale, and broccoli. The most concentrated in phylloquinone was in garnet amaranth ,red sorrel , green basil , pea tendrils and red cabbage microgreens. [25]

Carotenoids. [25]

Carotenoids and tocopherols were extracted under yellow light according to the modified method described by Lester et al. Red sorrel had the highest β-carotene concentration. The β-carotene concentration in these microgreens is comparable to that of carrot (Daucus carota L.) and sweet potato which are well known β-carotene-rich vegetables.

β-Carotene [25]

β-Carotene (provitamin A) is an important fat-soluble antioxidant and can protect cellular membranes by scavenging free radicals. Many microgreens are containing β-Carotene.

Lutein and zeaxanthin

There are xanthophyll carotenoids, accumulating in the macula of human eyes. Numerous epidemiological studies have shown lutein and zeaxanthin play a critical role in the prevention of age-related macular degeneration and cataract. Cilantro had the highest lutein/zeaxanthin levels following sorrel, red cabbage and garnet amaranth microgreens followed with lutein/zeaxanthin concentrations. These values were higher than that of mature spinach which contains high quantities of lutein/zeaxanthin [25]

Violaxanthin [25]

Violaxanthin is a natural orange-colored carotenoid found in photosynthetic organs of plants. The maximum concentration of violaxanthin in cilantro microgreens was more than 5 fold than that of mature cilantro leaves.

Tocopherol Concentrations [26]

Tocopherols and tocotrienols are together summarized as "vitamin E", known as fat soluble antioxidants. There are mainly 4 isomeres of tocopherols as α-, β-, γ- and δ-. Among them, α-tocopherol and γ-tocopherols are more active in plants. Studies have shown that those 2 tocopherols highy present in green daikon raddish microgreens.

Polyphenols [26]

Brassica and found 165 phenolic compounds comprising many highly glycosylated and acylated quercetin, kaempferol, cyanadin aglycones, and complex hydroxycinnamic and benzoic acids. They reported more complex polyphenol profiles and a greater variety of polyphenols in the microgreens than in their mature plant counterparts.

Minerals

Most of the microgreens are consisting with NO^-_3, K^+, Ca^{2+},Na^+,P ,S and Mg. [20] [22]

2.6 Health benefits

As microgreens are rich in above nutrients, they are very beneficial in healthy diet which can use to reach up to daily requirements of certain nutrients.

I. Heart Diseases [20]

Microgreens are a rich source of polyphenols, a class of antioxidents linked to a lower risk of heart diseases. Animal studies shows that microgreens may lower triglyceride and LDL cholesterol level. Moreover, crusiferous microgreens as cabbage and cauliflower also contain highest amount of chemical call sulforaphane. It gives protection against cardiovascular diseases. Chive microgreens contains a compound called allicin that improve heart health by lowering the amount of LDL cholesterol in blood. Red cabbage microgreens have been shown in animal studies to lower LDL cholesterol by 34%, triglycerides by 23% and reduce weight gain by 17%

II. Alzheimer's disease [22]

Due to contain polyphenols, studies have proven that microgreens can reduce the risk of Alzheimer's disease

III. Diabetes Mellitus [23]

Antioxidants reduce the type of stress that can prevent sugar from properly entering cells. Laboratory studies have showed. The fenugreek microgreens have showed the results of enhancing cellular sugar uptake by 25-44% .

Coriander microgreens have been proven that it has the ability to balance the blood sugar levels. Celery microgreens are consisted with low glycemic index, which is suitable to add to the diet of diabetic patients.

IV. Lowering Cancer risk [22]

Some research studies found that broccoli microgreens containing sulforaphene and it has the potencial to target cencer stem cells. Review studies have shown that high intake of fruits and vegetables may reduce the risk of common epithelial cancers and digestive tract cancers.

V. For enhance immunity [20]

As microgreens are containing antioxidants and vitamins that they can prevent harmful free radicals and protect from cell damages and can fight against infections.

VI. Reduce chronic disease risk [22]

According to the scientific studies, they have stated that fresh vegetable and fruit consumption is associated with lower risk of certain cancers, inflammation conditions and cardiovascular diseases.

VII. For healthy bones [23]

Most of the microgreens are containing Calcium. Specially Argula microgreens have proved that it can keep bones strong and healthy. As well as it contains low oxalates which can prevent body from full absorbing the Calcium.

VIII. For healthy eyes [20]

Most microgreens are containing Vit.A , β-Carotene, zeaxanthin and lutein which are necessary for proper eye health and maintaining good eye sight. Specially lutein and zeaxanthin play a critical role in the prevention of age-related macular degeneration and cataract

IX. For healthy digestive system [23]

As microgreens are containing dietary fibers, that they help to increase the bulkiness in stools and prevent the chance to get constipation.

X. For chronic kidney disease

Unlike the healthy population, for the patients with impaired kidney function ,it is prudent to recommend restriction of high potassium food. Thus it suggests to limit the consumption of vegetables as they generally contain high concentration of potassium. Microgreens are an emerging class of specialty crop , geno type were grown using a hydroponic system with different potassium levels in order to produce microgreens with low potassium content. [27]

3. Mechanisms how microgreens mitigate bioaccumulation of heavy metals and environmental toxicants

Due to a short harvest cycle, selective tissue compartmentalization, and active chelation in microgreens, the time and pathways available for pollutants to reach the food supply are reduced, thereby mitigating the bioaccumulation of heavy metals and toxins. The main physical and biological mechanisms like short lifespan and diluted exposure lead to shorter the window to absorb, transfer, and collect soil-borne pollutants due to their quick harvest cycle (7–21 days). Through physiological compartmentalization, rather than in the edible stems and cotyledon leaves, poisonous substances are frequently stored in the roots and seed coats during the early stages of seedling development.[28] Toxic Cadmium will also be reduced considerably. Microgreens generate antioxidant enzymes and metal-binding peptides, such as phytochelatins. That bind and neutralize harmful heavy metals. By doing this, systemic toxicity is reduced while the plant is actively growing. Producers and manufacturers can modify nutrient solutions to prevent heavy metal uptake through ion antagonism when cultivated in controlled indoor conditions (hydroponics). For example, sufficient zinc and iron can prevent the absorption of harmful cadmium.[20], [28]

Mechanisms	Nutrients in microgreens	Health Impact
Enhancement of Antioxident Defense system Heavy metals induced oxidative stress through excessive ROS generation	Vitamin C Vitamin E β-carotene Lutein Zeaxanthin Polyphenols Flavonoids	Neutralize free radicals Reduce lipid peroxidation Protect cellular membranes Prevent DNA damage
Activation of Nrf2 signaling pathway Nrf2 serves as the master regulator of cellular detoxification	Sulforaphane-rich microgreens activate: Nrf2 Heme oxygenase-1 (HO-1) NAD(P)H quinone oxidoreductase-1 (NQO1) Glutathione-S-transferase (GST)	Increased detoxification enzyme production Enhanced xenobiotic metabolism Reduced oxidative injury
Augmentation of Glutathione Synthesis Glutathione (GSH) is the primary intracellular detoxification molecule	Sulforaphane-rich microgreens activate: Nrf2 Heme oxygenase-1 (HO-1) NAD(P)H quinone oxidoreductase-1 (NQO1) Glutathione-S-transferase (GST)	Increased detoxification enzyme production Enhanced xenobiotic metabolism Reduced oxidative injury

Metal Chelation	Polyphenols and flavonoids present in microgreens possess natural metal-binding properties.	Chelation of lead Binding cadmium ions Reduction of metal absorption Facilitation of excretion
Gastrointestinal Binding and Elimination	Dietary fibers and chlorophylls	Adsorb toxic compounds Reduce intestinal absorption Interrupt enterohepatic circulation Promote fecal excretion

Table 5 Mechanisms how microgreens mitigate bioaccumulation of heavy metals and environmental toxicants [20] , [22]

DISCUSSION:

Considering to open-field agriculture, which is mostly susceptible to soil contamination, microgreens have several advantages. Regulating production techniques should be followed such as hydroponic, vertical farming, and sterile substrates. Controlled systems considerably lower the chance of toxin absorption into edible tissues. Further, it will restrict the exposure to heavy metals in soil.

According to a study evaluating heavy metal contamination in numerous microgreens, it can contain low amounts of metals. The levels are mostly genotype-dependent and controllable with stringent cultivation procedures. [11]

Though nutritional enrichment is the main function of microgreens, their potential for biofortification provides further advantages. Without having a detrimental effect on biomass, microgreens boosted phytochemicals and antioxidants which can counteract oxidative stress from toxins. Recent research also examined microgreens biofortified with mixes of selensate and selenite. It showed the enhanced nutrient profiles and improved functional properties, which may be valuable in health-oriented food applications. [21]

Further, the high phytonutrient profile of microgreens, especially antioxidants, lead to reduce the oxidative stress linked to toxic exposure in human metabolism.

CONCLUSION

In contemporary agriculture, microgreens have the potential to provide highly concentrated nutrients while lowering the dietary exposure to bioaccumulated pollutants. Their high vitamin and antioxidant content, along with their controlled production methods, facilitates the desirable functional food. In a world where environmental pollution and food safety issues are becoming a significant issue, the future researches should focus on controlled experiments that measure the uptake of toxins in microgreens under different pollution circumstances and study their ability to reduce systemic bioaccumulation in humans.

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