

Review

Medicinal plants as protective agents against zinc toxicity in aquatic and terrestrial organisms: Mechanisms and experimental evidence

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Abstract

Zinc is a vital trace element that takes part in various biological functions such as enzyme activity, immune response and metabolism of the cells but excessive exposure leads to acute toxicity among aquatic and terrestrial species such as fish, animals and humankind. High zinc levels interfere with metal ion homeostasis, stimulate the formation of reactive oxygen species, inhibit antioxidant defense systems and cause cellular and molecular damage that eventually results in physiological dysfunction and disease. The growing industrialization, agricultural effluents, environmental pollution and over-supplementation have increased the concern of the world on zinc induced toxicity in the environmental and biological systems. The ability of medicinal plants to prevent heavy metal toxicity has seen the development of medicinal plants as potential natural protective agents because of their good phytochemical compounds and multifunctional biological properties. The review is a critical evaluation of experimental studies, which illustrate the protective properties of medicinal plants against zinc induced toxicity amongst aquatic and terrestrial organisms. Special attention is given to the mechanistic actions of bioactive compounds of plant origin, such as antioxidant, metal chelation, regulation of inflammatory and apoptotic processes, and cellular redox regulation and homeostasis. The botanicals with reference to their mitigation of zinc-associated oxidative stress, tissue damage, and functional impairment are discussed using medicinal plants like *Withania somnifera*, *Curcuma longa*, *Allium sativum*, *Ocimum basilicum*, *Ginkgo biloba* and *Salvadora persica*. The review indicates the promise of medicinal plants as complementary and sustainable measures of controlling zinc toxicity with a view of solving the challenges that exist regarding standardization, optimization of doses, safety and translational applicability. Their potential therapeutic effectiveness and relevance to the environment needs to be confirmed in further mechanistic exploration and in the long term.

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Introduction

Zinc is the twenty-fourth most abundant element, making up about 0.02% of the Earth's crust (Simon-Hettich, [2001](#)). The average zinc concentration in the Earth's crust is 120 mg/kg (Hussain et.al, [2022](#)). Zinc, an essential trace element, is needed for various biological functions (Roohani et al., [2013](#)). Both zinc excess and deficiency can lead to oxidative stress, activating or inhibiting oxidant-sensitive transcription factors that can affect cell function, proliferation, and survival, leading to disease (Sinha, [2019](#)). It can lead to behavioral changes, impaired growth, and increased mortality (Li et al., [2018](#)). For instance, excessive intakes of zinc in over-the-counter supplements can block the absorption of copper as well as its dependent functions. Other causes of zinc poisoning include zinc-rich dental

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products, pathological consumption (pica) of metal particles containing zinc, such as coins; and ingestion of food or drink contaminated with zinc (Wolf et al., 2022). The World Health Organisation (WHO) has recommended the dietary intake values for zinc as 6.7mg for infants and 15mg for adults. Consumption of zinc above these recommendations may result in adverse effects such as anaemia, neutropenia and zinc induced copper deficiency. The European Food Safety Authority (EFSA) has set the tolerable upper intake level (UL) at 25mg per day while the Food and Drug Administration (FDA) has put it at 40mg per day (Schoofs et al., 2024). Excessive zinc can lead to toxicity, primarily in aquatic environments, affecting freshwater fish. Industrial ejection, mining activities, agricultural overflow and domestic wastewater are primary sources of zinc contamination in freshwater ecosystems (Gautam et al., 2014). Zinc causes loss of appetite, reduced growth and immunological abnormalities in fish (Hussain et al., 2022). Zinc exposure can lead to various genotoxicological and biochemical abnormalities and bioaccumulation in the kidney and liver, which are primary sites of biotransformation with excretion and detoxification, respectively (Trivedi et al., 2023). Due to heavy metal toxicity and non-biodegradable nature, it accumulates in biological systems and is potentially carcinogenic; they represent a great danger to the environment. Because of elements like Cd, Pb, As, Zn, etc. there is a significant risk to human health and the ecosystem (Balali-Mood et al., 2021; Asare et al., 2023). This review will highlight the protective effects of medicinal plants against zinc-induced toxicity in different organisms.

Mechanism of Zinc Toxicity

Overexposure to zinc impairs a number of physiological and cellular functions, resulting in tissue and systemic toxicity. Despite the fact that zinc is a vital trace element needed in many enzymatic and regulatory processes, excessive accumulation over physiological levels has adverse implications on mineral homeostasis, redox pathways and cell survival mechanisms (Figure 1). The pathogenesis of the toxic levels of zinc is a complex of factors, which can encompass changes in the metabolism of metals, oxidative stress, apoptotic pathways, and direct cell damage, especially in reproductive systems.

- 1. Induction of Copper Deficiency:** One of the main causes of the harmful effects seen is copper deficiency, which is brought on by prolonged exposure to excessive zinc levels (Hoffman et al., 1988). Above-recommended dietary values, zinc may lead to zinc-induced copper deficiency, anaemia and reproductive issues (Agnew & Slesinger, 2020).
- 2. Oxidative Stress:** An excess of reactive oxygen species (ROS) is the hallmark of oxidative stress, which is brought on by zinc poisoning (Kim et al., 2020).
- 3. Modulation of Apoptotic Pathways:** Zinc acts on several molecular regulators, such as caspases and proteins belonging to the Bcl and Bax families, to affect apoptosis, or programmed cell death. Fertility may be further impacted by this as it may result in increased cell death in reproductive tissues (Plum et al., 2010).
- 4. Direct Cytotoxic Effects on Reproductive Cells:** High levels of zinc can have direct cytotoxic effects (Pinho et al., 2020) on reproductive tissues, including germ cells, which can impede spermatogenesis (Vickram et al., 2021) and lower the quality of sperm (Wong et al., 2001).

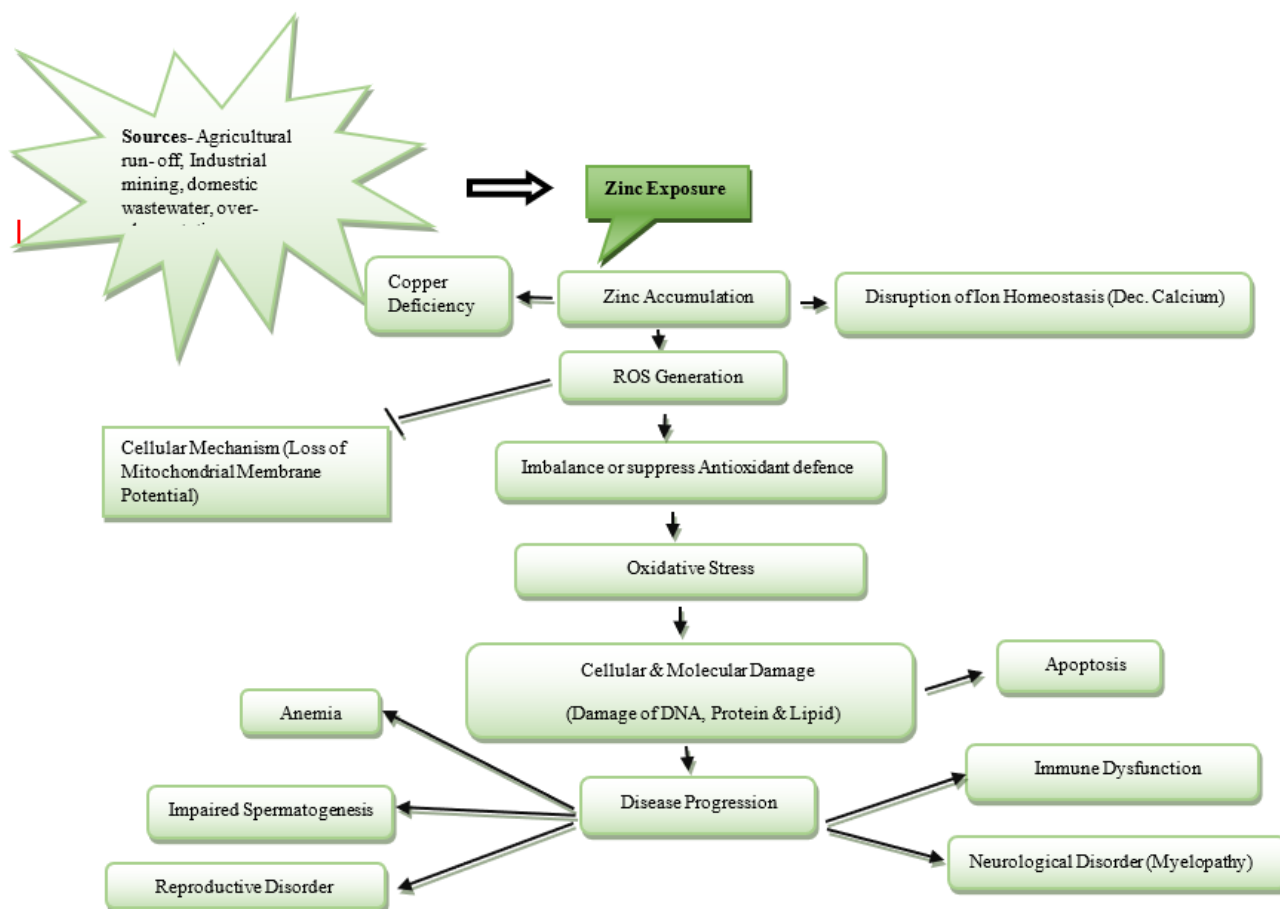


Figure 1. Zinc-induced reactive oxygen species (ROS) accumulation. Excessive exposure of Zn can increase ROS accumulation through directly increasing ROS generation and through an antioxidant system suppression, which then damages the DNA and prolonged exposure causes cellular damage, such as cell dysfunction and apoptosis (programmed cell death).

Significance of Using Medicinal Plants Against Zinc Toxicity

In the rural health care system, medicinal plants are a key source of readily accessible treatments. Trial and error were largely used to determine the pharmacological characteristics of plants, but people's religious and mythological beliefs also have an impact on how they are used (Sengar & Sachan, 2025). Herbal extract is usually obtained from several parts of plants, including leaves, roots, stems, and seeds. These parts contain a variety of bioactive compounds such as flavonoids, alkaloids, saponins, and tannins, known for their antioxidant, anti-inflammatory, and detoxifying properties (Zekeya et al., 2022). Medicinal plants possess phytochemicals such as flavonoids, alkaloids, terpenoids, and phenolics, which can be particularly beneficial in reducing heavy metal toxicity. Their antioxidant and metal chelation properties help to alleviate the oxidative stress induced by zinc and to restore homeostasis in cells. The increasing number of cases of heavy metal exposure and the resultant health risks make it essential that natural remedies be used for zinc toxicity treatment. More research on these alternative natural remedies is needed for the establishment of practical and effective methods to counteract zinc toxicity and improve public health outcomes. However,

overexposure to zinc has been known to cause toxicity toward both plant and human health. This review explores the ameliorative effects of medicinal plants against zinc toxicity, focusing on their ability to mitigate harmful effects via different biochemical pathways.

Experimental Evidence of Medicinal Plants Against Zinc Toxicity

Coffea arabica

Coffee contains chlorogenic acid and melanoidins, which contribute to the brown colour in coffee brews (Wen et al., [2005](#)). Researchers have studied the effects of Roasted Coffee Powder (RCP) on the growth of common carp and its tolerance to zinc toxicity. Five diets with different RCP ratios were prepared for common carp and fed twice daily for 10 weeks. Biochemical analysis of samples collected from the fish indicated that inclusion of RCP in the diet up to 1.0 g/kg did not cause significant growth retardation. High levels of RCP produced growth depression, resulting in an increased feed conversion ratio. There was no recorded fish health challenge or significant mortality throughout the period. The inclusion of RCP elicited immunostimulant activity as demonstrated by the enhanced production of oxygen radicals. Biochemical variables and zinc levels remained higher than expected, consistent with RCP and zinc exposure. RCP is hypothesized to decrease zinc toxicity by neutralizing free radicals and chelating the metal ions. In conclusion, RCP did not improve growth performance but decreased the effects of zinc on common carp (Abdel-Tawwab et al., [2017](#)).

Withania somnifera

The immunomodulatory and ameliorative effects of supplementing with *Withania somnifera* (WS) extract and Withaferin A (WA) on zinc oxide nanoparticle-mediated toxicity in Balb/c mice were investigated. Zinc oxide nanoparticles (ZnO NPs) are frequently used in consumer items and the food industry. The application of ZnO NPs spans nanomedicine, biosensors, semiconductors and drug delivery. Additionally, because of their antibacterial properties, they are utilized in livestock feed and food packaging. However, health complications and toxicity of ZnO NPs have raised concerns. In vitro studies demonstrate reduced mitochondrial function and oxidative stress by ZnO NPs, whereas in vivo studies determine cytotoxic effects on cellular viability and oxidative stress. The mice were divided into eight groups and treated for four weeks, with or without *W. somnifera* extract and Withaferin A. It was observed that ZnO NPs treatment significantly increased the body weights of the mice, decreased the viability of macrophage cells, and displayed no toxic effect at low dosages of ZnO NPs. The mechanism of oxidative stress was checked, and WS and WA were observed to be protective agents against ZnO NPs cytotoxicity. In conclusion, Withaferin A from *W. somnifera* is immunomodulatory in action, and WS and WA restored the macrophage activity against ZnO NPs toxicity. In conclusion ZnO NPs were found to be toxic at higher doses, and WS may serve as phytomedicine for the mitigation of toxicity (Kumar et al., [2019](#)).

Allium ampeloprasum

Allium ampeloprasum, commonly known as Egyptian leek, contains ellagic acid and has strong anti-inflammatory and antioxidant properties. In a study, researchers took the African catfish, *Clarias gariepinus*, acclimatized them to aerated freshwater and

fed a commercial diet at 2% of body weight (Authman et al., [2021](#)). Leek leaves were extracted and mixed with commercial pellets to create diets. Fish were categorized into six groups, some exposed to a sublethal dose of zinc. The trial lasted 45 days, and the fish were fed twice daily. Growth performance was evaluated, and zinc-treated groups showed significant changes. Hepatosomatic and gonadosomatic indicators were calculated. Blood samples were obtained for haematological analysis, and the biochemical analysis revealed significant changes in the biochemical parameters. Zinc exposure led to significant changes in biochemical markers, which indicate stress. The results displayed a protective effect of leek extract, but higher concentrations increased damage. The optimum supplement of leek extract was found to be 2% for which give best results. A diet with 2% leek extract is thus recommended.

Curcuma longa

Curcuma longa commonly known as turmeric, contains curcumin and has strong anti-inflammatory and antioxidant properties. Researchers studied the impact of zinc phosphide (ZnP) on rat liver and kidney and effect of turmeric as a natural antioxidant was studied with a control group of Wistar rats (Akinwunmi et al., [2021](#)). Five rat groups were given ZnP and curcumin. The results showed a significant increase in malondialdehyde (MDA) levels in the liver and kidney of the ZnP treatment, while the curcumin pre-administration decreased MDA levels to nearly control values. Curcumin decreased the enzymatic antioxidant activities of catalase and superoxide dismutase (SOD) activity. Curcumin brought antioxidant enzyme activities near to the control levels. Kidney enzyme activities were significantly affected by ZnP and improved by curcumin. This study shows the potential of curcumin in protection against oxidative damage caused by ZnP and that curcumin can protect against ZnP toxicity by reducing lipid peroxidation and restoring antioxidant activity. However, there is no antidote for ZnP, and prevention of exposure is important.

Allium sativum

Allium sativum, commonly known as garlic, contains Allicin and has strong antimicrobial protective mechanism. According to certain studies and research initiatives, garlic has a lot of health advantages including the amelioration of acute renal failure (Boozari & Hosseinzadeh et al., [2017](#)) anti-diabetic, hypotensive, and hypolipidemic qualities (Hosseini & Hosseinzadeh et al., [2015](#)), immunomodulatory activity, cardiovascular protective effects (Shang et al., [2019](#)) as well as antihypoxic (Hosseinzadeh & Sadati, [2003](#)), antimicrobial and antifungal properties. A previous study examined the toxic effect of zinc on goldfish testicular tissue and the protective impact of garlic. The research involved 75 healthy goldfish that were divided into five groups, including one group with exposure to zinc sulphate and another with the addition of garlic as supplements. The tissues of the testicles were collected after histopathological analysis, which showed severe lesions in the first group. The authors found that garlic may reduce zinc accumulation in the tissues of goldfish, being a chelator. Zinc concentration varied through the different fish tissues. The highest percentage of Zn in the fish tissue was reported in testis. Sulfur compounds of garlic can further reduce zinc toxicity (Hoseinifard et al., [2018](#)).

Ginkgo biloba

Ginkgo biloba is a tree (the oldest of all trees) belonging to the Ginkgoaceae family. Its leaves and bark have long been used to boost cognitive function and immunity, as well as treat tinnitus, sexual dysfunction, migraines, and the common cold. Major phytochemicals of *G. biloba* are flavonoids, glycosides, terpenes, lactones, ginkgolic acid, and Egb761 (Napryeyenko et al., [2009](#)). The extract of *G. biloba* has antioxidant, anti-inflammatory, hypolipidemic, anti-obesity and anti-tumour properties. Egb761 (*Ginkgo biloba* 761 extract) is a strong antioxidant and free radical scavenger that has anti-inflammatory, neuroprotective, and platelet aggregator properties. *G. biloba* extracts are commonly used as therapeutic agents in some cardiovascular disorders and a variety of neurological disturbances, including Alzheimer's disease (AD). A previous study explores the impact of Egb761, a *G. biloba* extract, on tau phosphorylation in zinc-treated neurons. Zinc concentration is elevated in Alzheimer's disease, influencing tau phosphorylation and amyloid processing. High zinc levels can increase tau phosphorylation and trigger cell death. Zinc treatment induced tau phosphorylation at Ser262 and neuronal cell death with intracellular reactive oxygen species in rat primary cortical neurons. Egb761 suggestively reduced zinc-induced tau hyperphosphorylation and neuronal cell death. Egb761 influenced tau protein kinases such as GSK3 β . Zinc's involvement in tau phosphorylation was specified with emphasis on GSK3 β . GSK3 β inhibition may be a therapeutic approach to the treatment of AD. The antioxidant action of Egb761 may prevent oxidative damage in neurons. The study emphasizes that tau phosphorylation at Ser262 has relevance in neurodegenerative pathology. Egb761 could regulate tau phosphorylation through ROS and GSK3 β inhibition and, therefore, may be a future therapeutic target for the treatment of tauopathies, such as AD. Zinc homeostasis regulation may be of importance in treating AD (Kwon et al., [2015](#)).

***Salvadora persica* (Miswak)**

Salvadora persica, commonly known as miswak (toothbrush), belongs to Salvadoraceae, and contains major phytochemicals, such as benzyl isothiocyanate, β -sitosterol, & avenasterol, etc which have antioxidant, antiplaque, analgesic, anticonvulsant, antibacterial, and antimycotic properties (Khatak et al., [2010](#)). It is commonly known as kharijal (Abhary & Al-Hazmi, [2016](#)). A previous study investigated the protective effects of Miswak (*Salvadora persica*) on Nile tilapia against zinc toxicity. Zinc is crucial for fish growth and aquaculture success, but can be toxic in excess. Miswak has antimicrobial and antioxidant properties, but its protective role against zinc toxicity has not been explored. The experimental design included Nile tilapia fingerlings acclimated in controlled conditions for two weeks, and zinc sulfate was used to induce zinc toxicity at a concentration of 7 mg/L. Miswak supplementation significantly improved growth performance and feed efficiency. Blood and tissue samples were collected for biochemical analysis. In this study, it was observed that zinc exposure caused significant pathological changes, which were mitigated by Miswak. The study concluded that Miswak alleviated growth performance and antioxidative response in tilapia exposed to zinc, and provided protection against zinc toxicity in various fish tissues (Abd El-Naby et al., [2020](#)).

***Ocimum basilicum* (Basil)**

Basil seeds, oil, and leaves, which have numerous medicinal properties, have antioxidant and enzyme-inhibitory activities, contributing to their health benefits. Major phytochemicals of basil are rosmarinic, caffeic, chicoric, and ferulic acid, which have antimicrobial, anti-inflammatory, anti-mutagenic, anti-viral, anticancer, antibacterial activity, antioxidant, immunostimulant activity, cardioprotective, and antiproliferative activity (Romano et al., [2022](#)). It was reported in one of the studies that new technologies have produced nanomaterials between 1 and 100 nm, with a 5.21% increase in products from 2006 to 2011. Nanomaterials can be poisonous due to their toxicity, which includes inflammation. Zinc oxide (ZnO) is widely used in various products but poses respiratory toxicity risks. In a study to assess the nephroprotective effect of basil seeds and oil against ZnO-induced nephrotoxicity, twenty-four male albino rats were categorized into four different groups, whose blood samples were taken for the biochemical and histopathological analyses. Results showed that basil seeds and oil reduced the weight of the organs and gained body weight of rats with renal injury, where ZnO nanoparticles induced weight loss and organ damage. The phytochemical compounds in basil contributed to its nephroprotective properties and overall health benefits (El-Wakeil et al., [2024](#)). Another study looked at the protective effect of basil leaves against zinc oxide nanoparticle-induced nephrotoxicity in rats. It was observed that there was an improvement in body weight gain and organ weights in the experimental rats that suffered from renal injury, where the ZnONPs caused considerable loss of body weight and organ weights (El-Hassanin, [2023](#)).

***Foeniculum vulgare* (fennel) & *Pimpinella anisum* (anise)**

Foeniculum vulgare is a medicinal plant native to the Mediterranean region and contains significant concentrations of phytoestrogens. Some of its leading constituents include anise oil, trans-anethole, coumarins, lipids, flavonoids, protein, carbohydrates, and minerals. It has also been observed to have antioxidant activity and serves as an active estrogenic agent. The unique flavour and Odor that characterizes the plant contribute to its medicinal use. A study evaluated the protective effects of fennel and anise against ZnO nanoparticles in male rats. The experimental animals were male albino rats, and the rats were divided into four groups for treatment over four weeks. The study found that ZnO nanoparticles caused hepatotoxicity, resulting in a significant increase in liver enzyme levels. Treatment with *F. vulgare* and *P. anisum* reduced enzyme levels compared to the ZnO group, and co-treatment with both plant extracts and ZnO nanoparticles decreased enzyme levels compared to ZnO alone group. The liver plays a significant role in metabolism and detoxification, making its health critical. Increased exposure to ZnO nanoparticles raises concerns about potential toxicity and adverse effects. High concentrations of ZnO nanoparticles can induce oxidative stress and liver cell apoptosis. *F. vulgare* and *P. anisum* demonstrated protective effects against ZnO-induced liver damage, and their antioxidant properties contributed to their hepatoprotective effects (Barakat, [2019](#)).

***Rosa damascene* (Damask rose)**

The damask rose, *Rosa damascene*, is one of the important species of the Rosaceae family (Kaul et al., [2000](#); Cai et al., [2005](#)), and its main components are anthocyanin, cyanidin, 3-5 diglucoside, kaempferol, quercetin, galactoside, arabinoside, citronellol, linalool, geraniol and terpenes (Velioglu & Mazza, [1991](#)), having antibacterial and antioxidant activities (özkan et al., [2004](#)). A study on the toxicological effects of damask rose extract on zinc toxicity in common carp was performed. 120 healthy common carp were acclimated and fed a commercial diet.

Four treatment groups were set up, comprising a control and three with varying *R. damascene* extract. The total phenols were found to be 18.6 mg/g and flavonoids 1.54 mg/g in *R. damascene* extract. When compared to the zinc-only treatment, damascene extract decreased the histopathological changes. The liver tissue of the zinc-only treatment group showed the highest concentration of zinc. The *R. damascene* extract resulted in decreased zinc levels in liver tissue and was comparable to the control. The results indicate that *R. damascene* may diminish the toxicity of zinc in the liver tissue of common carp (Taleghani et al., [2019](#)).

***Alchemilla vulgaris* (Lady's-mantle)**

Alchemilla vulgaris, also known as lady's mantle, belongs to the Rosaceae family and is a perennial herbaceous plant (Smolyakova et al., [2012](#)). *A. vulgaris* is used for its astringent, anti-hemorrhoidal, and antidiarrheal properties and contains major phytochemicals such as quercetin, gallic acid, and ellagic acid (Neagu et al., [2015](#)). *A. vulgaris*, shows medicinal properties, such as wound healing and anti-inflammatory effects, for health benefits. The effects of elevated ZnSO₄ levels in drinking water on the liver, spleen, and ovaries of female rats during an eight-week period were examined in a study. The study establishes whether the medicinal plant *A. vulgaris* can protect against zinc toxicity. A study on 30 healthy female albino rats demonstrated some pronounced hormonal shifts in treated groups, with elevated RBC count and different levels of certain liver enzymes. Exposure to zinc seems to interfere with hormone biosynthesis and thus reproduction. The study suggests that *A. vulgaris* has a preventive effect against zinc excess and may help improve liver function and hormone production due to its antioxidant property (Mohammed et al., [2019](#)).

Cichorium intybus

Chicory, or *Cichorium intybus* (CI), is a traditional perennial botanical medicine that comes from the Asteraceae family (Amirkhani et al., [2022](#)). *Cichorium intybus* includes sesquiterpene, lactones, caffeic acid derivatives, inulin, sugars, proteins, flavonoids, alkaloids, steroids, terpenoids, oils, volatile chemicals, coumarins, vitamins, and polyenes, with several pharmacological effects such as hepatoprotective, gastroprotective cardiovascular, antioxidant, hypolipidemic, anticancer, reproductive, antidiabetic, anti-inflammatory, analgesic, sedative, immunological, antimicrobial, anthelmintic, anti-protozoal, wound healing etc (Al-Snafi, [2016](#)). A study discusses the toxicity effects of ZnO-NPs on human health and that the particles have been used as immunostimulants, anti-inflammatory, in cosmetics, and health supplements. The chosen herb in the study was CI; it is an ancient herb and is used as a health-protecting plant for the liver. The exposed rats were treated with ZnO-NPs, showing an increase in the liver biomarkers and normalizing the level of enzymes. These results indicated that ZnO-NPs build up in the liver with hepatotoxicity effects on the organ. Therefore, CI could also protect animals from hepatotoxicity, caused due to nanoparticles (Ramadhan & Ghareeb, [2022](#)).

Medicinal plants can be used in the phytoremediation process that would reduce zinc exposure in aquatic and terrestrial ecosystems. Their ability to absorb and detoxify zinc offers long-term solutions for lowering heavy metal levels in the environment ([Table 1](#)).

Table 1. Medicinal plants with proven remediation efficiency against zinc.

Plant Name	Extracts	Active Compound	Protective Mechanism	References
<i>Coffea arabica</i>	Roasted Coffee Powder	Caffeine, Cafestol, Kahweol, & Chlorogenic acid	Antioxidant, Neuroprotective	(Abdel-Tawwab et al., 2017)
<i>Withania somnifera</i> (Ashwagandha)	Withaferin A & <i>Withania somnifera</i> extracts	Withaferin A & Withanolides	Immunomodulatory, Antibacterial, Chelating agent	(Kumar et al., 2019)
<i>Allium ampeloprasum</i> (Egyptian leek, kurrat)	Leaf extract	Ellagic acid	Anti-inflammatory, Antioxidant	(Authman et al., 2021)
<i>Curcuma longa</i> (Turmeric)	Rhizomes	Curcumin	Anti-inflammatory, Antioxidant	(Akinwunmi et al., 2021)
<i>Allium sativum</i> (Garlic)		Allicin	Antimicrobial, Antihypoxic, Antifungal	(Hoseinifard et al., 2018)
<i>Ginkgo biloba</i>	Leaf	Ginkgolides & Diterpenes etc.	Anti-inflammatory, Neuroprotective,	(Kwon et al., 2015)
<i>Salvadora persica</i> (Miswak)	Roots	Benzyl isothiocyanate, β -Sitosterol, & Avenasterol etc.	Antioxidant, Antiplateque, Analgesic, Anticonvulsant, Antibacterial, Antimycotic	(Abd El-Naby et al., 2020)
<i>Ocimum basilicum</i> (basil)	Seeds, Leaves, & Oil	Nolelinoleic acid	Antibacterial, Anti-hyperglycemic, Antiulcer, Antioxidant, Anticancer	(El-Hassanin et al., 2023 ; El-Wakeil et al., 2024)
<i>Foeniculum vulgare</i> (fennel) & <i>Pimpinella anisum</i> (anise)	Seeds	Fennel- Isoflavones, coumestans, & lignans Anise-trans-anethole, Coumarins, bergapten, rutin, and isovitexin	Analgesic, Antispasmodic, Antioxidant, Antimicrobial, Hepatoprotective and Anti-inflammatory	(Barakat, 2019)
<i>Rosa damascene</i> , (Damask rose)	Flower	Anthocyanin, Quercetin, Cyanidin, Kaempferol etc,	Antioxidant and Anti-aging	(Taleghani et al., 2019)
<i>Alchemilla vulgaris</i> (Lady's-mantle)	Aerial parts & Roots	Quercetin, Gallic Acid, Ellagic Acid	Anti-hemorrhoidal, Anticancer, Antimalarial	(Mohammed et al., 2019)
<i>Cichorium Intybus</i>	Herb supplement (Liv.52)	caffeic acid, lectones, sesquiterpene	antidiabetic, analgesic, anti-inflammatory	(Ramadhan & Ghareeb, 2022)

Challenges & Future Directions

Medicinal plants are very promising to treat various health issues, but they have some limitations in their massive use. Among them, the most significant challenge is standardization. The phytochemical composition of plants varies greatly according to genetic and environmental influences. Moreover, toxicities can arise with high dosages or even prolonged usage. Again, large-scale applications require more cost-effective and sustainable solutions. Therefore, future research should prioritize the identification of novel plants having great detoxifying potential and to formulate standardized formulations that can be used therapeutically. It can even further integrate plant-based approaches with advanced biotechnological methods for better efficacy and wider applications.

Conclusion

Medicinal plants can offer natural and effective solutions for mitigating zinc toxicity because of their antioxidative and chelating properties. To be able to take advantage of the potential of these medicinal plants requires an interdisciplinary effort in order to connect traditional knowledge with modern science. Medicinal plants represent a promising way of reducing adverse effects from zinc toxicity in agricultural systems. Their antioxidant properties, phytoremediation capabilities, and nutrient uptake regulation are some of the reasons why they can be used as natural means to

enhance plant resilience against heavy metal stress. Further research should be conducted on the specific mechanisms involved and the optimization of applications for these plants in sustainable agricultural practices.

Declarations

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