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REVIEW ARTICLE

Impacts of five selected heavy metals (Cd, Cu, Ni, Pb & Zn) on growth performance of wheat crop (*Triticum aestivum* L.): A brief review

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Abstract

Wheat is indeed a crucial dietary staple globally, but its quality and yield can be severely affected by heavy metal contamination in the soil. Heavy metals like cadmium, copper, nickel, lead and zinc are necessary in trace amounts for plant growth, but in high concentrations, they become toxic. Urbanization, industrial development and agricultural practices all contribute to the accumulation of heavy metals (HM) in the soil, primarily through atmospheric deposition, sewage, fertilizers, pesticides and irrigation. This contamination negatively impacts wheat seed germination, plant growth and ultimately, crop yield and quality. To mitigate heavy metal contamination, various remediation techniques can be employed, such as pH modifications and phytoremediation, which involves using plants to remove pollutants from the soil. Additionally, detecting contaminated areas and implementing focused investigations are essential to reduce human exposure to these harmful substances. It's also crucial to develop specific policies to limit heavy metal accumulation in hyperaccumulator plants like root and stem tubers, as they can further contribute to the contamination of crops. Overall, addressing heavy metal contamination in wheat crops requires a multi-faceted approach that combines remediation techniques, policy interventions and focused research to safeguard both agricultural productivity and human health.

Keywords: effects; heavy metals; heavy metals sources; seedling growth

Introduction

Wheat belongs to the family Poaceae and has high "economic significance, great consumption value and is a chief source of food for human beings". Due to high grain adaptability and fecundity rate, it is consumed worldwide. Wheat is the primary source of minerals for humans and it is the third most vital cereal crop after corn and rice (1). It is an integral part of dietary supplements and accounts for 60 % of calories per day. This is the main reason that it rules over agricultural policies at both provisional and governmental levels (2).

Germination effect on wheat crop stand

The establishment phase in wheat crops is divided into 3 parts, i.e., germination, emergence and early seedling growth. However, seed germination is critical in crop stands and all the phases are susceptible to any change in the environmental factors (3, 4). In the life table of a plant, seed is a stage that can resist various stresses very well. However, seeds often become sensitive to stress after water absorption and successive vegetative development when the seed coat softens. It is important to mention here that seeds must diligently monitor environmental factors like temperature, light and nutrients to ensure their protection until these factors turn advantageous for the next stages (5). An ideal wheat seed emerges after sexual fertilization having a mature ovule including a germ, stored food and a seed coat. The main features in seed growth and pubescence are the transfer of male pollen grains to female stigma (pollination), fusion of gametes (fertilization) and maturation of fertilized ovule (6). There are a variety of early developmental stages that are included in seed germination (7). These stages ultimately lead to metabolic transformation, which prompts the development of hypocotyls and radicle emergence (8).

Wheat seeds are sensitive to the action of radiant energy and they complete their growth and development in a particular set of time. The low-temperature treatment results in meager and inconsistent seed germination. As a result, the plant becomes fragile and incapable of gathering enough starch (9). The highly vigorous quality of the crop is attained by improving the seed germination by a process known as seed priming. It has been found that priming the seeds is a dual technique that can increase rapid and uniform emergence to obtain higher yields (10).

Factors conducive for seed germination and wheat growth

There are many factors that are important for seed germination that affect the crop yield. Temperature is an abiotic factor and is analysed as a serious issue for the wheat crop. Temperature also talks about the rate of moisture and other substrates required for seed germination and growth of plants. The optimal temperature is necessary for rapid seed germination, while low and high levels will prolong the germination. However, temperature fluctuations may affect the germination due to genotypic changes (11).

Another important factor that promotes seed germination is seed priming, which accelerates the enzymatic action by mobilizing pre-germination reserves, thereby activating the metabolic process required to initiate the germination. Usually, it reduces the time interval between the two germination stages, i.e., seed sowing and seedling emergence. The reason for this is that when the immersed seeds are sown it reduces the time required for the germination process. The seedlings may become resistant to substantial conditions of the soil that are deteriorating. It may also allow the wheat crop to grow faster with higher yields (12). There are also reports that seed priming can increase the rate of germination, stubble production, grain quality and harvesting index. It establishes a foothold until emergence and gives positive results associated with the germination and growth of seed.

Some authors conducted a study on beneficial aspects of seed priming in wheat crops. They analysed that the germination quality is positively correlated with the seed priming. Primed seeds are recommended over unprimed seeds due to their better performance in emergence and crop stand (13).

The addition of organic matter in the soil has a positive impact on the crop. It is added in the following forms: granulated lignite, compost, tree bark, ash and sawdust. It enhances seed germination by decreasing the degree to which a metal is absorbed by the seeds. After the repeated applications of organic matter, it retards metal absorption (14, 15). Hence, cultivated land all over the world is decreasing due to different types of soil pollution, which have become an alarming issue in many areas of the globe (16). Heavy metal accumulation occurs naturally in soil ecosystems as a paedogenesis, a process of weathering of rock. Other sources of HM pollution for different types of soils include emissions from volcanoes and the breakdown products of rocks enhanced with heavy metals ((17-19). Apart from all these natural sources, heavy metal accumulation can also occur broadly in cultivable soils due to human activities (Fig. 1). The accessibility of different heavy metals for plants is managed by numerous edaphic factors, such as pH, soil texture, cation exchange capacity (CEC), soil structure, organic matter contents and adsorption capacity of clays (20). Heavy metals, following accumulation within soil, enter the whole food chain and are consequently transported to the last trophic level, resulting in issues related to human health (21-24). The toxicity of different heavy metals that penetrate different vegetable organs, however, can slow down multiple vital physiological mechanisms of plants including wheat ultimately deteriorating human health (Fig. 2) (25-28).

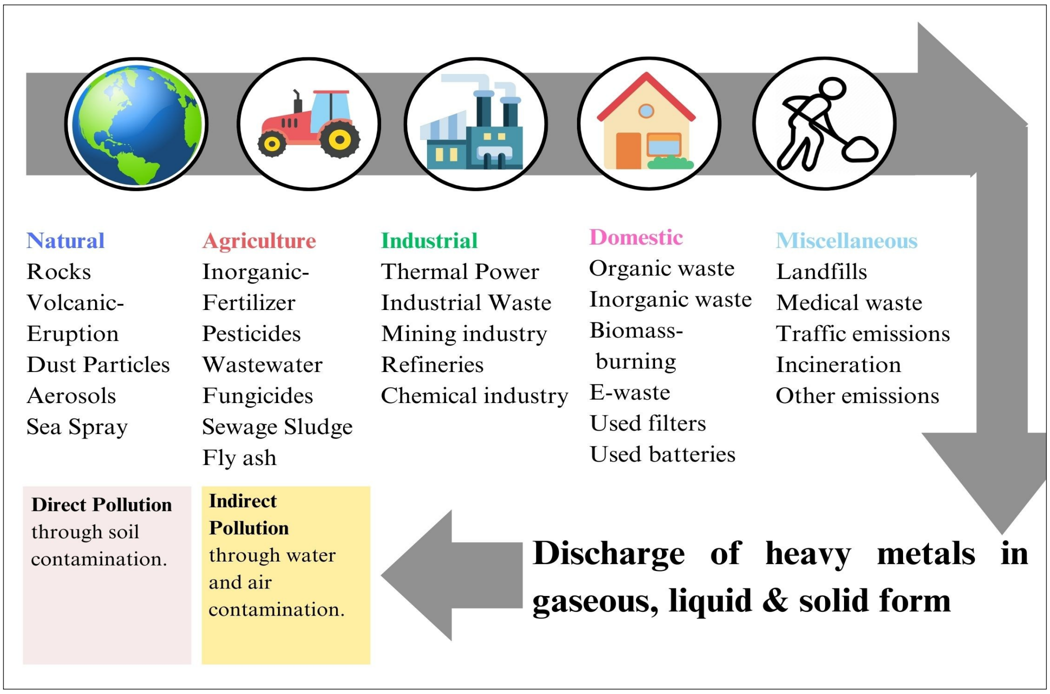

Fig. 1. Different sources of releasing heavy metal in the environment (29).

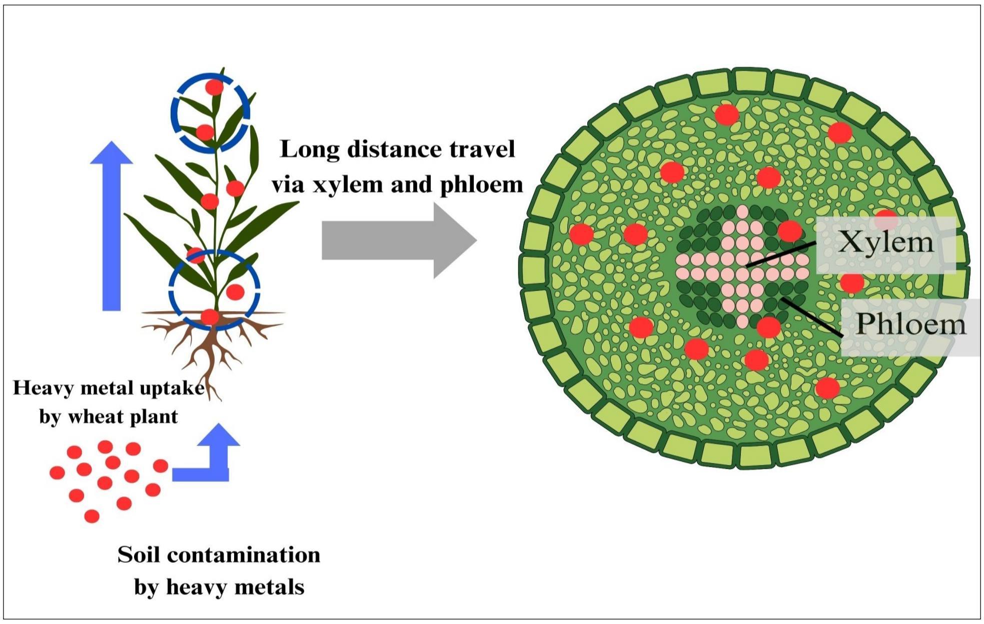

Fig. 2. Pathways for movement of toxic heavy metal from soil to plants and its various tissues (29).

Sources of different toxic heavy metals in the environment

The heavy metals are an emerging issue due to their excessive accumulation in the soil. These are abundant in the earth's crust and are well known either for their high density or atomic mass. Their accumulation is positively correlated with extensive urbanization, agricultural demand and industrial development (30). The rapid increase in global industry has greatly increased the risk of heavy metals polluting the environment. Human population explosion, urbanization, rapid industrialization and transportation as well as widespread use of fertilizers and harmful pesticides, cause toxic substances to accumulate in the soil (31-33).

Role of human activities in emission of heavy metals

The sources of pollution due to human activities are named linear emission, point emission and surface emission. The contamination due to automobiles and fuels is referred to as linear emission. The automobile is a source of lead contamination; it is also included in the gasoline in the form of (CH_3CH_2) Pb (34). Chemical emission by industrial technical processes, energy combustion of fuels and the emancipation of substances through vents systematically into the environment is known as point emission and causes nickel contamination. The emission due to the house heating in the public and domestic regions is referred to as surface emission.

Municipal sewerage

The wastewater from the industrial and public sectors is also a significant source of heavy metals. It comprises the effluent from domestic, medical, commercial, institutional, establishment and destruction activities. The municipal sewerage is used to irrigate the wheat crop due to the acute scarcity of water resources. The crop is irrigated by this untreated wastewater in some municipal areas. The reason behind using this water is to conserve the reservoirs for household perspectives, reducing risks of contamination and shortages of crop production. In addition to this, it also has some damaging effects, like reduced germination of seed and retarded seedling growth (35). Some workers evaluated that the use of sewerage for crop irrigation alters the physio-chemical parameters of the soil, resulting in absorption of the toxic heavy metals (36).

Industrial by-products

The industrial fly ash and other runoff that are released from electrical furnaces, contain zinc substitutes. These substitutes are used in the preparation of zinc fertilizers, applied to the soil to increase the richness of the soil. However, it also brings about the absorption of other impurities like lead, arsenic and cadmium that are harmful in higher concentrations. The continuous applications of these fertilizers to soil compensate for the zinc deficiency but also lead to the accumulation of other metals (37).

Accumulation of toxic heavy metals in wheat crops

There are several reports illustrating the effects of heavy metal stress on plant growth and development. The focus of these studies is on initial stages of growth such as premature stages: seed germination and seedling growth (38, 39). The heavy metals get accumulated in the soil via different sources as discussed earlier. Heavy metals pollution negatively affects the biochemical characteristics, seedling growth and biodiversity of different plants (Fig. 3). After the soil weathering and erosion processes, the toxic metals leach down and get absorbed by the various parts of the plant in addition to some vital nutrients. There is competition between the metals and nutrients for binding and absorption (Fig. 4). The metal ions take the place of nutrient cations in the root surface. Once metals penetrate the plant body, they interfere with the protein configuration and hit the thiol group in the protein structure resulting in the conformational changes of the protein, leading to genotoxic and cytotoxic effects (40).

Toxic effects of some selected heavy metals on growth of crops

Effects of cadmium

Cadmium (Cd) intrusion into the soil is the result of geological dating and human activities (43). The anthropogenic (man-made) activities are the main causes of Cd accumulation in the soil, i.e., thirteen million kilograms out of this quantity thirty million kilograms of Cd per annum is added by anthropogenic activities and taken up by wheat plants (44).

Cadmium is a potential pollutant that freely moves and can contaminate the soil, resulting in its higher concentration in

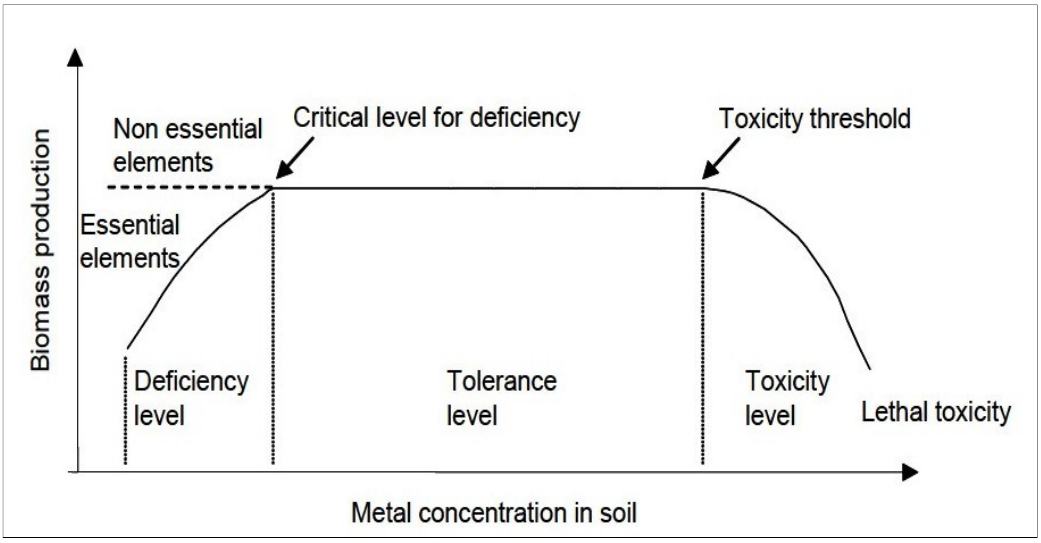

Fig. 3. Effect of metal concentration in soils on plant biomass production (41).

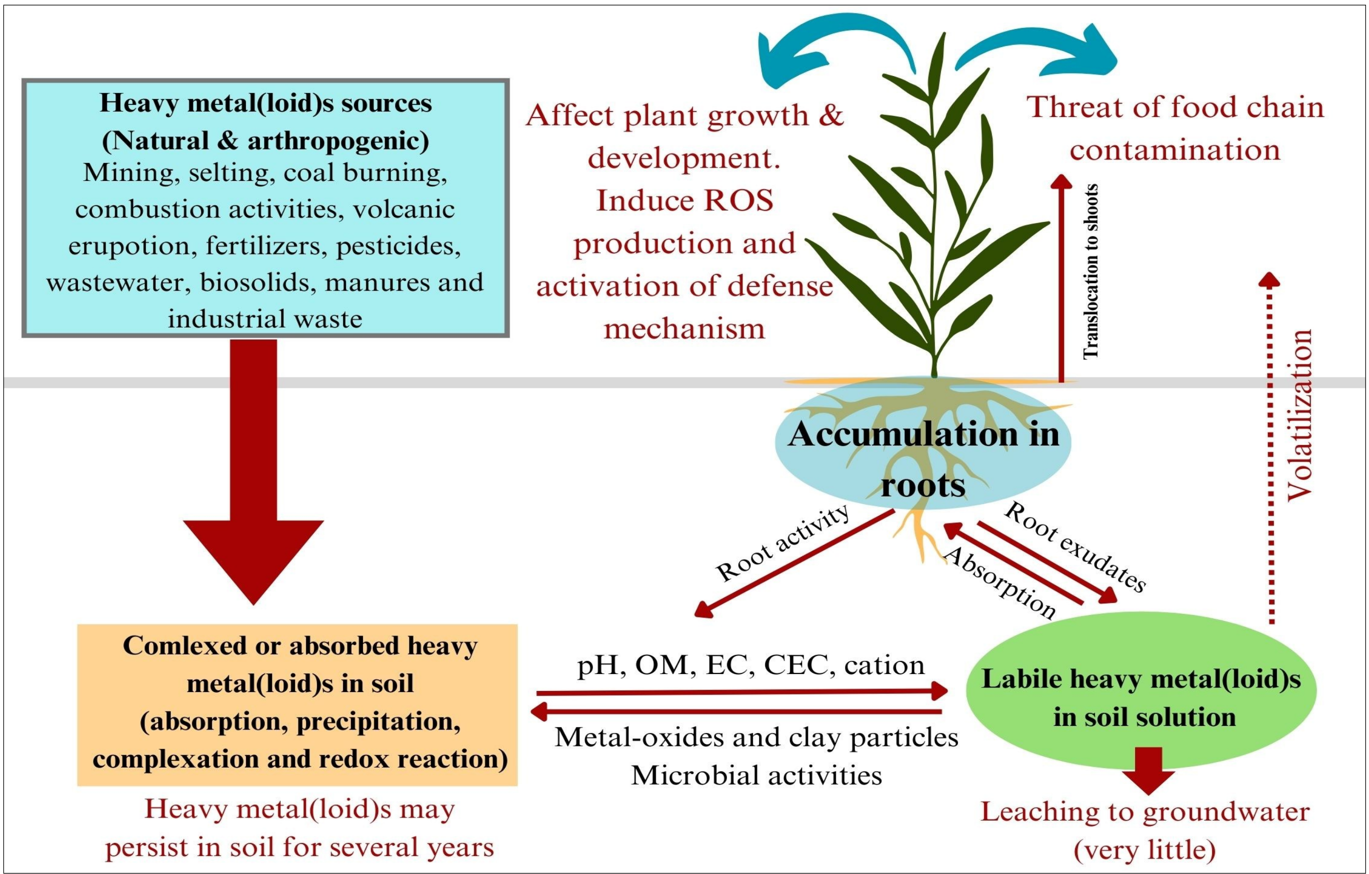

Fig. 4. Biogeochemical cycle of different toxic heavy metal in the soil-plant system (42).

various plant parts. It is absorbed by the plant and recycling is possible through human activities. Similarly, a study was carried out on cadmium existence in soil from various areas of Faisalabad (45). The industrial wastewater that is used to irrigate the crops contains large amounts of cadmium approximately 200 % more than the natural water. When these crops are consumed by the animals, they are also susceptible to their hazardous effects.

The attenuated seed germination is the prime and harmful effect of Cd deposition. The main observable signs due to cadmium contamination are cell injury in tissues (necrosis), loss of the green coloration (chlorosis), tanning at root tips and retarded growth, ultimately leading to plant death (46, 47). It also has an adverse impact on the growth of root and stem (48). As a result of this, both the quality and quantity of the spike are affected. It has a negative influence on yield coupled with short spike length, weight and number. The ear in the wheat crop shows less grain production per spike (49). It causes structural injury to the wheat membrane that affects the absorption of other essential nutrients. Due to its high dissolving property and toxic nature, cadmium has undesirable consequences on the growth of plants (50). The investigations of some researchers described that cadmium metal reacts with the thiol group to cause inactivation of enzymes in the crop. It also has an impact on utilization of minerals in the soil and prevents plants from absorbing nutrients (51, 52). It has been estimated that the seedling growth of common wheat is more susceptible to cadmium (53).

Effects of copper

The germination rate and poor seedling growth appear due to reduced degradation of starch. It is also regulated by poor activities of amylase in seeds. Enzymes like peroxidase and catalase are dependable for the inhibition of oxidative stress. Enzymes like peroxidase and catalase are dependable for the inhibition of oxidative stress. It can be done by the catalysis of a reaction in which the reduction of hydrogen peroxide (H_2O_2) occurs (54). When the plants are exposed to excess deposition of copper it can bring changes in the activity of catalase and peroxidase. Usually, it amplifies their activity that led to the elevated level of H_2O_2 (55). Hydrogen peroxide provides an essential substrate for the hardening of cell wall in the presence of peroxidase (56). Consequently, this method suppresses seed growth. The enzyme catalase is important in the antioxidant defense mechanism that helps in the eradication of hydrogen peroxide.

Effects of nickel

The role of nickel for plants as a micronutrient is undeniable and it is added into the environment by artificial and natural resources. Although it is essential for plant growth, its lethal effects are of greater attention than its shortage (57). There are reports that nickel contamination affects wheat plant growth, interferes with membrane functioning, prevents seed germination and the process of photosynthesis (58). When growing seedlings are exposed to nickel contamination it is absorbed by different plant parts and gets accumulated there. A higher concentration of nickel lowers the level of chlorophyll in stem tissues and reduces the seed germination that affects the biomass production of wheat crops (59, 60).

Effects of lead

Lead contamination is also noxious for seed and plant growth. Its toxicity has an impact on various seed developing procedures that may be physiological or morphological (61). When the metal combines with the functional group of a protein, it alters the action of many enzymes (62). The significant processes that are influenced due to lead toxicity are seed germination, early growth stages in seedlings, dry mass of stem and roots, changes in membrane permeability and endurance index (63). The entrance of lead into plant cells causes oxidative stress in various growing parts of the plant due to reactive oxygen species (ROS). Moreover, the lower crop yield is the result of cell injury caused by the lead toxicity (64).

The germination of a seed is the preliminary stage in plant life that starts by the modulation of enzymatic activity. In the hypocotyl and food reserves the enzyme action stimulates various metabolic processes like anabolism and catabolism, respectively. The disturbance in a sole element can suppress the germination process. Some researchers have reported that seed germination is reduced due to lead intrusion into metabolic processes (65, 66). It ultimately reduces the embryo`s ability to produce energy that is necessary for seed germination. When the seed germination is reduced, the growth and yield / biomass of the wheat crop are affected.

Effects of zinc

Zinc is an essential micronutrient for the wheat crop due to its direct impact on the establishment of pollen tubes. It enhances the quality of wheat grain by influencing the germination and fertilization process (67). The optimal concentration of zinc is required for quality yield of the crop. The range is 0.02 g to 0.035 per kg of wheat crop (68). The low concentration of zinc affects the seed germination, seedling strength and grain quality resulting in poor grain setting (69). The significant response against the zinc concentration was exhibited by crop stand and reduced seedling growth.

Conclusion

Although a variety of literature was studied to illustrate the toxic impacts of various heavy metals on the wheat crop. However, its yield is declining due to the addition of different heavy metals in the environment. Their higher concentration results in hazardous effects on the crop. When these metals get accumulated in the soil they are absorbed by the plants and then deposited in the tissue. Consequently, the plants become fragile, resulting in low grain quality, few grains per ear and reduced spikes. This review covers all these aspects regarding the special effects of different heavy metals on the seedling growth of wheat crops.

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Authors' contributions

Literature search and writing-original draft was done by MK, writing review and editing was completed by UEH. Drafting and grammar check was checked by MH, data correction and investigations were completed by AS and SR, supervision and critically review process was completed by MZI and MS, data correction and investigations were conducted by LA and ZA. Funding acquisition was completed with the support of PRDRE and EIA. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The first and all the co-authors have declared that there is no conflict of interest to declare.

Ethical issues: None

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