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REVIEW ARTICLE Bhartiya Krishi Anusandhan Patrika

Role of Micronutrients Towards Crop Productivity under Biotic and Abiotic Stresses: A Review

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10.18805/BKAP634

ABSTRACT

In recent scenarios, the world's food system is highly insecure and become a great challenge to the rapidly growing civilization. Agriculture is intricately tied to food security and life sustainability on earth. The arising climatic alteration forces plants to compete for nutrients from the soil. Crop yielding and their nutritional quality are highly influenced by environmental factors (biotic and abiotic stress), agronomic factors, pests and nutrient availability in the soil. These are the nanoparticle that monitors the elements in soil by sharing some signals. Micronutrients help to maximize plant growth and protect plants from diseases and pathogens. But the alteration of the environmental condition is highly responsible for nutrient limitation and growth inhibition. 35% of the world's agricultural lands are decreasing their soil fertility, which leads to nutrient deficiency in plants. These insufficient nutrients of crops lower the yield and nutritional quality of food and affected human health. In the reproductive stage of plant growth, environmental stress is highly responsible for flower drop, pollen tube deformation, ovule abortion, pollen sterility and yield losses. A sufficient quantity of micronutrients can help to reduce the biotic and abiotic stress in agricultural crops. The current review gives a brief knowledge to understand the current features of micronutrients in the agricultural crop which focus on the mechanism, absorption activity, toxicity and deficiency of micronutrients in plants and how it secures our food system by increasing the yield and nutritional quality.

Key words: Abiotic stress, Biotic stress, Food security, Global warming, Human health, Micronutrients, Nutritional quality, Plant growth.

The rapidly growing modern civilization drastically changes our climatic scenario and disturbs the natural balance for survival on the earth (Mrabet, 2023). The multiple activities warmed the atmosphere, oceans and land (Steela *et al*., 2022). Their activity also reduces carbon dioxide emissions and other greenhouse gases (GHGs). Agroeconomic conditions also highly affected and threaten food security worldwide (Kumari *et al*., 2022). Environmental stresses are the foremost factor that causes major losses in crop plant growth, quality and yield. Biotic stress includes the attack of various pathogens such as fungi, bacteria and harmful insects that directly targeted their hosts' nutrients which leads to the death of crop plants (Alessandro and Daniela, 2023). Abiotic stress is fully different from biotic stress, these factors are the major yield-limiting factors for crop plants. It harshly affected the crops through environmental factors such as temperature, drought, heavy metal, flood, salinity and heavy metals (Ullah *et al*., 2021) (Fig 1). These stresses are highly emitting CO_2, increasing soil salinization, augmenting and destroying the soil quality which leads to total for cultivation failure (Yang *et al*., 2023). Due to the abiotic stresses, the world's total one-third of arable lands are losing their fertility, so about 50% of yield losses in major food crops (Godoy *et al*., 2021). This increasing environmental factor is greatly responsible for limiting plant growth, yield and seed quality of the crop. The environmental alteration disbalances the micronutrient quantity and decreases the soil quality (Zhang *et al*., 2023). Micronutrition is the inorganic minerals that absorb by plants' roots as ions in soil water and develop a healthy plant. Boron, chlorine, copper, iron, manganese, molybdenum and zinc are the most essential minerals required for whole plant growth and development. These micronutrients widely involve in plants' biological functions like photosynthesis, respiration, chlorophyll synthesis, nitrogen fixation, nutrient uptake mechanisms, DNA synthesis, *etc* (Gui, *et al*., 2022). But due to the increasing biotic and abiotic stress, the micronutrient supply is gradually limited and restricts the quality of plant growth and production (Bolaji Umar *et al*., 2022) (Table 1). Micronutrients like Cu, B, Fe, Mn, Mo, Ni, Se and Zn activate scavengers for reactive oxygen species (ROS) (Tavanti *et al*., 2021). These are present as antioxidants in plants and fatal for soil fertility and crop yielding (Dumanovic *et al*., 2021). Plants get stimulated by external environmental stresses and then generate appropriate cellular responses (Prusty *et al*., 2022). Deficiency and excess of the micronutrients cause abnormalities in development, yielding and metabolism or even death of the plant (Fig 5). In mild or short-term stress

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How to cite this article: Mohapatra, M.D. and Sahoo, R.K. (2023). Role of Micronutrients Towards Crop Productivity under Biotic and Abiotic Stresses: A Review. Bhartiya Krishi Anusandhan Patrika. doi:10.18805/BKAP634.

Submitted: 15-02-2023 **Accepted:** 02-06-2023 **Online:** 04-07-2023

environment the plant can be recovered from injuries but in severe stresses, the crop plant cannot survive by preventing flowering, seed formation and induce signals (Zheng *et al.* 2023). The available data show that the interaction of different pathogens with multiple hosts can increase virulent strains (Stevens *et al*., 2021). Therefore, various techniques invented to improve plant performance such as varietal modification, exogenous supplementations of beneficial elements, growth-promoting hormones, advanced disease-pest management techniques, enzymes and nutrient management are used to develop the stress resistance plant. Among these techniques, nutrient management/regulations are eco-friendly and cost-effective (Kumar *et al*., 2022).

Types of micronutrients and their role in plant growth

In plant sciences, micronutrients are essential for various biological functions in plants such as nutrient regulation, fruit and seed development, reproductive growth, chlorophyll synthesis, plant metabolism, production of carbohydrates, *etc*. The nutrients are highly influenced by the availability of minerals and heavy metals in the soil (Boudjabi and Chenchouni, 2023). Previous research shows that the micronutrient deficiency in plants is gradually increasing and limiting plant growth and production. Plants required a specific amount of nutrients for their healthy development. But the increasing climatic stresses are responsible for the alteration of micronutrients in soil (Assuncao *et al*., 2022). The excess of micronutrients in the soil is proven toxic for plant cultivation and human health and less concentration decreases plant growth and limits productivity (Chrysargyris *et al*., 2022) (Fig 2). The acidic soil contained enough micronutrients. Globally, zinc and boron deficiency harshly disturb the productivity of crops such as maize, rice and wheat (Dwivedi *et al*., 2023). Micronutrients regulate a plant's ROS (Reactive Oxygen Species) scavenging system which involves enzymatic and non-enzymatic antioxidant mechanisms of plants. ROS have generated in plants' cellular metabolism under light regulation and increases the antioxidative activity Zandi and Schnug (2022).

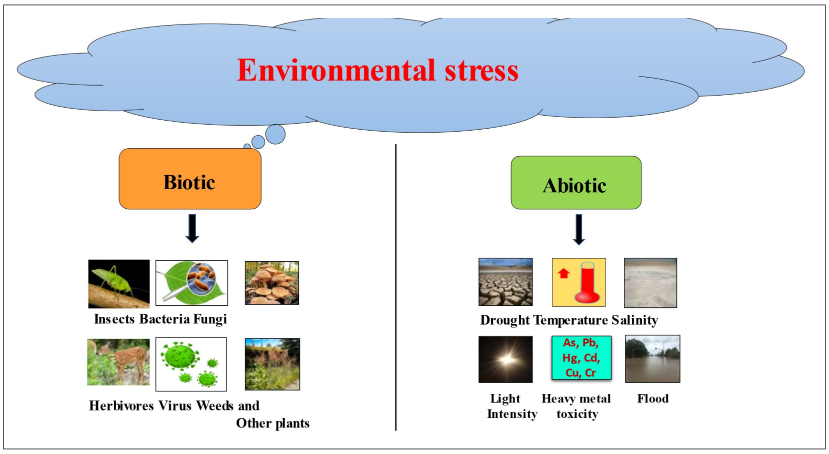

Fig 1: Different types of environmental stresses and their causative, agents.

Table 1: Types of micronutrients and their mode of action on plants.

Types of micronutrients	Mode of receive	Availability in plants (%)	Receive form in plants	Different functions
Iron (Fe)	Root interception	0.01	Iron ion ($Fe^{2+,}$ $Fe^{3+)}$	Component of enzymes, essential for photosynthesis and chlorophyll synthesis
Copper (Cu)	Mass flow	0.0001	Copper ion ($Cu2^{+}$)	Carries photosynthesis, Component of enzymes.
Zinc (Zn)	Root interception	0.002	Zinc ion ($Zn^{2+)}$	Balance plants hormone and auxin activity, Component of enzymes.
Molybdenum (Mo)	Mass flow	0.00001	Molybdenum ion (HM_0O^{4-} $M_0O_4^{2}$)	Essential for nitrogen fixation, involved in nitrogen metabolism.
Chlorine (Cl)	Root interception	0.01	Chloride (Cl^{-})	Disease resistance, used in turgor regulation, fruit quality and photosynthesis.
Boron (B)	Root interception	0.0001	Boric acid (H_3BO_3) Borate (BO_3^{3}) Teraborate(B_4O_7)	Cell division and amino acid production, essential for sugar transport.
Manganese (Mn)	Root interception	0.005	Manganese ion ($Mn^{2+)}$	Co-factor in plant reaction, chloroplast production, enzyme activation.

. In plants, genomes are encoded by several transporters which are specific in their expression, cellular localization and substrate specificities. The insufficient quantity of required nutrients in plants leads to nutrient deficiency in a growing plant. Boron, chlorine, copper, iron, manganese, molybdenum and zinc are the most 7 essential micronutrients required to maximize plant growth and production (Zhang *et al*., 2023). Among the micronutrients zinc, manganese, copper, iron and cations or positively charged molecules and boron, chlorine and molybdenum are anions or negatively charged molecules. These micronutrients are essential for healthy plant growth and cellular processes. But the alteration of micronutrients causes physical damage to the whole plant (Fig 3).

Cobalt is a mineral present in the form of vitamin B12 in plants and reduces transpiration rate to increase growth and regulate plant water utilization (Gombart *et al*., 2020). Nickel is another essential nutrient and it required very little amount to build a healthy plant. Molybdenum consists of more than 60 metalloenzymes and proteins, that enhance the total chlorophyll concentration in plants (Zhang and Zheng, 2020). Zinc induces several biochemical reactions in photosynthesis and is represented in all six classes of enzymes. Boron is an essential nutrient that is responsible for developing flower and fruit formation, pollination and seed formation and is involved in cell wall synthesis and other biological/cellular functions (Matthes *et al*., 2020). Unlike other micronutrients, copper is required to develop different organelles in plants by involving important biological processes and participating in an oxidation-reduction reaction (Atri *et al*., 2023). Iron (Fe) reduces chlorophyll production, which develops interveinal chlorosis. Fe also involves in plant respiratory and photosynthetic reactions (Li *et al*., 2021). The main symptom of Mn deficiency is interveinal chlorosis, the complete yellowing of the young leaves (Santiago *et al*., 2020). Copper is needed for chlorophyll production, respiration and protein synthesis. Copper also intensified flavour and colour in vegetables and colour in flowers. The action of Cu-deficient plants is chlorosis in younger leaves, delayed maturity, stunted growth, lodging and melanosis (Laporte *et al*., 2020). The highly increasing abiotic/biotic stresses are responsible for micronutrient deficiency in the soil and that is not beneficial for crop and their production (Table 2).

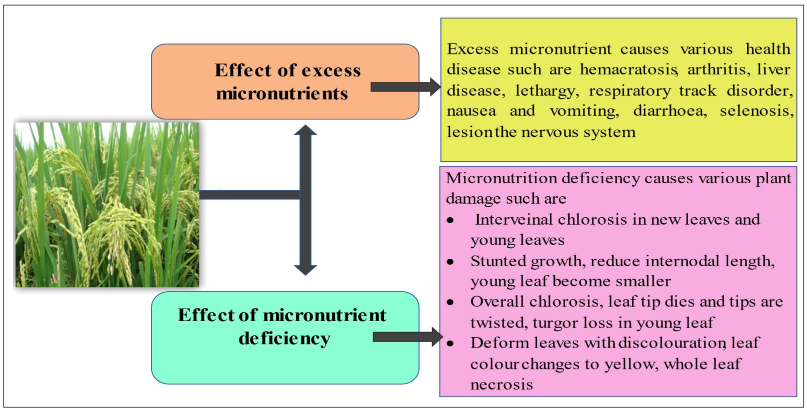

Fig 2: Action of excess and limited micronutrients on plants and human health.

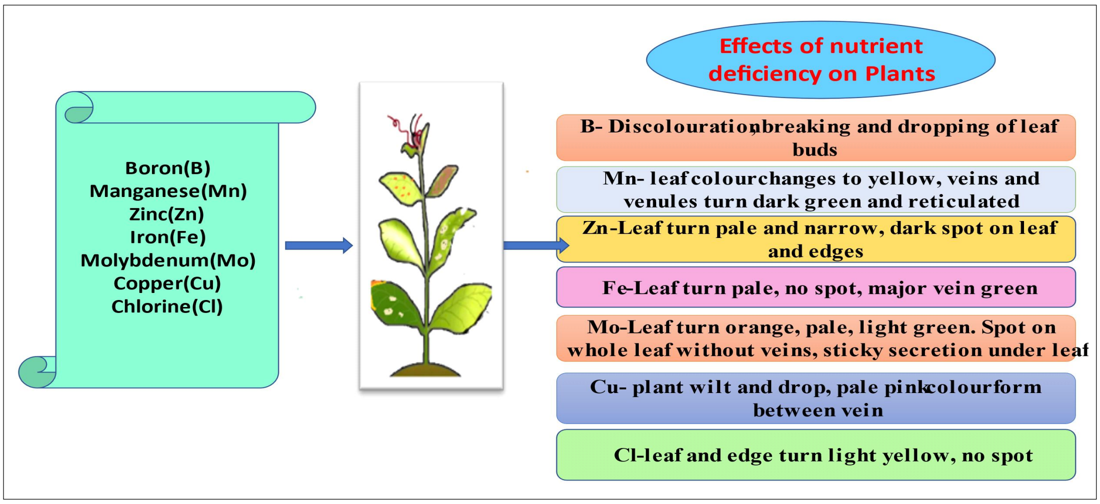

Fig 3: Micronutrient benefits on plants. Here M, B, Cu alleviates heavy metal stress and UV radiation: Cu, Mn, Zn alleviates Biotic and abiotic stress: Co, Ni, Fe increases plants growth and yielding and Mo, Co, Fe protects from insects/pest disease.

Role of stresses on plants' growth and productivity

Climate variation affects crop yield and productivity by altering plant metabolic homeostasis and modifying source-sink relationships. Under stress conditions, modification of the source-sink relationship has two processes such are (a) premature leaf senescence and yellowing, which degrade the chlorophyll and their components (b) decreased consumption in the sink tissues, which causes accumulation of assimilates in the source leaves, producing photosynthesis (Shafi and Zahoor, 2020). Stresses involved multiple functions of plants such are altered gene expression, cellular metabolism, changes in growth rates, crop yields, etc. Plants basically respond to two types of stresses such are abiotic and biotic stresses. These stresses differently affected soil fertility and decrease 20%-70% of agricultural production worldwide (Suleiman *et al*., 2021). Both abiotic and biotic stress have the common feature that enhanced ROS production which causes nutrient and water deficiency and alters soil pH, temperature, oxygen supply and mechanical pressure, injury to plants. Under abiotic stresses, plants get infected by bacteria, fungi, viruses and nematodes like pathogens and attack herbivore pests. Environmental factors like soil pH and moisture directly affect the soil microbes that help decompose soil organic matter (Fan *et al*., 2021). Drought stress and fungal infection decrease Root system architecture (RSA) causing total root length reduction, several root tips and magnitude of root branching (Xiong *et al*., 2021). Mainly drought stress involves in reduction of mass flow and micronutrients uptake by roots This stress also limits the diffusion rate of nutrients in the soil toward the roots (Guarnizo *et al*., 2023). Due to the stress plants get contaminant and disturb the nutrients transport to the shoots and limit active transport, transpiration flux and membrane permeability. Previous studies show drought increases Mn and Cu and decreased Fe content. Plant nutrient and physiological responses are both genotypes dependent under drought stress (Suleiman *et al*, 2021). Drought and different heavy metals like Ni, Cu, Co and Cr are responsible for the limitation of the growth of red maple, altering the xylem structure and hydraulic conductivity (Muhammad *et al*., 2021). Huang *et al*. (2022) reported that the presence of excess organic matter with high pH in the soil is highly responsible for the manganese deficiency in plants.

Salinity or salt stress is mainly responsible for nutritional disorders in plants. This adversely affected on availability of essential nutrient crops productivity and quantity (Gupta *et al*., 2021). Cold stress delayed the germination of rice and enhanced starch metabolism, respiration rate, antioxidative defense system (glutathione) and lower lipid peroxidation. This stress induces ionic and osmotic stress, which produces ROS in plants. High light and temperature stress accumulate ROS by damaging the membrane and photorespiration (Anderson *et al*., 2021). Flooding is another factor that causes hypoxia, programmed cell death and oxidative stress in plants (Leon and Gayubas, 2020). Sometimes it inhibits nutrient uptake and metabolism for healthy growth. UV radiation causes morphological changes, inhibit growth and photosynthesis and changes in ion

Table 2: Concentration of different micronutrients present in soil.

Micronutrients	Normal concentration (mg/kg)	Toxic concentration (mg/kg)
B	10-20	50-200
Mn	20-300	300-500
Zn	27-150	100-400
Cu	5-30	100-200
Fe	100-500	>500
Mo	0.1-2.0	>100
Ni	Nill	Nill
Cl	100-500	500-1000

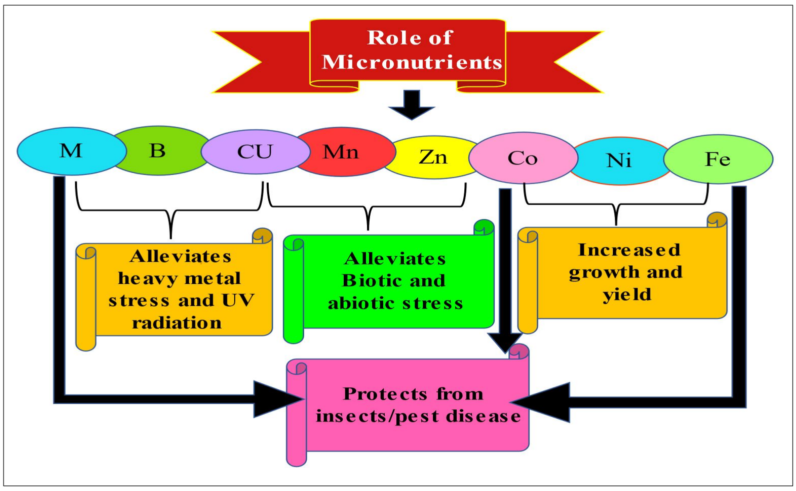

Fig 4: Different functions of micronutrients on a plant's organelles.

permeability of the thylakoid membrane and the level of pigments (Nassour and Abdulkarim, 2021) (Fig 4).

Biotic stress-causing agents are weeds, insects, fungi, bacteria, viruses, herbivores and other plants. This stress induces a hypersensitive reaction that causes physiological and biochemical changes in the plants (Chaudhary *et al*., 2022). Almeida *et al*. (2019) reported that over 80,000 fungal species are responsible for various plant diseases. Various pathogens cause plant wilt, leaf spot, root rot, or root damage in plants. Insects are causes severe physiological damage in plants that affect stem, leaf, bark and flowers. Insects also act as a carrier of various viruses and bacteria, which may be from infected plants or healthy plants (Kolliopoulou *et al*., 2020). Weeds highly damage the flower and reduce the crop productivity of plants.

Physiological activity of altered micronutrients on stress-inducing plants

Micronutrients can absorb and accumulate in plants by involving various mechanisms, which converse to more soluble ionic forms and are followed by specific/non-specific transporters (Pasala *et al*., 2022). The alteration of micronutrients is harmful to human health and the minerals deficiency causes yield reduction and improper plant growth. Recently, the WHO reported that every year more than 10 million people die because of micronutrient deficiency (Venkatesh *et al*., 2021). Under biotic and abiotic stresses, the micronutrient limitation decreases the resistance of plants (Kumari *et al*., 2022). These stresses increase the atmospheric CO_2 which can change the photosynthetic rate of plants. The alteration in photosynthetic rate reduces the plant growth rate and decreases the nutritional quality of crops (Huang *et al*., 2022) (Fig 5). The physiological activity like photosynthesis and gas exchange, nutrient translocation, the transcriptional activity of genes, transposable elements, cell death, changes in cell wall composition, lipid signalling, metabolites, proteins and antioxidant profile can be changed during stresses. The plant can improve its nutrient uptake by increasing soil mineral availability with the interaction of rhizosphere microorganisms (Zahra *et al*., 2021). The uptake, storage, mobilization and translocation of the micronutrients are excessing the seed micronutrient, that coordinates the regulation of many genes. A recent report has shown that zinc and iron content in grains should be increased by the association of two chromosome regions with quantitative trait loci (Calayugan *et al*., 2020). A proper understanding of plant nutrient distribution and its mechanisms can improve plant growth and food sources and reduces human malnutrition.

Micronutrients consumption of plants and their effects on human health

World Health Organization (WHO) reported that in human beings, micronutrients are present in the form of vitamins and minerals. The human metabolism required about 40 micronutrients for a healthy diet (https://www.who.int/health-topics/micronutrients#tab=tab_1). Nutritional food can improve infant, child and maternal health, safer pregnancy and childbirth, stronger immune systems and lower risk of non-communicable diseases (Behera *et al*., 2022). Vitamins and minerals produce energy and balance body fluid inside the human body. This is also highly required for immune function, blood clotting, growth and bone health (Alagawany *et al*., 2020). Micronutrient deficiency highly affected the DNA synthesis process and develops various types of chronic diseases such as cancer, congenital malformations in pregnancy, *etc*. (Berger *et al*., 2022). The excessive concentrations of harmful minerals in soil limit crop production and their nutritional quality and also affected human health. Sarangi *et al*. (2022) reported that the excess quantity of manganese (Mn) and aluminum (Al) damages about 40% of the world's agricultural land by producing acid soil which is highly toxic for crops and their production. Kumar *et al*. (2022) recently reported that micronutrients can prevent genome mutations and protect the genome by

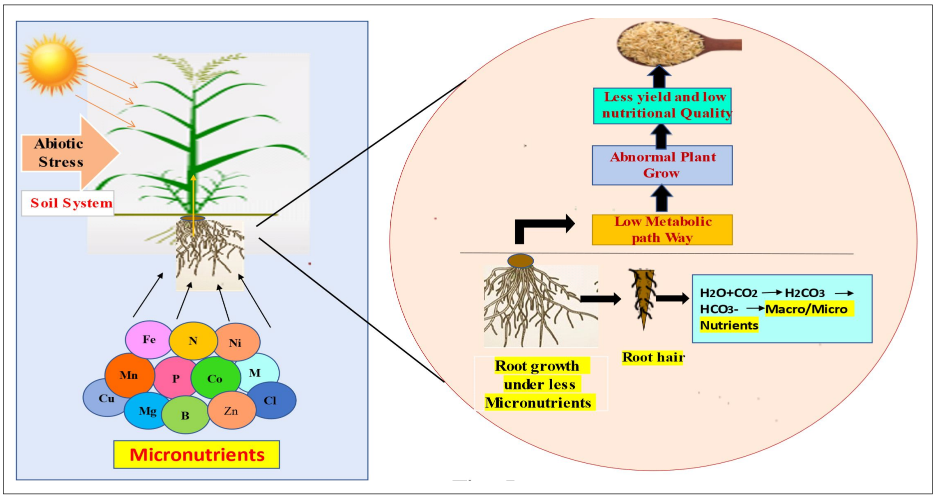

Fig 5: Plant root growth and yield under fewer micronutrients in the soil.

modulating transformation in the cellular processes. Micronutrients have antimutagenic potential and in the form of antimutagenic agents', they can stable the genome (Mishra *et al*., 2022).

CONCLUSION

Due to the fluctuating climate condition, plants lose their genetic potential for healthy growth and reproduction. Both abiotic and biotic stresses generate stressful conditions and severe damage in the plants which represents a new challenge for crop improvement in plant science. The interaction of stresses and their impact on plants is known as the "disease triangle". The interaction of stresses may negatively or positively affect plant growth. A sufficient micronutrient can develop healthy plants and secure food resources. But climatic variation causes micronutrient deficiency and limited crop productivity worldwide. Therefore, in recent years researchers are focusing on global food conservation and developed iron-and zinc-rich biofortified foods and low-cadmium rice. Agronomic practices have also developed that can decrease the accumulation of arsenic or cadmium in rice grains. Deficiency of plant nutrients could be reduced by the supply of mineral fertilizers or by the cultivation of genotypically modified (GM) crops with higher metal concentrations. The 'Climate-crop disease' model, breeding, or genetic manipulation are the most efficient and reliable techniques for healthy plant growth and production under biotic and abiotic stress conditions. To achieve greater successful results scientific research works on this topic are necessarily required.

ACKNOWLEDGEMENT

The author thanks Centurion University of Technology and Management, Bhubaneswar, India for providing the necessary support for the completion of this manuscript.

Author contributions

Monalisha Das Mohapatra, Ranjan Kumar Sahoo conceived the manuscript. Monalisha Das created figures and tables and wrote the manuscript with the help of Ranjan Kumar Sahoo.

Funding information

This research did not receive any specific grant from funding agencies.

Declarations

Conflicts of interest

The authors declare no conflicts of interest.

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