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Review Article

Use of zinc solubilizing biofertilizers for increasing the growth and yield of cereals: A review

Shivanshu Ladohia
Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, India
Navjot Rana*
Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, India
Prachi Srivastava
Master Program of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, India
Rajesh Kumar
Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, India
Swati Mehta
Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, India
Bheem Pareek
Department of Agronomy, Rajasthan Agricultural Research Institute, Durgapur (Rajasthan), India

*Corresponding author. E-mail: navjotrana7@gmail.com

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Abstract
In recent years, the increase due to the rise in the high yielding verities led to the high-rate application of chemicals and pesticides in the soil. These chemical fertilizers give great responses to the farmers on a short-term basis, but in the long term, they harm the soil and human health by interfering in the food chain. The use of biofertilizers is a very good alternative for crop production in a sustainable and environment-friendly manner. Numerous bacteria and fungi can be used as biofertilizers for making the essential nutrients available to the plants which are associated with the rhizosphere of different crops, either symbiotically or non-symbiotically. Zinc plays a vital role in crop growth and achieving a great yield among the various macro and micronutrients. Zinc is responsible for Auxin synthesis, chlorophyll formation, protein metabolism, carbohydrate fixation, disease and stress tolerance. Zn deficiency is a global issue that gradually lowers crop output and productivity. Using zinc solubilizing microorganisms is one of the most effective sustainable approaches to achieving higher yield and restoring soil productivity. These microorganisms solubilize the available zinc pool in the soil so plants can easily uptake zinc. *Bacillus subtilis, Thiobacillus thioxidans, Rhizobium, Pantoea sp., Gluconacetobacter*, *Saccharomyces sp.* and PGPR (Plant Growth Promoting Rhizobacteria) are involved in zinc solubilizing process and boost the soluble zinc in the soil. Using zinc solubilizers can reduce the fertilizer requirement of the crop to about 25-50% in combination with inorganic zinc fertilizers, so it reduces overall fertilizer cost.

Keywords: Biofertilizer, Inorganic fertilizers, Rhizosphere, Symbiotic , Non-symbiotic, Zinc solubilizing microorganisms

INTRODUCTION

Due to climatic change, increased population pressure, and negative environmental effects, global agriculture is currently at a crossroads. Food security through a sustainable crop production system that will provide adequate nutrition without harming the agroecosystem, new mechanisms must be found (Mrabet, 2023). Continuous use of chemical fertilizers initially increased crop yield but later had a detrimental effect on sustainability. The indiscriminate use of chemical fertilizers, especially urea, led to a shortage of nutrients other than those applied and a decline in soil organic carbon and additionally, soil's physical, chemical, and biological qualities are harmed by an imbalance and continued use of synthetic chemicals (Gummadala *et al.,* 2022). For the past 10 years, biofertilizers have been widely used as an environment-friendly method to reduce chemical fertilizers, increase soil fertility, and increase crop production through their biological activity in the rhizosphere. The quality and health of the soil and plant species are enhanced through the application of biofertilizers, and live formulations of microorganisms (useful bacteria and fungus), which improve the nutrients to the soil and crop plants (Fasusi, 2021). Numerous studies have been done on the use of Vascular Arbuscular Mycorrhiza (VAM) fungi and bacteria (*Azotobacter, Azospirillum, Rhizobium*, *Pseudomonas, Thiobacillus*) as biofertilizers to supplement fertilizers, and they have seen a significant improvement in the growth of many crop plants (Divya, 2022).

Biofertilizers are essential to environmentally friendly and sustainable farming methods (Kumar, 2022). Biofertilizers, also known as Microbial inoculants, can mobilize significant nutritional elements in the soil from inaccessible to usable forms for the crop plants through the biological processes (Nosheen *et al.,* 2021). *Rhizobium, Azotobacter, Azospirillum,* and Blue Green Algae (BGA) are some examples of biofertilizers that have already been in use for a very long time. *Rhizobium* culture to various legumes is a common agronomic practice for enhancing pulse production. (Kumar *et al.,* 2021). If a productive strain of *Rhizobium* gets added to a nitrogen-deficient soil, nitrogen fixation may increase, which may increase output (Charles & Dawson, 2023). *Azotobacter* is applied to wheat, maize, mustard, cotton, potato and other vegetable crops. Mostly sorghum, millets, maize, sugarcane, and wheat are recommended as crops for *Azospirillum* inoculants. (Dar *et al.,* 2021). *Rhizobium* inoculation is essential for all pulse crops to increase the yield of pulses. It is a biofertilizer that boosts symbiotic nitrogen fixation and, as a result, increases yield. (Sasidhar *et al.,* 2022).

The common microorganisms used as microbial inoculants (biofertilizers) can be divided into symbiotic and non-symbiotic systems. The symbiotic system includes Rhizobium sp., Frankia sp., and Azolla sp.; the non-symbiotic system includes *Azotobacter species, Azospirillum species,* and blue-green algae. (Rai, 2020). *Azospirillum*, blue-green algae, and members of the genus Rhizobium are examples of biological nitrogen (N) fixers. The most striking relation between these and plants is symbiosis, in which both participants gain benefits from one another. (Rehmaan *et al.,* 2022). Phosphorus mobilizers and Phosphate Solubilizing Microorganisms (PSMs) are two types of microorganisms involved in phosphorus utilization. *Pseudomonas, Aspergillus, Bacillus* are the phosphorus-solubilizing bacteria; conversely, mycorrhizal fungi act as phosphorus mobilizer. The majority of plants form symbiotic relationships with arbuscular *mycorrhiza* fungi (AMF), which act as bio-ameliorators and have the potential to significantly enhance rhizosphere soil characteristics and thus improve soil structure and promote plant growth under both normal and stressful conditions. (Silva *et al.,* 2023). *Bacillus* and *Pseudomonas* are potassium-solubilizing bacteria and are used as biofertilizers to make potassium available to plants (Kour *et al.,* 2020). *Thiobacillus* can make sulphur available to plants for growth and development. Numerous rhizobacteria taxa, including *Saccharomyces sp.* and *Pseudomonas sp.* as well as *Mycorrhiza* and *Bacillus sp.*, have been shown to enhance zinc availability in soil. *Bacillus subtilis, Thiobacillus thiooxidans,* and *Saccharomyces sp.* Are involved in zinc solubilizing process. Zinc and other fixed micronutrients can be solubilized by using these microbes as biofertilizers (Upadhayay, 2022).

Zinc solubilizing biofertilizer

Plants need zinc in their tissues at comparatively low quantities (5 mg/kg to 100 mg/kg) to grow and reproduce. Zinc-solubilizing biofertilizers include advantageous microorganisms that can increase the amount of zinc available to plants by changing insoluble zinc into soluble forms that plants easily absorb (Haroon *et al.,* 2022). These biofertilizers are made up of particular strains of fungi, bacteria, or other microorganisms that may dissolve zinc in soil by producing organic acids or enzymes. Microorganisms such as *Bacillus subtilis, Thiobacillus thiooxidans,* and *Saccharomyces sp., Pseudomonas sp.*, Plant Growth Promoting Rhizobacteria (PGPR) can solubilize zinc. Mostly bacteria are involved in the Zinc solubilization process. These bacteria invade the rhizosphere, solubilizing complex zinc compounds to increase zinc bioavailability and enhance plant development Yadav *et al.,* (2020). There are several ways that bacteria can solubilize zinc and one of the most important ones is acidity. The Pseudomonas aeruginosa strain of bacteria is responsible for the solubilization of the inaccessible form of zinc; according to *Bacillus species, Burkholderia cenocepacia, Pseudomonas striata* and *P. fluorescens* are engaged in the solubilization of zinc (Kushwaha *et al.,* 2020).

Some other species of microorganisms, like *Serratia marcescens* and *S. liquefactions* are also responsible in converting unavailable zinc to available form (Shakeel *et al.,* 2023). According to Nitu *et al.,* (2020) and Kumar *et al.,* (2018), *Gluconacetobacter diazotrophicus* as bacteria involved in zinc solubilization. Zinc and other fixed micronutrients can be solubilized by using these microbes as biofertilizers. These microorganisms release compounds like organic acids or chelating agents that dissolve or chelate the insoluble zinc compounds, converting them into a form that plants can uptake through their roots. By enhancing zinc availability, these biofertilizers can improve plant growth, development, and overall yield (Srithaworn *et al.,* 2023). Salman *et al.* (2020) demonstrated that a

Bacillus sp. can be used as a biofertilizer for zinc, either in soils with greater native zinc concentrations or in conjunction with less expensive insoluble zinc compounds, including zinc sulphate (ZnS), zinc oxide (ZnO), and zinc carbonate (ZnCO3).

According to (Khoshru *et al.,* 2020), PGPR is directly involved in solubilizing zinc, insoluble phosphates, potassium, fixation of atmospheric nitrogen, and release of hormones that include gibberellic acid, kinetin and IAA, promoting plant growth.

Zinc is a very important micro nutrient for the growth and yield dog cereal crops. The ZSB inoculum is implemented in the field either directly or by carriers, or through organic amendments. The ZSBs convert the insoluble zinc into soluble form by producing organic acids and chelating agents or by lowering the soil pH. The plants' roots also secrete some chemoattractant to attract ZSB. Application of ZSB increases Zinc content in grains and provides good yield (Fig. 1).

Impact of excessive use of chemical fertilizers on soil health

In past few years, there is a great boost in the world's population and the demand for food is also increasing. To overcome this, farmers are using chemical fertilizers drastically in their fields to increase productivity. Due to their low cost and quick nutrient release, inorganic fertilizers have gained much popularity due to their immediate effect. Synthetic fertilizers have been used blindly, killing beneficial insects and microorganisms, contaminating water basins, contaminating the soil, increasing crop susceptibility to disease, and decreasing soil fertility (Pahalvi *et al.,* 2021). The 20th century's agricultural revolution resulted in a huge change in farming practices with the widespread use of chemical fertilizers, which have raised crop yields dramatically (Kumar *et al.,* 2023). These fertilizers have been crucial in helping to fulfill the rising demand for food around the world since they contain vital elements for plant growth. Concerns have been made about their potential effects on the health of the soil, though (Kasirao *et al.,* 2023). Inorganic fertilizers have problems, though, and extensive research on their problems has shown that they are issues that should not be ignored (Craswell, 2021). Using inorganic fertilizers was the primary cause of most issues with harvested crops and some of the damage to our natural environment (Baweja *et al.,* 2020). Chemical fertilizers are not biodegradable, and prolonged usage of Chemical fertilizers causes the soil to become acidic and accumulate toxic materials, which reduces the soil's fertility (Ahmed *et al.,* 2020). Overuse of chemical fertilizers can harm the soil ecology, kill decomposers and other soil organisms, and decrease the mycorrhizal fungus ability to colonize plant roots. Blind use of chemical fertilizers also leads to nutrient imbalance, which reduces the crop yield (Bhatt *et al.,* 2019). Chemical fertilizers have effects on the soil that are not immediately apparent because the components of soils provide them great buffering power. With time, the current element's balance deteriorates due to pollution, declining soil fertility, and soil degradation reactions (Bisht *et al.,* 2020). The development and accumulation of mineral salts from fertilizers that are applied excessively—beyond the dosages allowed for continuous monoculture cropping leads to the eventual formation of a compaction layer and soil degradation. Soil degradation has a significant impact on both the soil's structure and nutrient uptake. (Belete and Yadete, 2023). Over application of chemical fertilizers reduces the soil biodiversity, reducing the population of mycorrhiza root colonizing fungi and reducing the *Rhizobia* population in the root zone of plants (Kumar *et al.,* 2019).

Biofertilizers in improving soil health

Bio-fertilizers play a key role in enhancing the fertility of the soil. Their incorporation into the soil also enhances its structure and reduces the need for chemical fertiliz-

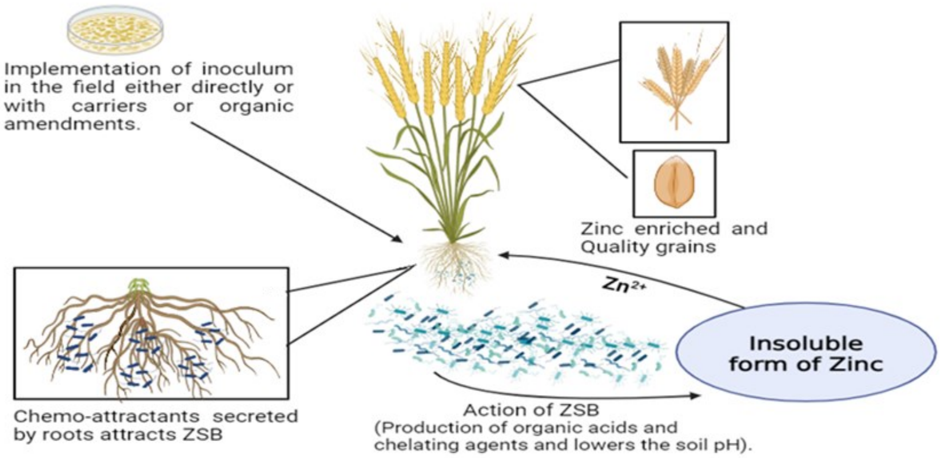

Fig.1. *Response of cereals towards the zinc solubilizing biofertilizers*

ers alone. Biofertilizers are effective in remediating polluted soils. They are ecologically friendly and do not pollute, in contrast to inorganic fertilizers that frequently wash into waterways when the nitrate level hits 10 mg/L and above, inducing eutrophication and methemoglobinemia, or "blue baby syndrome." (Asoegwu *et al.,* 2020). Biofertilizers provide supplements and bacteria that might not be found in soil or in smaller amounts. They lower the amount of disposable material. The effects of chemical fertilizers on the environment, particularly soil and water, are minimized by biofertilizers. Supplying nutrients and natural habitat in the rhizosphere, they aid in improving the quality of the soil. Microbial inoculants will also help to improve the effectiveness of applied fertilizers and reduce the quantity of chemical fertilizers used (Shahwar *et al.,* 2023). Using biofertilizers results from increased root development, vegetative growth, uptake of minerals and water, and nitrogen fixation. They work in combination with chemical fertilizers to supply the soil's integrated nutritional demand (Asoegwu *et al.,* 2020). The application of *Azospirillum* and BGA considerably increased grain yield in low-lying conditions. The most notable increase in the yield of straw and grain produced from wheat plants given rock phosphate is achieved through the inoculation of the plants with *Azotobacter, Rhizobium,* and VAM biofertilizers (Sammauria *et al.,* (2020). The microorganisms in biofertilizers are vital because they produce nutrients like phosphorus, potassium, and nitrogen necessary for plants' growth and development. Most biofertilizers also secreted hormones necessary for plant growth, such as auxins, cytokinins, biotins, and vitamins. By secreting antibiotics that are effective against various plant diseases, biofertilizers protect plants and plants from salinity and drought stress Biofertilizers are inexpensive and safe inputs which provide a wide scope for research in the areas of organic farming and development of a stress-free environment (Batabyal, 2020). Biofertilizers provide nutrients slowly, which is why their effects continue for a long time. Plants receive the nutrients from biofertilizers gradually throughout several seasons. Therefore, using biofertilizer over a long period causes the soil to accumulate nutrients, raising the soil's total fertility (Asoegwu *et al.,* 2020). In addition, biofertilizers also play a greater role in reducing soil-borne diseases and root nematodes. Biofertilizers enrich the soil, are compatible with long-term sustainability, and increase soil health.

Importance of zinc nutrition in cereals

A global nutritional limitation has been identified as zinc deficiency in soils, especially in calcareous soils found in dry and semi-arid regions. Zinc deficiency is common in soil and is caused by improper fertilizer application, intensive agriculture, and poor soil health. Zinc insufficiency is anticipated to rise from 42 % to 63 % by 2025 if the underlying issues are neglected. Zinc is necessary for growth hormone synthesis (Sharma *et al.,* 2022). Approximately 30% of the world's farmed soils are zinc deficient, according to global research started by the FAO (Waqeel and Khan, 2022). Zinc is also necessary for agricultural plants to regulate carbonic anhydrase, which is necessary for the fixation of carbohydrates (Hosamani *et al.,* 2020). It also affects chlorophyll synthesis and photosynthesis, nitrogen metabolism, nitrogen uptake, protein quality, and resistance to both abiotic and biotic stresses in plants (Cao *et al.,* 2020). In most of plants, the growth and operation of floral tissues, including anthers, tapetum, pollen, and pistil secretary tissues, depend on Zinc (Arrey-Salas *et al.,* 2021). Zinc exhibits privilege in disease resistance, protein metabolism, photosynthesis, pollen production, and cell membrane integrity. It also displays enhanced levels of antioxidant enzyme and chlorophyll content in plant tissues, and zinc is superior to plant insect pests (Aiqing *et al.,*2022). Zinc is necessary for cereals' growth and development, impacting their yield and quality. Sufficient zinc levels are essential for photosynthesis, hormone regulation, enzyme activation, and other physiological processes in plants. Studies show that a zinc deficiency can result in stunted development, decreased tillering, and low grain output in cereals (Suganya *et al.,* 2020). It has been demonstrated that incorporating zinc into cereals by fertilizer or soil amendments enhances growth characteristics such as plant height, leaf area, and root development. Zinc application has also been connected to higher grain yield and quality attributes such as grain weight, size, and nutrient content (Bashir *et al.,* 2021).

Zinc plays a significant role in the plant life cycle. It helps synthesise tryptophane, the precursor of Auxin, pollen germination, seed development, stress, and disease tolerance. It helps to maintain cell membrane integrity, protein metabolism, synthesis of antibiotics, nitrogen metabolism, and uptake and protein metabolism (Fig.2).

Mechanism of zinc solubilization

Zinc-solubilizing bacteria (ZSB) can change the insoluble form of zinc in the soil into soluble form, allowing plants to easily access it for growth, development, and final yield while maintaining the soil's fertility and health sustainably.

The zinc solubilization by microorganism depends on the soil's pH and moisture (Upadhayay *et al.,* 2022). As ZSBs can solubilize zinc from both organic and inorganic pools of the total amount of zinc present in soils to increase zinc availability to plants, their interaction with higher plant roots is implicated in the mobilization or solubilization, bio-fortification, and mineralization of zinc pools (Pradhan *et al.,* 2021). These bacteria have been highlighted for their increased efficiency in zinc solubili-

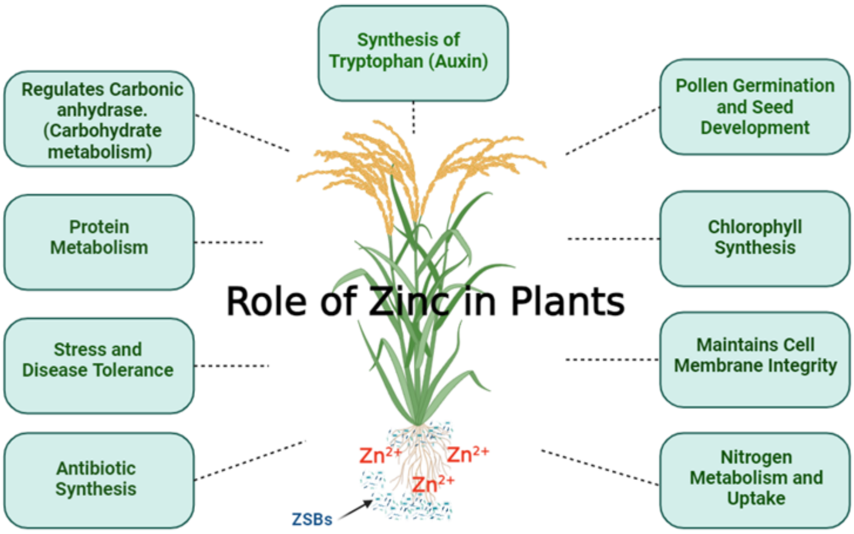

Fig. 2. *Role of zinc nutrition in cereal crops*

zation due to their interaction with plant roots, resulting in the production of root exudates that serve as chemo-attractants (Pradhan *et al.,* 2021). Zinc-solubilizing microorganisms can solubilize zinc carbonate, phosphate, and zinc oxide by producing organic molecules. Zinc-solubilizing microorganisms acidify the soil to produce different organic acids that sequester zinc cations and lower the pH of the surrounding soil (Upadhayay *et al.,* 2022). The medium pH, carbon supply, and buffering capacity are the primary determinants of the kind and quantity of diverse organic acids generated by distinct soil microorganisms. ZSB makes zinc unavailable by producing siderophore and chelating agents (Pradhan *et al.,* 2021). The microorganisms use another mechanism of their oxide-reductive system on cell membranes and chelated ligands for the zinc solubilization process (Upadhayay *et al.,* 2022). The Plant Growth Promoting Rhizobacteria stimulates plant growth by producing phytohormones, solubilizing nutrients and aiding in their uptake, and utilizing biocontrol agents to shield plants from various infections and their efficiency of zinc solubilization is very effective (Rion *et al.,* 2022).

Overall effect of zinc solubilizing biofertilizers on cereals

Cereals are denoted as the staple food for the human population. An appropriate zinc supply to cereals ensures zinc-enriched grains, which are considered a zinc supplement in the human diet. Numerous strains have been discovered to increase the zinc content in grains and straw of cereals and are also known to overcome zinc deficiency in the soil, such as *Pseudomonas spp., Bacillus spp., Pantoea spp., Gluconacetobacter, Thiobacillus spp.,* and PGPR Prajapati *et al.,* (2022). Yadav *et al.* (2022) found a favorable relationship between the amount of zinc and protein in grains. Zn inoculants may aid in greater Zn bioavailability and enhanced grain quality. ZBS seed inoculation increased the methionine content in the grains of wheat types as compared to no inoculation.

Effect of zinc solubilizers on growth and yield wheat

Bacteria such as *Pseudomonas fragi, Pantoea dispersa, P. agglomerans, Enterobacter cloacae,* and *Rhizobium spp*. improved plant development in sand culture by solubilizing zinc. The inoculation of the chosen strains improved the solubilization of zinc in wheat shoots, roots, and other tissues. (Yadav *et al.,* 2023). Zinc-soluble bacteria applied in conjunction with ZnO (0.005% Zn) showed a reduction in shoot length with a favorable effect of significant root length and Zn concentration in the shoot (Ali *et al.,* 2023). Wheat grain production in sandy loam soil in Argentina rises by 36% when seed-treated with *Pseudomonas aurantiaca*. Zinc content in several wheat plant parts at different stages of growth was significantly enhanced in wheat treated with *Azospirillum, Pseudomonas*, and *Rhizobium* (Ali *et al.,* 2023). From wheat rhizospheres, 175 bacterial isolates were found. Just six of the 175 rhizobacterial isolates discovered and examined proved useful in solubilizing insoluble zinc compounds. *Bacillus megaterium* CHW-22, *Bacillus licheniformis* MJW-38, and *Bacillus altitudinis* AJW-3 are three of the six zinc-solubilizing bacteria that, when inoculated with RDF and zinc phosphate improves wheat growth, grain yield, and grain content with zinc. They also increase the NUE of the applied fertilizers and zinc phosphate compared to RDF alone Yadav *et al.,* 2023). The microbial inoculation also facilitated effective nutrient uptake, resulting in plants of superior quality.

Effect of zinc solubilizes on growth and yield maize

Alternatives like zinc-solubilizing bacteria (ZSB) may be used to increase the bioavailability of zinc in soil. *Pantoea agglomerans* treated with graded doses of zinc responded considerably better in terms of zinc content and uptake by the plants and showed better growth of maize crop, Additionally, they demonstrated that the application of *P. agglomerans* increased the available status of zinc and elevated exchangeable, carbonate-bound, organically-bound, amorphous-bound, and crystalline zinc (Verma *et al.,* 2023). *Bacillus* and *Pseudomonas* inoculated seed boosted the amount of nutrients in the leaves of maize plants as well as their root volume (RV), shoot length (SL), total dry matter (TDM), and leaf areas (LA) (Shaji, 2021). The total dry weight of the plant (63.21 g/plant) and the levels of N (2.42%), P (0.432%), and Zn (25.79 ppm) were all significantly increased by *Aspergillus spp*. seed inoculation (Ghosh *et al.,* 2019). The use of zinc solubilizing bacteria, soil application of zinc sulphate, and recommended dose of fertilizer have greatly enhanced the growth and yield of the maize plant (Neelima *et al.*, 2021). *Aspergillus* species could be a useful bio input to increase plant output and growth. Additionally, depending on the circumstances, bacterial strains like *Bacillus subtilis* and *B. megaterium,* as well as fungal strains like *Aspergillus* and *Penicillium sp.* can be used in place of or in conjunction with chemical fertilizers to address nutrient deficiencies in crops and improve plant nutrition and productivity of maize and other cereals (Ghosh *et al.,* 2019).

Effect of zinc solubilizes on growth and yield rice

Zinc is a very important nutrient for the rice growth. The rice itself is very prone to zinc deficiency, leading to Khaira disease (Dawuni, 2023). For rice plants cultivated in soil lacking in zinc, *Bacillus aryabhattai* may be suggested as a possible bio-inoculant. Using *B. aryabhattai* bacteria in combination with $ZnSO4$ (25 kg ha^{-1}) may help provide a suitable amount of soluble zinc while simultaneously improving plant growth, nutrient uptake, biofortification, and production sustainably (Prathap *et al.,* 2022). ZSB inoculation increased plant growth and rice grains' zinc content by 42.7% in the field (Khalid *et al.,* 2020). When zinc-solubilizing fungi were added to soil together with a higher concentration of zinc, the DTPA extractable zinc content of the soil increased dramatically and zinc oxide in conjunction with zinc-solubilizing fungi had a beneficial effect on the amount of zinc in the soil, the number of tillers per hill, the number of panicles per plant, the production of grain and straw from paddy fields, etc.

Effect of zinc solubilizers on growth and yield of sugarcane

According to Deshmukh *et al.* (2019) revealed that in sugarcane crops use of zinc solubilizing biofertilizer indicated a 25% saving of zinc fertilizer and the use of zinc solubilizing fungi strains increased yield and yield-contributing parameter, the fungal strains gave higher response than the bacterial strains. Iron and zinc-solubilizing biofertilizers were applied at 5.0 lit/ha with a 50% iron and zinc supply. The B:C ratio increased noticeably to 1: 2.77, and zinc solubilizing microorganisms may improve the soil's Fe and Zn status, increasing the crop's cane and sugar output. It may also reduce the need for 25–50% of the necessary dose of Fe and Zn sources (Ghodke and Jadhav, 2023).

Effect of zinc solubilizing biofertilizers growth and yield of oats

Soil application of 5 kg chelated zinc in combination with zinc solubilizing bacteria improved the plant growth attributes, fodder yield, zinc bio-availability and soil zinc. Use of Zn solubilizing biofertilizer can be recommended for achieving a higher yield of fodder oats and efficient utilization of different sources of zinc present in the soil Chaudhary *et al.,* (2021). It is also evident that the zinc solubilizing bacteria is responsible for the uptake and translocation of zinc in oat plant and some genes are responsible for the uptake and transport of zinc in the oats plant (Chaturvedi *et al.,* 2020)

Future perspectives

Zinc-solubilizing biofertilizers (ZSBs) have a very promising future ahead of them since they can revolutionize farming practices and advance sustainable agriculture. By making more zinc available in the soil, ZSBs are expected to increase crop yields and enhance nutritional quality, thereby addressing the problems of human zinc deficiency and agricultural productivity. By maintaining soil health and promoting biodiversity, their environmentally beneficial qualities promote sustainable agriculture and offer a good substitute for artificial fertilizers. ZSBs and precision agriculture technology work together to maximize resource use and boost productivity. Genetic engineering and microbial diversity research developments are expected to provide more reliable and potent biofertilizers. Policy backing, farmer education, and awareness initiatives will be crucial for broad adoption. ZSBs can be developed and implemented more quickly thanks to international cooperation and research, reinforcing their role in advancing sustainable farming methods and enhancing food security.

Conclusion

In sustainable agriculture, biofertilizer is a natural input that can be used in addition to artificial fertilizer. Farm productivity can be increased more affordably, sustainably, and with less capital expenditure by the integrated use of biofertilizers. Zinc solubilizing biofertilizers have the potential to significantly improve soil fertility and stimulate plant development, especially in zinc-deficient soils. These biofertilizers can increase zinc availability to plants, reducing deficiencies and increasing crop yields by acting as a catalyst for certain microbes that can solubilize zinc from organic sources or soil minerals. Zinc solubilizers in conjunction with zinc fertilizers increase the availability of zinc to the plants and increase the crop's overall growth and yield. Zinc availability enhances the grain quality in cereals and gives rise to nutritious and enriched grains. The zinc solubilizing biofertilizers lead to the 25% saving of the zinc fertilizers.

Conflict of interest

The authors declare that they have no conflict of interest.

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