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Zinc-Solubilizing Bacteria: A Sustainable Approach for Enhancing Agricultural Productivity and Soil Health

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Abstract: -

The ongoing increase in the global population necessitates greater food production. To meet this demand, farmers often use various agrochemicals, particularly fertilizers, in large quantities to boost crop yields per area and time. However, excessive and imbalanced fertilizer application can lead to significant environmental issues. While macro nutrients are typically supplied through high-analysis fertilizers, micronutrients like zinc (Zn) are often overlooked, even though they are vital for plant health. Zinc is an essential micronutrient required in small amounts for all living organisms, playing a critical role in the plant life cycle. Zinc deficiency in soil is quite common, highlighting the need for alternative, eco-friendly solutions. One such solution is the use of zinc-solubilizing bacteria (ZSB), which can enhance zinc availability to plants and promote sustainable agriculture. These beneficial bacteria not only improve zinc solubilization but also contribute to increased crop yields

Key Words: Zn Solubilizing Bacteria, soils, Soil health, Bio inoculants, Sustainable agriculture, Nutrient availability

Introduction

Zinc is an essential micronutrient for crops, playing a vital role in their life cycle (Hirschi 2008). It directly and indirectly influences plant growth, development, and yield. Zinc is crucial for various physiological, biochemical, and metabolic processes,

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including photosynthesis, carbohydrate and auxin metabolism, nodulation, and protein synthesis (Nitu *et al* ., 2020). It is also linked to the RNA polymerase enzyme, which is necessary for protein production, and is required for the synthesis of growth hormones like IAA. A deficiency in zinc can cause physiological stress, leading to enzyme dysfunction and altered metabolic rates (Sinha *et al.,* 2024). Unfortunately, zinc is often not readily available to plants; only 1-5% of the applied zinc is utilized, while the remaining 95% becomes insoluble. Common insoluble forms include zinc oxide (ZnO), zinc carbonate ($ZnCO_3$), and zinc phosphate ($Zn_3(PO_4)_2$). Additionally, the use of chemical fertilizers is costly and environmentally harmful, making crops more susceptible to diseases and decreasing long-term soil fertility (Kumar *et al*., 2023), which also negatively impacts soil microorganisms. The heavy application of fertilizers has contributed to water and soil pollution, posing risks to both plant and human health (Kumar et al., 2024a). Fortunately, certain bacteria can convert insoluble forms of zinc, such as ZnO, $ZnCO_3$, and $Zn_3(PO_4)_2$, into bioavailable forms (Kumar *et al.,* 2024b). Notable zinc-solubilizing bacteria include *Pseudomonas fluorescens, Pseudomonas aeruginosa*, various *Bacillus* species, *Gluconacetobacter diazotrophicus, Klebsiella* species, *Acinetobacter calcoaceticus, Bacillus cereus, B. aryabhattai, Pseudomonas taiwanensis, Acinetobacter* species, and *Serratia* species.

Role of zinc in plants

Zinc (Zn) plays a vital role in numerous physiological and metabolic functions. It is a key element in processes such as photosynthesis, carbohydrate and auxin metabolism, nodulation, and protein synthesis, it is also suitable for maintain soil health (Meena *et.al.*, 2024). Zinc is closely associated with the RNA polymerase enzyme, which is essential for protein synthesis, and is also necessary for the production of growth hormones like indole-3-acetic acid (IAA) (Kumar et al., 2024)

Microorganisms for zinc solubilization

Zinc Solubilizing Bacteria (ZSB) play a crucial role in boosting agricultural productivity while ensuring environmental sustainability. These bacteria have the ability to convert insoluble forms of zinc into bioavailable forms that plants can easily absorb. Several bacteria, including *Pseudomonas fluorescens, Pseudomonas aeruginosa,* various *Bacillus species, Gluconacetobacter diazotrophicus, Klebsiella* species, *Acinetobacter calcoaceticus, Bacillus cereus, B. aryabhattai, Pseudomonas taiwanensis, Acinetobacter* species, *and Serratia* species, can effectively transform insoluble zinc compounds like zinc oxide

(ZnO), zinc carbonate ($ZnCO_3$), and zinc phosphate ($Zn_3(PO_4)_2$) into forms accessible to plants (Kumar *et al.*, 2019).

Mechanism of zinc solubilization

The formation of insoluble zincate due to zinc fertilizer applications poses a significant threat to the plant-soil system. Zinc Solubilizing Bacteria (ZSB) offers a promising alternative by converting insoluble soil zinc into soluble forms. As these microbes grow, they produce organic acids that interact with the minerals in the soil, effectively binding to zinc cations and lowering the local soil pH. Anionic organic acids, such as gluconic and ketogluconate, can chelate zinc through their carboxyl and hydroxyl groups, enhancing its solubility and facilitating mineral uptake by plants. Various organic acids are generated depending on the source of inorganic zinc in vitro, including keto-D-glutarate, propionic acid, formic acid, lactic acid, gluconic acid, citric acid, succinic acid, malic acid, and oxalic acid. In addition to organic acid production, other mechanisms such as siderophore production, proton exchange through cell membranes, and the action of chelating ligands also contribute to zinc solubilization (Kumar and Paswan., 2014; Kumar and Paswan., 2015). For example, the ability of soil bacteria such as *Bacillus* and *Pseudomonas* to solubilize zinc has been linked to their production of organic acids like formic, acetic, propionic, lactic, glycolic, fumaric, and succinic acids (Kumar *et al.*, 2014).

Importance of zinc solubilizing biofertilizer in agriculture

There is zinc deficiency in the whole country because there are many reasons behind it such as:- Low adoption rate of Zinc Biofertilizers, Lack of awareness among farming community regarding Zinc Biofertilizers, Spurious materials available in the market for Zinc Biofertilizers, Shelf life of Zinc Biofertilizers, mainly using lignite as Carrier based Preparation (Less Shelf life/ Moisture contents/ Non-autoclaving of carrier materials), Ecological fitness of Bio-inoculants related to Zinc Biofertilizers, Need to enhanced shelf-life and effectiveness, and need to shifts towards Liquid based preparation, Maintenance of Viable cell count even at the time of expiry, Aseptic condition for packaging of Zinc Biofertilizer products, This initiative represents a holistic approach to greener, sustainable and more productive farming, benefiting farmers, consumers and the environment.

Conclusion

Zinc-Solubilizing Bacteria (ZSB) play a vital role in addressing zinc deficiency in soils, which is crucial for improving crop yield and maintaining soil health. By converting insoluble forms of zinc into bioavailable forms, ZSB offer a sustainable alternative to chemical fertilizers, which often pose environmental risks and are less efficient in zinc utilization. Despite the challenges such as low adoption rates, limited awareness, and issues with the shelf life of zinc biofertilizers, these bacteria represent a promising solution for eco-friendly and sustainable farming practices. Enhancing the shelf life of biofertilizers, raising awareness among farmers, and shifting towards more stable liquid-based formulations will be key to maximizing the benefits of ZSB. This approach not only supports greener agricultural practices but also improves long-term productivity, benefiting both farmers and the environment.

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