Journal of Advanced Zoology

ISSN: 0253-7214

*Volume **44** Issue 05 **Year 2023** Page **2518-2522***

"Unlocking Agricultural Potential: Harnessing Zinc and Silicon Micro-Nutrient Releasing Bacteria as Biofertilizers for Sustainable Crop Growth"

Monalisa Mallik[1*], Srijan Haldar[2]

[1*]*Microbiology Department, Swami Vivekananda University, Barrackpore, India*
[2]*Biotechnology Department, Swami Vivekananda University, Barrackpore, India*

***Corresponding Author:** Monalisa Mallik*
[*]*Microbiology Department, Swami Vivekananda University, Barrackpore, India*

Article History

Received: 30/09/2023
Revised: 15/10/2023
Accepted:30/10/2023

Abstract

In the realm of agro-ecosystems and soil science, the intricate interplay between soil microorganisms and plant nutrition continues to be an area of profound scientific interest and practical significance. One facet of this complex dynamic, often overlooked but of critical importance, is the role played by micronutrient-releasing bacteria in mediating the acquisition of essential trace elements by plants. Zinc and silicon are essential micro-nutrients for plant growth, and their availability in soil significantly influences crop productivity. However, conventional fertilization methods often fall short in providing these crucial elements in an environmentally friendly manner. In response to this nutritional challenge, nature has devised a remarkable ecological strategy wherein a diverse assembly of microorganisms, herein referred to as "micronutrient-releasing bacteria," are enlisted as indispensable agents in the mobilization and delivery of these micronutrients to plants. This abstract explores the potential of zinc and silicon micro-nutrient-releasing bacteria as biofertilizers. These microorganisms have demonstrated the ability to solubilize and mobilize zinc and silicon from soil minerals, making them readily available to plants. This not only enhances nutrient uptake but also reduces the need for chemical fertilizers, thus mitigating the environmental impact associated with their production and application.

1. Introduction

Modern agriculture faces the challenge of ensuring food security while minimizing the environmental footprint. This has led to a growing interest in sustainable agricultural practices, including the use of biofertilizers. Zinc and silicon are essential micro-nutrients for plant growth, and their availability in soil significantly influences crop productivity. However, conventional fertilization methods often fall short in providing these crucial elements in an environmentally friendly manner. The application of zinc and silicon micro-nutrient-releasing bacteria as biofertilizers offers several additional advantages, including improved soil structure, enhanced stress tolerance in crops, and the potential to reduce pest and disease pressures. This abstract provides an overview of the mechanisms underlying the action of these bacteria, their potential benefits for sustainable agriculture, and the challenges and considerations associated with their practical implementation. harnessing zinc and silicon micro-nutrient-releasing bacteria as biofertilizers holds promise in promoting sustainable agriculture, increasing crop yields, and reducing the ecological footprint of modern farming practices. Further research and field trials are needed to fully realize the potential of these microbial agents and to develop effective strategies for their integration into agricultural systems.

2. Zn-Solubilizing Rhizobacteria (ZSR) and its working mechanism

Chemical fertilizer application only partially meets plant needs since, within 7 days of application, 96-99% of applied Zn transforms into various insoluble forms depending on the type of soil and physicochemical reactions (Saravanan et al. 2004). Zinc solubilizers, which have the ability to change different inaccessible forms of metal into available forms, can avert this issue. These bacteria have the uncommon ability to solubilize tiny amounts of insoluble zinc compounds like zinc phosphate, zinc oxide, and zinc carbonate from the topsoil surface.Many bacteria, primarily those connected to the rhizosphere, have the ability to mobilize Zn into a form that is readily available (Cunninghan and Kuiack 1992). By mobilizing complex Zn in the soil, the ZSB are a viable substitute that could provide Zn essentiality for plants. According to Saravanan et al. (2007), many genera of rhizobacteria related to Thiobacillusthiooxidans, Acinetobacter, Bacillus, Pseudomonas, and Thiobacillusferrooxidans are zinc solubilizers.Trichoderma and arbuscularmycorrhizae fungi have both been found to have the ability to solubilize zinc (Paul and Clark 1989).By using protons, chelated ligands, and oxidoreductive systems found on the cell surface and membranes, these microbes mobilized metal forms. The production of phytohormones, antibiotics, siderophores, vitamins, antifungal compounds, and hydrogen cyanide were only a few of the properties this bacterium displayed that were advantageous to plants (Goteti et al. 2013).On a sandy loam soil in Argentina, Rosas et al. (2009) noticed that the seed inoculation with Pseudomonas aurantiaca increased wheat grain yield by 36%. Cakmak et al. (2010) found a favorable association between grain Zn and protein concentration. It is anticipated that these inoculations will contribute to the production of grains with improved Zn bioavailability because they considerably increase the methionine content in both wheat types' grains compared to the control. The results showed that Pseudomonas and Bacillus seed inoculation considerably increased the nutritional concentration of N and P in maize leaves (Goteti et al. 2013).

Table:1-Effective microorganism with Zn solubilizing mechanism

Sr. No.	Name	Insoluble Zn form	Mechanism of solubilization	References
Fungi				
1	Penicilliumluteum	ZnO, Zn3(PO4)2	Production of Gluconic acid	White C. et al. (1997)
2	Aspergillusniger A. nomius A. oryzae	ZnO, Zn3(PO4)2	Production of Organic acids, citric acid and oxalic acid	White C. et al. (1997)
3	TrichodermaharzianumRifai	Metallic Zn	Sequestering Zn and increasing the oxidative dissolution process	Altomare C. et al. (1999)
4	Beauveriacaledonica	Zn3(PO4)2	Acidolysis	Fomina M. et al.(2004)
5	A. terreus (ZSF-9)	ZnO, ZnCO3, Zn3(PO4)2	Decrease in pH	Anitha S. et. al. (2015)
		Bacteria		
6	Pseudomonas fluorescens	Zn3(PO4)2	Production of organic acid	Di Simine C.D et al. (1998)
7	Pseudomonas aeruginosa	ZnO, Zn3(PO4)2	Production of gluconic acid and ketogluconic acid	Fasim F. et al. (2002)
8	Pseudomonas sp. & Bacillus sp.	ZnO, ZnS and ZnCO3	Production of organic acids36	Saravanan V.S. et al. (2004)
9	GluconacetobacterDiazotrophicus	ZnO ZnCO3 or Zn3(PO4)2	Production of gluconic acids and it's derivative 5-ketogluconic acid	Madhaiyan M. et al. (2004) & Saravanan V.S. et al. (2007)
10	Klebsiella sp. Pseudomonas sp.	ZnO, Zn3(PO4)2	Production of organic acids	Sharma P. et al. (2014)
11	Acinetobactercalcoaceticus	ZnO, ZnCO3	Organic acid production	Goteti P. K. et al. (2013)
12	Bacillus cereus	ZnO, Zn3(PO4)2	Organic acid production	Kumar A.S. et al. (2017)
13	B. aryabhattai	ZnO, Zn3(PO4)2 ZnCO3	Production of malic acid, malonic acid, succinic acid, citric acid, propionic acid, keto-D-gluterate and gluconic acid	Vidyashree D.N. et al. (2018)
14	B. megaterium, KY687496	ZnO, Zn3(PO4)2 ZnCO3	Production of gluconic acid	Dinesh R. et al. (2018)
15	Pseudomonas taiwenensis	ZnO, Zn3(PO4)2 ZnCO3	Production of keto-D-gluterate, citric acid, propionic acid,gluconic acid and oxalic acid	Vidyashree D.N. et al. (2018)
16	Acinetobacter sp. (TM56), Serratia sp. (TM9)	ZnO ZnSO4	Production of organic acids	Othman N.M.I. et al. (2017)

Numerous mechanisms, including the synthesis of chelating agents or the release of metabolites such organic acids and proton extrusion, can solubilize zinc (Sayer and Gadd 1997). Additionally, the creation of inorganic acids including carbonic, nitric, and sulfuric acids could aid in solubilization (Seshadre et al. 2002). Zinc solubilization results show that each isolate had a different solubilization potential. A key process of solubilization has been found to be the production of organic acids by microorganism isolate, particularly 2-ketogluconic acids (Fasim et al. 2002). In the cycle of nutrients, this solubilization quality is crucial.All cases had a pH decline and medium acidification. In 72 hours, a higher solubilization of soluble zinc sources was accomplished. Additionally, there was a correlation between the zinc-solubilizing potential and zinc levels found in plant leaves. Simine et al. (1998) showed that a strain of Pseudomonas fluorescens solubilized zinc phosphate. They discovered that the secretion of gluconic acids in the culture medium aids in the solubilization of zinc salts. According to their study's findings (Subramanian et al. 2009), an acidic pH can solubilize bacteria because it produces more organic acids, more readily available zinc in the rhizosphere of culture broths, and zinc absorption by plants.According to Fasim et al. (2002), Pseudomonas aeruginosa has the ability to solubilize ZnO in a liquid medium. Additionally, bacterial inoculation has the capacity to raise the amount of Zn that is bioavailable in rhizosphere soil (Whiting et al. 2001) and in plants (Biari et al. 2008). For the mobilization of zinc and iron, PGPR produced siderophores (Saravanan et al. 2011), derivatives of gluconic acids, such as 2-ketogluconic acid and 5-ketogluconic acid, and several other organic acids (Tariq et al. 2007). Since most soils are high in Zn content but low in soluble Zn, these bacteria can be employed to solubilize insoluble sources of Zn like ZnO and $ZnCO_3$.both Bacillus and Pseudomonas species.have a lot of potential to be dissolved in the soil system for the absorption of economically efficient Zn (Saravanan et al. 2003). Plants may benefit from rhizosphere microorganisms in a variety of ways, including through the mobilization of nutrients and their ability to act as a biocontrol agent (Khalid et al. 2009).

3. Silicon-Solubilizing Rhizobacteria (SSR) and its working mechanism

There are many different microbes in soil, but only a small number of them are capable of releasing silica from natural silicates (Meena et al. 2014a, b, c). These include Bacillus caldolytyicus, Proteus mirabilis, Bacillusmucilaginosusvar. siliceous, and Pseudomonas). These SSB are capable to breaking down silicate, particularly aluminum silicates (AI_2SiO_5). During their development, these bacteria created a number of organic acids that may be involved in the weathering of silicates. These organisms aid in the release of potassium from minerals that contain K.
There are several Bacillus species among the bacteria that have been found. Farmers all around the world use biofertilizers to increase plant growth and crop yield by releasing nutrients through seed inoculation and soil application. Microorganisms' solubilization of silica is regarded as a source of silicon for plants. According to Avakyan et al. (1986), these bacteria boost the growth, chlorophyll content, test weight, filled grains, biomass, and yield of rice crops. Higher yields of maize, potatoes, wheat, and tomatoes were obtained when SSB was applied to the soil. (Aleksandrov1958)

As part of their metabolism, silicon microorganisms emit organic acids that have a dual function in silicate weathering. These provide H^+ ions to the medium, which promotes hydrolysis, and make organic acids like citric acid, keto acids, oxalic acids, and hydroxylcarbolic acids readily available to plants. According to Joseph et al. (2015), some bacterial isolates can convert insoluble minerals such silicates, phosphates, and potash into soluble form by secreting organic acids, alkalis, and polysaccharides. By generating proton, organic ligands, hydroxyl anion, extracellular polysaccharides, and enzymes, bacteria make silicates available (Barker et al. 1998).

Table:2 List of various disease cause due to deficiency of Zn and Si micronutrients.

Sr. No.	Metal responsible for plant disease	crop	Common name of disease	Scientific name of disease
1	Zinc	Chickpea	Root Rot	Fusarium
		Citrus	Mold	Penicilliumcitrinum
		Cotton	Wilt	Verticillium
		Pea	Powdery Mildew	Erysiphepolygoni
		Peanut	Rot	Rhizoctoniabataticola
		Wheat	Head Scab	Fusariumgraminearum
2	Silicon	Paddy	Blast	*Magnaporthe oryzae*
			Brown spot	*Bipolaris oryzae*
		Turf grass	Powdery mildew	*Blumeria graminis*

Discussion and future prospective

In conclusion, harnessing Zinc-Solubilizing Rhizobacteria (ZSR) and Silicon-Solubilizing Rhizobacteria (SSR) as biofertilizers holds great promise for promoting sustainable agriculture, increasing crop yields, and reducing the ecological footprint of modern farming practices. These microorganisms play a pivotal role in solubilizing and mobilizing essential micronutrients, such as zinc and silicon, from soil minerals to make them readily available to plants. This not only enhances nutrient uptake but also reduces the dependency on chemical fertilizers, thus mitigating the environmental impact associated with their production and use.
However, to fully realize the potential of these microbial agents, further research and field trials are needed to fine-tune their application methods, optimize strain selection, and address specific challenges associated with different soil types and environmental conditions. Additionally, education and awareness programs should be implemented to encourage the adoption of ZSR and SSR biofertilizers among farmers and stakeholders in the agricultural sector. By doing so, we can advance sustainable agriculture, increase food security, and contribute to a more environmentally friendly and resilient farming system.

References:

1. Ahmed,Z. F., Javed, M.T.,& Naveen, M. (2010). Mechanism of action and importance of biofertilizers. African Journal of Microbiology Research, 4(1), 8-18.
2. Barre, P., &Moyano, E. (2015).Micronutrient-releasing biofertilizers and their roles in sustainable agriculture. In Sustainable Agriculture Reviews (pp. 37-53).Springer, Cham.
3. Chen, Y., Wu, Q., Mu, L., & Wang, Y. (2015).Solubilization of phosphorus and zinc by bacterial biofertilizers and its effect on crop production. In Sustainable Agriculture Reviews (pp. 5569).Springer, Cham.
4. Kumar, S., &Rao, V. (2010).Biofertilizers and sustainable agriculture. In Sustainable Agriculture (pp. 59-91).Springer, Berlin, Heidelberg.
5. Singh, R.P., &Kaur, M. (2012).Role of biofertilizers in sustainable agriculture. In Sustainable Agriculture Reviews (pp. 1-18).Springer, Berlin, Heidelberg.
6. White C., Sayer J.A. and Gadd G.M., Microbial solubilization and immobilization of toxic metals: key biogeochemical processes for treatment of contamination, FEMS Microbiology Reviews, 20(3-4), 503-516 (1997)
7. Altomare C., Norvell W.A., Björkman T. and Harman G.E., Solubilization of phosphates and micronutrients by the plantgrowth-promoting and biocontrol fungus TrichodermaharzianumRifai 1295-22, Appl. Environ. Microbiol., 65(7), 2926-2933 (1999)
8. Anitha S., Padma Devi S.N. and SunithaKumari K., Isolation and identification of zinc solubilizing fungal isolates from agricultural fields, Indian J. Agr. Sci., 85(12), 1638-1642 (2015)
9. Di Simine C.D., Sayer J.A. and Gadd G.M., Solubilization of zinc phosphate by a strain of Pseudomonas fluorescens isolated from a forest soil, Biol. Fert. Soils, 28(1), 87-94 (1998)
10. Dinesh R., Srinivasan V., Hamza S., Sarathambal C., Gowda S.A., Ganeshamurthy A.N., Gupta S.B., Nair V.A., Subila K.P., Lijina A. and Divya V.C., Isolation and characterization of potential Zn solubilizing bacteria from soil and its effects on soil Zn release rates, soil available Zn and plant Zn content, Geoderma, 321, 173- 186 (2018)
11. Fomina M., Alexander I. J., Hillier S. and Gadd G. M., Zinc phosphate and pyromorphite solubilization by soil plant-symbiotic fungi, Geomicrobiol. J., 21(5), 351-366 (2004)
12. Fasim F., Ahmed N., Parsons R. and Gadd G. M., Solubilization of zinc salts by a bacterium isolated from the air environment of a tannery, FEMS Microbiology Letters, 213(1), 1-6 (2002)
13. Goteti P. K., Emmanuel L. D. A., Desai S. and Shaik M. H. A., Prospective zinc solubilising bacteria for enhanced nutrient uptake and growth promotion in maize (Zea mays L.), Int. J. Microbiol., 2013 (2013)
14. Kumar A.S., Meenakumari K.S. and Anith K.N., Screening for Zn solubilisation potential of soil bacteria from Zn deficient soils of Kerala, J. Trop. Agric., 54(2), 194 (2017)
15. Madhaiyan M., Saravanan V.S., Jovi D.B.S.S., Lee H., Thenmozhi R., Hari K. and Sa T., Occurrence of Gluconacetobacterdiazotrophicus in tropical and subtropical plants of Western Ghats, India, Microbiol. Res., 159(3), 233-243 (2004)
16. Othman N.M.I., Othman R., Saud H.M. and Wahab P.E.M., Effects of root colonization by zinc-solubilizing bacteria on rice plant (Oryza sativa MR219) growth, Agriculture and Natural Resources, 51(6), 532-537 (2017)

17. Saravanan V.S., Kalaiarasan P., Madhaiyan M. and Thangaraju M., Solubilization of insoluble zinc compounds by Gluconacetobacterdiazotrophicus and the detrimental action of zinc ion (Zn2+) and zinc chelates on root knot nematode Meloidogyne incognita, Letters in Applied Microbiology, 44(3), 235–241 (2007)
18. Saravanan V.S., Subramoniam S.R. and Raj S.A., Assessing in vitro solubilization potential of different zinc solubilizing bacterial (ZSB) isolates, Braz. J. Microbiol., 35(1-2), 121-125 (2004)
19. Sharma P., Kumawat K.C., Kaur S. and Kaur N., Assessment of zinc solubilization by endophytic bacteria in legume rhizosphere, Indian J. Appl. Res., 4(6), 439-441 (2014)
20. Vidyashree D.N., Muthuraju N., Panneerselvam P. and Mitra D., Organic acids production by zinc solubilizing bacterial isolates, Int. J. Curr. Microbiol. App. Sci., 7(10), 626-633 (2018)
21. R. Suryanarayanan, Zinc oxide: from optoelectronics to biomaterial—a short review. In ZnONanocrystals and Allied Materials, Springer: 2014; pp. 289-307.
22. M.R. Broadley, P.J. White, J.P. Hammond, I. Zelko, A. Lux. (2007). Zinc in plants. New phytologist. 173(4): 677-702.
23. U. Krämer, I.N. Talke, M. Hanikenne. (2007). Transition metal transport. FEBS letters. 581(12): 2263-2272.
24. D. Hussain, M.J. Haydon, Y. Wang, E. Wong, S.M. Sherson, J. Young, J. Camakaris, J.F. Harper, C.S.Cobbett. (2004). P-type ATPase heavy metal transporters with roles in essential zinc homeostasis in Arabidopsis. The Plant Cell. 16(5): 1327-1339.
25. A. Papoyan, L.V. Kochian. (2004). Identification of Thlaspicaerulescens genes that may be involved in heavy metal hyperaccumulation and tolerance. Characterization of a novel heavy metal transporting ATPase. Plant Physiology. 136(3): 3814-3823.
26. A. Gravot, A. Lieutaud, F. Verret, P. Auroy, A. Vavasseur, P. Richaud. (2004). AtHMA3, a plant P1B-ATPase, functions as a Cd/Pb transporter in yeast. FEBS letters. 561(1-3): 22-28.
27. R.F. Mills, A. Francini, P.S.F. da Rocha, P.J. Baccarini, M. Aylett, G.C. Krijger, L.E. Williams. (2005). The plant P1B-type ATPase AtHMA4 transports Zn and Cd and plays a role in detoxification of transition metals supplied at elevated levels. FEBS letters. 579(3): 783-791.
28. M.J. Haydon, C.S. Cobbett. (2007). Transporters of ligands for essential metal ions in plants. New phytologist. 174(3): 499-506.
29. I. Cakmak. (2000). Tansley Review No. 111 Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. The New Phytologist. 146(2): 185-205.
30. Y. Genc, J.M. Humphries, G.H. Lyons, R.D. Graham. (2005). Exploiting genotypic variation in plant nutrient accumulation to alleviate micronutrient deficiency in populations. Journal of Trace Elements in Medicine and Biology. 18(4): 319-324
31. S. Clemens. (2006). Toxic metal accumulation, responses to exposure and mechanisms of tolerance in plants. Biochimie. 88(11): 1707-1719.