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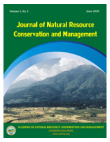

Zinc for enhancing crop growth of rice-A brief review

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ABSTRACT

This review elucidates the impact of soil and/or foliar zinc (Zn) fertilizer application on rice grain yield and grain zinc concentration. Zn deficiency is a well-documented public health concern and a significant constraint on crop production due to its effects on soil. The geographical overlap between soil deficiency of Zn and iron (Fe) and human deficiency highlights the pressing need to elevate micronutrient concentrations in food crops. The approach of biofortifying zinc (Zn) through foliar application emerges as an appealing strategy to alleviate human zinc deficiency. However, limited knowledge exists about the biofortification efficacy and rice grain bioavailability resulting from various forms of foliar zinc fertilizers. Based on the current study, $ZnSO_4$ stands recommended as an exceptional foliar zinc formulation for ongoing agronomic biofortification efforts.

Keywords: Zinc, Biofortification, Foliar, Rice

INTRODUCTION

Zinc stands as a pivotal micronutrient essential for the healthy growth and development of plants. In high-pH soils, zinc deficiency is prevalent. The application of zinc in soil can enhance grain yield; however, the concentration of zinc can be improved through foliar spray of zinc fertilizer. Various studies support that both soil and foliar applications of zinc contribute to enhanced crop yields. Flood-irrigated rice exhibits heightened sensitivity to zinc deficiency, while zinc availability can be increased by augmenting organic content and soil pH. Among micronutrients, zinc (Zn) deficiency poses a substantial threat to global and regional food security (Rana and Kashif, 2014). It stands out as the most deficient micronutrient in soils worldwide (Cakmak, 2002; Shivay *et al.*, 2008), with over 30% of soils demonstrating low zinc availability (Alloway, 2008; Gibbson, 2006). In areas where rice consumption is high, zinc deficiency has led to yield reduction and human zinc malnutrition (Tiong *et al.*, 2014; Yao *et al.*, 2012). Zinc acts as an essential component in numerous enzymes, controlling vital biochemical processes necessary for plant growth (IRRI, 2000).

Sudha and Stalin (2015) reported reduced rice grain yields due to low zinc concentrations in cases of inadequate zinc supply. However, the expense of zinc-containing fertilizers limits their usage to address this deficiency (Mustafa *et al.*, 2011). Among various methods, foliar zinc spray proves to be an efficient means of enhancing crop productivity. Post-flowering foliar application of zinc effectively increases zinc content in rice grains (Boonchuay *et al.*, 2013; Yuan *et al.*, 2013). Applying zinc to the soil and treating seeds or plants also leads to increased plant yields (Naik and Das, 2007; Shivay *et al.*, 2008; Rehman *et al.*, 2012). Mahmoodi and Mogadam's (2015) findings demonstrated that higher concentrations of zinc in foliar applications led to significantly increased yield and yield components in rice. Soil-applied zinc outperformed foliar spray in enhancing rice grain yield (Guo *et al.*, 2016). The combination of soil application and a 0.5% foliar spray during maximum tillering and panicle initiation stages resulted in the highest zinc content in different parts of rice grains (Ghasal *et al.*, 2017).

As a critical element for plant growth and development, zinc (Zn) plays a pivotal role in plants. It supports photosynthesis, carbohydrate and phosphorus metabolism, and grain development

(Cakmak, 2008). Zinc is also closely linked to human health, as its deficiency can hinder human growth, development, and weaken immunity (Gibson, 2006; Frossard *et al*., 2000). Rice, being a fundamental staple for global populations, provides essential energy, vitamins, mineral components, and vital amino acids for those who consume it daily (Yan *et al*., 2020; Phattarakul *et al*., 2012). However, the zinc content in rice remains exceedingly low at around 20 mg kg-1, falling short of the human body's demand of 40-50 mg kg-1 (Cakmak *et al*., 2010; Zeng *et al*., 2009). In recent decades, numerous studies have explored strategies to alleviate zinc deficiency in rice, including breeding, genetic modification, and biofortification through agricultural practices (Hussain *et al*., 2018; Rizwan *et al*., 2019).

The application of zinc fertilizer to leaves and soil can enhance zinc absorption and its transfer to edible plant parts. Foliar fertilization emerges as an effective and safe method for elevating zinc levels in crops. Substances applied to leaves can permeate the cuticle or use the stomatal pathway to enter the leaf. Fang *et al*. observed that zinc foliar fertilizer application during the flowering stage significantly increased rice zinc content (Fang *et al*., 2008). However, the sustainability of zinc ions adhering to rice leaf surfaces poses challenges, as sprayed zinc solutions can drip off leaves or be washed away by rain, affecting zinc absorption. Notably, applying zinc fertilizer to the soil not only increases grain zinc content but also enhances grain yield (Prakash *et al*., 2018; Wu *et al*., 2020). Many reports on zinc fortification of rice highlight that appropriate amounts of zinc fertilizer contribute to rice growth and increased yield (Naik *et al*., 2008; Yang *et al*., 2021). Unfortunately, iron and aluminum oxides, clay minerals, and humus in the soil can adsorb and immobilize zinc ions, reducing the effectiveness of zinc fertilizer in soil. Moreover, unabsorbed zinc fertilizer can accumulate in agricultural soil, potentially exerting adverse impacts on the agricultural ecosystem (Elemike *et al*., 2019). Consequently, the search for a new zinc-containing fertilizer with a positive performance and low environmental impact, capable of replacing conventional zinc fertilizers, becomes imperative.

Importance of zinc (Zn) as micronutrients

Zinc (Zn) stands as one of the 17 essential elements necessary for the proper growth and development of humans, animals (Broadley *et al*., 2007), and plants (Prasad 2008). On one hand, Zn is crucial for immune system functionality, healthy growth, and the physical and mental development of children. On the other hand, it is recognized as one of the eight micronutrients with a pivotal role in plants, participating in enzymatic and protein activities related to carbohydrate metabolism, protein synthesis, gene expression, auxin (a growth regulator) metabolism, pollen formation, the maintenance of biological membranes, protection against photooxidative damage and heat stress, and resistance to certain pathogens (Alloway, 2008). Zn's role in plant biochemical and physiological processes is multifaceted; even a slight deficiency can result in reduced growth, yield, and Zn content in edible plant parts.

The Zn content in food plays a critical role in human health, given the challenges of artificially supplementing essential minerals, particularly in developing countries. Thus, increasing Zn levels in staple foods like rice has been suggested to mitigate Zn deficiency (Graham *et al*., 1990; Ruel and Bouis, 1998; Welch and Graham, 1999). In India, Zn deficiency affects 26% of the population, with children being particularly vulnerable, as approximately 54% of them suffer from Zn deficiency (Sinha, 2004). Adequate Zn nutrition requires a daily intake of 15 mg of Zn, whereas our staple grains contain merely 15-35 mg of Zn per kilogram, of which only 13–35% is bioavailable (Cakmak *et al*., 2004). This disparity between daily requirement and intake necessitates food grains containing 40–60 mg of Zn per kilogram to bridge the gap (Pfeiffer and Mc Clafferty, 2007). Zn deficiency leads to hidden hunger or malnutrition, a condition affecting an estimated 2 billion people, primarily in impoverished countries (Verma, 2015).

Zn deficiency in both soil and rice is a global issue (Yoshida, 1972; Silanpaa, 1990; Fageria *et al*., 2002; Norman *et al*., 2003; Alloway, 2004; Gao *et al*., 2006; Cakmak, 2009). Nene (Neue *et al*., 1998) first reported Zn deficiency in rice from G. B. Pant University of Agriculture and Technology, India. It manifests as dark brown spots on leaves, which can merge into a uniform dark brown color across the plant in severe cases. This deficiency earned the name "kharia disease" due to the brown shade of the Acacia catechu extract. In India, approximately 49% of soils lack sufficient Zn (Behera *et al*., 2009a, 2009b). Beyond fertilizer usage, the presence of organic matter significantly enhances nutrient availability, including Zn. High-molecular-weight organic carbon exudates released into the rhizosphere stimulate microbial activity around roots, potentially influencing micronutrient solubility and availability (Curl and Truelove, 1986; Marschner, 1995). Microorganisms in the rhizosphere promote better plant growth by enhancing nutrient accessibility. In addition to dedicated Zn fertilizers, organic manures such as farmyard manure (FYM), compost, vermicompost, biogas slurry, and crop residues serve as valuable sources of Zn and other micronutrients. Their consistent application can help prevent or at least diminish the occurrence of micronutrient deficiencies. References related to the impact of applied organic matter, including green manure (GM) and chelated materials, are well-documented.

Biofortification

This strategy is deemed to be the most practical and cost-effective means of providing micronutrients to populations with limited access to diverse diets and other interventions targeting micronutrient deficiencies (Bouis, 2000). Among the various approaches to biofortification, the development of biofortified varieties often stands out as the most sustainable, especially when targeting major staple cereal crops. Once created, these biofortified varieties can be easily embraced by farmers with minimal cultivation costs, unlike agronomic biofortification, which involves additional expenses for external nutrient application. The biofortification of rice with zinc in polished rice emerges as a promising solution to tackle zinc deficiency in countries where rice constitutes the primary staple food crop.

Biofortification in rice

Biofortification is an effective process to enhance the micronutrient content in food crops, including rice. It offers a sustainable and viable approach to combat micronutrient deficiencies, especially among populations heavily reliant on rice consumption, limited in their access to diverse foods, food markets, and proper healthcare facilities (Datta, 2000). Within the realm of rice biofortification research, various strategies have been formulated worldwide to maintain, elevate, and introduce new micronutrients into rice grains. Rice, being a paramount global staple food, boasts a long history of cultivation. On average, the grain comprises around 80% starch, 7.5% protein, 0.5% fat, and 12% water. An average adult in China and India consumes roughly 300 grams of raw rice per day (Popkin *et al*., 1993; Krishnaswami, 1998), resulting in an annual consumption ranging from 62 to 190 kilograms per year (Lu *et al*., 2008). The daily zinc (Zn) requirement for both adults and children aged 4 and older is 15 mg, a quota that cannot be met by a typical rice-based vegetarian diet (Lu *et al*., 2008). Despite rice serving as the primary source of energy, protein, and micronutrients for over 50% of the global population, it falls short in supplying essential mineral nutrients to meet human dietary needs.

Effect of Environment on Grain Zinc Content of Rice

While biofortified rice varieties possess elevated grain zinc levels, the zinc content in these grains can exhibit significant variability due to factors such as soil composition, seasonal variations, and agronomic practices, as indicated by AICRIP and reported studies in India. Consequently, it becomes crucial to identify suitable locations with favorable soil conditions for large-scale seed production of biofortified varieties. Failing to do so might hinder the full potential of biofortified rice varieties due to underlying zinc deficiency in the soil (Cakmak, 2008). Therefore, the external application of zinc becomes imperative to actualize and sustain the nutritional performance potential of biofortified rice varieties.

CONCLUSION

In conclusion, this report compilesresearch on the efficacy of elevating zinc (Zn) levels in rice grains through foliar Zn application, especially when applied after flowering. High-Zn seeds offer both agronomic and nutritional advantages. Given the prevalence of Zn deficiency in human populations due to inadequate dietary Zn intake, particular emphasis should be placed on applying foliar treatments of Zn to staple food crops. As evidenced in this research focused on rice, this agricultural approach proves highly effective and swift in boosting grain Zn content. Foliar Zn spray emerges as a practical and valuable method for effectively biofortifying rice grains with Zn. This technique consistently and significantly contributes to increased grain Zn content in rice, irrespective of variations in cultivars, environmental conditions, and management practices.

REFERENCES

Alloway B. J. (2004). Zinc in Soils and Crop Nutrition, International Zinc Association: Brussels, Belgium.

Alloway B. J. (2008) Zinc in Soils and Crop Nutrition, IFA: Paris, France and IZA: Brussels, Belgium.

Alloway B.J. (2008). Zinc in soils and crop nutrition, Second edition, published by IZA and IFA Brussels, Belgium and Paris, France.

Behera S. K.; Singh D.; Dwivedi B. S.(2009a) Change in Fractions of Iron, Manganese, Copper and Zinc in Soil Under Continuous Cropping for More than Three Decades. Commun. Soil Sci. Plant Anal., 40 (9–10), 1380–1407.

Behera S. K.; Singh M. V.; Lakaria B. L. (2009b) Micronutrient Deficiencies in Indian Soil and Their Amelioration Through Fertilization. Indian Farm, 59 (2), 28–31.

Boonchuay P., Cakmak I., Rerkasem B., and Prom-U-Thai C. (2013). Effect of different foliar zinc application at different growth stages on seed zinc concentration and its impact on seedling vigor in rice. Soil Sci. Plant Nutr., 59:180-188.

Bouis HE, Saltzman A. (2016). Improving nutrition through biofortification: a review of evidence from harvest plus, 2003 through. Glob Food Sec. (2017) 12:49–58.

Broadley M. R.; White, P. J.; Hammond J. P. (2007). Zinc in Plants. Newphilol, 173,677–702.

Cakmak I. (2002). Plant nutrition research: priorities to meet human needs for food in sustainable ways. Plant & Soil, 247:3-24.

Cakmak I .; Torun A.; Millet E.; Feldman M.; Fahima T.; Korol A.; Nevo E.; Braun H. J.; Ozkan H. (2004). Triticum dicoccoides: An Important Genetic Resource for Increasing Zn and Fe Concentration in Modern Cultivated Wheat. Soil Sci. Plant Nutr., 50, 1047–1054.

Cakmak I. (2008). Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? Plant Soil, 302, 1–17.

Cakmak I.; Kalayci M.; Kaya Y.; Torun A.A.; Aydin N.; Wang Y.; Arisoy Z.; Erdem H.; Gokmen O.; Ozturk L.; (2010). Biofortification and localization of zinc in wheat grain. J. Agric. Food Chem., 58, 9092–9102.

Curl E. A.; Truelove B. (1986). The Rhizosphere. Springer: Verlag, NY.

Elemike E.E.; Uzoh, I.M.; Onwudiwe, D.C.; Babalola, O.O. (2019). The role of nanotechnology in the fortification of plant nutrients and improvement of crop production. Appl. Sci., 9, 499.

Fageria N. K.; Bajigar, V. C.; Clark, R. B. (2002). Micronutrients in Crop Production. Adv. Agron., 77, 187-266.

Fang Y.;Wang, L.; Xin, Z.H.; Zhao, L.Y.; An, X.X.; Hu, Q.H.(2008). Effect of foliar application of zinc, selenium, and iron fertilizers on nutrients concentration and yield of rice grain in China. J. Agric. Food Chem., 56, 2079–2084.

Frossard E.; Bucher, M.; Mahler, F.; Mozafar, A.; Hurrell, R.F. (2000). Potential for increasing the content and bioavailability of Fe, Zn and Ca in plants for human nutrition. J. Sci. Food Agric., 80, 861–879.

Gao X.; Zou, C.; Fan, X.; Zhang, F.; Hoffland, E.(2006). Form Flooded to Aerobic Conditions in Rice Cultivation: consequences from Zn Uptake. Plant Soil, 280, 41–47.

Ghasal P.C., Y. Singh, V. Shivay Pooniya,M. Choudhary and R.K. Verma (2017). Response of basmati rice (Oryza sativa) varieties to zinc fertilization. Indian Journal of Agronomy, 60: 403-409.

Gibbson R.S. (2006). Zinc: the missing link in combating micronutrient malnutrition in developing countries. Proceedings of the Nutrition Society, University of East.

Guo J.X., X.M. Feng, X.Y. Hu, G.L. Tian, N. Ling, J.H. Wang, Q.R. Shen and S.W. Guo (2016). Effects of soil zinc availability, nitrogen fertilizer rate and zinc fertilizer.

Hussain A.; Ali, S.; Rizwan, M.; Rehman, M.Z.U.; Javed, M.R.; Imran, M.; Chatha, S.A.; Nazir, R.(2018) Zinc oxide nanoparticles alter the wheat physiological response and reduce the cadmium uptake by plants. Environ. Pollut., 242, 1518–1526.

IRRI (2000). Nutritional disorders and nutrient management in rice. Inter. Rice Res. Ins. Manila, Philippines.

Krishnaswami K. (1998). Country profile:India.Nutritional disorders–old and changing. Lancet 351, 1268–1269.

Lu K., Li,L., Zheng, X., Zhang, Z., Mou,T., and Hu, Z. (2008). Quantitative trait loci controlling Cu,Ca, Zn, Mn and Fe content in rice grains. J. Genet. 87, 305–310.

Mahmoodi B. and M.N. Mogadam (2015). Effect of Zn application on yield and yield components of rice. Research Journal of Fisheries and Hydrobiology, 10(11): 72-77.

Marschner H.(1995) Mineral Nutrition of Higher Plants, 2nd ed.; Academic Press: London,; pp.889.

Mustafa G., A.N. Ehsanullah, S.A. Qaisrani, A. Iqbal, H.Z. Khan, K. Jabran, A.A. Chattha, R. Trethowan, T. Chattha and B.M. Atta (2011). Effect of zinc application on growth and yield of rice (Oryza sativa L.). Int. J. Agro Vet. Med. Sci., 5: 530- 535.

Naik S. K. and Das D.K. (2010). Evaluation of various zinc extractants in low land rice soil under the influence of zinc sulphate and chealated zinc. Communi. Soil. Sci. and Pl. Anal., 41: 122-134.

Naik S. K.; Das, D.K.(2008) Relative performance of chelated zinc and zinc sulphate for lowland rice (Oryza sativa L.). Nutr. Cycl. Agroecosyst., 81, 219–227.

Neue H. U.; Quijano, C. Senadhira, D.; Setter, T.(1998) Strategies for Dealing with Micronutrient Disorders and Salinity in Lowland Rice Systems. Field Crops Res., 56, 139–55.

Norman R. J.; Wilson, C. E. J.; Slaton, N. A.(2003) Soil Fertilization and Mineral Nutrition in US Mechanized Rice Culture. In Rice: Origin, History and Production; Smith, C. W., Dilday, R. H., Eds.; John Wiley: NJ, USA; pp 31–412.

Phattarakul N.; Rerkasem, B.; Li, L.J.; Wu, L.H.; Zou, C.Q.; Ram, H.; Sohu, V.S.; Kang, B.S.; Surek, H.; Kalayci, M.; (2012) Biofortification of rice grain with zinc through zinc fertilization in different countries. Plant Soil, 361, 131–141.

Popkin B.M.,Keyou,G.,Zhai,F.,Guo,X.,Ma,H.,and Zohoori,N.(1993).The nutrition transition in China:across-section alanalysis. Eur. J.Clin.Nutr. 47, 333–346.

Prakash P.; Hemalatha, M.; Joseph, M. (2018) Zinc accounting for lowland rice (Oryza sativa L.) under different methods of zinc application with green leaf manuring. Adv. Crop Sci. Tech., 6, 1000374.

Prasad A. S. (2008) Zinc in Human Health: Effect of Zinc on Immune Cells. Mol. Med., 14 (5–6), 353–357.

Rana W.H. and S.R. Kashif (2014). Effect of different zinc sources and methods of application on rice yield and nutrients concentration in rice grain and straw. Journal of Environmental and Agricultural Sciences, 1–9.

Rizwan M.; Ali, S.; Rehman, M.Z.U.; Adrees, M.; Arshad, M.; Qayyum, M.F.; Ali, L.; Hussain, A.; Chatha, S.A.S.; Imran, M.(2019) Alleviation of cadmium accumulation in maize (Zea mays L.) by foliar spray of zinc oxide nanoparticles and biochar to contaminated soil. Environ. Pollut., 248, 358–367.

Ruel M. T.; Bouis, H. E. (1998). Plant Breeding: A Long-term Strategy for the Control of Zn Deficiency in Vulnerable Populations. Am. J. Clin. Nutraceutical Suppl., 68, 488–494.

Shivay Y.S., D. Kumar, R. Prasad and I.P.S. Ahlawat (2008). Relative yield and zinc uptake by rice from zinc sulphate and zinc oxide coatings onto urea. Nutr. Cycl. Agroecosys, 80: 181– 188.

Silanpaa M. (1990). Micronutrient Assessment at the Country Level: An International Study; Food and Agriculture Organization (FAO) of the United Nations, Rome.

Sinha R. The National Seminar on Importance of Zinc in Human Health; Organized by International Life Sciences Institute (ILSI)-India and ILSI Human Nutrition Institute, Washington in Association with Indian Council of Medical Research and National Institute of Nutrition, Oct 25–26, 2004, New Delhi, India. http://indianpediatrics.net/ dec2004/dec-1213-1217.htm (accessed April 11, 2016).

Sudha S. and P. Stalin (2015). Effect of zinc on yield, quality and grain zinc content of rice genotypes. International Journal of Farm Sciences, 5(3): 17-27.

Tiong J., G.K. Mc Donald and Y. Genc (2014). HvZIP7 mediates zinc accumulation in barley (Hordeum vulgare) at moderately high zinc supply. New Phytol., 201(1):131–143.

Verma A.(2015) Food Fortification: A Complementary Strategy for Improving Micronutrient Malnutrition (MNM) Status. Food Sci. Res. J., 6 (2), 381–389.

Welch R. M.; Graham, R. D. (1999) A New Paradigm for World Agriculture: Meeting Human Needs: Productive, Sustainable, Nutritious. Field Crops Res., 60, 1–10.

Wu F.; Fang, Q.; Yan, S.W.; Pan, L.; Tang, X.J.; Ye, W.L.(2020) Effects of zinc oxide nanoparticles on arsenic stress in rice (Oryza sativa L.): Germination, early growth, and arsenic uptake. Environ. Sci. Pollut. Res., 27, 26974–26981.

Yan S.; Wu, F.; Zhou, S.; Yang, J.; Tang, X.; Ye, W. (2021). Zinc oxide nanoparticles alleviate the arsenic toxicity and decrease the accumulation of arsenic in rice (Oryza sativa L.). BMC Plant Biol., 21, 150.

Yang G.Y.; Yuan, H.Y.; Ji, H.T.; Liu, H.J.; Zhang, Y.F.; Wang, G.D.; Chen, L.G.; Guo, Z. (2021). Effect of ZnO nanoparticles on the productivity, Zn biofortification, and nutritional quality of rice in a life cycle study. Plant Physiol. Bioch., 163, 87–94.

Yao F., J. Huang and K. Cui (2012). Agronomic performance of high-yielding rice variety grown under alternate wetting and drying irrigation. Field Crops Res., 126:16–22.

Yoshida S. (1972) Climate and Rice; International Rice Research Institute: Manila, Philippines; p 211.

Yuan L ., W. Lianghuan, Y. Chunlei and L.V. Qian (2013). Effects of iron and zinc foliar applications on rice plants and their grain accumulation and grain nutritional quality. J. Sci. Food Agric., 93: 254–261.

Zeng Y.W.; Wang, L.X.; Du, J.; Wang, S.M.; Yang, Y.C.; Li, Q.W.; Sun, Z.H.; Pu, X.Y.; Du, W.(2009) Correlation of mineral elements between milled and brown rice and soils in Yunnan studied by ICP-AES. Spectrosc. Spect. Anal., 29, 1413–1417.