ZINC NUTRITION IN RICE BASED CROPPING SYSTEMS:A COMPREHENSIVE REVIEW

Abstract:

Rice-based cropping systems being the most practiced cropping system in India, it suffers zinc deficiency asmajority of the Indian soils are deficient in the Zn micronutrient. Zn is considered the fourth most important yieldlimiting nutrient of Agricultural crops. Apart from plant nutrition Zn also plays crucial role in human nutrition. Zn plays avital role in the physiological function of plants and it is associated with phytohormone activity, protein synthesisand carbohydrate metabolism. To understand better zinc nutrition and its associated benefits from optimum nutrition and ways to manage Zn in rice-based cropping systems, thepresent review critically examines nutrient mobilization and transformation of Zn in rice-based cropping systems of India.

Keywords: Rice-based cropping systems, phytohormone, protein synthesis, carbohydrate metabolism,optimum nutrition.

Introduction:

Zinc is considered the key element affecting thegrowth, development and life of living organisms along with playing anessential role in physiological activities (Fageria *et al.*, 2002; Stanton *et al.*, 2022;Wu *et al.*, 2022).Zn deficiency in people results in symptoms such as loss of appetite, anorexia, loss of taste and smell, and other symptoms. It can also have an impact on the immune system, leading to arteriosclerosis and anemia(Gondal *et al*., 2021).Growth retardation, congenital fetal abnormalities, and pregnancy and birthing problems have all been linked to zinc deficiency (Black, 2001).

Micronutrient deficits, particularly those of Zn, are one of the main causes of economic loss in developing nations(Stein, 2014). According to recommendations, an average individual needs 11 mg of zinc per day for males and 8 mg of zinc per day for females(NIH, 2021).

Zinc is a crucial element needed to improve crop growth and output; of all micronutrients, Zn is regarded as the most important nutrient(Samreen *et al.*, 2017).More than

300 enzymes, including carbonic anhydrase, alcoholic dehydrogenase, alkaline phosphate, carboxy peptidase, phospholipase, superoxide dismutase (SOD) and RNA polymerase depend on zinc for their structural and functional integrity. These enzymes regulate a variety of biochemical and physiological processes including cell division, protein synthesis, photosynthesis, gene transcription, nucleic acid metabolism and pollen development(Hacisalihoglu, 2020).

Rice is a majorstaple food cereal on which half the world’s population is dependent for energy and 20% protein requirements (Rehman *et al.*, 2012).Around 50% of Asia's population, or roughly 2 billion people, are indanger of Zn insufficiency, thoughAsia covers about 87% of the world's rice-growing area and consumes 90% of all rice produced (Chen *et al.*, 2017, FAO, 2018).Agronomic biofortification of Zn could be a potential option to address the problem of Zn deficiency(Zulfiqar *et al.*, 2021).

The primary cropping system used in India is the rice-based cropping system (RBCS), which rotates crops with vegetables, fodder crops, pulses and oilseeds. The productivity of a system is significantly influenced by how nutrients are managed during different seasons. Any farming system can be made more productive by using micronutrients(Tuti*et al.*, 2018).Zn is thought to be the micronutrient that is needed the most.

Rice-based cropping systems (RBCS)

Rice is the predominant crop in the world meeting 20% of the human food calories and India is considered as the largest producer occupying ~ 45 million ha under cultivation (Tuti *et al.*, 2018). Due to varying climatic situations during the crop year the annual crops are grown in progression. The crops may either be grown along with rice as inter-crop or in sequence according to the climatic conditions and feasibility to maximize resource utilization (Sarwar *et al.*, 2022).

Rice-based cropping system can be described as, in a farming practice considering rice as the major crop is succeeded by other adaptable crops. In India,rice-based cropping system is the major cropping system where, the major cropis rice followed by pulses, cereals, oilseeds, etc. (Tuti *et al.*, 2018).

The central principle in considering a crop ina cropping system lies with; a. the biological traits of the crop and how they interact with and are influenced by its physical, chemical, and ecological environment, b. the crop to be grown in sequence after the major crop, c. the management practices to be followed for the cropping system (Jensen *et al.*, 2010).The major crop in cropping systems was chosen based on the agro-climatic and socio-economic circumstances of the area. In India, rice-rice, rice-wheat, rice-pulse, and rice-potato are the most common rice-based cropping systems (Sravan and Murthy, 2018).

Table 1:Rice based cropping systems followedin Indian states (Tuti *et al.*, 2018)

Agro-climatic region	**Cropping system followed**
Western himalayan	Rice-wheat, rice-potato-potato
Eastern himalayan	Rice fallow, rice-rice, rice-pulses/oilseeds
Lower gangetic plain	Rice-rice, rice-wheat, rice-potato-jute/vegetables
Middle gangetic plain	Rice-wheat, rice-maize, rice-potato-sunflower
Upper gangetic plain	Rice-wheat, sugarcane-ratoon-wheat
Trans gangetic plain	Rice-wheat
Eastern plateau and hills	Rice-blackgram, rice-niger/linseed, rice-vegetables
East coast plain and hills	Rice-groundnut-greengram, Rice-greengram/blackgram, rice-rice
West coast plains and hills	Rice-rice
Andaman and Nicobar	Rice- fallow

Nutrient mobilization of zinc in RBCS

The movement of the nutrient Zn in thecrop sequence of the cropping system can be understood as nutrient mobilization. Cropping systems following the integrated mode of nutrient managementwere found to havea significant effect on soil fertility. Inclusion of pulse crops like green gram and vegetable crops in the rice-based cropping system along with supplementing nutrients through different sources of biofertilizers and organic manures significantly improves crop nutrient absorption by increasing the availability of soil nutrients, the total zinc nutrient uptake by the rice and wheat(Verma *et al.*, 2020).

The organic sources of nutrients and biofertilizers supply considerable amounts of the major and micronutrients continuously throughout the crop growth period unlike the inorganic sources, the nutrients are available to the plants in the earlier and the later stages of growth, organic sources provide long-term availability of nutrients(Singh *et al.* 2010;Garai *et al.* 2013 and Verma *et al.* 2017).

Change from the current, conventional cropping system to an enhanced cropping system including potato and cucumber between two seasons of rice has resulted in49% higher rice equivalent yield due to the greater profits gained under higher yield of cucumber and potato (Alam *et al.*, 2021).Rice-non rice crop-based cropping systems were more profitable compared to rice- rice cropping systems(Nagoli *et al.*, 2017).

In a rice-based cropping system, crop intensification results in a rice equivalent yield that is two to four times greater (Samant, *et al.*, 2015, Jat *et al.*, 2012). The rate of increase of REY depends on thetype of crop, thenumber of crops involved, and the ecosystem in which the crop is grown (Alam *et al.*, 2021).An improved cropping system consisting of transplanted Aman rice followed by potato, cucumber and transplanted Aus rice has received 49% higher rice equivalent yield compared to the existing cropping system consisting of transplanted Aman rice followed by potato and transplanted Boro rice (Alam *et al.*, 2021).

The Nutrient Index (NI) gauges reveals how well soil can supply nutrients to plants (Singh *et al.*, 2016). Cropping systems with pulse as a component will have a higher nutrient index than vegetables as a component (Singh *et al.*, 2020). Supply of therecommended dose of fertilizers along with theinclusion of pulse crops as a component/sequence in a cropping system will result in the improved nutrient response of the crop to Zn (Shankar *et al.*, 2021).Toachieve higher productivity and profitability from a cropping systemthe need-based application of Zn is essential along with the application of inorganic sources of fertilizers as the nutrients will be present in the available forms for plants toget maximum benefit (Xu *et al*., 2014).

Thus, the application of both organic and inorganic sources of nutrients will make the nutrients more available as is the case with DTPA-extractable Zn content in post-harvest soil of both rice and wheat, Customized fertilizer application had shown increased Zn content by 95% and 158%over 100% RDF in soils of wheat andrice, respectively (Kumar *et al.*, 2021).

Status of Zn in Indian soils

Fertility of Indian soils is generally poor with progressively emerging micronutrient deficiencies due to their catalyzed removal under agricultural intensification. According to latest estimates, out of about 188.4 thousand tonnes (Tt) of micronutrients removed by 263 Mt of food grains produced, nutrient removal forZn is 23.9 Tt and in Indian soils, total Zn content ranges from 7-2960 mg/kg and available Zn content ranges from 0.01-52.9 mg/kg.Currently, 36.5% of soil samples nationwide have deficiencies in available Zn, with acute, latent, and total deficiencies occurring in 8, 29, and 15% of the country, respectively(Shukla *et al.*, 2019). Zn is currently regarded as the fourth-most significant nutrient for crops in India that limits productivity. By 2025, zinc deficiency in Indian soils is predicted to rise from 42 to 63%(Sharma *et al*., 2021).According to a study of Indian soils, out of 2.52 lakh soil samples examined, 49% were found to be low in the available Zn spread throughout 20 states. There is widespread zinc deficiency throughout all agro-ecological zones (AEZ). Maximum Zn deficit extended, up to 60%, in AEZ 6 and 10 soils. Agro-ecological zones 3, 4, 7, 8, 13, and 14 had soils that were 50–60% zinc deficient. In states like Punjab, Haryana, Uttar Pradesh, Andhra Pradesh, Bihar, and Madhya Pradesh, the severity of Zn deficiency is decreasing.

The extent of zinc deficiency was found to be 55, 47, and 36% in Trans-northern, Central, and Eastern sections of IGP alluvial plains, according to analysis of 90419 surface soil samples from AEZ 4, 9, 13, and 16 of the Indo-Gangatic alluvial plains(IISS, 2021).

Map 1 : Map showing area having Zinc deficient soils

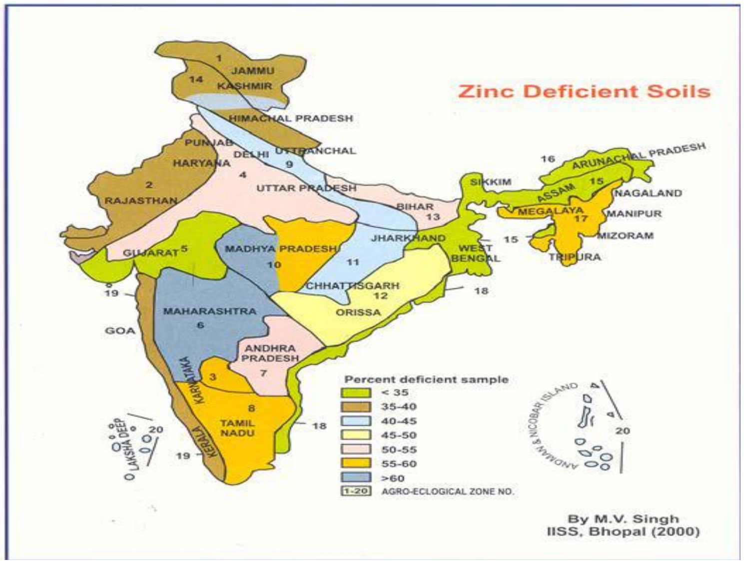
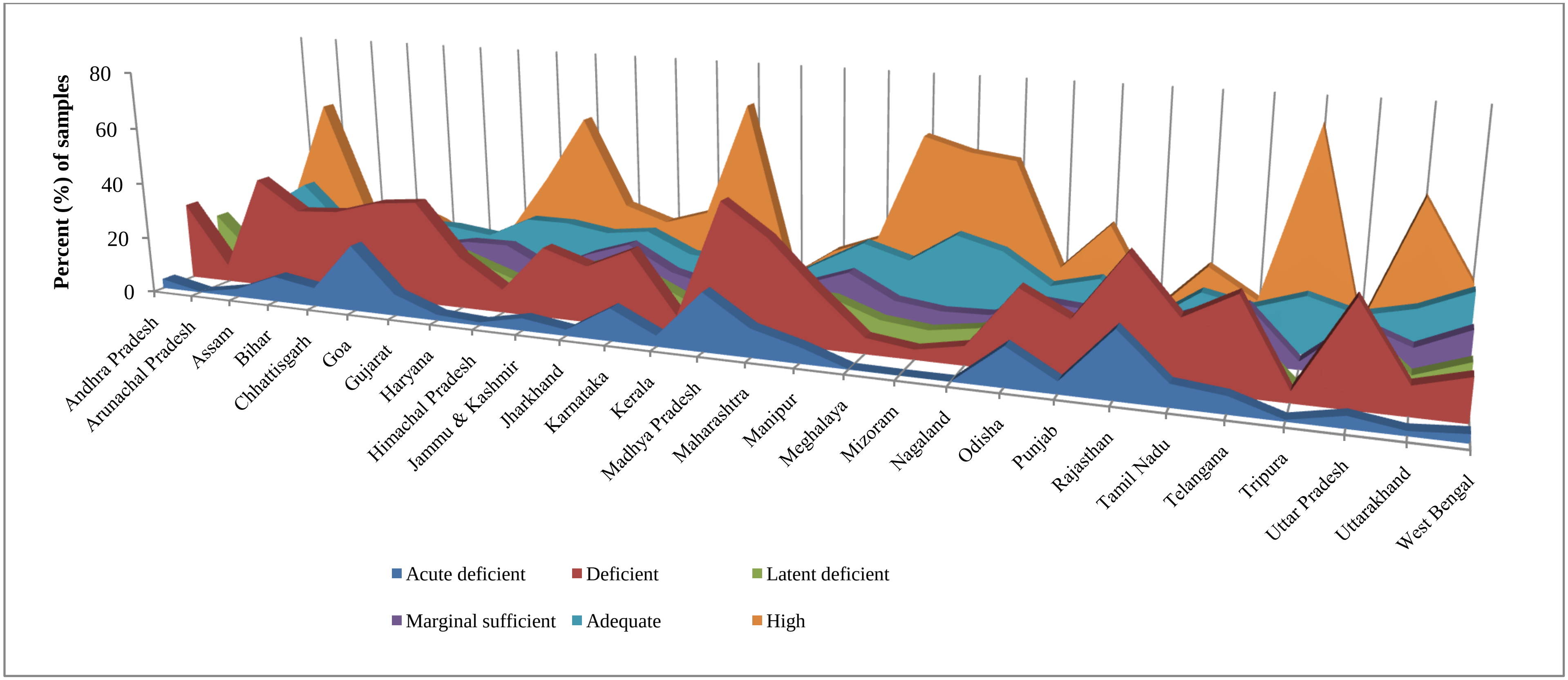


Table 2: Critical limits of available Zn for agricultural soils of India.

	AvailableZn(mgkg^{-1})
Acutedeficient	≤0.30
Deficient	>0.30–≤0.60
Latent deficient	>0.60–≤0.90
Marginalsufficient	>0.90–≤1.20
Adequate	>1.20–≤1.80
High	>1.80

Fig 1: Deficit by state (% of soil samples) available Zn. (Shukla *et al.*, 2021)



Physiological functions of Zn in plants

Zinc is the vital nutrient having its role in normal growth and productivity of the plants(Suganya A*et al.*, 2020).The nutrient was also found to have its role in structurally and functionally maintaining the cell membranes(Hafeez, B*et al.*, 2012). Optimum Zn nutrition helps in the improvement of the photosynthetic activityby 50%-70%and thus increases the chlorophyll content, net photosynthetic rate, transpirational rate, and stomatal conductance (Liu *et al.*, 2016,Rudani *et al.*, 2018). Zn application improves plant activity under drought conditions by enhancing the photosynthetic process (Hassan M.U*et al.*, 2020).A deficiencyof zinc in plants results inreductionof chlorophyll content and also affects the ratio of chl a: chl b. Reduced photosynthetic activity leads to reduced growth, leaf area (up to 72%) and reduced number of leaves (Hajiboland R*et al.*, 2010). Zinc plays role in phytohormone activity, enzyme activation, protein synthesis, carbohydrate metabolism and noticeable role in defending against phytopathogens (Grungreiff *et al.*, 2020,Suganya A*et al.*, 2020). Zinc is identified as the primary requisite of enzyme classes such as transferases, ligases, oxidoreductases, isomerases, lyases, hydrolases and is also a constituent of ribulose 1,5-biphosphate carboxylase (RuBpc) involved in photosynthesis. As the element is involved in different categories of enzymes the functions, indirectly involved in the metabolism of carbohydrates, proteins, auxins; the deficient conditions affect the productivity of the plants (Romheld and Marschner 1991,Singh *et al.*, 2005).The enzyme carbonic anhydrase which governs the fixation of carbohydrates by conversion of carbon dioxide to bicarbonates is managed by zinc (Kandil *et al.*, 2022).The most rudimentary effect of zinc in protein metabolism is its activity in maintaining the stability and functioning of genetic material (Rudani *et al.*, 2018). Living membranes are maintained by zinc, cell membrane integrity is often regulated by the availability of zinc which drives the detoxification of membrane-damaging ROS and thus involved in the plant water relations (Ghazi *et al.*, 2022). So, in the absence of the Zn sulphydryl groups and lipids in the membrane undergoes injury and organic compounds leaks through the cells, especially root cells exposed to certain situations leads to root diseases in Zn deficient plants(Mousavi, S.R*et al.*, 2013, Sadeghzadeh, B 2013. The defense mechanism of plants against the diseases is often correlated to the Zn nutrition through which the plants attainresistance by modifying the physiology and morphology of the plants(Kandil *et al.*, 2022).

Factors affectingthe availability of zinc:

Parent material from which the soils are derived has asignificant effect on theavailability of Zn. The soils originating from gneisses, granite, sandstone, and limestone are found to be lower in the available Zn contents (Barak and Helmke 1993). The major concern inthe availability of Zn lies in its fixed/ insoluble/ unexchangeable forms (Suganya *et al.*, 2020).

Availability of Zn is highly reliant on pH, with an increase in pH above 6, Zn availability decreases with an increase in pH. Precipitation of Zn into insoluble forms of Zn, $ZnSiO_4$or $ZnFe_2O_4$ will take place leading to reduced soluble Zn / available Zn.

Zn deficiency is more likely to be noticed in alkaline soils thaninacid soils. In soils withhigh hydroxyl (OH^-) ions, theresponse of the plants to external application of the Zn is negligible. Under alkaline situations Zn is precipitated as $Zn(OH)_2$or $ZnCO_3$(Barak and Helmke 1993, Suganya and Saravanan 2015). Soils with higher carbonate contents will relatively exhibit unavailability of the Zn due to absorption of Zn onto soil particles and turned to unexchangeable forms (Alloway 2004).

Zn deficiency is more prevalent in soils with low organic matter. In high organic matter-containing soils available Zn is accordingly high (Hafeez *et al.*,2013).

Humic acid and fulvic acids are the identified stable organic compounds comparablycontain more functional group ions like OH, COOH,and SH which show an affinity to Zn^{2+}(Suganya *et al.*, 2020). Fulvic acids generallyform chelates with Zn increasing themobility and solubility of Zn. In case of the high organic soils like peat and muck binding of zinc to humic substances takes place and makes Zn unavailable (Katyal and Randhawa 1983).

Soil texture also affectsthe Zn availability, sandy soils with lighter texture exhibit more deficiency in available Zn compared to the heavier textured clay soils. Clay soils with high CEC values certainly have more affinity to retain Zn (Hafeez *et al.*, 2013, Suganya *et al.*, 2020).

Soil moisture significantly affects the availability of nutrients to the plants as the diffusion of nutrients to roots is affected by soil moisture. Zn nutrition is considered to be at stake in arid and semi-arid regions due to the coincidence of prolonged water deficit periods during the growing season. Whereas, in water-logged situations Zn co-precipitates with iron and aluminiummaking Zn unavailable to the plants (Hafeez*et al.*,2013, Suganya *et al.*, 2020).Compared to dry soils, flooded soils are more prone to Zn deficiency because in the prior case, Zn reacts with free sulfide. In case of rice delayed application of Zn until after flooding rice decreases thefixing of zinc with sesquioxides (Suganya and Saravanan 2014, 2015).

Fluctuations in temperature towards the colder side below 16 ˚C during thegrowing period will hinder the zinc availability to the plants due to change in the rate of Zn mineralization. Besides plants suffer Zn deficiency as a result of unfavourable climatic situations (Alloway, 2008).

Available sources of Zn

The following order describes the reduction in solubility of several zinc minerals: Zn (OH)2 (amorphous) >$Zn(OH)_2$> $ZnCO_3$ (smithsonite) > ZnO (zincite) > Zn $(PO_4)_2.4H_2O$) (willemite) > soil Zn > Zn Fe_2O_4 (franklinite). Zinc forms soluble complexes with chloride, phosphate, nitrate, and sulfate ions however, the neutral sulfate ($ZnSO_4$) and phosphate ($ZnHPO_4$) species are the most significant and contribute to the overall concentration of zinc in solution. When acidifying fertilizers like ammonium sulphate [(NH_4 $(SO_4)_2$)] are employed, the $ZnSO_4$ complex accounts for the enhanced availability of zinc and may increase the solubility of Zn^{2+} in soils (Arunachalam *et al.,* 2013). Most commonly available forms of zinc sulfate are ($ZnSO_4.H_2O$)-33% Zn - Zinc sulfate monohydrate, ($ZnSO_4.7H_2O$)-21% Zn- Zinc sulfate heptahydrate and chelated form as (Zn EDTA)-9% Zn(Gite *et al.*, 2021).

Nano Zn- ZnO-Zinc oxide nanoparticles in a colloidal solution are utilized as fertilizer. A plant nutrient known as nano fertilizer is more than just a fertilizer because it not only gives plants the nutrients, they need, but also restores the soil to its organic state without the negative effects of chemical fertilizers. Nano fertilizers have the benefit of being able to be applied in extremely small quantities (Sabir *et al.,* 2014).ZnO asafertilizer source will aid in improved growth and yield resulting in anenhanced qualitative and quantitative value of the crop (Azam *et al* 2022).

Zinc deficiency symptoms in plants:

In general, the deficiency symptoms of Zn include: shortening of internodes leading to stunted growth, andmalformation of leaves which will be visible as little leaf and rosette leaf formation. Usually, the deficient symptoms tend to be visible in younger leaves because under deficient conditions Zn gets immobile in plants. Necrosis symptom is often seen in the middle-aged leaves, interveinal chlorosis is another predominant symptom visible underZn-deficient situations.

In rice**,**chlorosis of the basal leaves, loss of turgidity in leaves leading to wilting, bronzing of the leaves, anddeath of the young seedlings is seen. In younger seedlings of age 2-4 weeks after transplanting or sowing, chlorosis of the youngest leaves in the midrib at thebase is seen. The appearance of brown spots on the older leaves, which eventually enlarge and coalesce to form brown-colored leaves (Hafeez*et al.,* 2013). Other predominant symptoms include reduced tillering, stunted growth, loss of turgidity and plants fallingon the surface of the water and floating.

In many cases, the Zn deficiency can be mistaken for the deficiency of N, Mg, Mn, or Fe. So, plant analysis is often recommended to detect Zn deficiency.

Effective Zinc Management Methods in Rice Based Cropping Systems

Soil conditions and rice production systems play a crucial role in deciding the method of application of zinc to the plants to maximize benefits. The most promising methods followed in rice-based cropping systems are soil application, seed priming, zinc encapsulated fertilizers, foliar application, seed coating, seedling root dip method, bio-fertilizer-based application.

Soil application of Zn fertilizers is found to be effective in promotingthe growth, yield, and biofortification of the grains. Basal application of zinc has improved the yield by 18% compared to control (Zulfiqar *et al.*, 2020). Plants are capable of absorbing soluble compounds and gases through leaves. The application of foliar sprays makes the leaves absorb them and export themto the growing tissues. Jose (2019) reported that higher grain and straw yields of rice were recorded with foliar spray of $ZnSO_4$ at 0.1% at different growth stages. Combined soil + foliar applied Zn resulted in maximum kernel yield and kernel Zn concentration in fine rice (Ali *et al.*, 2021). Improved yield components and nutrient recovery through Zn foliar nutrition are observed by El-Sobky *et al.*(2022).

Seed coating with nutrients like zinc using plant-based substances as adhesives is also a possible method to maximize the benefits. Zulfiqar *et al.*(2020) reported 13 % increase in yield following seed coatingwith Zn in rice(.

By partially hydrating seeds, a practice known as "seed priming," germination-related metabolic processes can start to take place but radicle emergence is prevented.This is a feasible method to raise the Zn content in seeds to improve yield-attributing characteristics and yields because of the tiny amounts of Zn required for seed priming and the simplicity of the procedure (Sharma *et al.*, 2021). Seed priming hasa significant effect on yield and grain Zn contents in rice under different production systems and zinc application methods (Ali *et al.*, 2021).

The growth, Zn nutrient content, and Zn nutrient uptake of rice were all found to be improved by inoculating it with arbuscular mycorrhizal fungus (Purakayastha and Chhonkar, 2001). Replacing 25% of inorganic nutrients with bio-fertilizers has shown promising nutrient uptake and performance of zinc in rice (El-Sobky *et al.*, 2022).

CONCLUSION

The review of earlier studies highlights that India is highly atrisk of zinc malnutrition and the majority of soils are deficient in nutrientsin thefirst place and zinc nutrition is often neglected in agriculture.Correcting the zinc deficiency in rice-based cropping systems will be a significant endeavor to achieve the benefits of biofortification through fertilization because rice-based cropping systems are widely used in India and rice is the main diet for the majority of Indians. As availability of Zn to plants is dependable on various factors related to the soil pH, organic matter, moisture availability etc. and considering the factors responsible for unavailability from the available sources of Zn, effective zinc management methods like seed priming, foliar application etc. has to be adopted to deal with zinc deficiency.

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