Influence of Agronomic Zinc Fortification on Quality, Productivity and Profitability of Rice: A Review

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Abstract
Deficiency of zinc is a worldwide nutritional problem and intensity of the problem is even severe in developing countries. Rice grain contains the key to meet a person’s daily energy requirements, but they are very low in zinc concentration, especially when grown in Zn-deficient soil. There are ways to address zinc deficiency viz., nutritional diversification, food enrichment and biofortification. There are several limitations regarding nutritional diversification and food enrichment which favors biofortification of zinc as a perpetual solution of malnutrition. Among the potential biofortification methods to rectify Zn deficiency, plant breeding approaches and agronomic biofortification offers major advantage. This review appraised the role of Zn in plants, zinc uptake, translocation and partitioning efficiencies in rice that is driven by various agronomic, breeding and biotechnological approaches. There is a genuine need to integrate zinc in rice production systems using agronomic and conventional breeding methods. Agronomic biofortification is economically sustainable and practically adoptable solution to overcome the Zn deficiency problem in rice.

Keywords: Biofortification, agronomic fortification, zinc enriched rice

Introduction
Today, increasing grain Zn concentration of rice represents an important challenge to be met by using agricultural tools such as breeding and fertilization. Zinc concentrations of both polished and unpolished rice are inherently too low to meet human demands for Zn (Lee et al. 2009; Bouis and Welch 2010). The Zn concentration of rice germplasm at the International Rice Research Institute, which included advanced breeding lines, modern and traditional varieties and grown at Los Banos, Philippines averaged only 25.4 mg Zn kg⁻¹ for brown rice, compared with an average of 35.0 mg Zn kg⁻¹ for wheat germplasm of the International Maize and Wheat Improvement Center grown at El Batan in Mexico (Graham et al. 1999). In a screening study including about 1,000 genotypes, it has been found that there is a four-fold range of rice grain Zn concentration among the rice genotypes (e.g., 13.5–58.4 mg Zn kg⁻¹) (Graham et al. 1999). This impressive genotypic variation has led to a suggestion that such substantial genetic potential for Zn concentration in rice should be exploited through plant breeding (Welch and Graham 2004; Bouis and Welch 2010). Raising the Zn concentration of rice appears to be one of the most cost-effective means to overcome this malnutrition problem among low income rice eaters. In addition, sowing seeds containing high Zn concentration has a potential to benefit crop growth and yield by improving germination and seedling vigor, especially in Zn deficient soils (Cakmak 2008; Rengel and Graham 1995; Yilmaz et al. 1998). For example, in the US Zn coated rice seed (with 1.0–4.7 g Zn kg⁻¹) germinated better and more rapidly into seedlings with longer roots and better shoot growth than untreated seed (Slaton et al. 2001).

Nutrient management is an important issue in autumn rice and a precise schedule should be followed to get optimum result. Besides major nutrients, zinc is an essential micronutrient and have particular physiological functions in all living systems, such as the maintenance of structural and functional integrity of biological membranes and facilitation of protein synthesis and gene expression. Around 30% of the world’s human population is diets deficient in zinc.
Zinc deficiency in human affects physical growth, the functioning of the immune system, reproductive health and neuro-behavioral development. Therefore, the zinc content of staple foods, such as rice and wheat are of major importance. When the supply of zinc to the plant is inadequate, one or more of the many important physiological functions of zinc are unable to operate normally and plant growth is adversely affected.

Application of proper dose of zinc and at right time determines the availability of zinc in plant system, more particularly in grain. Zinc deficiency is a well-documented global health problem, affecting nearly 2 million people, near about 1.5 million children die each year from Zinc malnutrition, particular in developing countries, where high proportion of cereal crops, such as rice and wheat, consumed as a staple food. The total area under Zn deficiency is about 10 mha in India. On average, 50% of the Indian soils are deficient in zinc (Zn), rising to 63% by 2025, particularly in calcareous soils due to the formation of insoluble zinc hydroxide and its carbonate. Zn in soil and rice yield focused on basal application of ZnSO₄ along with the foliar application too. Zinc fertilizers could potentially be improved by using chelates that facilitate metal absorption by plant roots e.g. Zn-EDTA. Zn-EDTA was the most efficient source of Zn for lowland rice production. Zn-EDTA supplies a substantial amount of Zn to the plant without interacting with soil components because the central metal ion (Zn²⁺) is surrounded by chelate ligand and farmers use Zn-EDTA because of its cost effectiveness.

Zn is deficient in 50% of the world’s agricultural soils and is recognized as the world’s most critical micronutrient deficiency in crop. About 2 billion people in the world suffer from Zinc deficiency and near about 1.5 million children die each year from Zinc malnutrition. Globally, about 0.8 million people and nearly about 0.45 million children are at risk of dying each year from Zinc deficiency (WHO, 2015). India has one of the highest rates of Zn deficiencies in soils and diet of people. 50% of Indians soils are Zn deficient, rising to 63% by 2025, if no management is done. About 0.15 million children die each year in India due to Zinc deficiency. Lack of Zinc is contributing to cases of diarrhea, 25% of global diarrhea deaths amongst children under the age of five (IZA, 2014). Zn fortification in staple food could save the lives around 48,000 Indian children per year (WHO, 2015).

**Reason for rice biofortification**

Rice is a staple food crop for more than a billion people. The rice endosperm (starchy and most edible part of rice seed) is deficient in many nutrients including vitamins, proteins, micronutrients etc. The aleurone layer of dehusked rice grain is nutrient rich but is lost during milling and polishing. Unprocessed rice becomes rancid i.e. smelly or unpleasant in taste. Rice supplies 30-50% of daily calorie intake. Rice farming is the major source of employment in most of the part in India and globally. Rice plays an important role in food security for its wider adaptability.

**What is Biofortification?**

Biofortification is the development of nutrient dense staple food crops using the best conventional breeding practices and modern biotechnology, without sacrificing agronomic performance and important consumer preferred traits. Biofortification focused on making plant foods more nutritious as the plants are growing. In conventional fortification nutrients are added to the foods as they are being processed (Nestel et al., 2006).

![Fig 1: Process of biofortification of rice.](http://www.chemijournal.com)

**Types of biofortification**

There are several options for biofortification, among which genetic and agronomic biofortification are mostly used. Agronomic biofortification alternatively termed as ferti-fortification. Ferti-fortification, a term coined by Prasad (2009) involves fertilizing crops with micronutrients.

**Conventional breeding (genetic) method of bio fortification**

This can be done either through conventional selective breeding, or through genetic engineering. Biofortification differs from ordinary fortification because it focuses on making plant foods more nutritious as the plants are growing, rather than having nutrients added to the foods when they are being processed. E.g. Golden rice - A GM food crop It is a genetically modified provitamin A (β-carotene) enriched rice genome. All the credits of golden rice go to Rockefeller foundation, EU and the Swiss federal institute of technology. Professor Ingo Potrycus and Dr. Peter Beyer considered as the founder of β-carotene enriched golden rice. They used crtI gene from soil bacterium (Agrobacterium tumifascience) and Daffodil gene for modification of the genetic makeup. Golden rice cannot be achieved by breeding. There are two grades of golden rice;

- **Golden rice 1 (SGR1):** Promoter is modified here and it contains 5-7μg β-carotene per gram of rice.
- **Golden rice 2:** Replacement of daffodil Pys with maize gene and contain 31 μg β-carotene per gram of rice.
Agronomic biofortification

Agronomic biofortification of food crops, where fertilizers are used to increase micronutrient contents in edible crop parts, can be an effective component of a food system approach to reduce micronutrient malnutrition in human populations. Reasonably good responses to Zn fertilization have been obtained for a number of crops including rice and wheat (Katyal and Rattan, 2003; Prasad, 2006) [20]. Agronomic biofortification alternatively termed as ferti-fortification. Ferti-fortification, a term coined by Prasad (2009) involves fertilizing crops with micronutrients. It gives immediate results and in, general, goes well along with an increase in yield. Agronomic biofortification is usually done through soil application of efficient Zn sources at the right rate, time, and stage. The maximum level of Zn biofortification in rice ensured when Zn was applied through soil treatment (Nattinee et al. 2009) [42]. Furthermore, increased absorption of Zn into the leaves was noticed when Zn was applied with urea fertilizer, indicating that Zn-coated urea fertilizer is a very useful combination, increasing the values of both Zn and protein. In the future, there will be a need to monitor the available forms of Zn to ensure that Zn is not stored in the rhizosphere to a degree that can generate lethal effects (Velu et al. 2016) [59]. In agronomic biofortification, the seed treatment and foliar application techniques add less Zn to the total reserves, as most of the applied Zn will be retained by the foliage (Jiang et al. 2007) [25]. Most of the Zn accumulation in grains is taken up by the roots and not remobilize in the cells. This suggests that, Zn application to the soil is much more likely to be an efficient form of biofortification as compared with foliar application (Liu et al. 2016) [3].

β - carotene enriched popular rice varieties

- **IR 64, IR 36:** Mega varieties with broad Asian coverage.
- **BRRI Dhan 29:** The most popular boro rice variety in Bangladesh.
- **PSB Rc 82:** The most popular Rice variety of Philippines.
- **OS 6561:** Most popular in Vietnam.
- **Chehirang:** Leading variety in Indonesia.

Swarna (MTU 7029): Swarna is the most widely grown and consumed rice variety in India which constitutes 0.78mg Fe/100g white rice and 2.28mg Zn/100g brown rice. By consuming twice or thrice a day taking 100-150g rice/meal a person can get hardly 2-3mg Fe and 7- 8mg Zn which is 1/5th and respectively half of the recommended daily intake of Fe and Zn.

Need of biofortification in rice

Among the cereals, rice contains low nutritional value. Therefore, rice alone cannot meet the recommended daily allowance (RDA). Healthy and productive populations require adequate amounts of essential vitamins and minerals. As staple foods are eaten in large quantities everyday by malnourished poor, addition of even small quantities of micronutrients is beneficial. High zinc seeds are more vigorous and better able to withstand weed competition, and pathogen and pest attack (Gregorio et al. 2000) [10]. Deficiencies of zinc, iron and vitamin A in human population of developing countries were noticed and particularly, zinc deficiency is the fifth major cause of diseases and deaths in these countries. Health problems caused by zinc deficiency include anorexia, dwarfism, weak immune system, skin lesions, hypogonadism and diarrhea (McClain et al. 1985) [35]. Males aged 15 to 74 years need about 12 to 15 mg of zinc daily while females aged 12 to 74 years need about 68 mg of zinc daily (Sandstead, 1985) [49]. Iron dependent anemia in turn leads to maternal mortality, preterm births (Scholl et al. 1992) [50], decreases immunity (Kandoi et al. 1991) [24] and increases placental weight (Wingerd et al. 1976) [61] during pregnancy.

| Crops          | Protein (%) | Iron (ppm) | Zinc (ppm) |
|----------------|-------------|------------|------------|
| Rice           | 6-7         | 2-34       | 10-33      |
| Wheat          | 13-14       | 25-55      | 25-65      |
| Maize          | 8-11        | 10-63      | 13-58      |
| Sorghum        | 10-15       | 10-65      | 14-55      |
| Pearl millet   | 6-21        | 130-146    | 25-85      |

Singh et al. (2013) reported that rice contains low nutritional value as compare to other cereals. Malnutrition is the most common cause of zinc deficiency and 25% of the world’s population is at risk of zinc deficiency. Swarna is the most widely grown and consumed rice variety in India which constitutes 0.78mg Fe/100g white rice and 2.28mg Zn/100g brown rice. By consuming twice or thrice a day taking 100-150g rice/meal a person can get hardly 2-3mg Fe and 7-8mg Zn which is 1/5th and half of the recommended daily intake of Fe and Zn respectively. Rice endosperm, Embryo and bran contain 32%, 13% and 55% of Iron respectively and they also contain 57%, 9% and 34% of Zinc respectively. During de-hulling, polishing and cooking about 20.7%, 17.05% and 36.61% Zn loss occurs. Rice is mainly grown in flooded soil
where zinc is not much available to the crop as they bound to sulphur and carbonate in reduced condition.

Advantages of rice biofortification
Rice biofortification have certain advantages i.e. increase in nutritional value, reduced adult and child micronutrient caused mortality, reduced dietary deficiency diseases and healthier population with strong and quick immune responses to infections.

Disadvantages of rice biofortification
1. High production cost i.e. equipments, technology, patenting etc.
2. Potential negative interaction of biofortified rice on other plants/ non-GM rice crops causing loss of wild type rice varieties.
3. Low substantial equivalence i.e. inability to provide high micronutrient and protein content compared to supplements
4. Poor rural populations have limited access and resources to purchase biofortified rice.
5. Genetic engineering methods used may compromise immunity introduced in human increased risk of allergenicity

Growth and productivity of rice as influenced by zinc fortification
Varsheny et al. (2008) [58] evaluated the efficiency of different rates and frequency of Zinc application on yield, Zinc concentration and uptake of hybrid rice-wheat sequence and reported that zinc application significantly increased the grain yield of wheat and rice crop. Jat et al. (2011) [21] also studied the effect of zinc (Zn) fertilization on productivity and Zn-use efficiency of aromatic hybrid rice cv ‘Pusa Rice Hybrid 10’ (‘PRH 10’) and reported that zinc fertilization in aromatic hybrid rice increased yield attributes, grain and straw yield. Similar results were reported by Singh et al. (2008) [53]. Mustafa et al. (2011) [37-39] reported that maximum productive tillers per m² (249.80) were noted with basal application at the rate 25 kg ha⁻¹ 21% ZnSO₄ and minimum (220.28) were recorded with foliar application at 60 DAT @ 0.5% Zn solution. Zinc application methods and timing had significantly pronounced effect on paddy yield. Maximum paddy yield (5.21 t ha⁻¹) was achieved in treatment Zn (Basal application at the rate of 25 kg ha⁻¹ 21% ZnSO₄) and minimum paddy yield (4.17 t ha⁻¹) was noted in Zn₇ (foliar application at 75 DAT @ 0.5% Zn solution). Zinc application increases the crop growth rate of rice. Similar results were reported by Arif et al. (2006) [9] and Naik and Das (2007) [41]. Keram et al. (2013) reported that treatments applied with increasing levels of Zn produced more grain and straw yields as compared to treatments applied with NPK alone. Naik and Das (2010) [40] reported that the application of zinc in low land rice soil of West Bengal caused an increase in yield of grain and straw respectively over the control to the tune of 37.8% and 20.9%. In an experiment, Abbas et al., (2013) [2] studied that Zn and B application increased the paddy yield. Similar results were observed by Arif and Muhammad (2012).

**Fig 1**: Number of tillers, chlorophyll content, total biomass and paddy yield as affected by soil and foliar applications of different sources of zinc. Values are means of three replicate plots. Means with different letters are statistically different from each other at 5% level.

Rana and Kashif (2014) [27] satated that in cereals, tillering capacity is one of the main components of grain yield. Higher yield potential can be achieved by greater tillers per plant. The data regarding the number of tillers as influenced by Zn application is presented in Fig. 1.A. Zn application significantly increased number of tillers per plant ($P<0.05$). Among the Zn sources, soil applied Zn-EDTA (10.0 kg ha⁻¹) produced maximum number of tillers per plant (145 tillers), which was significantly different from all other treatments. Minimum of 60 tillers per plant were observed under treatment T1 (without fertilizer) followed by T2 (recommended N:P₂O₅:K₂O @ 110:90:60 kg ha⁻¹). In case of foliar Zn application, T9 produced significantly higher (131) number of tillers m⁻², when Zn-EDTA was applied @
1.00 kg ha⁻¹, which was statistically similar to other Zn sources applied as foliar fertilizer, except T10 (ZnO @ 0.65 kg ha⁻¹). Increased tiller production can be attributed to Zn induced enzymatic activity and auxin metabolism in plants. These results are similar to the findings of Ghani et al. (1990). Content of plant pigments like chlorophyll determines color and appearance, and is an indicator of plant health (Abbott, 1999). Zn is proposed to be involved in chlorophyll formation through regulation of nutrients homeostasis in cytoplasm (Aravind and Prasad, 2004). The analysis of the data showed that various treatments had significant effect (P<0.05) on chlorophyll content (Fig. 1B). The highest value (34.05 CCI) was obtained in T5 (Zn-EDTA was applied @ 10.00 kg ha⁻¹ in soil) followed value (32.83 CCI) of T10 (ZnO was applied @ 0.650 kg ha⁻¹ as foliar). The minimum value (29.90 CCI) was obtained in T1 (No fertilizer, no zinc). The maximum biomass ton ha⁻¹ was recorded in T5 (5.61) when Zn-EDTA was applied @ 10.00 kg ha⁻¹ in soil followed by T3 (5.28) when ZnSO₄·H₂O was applied @ 12.50 kg ha⁻¹ and T6 (5.22) when ZnO was applied @ 5.00 kg ha⁻¹ in soil as compared to T1 (2.72). Srivastava et al. (1999) also presented similar findings.

Beutler et al. (2014) conducted an experiment to study the effect of zinc sources in rice and reported that treating rice seeds by coating with ZnCl₂ provided 6.4% higher grain yield compared to that of ZnSO₄·7H₂O. Applying Zn by coating the seeds promoted 5.8% higher rice grain yield. Khaliq et al. (2014) also concluded that zinc application significantly increased the total biomass and paddy yield. Similar findings were reported by Mustafa et al. (2011, 2012). Singh et al. (2014) evaluated the effect of zinc on rice activity and observed that application of zinc recorded the highest Basmati rice grain (5.46 t ha⁻¹) and straw yields (9.89 t ha⁻¹) and the grain and straw yield increase by 23.5% and 12.9%, 5.6% and 2.9%, 8.98% and 5.1%, 17.4% and 9.8% with the application of ZnSO₄·7H₂O, ZnSO₄·H₂O, ZnP and ZnSO₄·7H₂O+ZnO (50%-50%), respectively over control (no Zn application). Grain yield of genotypes (Nipponbare and Jiaxing27), on an average, increased by 11.4%. (Wang et al., 2014).

Sudha and Stalin (2015) reported that reduced rice grain yields with low zinc concentrations when there is low supply of zinc. Flood-irrigated rice is more prone to Zn deficiency (Rehman et al., 2012) as submergence condition of rice cultivation influences electrochemical and biochemical reactions and alters pH, PCO₂ as well as the concentration of certain ions. Khattak et al. (2015) conducted an experiment to study the effect of zinc fortification in rice through different sources of zinc and reported that both soil addition and foliar spray of ZnSO₄ significantly increased grain yield, 1000 grain weight and grain protein content, and biological yield however grain protein composition was not significant. Foliar spray of 0.5% and 1.0% ZnSO₄ increased grain yield by 10 and 18.8%, respectively while its soil application at the rate of 5, 10 and 15 kg ha⁻¹ increased grain yield by 18, 32 and 41%, respectively over the control.

Ghoneim (2016) conducted a field experiment at the research farm of the Rice Research and Training Center, Sakha, Egypt, to evaluate the effects of different methods of Zn application on rice growth, yield of Sakha 104 and nutrients dynamics in soil and plant and reported that the Zn application by different methods, significantly increased 1000-grain weight; filled grains% and grains yield of Sakha 104.

Kulhare et al. (2017) conducted a field experiment in kharif during 2010 and 2011 to study the effect of foliar spray of 0.5, 1.0% Zn salts and 1.0% Zn salts +0.5% lime concentration of different sources of Zn (ZnSO₄·7H₂O, ZnCl₂, Zn₃(PO₄)₂, ZnO and Na₂Zn-EDTA) on yield, Zn content, uptake and Zn use efficiency in rice (Pusa Basmati) grown on Typic Haplusterts and reported that the rice grain yield significantly increased with the foliar application of Zn-EDTA over all the sources of Zn but the other Zn sources were found at par amongst themselves.

**Table 3: Effect of zinc application on performance of rice** [Source: Barua and Saikia, 2018]

| Treatments                  | Effective tillers/m row length | Grains/panicle | Panicle length (cm) | Grain yield (q/ha) | Straw yield (q/ha) |
|-----------------------------|--------------------------------|----------------|---------------------|--------------------|--------------------|
| Control                     | 40.8                           | 84.4           | 19.7                | 16.12              | 35.3               |
| ZnSO₄ @ 25 kg/ha as basal   | 49.2                           | 88.9           | 20.9                | 18.16              | 37.9               |
| ZnSO₄ @ 25 kg/ha as basal + seed priming with 2% ZnSO₄ | 52.7                           | 93.3           | 23.1                | 20.72              | 40.1               |
| ZnO @ 25 kg/ha as basal + foliar spray @ 0.5% at three stages | 56.1                           | 95.7           | 25.1                | 21.46              | 42.9               |
| Seed priming with 2% ZnSO₄ +foliar spray @ 0.5% at three stages | 50.7                           | 92.0           | 21.9                | 19.73              | 39.0               |
| CD (p<0.05)                 | 3.8                            | 6.2            | 1.5                 | 1.28               | 2.7                |

Barua and Saikia (2018) declared that significant variations in yield attributing characters were recorded due to different zinc fertilization. Plots receiving ZnSO₄ @ 25 kg/ha as basal + 0.5% foliar application produced significantly higher number of effective tillers/meter, more number of grains/panicle and length of panicle than that of other zinc.
fertilization treatments. This might be due to increase synthesis of carbohydrates and their transport to the site of grain formation (source to sink) causing high yield under this treatment (T4) as compared to other zinc treatments. Similar results were also observed by Peda Babu et al., (2007) [43]. The higher grain yield was obtained under treatment T4, where ZnSO4 was applied @ 2.5 kg/ha as basal + 0.5% foliar application. This might be due to the positive combined effect of yield attributing characters; like number of effective tillers per meter row length, number of grains per panicles and panicle length. The process of Zn storage in stem and Zn loading into the grains during grains filling have influence on more dry matter production. 0.5% foliar application of Zn under this treatment might have helped in transport process which ultimately resulted in about 33.13% yield over control. Significant increase in grain yield and straw contents were observed with foliar application of Zn as ZnSO4. Application of Zn in rice have shown similar results as reported by Singh et al., (1996) [51]; Maqsood et al., (1999) [34]; Kausar et al., (2001) [26] and Mehla et al., (2006) [36]. The effect of zinc fertilization on straw yield was also found significant. However, highest straw yield was recorded with treatment T4, when ZnSO4 was applied @ 25 kg/ha as basal + 0.5% foliar application, which might be due to favorable effect of zinc on the proliferation of roots and thereby increasing the uptake of plant nutrients from the soil supplying it to the aerial parts of the plant and ultimately enhancing the vegetative growth of plants, similar result was also reported by Beebout et al. (2011) [8].

Chhabra and Kumar (2018) [10] stated that direct seeded rice observed higher grain yield as compared to transplanted rice. Out of the methods of zinc application (basal and foliar spray @ 0.5%) basal application of zinc proved to be beneficial in getting higher grain yield when applied to direct seeded rice. Both basal application and foliar spray of zinc had the similar effect on transplanted rice as grain yield in both the treatments are at par. Direct seeded rice superseded in terms of grain yield production as compared to transplanted rice even in control plots also.

Table 4: Rice yield as influenced by zinc fortification [Source: Kumar et al., 2019]

| Treatments | Biomass yield (q/ha) | Grain yield (q/ha) | Straw yield (q/ha) | Harvest index (%) |
|------------|---------------------|--------------------|--------------------|-------------------|
| (T1) Control | 97.52               | 40.87              | 56.65              | 41.91             |
| (T2) Seedling treatment with 1% ZnO solution (5 min.) | 106.79 | 44.87 | 61.92 | 42.04 |
| (T3) 5 kg Zn/ha through ZnSO4 (21% Zn) as soil application. | 120.80 | 52.50 | 68.30 | 43.46 |
| (T4) 0.5 kg Zn/ha through Chelated zinc (Zn EDTA) as soil application. | 111.22 | 46.54 | 64.68 | 41.84 |
| (T5) 7.5 kg Zn/ha through ZnSO4 (21% Zn) as soil application. | 122.65 | 53.30 | 69.35 | 43.50 |
| (T6) 1 kg Zn/ha through chelated zinc (Zn EDTA) as soil application. | 119.90 | 51.90 | 68.00 | 43.29 |
| (T7) Foliar spray of ZnSO4 with lime (0.1% Zn solution). | 110.61 | 47.60 | 63.01 | 43.06 |
| (T8) Foliar spray of ZnSO4 with urea (0.1% Zn solution). | 111.29 | 48.27 | 63.02 | 43.37 |
| (T9) Foliar spray of ZnSO4 with lime (0.15% Zn solution). | 112.75 | 48.67 | 64.09 | 43.18 |
| (T10) Foliar spray of ZnSO4 with urea (0.15% Zn solution). | 113.31 | 49.17 | 64.14 | 43.41 |
| Mean | 112.66 | 48.75 | 63.37 | 43.21 |
| SD (P=0.05) | 8.04 | 2.69 | 6.93 | - |

Kumar et al. (2019) reported that among the various zinc sources and methods of zinc application T5 (7.5 kg Zn/ha through ZnSO4 (21% Zn) as soil application) gave maximum grain, straw and biological yield (Table 4). Crop productivity is the rate at which a crop accumulate biomass which depends primarily on the photosynthesis and conversion of light energy into chemical energy by green plants. The yield of rice is composed of yield components like as number of panicles, panicle length and 1000 grain weight. Though, 1000 grain weight an influence on grain yield but its effect is lower than panicle length and number of grains panicle1. All sources and methods of zinc application differ significantly from each other except T4 and T1 and T5. Positive effects of zinc application by soil and foliar sprays on grain yield of rice might be due to increase chlorophyll content of leaves of rice which might have increased photosynthesis and resulted in more dry matter accumulation and leaf area and hence lead to more capture of solar radiation that resulted in enhanced values of growth parameters and yield contributing characters and ultimately resulted in higher grain yield. These results are in line with Slaton et al. (2005) [54], Khattak et al. (2015) [29, 20] and Ghoneim (2016) [14, 15].

Zinc fortification and grain quality of rice

Table 4: Amylose content of grain of different varieties of rice as influenced by zinc fortification [Source: Ghasal et al., 2016] [13]

| Treatments | Amylose content (%) | PB-1401 | PB-1460 | PRH-10 | PB-1121 | PB-1509 | PUSA-2511 | Mean |
|------------|---------------------|---------|---------|--------|---------|---------|---------|-------|
| Control    | 25.9                | 25.8    | 22.8    | 24.8   | 22.8    | 23.3    | 22.4    | 23.1  |
| 2.5 kg Zn (ZnSO4/7H2O) | 25.9 | 25.6 | 22.6 | 24.0 | 23.0 | 22.8 | 24.0 | 23.9 |
| 2.5 kg Zn (ZnSO4/7H2O) + 0.5% Foliar spray at MT and PI | 26.0 | 25.7 | 22.59 | 24.3 | 23.8 | 22.7 | 24.4 |
| 2.5 kg Zn-EDTA | 25.8 | 25.7 | 22.7 | 24.0 | 23.0 | 22.6 | 24.1 | 24.1 |
| 1.25 kg Zn (Zn-EDTA) + 0.5% Foliar spray at MT and PI | 26.7 | 25.8 | 22.9 | 24.9 | 23.9 | 22.9 | 24.8 |
| Mean | 25.9 | 25.7 | 22.0 | 24.2 | 23.1 | 22.7 | - |

CD (P=0.05) | 3.19 | 1.19 | Varieties (V) - 3.19, Zn fertilizers (Zn) - 2.08, Zn x V- NS

Ghasal et al. (2016) [13] reported significant differences in different varieties of rice with respect to amylose content. The amylose content in different varieties were in the order of 'Pusa Basmati 1401' > 'Pusa Basmati 1460' > 'Pusa Basmati 1121' > 'Pusa Basmati 1509' > 'Pusa 2511' > 'Pusa Rice Hybrid 10. The highest amylose content was observed with application of 1.25 kg Zn ha-1 as Zn-EDTA as soil application + 0.5% foliar spray at maximum tillering and panicle initiation stages.
Ghasal et al. (2016) [13] also stated that the protein content in white rice kernel was found in order of 'Pusa Basmati 1509'>'Pusa Basmati 1460'>'Pusa Rice Hybrid 10'>'Pusa Basmati 1401'>'Pusa 2511'>'Pusa Basmati 1121. Zn fertilization significantly increased crude protein content in white rice kernel and higher values were recorded in soil + foliar application of Zn as compared to soil application alone. The highest protein content was observed with application of 1.25 kg Zn ha⁻¹ as Zn-EDTA as soil application + 0.5% foliar spray at maximum tillering and panicle initiation stages. Increase in crude protein content with Zn application is in agreement with the hypothesis that protein represents a sink for Zn in the grain. Application of Zn fertilizers in soil increased the Zn availability to the plants and Zn plays an important role in protein synthesis.

Table 5: Crude protein content in white rice kernel of different varieties of rice as influenced by zinc fortification [Source: Ghasal et al., 2016] [13]

| Treatments | Crude protein content in white rice kernel (%) | Mean |
|------------|-----------------------------------------------|------|
| Control | 9.8 | 9.9 | 9.9 | 9.9 | 10.2 | 9.9 | 9.7 |
| 5 kg Zn (ZnSO₄·7H₂O) | 9.9 | 9.8 | 10.3 | 9.8 | 10.6 | 9.6 | 10.0 |
| 2.5 kg Zn (ZnSO₄·7H₂O) + 0.5% Foliar spray at MT and PI | 9.8 | 10.4 | 9.9 | 9.7 | 10.7 | 9.8 | 10.1 |
| 2.5 kg Zn-EDTA | 9.8 | 10.0 | 9.9 | 9.9 | 10.6 | 9.9 | 10.0 |
| 1.25 kg Zn (Zn-EDTA) + 0.5% Foliar spray at MT and PI | 10.1 | 10.8 | 10.9 | 10.1 | 10.8 | 10.0 | 10.3 |
| Mean | 9.9 | 10.2 | 10.9 | 9.7 | 10.7 | 9.8 | 9.7 |

CD (p=0.05) Varieties (V) V 0.31, Zn fertilizers (Zn) V 0.33, Zn x V NS

Pooniya and Shivay (2012) stated that the application of 2.0% ZEU as ZnSO₄·2H₂O increased K concentration in rice grain significantly over remaining Zn fertilization treatments except 5 kg Zn ha⁻¹ through ZnSO₄·H₂O as soil application. In case of basmati rice straw, 2.0% ZEU as ZnSO₄·2H₂O recorded highest K concentration viz. 1.66 and 1.67%, and it remained on par with 2.0% ZEU as ZnO, 5 kg Zn ha⁻¹ through ZnSO₄·H₂O as soil application and 0.2% foliar spray of ZnSO₄·H₂O. 2.0% ZEU as ZnSO₄·2H₂O recorded significantly higher K uptake in grain, straw and total (grain+straw) of rice. The total K uptake in basmati rice was almost 23–25 times higher than that in grain.

Table 6: Effect of zinc fortification on concentration and uptake of potassium by rice [Source: Pooniya and Shivay, 2012]

| Treatment | K Content in grain (%) | K Content in straw (%) | Total K uptake (kg/ha) |
|-----------|------------------------|------------------------|------------------------|
| Absolute control | 0.27 | 1.48 | 197.6 |
| Control (only N) | 0.30 | 1.61 | 255.9 |
| 2.0% ZEU (ZnSO₄·2H₂O) | 0.33 | 1.67 | 297.9 |
| 2.0% ZEU (ZnO) | 0.32 | 1.66 | 285.5 |
| 5 kg Zn/ha (ZnSO₄·2H₂O) | 0.31 | 1.65 | 181.5 |
| 5 kg Zn/ha (ZnO) | 0.30 | 1.63 | 169.2 |
| ZnO slurry | 0.30 | 1.62 | 265.4 |
| 0.2% foliar spray (ZnSO₄·2H₂O) | 0.30 | 1.65 | 274.8 |
| CD (p=0.05) | 0.02 | 0.05 | 9.6 |
Fig 2: Nitrogen, phosphorus, potassium and zinc contents in rice paddy and straw as affected by soil and foliar applications of different sources of zinc. Values are means of three replicate plots. Means with different letters are statistically different from each other at 5% level.

Rana and Kashif (2014) reported that the N content in paddy and straw were significantly (P<0.05) increased with Zn application over both absolute and Zn-control (2014) (Fig.2A & 2B). Maximum N content in paddy (5.02%) and straw (2.22%) were recorded in T5 (Zn-EDTA applied @ 10.00 kg ha-1 in soil). The minimum N content in paddy (2.10%) and straw (0.97%) were observed under absolute control (T1). Concentration of N in paddy grains was higher as compared to straw, under all applied treatments. These results are in agreement with findings of Singh et al. (1990) and Takkar (1996). Lowest P concentrations for paddy and straw were recorded under absolute control (T1). When compared with Z-control (T2) different sources of Zn application resulted in decreased P content in paddy and straw (except Zn-EDTA application, both soil and foliar). Maximum value of P content in paddy (2.11%) and straw (1.09%) were obtained in T5 (Zn-EDTA applied @ 10.00 kg ha-1 in soil) followed by T2. Among the Zn treatments, T6 (ZnO applied @ 5.00 kg ha-1 in soil) recorded lower P contents in paddy (1.72%) and straw (0.77%). Similar results also reported Chaudhry et al. (1992) and Yaseen et al. (1999). Significantly maximum K contents in paddy (0.13%) and straw (0.42%) were observed in T5 (Zn-EDTA applied @ 10.00 kg ha-1 in soil) while minimum K content in paddy (0.05%) and straw (0.16%) were observed in T1 (Absolute control). Overall, paddy grains have significantly lower concentration of K as compare to that in straw. These results are confirmation findings of Iqbal et al. (2000), they reported that K concentration of both paddy and straw showed increasing trend with Zn fertilizer application. Zinc concentration in both paddy and straw significantly enhanced by Zn application as compared to absolute control (T1) and Zn-control (T2) (P < 0.05). Different sources of Zn were statistically similar except Zn-EDTA application. Maximum Zn contents in paddy (123.18 ppm) and straw (120.5 ppm) were observed in T5 (Zn-EDTA applied @ 10.00 kg ha-1 in soil), while minimum Zn content in paddy (111.07 ppm) and straw (108.9 ppm) were observed in T1 (Absolute control). Stunted growth of rice plants under Zn deficient conditions may reduce Zn uptake and ultimately compromised Zn concentration in paddy and straw. These results are in agreement with the finding of Devarajan and Ramanathan (1995).

Zinc fortification and economics of rice
Kumar et al. (2019) revealed that crop fertilized with zinc based nutrients application (T5) 7.5 kg Zn/ha through ZnSO4 (21% Zn) as soil application gave more ruminative in terms of gross return (117003 ha-1), net return (86605 ha-1) and B:C ratio (3.85) over rest of the treatments (Table 7). It was mainly because of more increase in grain yield and gross income in comparison to increase in cost of cultivation (Kumar et al., 2017). Higher B:C ratio might have been attributed to dual advantage i.e. saving in inputs and additional returns due to higher yields (Ghaasali et al., 2015) [11, 12]. Whereas, maximum cost of cultivation (29517 ha-1) was recorded with the application of (T6) 1 kg Zn/ha through Chelated zinc (Zn EDTA) as soil application. It may be due to high cost of fertilizer (Abbas et al., 2010) [1].
Table 7: Effect of zinc fortification on profitability of rice [Source: Kumar et al., 2019]

| Treatments | Cost of cultivation (Rs/ha) | Gross return (Rs/ha) | Net return (Rs/ha) | Benefit: cost ratio |
|------------|-----------------------------|----------------------|-------------------|--------------------|
| (T1) Control | 28898 | 90237 | 61339 | 3.12 |
| (T2) Seeding treatment with 1% ZnO solution (5 min.) | 30715 | 99028 | 68313 | 2.22 |
| (T3) 5 kg Zn/ha through ZnSO₄ (21% Zn) as soil application. | 29898 | 115245 | 85347 | 3.85 |
| (T4) 0.5 kg Zn/ha through Chelated zinc (Zn EDTA) as soil application. | 31058 | 102775 | 71717 | 3.31 |
| (T5) 7.5 kg Zn/ha through ZnSO₄ (21% Zn) as soil application. | 30398 | 117003 | 86605 | 3.85 |
| (T6) 1 kg Zn/ha through Chelated zinc (Zn EDTA) as soil application. | 33218 | 114000 | 80782 | 3.43 |
| (T7) Foliar spray of ZnSO₄ with lime (0.1% Zn solution). | 29452 | 106452 | 75200 | 3.55 |
| (T8) Foliar spray of ZnSO₄ with urea (0.1% Zn solution). | 29392 | 105987 | 76595 | 3.61 |
| (T9) Foliar spray of ZnSO₄ with lime (0.15% Zn solution). | 29517 | 106946 | 77429 | 3.62 |
| (T10) Foliar spray of ZnSO₄ with urea (0.15% Zn solution). | 29457 | 107962 | 78505 | 3.67 |

Conclusion

This review paper emphasized the role and importance of zinc fortification in rice. The excess use of inorganic fertilizers in agriculture can lead to soil deterioration, soil acidification and environmental pollution. Balanced applications of macro nutrient and zinc improve soil fertility, productivity and reduce the impact of heavy use of inorganic fertilizers on environment. So, it is an alternative way for sustainable soil fertility and productivity. On the basis of foregoing discussion, it can be concluded that zinc fortification enhances the quality and productivity of rice. Combined application of zinc with 100% RDF resulted in good growth parameters, yield attributes, significantly higher yield and grain quality of rice. Use of zinc with macronutrients provides the scientific basis for balanced fertilization not only between the fertilizer nutrients themselves but also that with the soil available nutrients. Moreover, the application of ZnSO₄ as soil application + foliar spray at different stages recorded the highest grain yield with high Zn content in grain and brown rice. Application of Zn through Zn-EDTA as soil application better growth and yield parameters as well as Zn content in grain too. Split applications (soil + foliage) of zinc proved better than the basal application in terms of growth characteristics. There is more impact of chelated Zn than other fertilizer sources in respect of growth. There are several aspects of biofortification but agronomic aspect (Fertification) is simpler one and is mostly followed.

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