Chronicle of Bioresource Management 2025, 9(3):099-106

Chronicle of Bioresource Management
An International E-magazine

September, 2025 Popular Article

Zinc Biofortified Rice Varieties-Impact in Human Health

K. Suman, I. Keerthi, V. Jaldhani, R. M. Sundaram and C. N. Neeraja*

Open Access
Corresponding Author
C. N. Neeraja
e-mail: cnneeraja@gmail.com

Citation: Suman et al., 2025. Zinc Biofortified Rice Varieties-Impact in Human Health. Chronicle of Bioresource Management 9(3), 099-106.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

Keywords:

Rice, zinc, malnutrition, biofortification

Article History

Article ID: CBM6292
Received on 13th April 2025
Received in revised form on 18th August 2025
Accepted in final form on 05th September 2025

Abstract

Rice is one of the commonly consumed staple foods across the world and more than 50% of the calorific needs are met by rice for most of the population in many Asian countries. Most of the modern high-yielding rice varieties are reported to be poor in nutrient content after polishing especially zinc (13-16 ppm). Biofortification is the process of increasing the density of vitamins and minerals in a crop through various approaches can help in tackling hidden hunger. More than two billion people across the world, mostly children and pregnant and lactating women suffer zinc deficiency. To overcome malnutrition especially zinc, iron and protein, ICAR initiated a national level research programme on Biofortification across various crops with Indian Institute of Rice Research (ICAR-IIRR) as main coordinated centres in collaboration with other national research institutes in India. ICAR-IIRR tested the nominated biofortified rice entries with high yield in the national wide research zones from 2013 through IIRR-AICRIP Biofortification programme. Since 2015, four popular zinc biofortified (>24 ppm in polished rice) rice varieties released by ICAR-IIRR. These varieties could play a significant role in combating malnutrition where rice is a major staple food.

1. Introduction

Cereal crops such as wheat, rice, and maize are foundational to global food security, serving as staple foods for billions of people. These grains, which are the edible seeds, include key parts like the germ, endosperm, and bran. They offer not only prolonged shelf-life but also substantial nutritional value, acting as rich sources of carbohydrates, proteins, dietary fibers, vitamins, and minerals. As primary components of human diets, cereals play a critical role in supplying energy and nutrients, especially in developing countries. Factually, cereals have facilitated the shift from nomadic lifestyles to settled agricultural societies and have remained essential to both the global food economy and human survival. Among cereals, rice (*Oryza sativa* L.) stands out as a primary staple food, especially in Asian countries, where it meets more than 50% of the caloric requirements of the population (Neeraja et al., 2017).

Author's Address

ICAR-Indian Institute of Rice Research, Hyderabad, Telangana (500 030), India

However, a significant nutritional concern arises from the preference for polished rice, which undergoes processing that strips away many of the essential nutrients. Although brown rice retains these nutrients, it is less commonly consumed. This loss is particularly concerning given that many of the modern, high-yielding rice varieties tend to have low nutrient density post-polishing. As a result, populations that rely heavily on rice are at increased risk of micronutrient malnutrition, or "hidden hunger". Dietary diversification, supplementation, and postharvest food fortification are some of the possible important strategies to address the malnutrition (Swamy et al, 2016; Garcia-Oliveira et al, 2018; Pradhan et al, 2020).

1.1. Multiple facets of malnutrition

Malnutrition results from the consumption of an unbalanced diet and can impact individuals at any stage of life from infancy to old age. It is a global concern, affecting people across all countries, regions, and socioeconomic backgrounds, whether rich or poor.

Malnutrition demonstrates in several forms (Figure 1), including:

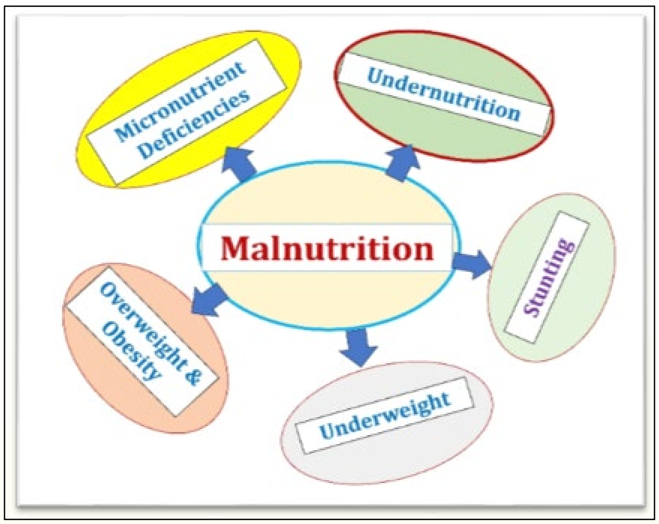

Figure 1: Micronutrient malnutrition and forms

Undernutrition: Occurs when there is insufficient food intake, leading to a lack of essential nutrients required for healthy growth and function.

Stunting: Characterized by low height for age in children under five, stunting is often the result of chronic undernutrition due to inadequate access to nutritious food, healthcare, and nurturing care.

Micronutrient Deficiencies: These occur when the body does not receive or cannot absorb enough essential vitamins or minerals, resulting in impaired physiological functions and increased health risks.

Moderate and Severe Underweight: In adults, a Body Mass Index (BMI) of less than 18.5 indicates underweight status. A BMI below 17.0 is classified as moderate to severe thinness.

Overweight and Obesity: These conditions involve excessive body weight in relation to height. In adults, a BMI of 25 or higher indicates overweight, while a BMI of 30 or above is classified as obesity.

1.2. Global scenario of malnutrition

Worldwide, approximately two billion people are suffering from micronutrient deficiencies, this condition often referred to as 'hidden hunger'. In addition, around 820 million people are undernourished, lacking sufficient caloric intake to maintain basic health. Child malnutrition is particularly alarming, with 149 million children under the age of five (21.9%) experiencing stunted growth, and 49.5 million (7.3%) suffering from wasting. Tragically, nearly 45% of deaths among children under five are related to malnutrition. The problem is widespread, affecting 88% of countries with at least two forms of malnutrition, while 29% of countries face all three major forms. South Asia bears a significant burden, with 31.7% of children under five being stunted and 14.3% wasted. Beyond its human toll, malnutrition severely impacts economies, contributing to an estimated 11% loss in GDP across Asia and Africa. Globally, the economic burden of malnutrition is projected to cost up to US$3.5 trillion annually (NFHS-5, 2019).

1.3. Malnutrition in India

India continues to face significant challenges related to poverty and malnutrition. Currently, 21.9% of the population lives in extreme poverty, while 15.2% suffers from undernourishment. Child health indicators reveal alarming trends, with 38.4% of children under five being stunted, 21.0% wasted, and 35.7% underweight. The issue of stunting is particularly widespread, with 239 out of 640 districts reporting stunting levels exceeding 40%. Micronutrient deficiencies are also a major concern, as 58.4% of children aged 6–59 months, 53% of adult women, and 22.7% of men are anaemic. Additionally, 70% of children under five are iron deficient, and 38% are zinc deficient, highlighting the urgent need for comprehensive nutritional interventions across the country. India loses over US$12 billion annually in GDP due to vitamin and mineral deficiencies (Chattopadhyay et al., 2024; Yadava et al., 2017).

2. Role and Importance of Zinc

Micronutrient deficiencies, especially in iron and zinc, are widespread in developing nations, disproportionately affecting vulnerable groups like children, and pregnant and lactating women. Iron is vital for hemoglobin formation, oxygen transport, and cellular functions such as DNA synthesis and electron transfer. Zinc supports the activity of over 300 enzymes and is essential for immune function and gene expression.

Iron and zinc are two of the most essential micronutrients for human health. Globally, over two billion people—primarily children and pregnant or lactating women—suffer from deficiencies in these nutrients. Iron plays a crucial role in the human body as a core component of hemoglobin, vital for oxygen transport, DNA synthesis, and electron transfer. Zinc, on the other hand, is indispensable for the activity of over 300 enzymes and more than 1,000 transcription factors, and it also serves as a key second messenger in immune cells. Diarrhea is also a common zinc deficiency symptom in infants and children. In human, the zinc deficiency manifest in various ways, including slowed growth, hair loss, skin rashes, slowed growth, and increased susceptibility to infections, diminished sense of taste and smell (Abbaspour et al, 2014; Suman et al, 2021; Hussain et al, 2022).

These micronutrients are equally important for plant growth and development. Genetic studies in rice have revealed considerable variation in iron and zinc concentrations. For instance, iron content in brown rice can range from 2 to 17 ppm. However, polishing can reduce iron levels by up to 85%, drastically lowering its nutritional value. Similarly, zinc content in brown rice ranges from 7.3 to 58.4 ppm and in polished rice with losses ranging from 11.1% to 28%. Zinc accumulation in rice grains is a quantitative trait influenced by multiple physiological processes including uptake from soil, internal assimilation, and remobilization to the grain. Environmental factors such as soil type and water availability also significantly affect zinc levels in rice (Rao et al, 2020; Neeraja and Suman, 2023).

2.1. Zinc deficiency

Globally, over two billion people suffer from zinc deficiency, a condition that affects plants, animals, and humans alike, as zinc is an essential element involved in numerous functional proteins. This deficiency largely stems from insufficient dietary intake, particularly among populations whose diets are heavily cereal-based. Due to poverty and cultural practices, many rural communities rely predominantly on cereals, which are typically low in zinc content. To address this issue, crop breeding efforts have increasingly focused on enhancing zinc concentrations in grains, while the application of zinc-based fertilizers is also being used to boost zinc levels in crops (Bouis et al, 2011).

3. Strategies to Combat Malnutrition

To combat malnutrition in India, several strategies have been adopted focusing on improving the nutritional quality of food and promoting better dietary habits (Figure 2) (Yadava et al, 2017).

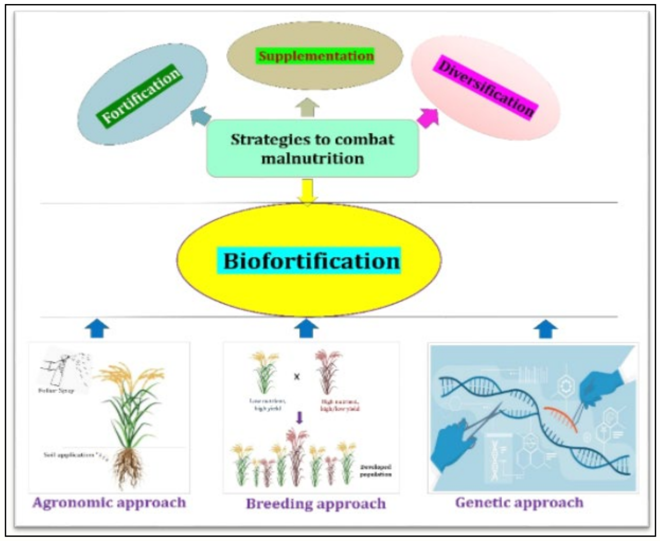

Figure 2: Strategies to combat malnutrition and Biofortification approaches

3.1. Fortification

Fortification is a key approach in rice fortification, which involves enriching rice with essential micronutrients like iron, zinc and folate to enhance its nutritional value. The Food Safety and Standards Authority of India (FSSAI) has introduced regulations under the Food Safety and Standards (Fortification of Foods) Regulations, 2016 to guide such initiatives. Fortified rice can be quickly implemented and shows rapid nutritional benefits.

3.2. Medical supplementation

It is another vital measure, involving the direct provision of nutrients through pills. Government programs such as the Weekly Iron and Folic Acid Supplementation (WIFS) for adolescents and the Vitamin-A Supplementation (VAS) for children under five aim to address common deficiencies.

3.3. Dietary diversification

Promoting dietary diversification is also crucial. Encouraging the inclusion of various cereals, pulses, oilseeds, vegetables, and fruits in daily diets improves overall nutrition. The introduction of cereals alongside rice has the potential to enhance dietary quality and reduce malnutrition.

3.4. Biofortification

Moreover, biofortification of rice, which involves breeding or genetically modifying rice to increase its nutrient content especially zinc and protein offers a sustainable solution to improve nutrition at the source. Several high-yielding, nutrient-rich rice varieties have already been developed in India through such efforts.

4. Biofortification and Significance in India

Among these, biofortification has emerged as a cost-effective and sustainable solution. Biofortification refers to the enhancement of nutrient content in crops during their growth cycle through conventional breeding, agronomic interventions, or modern biotechnological techniques.

Biofortification targets increasing beneficial elements such as iron, zinc, provitamin-A, lysine, tryptophan, anthocyanins, oleic acid, and linoleic acid, while reducing harmful compounds like erucic acid, glucosinolates, and trypsin inhibitors all without compromising crop yield. Unlike post-harvest fortification, which involves adding nutrients during food processing, biofortification ensures that essential nutrients are naturally present in the edible parts of the crops at harvest.

This approach is particularly relevant in countries especially India, where 21.9% of the population lives below the poverty line. The widespread micronutrient deficiency in soils, coupled with socioeconomic challenges and chronic undernutrition across age groups, underscores the urgency of scalable interventions. In this context, biofortification offers a promising path forward. It enhances nutritional quality at the source, ensuring that nutrient-dense food reaches even the most resource-constrained communities.

India currently accounts for approximately 17.7% of the global population, and this population is growing at an alarming rate. Despite this pressure, the country has made significant strides in agricultural production, achieving nearly 332 million tonnes of food grain output enough to feed its vast population. However, a critical concern remains: the nutritional quality of food has declined due to the dilution effect, where higher yields often come at the cost of reduced nutrient density. Therefore, enriching food with essential nutrients while ensuring a sustainable production system is crucial. According to the National Family Health Survey Report-5 (2019–21), undernutrition was responsible for around 0.5% of total deaths in India in 2016. Alarmingly, the prevalence of anaemia has shown a rising trend affecting 67% of children (up from ~58.6%), 57% of women (up from ~53.1%), and 25% of men (up from ~22.7%). Further, a report by Harvest Plus-India (2022) indicated that 70% of children under the age of five were iron-deficient, and 38% were deficient in zinc (Yadava et al, 2017).

4.1. Biofortification methods

Biofortification of essential micronutrients in crops can be achieved through three main approaches: agronomic, conventional breeding, and genetic modification (Figure 2).

4.1.1. Agronomic approach

The agronomic approach involves the application of fertilizers to enhance the micronutrient content of plants, particularly in soils that are deficient in these nutrients. This method is practical and environmentally dependent, focusing on improving nutrient uptake through soil and foliar applications.

4.1.2. Conventional breeding approach

The conventional breeding method, also known as selective breeding, uses traditional cross breeding techniques to develop crop varieties with enhanced nutritional traits. It involves identifying genetic variations for specific nutrients and crossing plants over generations to produce nutrient-rich varieties. This is the most widely adopted biofortification method in India.

4.1.3. Genetic modification approach

The genetic modification approach involves inserting specific genes into a plant's DNA to introduce or enhance a desired nutritional trait. While effective, this method involves advanced biotechnological tools and is subject to regulatory and public acceptance challenges.

Together, these three strategies provide a comprehensive framework for improving the nutritional quality of staple crops and combating micronutrient deficiencies.

5. Institutional Importance and its Contributions to Biofortification Research

The Indian Council of Agricultural Research-Indian Institute of Rice Research (ICAR-IIRR) located in Hyderabad, India, plays a crucial role in agricultural advancement, particularly in the area of rice research and food security. As a national leader in rice science, IIRR is not only focused on enhancing rice productivity but also on improving its nutritional quality through biofortification. This initiative directly addresses the pressing issue of micronutrient malnutrition, which remains a major public health challenge in India. The institute employs both traditional breeding techniques and modern biotechnological tools to incorporate nutrient enhancing genes into rice varieties. By carefully selecting and crossing diverse rice varieties, IIRR develops cultivars with improved nutritional profiles, ensuring that these nutrients are not only present in higher quantities but are also bioavailable—meaning they can be efficiently absorbed and utilized by the human body.

5.1. Biofortified rice varieties released from ICAR-IIRR

The ICAR has significantly enhanced the nutritional quality of major crops, including rice, by employing both conventional and modern breeding techniques. A major initiative in this direction began during the 12th Five-Year Plan with the launch of the Consortium Research Platform on Biofortification. This focused effort led to the development of several high-yielding, biofortified rice varieties featuring stable and promising levels of zinc (>24 ppm in polished rice) and/or elevated protein content (above 10%). These improved varieties have been identified through the All India Coordinated Rice Improvement Project (AICRIP) and officially released by the Central Variety Release Committee (CVRC) and State Variety Release Committees (SVRC) since 2015-16. Some of the high zinc rich rice varieties include DRR Dhan 45, DRR Dhan 48, DRR Dhan 49 and DRR Dhan 63 were released from ICAR-IIRR.

5.1.1. DRR Dhan 45

DRR Dhan 45 is a first biofortified rice variety developed and released by the IIRR, Hyderabad, in 2016, is a significant advancement in rice biofortification. Notable for its special nutritional quality, it contains a high grain zinc content >24.6 ppm in polished rice, addressing micronutrient deficiencies. This variety developed from a cross between IR 73707-45-3-2-3 and IR 77080-B-34-3. The variety exhibits a grain yield potential of more than 5000 kg/ha with a maturity duration of 125 days and an average plant height of 105 cm. It is a long slender grain with a 1000 grain weight of 26.4 g. This variety have 21.1% of amylose content, 54 mm of gel consistency and 55.6% of head rice recovery with moderate resistance to major rice diseases such as blast, sheath rot, and rice tungro virus. The breeder seed indent for this variety has reached 80.72 quintals till 2024, reflecting its growing demand and potential for contributing to nutritional security in rice-growing regions. This variety is suitable for irrigated ecology and specifically identified for the southern zone of India, covering the states of Karnataka, Tamil Nadu, Andhra Pradesh, and Telangana (Table 1) (https://www.icar-iirr.org/index.php/en/).

Figure 3: Field view of the DRR Dhan 45

5.1.2. DRR Dhan 48

DRR Dhan 48 is another popular biofortified rice variety developed and released by the IIRR in 2018, for its high grain zinc content >24 ppm in polished rice. It was developed through a backcross followed by pedigree selection using the parental lines RPBio226 / CSR27. The variety has a maturity duration of 138 days and a plant height of 92 cm, yielding more than 5200 kg/ha. It possesses important resistance traits, with the *Xa21*, *xa13* and *xa5* genes conferring resistance to bacterial leaf blight. Additionally, it is moderately resistant to rice tungro disease, sheath rot, neck blast, and brown spot. The grain type is medium slender with 24% of an amylose content, 28 mm of gel consistency, and 60.9% of head rice recovery (HRR). The breeder seed indent for this variety stood at 7.52 quintals till 2024, indicating its role in strengthening nutritional and disease-resilient rice cultivation in southern India. This variety suitable for irrigated ecology during the kharif (wet) season, this variety is recommended for cultivation in the states of Telangana, Andhra Pradesh, Karnataka, Tamil Nadu, and Kerala (Table 1) (https://www.icar-iirr.org/index.php/en/).

Table 1: Details of developed and released Zinc biofortified rice varieties by ICAR-IIRR, Hyderabad

	DRR Dhan 45	DRR Dhan 48	DRR Dhan 49	DRR Dhan 63
IET Number	IET 23832	IET 24555	IET 24557	IET 26383
Zinc in polished rice	> 24 ppm	24 ppm	25.2 ppm	24.2 ppm
Grain type	Long slender	Medium slender	Medium slender	Short bold
Ecology and suitable season (Kharif / Rabi)	Irrigated and both Kharif & Rabi	Irrigated and Kharif season	Irrigated and both Kharif & Rabi	Irrigated ecology for both Kharif & Rabi
Year of release	2016	2018	2018	2021
Pedigree	IR 73707-45-3-2-3 /			
IR 77080-B-34-3	RPBio226*1 / CSR27	Bio226*1 / CSR27	IET 17280 / Pusa Bas-mati 1	
Identified for Zones	Southern	Southern	Southern and Western	Southern and east-ern
Identified for state	Karnataka, Tamil Nadu, An-dhra Pradesh and Telangana	Telangana, Andhra Pradesh, Kar-nataka, Tamilnadu and Kerala.	Gujarat, Maharashtra and Ker-ala	Uttar Pradesh, Od-isha, Kerala
Grain yield for Zone/s	>5000 kg/ha	> 5200 kg/ha	> 5000 kg/ha	> 6000 kg/ha
Maturity duration	~ 125 days	~ 138 days	~ 130 days	~ 130 days
Plant height	105-110 cm	92-95 cm	100-105 cm	101-105 cm
Amylose content	21.10%	24%	24.49%	24.66%
GC	54 mm	28 mm	22 mm	22 mm
HRR	55.60%	60.90%	63.10%	68.20%
Resistance to insect-pests and diseases	Moderately resistant to neck blast, sheath rot and rice tungro virus	This variety has Xa21, xa13 and xa5 genes in-trogressed for bacterial leaf blight and is resis-tant to bacterial leaf blight, also moderately resistant to rice tun gro virus, sheath rot, neck blast and brown spot.	This variety has Xa21 and xa13 genes intro-gressed for bacterial leaf blight resistant and is moderately tolerant to Blast.	Moderately resistant to planthoppers, leaf and neck blast and bacterial leaf blight.

Figure 4: Field view of the DRR Dhan 48

5.1.3. DRR Dhan 49

This biofortified rice variety enriched with high grain zinc content >25.2 ppm in polished rice developed through a backcross followed by pedigree selection method using the cross combination of Bio226*1/CSR27 in 2018 by IIRR. It has a maturity duration of 130 days, a plant height of 100 cm, and yields around 5000 kg/ha. The variety features medium slender grains with 24.49% of an amylose content, 22 mm of gel consistency, and 63.1% of high head rice recovery (HRR). It carries the *xa21* and *xa13* genes, conferring resistance to bacterial leaf blight, and shows moderate tolerance to blast disease. With a breeder seed indent of 2.92 quintals till 2024, this variety contributes to improving nutritional intake while offering resilience against major rice diseases. It is suitable for irrigated ecosystems across both kharif and rabi (dry) seasons. This variety developed for the southern and western zones of India, specifically in the states of

Figure 5: Field view of the DRR Dhan 49

Gujarat, Maharashtra, and Kerala (Table 1) (https://www.icar-iirr.org/index.php/en/).

5.1.4. DRR Dhan 63

DRR Dhan 63 is an another popular biofortified rice variety developed and released by the IIRR in 2021, for its high grain zinc content >25.2 ppm in polished rice. It was developed through a backcross followed by pedigree selection using the parental lines IET 17280 / Pusa Basmati 1. The variety has a maturity period of 130-135 days with plant height of 101 cm and grain yield potential of 6000 kg/ha. It features short bold grains with 24.66% of an amylose content, 22 mm of gel consistency, and 68.2% of head rice recovery. DRR Dhan 63 is moderately resistant to key pests and diseases including leaf and neck blasts, bacterial leaf blight and rice plant hoppers. With the breeder seed indent of 0.1 quintal till 2024, this variety reflects emerging interest in high-yielding, nutrient-rich rice that supports both productivity and public health. It is suitable for irrigated ecology in both kharif and rabi seasons and recommended for cultivation in the southern and eastern zones of India, particularly in the states of Uttar Pradesh, Odisha, and Kerala (Table1) (https://www.icar-iirr.org/index.php/en/).

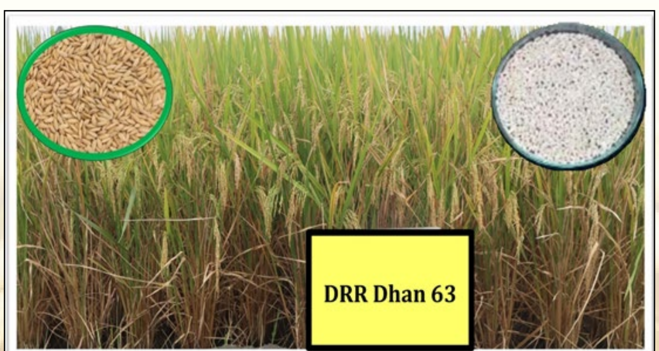

Figure 6: Field view of the DRR Dhan 63

6. Conclusion

The nutrient rich zinc biofortified rice varieties with higher yields and moderate resistance to major pests and diseases, developed and released by ICAR-IIRR, Hyderabad, offer significant benefits to farmers. These varieties not only enhance agricultural productivity but also contribute to improved public health by addressing micronutrient deficiencies or malnutrition's.

7. References

Abbaspour, N., Hurrell, R., Kelishadi, R., 2014. Review on iron and its importance for human health. Journal of research in medical sciences: the official journal of Isfahan University of Medical Sciences 19(2), 164.

Bouis, H.E., Hotz, C., McClafferty, B., Meenakshi, J.V., Pfeiffer, W.H., 2011. Biofortification: a new tool to reduce micronutrient malnutrition. Food and Nutrition Bulletin 32, S31–S40.

Chattopadhyay, K., Anilkumar, C., Sah, R.P., Bagchi, T.B., Bisen, J., Samantaray, S., Nayak, A.K., 2024. Biofortified Rice Varieties in India: Key to Nutritional Security Krishnendu.

Garcia-Oliveira, A.L., Chander, S., Ortiz, R., Menkir, A., Gedil, M., 2018. Genetic basis and breeding perspectives of grain iron and zinc enrichment in cereals. Frontiers in Plant Science 9, 937.

Hussain, A., Jiang, W., Wang, X., Shahid, S., Saba, N., Ahmad, M., Dar, A., Masood, S.U., Imran, M., Mustafa, A., 2022. Mechanistic impact of zinc deficiency in human development. Frontiers in Nutrition, 717064

Neeraja, C.N., Suman, K., 2023. Molecular mechanisms leading to grain Zn accumulation in rice. In Genetic Engineering and Genome Editing for Zinc Biofortification of Rice (1–13). Academic Press.

Neeraja, C.N., Babu, V.R., Ram, S., Hossain, F., Hariprasanna, K., Rajpurohit, B.S., Prabhakar, Longvah, T., Prasad, K.S., Sandhu, J.S., Datta, S.K., 2017. Biofortification in cereals: progress and prospects. Current Science 1050–1057.

NFHS-5: International Institute for Population Sciences (IIPS) and ICF (2021). National Family Health Survey (NFHS-5), 2019–2021: India, Vol-I, Mumbai, IIPS.

Pradhan, S.K., Pandit, E., Pawar, S., Naveenkumar, R., Barik, S.R., Mohanty, S.P., Nayak, D.K., Ghritlahre, S.K., Sanjiba Rao, D., Reddy, J.N., Patnaik, S.S.C., 2020. Linkage disequilibrium mapping for grain Fe and Zn enhancing QTLs useful for nutrient dense rice breeding. BMC Plant Biology 20, 1–24.

Rao, S.D., Neeraja, C.N., Madhu Babu, P., Nirmala, B., Suman, K., Rao, L.S., Surekha, K., Raghu, P., Longvah, T., Surendra, P., Kumar, R., 2020. Zinc biofortified rice varieties: challenges, possibilities, and progress in India. Frontiers in Nutrition 7, 26.

Suman, K., Neeraja, C.N., Madhubabu, P., Rathod, S., Bej, S., Jadhav, K.P., Kumar, J.A., Chaitanya, U., Pawar, S.C., Rani, S.H., Subbarao, L.V., 2021. Identification of promising RILs for high grain zinc through genotype× environment analysis and stable grain zinc QTL using SSRs and SNPs in rice (*Oryza sativa* L.). Frontiers in Plant Science 12, 587482.

Swamy, B.M., Rahman, M.A., Inabangan-Asilo, M.A., Amparado, A., Manito, C., Chadha-Mohanty, P., Reinke, R., Slamet-Loedin, I.H., 2016. Advances in breeding for high grain zinc in rice. Rice 9, 1–16.

Yadava, D.K., Choudhury, P.R., Hossain, F., Kumar, D., 2017. Biofortified varieties: sustainable way to alleviate malnutrition. Indian Council of Agricultural Research, New Delhi.