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Biofortification in Rice: Strategies, Achievements and Future Prospects

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INTRODUCTION

Hidden hunger, also known as micronutrient deficiency, is a major global health challenge affecting billions of people, particularly in developing countries. According to the Food and Agriculture Organization (FAO), nearly 2.8 billion people worldwide cannot afford a healthy diet, leading to widespread deficiencies of essential nutrients such as iron, zinc, and vitamin A (FAO, 2023). These deficiencies weaken the immune system, impair physical and cognitive development, and increase the risk of disease and mortality. Rice (Oryza sativa L.) is the staple food for more than half of the global population and contributes significantly to daily caloric intake, especially in Asia and Africa. Global rice production reached approximately 800 million tonnes in 2023, highlighting its importance in ensuring food security. However, milled white rice, which is widely consumed, is poor in essential micronutrients and amino acids because polishing removes the nutrient-rich bran and germ layers. As a result, populations dependent on rice-based diets are highly vulnerable to micronutrient deficiencies, including iron deficiency anemia, zinc deficiency, and vitamin A deficiency. Biofortification, which involves increasing nutrient content in crops through conventional breeding, genetic engineering, or molecular techniques, has emerged as a sustainable solution to improve the nutritional quality of rice. Bio fortified rice varieties enriched with iron, zinc, and pro vitamin A offer a promising approach to combat hidden hunger and improve global nutrition, particularly among vulnerable populations with limited dietary diversity.

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Micronutrients deficiency: Micronutrient deficiency refers to the lack of essential vitamins and minerals required in small amounts for proper growth, development, and physiological functions in the human body. These micronutrients include iron (Fe), zinc (Zn) and vitamin A etc. Micronutrient deficiency occurs mainly due to poor dietary intake, consumption of nutrient-poor staple foods, lack of dietary diversity, and poor absorption of nutrients. It is commonly known as "hidden hunger" because its symptoms are not always immediately visible but can cause serious long-term health problems. Iron deficiency causes anemia, fatigue, and weakness. Zinc deficiency leads to poor immune function and stunted growth. Vitamin A deficiency causes night blindness and increases infection risk.

Strategies for Biofortification:

Biofortification can be achieved through four main strategies:

- **Conventional Plant Breeding:** This involves developing nutrient-rich crop varieties by selecting and crossing plants that naturally contain higher levels of micronutrients.
- **Genetic Engineering (Transgenic Approach):** This method involves introducing specific genes into crops to increase nutrient content or improve nutrient absorption and storage.
- **Agronomic Biofortification:** This strategy increases micronutrient content by applying mineral fertilizers to soil or plants.
- **Genome Editing (Advanced Strategy):** This method involves precise modification of plant genes using tools like CRISPR/Cas9 to enhance nutrient accumulation.

Achievements in Rice Biofortification: Rice Biofortification has made significant progress in improving the micronutrient content of rice to combat hidden hunger. Rice Biofortification has successfully developed nutritionally enhanced varieties without compromising yield and grain quality. It is considered a sustainable, cost-effective strategy to address micronutrient malnutrition in rice-dependent populations. Major achievements include:

Variety	Nutrient	Developed by
DRR Dhan 45	High Zinc	ICAR-IIRR, Hyderabad (India)
DRR Dhan 48	High Zinc	ICAR-IIRR, Hyderabad (India)
DRR Dhan 49	High Zinc	ICAR-IIRR, Hyderabad (India)
IR69428	High Zinc	IRRI, Philippines
Zhen Shan 97	High Iron & Zinc	Chinese Academy of science, China
IR68144	High Iron	IRRI, Philippines
CR Dhan 310	High protein	ICAR-NRRI, Cuttack (India)
CR Dhan 311 (Mukul)	High protein & Zinc	ICAR-NRRI, Cuttack (India)
CR Dhan 411	High protein	ICAR-NRRI, Cuttack (India)
Golden Rice (GR2E)	High provitamin-A	IRRI, Philippines

Challenges:

- Limited natural genetic variability for iron, zinc, and pro vitamin-A concentration in rice endosperm restricts the effectiveness of conventional breeding approaches.
- Significant loss of micronutrients occurs during milling and polishing, as most minerals are concentrated in the bran and aleurone layers, while consumers prefer polished white rice.
- Low bioavailability of micronutrients due to the presence of antinutritional compounds such as phytic acid, which binds iron and zinc and reduces their absorption in the human body.
- Environmental factors such as soil fertility, water availability, climate, and agricultural practices influence micronutrient uptake and accumulation in rice grains.
- Limited availability of efficient molecular tools and suitable donor germplasm for improving micronutrient content in elite rice varieties.

- Low awareness among farmers and consumers regarding the nutritional benefits of bio fortified rice, which affects adoption and large-scale dissemination.

Future Prospects:

- Bio fortified rice has significant potential to reduce micronutrient deficiencies, particularly iron, zinc, and provitamin-A deficiencies in populations dependent on rice as a staple food.
- Further research is required to understand the physiological and molecular mechanisms involved in micronutrient uptake, transport, and accumulation in rice grains.
- Improving the transfer and accumulation of micronutrients in the endosperm is essential to ensure higher nutrient levels in polished rice.
- Uniform distribution of micronutrients within the grain can help reduce nutrient loss during milling and post-harvest processing.
- Advanced biotechnological approaches such as molecular breeding, transgenic technology, and genome editing can accelerate the development of nutrient-rich rice varieties.
- Supportive policies, awareness programs, and effective dissemination strategies are necessary to promote large scale adoption of bio fortified rice.
- Maintaining desirable grain quality, cooking characteristics and sensory attributes is important for consumer acceptance.

CONCLUSION

Biofortification in rice represents a sustainable and cost-effective strategy to address micronutrient malnutrition, particularly iron, zinc, and vitamin A deficiencies, in populations dependent on rice as a staple food. Conventional breeding, agronomic approaches, and modern biotechnological tools such as transgenic methods and genome editing have significantly improved the micronutrient content of rice without compromising yield and grain quality. The successful development and release of zinc-enriched rice varieties and pro vitamin A–rich Golden Rice demonstrate the practical feasibility of this approach. Future research should focus on improving nutrient accumulation in the rice endosperm, enhancing bioavailability, and integrating advanced genomic tools such as CRISPR/Cas9 for precise genetic improvement. In addition, supportive government policies, farmer awareness programs, and effective seed distribution systems are essential for large-scale adoption.

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