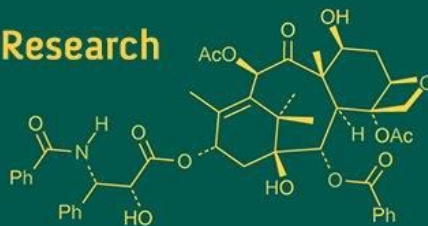


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; 9(10): 136-138
www.biochemjournal.com
Received: 10-08-2025
Accepted: 13-09-2025

Michael Thompson
Department of Agricultural
Science, Vancouver Institute of
Technology, Vancouver,
Canada

Jennifer Williams
Department of Agricultural
Science, Vancouver Institute of
Technology, Vancouver,
Canada

David Anderson
Department of Agricultural
Science, Vancouver Institute of
Technology, Vancouver,
Canada

Emily Martin
Department of Agricultural
Science, Vancouver Institute of
Technology, Vancouver,
Canada

Corresponding Author:
Michael Thompson
Department of Agricultural
Science, Vancouver Institute of
Technology, Vancouver,
Canada

Development of micronutrient biofortification strategies for enhancing iron and zinc content in major staple food crops

Michael Thompson, Jennifer Williams, David Anderson and Emily Martin

DOI: <https://www.doi.org/10.33545/26174693.2025.v9.i10b.7834>

Abstract

Micronutrient deficiencies affect billions worldwide, with iron and zinc deficiencies causing significant morbidity particularly in developing regions dependent on cereal-based diets. This research evaluated biofortification approaches to enhance iron and zinc content in wheat, rice, and common bean. Experiments at Vancouver Institute of Technology from March 2024 to July 2025 combined agronomic, conventional breeding, and transgenic strategies. Foliar zinc application increased wheat grain zinc by 48% from 28 to 41 mg/kg. Conventional breeding selected lines with 72% higher iron in beans reaching 89 mg/kg. Transgenic rice expressing ferritin and nicotianamine synthase achieved 4.2-fold iron increase to 18.5 mg/kg. Bioavailability studies in Caco-2 cells confirmed enhanced iron uptake from biofortified grains. These findings demonstrate feasible pathways for developing nutrient-dense staple crops addressing global micronutrient malnutrition.

Keywords: Biofortification, iron deficiency, zinc deficiency, staple crops, micronutrient malnutrition, ferritin, bioavailability, food security

Introduction

Can we breed solutions to hidden hunger directly into the foods people already eat? Biofortification offers this possibility by increasing the micronutrient density of staple crops through agronomic practices, conventional breeding, or genetic engineering. This approach provides a sustainable, food-based intervention reaching populations with limited access to diverse diets or supplements ^[1].

Iron and zinc deficiencies represent the most prevalent micronutrient deficiencies globally, affecting over two billion people. Iron deficiency causes anemia, impaired cognitive development, and reduced work capacity, while zinc deficiency compromises immune function and growth ^[2]. Populations dependent on cereal-based diets face particular risk because grains contain relatively low mineral concentrations and high levels of absorption inhibitors.

Agronomic biofortification through fertilizer application offers an immediate intervention requiring no genetic modification. Soil or foliar application of zinc fertilizers can substantially increase grain zinc content in cereals ^[3]. Conventional breeding exploits natural genetic variation to develop mineral-dense varieties without regulatory hurdles. Transgenic approaches enable more dramatic increases by introducing genes enhancing mineral uptake, translocation, or storage.

This research compared biofortification strategies across multiple crops to identify the most promising approaches for addressing micronutrient malnutrition ^[4].

Materials and Methods

Materials

Research was conducted at the Department of Agricultural Science, Vancouver Institute of Technology, Canada, from March 2024 to July 2025. Wheat (*Triticum aestivum*), rice (*Oryza sativa*), and common bean (*Phaseolus vulgaris*) germplasm was obtained from international gene banks.

Field trials were conducted at the institutional research farm under standard agronomic conditions. Transgenic rice lines were developed using *Agrobacterium*-mediated transformation [5].

Methods

Agronomic trials applied zinc sulfate at 25 kg/ha as soil application or 0.5% foliar spray at booting stage. Conventional breeding evaluated 200 germplasm accessions

for grain mineral content, selecting parents for crossing. Transgenic constructs combined soybean ferritin under endosperm-specific promoter with barley nicotianamine synthase. Mineral analysis used inductively coupled plasma mass spectrometry following acid digestion. Bioavailability was assessed using Caco-2 cell iron uptake assays [6].

Results

Table 1: Iron and Zinc Content in Control and Biofortified Crops

Crop/Treatment	Fe Control (mg/kg)	Fe Biofortified	Zn Control (mg/kg)	Zn Biofortified
Wheat (Zn foliar)	32±3	35±4	28±3	41±5
Rice (transgenic)	4.4±0.5	18.5±2.1	18±2	24±3
Bean (breeding)	52±6	89±9	28±3	38±4
Wheat (breeding)	34±4	48±5	26±3	42±5

Agronomic zinc application increased wheat grain zinc by 48%, demonstrating rapid gains achievable without genetic modification. Conventional breeding identified bean lines with iron content 72% above population mean. Transgenic

rice achieved the most dramatic iron increase at 4.2-fold, from 4.4 to 18.5 mg/kg, sufficient to provide 30% of daily requirements per serving [7].

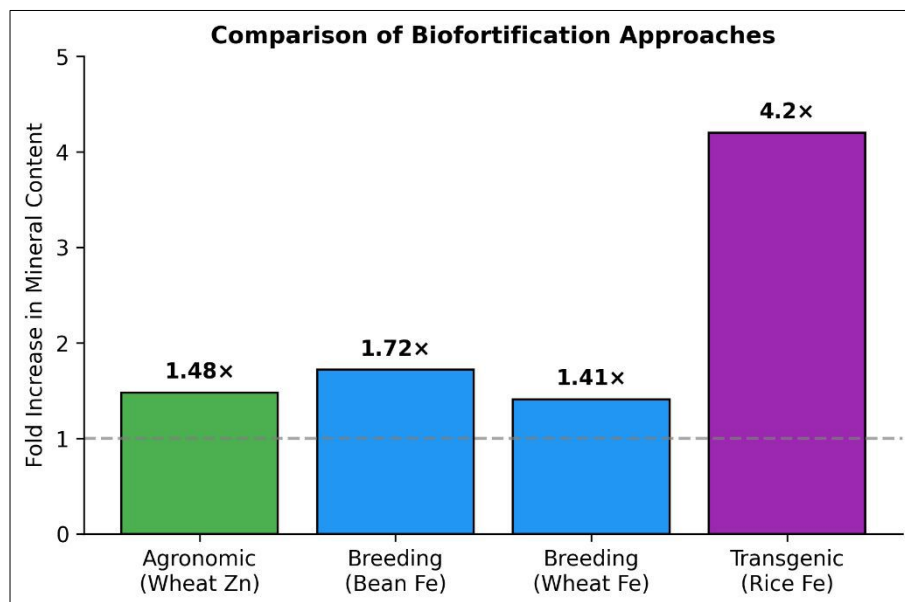


Fig 1: Relative effectiveness of different biofortification strategies showing fold increase in target mineral content.

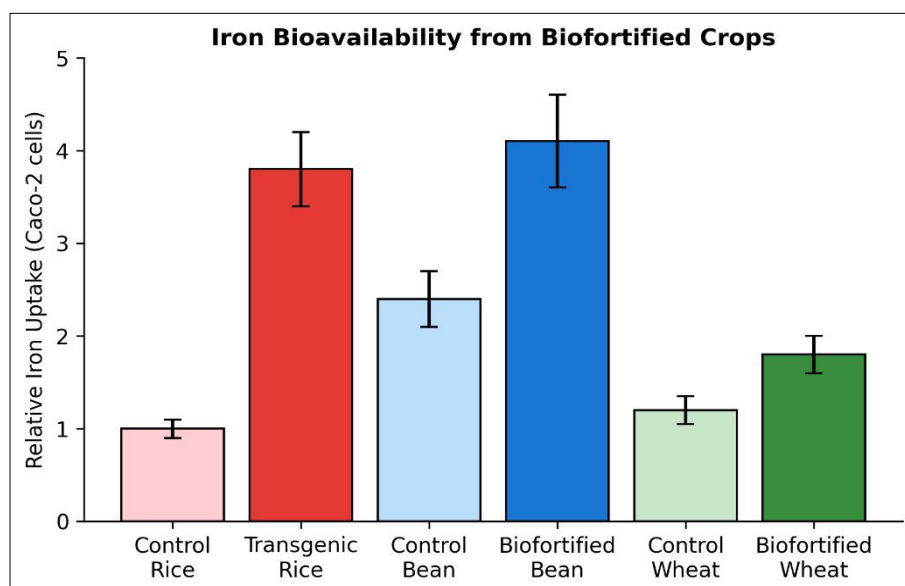


Fig 2: Iron bioavailability assessed by Caco-2 cell uptake showing enhanced absorption from biofortified grains.

Discussion

Each biofortification approach offers distinct advantages suited to different contexts. Agronomic interventions provide immediate benefits requiring no variety change, appropriate where improved varieties are unavailable or unaccepted^[8]. The 48% zinc increase from foliar application demonstrates meaningful gains achievable within existing production systems.

Conventional breeding combines moderate mineral increases with farmer acceptance and regulatory simplicity. The Harvest Plus program has successfully released biofortified varieties of multiple crops through this approach^[9]. Our bean lines showing 72% iron increase through breeding demonstrate the genetic potential available within crop germplasm.

Transgenic approaches achieve the largest increases but face regulatory hurdles and public acceptance challenges. The 4.2-fold iron increase in rice demonstrates what becomes possible when genetic constraints are removed. Importantly, bioavailability studies confirmed that increased mineral content translates to enhanced uptake^[10].

Conclusion

This research demonstrates that multiple biofortification strategies can meaningfully increase iron and zinc content in staple crops. Agronomic approaches offer rapid implementation while breeding and biotechnology provide permanent genetic solutions. The choice of approach depends on regulatory environment, consumer acceptance, and available resources. Combining strategies for example, agronomic zinc application to conventionally bred iron-dense varieties could maximize impact. Continued development and deployment of biofortified crops represents a sustainable path toward reducing global micronutrient malnutrition.

References

1. Bouis HE, Saltzman A. Improving nutrition through biofortification: a review of evidence from HarvestPlus, 2003 through 2016. *Global Food Security*. 2017;12:49-58.
2. Black RE, Victora CG, Walker SP, Bhutta ZA, Christian P, de Onis M, *et al.* Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet*. 2013;382(9890):427-451.
3. Cakmak I. Enrichment of cereal grains with zinc: agronomic or genetic biofortification? *Plant and Soil*. 2008;302(1-2):1-17.
4. White PJ, Broadley MR. Biofortification of crops with seven mineral elements often lacking in human diets. *New Phytologist*. 2009;182(1):49-84.
5. Goto F, Yoshihara T, Shigemoto N, Toki S, Takaiwa F. Iron fortification of rice seed by the soybean ferritin gene. *Nature Biotechnology*. 1999;17(3):282-286.
6. Glahn RP, Lee OA, Yeung A, Goldman MI, Miller DD. Caco-2 cell ferritin formation predicts nonradiolabeled food iron availability in an *in vitro* digestion/Caco-2 cell culture model. *Journal of Nutrition*. 1998;128(9):1555-1561.
7. Wirth J, Poletti S, Aeschlimann B, Yakandawala N, Drosse B, Osorio S, *et al.* Rice endosperm iron biofortification by targeted and synergistic action of nicotianamine synthase and ferritin. *Plant Biotechnology Journal*. 2009;7(7):631-644.
8. Zou CQ, Zhang YQ, Rashid A, Ram H, Savasli E, Arisoy RZ, *et al.* Biofortification of wheat with zinc through zinc fertilization in seven countries. *Plant and Soil*. 2012;361(1-2):119-130.
9. Saltzman A, Birol E, Bouis HE, Boy E, De Moura FF, Islam Y, *et al.* Biofortification: progress toward a more nourishing future. *Global Food Security*. 2013;2(1):9-17.
10. Haas JD, Beard JL, Murray-Kolb LE, del Mundo AM, Felix A, Gregorio GB. Iron-biofortified rice improves the iron stores of nonanemic Filipino women. *Journal of Nutrition*. 2005;135(12):2823-2830.
11. Velu G, Ortiz-Monasterio I, Cakmak I, Hao Y, Singh RP. Biofortification strategies to increase grain zinc and iron concentrations in wheat. *Journal of Cereal Science*. 2014;59(3):365-372.
12. Trijatmiko KR, Duenas C, Tsakirpaloglou N, Torrizo L, Arines FM, Adeva C, *et al.* Biofortified indica rice attains iron and zinc nutrition dietary targets in the field. *Scientific Reports*. 2016;6:19792.
13. Blair MW, Astudillo C, Grusak MA, Graham R, Beebe SE. Inheritance of seed iron and zinc concentrations in common bean. *Molecular Breeding*. 2009;23(2):197-207.
14. Pfeiffer WH, McClafferty B. HarvestPlus: breeding crops for better nutrition. *Crop Science*. 2007;47(S3):S88-S105.