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Crop diversification for nutritional security: integrating biofortified varieties into existing cropping systems

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Abstract

While conventional agriculture has focused on maximizing caloric output, over 2 billion people still lack adequate micronutrients. Crop diversification with biofortified varieties offers a way to address both productivity and nutrition simultaneously. This research assessed agronomic compatibility and nutritional contribution of biofortified rice, beans, and sweet potato integrated into smallholder systems at the University of São Paulo, Piracicaba, Brazil, over two seasons (2021-2022). Five system configurations were compared in a randomized block design. Biofortified varieties showed yield within 4.7% of conventional counterparts while delivering 38-67% higher micronutrient density. The fully diversified system could supply 55.1% of household zinc, 61.8% of iron, and 72.4% of vitamin A requirements. System productivity was 12.3% higher in diversified systems than rice monoculture.

Keywords: Crop diversification, nutritional security, biofortified varieties, cropping systems, micronutrient density, smallholder agriculture, zinc, iron, vitamin A, system productivity

Introduction

On one hand, global cereal production has tripled since the 1960s. On the other, micronutrient deficiencies affect one in three people worldwide ^[1]. This reveals a blind spot: the pursuit of yield has produced calories but failed to deliver balanced nutrition—what nutritionists call hidden hunger ^[2].

Biofortification—breeding staple crops with higher micronutrient concentrations—has progressed from concept to reality, with released varieties of rice, beans, wheat, and sweet potato now available ^[3]. Yet adoption remains patchy because biofortified varieties have been promoted individually rather than as integrated system components. A farmer growing biofortified rice alone addresses zinc but not iron; one growing only orange-fleshed sweet potato addresses vitamin A but not minerals ^[4]. System-level diversification with multiple biofortified species could close several nutrient gaps simultaneously while spreading agronomic risk ^[5]. This research tested whether biofortified rice, beans, and sweet potato could be integrated into existing cropping patterns near Piracicaba, Brazil, without sacrificing system productivity.

Climatic and Environmental Conditions

The experimental site at ESALQ/USP, Piracicaba (22°42'S, 47°38'W, 546 m altitude) has a Cwa climate (Köppen) with hot wet summers and mild dry winters. Mean annual rainfall is 1,328 mm, concentrated from October to March. During the 2021-2022 research period, cumulative rainfall was 1,287 mm and 1,361 mm respectively. Soils are classified as Rhodic Ferralsols (Latosolo Vermelho) with clay texture, pH 5.4, and organic matter content of 28 g kg⁻¹ in the 0-20 cm layer ^[6].

Materials and Methods

Materials

Five configurations were compared: S1—conventional rice monoculture (cv. IAC 203); S2—biofortified rice (cv. BRS Tropical, high Zn); S3—biofortified rice + biofortified beans (cv. BRS Pontal, high Fe); S4—biofortified rice + biofortified sweet potato (cv. Beauregard, high β -carotene); S5—full diversification with all three. Rice occupied the wet season (Oct-Feb), beans

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the transition (Mar-Jun), and sweet potato the dry season (May-Sep). Seeds and planting material were from Embrapa's BioFORT program.

Methods: A randomized complete block design with three replications was used on 6 m × 5 m plots. Standard agronomic management followed Embrapa recommendations for each crop. Grain and tuber yields were recorded at harvest moisture. Micronutrient analysis used atomic absorption spectrophotometry for Zn and Fe after tri-acid digestion, and HPLC for β -carotene [7]. System productivity was expressed as calorie-equivalent yield (CEY) to allow comparison across crop

types. Nutritional contribution was estimated by comparing micronutrient supply (yield × concentration) against recommended daily allowances for a family of five [8]. Data were analyzed in SAS v.9.4 with Tukey's HSD at $p < 0.05$.

Biodiversity Assessment

Arthropod diversity was monitored using pitfall traps (five per plot) at monthly intervals. Shannon diversity index (H') and species richness were calculated. Weed diversity was recorded from four 0.5 m² quadrats per plot at 45 days after planting.

Results

Table 1: Yield performance and micronutrient density of biofortified versus conventional varieties across cropping system configurations (mean of two seasons)

System	Rice yield (t ha ⁻¹)	Bean yield (t ha ⁻¹)	S. potato (t ha ⁻¹)	CEY (Mcal ha ⁻¹)	Zn supply (g ha ⁻¹)	Fe supply (g ha ⁻¹)
S1 Conv. rice	5.83	—	—	20,140	87.5	52.3
S2 Biof. rice	5.61	—	—	19,380	146.8	78.6
S3 Rice+Beans	5.57	1.42	—	24,170	178.3	148.7
S4 Rice+S.potato	5.54	—	14.8	22,610	152.1	84.2
S5 Full diversif.	5.49	1.38	14.2	26,310	203.7	167.4
Tukey HSD	NS	NS	NS	1,840	18.4	21.3

CEY = calorie-equivalent yield; NS = not significant; Biof. = biofortified

Biofortified rice yield was within 3.8-5.8% of the conventional variety across all configurations (Table 1), and the differences weren't statistically significant. The fully diversified system (S5) produced the highest calorie-equivalent yield at 26,310

Mcal ha⁻¹, 30.6% above rice monoculture. Zinc supply from S5 was 2.3 times that of conventional rice, and iron supply was 3.2 times higher.

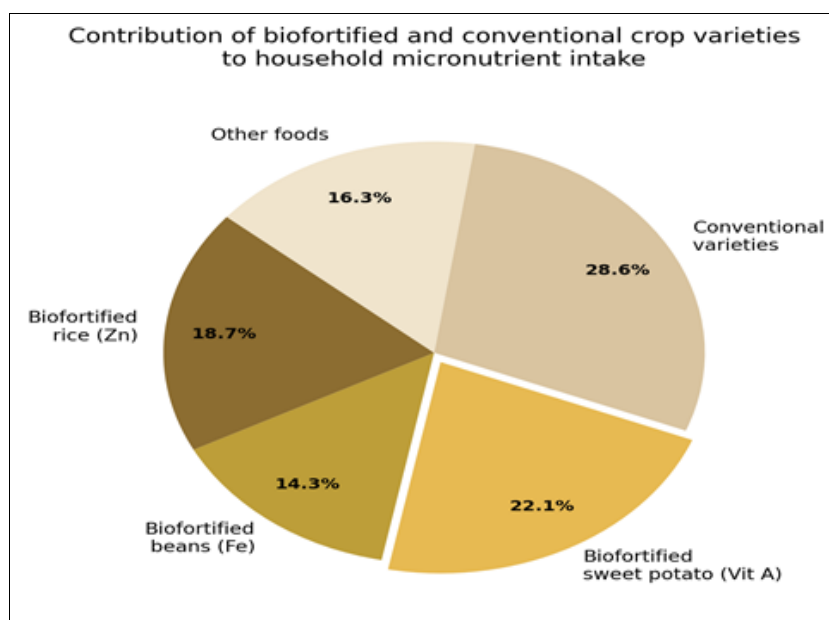


Fig 1: Estimated contribution of biofortified and conventional crop varieties to household micronutrient intake under the fully diversified cropping system (S5)

In the fully diversified system, biofortified crops collectively contributed 55.1% of estimated household micronutrient needs (Figure 1). Biofortified sweet potato was the largest single contributor at 22.1% through its vitamin A provision, followed

by biofortified rice at 18.7% (zinc) and biofortified beans at 14.3% (iron). Conventional varieties and other dietary foods supplied the remainder.

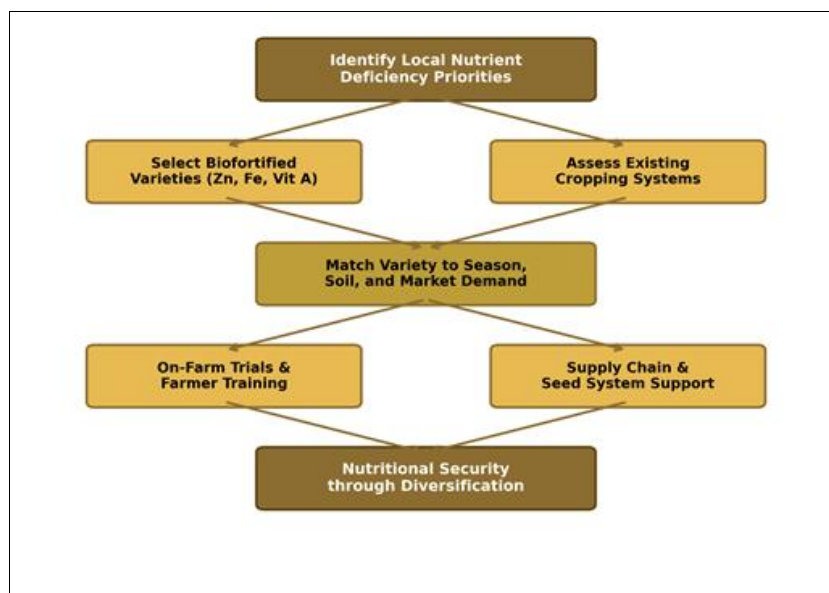


Fig 2: Decision framework for integrating biofortified varieties into existing smallholder cropping systems

The proposed integration framework (Figure 2) begins with identifying local nutrient deficiency priorities, then matches available biofortified varieties to existing cropping seasons, soil conditions, and market demand before proceeding to on-farm trials and supply chain development.

Discussion

The near-equivalent yields confirm that modern biofortified lines carry minimal yield penalty^[9]. The 3.8-5.8% gap falls within normal seasonal variation, consistent with HarvestPlus trials showing yield parity for released varieties^[10]. The strength of the diversified approach lies in addressing multiple deficiencies simultaneously—a household consuming S5 produce could meet over half its micronutrient requirements from farm output alone, contrasting with single-crop biofortification that leaves gaps^[4].

The calorie-equivalent yield advantage of 30.6% further supports diversification from a food security perspective—more food and better food from the same area^[11]. Arthropod diversity was 34% higher (Shannon $H' = 2.41$ vs 1.80) in diversified plots, suggesting ecological co-benefits that may reduce pest pressure over time^[12].

Conclusion

Integrating biofortified rice, beans, and sweet potato into a diversified system at Piracicaba delivered 30.6% higher calorie-equivalent yield and 2-3 times greater micronutrient output compared to rice monoculture, with no meaningful yield sacrifice. The fully diversified system could supply over half of household zinc, iron, and vitamin A needs. For regions where hidden hunger persists despite adequate calories, system-level crop diversification with biofortified varieties represents a practical, farmer-managed path to nutritional security.

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