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Biofortification: A long-term solution to improve global health: A review

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Introduction

Biofortified crops are staple foods (like rice, wheat, maize, sweet potato) bred to have higher levels of essential vitamins and minerals (iron, zinc, Vitamin A) using traditional breeding or biotechnology, providing a sustainable way to combat "hidden hunger" (micronutrient deficiencies) without changing diets or requiring extra processing, offering a long-term, cost-effective health solution for vulnerable populations. Nutritious diet is vital for proper growth and development in humans. It helps in preventing diseases, besides maintaining the body metabolism for physical- and mental- well-being. Food provides energy, protein, essential fats, vitamins, antioxidants and minerals to meet our daily metabolic requirement. Most of them cannot be synthesized in human body, therefore are to be supplemented through diet. Further, anti-nutritional factors present in edible parts of the food exert adverse effects on human health. Indian Council of Agricultural Research (ICAR) has improved the nutritional quality in high yielding varieties of cereals, pulses, oilseeds, vegetables and fruits using breeding methods. Special efforts were initiated during 12th Plan with the launching of a special project on Consortium Research Platform on Biofortification. Concerted efforts in collaboration with other national and international initiatives has led to the development of 87 varieties of rice (8), wheat (28), maize (14), pearl millet (9), finger millet (3), small millet (1), lentil (2), groundnut (2), linseed (1), mustard (6), soybean (5), cauliflower (1), potato (2), sweet potato (2), greater yam (2) and pomegranate (1). In addition, a large number of advance elite materials are in pipelines and will be released in due course of time. These biofortified varieties assume great significance to achieve nutritional security of the country. Special efforts are being made to popularize these biofortified varieties among masses. Quality seeds of biofortified varieties are being produced and made available for commercial cultivation. Extension Division of ICAR has also launched two special programmes viz. Nutri-sensitive Agricultural Resources and Innovations (NARI) and Value Addition and Technology Incubation Centres in Agriculture (VATICA) for up-scaling the biofortified varieties through its Krishi Vigyan Kendra's (KVK's).

Types of Malnutrition

Malnutrition is caused by consumption of unbalanced diet. It affects most of the world's population at some point in their lifecycle during infancy to old age. Every country experience one or the other form of malnutrition. It affects all geographies, age groups and people from rich to poor. Malnutrition exists in different forms:

* Undernutrition: Lack of proper nutrition caused by not having enough food.
* Stunting: Low height as per age in children under five years of age due to limited access to food, health and care.
* Wasting: Thin for their height in children under five years of age because of acute food shortages or disease.
* Micronutrient deficiencies: Suboptimal nutritional status

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caused by lack of intake, absorption or use of one or more vitamins or minerals.

* Moderate and severe thinness or underweight.

Global Hunger Index

The Global Hunger Index (GHI) is a tool for comprehensively measuring and tracking hunger at global, regional, and national levels over recent years and decades. GHI score is based on a formula that involves three dimensions of hunger, viz., (i) insufficient caloric intake (undernourishment) in the population, (ii) undernutrition among children, and (iii) child mortality using four indicators:

Undernourishment: Share of the population that is undernourished, reflecting insufficient caloric intake.

Child wasting: Share of children ((<5 years) who possess low weight for height, reflecting acute undernutrition.

Child stunting: Share of children (<5 years) who possess low height for age, reflecting chronic undernutrition.

Status of Malnutrition

Malnutrition contributes to increased morbidity, disability, stunted mental and physical growth, and reduced national socio-economic development. The extent of malnutrition worldwide as well as in India is presented below:

Global scenario

* 2.37 billion do not have access to adequate food.
* 768 million people are undernourished.
* 118 million more people faced hunger in 2020 in comparison to 2019.
* 20.5 million new-borns (14.6 % of all live births) have a low weight at birth.
* 149.2 million (22.0 %) children (12 million avoidable deaths among adults.
* In Southern Asia, 30.7 % and 14.1 % of the children (<5 years) are stunted and wasted, respectively.

Indian scenario

* 15.3 % of the population are undernourished.
  Neonatal mortality rate (NNMR): 24.9 per 1,000 births.
* Infant mortality rate (IMR): 35.2 per 1,000 births.
* Child (< 5 years) mortality rate (U5MR): 41.9 per 1,000 live births.
* 35.5 % of the children (<5 years) are stunted, 19.3 % wasted and 7.7 % severely wasted.
* 32.1 % of the children (<5 years) are under-weight.
* 3.4 % of the children (<5 years) are over-weight.
* 18.7 % women and 16.2 % men possess BMI below normal (<18.5).
* 24.0 % of women and 22.9 % of men are overweight or obese (BMI e"25.0).
* 67.1 % of the children (6-59 months) are anaemic.
* 57.2 % of non-pregnant, 52.2 % pregnant and 57.0 % of all women (15-49 years) are anaemic.
* 59.1 % of all women (15-19 years) are anaemic.
* 25.0 % of men (15-49 years) are affected due to anaemia.
* 31.1 % of men (15-19 years) are anaemic.
* 13.5 % of women and 15.6 % of men possess high or very high blood Sugar.
* 21.3 % women and 24.0 % men possess elevated blood pressure.
* India's GHI score is 27.5 (serious category).
* India ranks 101 among 116 countries in relation to GHI.
* India loses over US$12 billion in GDP per year to vitamin and mineral deficiency.

Biofortification

Four avenues are generally practiced to alleviate malnutrition

Food fortification

It is a process of physically adding vital nutrients to the food in order to enrich it. For example, (i) iron, folic acid and vitamin B12 fortified wheat and rice flour, (ii) iron and iodine fortified salts, (iii) vitamin-A and vitamin-D fortified oil and milk, have been permitted by Food Safety and Standards Authority of India (FSSAI), Govt. of India.

Medical supplementation

It is a process of providing vital nutrients through pills. For example, Govt. sponsored programmes, (i) Weekly Iron Folic Acid Supplementation (WIFS) programme for school adolescent boys and girls (10- 19 years) and out of school girls (10–19 years) in urban and rural areas, and (ii) Vitamin-A Supplementation (VAS) programme for children under five, are in place India.

Dietary diversification

It is a process of including diverse cereals, pulses, oilseeds, vegetables and fruits in the diet in order to enhance the nutritional status.

Crop biofortification

It is a process of enhancing the nutritional quality of edible parts of the plants through genetic approach such as plant breeding. For example, iron and zinc rich wheat grains (ii) protein and zinc rich rice grains, and (iii) vitamin-A rich maize grains.

Merits of biofortification

* It is regarded as the most sustainable approach to alleviate malnutrition.
* It provides nutrients in natural form; thus, nutrients enter the body as part of natural food matrix.
* People can afford the 'biofortified food' as it does not involve any additional price.
* 'Biofortified varieties' are as high yielding as 'traditional varieties', thus no loss is incurred to the farmers.
* It does not require elaborate infrastructure facility as required in 'food fortification'.
* It does not need elaborate distribution system as required in 'medical supplementation'.
* It does not involve additional cost on preparing the enriched food grains.

How they work

Increased nutrient density: The plants naturally accumulate more micronutrients during growth.

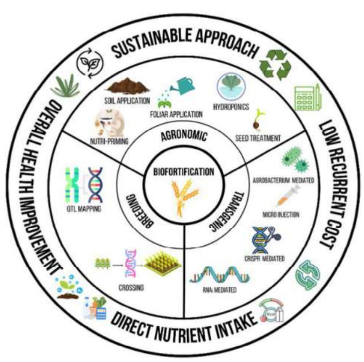
Simple mechanism: Eating more of these nutrient-dense crops means consuming and

absorbing more essential vitamins and minerals.

Key benefits

Sustainable: A one-time investment in breeding provides continuous nutritional benefits.

Cost-effective: No extra cost for farmers or consumers during cultivation or consumption.



Addresses "hidden hunger": Fights widespread micronutrient deficiencies impacting growth, immunity, and sight.

Common examples:

Vitamin A: Golden Rice, sweet potato, cassava, maize.

Iron: Beans, pearl millet, wheat, rice.

Zinc: Maize, rice, wheat, pearl millet.

Breeding methods of development:

* Conventional breeding: Selecting and crossing plants with desired traits.
* Genetic engineering/biotechnology: Modifying genes (e.g., CRISPR) for enhanced nutrition.
* Agronomic practices: Applying specialized fertilizers (e.g., zinc-enriched).

Why they matter

* Unlike food fortification (adding nutrients during processing), biofortification enriches the food at the source.
* They reach rural populations who may not access fortified foods, improving public health in resource-limited settings.

Releases of Biofortified Crops

Cumulatively, more than 400 biofortified varieties of 12 crops have been released in more than 40 countries, which includes all varieties facilitated by Harvest Plus plus orange sweet potato varieties developed independently by CIP. Candidate biofortified varieties across 12 crops are being evaluated for release in an additional 20 countries.

Conclusion

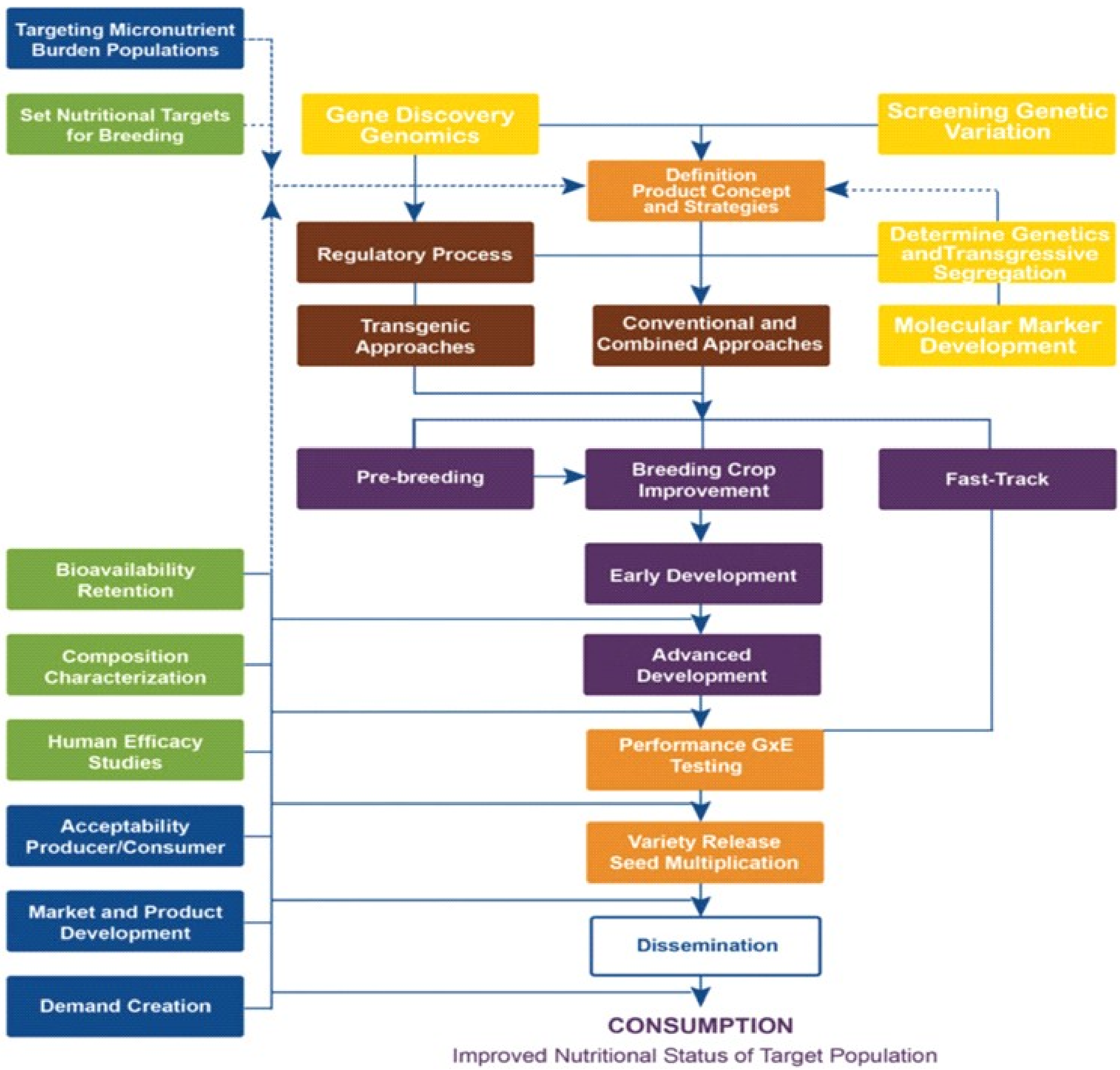
Current successes and impact

Proven Effectiveness: Randomized controlled trials have confirmed that biofortified crops, such as iron-rich beans in Rwanda and vitamin A-rich orange sweet potatoes in Mozambique, significantly improve nutritional status and cognitive performance in vulnerable populations.

Cost-Effectiveness: Biofortification is a highly economical intervention. Every $1 invested can yield up to $17 in economic benefits. Unlike traditional fortification, which requires recurring costs, biofortification utilizes a one-time investment in seed development that stays "fixed" in the germplasm.

Reach: It uniquely targets underserved rural populations who rely on home-grown staples and lack access to commercial supplements or processed fortified foods.

India's Progress: India has emerged as a leader, developing over 70 nutrition-rich crop cultivars across staples like wheat, rice, maize, and pearl millet.



Future prospects and emerging frontiers

Multi-Nutrient "Stacked" Biofortification: The future is shifting from single-nutrient improvements to "multi-nutrient" or "combinatorial" biofortification. Researchers are using gene-stacking and genetic engineering (e.g., CRISPR-Cas9) to simultaneously increase iron, zinc, and provitamin A in a single variety.

Climate-Smart Traits: To combat declining nutrient densities caused by rising CO2 levels, future varieties are being developed to combine high nutrition with climate-resilient traits like drought and pest resistance.

Precision Agronomy and Nanotechnology: Emerging "Nano-fertilizer-assisted biofortification" offers a way to precisely deliver nutrients to plants, increasing absorption efficiency and reducing environmental runoff compared to traditional fertilizers.

Microbe-Mediated Approaches: The use of beneficial soil microorganisms (like *Bacillus* and *Pseudomonas*) is a growing sustainable frontier to enhance nutrient solubility and uptake in the rhizosphere.

Mainstreaming Goals: A major strategic goal for 2030 is to "mainstream" biofortified traits into all public plant breeding programs, making high mineral and

Table 1: Varieties developed through conventional breeding

Crop	Variety	Trait	Country	Year release
Rice	DRR Dhan 45	Zn	India	2016
	DRR Dhan 48, DRR Dhan 49	Zn	India	2017
	Saurbhi	Zn	India	2017
	Fedearroz BIOZn 035	Zn	Colombia	2021
	Inpara 11 Siam HiZInc	Zn	Indonesia	2022
	BRRI Dhan 64	Zn	Bangladesh	2014
	CR 310, CR 311	Protein	India	2018
	Zinco Rice MS	Zn	India	2018
	WB 02, HPBW 01	Fe, Zn	India	2017
	Pusa Tejas	Protein, Fe	India	2017
	Pusa Ujala	Protein, Fe, Zn	India	2017
Wheat	HD 3171	Zn	India	2017
	Nohely F2018	Zn	Mexico	2018
	TARNAB-REHBAR	Zn	Pakistan	2023
	TARNAB-GANDUM-I	Zn	Pakistan	2023
	Zinc Gahun-1	Zn	Nepal	2020
	HI 8777	Zn, Fe	India	2018
	MACS 4028	Protein, Zn and Fe	India	2018
	PBW 752	Protein	India	2018
Maize	Vivek QPM 9	lysine and tryptophan	India	2008
	Pusa HM8 Improved, Pusa HM4	lysine and tryptophan	India	2017
	Pusa Vivek QPM9 Improved	provitamin-A, lysine and tryptophan	India	2017
	ZS246A	Vitamin A	Africa	2016
	ZS500A	Vitamin A	Africa	2019
	ICTA HB-18ACP + Zn	Zinc	Guatemala	2018
	Fortaleza 17	Zinc	Guatemala	2020
	SGBIOH2	Zinc	Colombia	2019
	Pusa HQPM 5 Improved, Pusa HQPM 7 Improved, IQMH 201	provitamin-A, lysine and tryptophan	India	2020
Pearl-millet	RHB 233, RHB 234	Iron and zinc	India	2019
	ICSR 14001, ICSH 14002	Iron	India	
	VR 929	Iron	India	2020
	LCIC MV5	Iron	Nigeria	2023
	Chakti	Iron	Nigeria	2018
	CFMV1, CFMV 2	Calcium, iron and zinc	India	2020
Sorghum	CLMV1	Iron and zinc	India	2020
	Parbhani Shakti	Zinc	India	2018
Finger	Pusa Ageti Masoor	Iron	India	2017
Millet	IPL 220	Iron and zinc	India	2018
Little Millet	IPL 220	Iron and zinc	India	2018
Lentil	Kufri Manik, Kufri Neelkanth	Anthocyanin	India	2020
	Bhu Sona, Bhu Krishna	Provitamin-A, Anthocyanin	India	2017
	Rasuwa black	Iron	Nepal	2020
	Barimasur-4, B-5, B-6	Iron	Bangladesh	2010
Cowpea	CBC6	Iron	Zimbabwe	2021
	Pant Lobia-7	Iron	India	2019
	BRS Araca	Iron	Brazil	2009
Beans	RWR 2245; RWR 2154; MAC 42; MAC 44; CAB 2; RWV 1129; RWV 3006; RWV 3316; RWV 3317; RWV 2887	Iron and zinc	Rwanda	2014

Sweet Potato	Delvia	Vitamin A	Zimbabwe	2021
	Kokota, Chumfwa, Olympia	Vitamin A	Zambia	2014
	Gerald, Joweria	Vitamin A	Uganda	2013
Cassava	Slicass 12	Vitamin A	Sierra Leone	2014
	UMUCASS 44	Vitamin A	Nigeria	2014
	UMUCASS 52, UMUCASS 53, UMUCASS 54	Vitamin A	Nigeria	2022
Banana	Apantu, Bira, Pelipita, Lai, To'o	Vitamin A	Uganda	2022
Mango	Amarpali, Pusa Arunima, Pusa Surya, Pusa Pratibha, Pusa Peetamber, Pusa Lalima, and Pusa Shreshth	Beta-carotene, Vitamin C	India	2022
	Ataulfo	Beta-carotene, Vitamin C	Mexico	2022
Grapes	Pusa Navrang	Antioxidants	India	2022

vitamin content a standard requirement for all new variety releases.

Key challenges for the future

Consumer Acceptance: Visible traits, like the orange colour in vitamin A-rich maize or rice, require sustained social marketing to gain public trust.

Regulatory Barriers: Transgenic (GM) crops often face strict regulatory hurdles and political opposition, particularly in Europe, despite their potential for higher nutrient densities.

Scaling and Policy: Full impact depends on integrating biofortified crops into government programs like school feeding schemes and public distribution systems (e.g., India's PDS).

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