Reg. No.: COOP/2023/KOTA/201080/26/193

AGRICULTURE FORUM FOR TECHNICAL EDUCATION OF FARMING SOCIETY

Kota, Rajasthan

Biofortification: Breeding for Better Nutrition

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Leaflet History

Received : 05.09.2026
Revised : 10.09.2026
Accepted : 15.09.2026

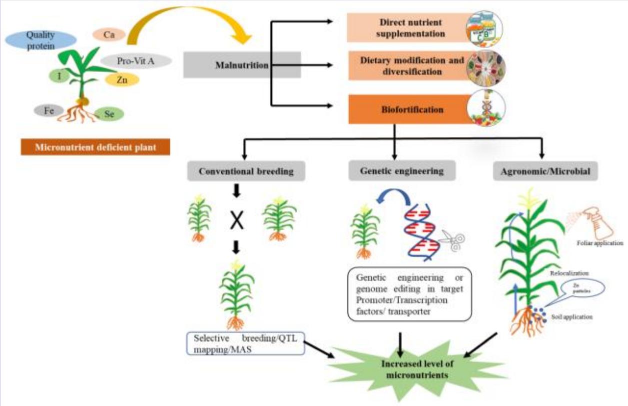
INTRODUCTION

Hidden Hunger: A Silent Challenge

A well-fed body is not the same as a well-nourished body. Millions of people eat their fill but do not obtain sufficient micronutrients such as iron, zinc and vitamin A. This phenomenon, known as hidden hunger, can weaken immunity, stunt growth, limit learning capacity, reduce physical performance, and affect mental health. Children, adolescent girls, pregnant women, and poor households are particularly at risk. Dietary diversification, supplementation and industrial fortification of foods remain vital but these may not always adequately reach remote or vulnerable populations. Biofortification breeding provides a sustainable complementary approach by enhancing the nutrition of the very crops that families grow and eat every day.

What is Biofortification Breeding?

Breeding for biofortification is the development of crop varieties to enhance the content, bioavailability or stability of essential nutrients in the edible parts of the crops. Plant breeders select nutritionally enhanced genetic material and integrate their nutrient quality traits with high yield, good taste, climate resilience, and pest and disease resistance. After the enhanced trait is introduced into a stable variety, it can be propagated using seeds or planting materials and cultivated multiple times. Thus, biofortification integrates nutrition within the crop-production system and provides micronutrients via staple foods rather than asking consumers to switch diets.



Biofortification is Different from Food Fortification

Biofortification enhances the nutrient content of crops during their development or growth. Unlike typical food fortification, where vitamins or minerals are added during industrial processing (e.g., iodized salt or iron-fortified flour), agronomic biofortification uses fertilizers or foliar sprays to increase nutrient accumulation. In contrast, breeding-based biofortification uses heritable genetic variation to develop crop varieties with enhanced nutritional quality. These techniques are not mutually exclusive but rather complement each other. Biofortified crops are not a substitute for a varied diet, supplements, public health programmes or medical treatment. Biofortified foods are particularly effective among farming families and rural populations with limited access to commercially processed foods or regular supplementation programmes.

How is a Nutritious Variety Developed

The process starts with screening of cultivated, landrace, wild and genebank accessions to discover naturally nutrient rich plants for the target nutrient.

Good donor lines are crossed with high yielding, locally adapted varieties. Breeders select for nutrient density in the progeny as well as for yield, maturity, grain/root quality, stress tolerance and consumer preference. Because nutrient concentration can vary with soil, climate, and crop management, promising lines are tested for several years and at multiple sites. Laboratory analyses are conducted to quantify the nutrient content of biofortified lines, while nutritional and efficacy studies assess the bioavailability of the target nutrient, its absorption in the human body, and its potential health benefits. Promising lines must subsequently undergo national testing, evaluation, and varietal release procedures before being multiplied and distributed for cultivation.

Important Breeding Approaches

Conventional Breeding

Traditional breeding and selection are still the basis for most released biofortified crops. This approach capitalizes on natural variation and is accepted by farmers and consumers alike. It is most successful when beneficial nutrient variability exists within the crop or among the compatible relatives of the crop.

Marker-Assisted Breeding

DNA markers allow breeders to monitor genes or genomic regions controlling the accumulation, transport, storage and retention of nutrients. This allows for the selection of seedlings with the desired alleles before they reach maturity, which reduces the time and resources needed for field evaluation.

Genomic Selection and Multi-Omics

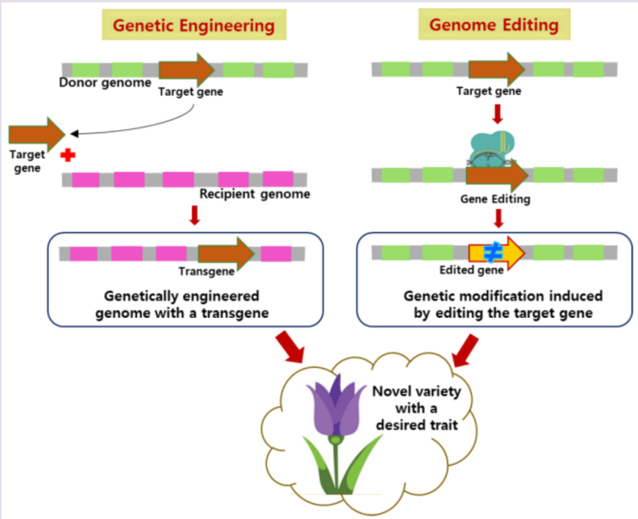
Genomic selection uses markers throughout the genome to estimate the breeding value of plants. Genomics, transcriptomics, proteomics, metabolomics and ionomics assist in the study of how nutrients are absorbed by roots, transported throughout the plant, and concentrated into edible tissues. These tools are particularly useful for traits controlled by many genes.

Speed Breeding and High-Throughput Screening

Artificial light and temperature can be manipulated to shorten crop generations, while rapid analytical methods such as X-ray fluorescence enable breeders to screen thousands of grain samples for iron and zinc. The integration of these techniques has the potential to speed up the delivery of nutritionally enhanced varieties.

Gene Editing and Genetic Engineering

Editing of genes can enable precise changes to those involved in the synthesis, transport, or antinutritive compounds related to nutrients. The gene pool of a crop can be supplemented by beneficial pathways through genetic engineering which do not occur naturally. These products need to undergo strict biosafety evaluation and meet national regulations and consumers' expectations.



Nutritious Crops Making a Difference

A growing range of biofortified crops is now available or under development:

- **Iron-rich pearl millet:** Contributes to increased iron intake in the diet and is particularly useful in regions where pearl millet is an important staple food. Examples: **Dhanashakti, HHB 299, ABV 04, Phule Mahashakti, RHB 233 and RHB 234**.
- **Iron- and zinc-rich finger millet:** Provides enhanced levels of iron, zinc and calcium and can contribute to improved micronutrient intake. Examples: **VR 929 (Vegavathi), CFMV 1 (Indravati) and CFMV 2**.
- **Iron- and zinc-rich lentil:** Combines the nutritional benefits of a protein-rich pulse with enhanced iron and zinc concentrations. Examples: **Pusa Ageti Masoor and IPL 220**.
- **Zinc- and protein-rich wheat:** Provides enhanced protein, iron and/or zinc concentrations and can improve the nutritional value of a staple cereal without requiring major dietary changes. Examples: **WB 02, HPBW 01, Pusa Tejas (HI 8759), Pusa Ujala (HI 1605), HD 3171, MACS 4028, PBW 752, DBW 187, DDW 47, PBW 771, HI 8802, HD 3249, DBW 303, DBW 327, HI 1636 and HUW 838**.
- **Protein- and zinc-rich rice:** Helps improve protein and zinc intake while maintaining rice as a familiar staple food. Examples: **CR Dhan 310, DRR Dhan 45, DRR Dhan 48, DRR Dhan 49, Zinco Rice MS, CR Dhan 311 (Mukul), CR Dhan 315 and CR Dhan 411**.
- **Quality protein maize:** Possesses enhanced levels of the essential amino acids lysine and

tryptophan, thereby improving the nutritional quality of maize protein. Examples: **Vivek QPM 9, Pusa HM 4 Improved, Pusa HM 8 Improved, Pusa HM 9 Improved, Pusa Vivek QPM 9 Improved, Pusa HQPM 5 Improved and Pusa HQPM 7 Improved**.

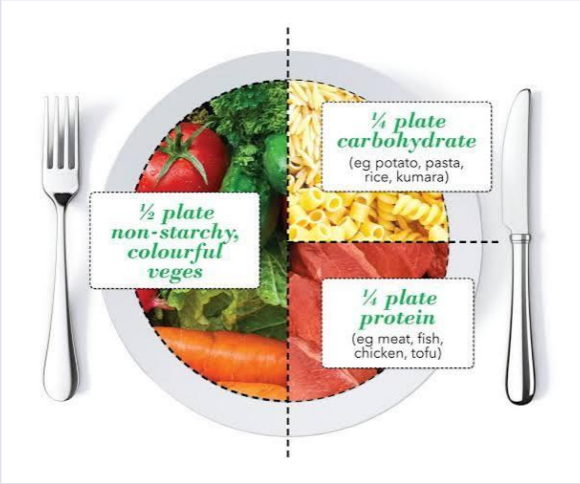
- **Provitamin-A-rich maize:** Contains enhanced carotenoid levels that can contribute to vitamin-A nutrition, with some varieties also combining provitamin-A with improved lysine and tryptophan. Examples: **Pusa Vivek QPM 9 Improved, Pusa VH 27 Improved, Pusa HQPM 5 Improved, Pusa HQPM 7 Improved and Pusa Biofortified Maize Hybrid 1**.
- **High-oleic groundnut:** Contains a higher proportion of oleic acid, a monounsaturated fatty acid, improving the nutritional quality and oxidative stability of groundnut oil. Examples: **Girnar 4 and Girnar 5**.
- **Linoleic-acid-rich linseed:** Provides enhanced linoleic acid content and can contribute to improving the fatty-acid composition of the diet. Example: **TL 99**.
- **Low-erucic acid and low-glucosinolate mustard:** Has reduced levels of erucic acid and glucosinolates, improving the nutritional quality of mustard oil and meal. Examples: **Pusa Mustard 30, Pusa Double Zero Mustard 31, Pusa Mustard 32, Pusa Double Zero Mustard 33, RCH 1 and PGHS 1699 (GSH 1699)**.
- **Improved-quality soybean:** Includes varieties developed with reduced anti-nutritional factors such as trypsin inhibitor and lipoxygenase activity, along with improved oleic acid content, thereby enhancing nutritional and processing quality. Examples: **NRC 127, NRC 132, NRC 147, NRC 142 and MACSNRC 1667**.
- **Provitamin-A-rich cauliflower:** Provides enhanced provitamin-A content compared with conventional cauliflower and can contribute carotenoids to the diet. Example: **Pusa Beta Kesari 1**.
- **Anthocyanin-rich potato:** Contains enhanced anthocyanin levels, providing antioxidant compounds in the edible tuber. Examples: **Kufri Manik and Kufri Neelkanth**.
- **Provitamin-A- and anthocyanin-rich sweet potato:** Orange- and purple-fleshed types can provide enhanced levels of provitamin-A carotenoids and anthocyanins, respectively. Examples: **Bhu Sona and Bhu Krishna**.
- **Nutrient-rich greater yam:** Provides enhanced levels of anthocyanins, protein, iron, zinc and calcium, making it a nutritionally improved root crop. Examples: **Sree Neelima and Da 340**.
- **Iron-, zinc- and vitamin-C-rich pomegranate:** Provides enhanced concentrations of iron, zinc and vitamin C in the edible arils and can contribute to improved micronutrient intake. Example: **Solapur Lal**.

India's Nutrition-Sensitive Breeding Opportunity

There is significant potential to popularize biofortification in India as wheat, rice, pearl millet, maize and pulses are widely consumed by large population on a daily basis. Iron-rich pearl millet and zinc-fortified wheat and rice are particularly relevant in the regions with high incidence of anaemia and zinc deficiency. Indian breeding programmes have already shown that higher levels of nutrients can be incorporated into high-yielding varieties with good disease resistance and adaptation to local environments. Recent efforts are also attempting to establish minimum micronutrient standards in variety testing, which would integrate nutrition into routine breeding practices instead of treating it as a specialized trait.

Nutrition Must Reach the Plate

High concentration of nutrients in raw grain cannot alone ensure higher nutritional value. The amount of the nutrient left after processing and storage (milling, soaking, fermentation, cooking, etc.) and its bioavailability needs to be quantified by the researchers. Dietary ensembles can also modify the bioavailability of minerals; e.g. phytate, an antinutritional factor that interferes with mineral bioavailability, especially Fe and Zn, can be partially degraded through some food processing methods such as fermentation. Breeding strategies in the future should therefore be directed not only at raising the concentration of the mineral but also at decreasing the level of antinutrient or increasing that of the nutrient absorption promoter. Therefore, the goal of biofortification is not simply to produce nutrient-rich grain, but to develop crops that can provide nutrients effectively and contribute to improved human nutrition.



Benefits for Farmers and Consumers

Biofortified varieties have the potential to generate advantages beyond nutrition. When nutritionally enhanced crops are also high-yielding, early maturing, drought tolerant and resistant to pests and diseases, they are production options rather than only health interventions. A family may eat part of what it harvests and sell the rest, generating nutrition and income. Seed companies, women's groups, food processors and rural enterprises, among others, can produce new products like iron-rich pearl millet flour, zinc-wheat bread, orange sweet potato snacks, and nutrient-packed complementary foods. Nutrition-sensitive value chains can thus link farm productivity, employment, food processing and public health.

Challenges that Need Attention

The concentration of nutrients in a variety may differ with soil and environmental conditions; hence, genotype testing at multiple sites is necessary. Undesirable trade-offs in yield, cooking quality, taste, colour or storage life must also be avoided by breeders. Some consumers could be put off initially by crops with unexpected colours, like orange maize or sweet potato, unless benefits and how to cook them are clearly explained. Adoption can be hindered by scarce seed, insensitive market demand, poor quality testing and weak awareness. Continuous monitoring is necessary to ensure that the genetic purity and nutrient levels of released varieties are maintained throughout seed multiplication and distribution. Success thus hinges on joint efforts in breeding, nutrition education, seed delivery, processing and market development.

Priorities for the Future

Biofortification in the next generation should go beyond the enhancement of a single nutrient to the shaping of crops that achieve balanced nutritional profiles. Breeding takes a holistic approach to incorporating iron, zinc, provitamin A, quality protein and health-promoting phytochemicals alongside minimal concentrations of contaminants and antinutritional factors. Additional focus is needed on vegetables, fruits, pulses, millets and other neglected crops besides staple cereals. Stability of nutrients under high temperature and drought, elevated carbon dioxide and poor soil nutrients should become breeding targets. Digital phenotyping, artificial intelligence, genomic prediction and precise gene editing may speed progress but ultimately every innovation must be proven in farmer's fields, their kitchens and nutrition studies.

The Message to Remember

The cultivation of biofortified crops changes crop development from the pursuit of higher yield alone into a pledge to better human health. A biofortified variety that works in practice needs to be productive for the farmer, acceptable to the consumer and suitable to local food traditions, as well as delivering nutrients the body is able to utilise. It is not a single cure for malnutrition, but it is a scalable and sustainable element of nutrition-sensitive agriculture.