



Enriching horticultural crops through biofortification

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INTRODUCTION

India has achieved food security in terms of calories. Nutritional security is still incomplete. Deficiency of iron, zinc, vitamin A, folate and iodine remains widespread and is described as hidden hunger, since it produces no visible sign of undernutrition in the early stage. The National Family Health Survey of 2019 to 2021 recorded anaemia in about 57 per cent of women aged 15 to 49 years and in 67 per cent of children below five years. The Comprehensive National Nutrition Survey placed subclinical vitamin A deficiency at roughly one in five preschool children, with zinc deficiency in a similar share. Cereal based diets with a low share of fruits, vegetables and animal products are the main reason for this pattern.

Three measures are used against this problem. Supplementation through health centres acts quickly but needs a delivery chain that runs without a break. Industrial fortification adds the nutrient during processing, as in iodised salt or fortified oil, so it covers only foods that pass through a mill. The third measure works in the field itself, where the crop is made to carry more of the nutrient during growth. This approach is called biofortification.

Concept of biofortification

Biofortification is the raising of a target vitamin or mineral in the edible part of a crop through agronomic management, plant breeding, molecular techniques or beneficial soil organisms. The nutrient enters the food where the food is produced, so no extra step is needed at the market, the kitchen or the health centre.

HarvestPlus took the idea into a global programme around 2003 along with the CGIAR centres. The cost pattern is what attracted attention. Breeding a nutrient rich variety needs money once. After release, every farmer who plants it gains at no added cost, season after season, which makes it a cheap way to reach households that supplement programmes rarely cover.

Scope in horticultural crops

Cereals mainly supply starch. Fruits and vegetables supply the vitamins and minerals, so any gain made in them goes straight to the target. Horticultural crops also carry a large natural variation for these compounds. Carrot roots are found in white, orange, red and black types. Sweet potato flesh varies from white to deep orange. Tomato, guava, pumpkin, amaranth and leafy greens differ several times over in carotenoid, anthocyanin or vitamin C content from one variety to another, so a breeder gets ready material to work with.

These crops are eaten with very little processing. Milling removes the outer layer of wheat grain with much of its iron, while a

carrot or a spinach leaf loses nothing of that kind. Many are propagated through vines, tubers, suckers or grafts, so once a nutrient rich clone is selected the trait stays fixed in every following crop, as in sweet potato, potato and banana.

Types of biofortification

The methods are grouped by the way the nutrient is put into the crop. Three routes are in use and they differ in speed, cost and durability of the gain. In practice they are often combined, since a bred variety still responds to zinc sprays, so both gains add up in the same field.

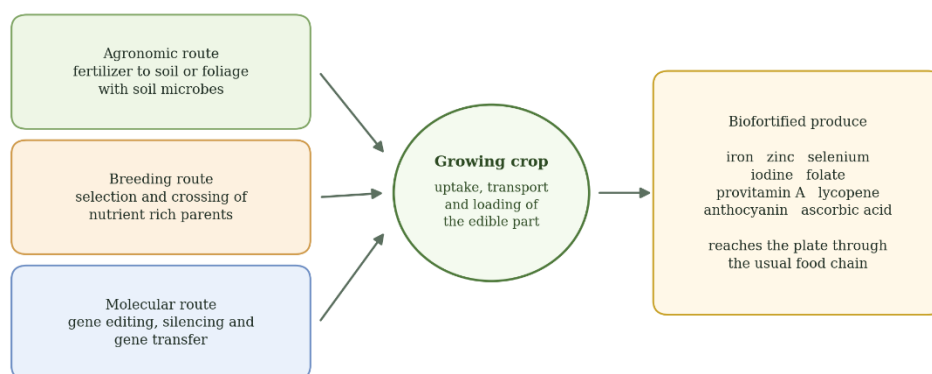


Figure 1: Routes of biofortification in horticultural crops

Agronomic biofortification

This is fertilizer management aimed at the edible part rather than at yield. Zinc sulphate, ferrous sulphate, sodium selenate, potassium iodate or borax are applied to the soil, sprayed on the foliage, dipped with the seedling roots or supplied through fertigation. The crop absorbs the element and moves part of it to the storage organ.

Zinc responds best because it moves freely in the phloem. Two foliar sprays of 0.5 per cent zinc sulphate on spinach, potato or okra raise the zinc content of the harvested part in a single season. Iron turns insoluble in alkaline soils, so foliar sprays or chelated forms work better. Finland added sodium selenate to all fertilizer from 1984 onward, after which blood selenium of the population

rose within a few years. Potassium iodate sprayed on lettuce, spinach or tomato raises tissue iodine within weeks.

Soil microbes form part of the same route. Plant growth promoting rhizobacteria such as *Bacillus* and *Pseudomonas* release organic acids and siderophores that bring zinc and iron out of unavailable soil pools, while arbuscular mycorrhizal fungi extend the absorbing surface beyond the root hair zone and pass zinc, copper and phosphorus into the root. Applied as a seed treatment, a nursery drench or a seedling root dip, these inoculants raise the mineral content of the harvested part along with root growth. Vegetable nurseries suit the method well, though field results still vary with soil type, native microbial load and carrier quality.

The method is quick and needs no new variety, since the response shows in the same crop. The gain ends when the spraying stops, the cost comes back every season and elements such as selenium and iodine have a narrow safe range between deficiency and toxicity.

Biofortification through conventional breeding

Here the nutrient trait is built into the variety itself. Germplasm, including landraces and wild relatives, is screened for high nutrient lines. Selected parents are crossed with agronomically good types, followed by six to seven generations of selection or by backcrossing. Marker assisted selection shortens the work where a reliable marker exists, since seedlings can be tested instead of the harvest.

Two conditions decide success. Useful variation must exist within the crossable gene pool and the nutrient trait must not drag yield down. Orange fleshed sweet potato is the standard example of the method working at scale. Cauliflower with orange curds, black and red carrots along with iron rich common bean all came from the same route.

The gain is lasting and costs the farmer nothing, since the variety itself carries the trait. The price paid is time, as such a

programme usually needs eight to twelve years from screening to release.

Biofortification through molecular tools

Some targets cannot be reached by crossing because the required variation is absent in the crop. Rice endosperm has no provitamin A pathway to select for and banana pulp carries very little of it. In such cases the pathway itself has to be introduced, switched on, silenced or edited.

Gene transfer moves a gene from another organism into the crop. Golden Rice carries a phytoene synthase gene from maize with a bacterial carotene desaturase. A cooking banana in Uganda carries a phytoene synthase gene from a wild banana. A purple tomato with two anthocyanin genes from snapdragon cleared review in the United States in 2022.

Gene overexpression uses a strong promoter to raise the output of a gene the plant already has, as with ferritin and iron related transcription factors. RNA interference silences a competing branch of a pathway. Genome editing with CRISPR knocks out genes that work against nutrition, such as those of the phytic acid pathway that lock up iron and zinc during digestion. Figure 2 places these approaches beside the agronomic and breeding routes.

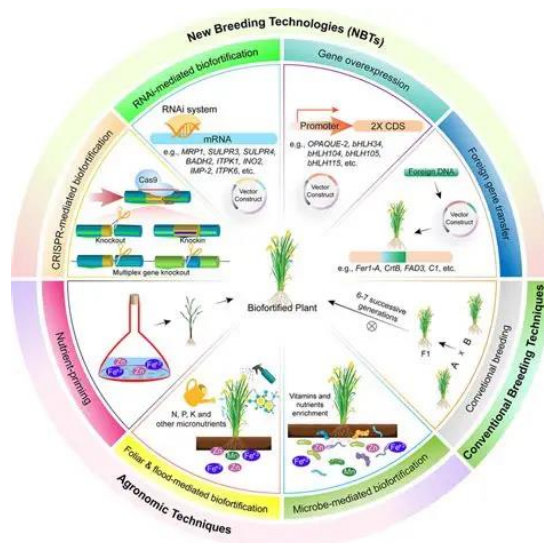


Figure 2: Approaches used to develop a biofortified plant

Precision is the advantage, since a single nutrient can be raised in one tissue without disturbing the rest of the plant. The obstacles are regulatory clearance, development cost and consumer acceptance.

Biofortified horticultural crops

Indian institutes have released several nutrient dense vegetable and fruit varieties over the

past decade. Table 1 lists the main ones with the target compound. Fruit crops such as mango, papaya, pomegranate, guava and aonla carry useful variation for carotenoid, anthocyanin and vitamin C, so selection within the existing germplasm gives quick returns in these crops.

Table 1: Nutrient rich varieties of horticultural crops in India

Crop	Variety	Nutrient	Nutrient content	Developed by
Sweet potato	Bhu Sona	Beta carotene	About 14 mg per 100 g of fresh root	ICAR-CTCRI, Bhubaneswar
Sweet potato	Bhu Krishna	Anthocyanin	About 90 mg per 100 g of fresh root	ICAR-CTCRI, Bhubaneswar
Cauliflower	Pusa Beta Kesari-1	Beta carotene	8 to 10 ppm in curd against traces in white curd	ICAR-IARI, New Delhi
Carrot	Pusa Asita	Anthocyanin	Black root type rich in anthocyanin	ICAR-IARI, New Delhi
Carrot	Pusa Rudhira	Lycopene with beta carotene	Red root type with high lycopene	ICAR-IARI, New Delhi
Potato	Kufri Neelkanth	Anthocyanin with higher antioxidant value	Purple skinned tuber with raised antioxidant content	ICAR-CPRI, Shimla
Guava	Lalit	Lycopene	Pink pulp with markedly higher lycopene than white pulp types	ICAR-CISH, Lucknow
Mango	Amrapali	Beta carotene	Pulp carotene higher than in most commercial varieties	ICAR-IARI, New Delhi
Papaya	Arka Prabath	Carotenoid with lycopene	Deep red pulp with high total carotenoid content	ICAR-IIHR, Bengaluru
Pomegranate	Bhagwa	Anthocyanin	Deep red aril with high anthocyanin content	ICAR-NRCP, Solapur
Aonla	NA-7	Ascorbic acid	Fruit vitamin C in the range of 500 to 600 mg per 100 g	NDUAT, Faizabad

Table 2. Nutrient sprays and soil doses used in horticultural crops

Crop	Nutrient	How it is given	Effect on the eaten part
Spinach and amaranth	Zinc	Two foliar sprays of 0.5 per cent zinc sulphate at 25 and 40 days after sowing	Leaf zinc rises along with leaf yield
Potato	Zinc with iron	Soil application of zinc sulphate followed by foliar spray at tuber bulking	Tuber zinc improves, iron gain is smaller
Onion and garlic	Selenium	Sodium selenate through soil or fertigation at low rates	Bulbs accumulate selenium as selenomethylselenocysteine
Broccoli	Selenium	Selenate applied to the root zone	Florets carry selenium in an organic form suited to absorption
Lettuce and leafy greens	Iodine	Potassium iodate applied through foliage or nutrient solution	Leaf iodine increases within two to three weeks
Tomato	Selenium with zinc	Foliar spray during fruit set and fruit development	Fruit mineral content improves with firmer fruit at harvest
Carrot	Iron	Foliar spray of 0.5 per cent ferrous sulphate with a wetting agent	Root iron improves moderately since iron moves poorly in phloem
Guava and citrus	Zinc with boron	Two foliar sprays of 0.5 per cent zinc sulphate with 0.2 per cent borax before flowering and at fruit set	Fruit zinc rises along with fruit set and size

Work outside India shows what the same routes can deliver. Orange fleshed sweet potato bred for provitamin A is now grown across Uganda, Mozambique and other African countries. The team behind it received the World Food Prize in 2016. Iron rich common bean has been released in Rwanda and the Democratic Republic of Congo, while yellow rooted provitamin A cassava has reached farmers in Nigeria. Among transformed crops, a provitamin A cooking banana has been field tested in Uganda, a purple tomato carrying snapdragon genes cleared review in the United States in 2022 and a lycopene rich pink pineapple has been on sale there since 2020.

Limitations and precautions

A high figure in a laboratory report does not by itself mean better nutrition in a household. Bioavailability decides how much of the nutrient the body absorbs. Phytic acid and polyphenols bind iron and zinc in the gut, while carotenoids need a little fat in the meal to be absorbed. Breeding programmes

therefore keep phytate reduction as a parallel target.

Retention during storage and cooking matters just as much. Beta carotene breaks down in sunlight and long heating, so open sun drying of sweet potato chips destroys much of it unless the slices are blanched and shade dried. Post harvest handling is thus part of the package.

Farmer acceptance rests on yield, disease reaction and price, since a variety with more iron but lower yield stays inside the research farm. Consumer acceptance rests on colour and taste. Dose control is a real safety point with selenium and iodine, so soil testing and fixed rates are needed instead of a blanket recommendation.

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