

Biofortification of crops:

a sustainable tool for nutritional security in India

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Southern Asia has affected the most by malnutrition with 34.1% and 15.4% of the children (<5 years) are stunted and wasted compared to global average of 22.9% and 7.7%, respectively. In India 21.9% of population lives in extreme poverty and it is estimated that 15.2% of people are undernourished. Among Indian children (<5 years), 38.4% are stunted, 21.0% are wasted and 7.5% are severely wasted due to consumption of food low in nutrition. Further, 58.4% of children (6-59 months), and 22.7% and 53.0% of adult men and women (15-49 years) suffer from anaemia in India. Thus, malnutrition poses serious socio-economic implications to the country. Considering its wide spread ramification, alleviation of malnutrition was identified as one of the most important step for hunger free world. In 2015, global community at the United Nations has laid down 'Sustainable Development Goals' for eradicating poverty, hunger, and malnutrition by 2030. Of the 17 goals, Sustainable Development Goals (Zero Hunger) vows to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. It is estimated that alleviating malnutrition is one of the most cost-effective steps with every \$1 invested in proven nutrition programme offers benefits worth \$16.

Key words: Biofortification, Crops, Nutritional security, Sustainable

GLOBALLY, around two billion people suffer from malnutrition, whereas 815 million people are undernourished. Among children (<5 years), 155 million are stunted and 52 million do not weigh enough according to height (wasting). Nearly 45% of deaths among children under age of five years are linked to malnutrition. The problem is so widespread that 88% of the countries experience two or three forms of malnutrition. The various strategies for tackling malnutrition are discussed here.

Food-fortification: It is a process where food is enriched with specific nutrient(s) through physical addition. One of the best examples is iodized salt, where required quantity of iodine (I) is consumed along with the salt.

Medical-supplementation: It is a

process where specific nutrient(s) is directly provided to population in the form of pills or capsules. One of the best examples is vitamin-A pills that are distributed in the targeted area to address the vision related problem especially among children. Supplementation of iron (Fe) tablets to the pregnant women is also widely used worldwide.

Dietary-diversification: It is a process where type of food consumption being practised at the house-hold is changed. Cereal-based diet is the main stay of food among the resource poor. Inclusion of pulse, fruits and vegetables and even animal-proteins in the diet makes the food more balanced.

Biofortification: It is process where the concentration of nutrients in the edible parts of the crop is increased through genetic means like breeding

or transgenic approaches. Natural variants of the target genes in the gene pool that specifically enhances the accumulation of a specific nutrient can be introgressed into an elite genetic background through breeding approach. Development of quality protein maize (QPM) with high lysine and tryptophan in endosperm protein is an example. In case the variation for the target trait is not available in the gene pool, then gene(s) from cross incompatible organism is used through genetic engineering. Golden rice with high concentration of provitamin-A is a classical example of crop biofortification achieved through transgenic approach.

Among the above four avenues, food-fortification, medical-supplementation and dietary-diversification in general have not

been found viable in the long run due to various reasons. Lack of purchasing power of the poor due to poverty, restricts the access to the fortified foods, thereby reducing their efficiency and application. Poor infrastructure in developing countries has limited the widespread use of medical-supplementation. Dietary-diversification is often limited by crop seasonality, expense and lack of purchasing power by the poor. Biofortification on the other hand is regarded as the most sustainable and cost effective approach, and nutrients reach the human body in pure form.

Importance of nutrition: Among various nutrients, protein, lysine, tryptophan, iron, zinc, vitamin A and vitamin C are essential for human nutrition, and their deficiency leads to various symptoms and health disorders. While protein is a macronutrient as it is required in higher quantity, others are regarded as micronutrients due to their minute requirement. On the other hand, erucic acid, glucosinolate and Kunitz Trypsin Inhibitor are the anti-nutritional factors as consumption in higher level effects adversely on human beings and livestock health. Various function and deficiency symptoms of the important nutrients are presented below:

Protein: Staple diet unbalanced in protein generally leads to the development of *kwashiorkor* and *marasmus* among humans beings. While, *kwashiorkor* involves insufficient consumption of protein with fair to normal calories intake, *marasmus* involves inadequate consumption of both protein and calories. Poor intellectual development, disorderly physical functioning and even mortality are consequences of protein deficiency.

Lysine: The deficiency of lysine leads to fatigue, dizziness, nausea, anaemia, delayed growth, loss of appetite and reproductive tissue.

Tryptophan: Depression, anxiety, impatience weight loss and slow growth in children are the major symptoms of tryptophan deficiency.

Iron: Anaemia is considered as one of the hallmarks of iron (Fe) deficiency in human beings. It reduces intelligence, causes mild-

mental retardation, goitre and eye problems along with profound effects on cognitive development, growth, reproductive performance and work productivity.

Zinc: The clinical symptoms of severe zinc deficiency are growth retardation, delayed sexual and bone maturation, skin lesion, diarrhoea, impaired appetite, and increased susceptibility to infections. Severe form of zinc (Zn) deficiency is characterized by short stature, hypogonadism, impaired immune function, skin disorders, cognitive dysfunction and anorexia.

Vitamin- A: An early symptom of deficiency is night blindness. Structural alterations of the conjunctiva and cornea such as xerophthalmia and keratomalacia may follow, and subsequent inflammation and infection result in irreversible blindness. It also results in predisposition of several diseases like anaemia, diarrhoea, measles, malaria and respiratory infections.

Vitamin- C: Deficiency of vitamin-C leads to scurvy which is characterized by bruising and bleeding specially in the teeth and is also associated with joint and muscle pains.

Erucic acid: High amount of erucic acid in edible oils was reported to impair myocardial conductance, causes lipidosis in children and increases blood cholesterol.

Glucosinolates: Cleavage products from hydrolysis are detrimental to animal health as they reduce the feed palatability and affect the iodine uptake by the thyroid glands thus reducing feed efficiency and weight gains especially in non-ruminants such as pigs and poultry.

Kunitz trypsin inhibitor: It is an antinutritional factor, which binds trypsin (released by pancreas) thereby interfering with the protein digestibility and may cause pancreatic hypertrophy

Development of biofortified cultivars: Indian Council of Agricultural Research is the flagship organization for agricultural research in the country. ICAR has contributed immensely to make India self-sufficient in food production. From 50.82 million tonne of food

production in 1950-51, India has touched 284.8 million tonne during 2017-18 (Fourth Advance Estimates). Similarly, horticultural crops also experienced increase from 96.56 million tonne during 1991-92 to 306.8 million tonne during 2017-18 (Third Advance Estimates). The tremendous gain achieved in yield potential has been possible due to the development of high-yielding varieties and heterotic hybrids across crops. These high-yielding cultivars generally possess low concentration of essential nutrients, thus warrants targeted approach. Nutritional status of different essential nutrients in popular varieties of different crops is: *Rice* 7.0-8.0% protein and 12.0-16.0 ppm zinc in polished grain; *Wheat* 32.0 ppm zinc and 28.0-32.0 ppm iron; *Maize* 1-2 ppm provitamin-A, 1.5-2.5% lysine and 0.3-0.4% tryptophan; *Pearl millet* 45.0-50.0 ppm iron and 30.0-35.0 ppm zinc; *Lentil* 55.0 ppm iron; *Mustard* >40.0% erucic acid and >120.0 ppm glucosinolates; *Soybean* - presence of KTI; *Cauliflower* - negligible α -carotene; *Sweet potato* - 2.0-3.0 mg/100 g of α -carotene and negligible anthocyanin and *pomegranate* 2.7-3.2 mg/100g iron, 0.50-0.54 mg/100g zinc and 14.2-14.6 mg/100 g vitamin C. Research efforts at ICAR institutes as well as SAUs have now led to the release of a series of biofortified varieties through All India Coordinated Research Projects which not only provide enough calories, but also deliver essential nutrient(s) needed for adequate growth and development. The details of the some of the recently developed biofortified varieties across crops are presented below:

Rice

CR Dhan 310: It is a pure line



variety and contains high protein (10.3%) in polished grain as compared to 7.0 to 8.0% in popular varieties. It was released and notified in 2016 for Odisha, Madhya Pradesh and Uttar Pradesh. Its average grain yield is 45.0 q/ha. It matures in 125 days. This biofortified variety has been developed by National Rice Research Institute, Cuttack.

DRR Dhan 45: It is a pure line variety and possesses high zinc (22.6 ppm) in polished grains in comparison to 12.0 to 16.0 ppm in popular varieties. It has been released and notified in 2016 for Karnataka, Tamil Nadu, Andhra Pradesh and Telangana. Its average grain yield is 50.0 q/ha. It matures in 125-130 days. This biofortified variety was developed by Indian Institute of Rice Research, Hyderabad.

DRR Dhan 49: A pure line variety with high Zinc (25.2 ppm) in polished grains. It was released and notified in 2018 for Gujarat, Maharashtra and Kerala. Its average grain yield is 50.0 q/ha. It matures in between 125 and 130 days. It is bacterial leaf blight resistant variety having genes *Xa21+xa13*. It was developed by Indian Institute of Rice Research, Hyderabad.

Wheat

WB 02: It is a pure line wheat variety and rich in zinc (42.0 ppm) and iron (40.0 ppm) in comparison to 32.0 ppm zinc and 28.0-32.0 ppm iron in popular varieties. It was released and notified in 2017 for Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur division), western Uttar Pradesh (except Jhansi division), Jammu and Kathua district of Jammu and Kashmir, Paonta Valley and Una district of Himachal Pradesh and *Tarai* region of Uttarakhand. Its average grain yield is 51.6 q/ha. It



matures in 142 days, and is suitable for irrigated timely sown conditions. This biofortified variety was developed by Indian Institute of Wheat and Barley Research, Karnal.

HPBW 01: It is a pure line wheat variety and contains high iron (40.0 ppm) and zinc (40.6 ppm) in comparison to 28.0-32.0 ppm iron and 32.0 ppm zinc in popular varieties. It was released and notified in 2017 for Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur division), western Uttar Pradesh (except Jhansi division), Jammu and Kathua district of Jammu and Kashmir, Paonta Valley and Una district of Himachal Pradesh and *Tarai* region of Uttarakhand. Its average grain yield is 51.7 q/ha. It matures in 141 days, and is suitable for irrigated timely sown conditions. This biofortified variety was developed by Punjab Agricultural University, Ludhiana under All India Coordinated Research Project on Wheat and Barley.

Pusa Tejas (HI 8759): A high protein (12%), iron (42.1 ppm) and zinc (42.8 ppm) content *durum* wheat dual purpose variety suitable for making *chapatti*, *pasta* and other traditional food products. It was released and notified in 2017 for Madhya Pradesh, Chhattisgarh, Gujarat, Rajasthan and Uttar Pradesh. Average yield of this variety is 57.0 q/ha under timely sown irrigated conditions. It was developed by Indian Agricultural Research Institute, Regional Station, Indore.

Pusa Ujala (HI 1605): A high protein (13%) and iron (43 ppm) variety with 35 ppm zinc and excellent *chapatti* making quality. It was released and notified in 2017 for Maharashtra, Karnataka and Tamil Nadu. Its average yield is 30.0 q/ha under timely sown, restricted irrigation conditions. It has high levels of resistance to black and brown rust diseases. It was developed by Indian Agricultural Research Institute, Regional Station, Indore.

MACS 4028 (d): A *durum* wheat variety with high protein (14.7%), iron (46.1 ppm) and zinc (40.3 ppm) content. It was released and notified in 2018 for Maharashtra and Karnataka. Its average grain yield is

19.3 q/ha under rainfed-low fertility, timely sown conditions in Peninsular Zone. It matures in 102 days. It was developed by Agharkar Research Institute, Pune under All India Coordinated Research Project on Wheat and Barley.

Maize

Pusa Vivek QPM9 Improved: It is an early maturing hybrid and possesses high provitamin-A (8.15 ppm) compared to 1-2 ppm in traditional maize. It also contains high tryptophan (0.74%) and lysine (2.67%) in protein, and thus is a multi-nutrient maize hybrid as well. It was released and notified in 2017 for Jammu and Kashmir, Himachal Pradesh, Uttarakhand (Hills), North-



Eastern states, Maharashtra, Karnataka, Andhra Pradesh, Telangana and Tamil Nadu. Its average grain yield is 55.9 and 59.2 q/ha, with maturity of 93 and 83 days in the two different agro-climatic zones, respectively. This biofortified variety was developed by Indian Agricultural Research Institute, New Delhi.

Pusa HM4 Improved: It is a medium maturing hybrid that possesses high tryptophan (0.91%) and lysine (3.62%) in endosperm protein compared to 1.5-2.5% lysine and 0.3-0.4% tryptophan found in traditional maize. It was released and notified in 2017 for Punjab, Haryana, Delhi, Uttarakhand (plains) and western Uttar Pradesh. Its average grain yield is 64.2 q/ha. It matures in 87 days. This biofortified variety was developed by Indian Agricultural Research Institute, New Delhi.

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Pusa HM 8 Improved: It is a medium maturing hybrid that possesses high tryptophan (1.06%) and lysine (4.18%) in endosperm protein compared to 1.5-2.5% lysine and 0.3-0.4% tryptophan found in traditional maize. It was released and notified in 2017 for Maharashtra, Karnataka, Andhra Pradesh, Telangana and Tamil Nadu. It's average grain yield is 62.6 q/ha. It matures in 95 days. This biofortified variety was developed by Indian Agricultural Research Institute, New Delhi.

Pusa HM9 Improved: It is a medium maturing hybrid that possesses high tryptophan (0.68%) and lysine (2.97%) in endosperm protein compared to 1.5-2.5% lysine and 0.3-0.4% tryptophan found in traditional maize. It was released and notified in 2017 for Bihar, Jharkhand, Odisha, West Bengal and Eastern Uttar Pradesh. It's average grain yield is 52.0 q/ha. It matures in 89 days. This biofortified variety was developed by Indian Agricultural Research Institute, New Delhi.

Pearl millet

HHB 299: It is a hybrid and possesses high iron (73.0 ppm) and zinc (41.0 ppm) as compared to 45.0-50.0 ppm iron and 30.0-35.0 ppm zinc in popular varieties and hybrids. It was released and notified in 2017 for Haryana, Rajasthan, Gujarat, Punjab, Delhi, Maharashtra and Tamil Nadu. It's average grain yield is 32.7 q/ha, and dry fodder



yield is 73.0 q/ha. It matures in 81 days. This biofortified variety was developed by CCS-Haryana Agricultural University, Hisar in collaboration with ICRISAT, Patancheru under All India Coordinated Research Project on Pearl millet.

AHB 1200: It is a hybrid and rich in iron (73.0 ppm) in comparison to 45.0-50.0 ppm in popular varieties and hybrids. It was released and notified in 2017 for Haryana, Rajasthan, Gujarat, Punjab, Delhi, Maharashtra and Tamil Nadu. It's average grain yield is 32.0 q/ha, dry fodder yield is 70.0 q/ha. It matures in 78 days. This biofortified variety was developed by Vasant Rao Naik Marathwada Krishi Vidyapeeth, Parbhani (Maharashtra) in collaboration with ICRISAT, Patancheru under All India Coordinated Research Project on Pearl millet.

Lentil

Pusa Ageti Masoor: It is a pure line variety, and contains 65.0 ppm iron as compared to 55.0 ppm iron in popular varieties. It was released and notified in 2017 for Uttar Pradesh, Madhya Pradesh and Chhatisgarh. It's average grain yield is 13.0 q/ha.



It matures in 100 days and is suitable for rainfed condition. This biofortified variety was developed by Indian Agricultural Research Institute, New Delhi.

IPL 220: It is a pure line variety with high iron (73 ppm) and zinc (51 ppm) content. It was released and notified during 2018 for Eastern Uttar Pradesh, Bihar, Assam and West Bengal. Average yield of IPL-220 is 13.8 q/ha. It matures in 121 days and is suitable for rainfed situation during

rabi. Resistant to major diseases including rust, *Fusarium* wilt and stemphylium blight. It was developed by Indian Institute of Pulses Research, Kanpur.

Mustard

Pusa Mustard 30: It is a pure line variety and contains low erucic acid (<2.0%) in oil as compared to >40% erucic acid in popular varieties. It was released and notified in 2013 for Uttar Pradesh, Uttarakhand, Madhya Pradesh and Rajasthan. It's average oil content is 37.7%, with a seed yield of 18.2 q/ha. It matures in 137 days and is suitable for timely sown irrigated conditions. This biofortified variety was developed by Indian Agricultural Research Institute, New Delhi.



Pusa Double Zero Mustard 31: It is a pure line variety and contains low erucic acid (<2.0%) in oil and glucosinolates (<30.0 ppm) in seed meal as compared to >40.0% erucic acid and >120.0 ppm glucosinolates in popular varieties. It was released and notified in 2016 for Rajasthan (north and western parts), Punjab, Haryana, Delhi, western Uttar Pradesh, Plains of Jammu & Kashmir and Himachal Pradesh. It's average oil content is 41.0%, with a seed yield of 23.0 q/ha. It matures in 142 days, and is suitable for timely sown irrigated conditions. This biofortified variety was developed by Indian Agricultural Research Institute, New Delhi.

Soybean

NRC-127: First Kunitz Trypsin Inhibitor (KTI) free marker assisted selection derived soybean variety developed by introgressing null allele of KTI in cv JS 97-52. It was released in 2018 for Madhya Pradesh,



Bundelkhand region of Uttar Pradesh, Rajasthan, Gujrat and Marathwada and Vidarbha region of Maharashtra. Average yield of NRC-127 soybean is 18.0 q/ha and it matures in 104 days. It has 18.5-20.0% oil content and 38.0-40.0% protein content. It was developed by Indian Institute of Soybean Research, Indore.

Cauliflower

Pusa Beta Kesari 1: It is a pure line variety and contains high α -carotene (8.0-10.0 ppm) in comparison to negligible α -carotene in popular varieties. It was released and notified in 2015 for National Capital Region of Delhi. Its average curd yield is 40.0-50.0 tonne/ha. This biofortified variety was developed by Indian Agricultural Research Institute, New Delhi.



Sweet potato

Bhu Sona: It is a pure line variety and contains high α -carotene (14.0 mg/100 g) as compared to 2.0-3.0 mg/100 g of α -carotene in popular varieties. It has been released and notified in 2017 for Odisha. Its average tuber yield is 19.8 tonne/ha



with dry matter of 27.0-29.0%, starch of 20.0% and total sugar of 2.0-2.4%. This biofortified variety was developed by Central Tuber Crops Research Institute, Thiruvananthapuram.

Bhu Krishna: It is a pure line variety and contains high anthocyanin (90.0 mg/100g) in comparison to popular varieties which have negligible concentration. It was released and notified in 2017 for Odisha. Its average tuber yield is 18.0 tonne/ha, with dry matter of 24.0-25.5%, Starch of 19.5% and total sugar of 1.9-2.2%. It is also salinity stress tolerant. This biofortified variety was developed by Central Tuber Crops Research Institute, Thiruvananthapuram.

Pomegranate

Solapur Lal: It is a hybrid variety and contains high iron (5.6-6.1 mg/100 g), zinc (0.64-0.69 mg/100 g) and vitamin-C (19.4 -19.8 mg/100 g) in fresh arils in comparison to 2.7-3.2 mg/100g, 0.50-0.54 mg/100g and 14.2-14.6 mg/100g, respectively in popular variety, Ganesh. It was released and notified in 2017 for semi-arid regions of the country. Its



average fruit yield is 23.0-27.0 tonne/ha. This biofortified variety was developed by National Research Centre on Pomegranate, Pune.

Challenges

There are some operational challenges in adoption of nutritionally-rich cultivars of various crops viz.,

(i) wrong perception of low-yielding potential of biofortified varieties among the farmers,

(ii) most of the nutritional traits are phenotypically invisible (protein, lysine, tryptophan, iron, zinc and vitamin-C) and is difficult to convince the farmers and traders regarding the extent of quality of the produce,

(iii) quality maintenance is an issue as some of the nutritional traits (lysine and tryptophan) are governed by recessive genes and contamination by foreign pollen grains from neighbouring field dilutes the quality of the produce in the cross-pollinated crops,

(iv) enrichment of nutrients such as provitamin-A and anthocyanin leads to altered appearance of the produce (yellow vs. white maize, and normal vs. yellow/purple sweet potato), hence, consumers at the village level, generally hesitate in accepting the biofortified produce as food,

(v) lack of awareness on health benefits of the biofortified varieties,

(vi) lack of profitable markets for commercial producers,

(vii) unwillingness among food processors in marketing biofortified produce as a premium product,

(viii) no provision of premium on minimum support price of biofortified produce across crops and

(ix) in case of maize, weak linkages between farmers and local poultry.

The way forward

Intensive efforts by public sector institutions and policy for intense promotional campaigns can effectively ensure significant increase in adoption and acceptance of biofortified crop varieties. Strengthening the seed chain to produce and supply good quality

seeds is one the important steps for the popularizing biofortified varieties. Maintenance of genetic purity is very essential for keeping the quality trait intact, hence, special seed production areas need to be identified. Seed village programme can also be one option for taking the seed/commercial production of such varieties to avoid outcrossing from other conventional varieties. Providing subsidized seeds and other inputs would further contribute to the rapid dissemination of nutritionally improved cultivars among the farmers. Assured premium remunerative price through minimum support price for biofortified grains in the market will encourage the farmers to grow more biofortified crops. Investment on extension activity would make the farmers, industry and consumers aware of the availability and benefits of biofortified crops.

Recently unveiled National Nutrition Strategy-2017 by *NITI Aayog*, Government of India envisages alleviation of malnutrition in the country through food-based solution. Inclusion of these biofortified cereals in different Government sponsored programme like National Food Security Mission, *Rashtriya Krishi Vikas Yojna* as well as nutrition intervention programmes of various Ministries of Government of

India such as Integrated Child Development Services scheme, *Anganwadi* Scheme, Public Distribution System, 'Mid-Day Meal' scheme in schools and Nutrition Education and Training through Community Food and Nutrition Extension Units would help in providing the much needed balanced food to poor people. Central government has recently declared millets comprising sorghum, pearl millet, finger millet, foxtail millet, proso millet, kodo millet, barnyard millet, little millet and two pseudo millets (buck-wheat and *Amaranthus*) as *Nutri-Cereals* because of their high nutritive value. This would boost their demand and allow farmers to get higher prices. Inclusion of biofortified products in these government sponsored schemes would specially benefit the children, pregnant women and elderly people, and would help in their quick dissemination.

SUMMARY

ICAR is committed to meet the sustainable development goals and achieve country's slogan of '*Kuposhan Mukh Bharat*' (Malnutrition Free India). Development of biofortified crops with enhanced micronutrients was a major focus area of ICAR. To further expedite the process of development of biofortified crops,

ICAR has funded a Consortia Research Platform on 'Biofortification in Selected Crops for Nutritional Security', where rice, wheat, maize, pearl millet, sorghum and minor millets were targeted for nutritional enrichment. These high-yielding biofortified crops besides serving as an important source for livelihood to poor people, assume great significance in nutritional security. Further Extension Division of ICAR has launched two very important projects viz., Nutri-sensitive Agricultural Resources and Innovation and Value Addition and Technology Incubation Centres in Agriculture through Krishi Vigyan Kendras which will definitely help in popularization and promotion of the biofortified crop varieties and their products. KVKs are already working on Agri-Nutri Smart Village (A2N) Model which focuses on Nutri Farming System, Agri-Nutri Education, Agri-Nutri Capacity Building and SHG-Farmer Nutri Clubs.

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Reasons Why Zero Hunger Changes the World?

1. Zero hunger could save the lives of 3.1 million children a year
2. Well-nourished mothers have healthier babies with stronger immune systems
3. Ending child undernutrition could increase a developing country's GDP by 16.5%
4. A dollar invested in hunger prevention could return between \$15 and \$139 in benefits
5. Proper nutrition early in life could mean 46% more in lifetime earnings
6. Eliminating iron deficiency in a population could boost workplace productivity by 20%
7. Ending nutrition-related child mortality could increase a workforce by 9.4%
8. Zero hunger can help build a safer, more prosperous world for everyone

(Courtesy, FAO)