Biofortification in cereals: progress and prospects

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Food security of the country has been improved due to green revolution and enhancement of cereal production. However, recent surveys showed 35.8% of children suffer from malnutrition in India. The Indian Council of Agricultural Research has taken lead for the biofortification of cereal crops based on earlier national and international research efforts, targeting the enhancement of nutrients in staple food crops. In this article, the significant progress made in rice, wheat, maize and millets for identification of genotypes, development, evaluation and release of the varieties with high nutrient contents and their bioavailability studies is discussed.

Keywords: Biofortification, breeding, bioavailability, nutrients, varieties.

ATTAINMENT of self sufficiency in food grains at national level, especially cereals, is one of the major achievements of the green revolution during mid-sixties in India. The nation's food grains production increased markedly from 50.82 million tonnes in 1950–51 to 252.22 million tonnes during 2015–16, and a similar trend has been reported in the production of food grains since the past decade[1]. Despite increased production of food grains, the 2016-Global Hunger Index (GHI) Report ranked India as 9th comprising 25% of world's hungry population amongst the top 118 countries[2]. According to Rapid Survey on Children (2013–14) conducted by the Ministry of Women and Child Development, New Delhi, about 18.6% of new borns, 34.6% of children up to 3 years and 62.5% of adolescent girls suffer from malnutrition[3] (Figure 1). Food deficiency disorders directly affect the health of an individual and indirectly the economy of the nation by increasing the number of Disability-Adjusted Life Years (DALYs – a framework, which quantifies the economic impact of disability and disease)[4]. According to the World Bank–South Asia report, micronutrient deficiencies are responsible for losses amounting to \$2.5 billion in India every year.

The Government of India has made several interventions to address malnutrition; however, the incidence of malnutrition among women and children remains severe. The issue of malnutrition in the country is compounded not only by access to food, but also by social and cultural issues. Conventional strategies to combat malnutrition include dietary supplements and food fortification programmes. Efforts are now being made to fortify rice and wheat flour for iron (Fe), vitamin B_{12} and folic acid[5]. Some of the constraints with these interventions include poor dissemination to the target population especially those residing in rural areas; sustaining them over a period of time and addressing the symptoms rather than the cause of the problem. Dietary diversification is the ideal solution to alleviate malnutrition but not viable in the Indian situation considering the inadequate purchasing power of the poor people. Thus, the long-term solution lies in increasing the essential nutrient contents of the staple food crops, viz. cereals through crop biofortification strategy.

Biofortification

Biofortification refers to the genetic enhancement of key food crops with enhanced nutrients[6]. It differs from fortification (addition of exogenous nutrients as in iodized salt) by increasing the nutrients of crops at source through agricultural interventions, viz. agronomy, breeding and biotechnology.

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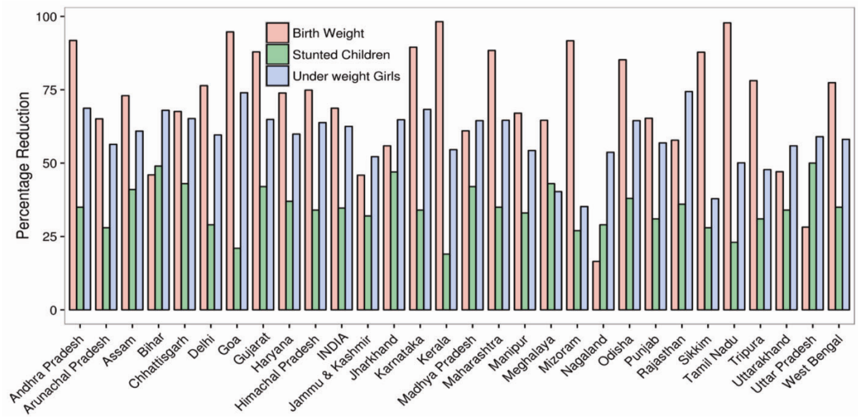

Figure 1. State-wise (%) of birth weight <2.5 kg; stunted children and underweight adolescent girls[3].

Table 1. Range of variation in target crops for protein, Fe and Zn

Crops	Protein (%)	Fe (ppm)	Zn (ppm)
Rice (brown)	6–7	2–34	10–55
Wheat	12–14	25–55	25–45
Maize	8–10	11–83	4–53
Sorghum	10–12	10–65	10–45
Pearl millet	6–21	30–130	25–85
Small millets:	8–14	28–142	5–60
Finger millet			
Foxtail millet			

Source: Institutes associated with ICAR-CRP biofortification.

Approaches of biofortification

Agronomic

Addition of the appropriate nutrient as an inorganic compound to the fertilizer increases the mineral content of the plant as demonstrated successfully in crops like rice, wheat and maize[7]. However the strategy is difficult to apply generally because of the additional expenses involved and the properties of nutrient and crop.

Conventional breeding

India is one of the mega centres of agro-biodiversity and limited efforts have been made to evaluate the promising germplasm for enhanced nutrients in several crops. With some identified donors for high nutrients, varieties are being developed through conventional breeding by crossing with popular varieties (Table 1). The breeding lines with adequate amounts of nutrients and promising yield thus developed are evaluated under the Indian Council of Agricultural Research (ICAR) – All India Coordinated Research Projects (AICRP) for varietal release. Recent approaches for biofortification include identification of genomic regions/candidate genes for high nutrients through tagging/identification of major genes or mapping of quantitative trait loci (QTL) followed by their introgression into popular varieties. Being a genetic solution, growing biofortified crops do not require any additional expenditure for farmers as this approach uses intrinsic properties of crops. Since biofortified crops are developed through conventional breeding, regulatory constraints are not applicable for their release[7].

Genetic modification technology

In some cases, genetic variability for desirable target traits for biofortification is not available in the germplasm. Hence, transgenics approach using genetically modified (GM) technology is the only viable option. The methodology involves introduction of genes from novel sources for desirable target traits and has advantages of unlimited access to the genes of interest, targeted expression in tissues of interest, rapid and direct application by introduction into popular varieties and stacking of different genes. Several transgenic experiments in many agricultural crops targeted protein and micronutrient accumulation in target tissues. The popular example is 'Golden Rice' for β-carotene. However, limited progress for release has been made so far, mainly due to constraints of intellectual property and regulatory issues[8].

Biofortification, therefore, can be a sustainable approach for achieving nutritional security along with dietary diversification, supplementation and commercial fortification strategies. The typical advantages of biofortification are:

- It capitalizes on the regular daily intake of a consistent and large amount of food staples across populations regardless of age, gender and economic status.
- It is a one-time investment to develop seeds those fortify themselves, and thus cost-effective.
- Once in place, the biofortified crop system is highly sustainable and hence constant monitoring is not needed.
- More importantly biofortification does not compromise yield *per se* and thus is economically sustainable to farmers.

- Since the nutrients are provided through food in natural form, toxicity issue does not generally arise.

Realizing the importance of crop biofortification in achieving the country's nutritional security, ICAR has sanctioned a Consortia Research Platform (CRP) to ICAR-Indian Institute of Rice Research (IIRR), during the plan period of 2014–17. This has been done to enhance the nutritional status of major food crops of the country such as rice, wheat, maize, sorghum, pearl millet and small millets through biofortification approach and involving institutes of ICAR, Indian Council of Medical Research (ICMR), state agricultural universities (SAU) and traditional universities. With the availability of genotypes and genes as proof of concept for biofortification and considering the significant progress witnessed in several crops with respect to biofortification, CRP aims at development of cereals biofortified with enhanced β-carotene, quality protein, Fe and zinc (Zn).

Proof of concept

Initially research efforts in agriculture were prioritized for achieving self-sufficiency of food grains. Now the scope is also extended to biofortification of major food crops as a strategy to ensure nutritional security to address malnutrition. In India, recently, two varieties with high Zn (DRRDhan 45) and high protein (CRRDhan 310) in polished rice were developed through conventional breeding without compromising yield, and were released nationally through AICRP-Rice. A high-Fe pearl millet variety (Dhanashakti with 71 ppm Fe) was released through AICRP-Pearl millet along with private seed sector and has been widely adopted by farmers. In India and around the world, several quality protein maize (QPM) hybrids with enhanced lysine and tryptophan have been released and are currently under cultivation. Further, provitamin A rich version of Vivek QPM-9 (a single cross hybrid) developed at ICAR-Indian Agricultural Research Institute (IARI) has recently been identified in AICRP-Maize. One of the lentil varieties, 'PusaVaibhav' was identified as rich in Zn. In Bangladesh, the first high Zn rice (BRRIdhan 62) was released in 2013. Wheat lines with increased Zn content developed through the HarvestPlus programme are under field trials in India and Pakistan. Further, several provitamin A rich maize cultivars have been released in several African countries, viz. Malawi, Zimbabwe, DR Congo, Zambia, Nigeria and Ghana. Cassava varieties enriched with provitamin A were released in Nigeria and are under field trials in DR Congo. In Uganda and Mozambique, sweet potato varieties with provitamin A were released and the impact was studied. Field trials for beans with enhanced Fe are being conducted in DR Congo and Rwanda[9].

However, a major concern for biofortified crops is the bioavailability of enhanced nutrients like Fe and Zn in humans, that is affected by antinutrient factors like phytate (phytic acid or phytin)[10]. Though breeding for low phytate genotypes is important from bioavailability point of view, phytate is important in metabolism of crop plants and thus calls for a proper balance of levels of phytate for bioavailability of nutrients and yield. The high variation in Fe and Zn as observed across different growing locations because of variations in soil mineral contents is also another issue.

Rice

Rice is the major calorie supplement for two thirds of the Indian population with a consumption of ~220 g per day. However polished rice is a poor source of micronutrients[11]. It is observed that in polished rice, Zn and protein content can be enhanced through conventional breeding. However for increasing β-carotene and Fe, transgenics appears to be the only viable solution.

Fe and Zn

Thousands of rice germplasm lines have been screened for Fe and Zn content in brown and polished grain across the world, and many promising donors were identified. However, 90% of Fe and 40% of Zn are lost during polishing[12,13]. Several QTL for grain Zn concentration and genes associated with Zn metabolism have been reported in rice[14]. Using donor from the HarvestPlus programme, 'DRRDhan 45' was released by IIRR. Two more varieties with high nutrient content in polished rice were released as 'Chattisgarh zincrice-1' for the state of Chattisgarh by Indira Gandhi Krishi Viswavidyalaya (IGKV) and as 'Mukul' (CRRDhan 311) for the state of Odisha by ICAR-National Rice Research Institute (NRRI). Transgenics in rice have been developed with 3–4 times as much Fe than wild-type using different sources of ferritin gene[15,16].

Protein

Several landraces and released varieties have been characterized for their protein and amino acid profiles in rice, and 'Heera', an old variety of rice, was found to have >10% protein. The mean crude protein content of the varieties as estimated using Kjeldahl method was in the range of 6–8% (ref. 17). 'CRRDhan 310' with >10% protein in polished rice developed by NRRI has also been nationally released. Genomic regions and genes associated with protein in rice are being deciphered[18].

Provitamin A

Golden rice was developed with three genes for biosynthesis of β-carotene in grain and the latest version is

GR2R with >20 ppm of total carotenoids[8]. Three research groups in India, viz. IARI, IIRR and Tamil Nadu Agricultural University (TNAU) have been involved in the development of Indian versions of golden rice from the original prototype in collaboration with the International Rice Research Institute (IRRI) supported by the Department of Biotechnology (DBT), India.

Wheat

Wheat is another major staple food crop of India and has contributed significantly in the reduction of hunger and malnutrition.

Fe and Zn

Studies indicate two-fold variations (25–55 ppm) in Fe and Zn content among hexaploid wheat genotypes and four-fold (up to 100 ppm) in diploid accessions[19,20]. However, exploitation of diploids in improving micronutrient density in wheat remains to be realized because diploids have very thin grains with higher micronutrient concentrations in bran portion. From the studies at ICAR-Indian Institute of Wheat and Barley Research (IIWBR), higher Fe and Zn content in wheat varieties developed before green revolution and comparatively lower levels in varieties developed after green revolution were observed. The reason could be the selection for high yields rather than the nutritional quality. Reports indicate significant genotypic effect on Zn content and lesser genotype × environment (G × E) effects demonstrating the possibility of enhancing Zn content using breeding approach[21].

Protein

Genetic resources such as wild tetraploid emmer wheat (*Triticum turgidum* ssp. *dicoccoides*) with higher levels of micronutrient and grain protein content have been identified. A QTL (*Gpc-B1)* was identified in *dicoccoides* and transferred into cultivated bread and durum wheat for higher grain protein and mineral content[22]. In India, Punjab Agricultural University (PAU), IIWBR and IARI transferred the *Gpc-B1* QTL into high yielding backgrounds of wheat and the materials developed are being tested under AICRP-Wheat. Initially 40 ppm was put as target for Zn content in high yielding backgrounds. Agronomic interventions with foliar application of $ZnSO_4$ exhibited increased Zn content in wheat grains especially under Zn-deficient soils.

Low phytate

Studies showed larger variability (six-fold) in phytase levels in synthetic hexaploids of wheat. Thus the trait of high phytase levels is being transferred into high yielding backgrounds using microlevel test developed in IIWBR[23].

Maize

India is the second-most important maize growing country in Asia, and out of the total production of maize in India, 10% is used for human food, while 60% is utilized for poultry- and animal-feed[24].

Fe and Zn

Sufficient genetic variation is available in maize germplasm for Fe (15 to 159 ppm in mid-altitude and 14 to 134 ppm for low land inbred lines) and Zn (12 to 96 ppm for mid-altitude and 24 to 96 ppm for lowland inbred lines)[25]. Several QTLs governing the accumulation of Fe and Zn in maize have been reported. Wide genetic variation for kernel Fe and Zn in diverse set of normal and QPM – inbreds was reported by IARI[26].

Low phytate

Phytase, the enzyme used for reducing the phytate content in animal feed has big market potential, particularly for poultry and pig feeds. In maize, three low phytic acid (*lpa*) mutants have been isolated, viz. *lpa1*, *lpa2* and *lpa3* with 66%, 50% and 50% reduction in phytic acid content respectively. In India, *lpa2-2* allele has been successfully introgressed into elite inbreds at TNAU and marker-assisted introgression of *lpa1* and *lpa2* mutants in early maturing inbreds, viz. ‘CM145’ and ‘V334’, has been carried out at Vivekanda Parvatiya Krishi Anusandhan Sansthan (VPKAS)[27,28].

Protein

Traditional maize possesses poor endosperm protein due to low levels of essential amino acids such as lysine and tryptophan. With the discovery of the enhanced nutritional quality of the maize mutant *opaque2*, diverse open pollinated varieties and hybrids in quality protein maize (QPM) genetic backgrounds have been released worldwide and marker assisted selection has been applied to develop locally adapted QPM germplasm[29]. India released its first soft endosperm-based nutritious maize composites in 1970, the first hard-endosperm QPM composite in 1997 and the first QPM hybrid in 2001. Since then, research efforts at various ICAR institutes and SAUs have led the development of QPM version of elite commercial hybrids for different agro-ecologies of the country[30]. First report of marker-aided selection (MAS) of *opaque2* led to the commercial release of ‘Vivek QPM-9’ in India[30].

Provitamin A

Traditional yellow maize contains low provitamin A (<2.5 ppm) as compared to global target of 15 ppm. Screening of a diverse set of 380 maize inbred lines has identified a few inbreds with favourable alleles of *lycopene epsilon cyclase* (*lcyE)* and *β-carotene hydroxylase 1* (*crtRB1)*[31]. The favourable allele of *crtRB1* capable of enhancing *β*-carotene to 15 ppm was introgressed into parental inbreds of commercial hybrids. The first ever pro-vitamin A rich version of Vivek QPM9 developed through breeding efforts in India by IARI was recently identified in AICRP-Maize. Besides, *crtRB1*-based popular four QPM hybrids are being evaluated.

Sorghum

Sorghum is the fifth most important cereal crop across the world, and in the semi-arid tropics, it is the second cheapest source of energy and micronutrients after pearl millet[32]. In India, sorghum contributes around 50% of the total cereal intake (75 kg grain per head per year), especially by rural consumers in the major production regions.

Wide variability for grain Fe (12–68 ppm) and Zn (11–44 ppm) was also observed among the public bred cultivars and parental lines in the studies at ICAR-Indian Institute of Millets Research (IIMR)[33]. The rainy season specific sorghum commercial hybrids possess better Fe and Zn contents compared to post-rainy sorghums[34]. A biofortified, dual purpose (grain and fodder) tall hybrid with high Fe (46 ppm) and Zn (29 ppm) was developed by a private company recently. Agronomic biofortification attempts did not result in significant increase in grain Fe or Zn due to external application of Fe and Zn fertilizers[35].

High variability for antinutritional factors like polyphenols, phytate, fibre, etc. has also been observed which affects bioavailability of grain Fe and Zn[36]. Bioaccessibility of Fe and Zn from sorghum was reported to be very low at 4.13% and 5.51% respectively[37].

At International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), a total of 2267 core germplasm accessions were screened and promising donors were identified with Fe ranging from 20 to 70 ppm and Zn from 13 to 47 ppm under the HarvestPlus programme. New sorghum parental inbred lines and hybrids with high Fe and Zn are being developed at national and international programmes. A sorghum variety, '12KNICSV-188', with three times higher Fe (129 ppm) content and high yield has been released in Nigeria recently.

Pearl millet

Pearl millet biofortification programme was intensively supported by HarvestPlus and ICRISAT for the genetic improvement of grain Fe with Zn content as an associated trait. Large variability for both the micronutrients has been reported in advanced breeding lines, populations and parental lines of hybrids[38]. Using parental lines with high Fe, hybrids are being developed and tested by national and international programmes. New sources of Fe and Zn content (other than *iniadi*) in the germplasm collections are also being explored for genetic diversification for high Fe and Zn content.

The released variety 'Dhanashakti' is the first biofortified crop cultivar for Fe in public domain in India and has been included in the Nutri-Farm Pilot Project of Government of India for addressing Fe deficiency in India[39,40]. In addition, many more hybrids have been identified with high Fe content (>55 ppm) and are under cultivation in ~one lakh hectares. The high adoption of biofortified pearl millet hybrids/varieties is due to high yields, downy mildew resistance and drought tolerance. Three independent studies showed that consumption of 200 g of 'Dhanshakti' can meet 100% of recommended daily allowance (RDA) of Fe in adult men and children in India and 60% of the RDA in NPNL (non-pregnant and non-lactating) women. In AICRP-Pearl millet, IHT-Biofortification trials have been constituted and several advanced breeding lines with >80 ppm Fe and >50 ppm Zn content are being evaluated. One hybrid 'MH 1928' that was identified for release at national level possesses high Fe (>61 ppm) along with high grain yield. Another four hybrids (>70 ppm) bred for high yield combining with high Fe and Zn content are in the third year of testing in AICRP-Pearl millet trials. Pearl millet has also been added to the cereals of Public Distribution System as part of the National Food Security Act of Indian Government.

Small millets

Fe and Zn are relatively in higher concentrations in small millets compared to other major cereal crops of the country. Reports from National Institute of Nutrition (NIN) showed the Fe content of little millet (93 ppm) as compared to finger millet (39 ppm), wheat (35 ppm) and rice (18 ppm); however, varietal variations exist for both Fe and Zn content[41,42]. Finger millet grains have been found to accumulate anti-nutritional factors like tannin (3880 ppm) followed by ferulic acid (70.8 ppm) in larger quantities with strong negative correlations with Fe and Zn[43]. Further, variation of phytic acid contents observed among the genotypes could be as a result of adaptation of different genotypes to the different environmental conditions[44]. It was found that 50% of the Fe present in the diet might be bound to tannins and phytic acid. Processing techniques like soaking, roasting, boiling, germination, fermentation and malting tend to reduce tannin content[45,46].

At the AICRP-Small millets, nutritional aspects of small millets are being studied for Fe, Zn and calcium along with antinutrient factors. The foliar application of $ZnSO_4$ at the time of flowering and 15–20 days after flowering in finger millet genotype 'GPU-28' enhanced the grain Zn content up to 16% (ref. 47). The bioavailability is being increased by processing technique called 'popping' that enhances the bioavailability of Fe from 12.1 to 16.4 ppm and Zn from 15.3 to 22.8 ppm without altering the whole grain contents. The enhancement of the bioavailability of Fe to the extent of 50% and Zn to the extent of 75% through processing technologies like popping, malting is being studied[48].

Biofortified crops in human nutrition

The sole purpose of biofortification is to improve the nutrient quality of food grains. However, the quantity of nutrient does not often correlate with that of its efficacy in consumers, due to poor bioavailability. The term 'bioavailability', refers to the proportion of the quantity of nutrient ingested that undergoes intestinal absorption and utilization by the body (i.e. haemoglobin synthesis and improvement in serum Zn and vitamin A levels, etc.). Therefore, ensuring the bioavailability of nutrients from biofortified crops is often the key to success. Supplementation of Fe-biofortified rice among Fe-deficient, non-anaemic Filipino women improved the Fe status, by providing an average additional 1.4 mg d^{-1} of Fe[49]. A recent meta-analysis of four randomized trials on the effects of Fe status of Fe-biofortified staple food crops: (1) Fe-biofortified rice in 191 adult nuns in Manila, Philippines, (2) Fe-biofortified pearl millet in 246 adolescents in SarolePathar, India, (3) Fe-biofortified beans in 234 female university students in Butare, Rwanda, (4) Fe-biofortified beans in 568 male and female primary school students in Oaxaca, Mexico concluded that Fe-biofortification interventions improved indicators of Fe status[50]. Similarly, Zn biofortified rice improved the Zn status in healthy adults, to comparable levels to that of Zn fortified food, implying that biofortification is equivalent to that of food fortification[51]. Studies in Zambian children reported that feeding Zn-biofortified maize is sufficient to meet the Zn requirements in vulnerable children[52]. In India, feeding 'Dhanashakthi', Fe rich pearl millet significantly improved the Fe status in children compared to control-pearl millet[53]. In another study, feeding of Fe (124 ppm) and Zn (84 ppm) biofortified pearl millet as the major staple food in children aged two years was reported to be more than adequate to meet the physiological requirements for these micronutrients[54]. These studies unequivocally demonstrate the potential of biofortified crops in improving the targeted nutrient status, and therefore serving the intended benefit.

Status and progress of CRP biofortification

Under CRP Biofortification in rice, along with support from HarvestPlus, DBT and other supporting agencies, several genotypes with high Zn and protein content in polished rice and Fe content in brown rice were identified across IIRR, NRRI, IARI, IGKV, University of Agricultural Sciences (UAS) (Bengaluru) and TNAU. Many breeding lines with higher nutritional quality are being evaluated under AICRP-Rice. Transgenic rice lines for high β-carotene, Fe and low phytate are under glasshouse studies. For wheat, genotypes with higher Fe and Zn content have been identified by IIWBR, IARI, PAU, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), UAS (Dharwad) and are being tested at multi-locations. The QTL (*Gpc-B1*) for high protein content is being transferred into high yielding wheat varieties. A few synthetic hexaploids were identified as having very high phytase levels and these are being used in breeding for improving phytase levels in bread wheat varieties with high yield potential. Several experimental QPM hybrids are currently under different stages of AICRP-Maize. Research efforts at IARI have led to introgression of *crtRB1* into parental lines of elite hybrids, and one provitamin A rich maize hybrid has been identified in AICRP-Maize. Besides, *opaque2*, *crtRB1* and *lcyE* have been combined to develop multi-nutrient maize at IARI. For sorghum, the identified donors were assembled and are being used in generating new variability by crossing with popular cultivars and parental lines. Development of food products with multi-grain/ready-to-cook suitable for mid-day meal with fortification using natural sources of Fe and Zn is in progress. In pearl millet, many parental lines, germplasm and hybrids/varieties with Fe content (>70 ppm) and Zn content (>40 ppm) have been developed and are being evaluated. Promising lines of foxtail millet, finger millet and small millets for grain Fe content have been identified and processing for enhancing the bioavailability is being standardized. *In vitro* nutrient composition, gas production and digestibility data of biofortified straw samples of small millets at ICAR-National Institute of Animal Nutrition and Physiology (NIANP) suggested that biofortified straw samples are better as staple roughage source for feeding of ruminants. Under the CRP, NIN has been mandated to study the bioavailability of nutrients among human populations using biofortified crops developed/being developed in the country. With the exclusive facility for coupled *in vitro* digestion/*Caco-2* cells model at NIN, the bioavailability of Zn from 'DRRDhan 45' was assessed[55,56]. The results demonstrate that the Zn bioavailability from 'DRRDhan 45' was about 11%, which is similar to its check variety (IR64). However, Zn accumulated in intestinal cells with 'DRRDhan 45' was 1.5 fold higher compared to its check variety, implying higher absorbable Zn content in this variety.

Challenges

- Though several products in various crops were developped as a proof of concept for biofortification, systematic studies of their nutritional impact are needed so that the demand for biofortified food drives research and product development (as for diabetic rice).

- Research coordination between the agriculture and nutrition specialists requires further strengthening to decide upon the target level of protein and micronutrients, their retention after storage, processing and cooking and potential levels of consumption by the target population.
- For GM technology, the major problem of developing fortified crops is the cost of research and the regulatory compliances. Food safety experiments on GM foods are required to be intensified.
- Adequate information programmes are needed to create public awareness for the adoption of the varieties by farmers and public acceptance by consumers, especially if there are obvious changes in the qualities of the crop, such as colour as in golden rice and white maize.
- Strong policy interventions are needed to create interlinking of biofortified produce with various National Programmes like Rashtriya Krishi Vikas Yojna. Higher profits would make the farmers interested to grow these improved cultivars.
- Integration of biofortified grains in mid-day meal scheme and several government sponsored programmes such as National Food Security Mission and Integrated Child Development Programme would provide impetus for its popularization.
- Biofortification programmes are also being challenged for 'further simplification of human diets and food systems', as it further restricts the dietary diversity and increases the dependence on overly dependent cereal staple foods.

Conclusion

Biofortification can complement existing interventions for malnutrition with its far-reaching implications in achieving the nation's nutritional security. Various government organizations like ICAR, DBT and ICMR, along with international organizations, viz. HarvestPlus, IRRI are now converging their research efforts of biofortification for product development, testing and validation. With proper planning, execution and implementation, biofortified food crops will help India address the malnutrition problem with minimum investment in research and have a significant impact on the lives and health of millions of needy people of the country.

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