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Nutrition-sensitive food systems and biofortified crops

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Abstract The realization that economic growth is a necessary but insufficient condition for improving the nutritional status has led to a paradigm shift in addressing malnutrition through nutrition-sensitive development. Biofortification is one such nutrition-sensitive food system intervention designed to supply crucial micronutrients through staple diets to undernourished populations that may not otherwise be able to consume diversified diets. Biofortified foods can provide 35–50% of the daily estimated average requirement of micronutrients. Biofortification is still at a nascent stage, however, and the state may help in developing a value chain for biofortified. The paper discusses pragmatic policy interventions in that direction.

Keywords Hidden hunger; biofortification; conventional plant breeding; value chain; brand building

JEL codes I31, L66, Q13, Q16, Q18

A healthy immune system is the first line of defence against health threats, including viruses such as the corona virus. Hidden hunger, arising out of micronutrient deficiency, constitutes a roadblock for a healthy immune system, and it is a serious problem (FAO, IFAD, UNICEF, WFP, WHO 2020). Malnutrition is estimated to affect 2 billion people in the world; its burden is unacceptably high (Fan et al. 2019). Hidden hunger is much more widespread in South Asia than in any other part of the world. The extent of anemia among pregnant women in South Asia is 52%, more than the global prevalence of 38%, and 58% among children under five years in Asia (but 43% worldwide). Zinc intake is inadequate for 30% of the population in South Asia but for only 17% worldwide. About 31–57% of preschool children are alarmingly deficient in Vitamin A. Nearly 45% of childhood deaths are associated with malnutrition (Harding et al. 2018).

The diets of rural Indians have much to be desired. The rural population consumes a relatively high share of calories from whole grains and substantially less from protein sources vis-à-vis the EAT-Lancet reference diet (Sharma et al. 2020). The EAT-Lancet diet requires a certain amount of spending but most people in rural India spend just one-fifth of the required budget, with a very meagre amount on meat fish poultry, dairy, and fruits (Gupta et al. 2021). Climate change reduces the iron, zinc, and protein in plants like wheat, rice, maize, and soybean and aggravates the burden of malnutrition in South Asia (Myers et al. 2014).

It is feared that through the economic downturn and other disruptions, the COVID-19 pandemic might worsen all types of malnutrition, including hidden hunger (Osendarp et al. 2020). Deficiencies in micronutrients result in poor health and lower cognitive development, educational outcomes, work productivity, and earnings, thereby reducing the total welfare in society. The malnutrition-related cost is 2.5% of the national income in India (Jitendra 2013) and 9 billion disability-adjusted life years (Qaim et al. 2007).

Paradigm shift in combating malnutrition

Income growth is a necessary but not sufficient condition for reducing malnutrition. This realization led the international development community to focus on direct nutrition-sensitive interventions in the first decade of the 21st century (Gillespie et al. 2013). This is akin to the paradigm shift worldwide in the mid-1970s to taking the basic needs approach and making the associated policy changes to attack deprivation directly.

The chain of events that led to the catapulting of malnutrition to the centre of policy focus started with the widespread outrage at the hunger and malnutrition during the 2007–08 global crisis and the publication of the first Lancet Series in 2008 on maternal and child malnutrition. Frustrated with the lack of discernible improvements in the nutrition status of the masses, several concerned individuals in the United Nations (UN), government, donors, and civil society launched the Scaling Up Nutrition movement in 2010 on the principle that everyone has a right to food and good nutrition. The Scaling Up Nutrition movement has 61 national governments and four Indian states (Jharkhand, Maharashtra, Uttar Pradesh, and Madhya Pradesh) as members. The subsequent Rome Declaration on Nutrition in 2014 at the Second International Conference on Nutrition brought malnutrition into sharp policy focus.

These concerted endeavours crystallized in the form of Sustainable Development Goal 2 in 2015 to “end hunger, achieve food security and improved nutrition, and promote sustainable agriculture” that virtually made the links between agriculture and nutrition explicit (Allen and de Brauw 2018). This brings about a paradigm shift that requires all the development programmes and processes in general and all the programmes in the food system in particular to be nutrition-sensitive (Pingali and Sunder 2017).

The UN General Assembly proclaimed 2016–25 as the Decade of Action on Nutrition, based on the Rome Declaration of Nutrition (RDN. and established institutional mechanisms. Five international organizations[1] have been working together for the first time and publishing annual reports entitled State of Food Security and Nutrition in the World. The International Food Policy Research Institute (IFPRI) has begun publishing annual Global Nutrition Reports. Several governments have started to act to combat malnutrition. India, along with other SUN countries, announced a slew of measures to combat hidden hunger. India’s National Nutrition Strategy 2016 includes biofortification through micronutrient-dense foods. The country also started the POSHAN Abhiyaan, a flagship programme, in 2017 (Menon et al. 2021; Suri and Kapur 2020).

Biofortification for combating hidden hunger

Dairy and livestock products, fruits, vegetables, and pulses are dense in micronutrients, but the poor in developing countries do not eat enough of these foods. In India, investments in the improvement of staple crops drove down food prices for a long time in the aftermath of the green revolution, but other foods are inaccessible and unaffordable. Markets have failed to promote the dietary diversity needed for nutritional security. The state must bring the diversity about through supplementation, fortification, and the new route called biofortification (Pingali and Sunder 2017).

Biofortification is the process of increasing the density of vitamins and minerals in a crop through conventional plant breeding and through agronomic and transgenic techniques. The existing biofortified crop varieties follow only the conventional plant breeding methods. The level of nutrients in biofortified crops cannot be as high as in industrial fortified foods but can increase the daily micronutrient intake. Plant breeders endeavour to enrich the plants to provide a sufficient part of the daily estimated average requirement of micronutrients and ease the deficiency in the population.

The deficiency varies by age group, gender, and a host of other factors (Bouis et al. 2017). If C_f is the per capita consumption of the staple, D_f is the density of mineral/vitamin to be enhanced in the staple, R_p is the retention of the mineral/vitamin after processing or storage or cooking, and B_c is the percentage availability after consumption, the extra nutrient supplied through biofortification (EN_b) can be shown as

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[1] Food and Agriculture Organization (FAO). International Fund for Agricultural Development (IFAD). United Nations Children’s Fund (UNICEF). World Food Programme (WFP). and World Health Organization (WHO).

$$EN_b = C_f D_f R_p B_c \qquad \ldots(1)$$

The additional percentage of the estimated average requirement supplied (A_E) can then be obtained by dividing EN_b by the estimated average requirement (E) of the particular mineral/vitamin:

$$A_E = \frac{EN_b}{E} \qquad \ldots(2)$$

Biofortification complements the existing interventions and provides micronutrients to vulnerable populations in a relatively easy, cost-effective, and sustainable manner. In rural areas, farm households' consumption of biofortified crops helps reduce malnutrition initially, and the predominantly rural nature of poverty places South Asia in an advantageous position in harnessing biofortification. Later, as markets develop, the urban households start consuming these foods.

The biofortified varieties of food crops have been diffusing in developing countries. These varieties, cultivated by 8.5 million farming households across 14 countries of Africa, Asia, and Latin America, and the Caribbean in 2019, benefitted 42.4 million people (Bouis et al. 2019). In 2018, 500,000 people from farming households consumed iron pearl millet in India, while 240,000 farmers cultivated it in 2019 (Foley et al. 2021). A multi-institutional approach to biofortification was implemented as a global plant breeding strategy, and the pioneering work by Harvest Plus of IFPRI led to the rapid diffusion of biofortified food crops.[2]

Few studies examine the impacts of biofortification on poor farmers in rural areas. These studies find that biofortification raises the micronutrient intake among children and women and that the benefits can be directed towards lower-income groups (Garcia-Casal et al. 2017; Dizon et al. 2021). Studies in several countries find that consumers accept or prefer biofortified foods (Talsma et al. 2017). Biofortified crops provide 35–50% of the daily estimated average requirement of the micronutrients.

For children 4–6 years old and for non-pregnant, non-lactating women of reproductive age, biofortified beans provides an additional 35% of the estimated average requirement of iron and biofortified pearl millet an additional 40%. The additional zinc in wheat provides up to 25% of the estimated average requirement and, in rice, up to 40%. Biofortified crops provide the maximum estimated average requirement of 50% in the case of vitamin A in cassava, maize, and sweet potato (Bouis et al. 2019).

Recent studies show that processing methods like cooking do not degrade maize biofortified with zinc (Gallego-Castillo et al. 2021). A meta-analysis determines that consumers are willing to pay 21.6–23.7% more for these crops (Garcia-Casal et al. 2017).

Randomized control trials were conducted in India to test the effectiveness of biofortified crops in reducing micronutrient deficiencies. The results of the trials were positive. When pearl millet fortified with iron and zinc is fed as the staple food to children 2 years old, the quantities absorbed are more than adequate to meet the physiological requirements of iron and over 80% of the physiological requirement of zinc (Kodkany et al. 2013).

Another study (Finkelstein et al. 2017) finds that children eating *roti* and a savory snack (*sev*) made with biofortified pearl millet are 64% more likely to become iron-replete by six months; it increases serum ferritin and total body iron to reverse the deficiency. Biofortified pearl millet improves reaction time in schoolchildren and cognitive skills like attention and memory (Scott et al. 2018) and improves light physical activity in adolescent schoolchildren (Pompano et al. 2021). Eating the high-zinc wheat in New Delhi as whole wheat flour chapatti or porridge reduced the number of days children were sick with pneumonia by 17% and vomiting by 39%; in women, it reduced the number of days they had fever by 9% (Sazawal et al. 2018).

Biofortification is one of the most cost-effective solutions to combat hidden hunger, as per the 2008 Copenhagen Consensus; every dollar spent on biofortification provides a benefit worth 17 dollars (Bouis et al. 2017). Biofortified varieties of food crops yield agronomical gains; infusing micronutrients into cultivars helps growth and yield and does not entail a yield penalty (Yadava et al. 2018). Ex ante studies from

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[2] Howarth Bouis, the founder of HarvestPlus, won the World Food Prize in 2016, along with Maria Andrade, Robert Mwanga, and Jan Low.

India and other countries find that the internal rates of return in the pessimistic biofortification scenario are as high as 61% for iron, 53% for zinc, and 35% for vitamin A (Qaim et al. 2007).

More than 290 varieties of 12 biofortified crops have been officially released in over 30 countries: key staples such as iron beans and pearl millet; vitamin A cassava, maize, and orange sweet potato; and zinc maize, rice, and wheat (Bouis et al. 2019). The concerted efforts by the Indian Council of Agricultural Research (ICAR) to harness this process, with active support from HarvestPlus, resulted in the release of several biofortified crop varieties, including multi-nutrient rich cultivars (Table 1). HarvestPlus and its partners have developed wheat lines that can achieve zinc concentration of 60–70 ppm to add 20–25 ppm in the daily diet of children and reproductive-age women (Sazawal et al. 2018).

In 2012, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) released the first biofortified crop in India, the iron-rich ICTP 8203 pearl millet variety. Later, hybrids like Dhanshakti and ICMH 1201 with 65–74 ppm iron were released. Private companies commercialize these crops under licence from public developers; some crops were included in the Nutri-Farm Pilot Programme of the Government of India. Similarly, high-zinc and high protein varieties are released in rice for cultivation in several states. While high zinc rice Dhan 45 is being cultivated, protein-rich CR Dhan 310 is diffusing faster in Odisha due to its popular base Naveen.

Ex ante studies at the Directorate of Rice Research, Hyderabad show that zinc-enhanced rice can reduce zinc deficiency up to 35% and, at USD 3 for each life-year saved, it is quite cost-effective (Nirmala et al. 2016). The agronomic performance of Dhan 45 is similar to the local check variety. Several multi-nutrient rich cultivators are also released to simultaneously address the deficiency of several nutrients (Table 1).

Several ICAR institutes have developed many biofortified varieties of crops. The Prime Minister of India released 17 varieties on World Food Day 2020 (ICAR-DKMA 2020). The varieties include CR DHAN 315 of rice (excess zinc), HD 3298 wheat (protein- and iron enriched), DBW 303 wheat (protein-enriched), DDW 48 wheat (iron enriched), and maize hybrid varieties 1, 2, and 3 (enriched with lysine and tryptophan). Other varieties of biofortified crops are finger millet CFMV 1 and 2 (rich in calcium, iron, and zinc), small millet variety CCLMV1 (rich in iron and zinc), and yam varieties Shri Neelima and DA 340 (enriched with anthocyanin).

Value chain development and the global experience

To achieve SDG 2, value chains need to be developed for micronutrient-rich foods (Allen and de Brauw 2018). And actors at all nodes of the value chain—consumers, producers, seed developers, breeders—and enablers like civil society groups need to act to develop the value chain (Figure 1).

Consumers accept biofortified food crop varieties to some degree but, as evidenced in the case of iron beans in Rwanda, they do not prefer to trade off nutrition attributes against consumption attributes (Birol et al. 2015). If the information on the nutrition and health benefits of biofortified crops is not provided, consumers pay little more. If the information is provided, however, they pay a significant premium, and they prefer international brands to local brands (Banerji et al. 2016).

The biofortified crop varieties are developed to be more adaptable and find favour with growers (Nestel et al. 2006). Shorter-duration zinc rice with better submergence tolerance became popular in Bangladesh. In India, improving the shelf life of high-iron pearl millet and enabling farmers to cultivate it in the cool season is expected to improve reach in both cultivation and food products (Bouis et al. 2017).

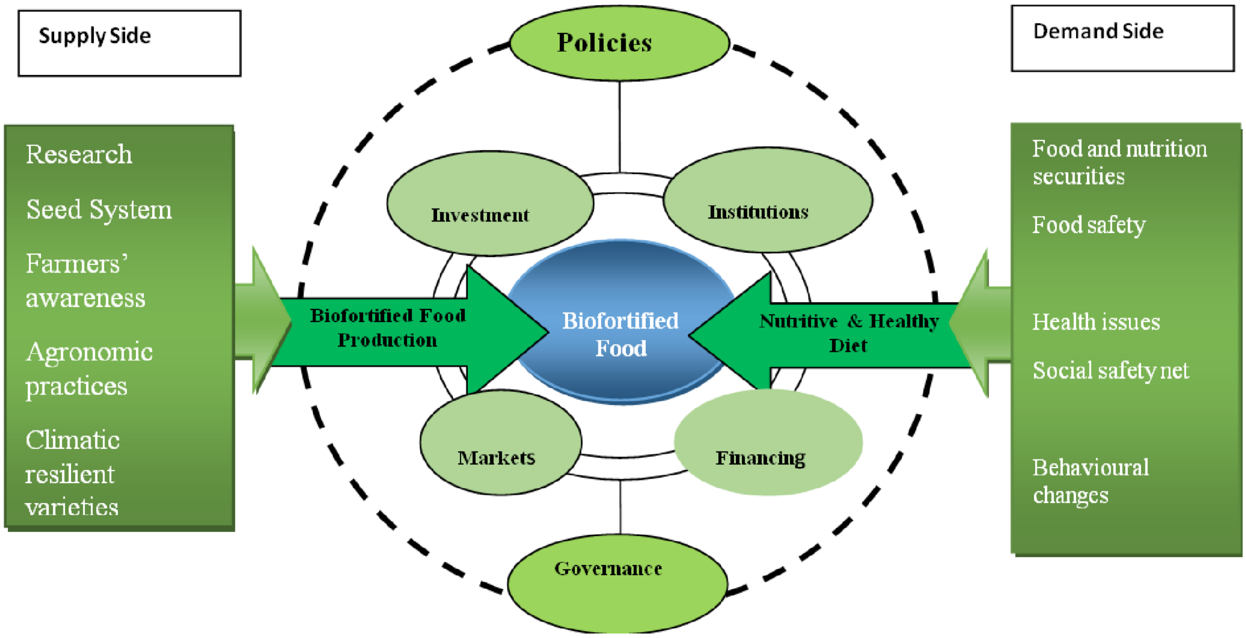
The vibrancy of seed markets determines the strategy for diffusion among growers. The approach in most countries is to engage with the public and private sectors. In countries like Zambia, vibrant seed markets enable the harnessing of seed company networks to mass multiply (Simpungwe et al. 2017). The same strategy is followed in the active seed markets of India. The examples include ICRISAT in the case of pearl millet, HarvestPlus of IFPRI in the case of zinc fortified wheat, and ICAR in the case of rice in Odisha, Telangana, and Chhattisgarh.

However, farmers will grow biofortified food crop varieties only if these fetch better prices than the older

Table 1 Progress in the release of biofortified crop varieties in India

Crop	Variety/Hybrid	Improved vitamin/ mineral/amino acid	Developer
Pearl millet	ICTP 8203 ICMH 1201 HHB 299, AHB 1200	Iron Iron and zinc Iron	HarvestPlus Indian Council of Agricultural Research Chaudhary Charan Singh-Haryana Agricultural University and ICRISAT Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani under AICRIP of Indian Council of Agricultural Research
Rice	DRR Dhan 45,	Zinc	Indian Institute of Rice Research, Hyderabad
	DRR Dhan 49 CR Dhan 310	Protein	National Rice Research Institute, Cuttack
	CR Dhan 311	Protein and zinc	National Rice Research Institute, Cuttack
Wheat	BHU 3 and BHU 6	Zinc	HarvestPlus
	WB 02	Zinc and iron	Indian Institute of Wheat and Barley Research, Karnal
	HPBW 01	Iron and zinc	Punjab Agricultural University, Ludhiana
	Pusa Tejas, Pusa Ujala	Protein, iron, and zinc	ICAR-Indian Agricultural Research Institute, Regional Station, Indore
	MACS 4028	Protein, iron, and zinc	Agharkar Research Institute, Pune
Sweet potato	Orange fleshed Sweet Potato	Vitamin A	HarvestPlus
	Bhu Krishna	Anthocyanin	Indian Council of Agricultural Research
Maize	Pusa Vivek QPM9 Improved	Provitamin A, lysine, and tryptophan	Indian Agricultural Research Institute, New Delhi
	Pusa HM4 Improved	Tryptophan and lysine	Indian Agricultural Research Institute, New Delhi
	Pusa HM8 Improved	Tryptophan and lysine	Indian Agricultural Research Institute, New Delhi
	Pusa HM9 Improved	Tryptophan and lysine	Indian Agricultural Research Institute, New Delhi
Lentil	PusaAgeti Masoor IPL 220	Iron Iron and zinc	Indian Agricultural Research Institute, New Delhi Indian Institute of Pulse Research, Kanpur
Soybean	NRC-127	KTI-free	Indian Institute of Soybean Research, Indore
Mustard	Pusa Mustard 30	Low erucic acid	Indian Agricultural Research Institute, New Delhi
	Pusa Double Zero Mustard 31	Low erucic acid and low glucosilates	Indian Agricultural Research Institute, New Delhi
Cauliflower	Pusa beta Kesari 1	Beta carotene	Indian Agricultural Research Institute, New Delhi
Potato	Bhusona	Beta carotene	Central Tuber Crops Research Institute, Trivandrum
Pomegranate	Solapur lal	Iron, zinc, and vitamin C	National Research on Pomegranate, Pune

Source Adapted from Yadava et al., (2018)



Source Adapted from Joshi (2018)

Figure 1Value chain development of biofortified food crops

varieties, only if they can improve production and income (Nuthalapati et al. 2020), and they have access to processing techniques and processors (Low et al. 2017). These factors of adoption must be kept in mind when biofortifying a food crop variety and promoting cultivation—through the use of demonstration plots by agricultural extension personnel, public service radio programmes, and social marketing techniques such as those used by food companies (Bouis et al. 2017).

In producing and diffusing micronutrient-dense biofortified foods, behavioural change communication — common in health sector interventions—is central (Meenakshi et al. 2010). The heterogeneity of consumers warrants that communication strategies are segmented and targeted. Short messages are more impactful and cost-effective (Banerji et al. 2016). Social marketing strategies can catalyse the diffusion and consumption (Uchitelle-Pierce and Ubomba-Jaswa 2017) of biofortified crops as demonstrated in a randomized trial by Cornell University in Maharajganj of Uttar Pradesh (Merckel 2019). The study concluded that information and knowledge must be curated and made accessible to the target population physically, culturally, and timely. The experience of diffusing high-iron varieties of pearl millet in India reveals that the rabi crop does not have suitable varieties, the trait is invisible, the grains are not segregated, and their shelf life is poor (Karandikar et al. 2018). Brand building and detection kits ought to be developed to overcome this, apart from developing biofortified pearl millet varieties suitable for rabi and with better shelf life.

The interest of multinational companies is slow to develop, and small and medium-size companies can create demand for biofortified grains and food even before supplies reach scale. When the production and supply of foods become sufficient, food products with desirable consumption attributes need development and distribution by small and medium-size processing companies that can detect nutrients and have a certification system. Private sector participation is essential in creating sustainable markets for biofortified seeds and foods, but NGOs remain important in delivering the nutrition information to vulnerable households. The partnership between World Vision and HarvestPlus is an example (McDonald et al. 2017).

In India, ICAR has stipulated the minimum iron content for pearl millet hybrids; this is the first global standard. Also, ICAR has set up a Consortia Research Platform for biofortification research; the platform conducts research on nutritionally enhancing rice, wheat, maize, pearl millet, sorghum, and minor millets. The government declared millets with high nutritive value as nutricereals and includes them in the public distribution system (PDS). That might help the distribution of iron-rich pearl millet.

Biofortification is endorsed as a public health strategy to fight hidden hunger by World Bank, World Food Programme, Bill and Melinda Gates Foundation, USAID, UKAID, several UN organizations, donor agencies, and national and subnational governments. The State of Food Security and Nutrition 2020 has, for the first time, endorsed biofortified foods to reduce micronutrient deficiency (FAO, IFAD, UNICEF, WFP, and WHO 2020). Several countries including India support this intervention and have incorporated biofortification into their national nutrition strategies. But much more needs to be done to produce these novel crops, create demand, and facilitate consumption.

So far, biofortification has centred on coaxing producers to grow orange-fleshed sweet potato because the biofortified varieties of other crops have been commercialized only in the past few years—the development of the value chain for biofortified crops is a recent phenomenon. Consumers are wary of mixing regular sweet potatoes with orange-fleshed sweet potato and complain that it is soft and mushy, indicates market research by HarvestPlus. A nuanced approach is needed to attract the different age groups to consume these foods. The adopting farmers sometimes stifle the flow of information to other prospective growers out of the fear of losing their niche, though there is a contagion effect (Uchitelle-Pierce and Ubomba-Jaswa 2017). The strategies for the delivery of biofortified food crops in any country or region have to be devised considering these factors and undertaking some research.

Conclusions

Economic growth and agricultural production have been consistent and high but have not reduced malnutrition or hidden hunger; therefore, the food system must become sensitive to nutrition. The SDG 2 formalizes the notion.

Biofortification has the potential to ameliorate malnutrition and its adverse consequences. Its cost effectiveness increases with time because once the initial investment, in breeding, is over, the incremental costs are minimal. When used as part of a comprehensive approach, biofortification provides 35–50% of the daily estimated average requirement of micronutrients, especially for the rural poor.

Consumers are willing to pay 21.6–23.7% more for high iron pearl millet and high zinc wheat. Several food products are developed from these crops. Mainstreaming the nutrient traits into all relevant crop pipelines is a challenge. The criteria for minimum micronutrient levels should be set during the varietal release stage, duly considering all relevant facts.

Generating demand is another challenge. The agriculture and health ministries need to communicate and collaborate with other government organizations and stakeholders to educate producers and consumers on the nutrition from food agenda. Social marketing methods and behavioural change communication will help in promoting the consumption of biofortified varieties.

The seed sector must be incentivized to promote adoption and production. The evidence from the adoption of orange-fleshed sweet potato in Africa shows that subsidies will be required for the initial diffusion of biofortified crop varieties (Low et al. 2017). Farmer producer organizations can be encouraged to produce biofortified varieties and develop linkages with private sector organizations that can brand and package the produce for sale. Product labeling, or certification, is important for developing the value chain for biofortified grains and processed foods, as are detection kits for easily and cheaply determining the micronutrient level in food products.

Processors and private retailers can be persuaded to carry biofortified foods, and these can be included in the Mid-Day Meal Scheme and PDS. Scaling up would require researching the kind of food products that would attract urban consumers, labelling them appropriately, and developing niches. The Food Safety and Standards Authority of India may promote processed biofortified foods and include these as a certain share of fortified foods, as the governments in several states have mandated fortification.

The use of biofortification to fight against hidden hunger has some limitations, however. Biofortification has only just progressed beyond orange-fleshed sweet potato with many varieties of several crops; and the current studies on consumer acceptance and willingness depend on the scanty data of only a few crops like sweet potato and cassava. In the long run, nutritional security is conditional on achieving dietary diversity with higher incomes and better functioning markets. Research is needed to understand the impact of consuming several biofortified crops on nutrient intake, total nutrient absorption, nutrition, and health and on the efficacy of these foods for a wider range of age and gender groups, including infants, over a longer period.

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