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Anurag Tripathi
Department of Genetics and Plant Breeding, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology Pantnagar, Uttarakhand, India

Jeet Ram Choudhary
Division of Genetics and Plant Breeding, IARI, New Delhi, India

Nitish Ranjan Prakash
Division of Genetics and Plant Breeding, IARI, New Delhi, India

Correspondence
Anurag Tripathi
Department of Genetics and Plant Breeding, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology Pantnagar, Uttarakhand, India

Bio fortification-Breeding for nutritional security

Anurag Tripathi, Jeet Ram Choudhary and Nitish Ranjan Prakash

Abstract

Biofortification is the process of breeding nutrients into food crops, provides a sustainable, long-term strategy for delivering micronutrients to rural populations in developing countries. Biofortified staple crops such as rice, maize and wheat harbouring essential micronutrients to benefit the world's malnutrient population are under development as well as new varieties of crops which have the ability to combat chronic disease. This review discusses the improvement of the nutritional status as well as approaches of crops to make a positive impact on mankind. Crops are being bred for higher levels of micronutrients using both conventional and molecular Breeding methods; several conventional varieties have been released, while additional conventional and transgenic varieties are in the breeding pipeline. Biofortification is a promising strategy for combating hidden hunger in all over world.

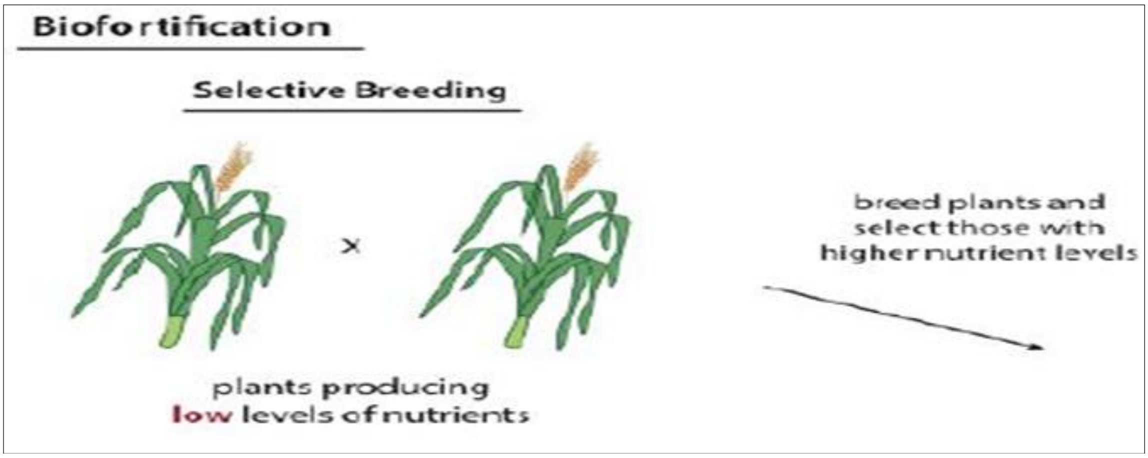
Keywords: biofortification, bioavailability, golden rice, transgenic techniques, micronutrient malnutrition (MNM), molecular breeding, provitamin a, zinc

Introduction

Biofortification is the process of breeding for nutrients rich food crops, provides a comparatively cost-effective, sustainable, and long-term means of delivering more micronutrients (Saltzman *et al.* 2014). Biofortification relies on the plant's biosynthetic (vitamins) or physiological (minerals) capacity to produce or accumulate the desired nutrients. Biofortified crops can be obtained through breeding, provided sufficient genetic variation is present in the diversity spectrum or by exploiting transgressive segregation or heterosis (Mayer *et al.* 2008) [12]. The goal of biofortification strategy is to incorporate the micronutrient-dense traits (like Fe, Zn and Carotene content) in those varieties which already have preferred agronomically and for the consumption purposes by the farmers as well as the consumers. Micronutrient malnutrition (MNM) is the major constrain to provide nutritional security to world population of underdeveloped and developing countries. Among the 20 major risk factors of the global burden of disease estimates, Fe deficiency ranks 9th and Zn deficiency ranks 11th, while in the high mortality countries, including India, they rank 6th and 5th, respectively (WHO 2002) [25]. One in three people in the world suffer from hidden hunger, caused by a lack of minerals and vitamins in their diets, which leads to negative health consequences (Kennedy *et al.* 2003). Today, approximately 842 million people around the globe are undernourished, meaning that they do not get enough food to eat (FAO, 2013) [9]. The global significance of MNM is known as hidden hunger came to the attention of the nutrition community as recently as the mid, 1980s, when protein-energy malnutrition was widely seen as the culprit of the world's nutrition problems (Allen, 2000) [2]. In 1990, The World Summit for Children convoked the governments and facilitated by the UN with support from UNICEF, the World Bank, WHO, FAO, UNDP, CIDA and USAID, was a landmark event in the history of fight against MNM. The development and implementation of biofortification food programs is still in the early stages of growth. Harvest Plus, part of the Consultative Group on International Agriculture Research (CGIAR) Research Program on Agriculture for Nutrition and Health (A4NH), is currently supporting the research and dissemination of staple crops biofortified through conventional as well as molecular plant breeding and through transgenic techniques.

How are Crops Biofortified?

Conventional breeding research has thoroughly demonstrated that micronutrient density can be increased in food staples without negative effects on other farmer-preferred traits. However, Protein content enhancement is negatively correlated with grain yield.



Progress in breeding orange sweet potato, provitamin A maize, provitamin A cassava, high zinc rice and high zinc wheat, and high iron beans and high iron pearl millet is reviewed below. As of 2013 [21], released crop varieties are being disseminated through Harvest Plus and its partners in Uganda (OFSP), Zambia (maize), Nigeria (cassava), the Democratic Republic of the Congo (DRC) (cassava and beans), Rwanda (beans), and India (pearl millet) (Saltzman *et al.* 2013) [1]**.**

Breeding Strategy

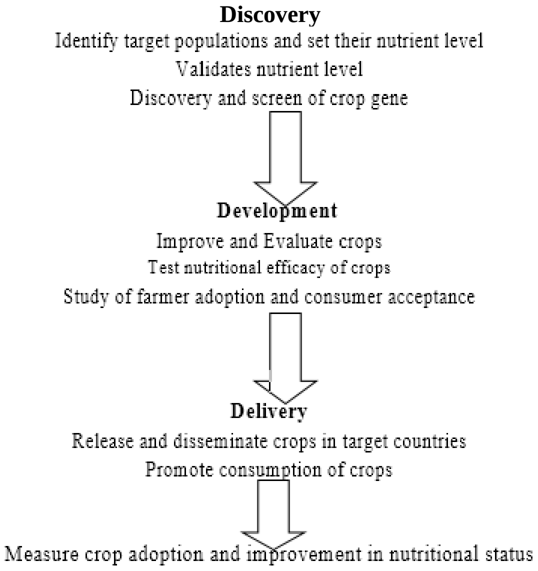


Fig 2: Harvest plus Impact Pathway

Rice

Rice is the staple food of Asian countries, rice provides up to 80 percent of the energy intake of the poor and world’s most important cereal crop for human consumption of more than 3billion people. A high zinc rice variety for Bangladesh and India are developed by the International Rice Research Institute (IRRI) and the Bangladesh Rice Research Institute (BRRI) and was released to farmers in Bangladesh in 2013 (Chowdhury, 2014). The breeding target has been set at 28 ppm zinc in polished rice, an increment of 12 ppm above the baseline zinc concentration of commercially available rice. High-yielding varieties with more than 75 percent of the target are in official registration trials in Bangladesh and India; released in 2013. The highest grain Fe concentration reported in glasshouse studies of genetically modified (GM) temperate japonica rice was a 4.2-fold increase13, reaching 18 μg g^{-1} from a baseline of 4.5 μg g^{-1}, while a maximum of a 6-fold increase was achieved (Wirth *et al.,*2009). Different labs have demonstrated the potential to increase the Zn concentration of rice grains through soil–plant interactions, traditional breeding, and marker-assisted breeding (Impa and Johnson-Beebout, 2012) [11]. Studies using transgenic rice that have been biofortified with iron have centered on the overexpression of iron storage proteins such as ferritin. Rice cultivated from these transgenic plants contain 3–4 times as much iron as their wild-type counterparts (Moretti *et al.*, 2014, Lucca *et al.,* 2002). Transgenic rice crops have been developed by manipulating the phytic acid biosynthetic pathway through RNAi-mediated gene silencing of the IPK1gene, which is involved in catalyzing the final step of phytic acid biosynthesis(Pillay *et al.*, 2014) [20]. Engineering of the provitamin A (β-Carotene) biosynthetic pathway into (Carotenoid-Free) rice endosperm increased the level of β-carotene in rice (Ye *et al.*, 2000) [26]. The biofortified rice was named Golden rice due to their golden grain colour. Golden rice was created by transforming rice with three beta-carotene biosynthesis genes including psy (phytoene synthase) and lyc (lycopene cyclase) both from daffodil (Narcissuspseudo narcissus) and crtI (carotene desaturase) from the soil bacterium *Erwinia uredovora*. Golden Rice 1 contains the PSY gene from daffodil and the CRTI gene from the bacterium *Erwinia uredovora*, both expressed only in the rice seed (Ye *et al.,* 2000) [26]. In Golden Rice 2, β-carotene concentration has reached 37 μg/g dry weights which is 23 times more than Golden Rice1 by replacing PSY with genes from maize (Paine *et al.*, 2005 [18]; Dawe and Unnevehr, 2007). Half the daily recommended allowance of vitamin A for a 1-3 year old child would therefore be provided for in 72g of Golden Rice 2 (Slater *et al.*, 2008) [22].

Maize

Maize breeding is led by the International Maize and Wheat Improvement Centre (CIMMYT) and International Institute of Tropical Agriculture (IITA) in conjunction with NARES in South Africa to make biofortified crop. Germplasm screening discovered genetic variation for the target level (15 ppm) of provitamin A carotenoid in temperate maize, which was then bred into tropical varieties. Recent developments in marker-assisted selection technology have been increased efficiency and accuracy of identifying genes controlling the traits of interest for enrichment of provitamin A in maize. Naqvia *et al* (2009) created elite inbred South African transgenic corn plants in which the levels of 3 vitamins were increased specifically in the endosperm through the simultaneous modification of 3 separate metabolic pathways. The transgenic kernels contained 169-fold the normal amount of -carotene, 6-fold the normal amount of ascorbate, and double the normal amount of folate (Jeong and Guerinot, 2008) [13].A triple-vitamin fortified maize which expresses high amounts of β-carotene, ascorbate, and folate has been developed in the endosperm through metabolic engineering (Mugode *et al.*, 2014) [17]. Biofortified studies in maize began with evaluation in animal models, which all showed very encouraging results. Since traditionally bred maize did not have high levels of provitamin A at the start of the Harvest Plus project (Pixley *et al.*, 2013). Many workers studies proved the feasibility of the method with mid-target level provitamin A maize (Howe 2006, Davis, 2008) [5, 6]. Effectiveness studies after biofortified maize is broadly introduced and disseminated are needed to measure its impact on vitamin A status under normal market conditions as well as the generational effects of feeding β-carotene enhanced staple crops to population groups (Tanumihardjo, 2010). Therefore, maize that has quality protein, enhanced zinc, and increased provitamin A carotenoid may supply better nutrition than any single nutrient approach for populations that have high maize in takes.

Wheat

The initiatives of Biofortified wheat with zinc for Indian subcontinent have been started by CIMMYT. The initial breeding target for whole wheat was revised to 37 ppm zinc, an increment of 12 ppm above the baseline zinc concentration (Amysaltzman *et al.,* 2014). It is expected that adoption of high-zinc wheat will be driven by its improved agronomic properties i.e. N fertilization can promote Fe and Zn accumulation in cereal grains, it has been investigated the influence of nitrate- or ammonium-based N fertilization on the accumulation of Fe and Zn, act as metal chelator pulls in flag leaves and grains of winter wheat (Barunawati *et al.*, 2013) [3]. High N supplies to wheat plants enhanced not only the acquisition and translocation of Fe and Zn to grains but also appeared to stimulate Zn retranslocation out of flag leaves and other plant organs (Kutman *et al.*, 2012 [15]; Erenoglu *et al* 2011) [8]. Hence, Nitrogen availability play as a key component for the zinc biofortification of wheat and thus can improve the nutritional quality of grains as well as who have staple food particularly in developing countries.

Pearl Millet

Pearl millet is consumed by populations in India and West Africa who reside in arid terrain where iron deficiency is prevalent. The fractional absorption of iron in biofortified pearl millet was found to be similar to a low iron variety when fed to young children in India (Hambidge *et al.*, 2013). Pearl millet is a regionally (Maharashtra, Rajasthan, Gujarat, and Uttar Pradesh) important staple crop in the India, are focussed area for biofortified pearl millet. The breeding goal was set at 77 ppm iron, an increment of 30 ppm above the baseline. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) carries out the pearl millet breeding research in Collaboration with NARES, supported by Harvest Plus Challenge Program of the Consultative Group on International Agricultural Research (CGIAR) and the private sector has initiated a major effort towards the development of high-yielding cultivars with high Fe and Zn density. The popular open pollinated variety (OPV) ICTP 8203 was improved to create the first biofortified variety, called ICTP 8203-Fe (HarvestPlus data 2010). It contains the full iron target and was officially released in 2013.

A recent study reflected that pearl millet accounts for 19–63% of the total Fe intake and 16–56% of the total Zn intake from all food sources in some parts of the major pearl millet growing states of India (Rao *et al.* 2006). Since almost all the high-Fe breeding lines and populations were reported to be entirely or largely based on iniadi germplasm (Velu *et al.*, 2011). GB 8735, a progeny from a released variety, AIMP92901, and a commercial seed parent 863B had high levels of Fe (68-82 mg kg^{-1}) and Zn (51-63 mg kg^{-1}), respectively (HarvestPlus data 2010). In pearl millet, Fe and Zn contents are highly stable characters. Studies also showed that from a 40-population trial in Niger two lines, GB 8735 and GGP (both having an iniari land race base like ICTP 8203 and AIMP 92901) were found to have the highest content of Fe and Zn. One cycle of progeny based recurrent selection in two populations (AIMP 92901 and GB 8735) improved the Fe levels by 11-12%, and Zn levels by 5-6%. A yellow-endosperm germplasm-derived line with high -carotene (>130 g/100 g grain) was also identified (Deepak *et al.*, 2012).

Conclusion

Make enhanced mineral and vitamin content of the edible portions of new crop varieties core breeding objectives at agricultural research will contribute to ensuring that biofortified staple food available for the nutritional security to world population of underdeveloped and developing countries. Developing cultivar with multiple micronutrient content to balance the synergistic effects between micronutrients. Through effectiveness studies demonstrated that deployment of biofortified crops can be effectively targeted in selected countries. To achieve the goal of providing biofortified crops with additional health benefits on a global scale, much work is required and necessary to work with inter disciplines including plant breeders, molecular biologists, nutritionists and even social scientists. Plant breeding, conventional as well as molecular is the most powerful agricultural approach to biofortified crops. These approaches require fertile and nutrient responsive soil and may not effectively work in regions where soils have very low plant-available pools of micronutrients due to very adverse soil chemical and physical conditions (Cakmak, 2008). The fortification of cereal grains with metal micronutrients is a major target to combat human malnutrition of Fe and Zn. Based on recent studies showing that N fertilization can promote Fe and Zn accumulation in cereal grains, we investigated here the influence of nitrate- or ammonium-based N fertilization on the accumulation of Fe, Zn, and Cu as well as metal chelator pools in flag leaves and grains of winter wheat (Barunawati *et al.*, 2013) [3]. Pearl millet is projected as a climate change compliant crop. It is a rich source of energy, protein, vitamins and minerals for the poorest of the poor.Hence, biofortification on pearl millet is a promising technol ogy ((Deepak *et al.*, 2012) [7]. Though the sustainability of biofortified crops remains a major challenge, biofortification per se is a poten tial and promising technology (Waters and Sankaran, 2011). High-yielding open-pollinated varieties (OPVs) and hybrids with higher levels of Fe and Zn densities as target traits have been developed found in most of the commercial cultivars(Rai *et al.*,2013) [21]. Research and development of nutritionally enhanced “orphan crops” sorghum, millet, and pigeon pea, which are important tothe world’s poor but overlooked by industrialized countries, must also be implemented (Kathleen, L. H., 2015) [14]. Biofortification is yet to be fully scaled-up in a single country, but much evidence an experience has been assembled to support its eventual effectiveness. As evidence continues to mount, it should be included in the policy framework to address today’s major nutrition challenges and considered a priority area for enhanced international cooperation.

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