Soil health to human and animal health through breeding biofortified cultivars and balanced nutrient management for nutrition revolution in India

Suhas P Wani and Mahalingam Govindaraj

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Summary

India has larger prevalence of micronutrient malnutrition as 50% of children and women are suffering from one or more essential micronutrient deficiency. There is an urgent need for the country to address this issue of malnutrition holistically through addressing the issue of soil health to animal and human health. Widespread multi-nutrient deficiencies in soil are resulting in nutrient deficient food leads to malnutrition. Feeding the children with supplements to address the issue is good to fix the issue quickly. However, in long-term, to find a sustainable solution, we need to adopt holistic approach. Along with demonstrated soil health management, biofortification research at ICRISAT is focused on improving grain Fe and Zn density. Our approach is to provide a "proof of concept" to address the issue of malnutrition through soil health management and biofortification of staple food crops.

Research Program-Asia, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru-502 324, India.
E-mail: s.wani@cgiar.org

To make impact, soil health mapping, balanced soil nutrient for increasing crop yields and quality are proposed. Government of India has taken up soil health mapping and issuing soil health cards to all the farmers. Further, integration of biofortified cultivars of crops like millets in the states and country strategy, would help to achieve future targets of biofortified cultivars to reach one billion people by 2030. Market is a key driver for long-term adoption of biofortified cultivars by farmers and consumers, and a recent initiative on Smart-foods on millets and pulses by ICRISAT is expected to enhance this uptake process in collaboration with food industries. Holistic approach starting with identifying the soil nutrient deficiencies, meeting the crop demands through balanced soil nutrient management and using biofortified cultivars, can have increased micronutrient uptake capacity as well as capacity to have nutrient dense grains and fodder by increased nutrient-use efficiency and would significantly contribute to improved nutrition by increasing the daily micronutrient intakes as evidenced by bioavailability studies in millets.

Nutrition revolution in India is need of the hour?

The ever increasing population and to match with food production in India is a

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biggest challenge. The nutrient requirements of the people are also on the rise. On the other side, increased depletion of soil nutrients particularly micronutrients, due to high yielding mono-cropping is observed. The widespread deficiencies of iron and zinc leading to numerous adverse health consequences, are now increasingly being recognized as serious public health problems, affecting more than a billion people worldwide (Darnton-Hill and Mkparu, 2015). Whereas in India, government supported program showed reduction in malnutrition over the decades, however, there is slow progress as National Family Health Survey (NFHS, 2016) revealed unacceptably high prevalence of anaemia, under-weight and stunting among children under 5 years. More than 50% of children and women in 20 states in India are being reported anaemic. The fact is that fine cereals constitutes major Indian diets and these are relatively lower in essential minerals (iron, zinc and Vitamin A) and does not effectively address the malnutrition issue. For instance, pearl millet, is an important staple food in semi-arid regions in the country, but over the decades, its consumption as a proportion of the total cereals, has significantly reduced, primarily due to minimum support price and subsidized rice and wheat through PDS, available in ready-to-cook forms. Today, diversity of food crops becomes narrow as dominated by few crops with the high-level investment and marketing by multi-national government and corporates and all these crops were highly water-spending. Hence, millets disappeared from our food plate which is the cheapest source of energy, micronutrients and protein among all cereals and pulses. Therefore, on the cost effectiveness and sustainability perspective, cropping system-based dietary diversification and crop biofortification have been suggested to improved human and animal nutrition. Biofortification is defined as breeding crops to increase their nutritional level to have measurable impact on human health. Both CGIAR and Indian research institutes are making progress in developing and testing of biofortified cultivars in rice, wheat, sorghum and pearl millet. This paper will focus on pearl millet as biofortification research in this crop has made good progress on cultivar pipelines and its adoption in India.

Are Indian soils healthy enough to produce healthy food?

Studies conducted by ICRISAT as well as several research institutions in India have shown that most Indian soils are suffering from widespread deficiencies of multiple nutrients (Wani *et al.* 2015, 2013, 2011; Sahrawat *et al.* 2010; Chander *et al.* 2014). Detailed soil mapping work of farmers' fields undertaken by ICRISAT in Karnataka and several states in India showed that most farmers fields were deficient in zinc, boron, Sulphur along with phosphorus and nitrogen (Wani *et al*. 2015). Balanced nutrient management in farmers' fields have clearly demonstrated that farmers' crop productivity was increased by 20 to 70 % over the farmers' practice in Karnataka, Andhra Pradesh, Rajasthan, Madhya Pradesh, Chattisgarh, Gujarat, Telangana, Tamil Nadu, Maharashtra, Uttar Pradesh and Odisha (Wani and Chander, 2016). We can infer that, in most developing countries in Asia and Africa, most soils are

degraded in terms of nutrient depletion and are not healthy soils to produce healthy foods at present.

Base lines and breeding targets for pearl millet

Pearl millet as such is a high-iron crop with fairly high zinc content as well. However, not all available cultivars have high-iron and zinc content. For instance, the average of Indian commercial cultivars so far released has 42 ppm content (Rai *et al*., 2016). But pearl millet has large variability for iron and zinc i.e. 300-600% more than that of rice and wheat. This indicates that the pearl millet is a major target crop for iron biofortification. Unlike other crops, pearl millet foods are prepared using wholegrain flour thus no significant nutrient loss in the grain as such. The global baseline for iron in wholegrain pearl millet irrespective of cultivars (hybrid or OPVs) is set at 47 ppm and targets at 77 ppm (+30 ppm). These targets are set by considering biofortified cultivars are expected to lessen iron deficiencies by providing 30% to 80% of woman's and children daily needs, depending on the nutrient and the amount of the biofortified food consumed regularly (HarvestPlus, www.harvetsplus.org). In addition to that, HarvestPlus developed the Biofortification Priority Index (BPI) to identify staple food crop and target country for higher impact in reducing micronutrient deficiencies (Asare-Marfo *et al*., 2013), which includes iron pearl millet, zinc rice, and zinc wheat for India. Therefore, exploration of biofortified cultivars in India is highly important at the research and development fronts complementing existing programs to address malnutrition.

Cultivar development strategy and its progress

The first-wave of progress in breeding high-iron hybrid in colloboration with national partners is highly impresive as advanced hybrids showed more than 70-90 % of iron target increments and about 80-90% of grain yield compared to high yielding commercial checks. This yield gap exists because of few options of seed parents with high iron level, suggesting accelerated efforts to diversification of seed parents. Therefore, to fulfill the long-term objective and continued supplies of breeding material, ICRSIAT continue to mainstream breeding for iron and zinc in pearl millet in Africa and Asia programs. CGIAR centers made full commitments to mainstreaming breeding for mineral and vitamin traits into conventional food crop development programs at the Second Global Conference on Biofortification in Kigali, Rwanda (www.cgiar.org/consortium-news, 2014). For country-level, public-private sector need to increase the use of biofortified lines and germplasm from ICRISAT, and commit to micronutrient deployment in their breeding programs.

Biofortified Breeding pipelines

Pearl millet biofortification breeding at ICRISAT is gradually shifting from discovery to product development (lines/hybrids). ICRISAT in association with national partners, developed and identified a high-iron variety 'Dhanashakti' that has highest level of iron content (71 mg/Kg grain) in any pearl millet cultivar produced so far and released in the country. The same

variety also contained 40 ppm Zinc. This marks the first high-iron biofortified cultivar of any crop variety officially released and already adopted by farmers in India. Over 140,000 farming households in the country have taken up cultivation of 'Dhanashakti' (HarvestPlus, 2015). Dhanashakti was initially targeted for Maharashtra state, but it also performed equally well in other states of central and southern India. Other High-Fe hybrids have been developed with good yield potential and two of these (ICMH 1201 and ICMH 1301) have been most widely tested. ICMH 1201 has 75 ppm Fe density (similar to Dhanashakti) but has 38% more grain yields while ICMH 1301 has 74 ppm Fe density with 33% more grain yield. Further, six biofortified hybrids are advanced to AICPMIP-Biofortification Hybrid Trial for final year testing (AICPMIP, 2016). This initiative of AICPMIP is expected to have more number of hybrids with high-Fe in near future. For the first time, six seed parents (A/B pairs) deliberately bred for high-Fe (70-110 ppm), were designated as ICMA/B 1501 to 1506, with disease resistance in two diverse cytoplasm's (A_1/A_4).

Bioavailability of micronutrients

To address the malnutrition, nutritious coarse grain crops, such as pearl millet, either of its per capita consumption or iron level of grains has to be increased to get adequate nutrition by an individual. For instance, Studies in India and Benin (Kodkany et al., 2013, Tako et al., 2015) have shown that total iron and zinc absorbed from biofortified pearl millet variety were higher than those from the non-biofortified variety, implying the significant contribution that biofortification can make in addressing their deficiencies in the population consuming this nutritious cereal. For instance, consumption of 200 g of Dhanshakti can meet 80% of the Recommended Daily Allowance (RDA) of Fe in adult men and 66% of the RDA in non-pregnant and non-lactating women in India. It can also meet 65% of the RDA of Zn both in men and women. The above RDAs are based on the assumption of 5% bioavailability for Fe and 25% bioavailability for Zn content.

Suggested future directions

Biofortification, in general, has led to several success stories in many staple food crops including pearl millet for which HarvestPlus was recognized with the World Food Prize in 2016. Now it's time to the policy makers and politicians to make use of this science driven and country-based business models. Several positive attributes of pearl millet need to be tapped appropriately for drylands and possible future way forward at national and international agendas are briefly described hereunder;

- *Public-private partnership (PPP):* Seed companies have well established network in India, and dominating the pearl millet hybrid seed market in India, and thus hybrids occupy approximately 90% of the area under improved cultivars. Therefore, first-biofortified cultivar-being an OPV, less area coverage, was limited than its potential impact. To address this gap, PPP model need to be strengthened by institutional policy of nutrition commitments and special price allocation for mineral-dense seeds with

Government incentives in the markets to promote biofortified cultivars.

- *ICRISAT contribution:* ICRISAT has contributed immensely in diversifying the hybrid parents and its contribution to achieving higher genetic gain at farm level through PPP partnership. About dozen seed companies those had research and development division, capture more than 80% of the pearl millet hybrid seed market in India. Thus, the sustainability of biofortified pearl millet will depends on mainstreaming of biofortification with seed companies, state seed corporations and agricultural universities.
- *Farmer and consumer acceptance:* The biofortified cultivars have been developed using natural genetic variability in pearl millet and are not GMO products. These micronutrients have no influence on color of the grains and food taste which is key factor for consumer acceptance. With these, there is no potential threats for biofortified cultivars release and has great prospects for acceptance of these cultivars by farmers and consumers.
- *Government initiatives*: Large scale field and food product demonstrations through State agricultural universities, line departments and Krishi Vigyan Kendras (KVKs) are needed to popularize bio fortified foods, like pearl millet. Large scale production and procurements of biofortified cultivar grains for making food for anaemic populations/children through Anghanwadi (childcare centre) School feeding (mid-day meal) and PDS system needs to be promoted to address the iron and zinc deficiency.
- *Smart food*: Pearl millet is climate smart crop by itself - dryland resilient with high metabolizable energy, high gluten-free protein, and more of balanced amino acids. So, this crop has potential role to play in the smartfood initiative taken by ICRISAT which aims to build food systems where the food is good for you (highly nutritious), good for the planet (climate resilient) and good for the smallholder farmer.
- *Soil fertility map-based cropping*: Soil test-based fertilizer recommendations are needed to be promoted as per the soil requirements for sustainable intensification which will bring in not only increased production but nutritional quality as well.

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