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CASE STUDIES

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Delivering bioavailable micronutrients through biofortifying sorghum and seed chain innovations

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1. Abstract

Micronutrient malnutrition, particularly among women and children, is one of greatest global challenges of our times and the national Governments and international organizations are following various approaches to combat it. Biofortification –increasing the micronutrient density in edible plant parts by genetic means, is one of the cost-effective and sustainable methods to address the micronutrient malnutrition. Sorghum is one of the major staples globally and it meets more than 50% micronutrient requirements of low-income group populations in predominantly sorghum eating areas. We developed biofortified sorghums with elevated levels of grain Fe and Zn combined with higher grain yield possessing farmer-preferred grain and stover traits. The first biofortified sorghum cultivar 'Parbhani Shakti' was released in India in 2018, which, besides high Fe and Zn, has higher protein content and lower phytates content. An innovative 'Seed Consortium' was built to take this variety to the farmers in shortest possible time to benefit the farmers and consumers. Multi-stakeholder partnership was the key in this endeavour and Indian NARS, farmers, public sector seed organisations, media and Government played a key role along with ICRISAT.

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2. Context and challenge, including key interactions (range and nature) the case study addresses

Micronutrients (MNs) are essential for living organisms, which are limiting in many diets, particularly in the low-income group populations. MNs although only required by the body in small amounts, are vital for development, disease prevention, and wellbeing. Micronutrients are not produced in the body and must be derived from the diet. Deficiencies in micronutrients such as iron, iodine, vitamin A, folate, and zinc can have devastating consequences. At least half of the children worldwide ages 6 months to 5 years suffer from one or more micronutrient deficiency, and globally more than 2 billion people are affected.

Iron (Fe) is an essential mineral critical for motor and cognitive development. Children and pregnant women are especially vulnerable to the consequences of iron deficiency. Low hemoglobin concentration (anemia) affects 43% of children 5 years of age and 38% of pregnant women globally (Stevens GA, et al. 2013). Flour fortification with iron and folic acid is globally recognized as one of the most effective and low-cost micronutrient interventions (Copenhagen Consensus 2012).

Zinc (Zn) is a mineral that promotes immunity, resistance to infection, and proper growth and development of the nervous system, and is integral to healthy pregnancy outcomes. Nearly 17.3% of the global population is at risk for zinc deficiency due to dietary inadequacy, though up to 30% of people are at risk in some regions of the world (Wessells et al., 2013). Zinc supplementation reduces the incidence of premature birth, decreases childhood diarrhoea and respiratory infections, lowers all-cause mortality, and increases growth and weight gain among infants and young children (Zimmerman, 2011).

Globally, efforts are underway to eliminate deficiencies in iron, zinc along with vitamin A, iodine, and folate. However, there are constraints in terms of access, affordability, and sustainability of these interventions. Therefore, we chose biofortification (increasing the minerals/vitamins in edible plant parts by genetic means) to improve the grain Fe and Zn concentration in staple crops. Here the intake is regular with no additional costs to the consumers.

Sorghum is a major food crop globally and it forms principal staple for more than 500 million people in Sub-Saharan Africa and South Africa which incidentally are the major food insecure and micronutrient malnutrition prone areas (Fig 1). The idea is to significantly increase the grain Fe and Zn concentration in the high yielding, farmer-preferred sorghum cultivars and pumping them in to the food chain by increasing their adoption by the farmers though innovative seed chain. Here we are describing the success story of developing a novel biofortified cultivar ‘Parbhani Shakti’ and an innovative seed chain built to increase its seed production and dissemination to farmers in Maharashtra state of India through a range of partnerships that include academia, Govt, public funded seed agencies and the farmers’ groups.

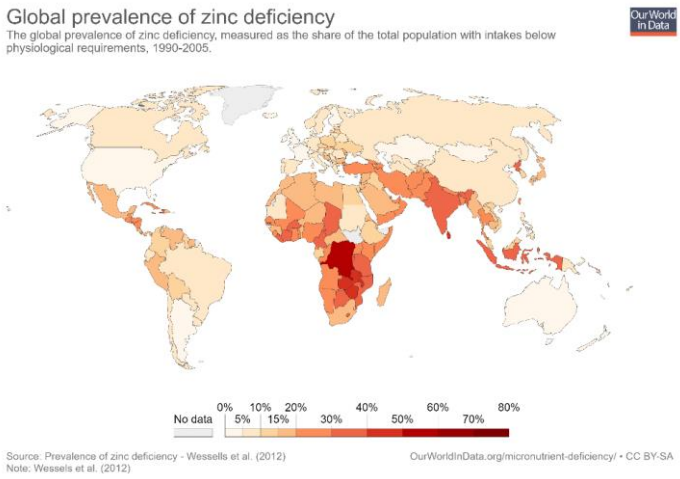

Fig 1. *Global prevalence of zinc deficiency (Wessells et al., 2012)*

To start with, we standardized the precise phenotyping methods for assessing the grain Fe and Zn in sorghum. The Inductively Coupled Plasma (ICP) – Optical Emission Spectrometry (OES) method standardized for assessing the germplasm, fixed breeding lines and cultivars for Fe and Zn in sorghum. Also standardized the X-ray fluorescence spectrometer (XRF) for assessing the Fe and Zn which is a low-cost, robust and non-destructive method (Fig 2). There is good correspondence between ICP and XRF methods for assessing the grain Fe and Zn but ICP is more accurate. So we used XRF for discarding the lines, segregating populations with low Fe and Zn and validate all high Fe and Zn lines with ICP method. To set up the baselines, the entire spectrum of sorghum cultivars (66) grown in India were assessed, and the Fe and Zn concentration in the most preferred cultivars was found to be low (30 ppm Fe and 20 ppm Zn), which were freezed as baselines for sorghum for increasing the grain Fe and Zn. We targeted to improve the Fe and Zn at least 50% higher than the baseline without compromising the grain yield, stover yield and other preferred traits.

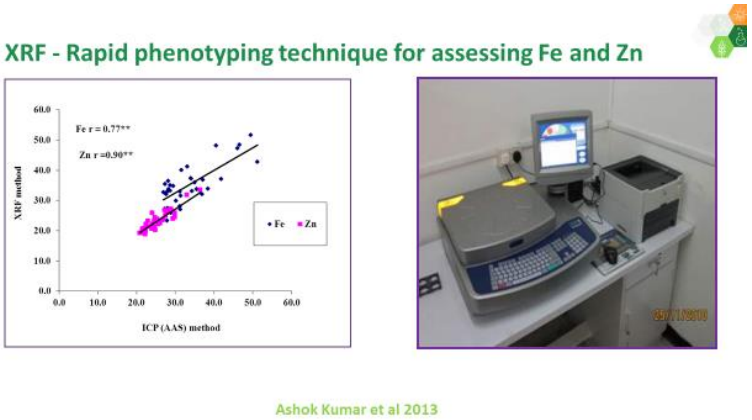

Fig 2. *XRF -low-cost, non-destructive, robust phenotyping technique for assessing Fe and Zn*

With the funding support received from HarvestPlus over several years, assessed the variability for grain Fe and Zn concentration in a large number of sorghum germplasm and breeding lines, parents; studied the gene action, trait associations, effect of micro and macro nutrient fertilization on grain Fe and Zn; used micronutrients rich donors in crossing program and developed a strong breeding pipeline; developed a number of new hybrids (with selected

parents for higher Zn and Fe), varieties and hybrid parents with high Zn and Fe concentration, which are under multilocation evaluation (Ashok Kumar et al., 2012, 2013 and 2015; Phuke et al., 2017).

One of the improved varieties developed in the project, ICSR 14001, showed its yield superiority in multilocation on-farm testing in Maharashtra State of India and our partner Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani released it for commercial cultivation as 'Parbhani Shakti' (Fig 3 and 4). Besides high Fe (45 ppm) and Zn (32 ppm) it has higher protein content (11.9%) and low phytates (4.1 mg/100g) means higher bioavailability of improved nutrients. Further, it is an excellent male parent for hybrids development and we developed more than 100 hybrids using it. Two more promising hybrids (ICSH 14001 and 14002) are under large-scale on-farm testing by the same partner in Maharashtra.

Fig 3. *Improved sorghum variety (ICSR 14001) with high yield and higher grain Fe and Zn*

Fig 4. *Parbhani Shakti - First biofortified sorghum released in India with 45 ppm Fe and 32 ppm Zn (50% higher Fe and 60% higher Zn than the base line)*

The release of first biofortified sorghum cultivar is a landmark towards addressing the micronutrient malnutrition. However, it is important to ensure that this variety is adopted by farmers to realize its benefits by farmers and the consumers. 'Parbhani Shakti' being an OPV, private sector is less interested to multiply it. So to enhance large-scale seed multiplication and dissemination of OPVs, an innovative 'Seed Consortium' was developed by ICRISAT bringing together all the major actors in seed chain to a common platform.

The 'Seed Consortium' was formed during 2013 involving the Indian NARS [ICAR –Indian Institute of Millets Research (IIMR), Mahatma Phule Krishi Vidyapeeth (MPKV) and Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV)], public sector seed agencies [Maharashtra State Seeds Corporation Ltd (Mahabeej) and Maharashtra State Seeds Certification Agency (MSSCA)], Department of Agriculture, Govt of Maharashtra and the seed farmers. Under this Consortium, in an annual meeting, all the partners come together, fix the targets to be achieved annually for the seed chain sustainability and work together to achieve the targets on yearly basis. The State seed development corporation (Mahabeej) gives the buy-back guarantee and procure the seeds from the seed farmers. It processes the seeds and supply to the farmers though its network in the entire country. With the concerted efforts by all the partners, the Seed Consortium made tremendous progress (Table 1; Fig 5 and 6). With this adoption of improved seeds coupled in increased adoption of management technologies, there is a steady increase in postrainy sorghum productivity in Maharashtra which is now more than 850 kg/ha and increasing.

After the release of first biofortified sorghum cultivar –Parbhani Shakti, Mahabeej came forward to mass multiply its seeds. In the 2018 postrainy season 'Parbhani Shakti' will be multiplied by both VNMKV and Mahabeej so as to reach maximum number of farmers in 2019 and beyond.

***Table 1**. Sorghum seed production under the Seed Consortium initiative in Maharashtra*

Year	Quantity of seed produced (tons)	No. of farmers supplied with improved variety seeds
2013	300	30,000
2014	1000	100,000
2015	1500	150,000
2016	2200	220,000
2017	2800	280,000

Fig 5. *Improved sorghum variety being mass multiplied in famers fields in Maharashtra*

The biofortified grain is available in market at the same price as normal sorghum grain and consumers get the benefit of higher micronutrients consumption without extra costs. As the intake is continuous (being staple crop) biofortified sorghum provides huge nutrition and health benefits to consumers, farmers including the women and children.

Fig 6. *Sorting the best panicles for planting in next season*

3. How did research efforts deal with the synergies and trade-offs?

a) in the development of the TOC and impact pathways

Once the improved cultivars developed and found highly suitable for scaling, to harness the synergies, the partners were identified in a way that all the partners in this endeavor have more or less similar goals – to improve the food and nutritional security of farmers, reduce the poverty and increase their incomes. However not all partners were on the same page to readily come together. It needed demonstrations, joint field visits, farmers' explanations to convince 'Mahabeej' to change its preferred cultivar for large-scale seed multiplication. While it had strong preference for multiplication of M 35-1, widely adapted landrace cultivar, the partnership could convince it to change its mind set by

providing all the evidence, data, experiences and preferences of farmers and finally the business opportunity in improved OPV seed multiplication. Then they agreed to give buy-back guarantee to the seed farmers. The perceived trade-offs by Mahabeej could be addressed by providing field evidences.

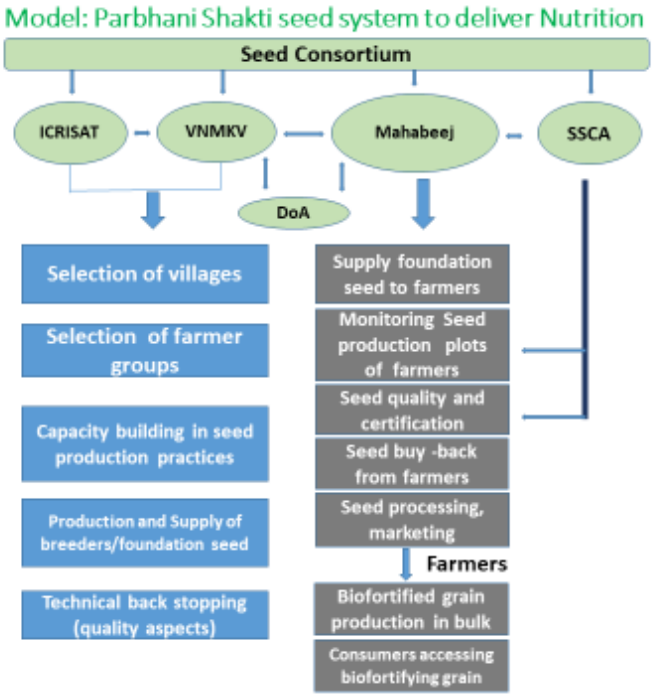

Fig 7. *Model seed system for biofortified sorghum variety "Parbhani Shakti'*

b) in the development of partnerships/delivery approaches

In this partnership, each partner had different competencies. Some are good in research (ICRISAT, ICAR-IIMR, VNMKV, MPKV), some have high capabilities in testing, release (MPKV, VNMKV); some are leaders in seed increase and commercialization (Mahabeej) and some in seed certification (MSSCA) and more importantly the farmers, as integral part of this initiative. The Dept. of Agriculture also played key role in bringing the farmers together, in capacitating farmers in seed production.

c) in the development of metrics

The group meet every year and fix the targets for seed production with an aim to cover 10% of total area in the state with improved seeds. The areas (geographies and extent) and farmers (numbers) for seed production are identified as per the targets fixed for the year. Each partner has designated roles and responsibilities and the entire activities are monitored from time to time. Farmers Rallies (4) are organized before crop harvest to ensure that more and more farmers (4 X 1500) are aware of these improved technologies and production packages and also to attract new farmers for seed production. At the end of the year, the progress made is reviewed, shortfalls addressed and targets fixed for next year. And the cycle continues. New varieties are introduced in to Seed Consortium as per the need.

d) other

The entire Seed Consortium initiative is well documented and policy makers are informed about the progress made. They are invited for the Annual Meeting of the 'Seed Consortium' partners and their suggestions are taken for further improvement. The Govt of India is coming up with a 'Millet Mission' to give a thrust for sorghum and millets production and both our University partners, VNMKV – Parbhani and MPKV – Rahuri are identified as 'Seed Hubs' in their Mission. Wide media coverage is given for all the on-farm activities to enhance the awareness and eventually the adoption rates.

4. What kinds of partnerships were critical?

Multi-stakeholder partnerships with diverse competencies are very critical to carry forward the research and development initiatives. For e.g. it is first time in 40 years that ICRISAT worked with Mahabeej (one of the largest public sector seed production bodies in the world) for large-scale seed production which helped the outreach, reaching 300,000 farmers per year and increasing every year. Developing mutual trust and respect and keeping all the partners on same page through continuous engagement is very critical. Sharing credit and engaging them from the beginning of variety release is the new approach we are following to have their buy-in from Day 1 of the new variety.

5. Lessons learnt, including knowledge gaps and good practices in employing these approaches at scale

- Identification of right partners for the initiatives and convincing them of the need for the partnership
- Giving equal status to all partners and involving them from beginning
- Making every partner own the activities and apply themselves to achieve intended objectives
- Continuous engagement with partners for smooth flow of targeted activities
- Demonstrating the utility of initiatives by taking partners to farmers' fields
- Giving more credit to the partners upon achieving results
- Extensive coverage of activities and success stories in mainstream media

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