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Breeding high-iron pearl millet cultivars: present status and future prospects

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Rationale

Micronutrient malnutrition, widespread in resource poor families in the developing world where large populations rely on cereals as staple food, has emerged as a major health challenge. Over 60% and 30% of the world's populations are deficient in iron (Fe) and zinc (Zn), respectively[1]. About 80% of pregnant women and 70% children are reported to suffer from Fe deficiency, while 52% children (<5 years) have stunted growth in India[2,3]. Biofortification is a cost-effective and sustainable agricultural approach to deliver essential micronutrients through staple foods. Pearl millet is an important staple food in the arid and semi-arid regions of Asia and Africa. The primary focus of HarvestPlus-supported pearl millet biofortification research at ICRISAT is on improving Fe density with Zn density as an associated trait.

1. Genetic Variability

- Large variability for grain Fe (31-125 mg kg^{-1}) and Zn (35-82 mg kg^{-1}) densities observed among advanced breeding lines, population progenies, hybrid parents and hybrids released or commercial hybrids (Table 1).
- *Iniadi* germplasm identified as valuable source of high-Fe and Zn density for genetic improvement.

Table 1. Variability for Iron (Fe) and Zinc (Zn) densities in pearl millet.

Material	Entries (no)	Percent entries in micronutrient class (mg kg^{-1})							
		Fe density							
		≤ 45	46-55	56-65	66-75	76-85	86-95	96-105	>105
Mainstream hybrid parents	290	24	31	18	10	7	7	3	1
Commercial cultivars	140	56	35	9	1	0	0	0	0
Germplasm accessions	406	11	19	16	19	17	12	5	1
Biofortified breeding lines	514	0	0	0	2	11	22	27	38
		Zn density							
		≤ 35	36-45	46-55	56-65	66-75	76-85	86-95	>95
Mainstream hybrid parents	290	5	47	34	11	2	0	0	0
Commercial cultivars	140	8	76	16	0	0	0	0	0
Germplasm accessions	406	2	16	31	32	17	2	0	0
Biofortified breeding lines	514	8	45	40	7	0	0	0	0

2. Efficient Screening Tool

- Highly significant and high positive correlation between X-ray Fluorescence Spectrometry (XRF) and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) estimates for Fe density (r=0.77 to 0.97; p<0.01) and Zn density (r=0.67 to 0.98; p<0.01) in a large no. of trials (Figure 1).
- XRF can be used as a rapid, non-destructive and cost-effective tool for screening large number of breeding materials, thus enhancing the breeding efficiency.

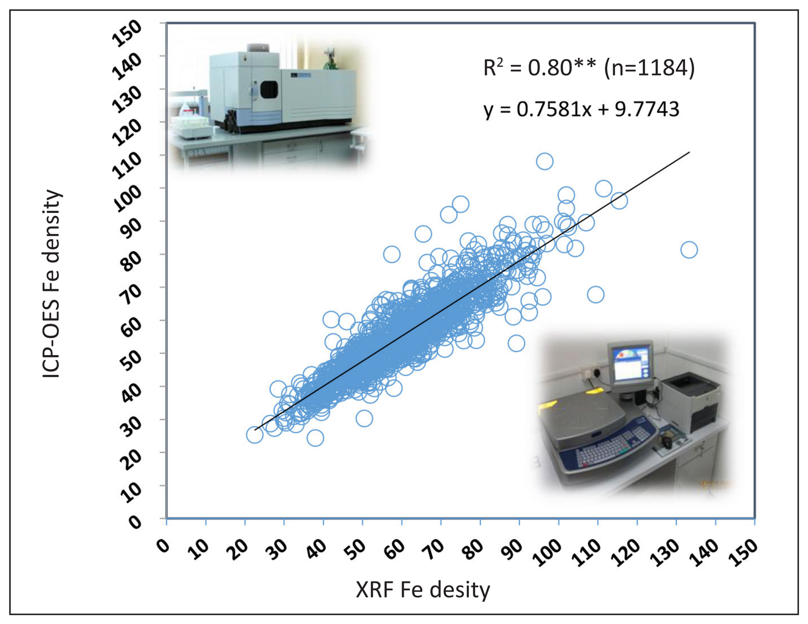

Figure 1. Relationship between XRF and ICP-OES estimates for Fe density.

3. Strategic Research for Improving Breeding Efficiency

Table 2. Strategic research results and its breeding implications[4].

Research result	Breeding implication
Fe and Zn predominantly under additive genetic control, and no-better-parent heterosis	Need to breed for high Fe and Zn in both parental lines of hybrids
Highly significant and high positive association between line per se and general combining ability (GCA)	Per se performances would be highly effective in selecting for GCA
Large environment effect and large G×E interaction: G×E for Fe lower than for grain yield	Need for multi-location testing through partnerships
Cost-effective tool (XRF) for rapid analysis of Fe and Zn	Facilitates handling of large number of breeding lines (250-300 samples/day @ US$2/sample)
Large seed set effect, no xenia effect and dust contamination	Open-pollinated seeds can be used for reliable estimation of Fe and Zn
Fe and Zn highly significantly correlated, while Fe and Zn vs grain yield mostly negatively correlated, but low to moderate and always not significant	Simultaneous improvement for both micronutrients. High grain yield can be combined with high Fe/Zn by using large segregating populations

4. Cultivar Development

- Utilizing intra-population variabilty, a higher-iron verstion of a commercial variety was developed and released.
- Several breeding lines and germplasm accessions with >90 mg kg^{-1} Fe and >50 mg kg^{-1} Zn density have been identified and are being utilized to develop hybrids.
- The Public-Private Partnership (PPP) for pearl millet biofortification research in India, consisting of 26 partners (6 NARS and 20 private seed companies).
- Several hybrids with target level (75 mg kg^{-1}) Fe density but 25-35% higher grain yield have been developed, which are at various stages of testing in national trials in India.
- All India Coordinated Pearl Millet Improvement Project (AICPMIP) has initiated the first Coordinated Initial Biofortified Hybrid Trial in 2014, with 15 hybrids, including 9 hybrids that are bred at ICRISAT.

5. Cultivar Adoption

- The PPP model for pearl millet biofortification research delivered the first biofortified cultivar **'Dhanashakti'** (Fe: 71 mg kg^{-1}, Figure 2). It was adopted by more than 60,000 farmers in India in 2014.
- **Dhanashakti** included for grain production in Nutri-Farm pilot program of Government of India.
- A high-Fe and high-yielding hybrid (**ICMH 1201**), commercialized (Truthfully Labelled Seeds) since 2014 as **Shakti 1201** by a seed company in India.
- No relationship between grain yield of hybrids and its Fe/Zn density at various productivity levels (Figure 3).

Figure 2. Dhanashakti - a first biofortified pearl millet variety.

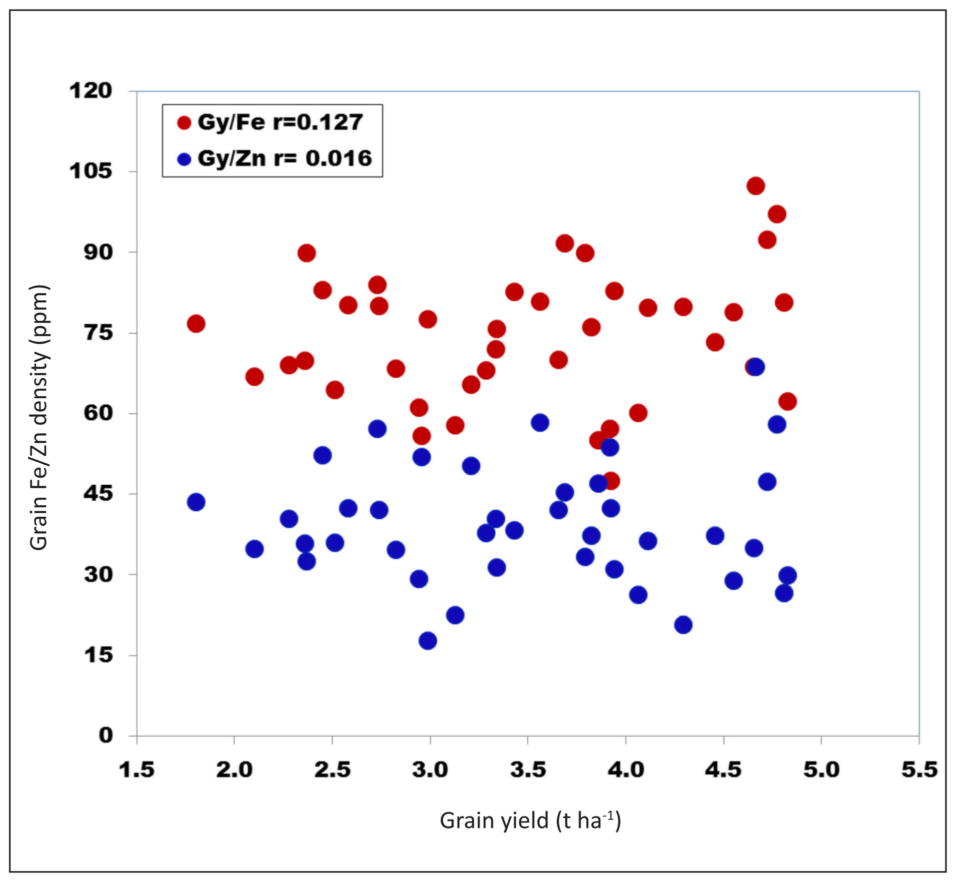

Figure 3. Relationship between grain yield and Fe/Zn density in a commercialized high-iron hybrid.

6. Future prospects

- For the long-term, pearl millet biofortification program at ICRISAT is now being integrated with mainstream breeding for continued supply of high-Fe breeding lines and hybrid parents to national and international partners.
- Greater utilization of breeding lines and germplasm identified at ICRISAT for high-Fe and Zn density by national program and seed companies in India.
- High-Fe cultivars and sources identified/developed at ICRISAT in India will have a direct bearing on accelerated pearl millet biofortification breeding in the African regions.
- Wide ranging research partnerships with public and private sectors will accelerate development and delivery.
- Integration of genomic tools with conventional breeding for increased breeding efficiency.
- Bio-fortified pearl millet cultivars meat 100% RDA of Fe in children, adult men while >60% RDA in women.

Reference

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