# Biofortification of Cereals for Enhanced Nutrition: Strategies, Status and Future Directions

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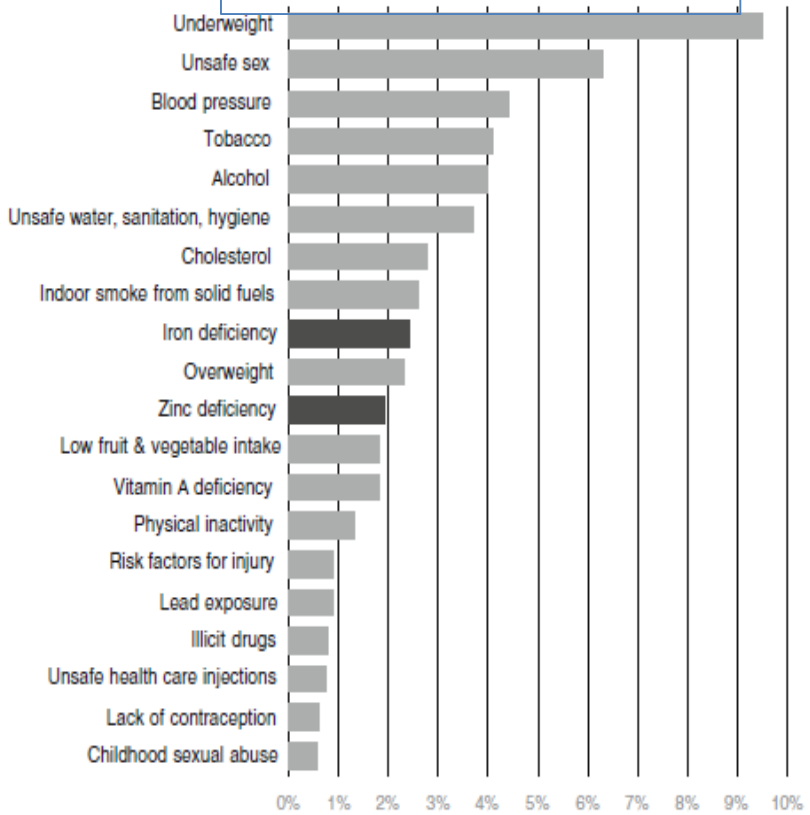
# MICRONUTRIENT MALNUTRITION AND INTERVENTION STRATEGIES

## Malnutrition




The 20 leading health risk factors and their share in the overall burden of disease (WHO, 2002)

## INDIAN POPULATION

**Fe deficiency**

- **80% pregnant women**
- **52% non-pregnant women**
- **74% children (6-35 months age)**

**Zn deficiency**

- **52% children (<5 year age)**

## Strategies

- **Pharmaceutical supplementation**
- **Industrial fortification**
- **Dietary diversification**
- **Biofortification**

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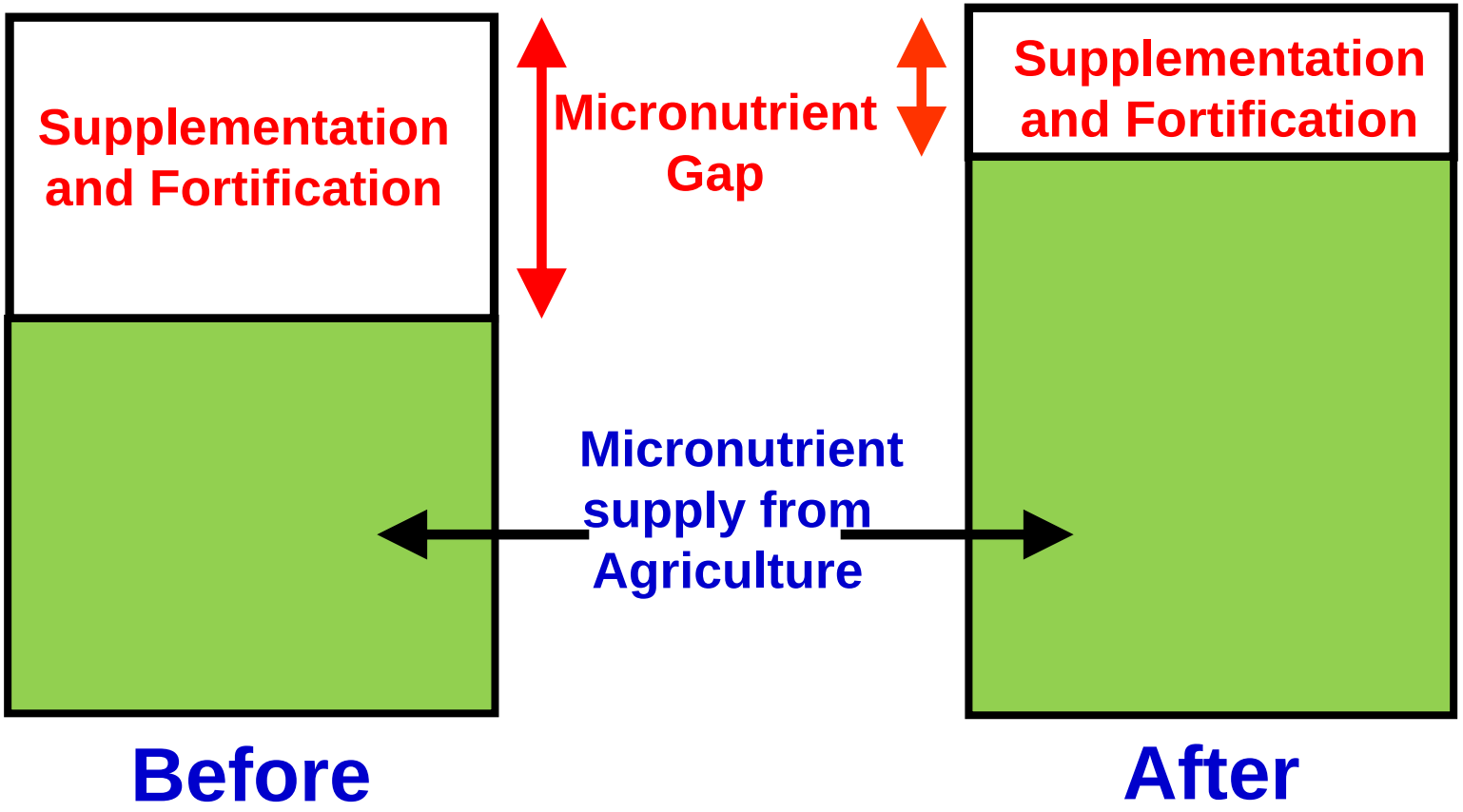
# Role of Agriculture in Reducing Micronutrient Gap



# Cost-effectiveness of Zinc Biofortification and Other Interventions

| Country | Intervention cost per DALY saved (US$) | | |
|---|---|---|---|
| | Biofortification | Fortification | Supplementation |
| Bangladesh | Rice: 11-32 | Wheat: 19 | 7 |
| India | Rice: 0.6-2.0 | Wheat: 16 | 7 |
| Pakistan | Wheat: 3-18 | Wheat: 27 | 58 |
| India | Wheat: 1-4 | Wheat: 16 | 7 |

# Crop-Trait-Geographical Focus for Cereal Biofortification

| Crop | Micronutrient | Region |
|---|---|---|
| Wheat | Zinc | Northern India and Pakistan |
| Rice | Zinc | Eastern India and Bangladesh |
| Pearl Millet | Iron (Zinc) | All pearl millet growing areas of India |

# Micronutrient Targets in Cereals Biofortification Research

| Crop-Micronutrient | Baseline | Target |
|---|---|---|
| Rice-zinc | 16 ppm | 28 ppm |
| Wheat-zinc | 25 ppm | 37 ppm |
| Pearl millet-iron | 47 ppm | 77 ppm |

# Evaluation and Utilization of Genetic Materials for Biofortified Cultivar Development

**High-Fe/Zn Commercial cultivars** : **Meet immediate objective; promote and improve**

**High-Fe/Zn Hybrid parents** : **Develop experimental hybrids; release / commercialization**

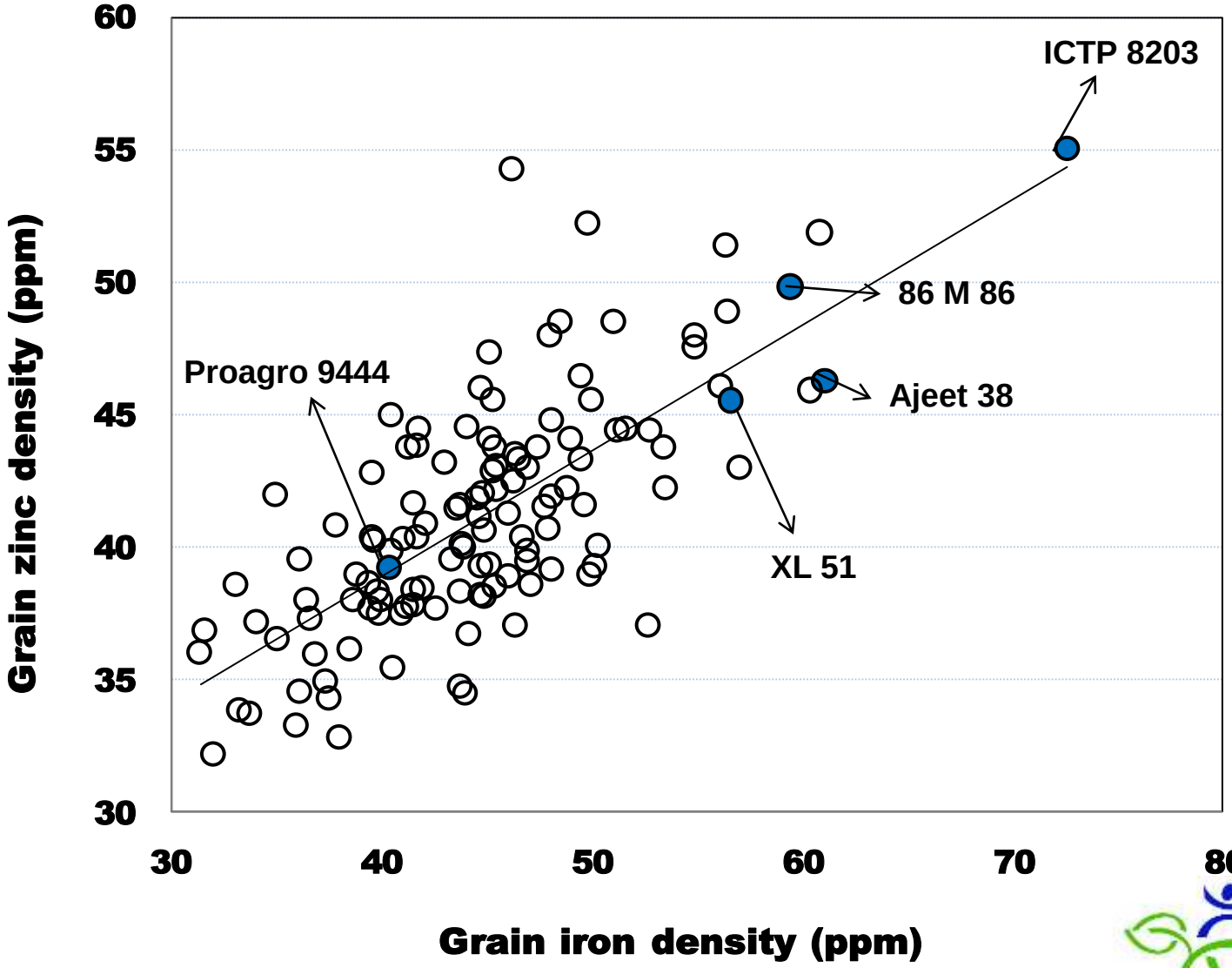
**High-Fe/Zn Breeding lines** : **Develop new hybrid parents** ↓ **hybrids**

**High-Fe/Zn Germplasm** : **Diversify the genetic base and further improve Fe/Zn levels**

# Breeding Approaches for Biofortified Cultivar Development

- Conventional breeding
- Application of genomic tools
- Transgenic approach to GMO

# Variability for Iron and Zinc Content in Commercial Cultivars of Pearl Millet

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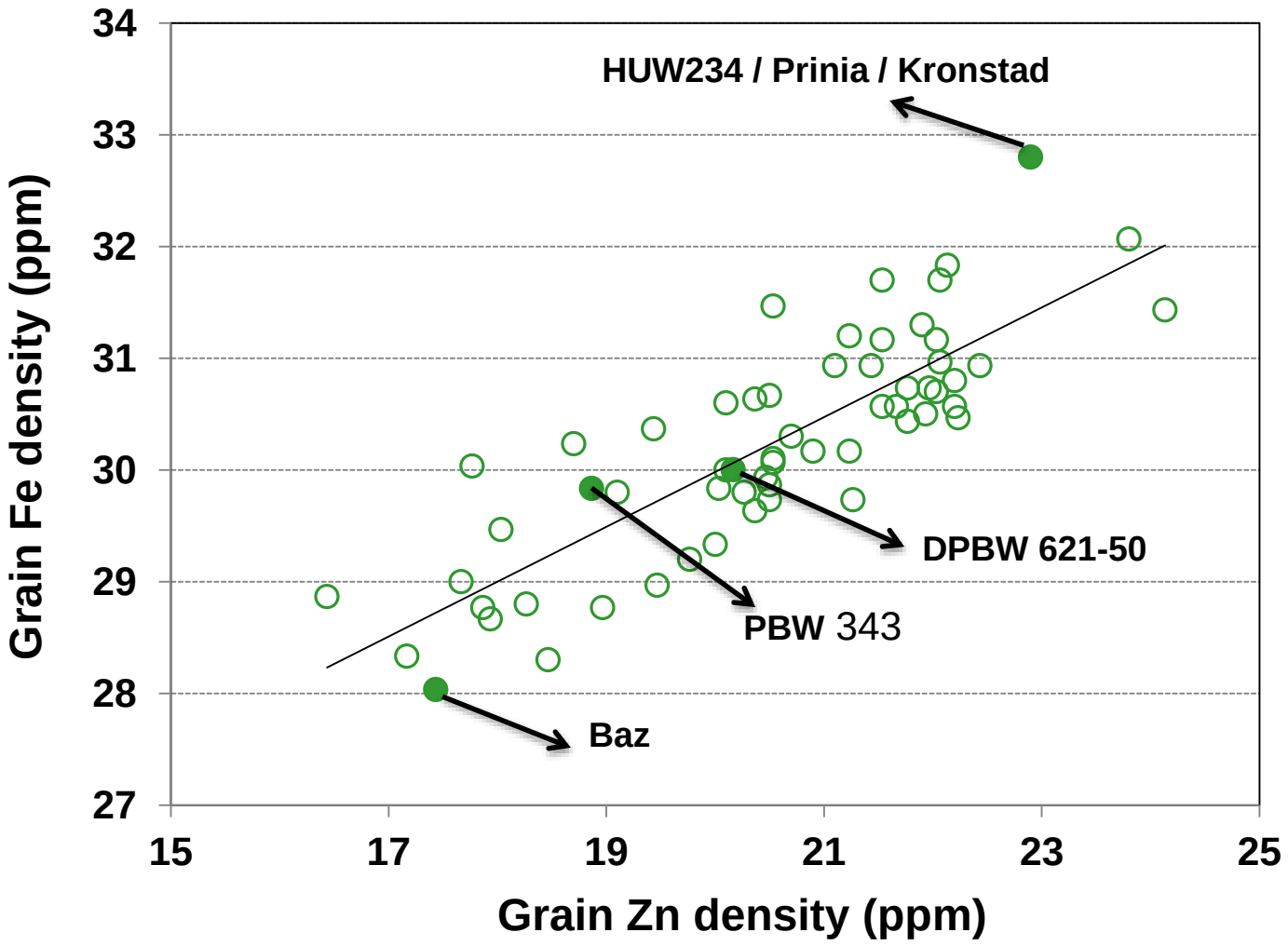
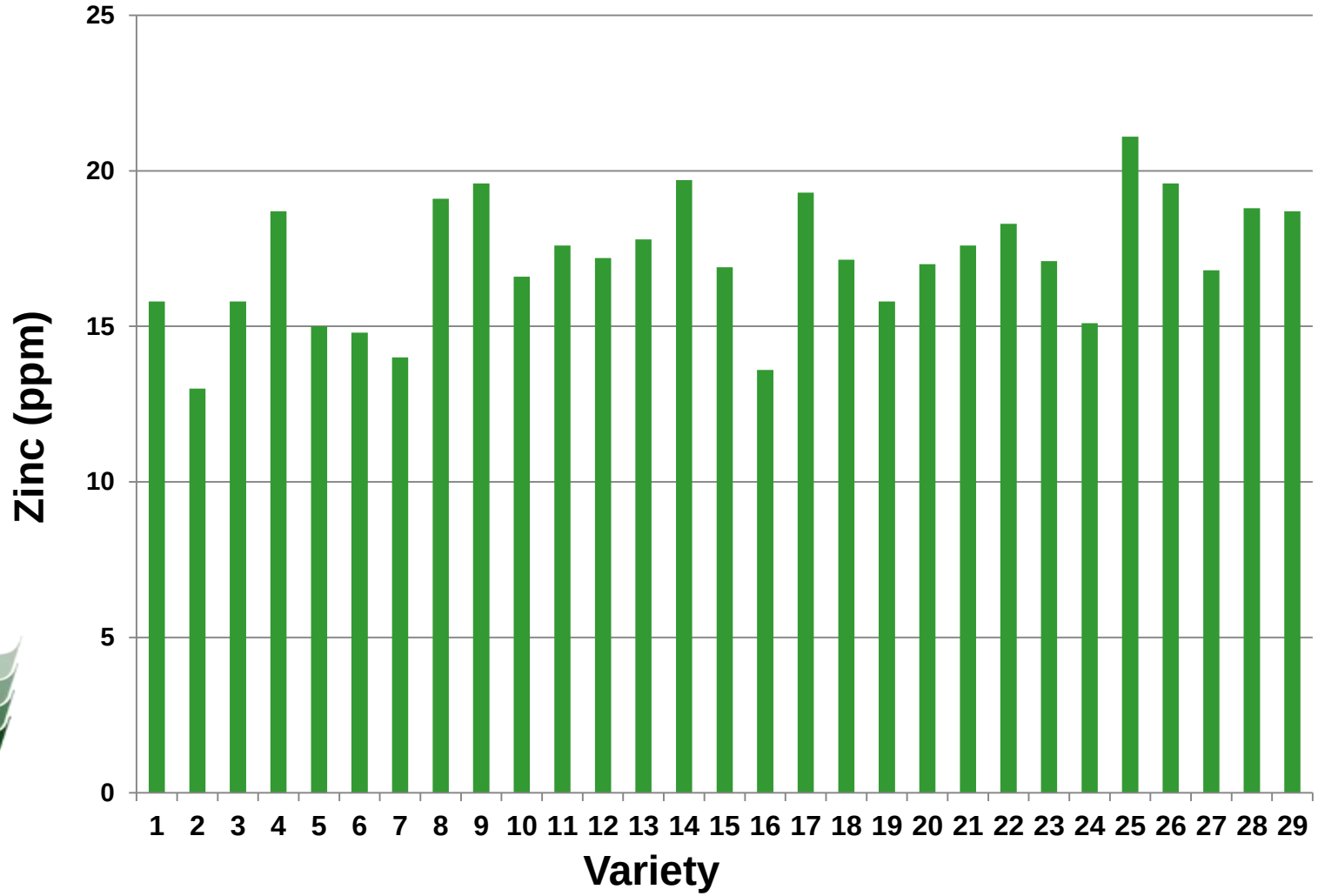
# Variability for Fe and Zn concentrations in commercial wheat varieties



# Variability for zinc content in commercial cultivars of rice

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# Dhanashakti : Biofortified High-Iron Pearl Millet Variety

- Evaluated in 42 field trials (2010–2011)
- Fe: 71 ppm (9% over ICTP 8203)
- Zn: 40 ppm (similar to ICTP 8203)

- Grain yield : 2.21 t/ha (11% over ICTP 8203)
- Stover yield : 5.30 t/ha (13% over ICTP 8203)
- Time to 50% flowering : 45 days (similar to ICTP 8203)

- Official release as Dhanashakti
  - 2013 for Maharashtra
  - 2014 for All India
  - >800 kg breeder seed produced

# Biofortified High-Iron Pearl Millet Hybrid (ICMH 1201)

- **Evaluated in 48 field trials (2011-2013)**

  **Grain yield 3.58 t ha$^{-1}$ (38 % over ICTP 8203)**

  **Fe density : 75 ppm (71 ppm in ICTP 8203)**

  **Zn density : 39 ppm (43 ppm in ICTP 8203)**


- **Time to 50% flower : 48 days (3 days later than ICTP 8203)**
- **Under commercial production by Shakti Vardhak Seeds**

# High-Zn wheat varieties

- Zn Shakti Sai : 40 ppm Zn
- Additional 4 leads :  33-35 ppm Zn

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**BRRI dhan62, the world's first zinc-rich rice variety has been released in Bangladesh and will be available to farmers in T. Aman, the rainfed lowland, season of 2014. The major features of BRRI dhan62 are shown below:**

# BRRI dhan62

**World's first zinc-rich rice variety released in Bangladesh**

High protein content (9%)


High zinc content in polished rice (22-27 mg/kg)

Average yield potential 4.2 t/ha in T. Aman season

Long slender Grain similar to BRRI dhan28

Shortest duration (100 days) T. Aman rice variety ever released in Bangladesh suitable for T. Aman-Potato/Rabi-Boro cropping pattern

## BRRI DHAN62

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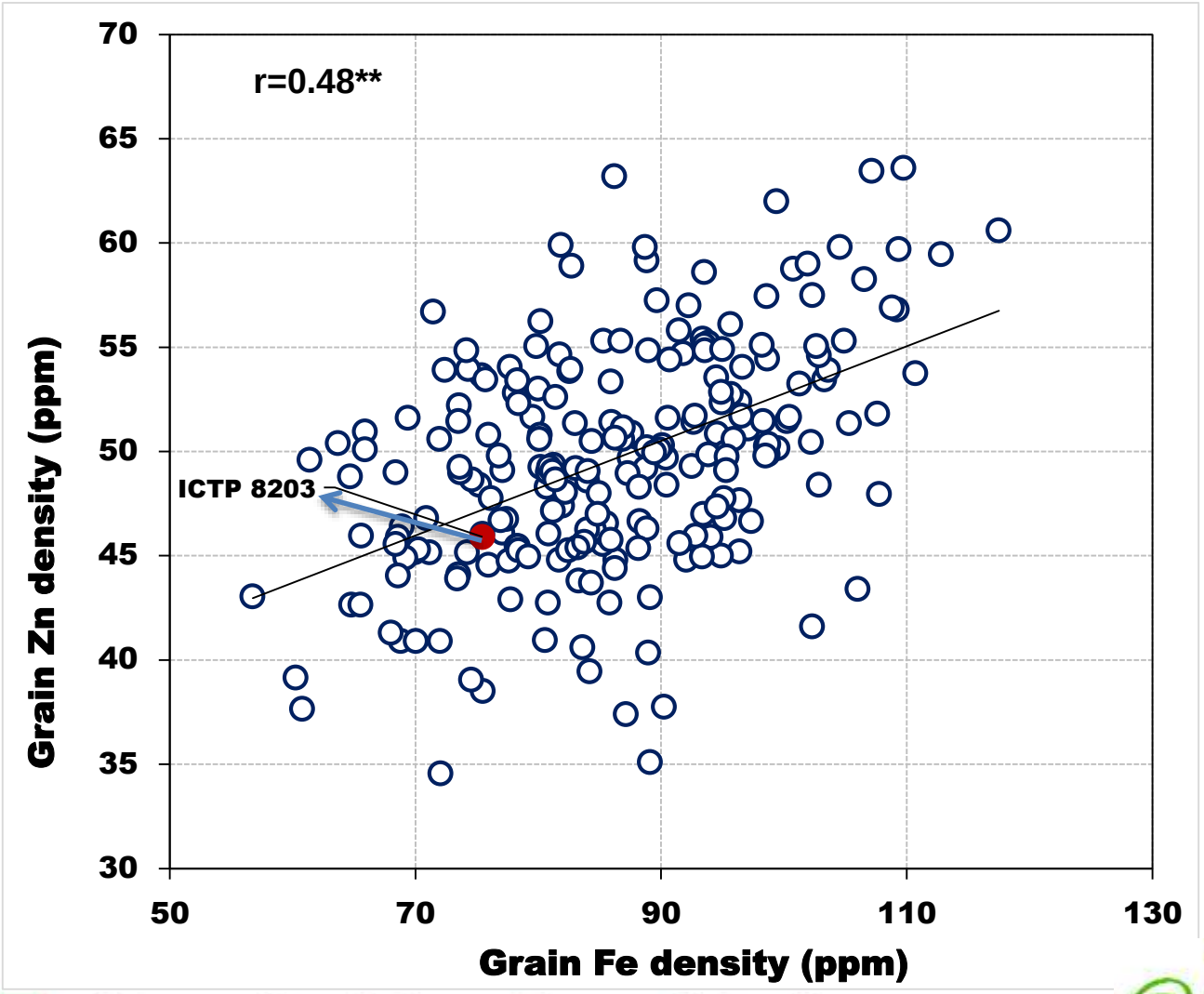
# Variability and relationship between grain Fe and Zn density in early-generation breeding lines

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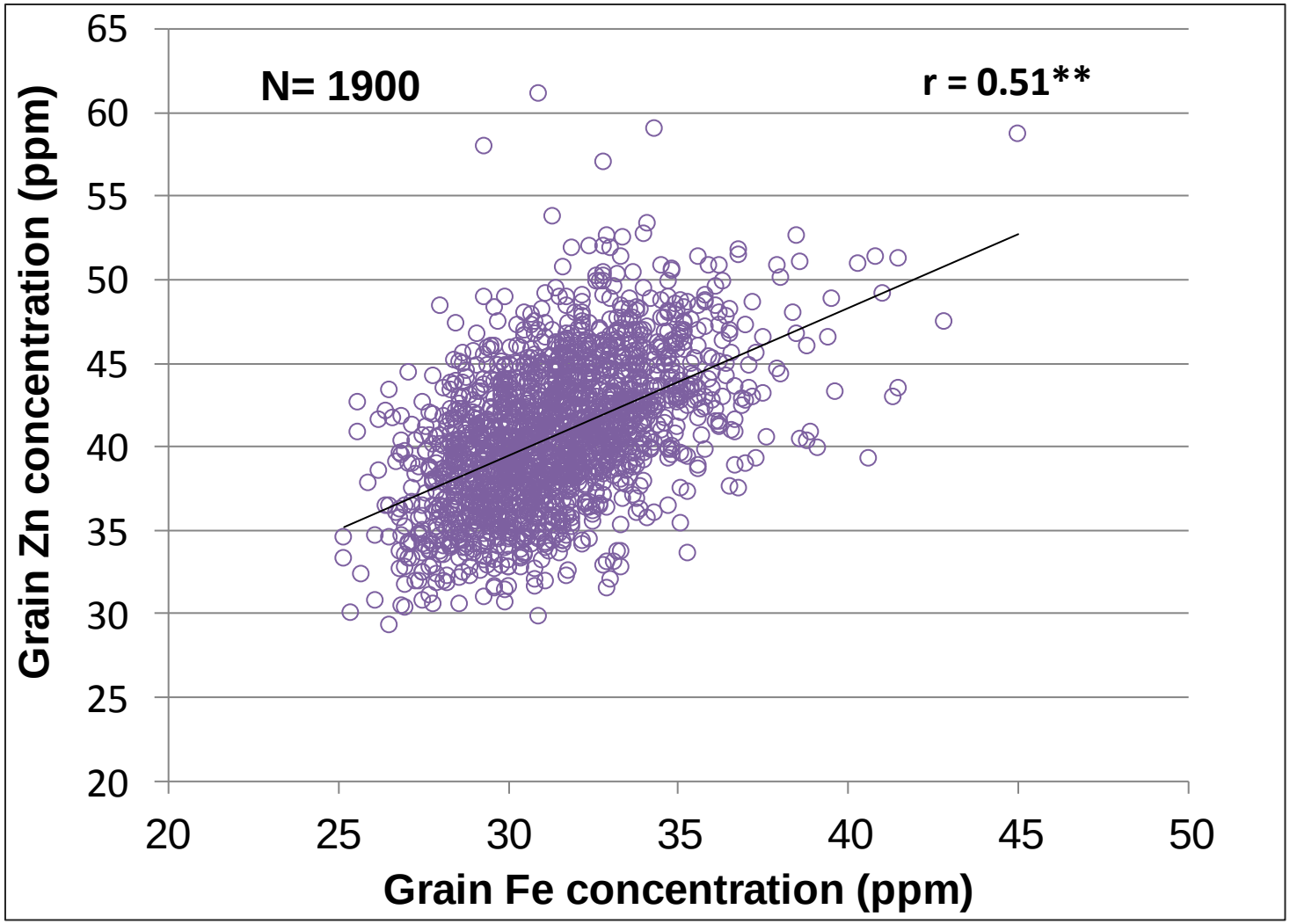
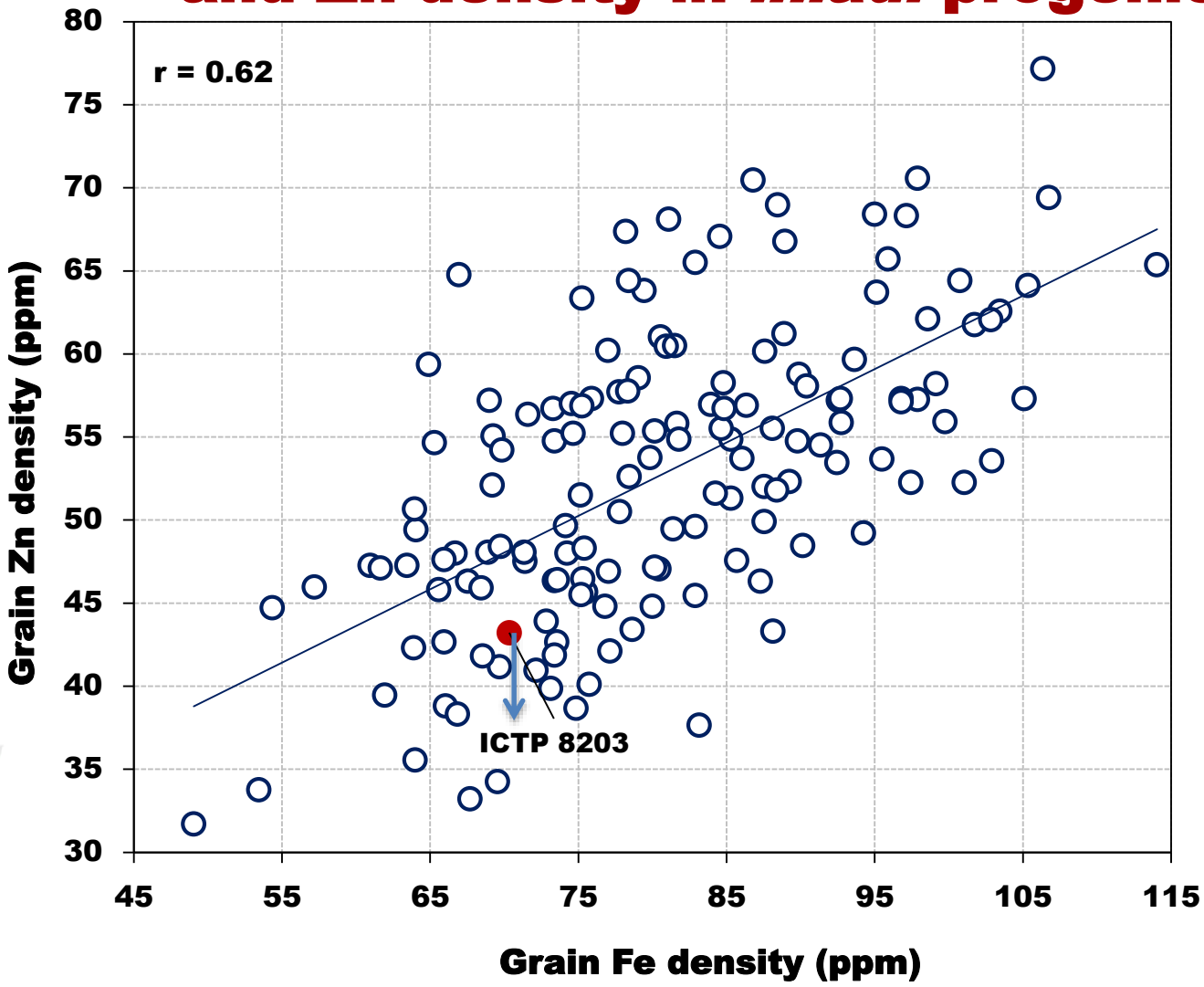
# Relationship between Zn and Fe in F5-F6 lines of wheat



# Variability and relationship between grain Fe and Zn density in *iniadi* progenies

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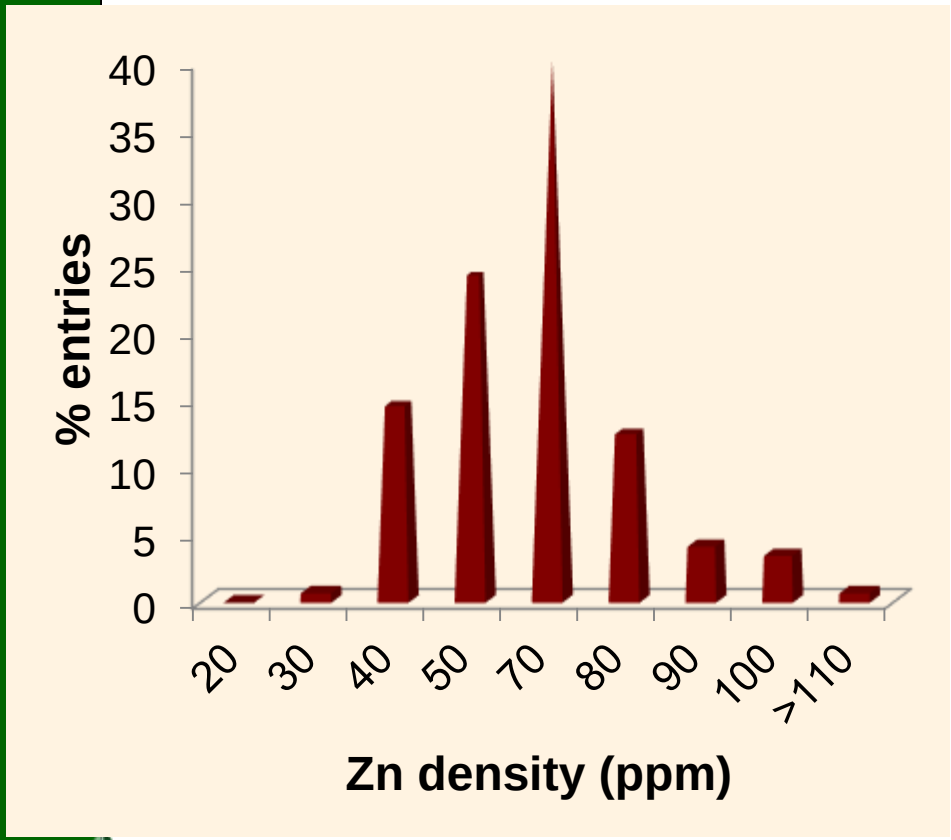
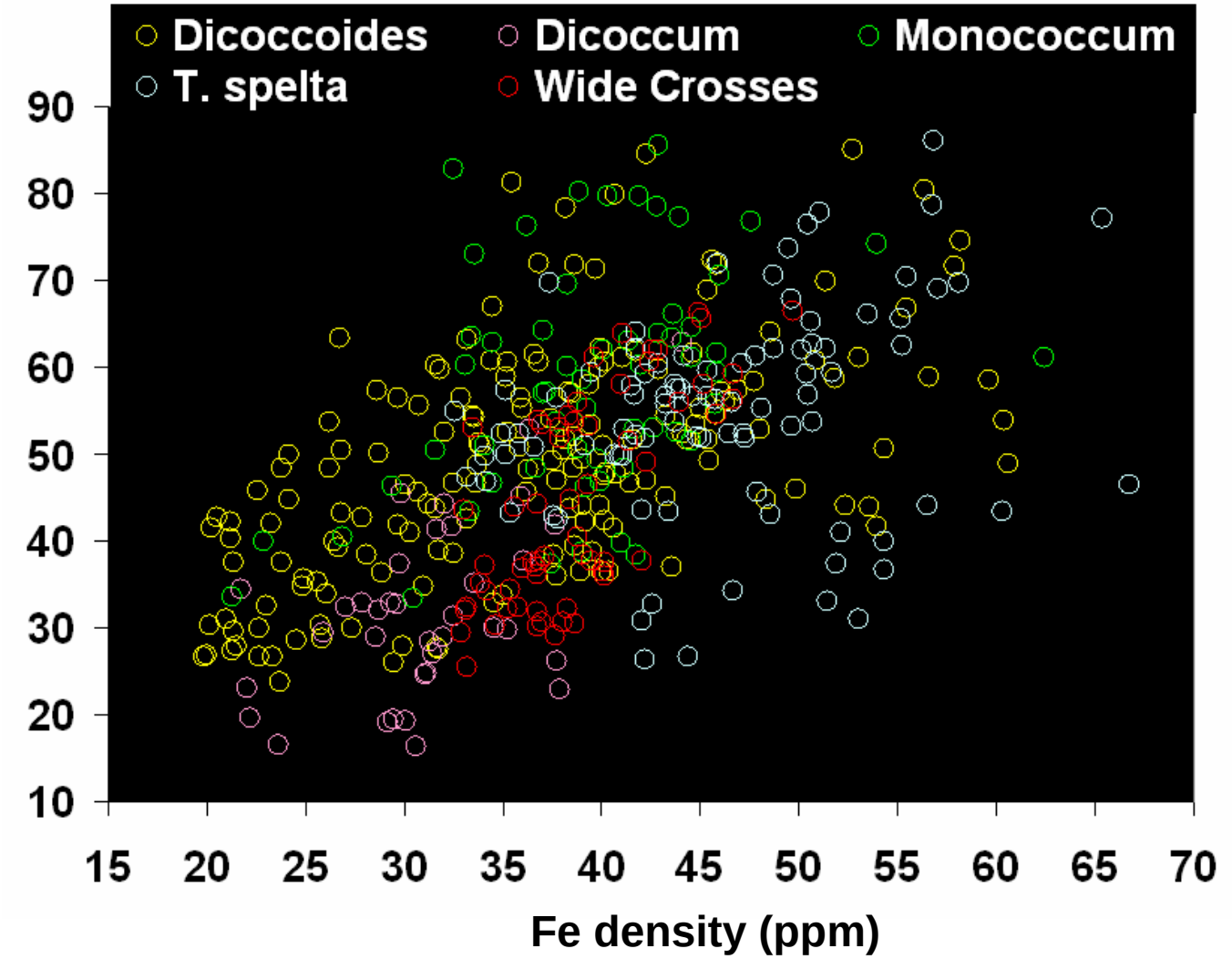
# *T. dicoccoides*: a potential source for high Zn density




- **3-fold variation for Zn density in *T. dicoccoides* originating from Israel (>300 accessions)**
- **Crossable with hexploid wheat- high Zn alleles being introgressed into adapted genetic background**

# Wild Relative of Wheat Species

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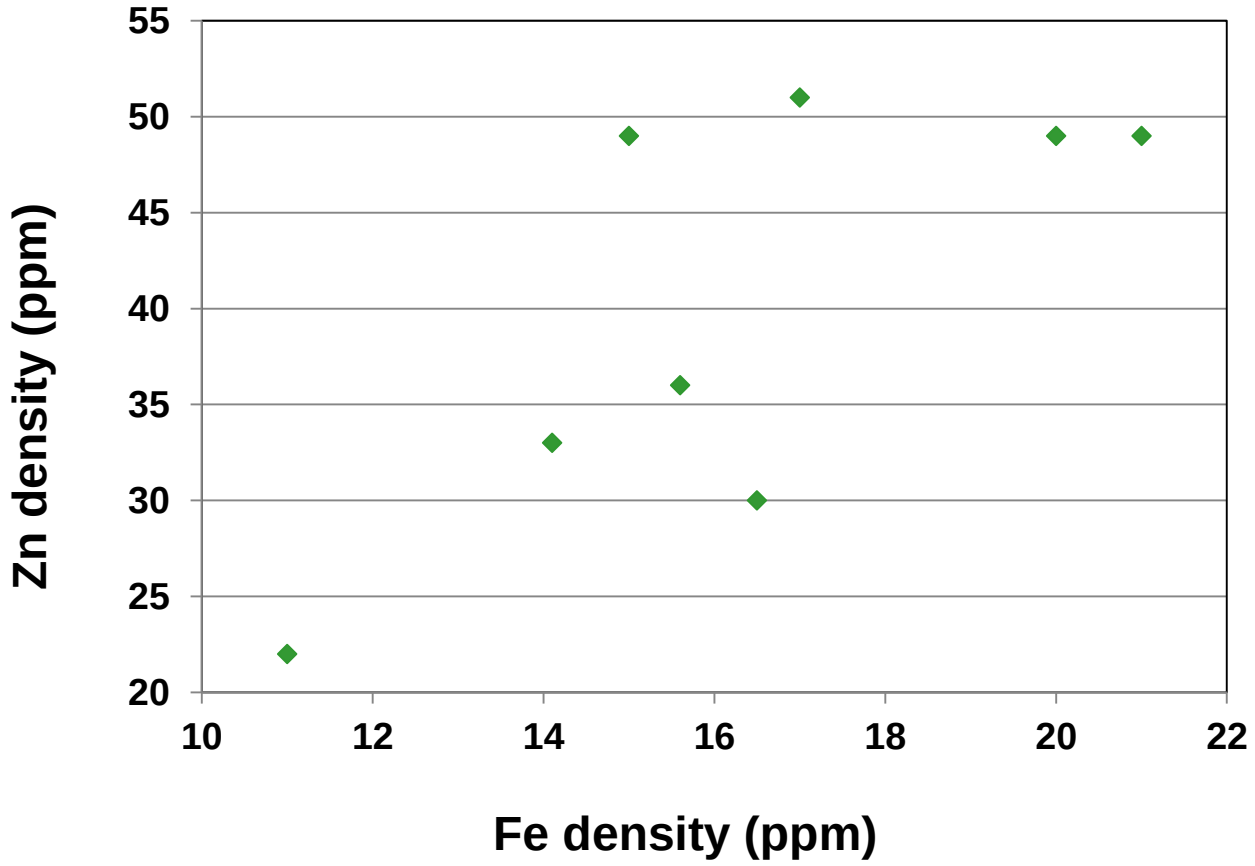
# Promising land races of rice for high zinc from North East India

| Land races | Zn (ppm) |
|---|---|
| VRB/NIN/C3 1050 | 46.7 |
| VRB/NIN/C3 1056 | 44.4 |
| VRB/NIN/C3 1097 | 42.9 |
| VRB/NIN/C3 1076 | 41.0 |
| VRB/NIN/C3 1084 | 40.9 |
| VRB/NIN/C3 1010 | 40.7 |
| VRB/NIN/C3 1087 | 40.6 |
| VRB/NIN/C3 1038 | 38.7 |
| VRB/NIN/C3 1083 | 38.6 |
| VRB/NIN/C3 1022 | 38.2 |

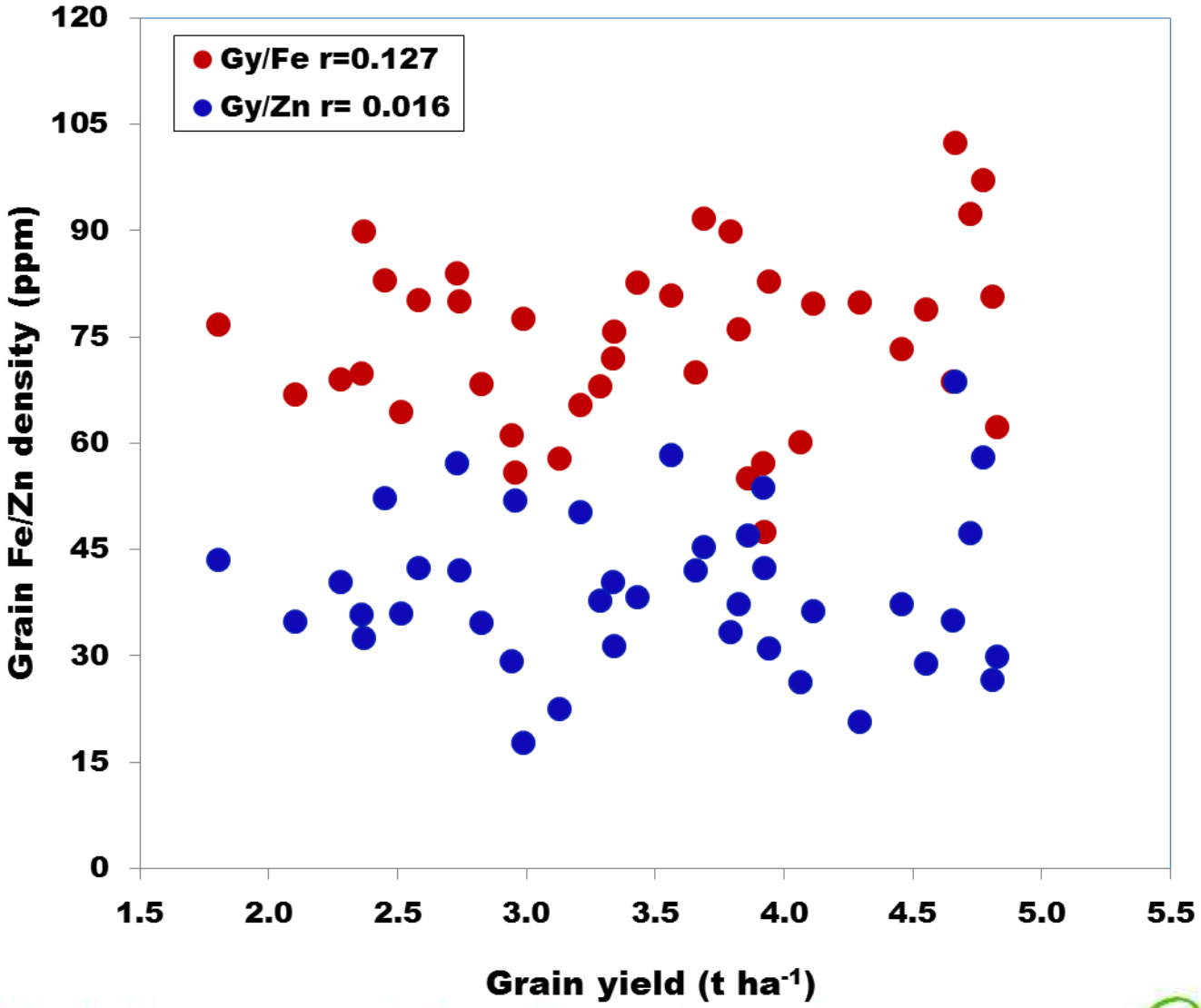
# Rice wild species (*O. rufipogon*)



# Correlation of Iron and Zinc with Grain Yield

| Correlation between | Crop | Correlation coefficient |
|---|---|---|
| Iron and Zinc | Pearl Millet | 0.43 to 0.90 |
| | Wheat | 0.59 to 0.78 |
| | Rice | 0.08 |
| Iron and grain yield | Pearl Millet | -0.50 to 0.16 |
| | Wheat | 0.02 to 0.23 |
| | Rice | 0.05 |
| Zinc and grain yield | Pearl Millet | -0.26 to 0.33 |
| | Wheat | -0.31 to 0.16 |
| | Rice | -0.02 |

# Grain Iron and Zinc Content of Pearl Millet Hybrid Shakti 1201 at Different Production Levels

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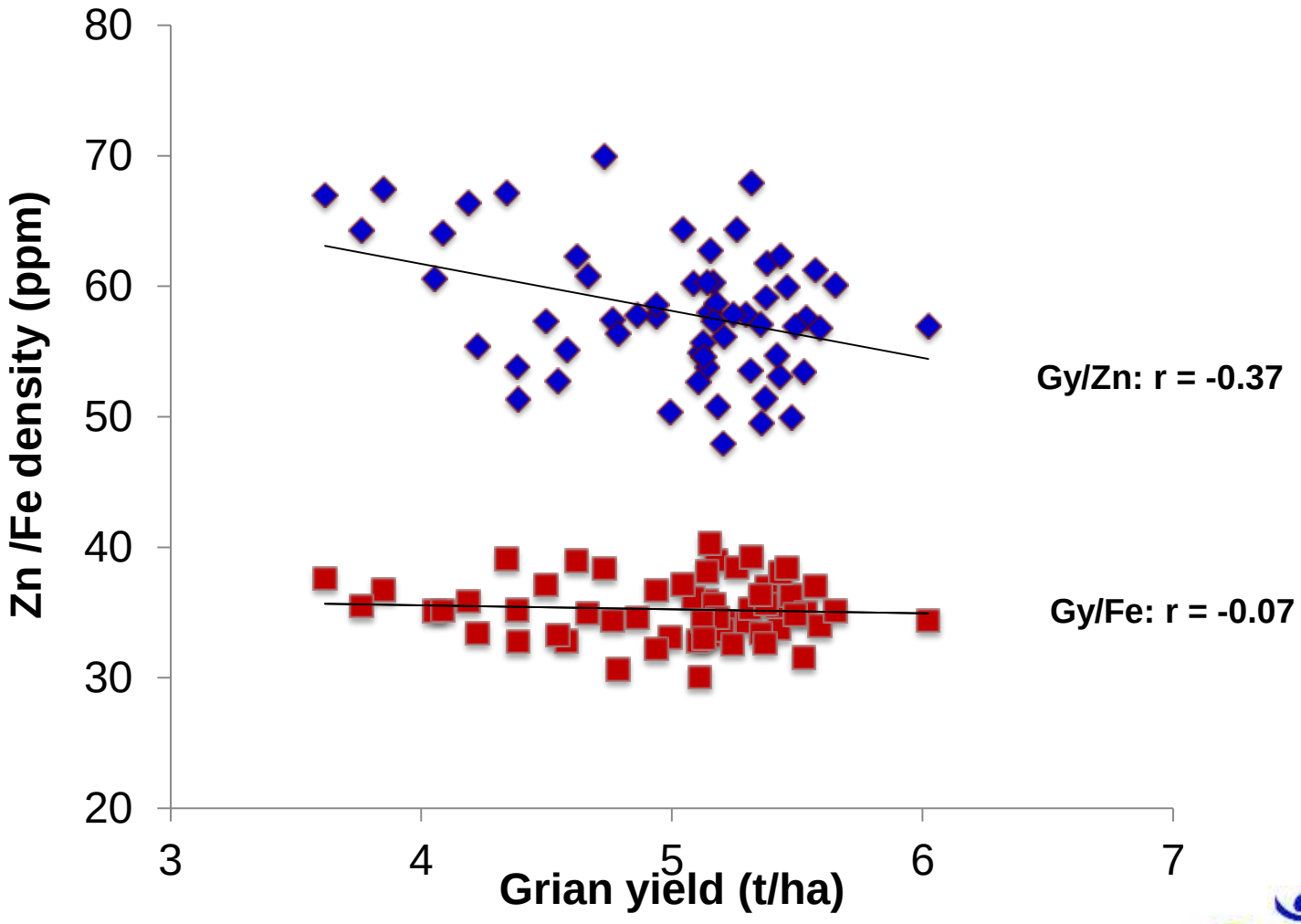
# Association of grain yield with grain Zn (♦) and Fe (■) in 4th HPYT wheat trial

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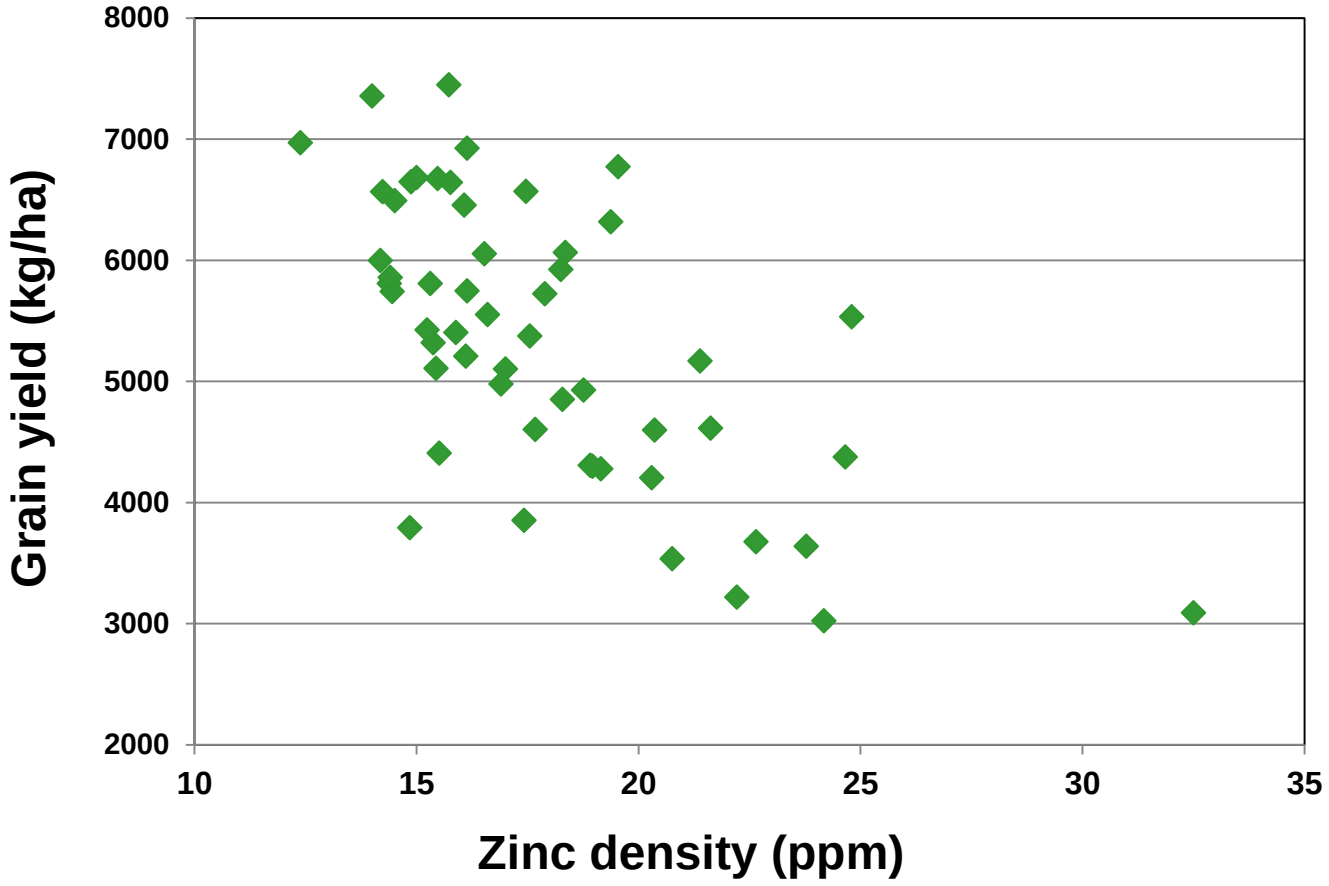
# Relationship between grain yield (kg/ha) and zinc (ppm, brown rice) in elite breeding lines at IRRI



# Rapid and cost-effective XRF screening technique

| Trial | Correlation coefficient between XRF and ICP estimation | | | | | |
|---|---|---|---|---|---|---|
| | Pearl Millet | | Wheat | | Rice | |
| | Iron | Zinc | Iron | Zinc | Iron | Zinc |
| 1 | 0.95** | 0.98** | 0.65** | 0.91** | 0.16 | 0.90** |
| 2 | 0.90** | 0.93** | 0.58** | 0.88** | | |
| 3 | 0.92** | 0.95** | 0.64** | 0.79** | | |
| 4 | 0.91** | 0.92** | 0.55** | 0.76** | | |
| 5 | 0.94** | 0.89** | 0.59** | 0.89** | | |
| 6 | 0.93** | 0.96** | | | | |
| 7 | 0.91** | 0.92** | | | | |
| 8 | 0.94** | 0.88** | | | | |

# Partnership for Development and Delivery in Pearl Millet Biofortification

- 5 State Agricultural University
- 14 Seed Companies

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# Commercialization of high-iron pearl millet cultivars

## Dhanashakti

- Produced and marketed by Nirmal Seeds company to 25000-35000 farmers annually in 2012-2014
- Expected to reach >150,000 farmers in 2015


## Shakti 1201

- Pearl millet hybrid Shakti 1201 under seed production by Shakti Vardhak Seeds company

# Wheat India - Test Marketing of 5 Leads

- **Test marketing of 5 high zinc wheat leads - 1000 mini- kits during 2013-14**

# HarvestPlus Initiative on Other Crops

| S.No. | Crop | Target micronutrient | Geographical focus |
|---|---|---|---|
| 1 | Beans | Fe (Zn) | Rwanda, DRC, Uganda |
| 2 | Maize | Vitamin A | Zambia (Nigeria, Ghana) |
| 3 | Cassava | Vitamin A | Nigeria, DRC |
| 4 | Sweet potato | Vitamin A | Uganda |
| 5 | Lentil | Fe (Zn) | India, Bangladesh, Nepal |
| 6 | Cowpea | Fe | India, Bangladesh, Nepal |
| 7 | Potato | Zn | Rwanda, Ethiopia |
| 8 | Sorghum | Fe, Zn | India, Mali |

# Future Directions

| | |
|---|---|
| **Mainstream biofortification breeding** | • **Mainstreaming at CG centers underway**<br>• **Mainstreaming at NARS centers yet to start**<br>• **Include micronutrients in cultivar release policy** |
| **Partnership building** | • **Public and private seed sector partnerships to be further strengthened**<br>• **Need for broader inter-sectorial partnership involving agriculture, nutrition, food industry and medical community** |
| **Modern tools and techniques** | • **Integrate conventional breeding with genomics**<br>• **Conduct strategic research on GM cultivar development**<br>• **Machines for more precise large scale screening for micronutrients** |

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