Prospects of Breeding Fe, Zn and β-carotene-dense sorghums

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Introduction

- Micronutrients [Fe & Zn) and pro-vitamin A (β-carotene)] malnutrition, primarily the result of diets poor in bio-available vitamins and minerals, causes blindness and anemia in more than half of the world's population, especially women and pre-school children of South and Southeast Asia and sub-Saharan Africa (Underwood 2000).
- These are also the regions where sorghum is cultivated and consumed by millions of people.
- The micronutrient-risk groups have poor access to other sources of these micronutrients.
- The introduction of crop varieties selected and/or bred for increased Fe, Zn and pro-vitamin A contents through plant breeding is the most cost effective approach.
- The plant breeding approach would complement the existing approaches (fortifying foods and providing vitamin and mineral supplements) to combat micronutrient deficiency.

The rationale

- As micronutrients are not visible, the approach does not require any programs to change the behavior of farmers/consumers.
- The micronutrients are loaded in cultivars in high-yielding background and with farmer-preferred grain traits; therefore micronutrient-dense cultivars are readily adopted.

Research at ICRISAT, Patancheru, India

- Pre-breeding research was carried out at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India as a short-term strategy of HarvestPlus, [the Consultative Group on International Agricultural Research's (CGIAR's) challenge program].
- Two experiments were conducted; one to assess the genetic variability and the other to assess the relative variances due to genotype and genotype × environment (soil nitrogen fertility and location) interaction for Fe, Zn and β-carotene contents.

Material and methods

Field evaluation

The material: A set of 84 diverse sorghum lines- 19 maintainer (B-) lines, 47 varieties/restorer (R-) lines and 18 germplasm lines **(Experiment 1).**

A set of 40 lines (with high and low Fe and Zn contents) selected based on their performance in the experiment 1 **(Experiment 2)**

The experimental design, location, and year : Three-replicated randomized block design (RBD) with recommended crop production packages at ICRISAT, Patancheru, India in a during 2003-04 postrainy season **(Experiment 1).**

Three replicated strip-plot design at three managed soil nitrogen fertility levels (40, 80 and 120 kg N ha^{-1}) at ICRISAT, Patancheru, India. The same set was evaluated at National Research Centre for Sorghum, Hyderabad in RBD at recommended dose of fertilizer levels **(Experiment 2).**

Plot size and spacing: In both the experiments, each entry was planted in 4 rows of 2 m length. A spacing of 0.45 m between the rows and 0.1 m between plants in a row was maintained.

Sampling procedure

Agronomic traits: The randomly selected five plants from the middle two rows of each entry were used for recording data days to flowering, plant height (m), grain yield (t ha^{-1}), stover yield (t ha^{-1}), and grain traits [100-grain weight (g) and grain hardness]. The grain hardness (breaking strength) was determined as force (in kg) required to break the grain, using Kiya grain hardness tester.

Micronutrients: The hand-threshed grain samples from selfed plants of each entry from only two replications were sent to National Institute of Nutrition, Hyderabad, India for estimation of grain Fe and Zn and β-carotene and phytate contents .

Laboratory analysis of grain samples: The grain Fe, Zn and phytate contents were estimated using Inductively Coupled Plasma Spectrometry (Houk 1986). The β-carotene content was estimated spectrophotometrically and was confirmed by High-performance Liquid Chromatography (HPLC) in selected samples.

Statistical analysis

The computed mean values of the data recorded on agronomic traits and grain micronutrients and antinutrient (phytates) contents were subjected to statistical analysis.

Analysis of variance (ANOVA) was carried out to partition the total genetic variability due to genotype, genotype × environment (soil nitrogen fertility and location) interaction.

Based on the ANOVA, broad-sense heritability was estimated. The correlation coefficients of grain Fe and Zn contents with agronomic and grain traits were estimated.

Results and Discussion

Genetic variability

- The ANOVA indicated significant genetic differences for grain Fe and Zn contents and phytate contents (Table 1).
- The high broad-sense heritability suggested limited influence of the environment.

Table 1: Estimates of mean, and variability parameters and heritability for grain Fe, Zn, & phytates contents in sorghum, 2003 postrainy season, ICRISAT-Patancheru, India.

Micronutrient	F-test	Mean±SE	Range	Heritability (%)
Fe (ppm)	**	28.0±0.9	20.1-37.0	85
Zn (ppm)	**	19.0±0.8	13.4-31.0	86
Phytates (mg g^{-1})	**	7.6±0.1	3.8-13.5	99

** Significant at P <0.01; Source: Reddy et al. 2005

Micronutrients contents and the kind of genetic material

- The mean grain Fe and Zn contents in germplasm lines were significantly different from those in other categories of materials (B-lines and R-lines/varieties). However, the differences were not large (Table 2).
- While mean grain Fe content was slightly higher in B-lines compared to that in R-lines/varieties, there seemed to be no significant differences in grain Zn contents between B-lines and R-lines/varieties.
- While there were genetic differences for β-carotene content in yellow-endosperm germplasm lines, the differences were not large as evident from the range (0.56-1.13 ppm).
- Several B-lines such as ICSB 37, ICSB 37, ICSB 38, ICSB 39, ICSB 52, ICSB74 and ICSB 101 (high yielding), ICSB 418 (shoot fly resistant) and ICSB 472 (stem borer resistant) and R-lines such as ICSV 745, IRAT 204, PVK 801 and ICSV 21005 had grain Fe content more that the experimental average (30ppm). Similarly, the hybrid parents with higher Zn content (than the experimental average of 20 ppm) include;ICSB 472, ICSB 484 (among B-lines) and IRAT 204, ICSR 90017 (among the R-lines)

Table 2: Category wise performance of the sorghum lines for mean grain Fe and Zn and phytates, 2003 postrainy season, ICRISAT-Patancheru, India.

Material	# of lines	Iron (ppm)	Zinc (ppm)	Phytates (mg g^{-1})
Maintainer (B-) lines	19	29.5	18.9	7.6
Varieties/restorer (R-) lines	47	26.8	18.1	7.8
Germplasm lines	18	30.0	21.9	7.2
F-test	-	**	**	NS
LSD (5%)	-	0.15	0.18	-

Association of grain Fe and Zn contents with agronomic traits: Significant and fairly higher positive correlation between grain Fe and Zn and their poor correlation with agronomic traits such as days to 50% flowering and plant height and with farmer-preferred traits such as grain size and grain hardness (Table 3) indicated the possibility of delivering high Fe and Zn contents in cultivars with farmer's preferred traits.

Table 3: Estimates of correlation coefficients of grain Fe and Zn contents with agronomic traits in sorghum, 2003 postrainy season, ICRISAT-Patancheru, India.

Grain micronutrient /agronomic trait	Phytate (mg g^{-1})	Iron (ppm)	Zinc (ppm)	Time to 50% flowering (days)	Grain yield (t ha^{-1})	100-grain weight (g)
Iron	0.02	1.00				
Zinc	0.12	0.55*	1.00			
Time to 50% flowering	-0.06	0.18	0.12	1.00		
Grain yield	0.04	-0.32**	-0.54**	0.06	1.00	
Grain size	-0.16	-0.18	-0.11	-0.15	-0.22*	1.00
Grain hardness	0.23*	-0.10	-0.09	-0.14	0.05	0.02

* Significant at P=0.01; Source: Reddy et al. 2005

Genotype × environment interaction

☐ Neither the differences in managed soil nitrogen fertility levels nor their interaction with the genotypes did have any effects on grain Fe and Zn contents, as indicated from non-significant mean squares due to fertility level and fertility × genotype interaction, respectively (Table 4).

☐ Though soil fertility levels had significant influence on grain phytates contents, the genotypes fertility rankings did not alter across soil fertility levels.

☐ The combined analysis of the data from ICRISAT, Patancheru and NRCS, Hyderabad locations indicated that the production environments at the two locations did not appear to have significant influence on grain Fe and phytates contents (Table 5). However, Zn content of the entries appeared to vary with the locations.

Table 4: ANOVA for Fe, Zn & phytate contents, ICRISAT, Patancheru, 2004-05 postrainy season.

Sources of Variation	d.f.	Mean Sum of Squares		
		Fe (ppm)	Zn (ppm)	Phytates (mg g^{-1})
Genotype (G)	39	79.7**	118.8**	3.0*
Fertility (F)	2	703.5	43.2	539.6*
G × F	74 (4)	38.4	17.9	2.1
Error	113 (4)	40.8	12.5	1.9

*Significant at P=0.05 and **Significant at P=0.01; Figures in parentheses indicate missing values

Table 5: Combined analysis of variance for Fe, Zn and phytates contents of selected sorghum lines evaluated at ICRISAT, Patancheru and NRCS, Hyderabad locations, 2004-05 postrainy season

Source of variation	df	Mean sum of squares		
		Iron (ppm)	Zinc (ppm)	Phytates (mg g^{-1})
Location (L)	1	555.3	501.2**	12.6
Residual	2	154.9	16.3	1.6
Genotype (G)	39	119.2**	32.9**	3.0
L × G	39	42.9	21.9**	3.4
Error	78	31.7	6.3	4.5

**Significant at P=0.01

Conclusions

- The study indicated significant genetic variability coupled with high broad-sense variability for grain Fe and Zn contents.
- There was a high and positive correlation of Fe and Zn contents with important agronomic traits such as days to 50% flowering and plant height.
- The association of grain Fe and Zn contents with farmer-preferred traits such as grain size and grain hardness was weak.
- Poor evidence of genotype × soil fertility interaction for grain Fe and Zn contents.
- The results suggests the good prospects of breeding sorghum for Fe and Zn contents in high yielding and farmer's/consumer preferred grain traits.

Looking ahead

- ✓ Genetic variability in the core collection (10% of global collection) (nearly 2500 lines) would be accessed to enhance the pace and efficiency of breeding micronutrient-dense sorghums.
- ✓ The selected micronutrient-dense lines will be evaluated for stability of micronutrients contents across different soil types and fertility levels typical in the areas for which micronutrient-dense sorghum cultivars are targeted.

References

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