

## Database for grain Fe and Zn in sorghum – A proposal

A Ashok Kumar\*, Belum VS Reddy and B Ramaiah

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India

\*Corresponding author: a.ashokkumar@cgiar.org

Ashok Kumar A, Reddy BVS and Ramaiah B. 2012. Database for grain Fe and Zn in sorghum – A proposal. Journal of SAT Agricultural Research 10.

### Introduction

Sorghum (*Sorghum bicolor*) is the fifth most important cereal staple crop in subtropical and semi-arid regions of Africa and Asia (Reddy et al. 2011). It is the second cheapest source of energy and micronutrients, after pearl millet (*Pennisetum glaucum*) with a vast majority of the population in Africa and Central India depending on it for their dietary energy and micronutrient requirements (Parthasarathy Rao et al. 2006). Micronutrient malnutrition, primarily the result of diets deficient in bio-available vitamins and minerals, causes blindness and anemia (even death) in more than half of the world's population, especially among women of reproductive age, pregnant and lactating women and pre-school children (Underwood 2000, Sharma 2003, Welch and Graham 2004). Efforts are being made to provide fortified foods to these vulnerable groups. Biofortification, where possible, is the most cost-effective and sustainable solution for tackling micronutrient deficiencies in developing countries of arid-tropical and subtropical regions as the intake of micronutrients is on a continuous basis with no additional cost to the consumer. Widespread interest is being shown in biofortification of sorghum by increasing mineral micronutrients [especially iron (Fe) and zinc (Zn)] in grains (Pfeiffer and McClafferty 2007, Ashok Kumar et al. 2009).

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) conducts research on sorghum biofortification to enhance the grain Fe and Zn concentrations. Preliminary studies by Reddy et al. (2005) indicated limited variability for grain Fe and Zn concentrations in sorghum hybrid parents, advanced breeding lines and germplasm accessions. Large genetic variability for grain Fe and Zn concentrations however, was reported in sorghum landrace accessions, hybrid parents and commercial hybrids (Ashok Kumar et al. 2009, 2012). Significant positive correlation was observed between grain Fe and Zn concentrations (Reddy et al. 2010, Ashok Kumar et al. 2011). In a field study conducted at ICRISAT-Patancheru, India to enhance

grain Fe and Zn under balanced nutrient application, nitrogen (N), phosphorus (P), potassium (K) along with sulfur (S), boron (B), Fe and Zn were applied to the soil. However, these did not increase grain Fe and Zn concentrations, probably because the inherent availability of these nutrients in the soil was not limiting (Ashok Kumar et al. 2010).

Therefore, genetic enhancement for grain Fe and Zn concentrations is of critical importance. Availability of genetic variability and an understanding of the nature and magnitude of genes help in developing an effective breeding program to improve Fe and Zn concentrations. In attempting this, ICRISAT evaluated a large number of landraces (2246), hybrid parents (>500 B-lines and 100 R-lines), breeding lines and commercial sorghum cultivars (67) over the years from 2005 to 2011 for assessing grain Fe and Zn concentrations and important agronomic traits. This paper is an attempt to present the vast variability observed in sorghum for grain Fe and Zn concentrations and to keep the entire information in public domain in the form of a database so that researchers interested in improving sorghum grain Fe and Zn concentrations make use of the information and the material. In addition to Fe and Zn, this database also contains information on traits like time to 50% flower, plant height, grain yield and grain size which are critical in any crop improvement program.

### Materials and methods

The materials used for this study included sorghum landraces (2246), which are part of core collections from ICRISAT Genebank, a total of 623 ICRISAT-bred trait based hybrid parents (523 B-lines and 100 R-lines), breeding lines (20) and 67 commercial sorghum cultivars developed by public and private sector partners from Indian NARS, either directly or in partnership with ICRISAT. The landraces were evaluated as a nursery in two different years (1401 landraces in 2005 and 845 in 2006). The best among them (353) were identified and evaluated in replicated trials in five different sets over two seasons in different years (Table 1). Similarly

**Table 1. Details of the sorghum material evaluated for grain Fe and Zn and agronomic traits during 2005 to 2011.**

Annexure <sup>1</sup>	Material	No. of genotypes	Years of testing	Remarks
1	Landrace accessions (part of sorghum core germplasm)	2246	2005 and 2006	Initial analysis in nurseries; 1 row of 2 m length unreplicated trial with controls planted at regular intervals
2	Landrace accessions selected from Annexure 1	48	2007 and 2008	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
3	Selected landrace accessions from Annexure 1 with freely threshable grains	116	2007 and 2008	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
4	Selected landrace accessions from Annexure 1 with non-threshable grains	46	2008	Replicated trial (RCBD with 3 replications; 2 rows of 2 m length plot size)
5	Selected micronutrient-dense landraces from Annexure 1	41	2008 and 2009	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
6	Selected micronutrient-dense landraces from Annexure 1	100	2010 and 2011	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
7	Selected micronutrient-dense landraces from Annexures 2 and 3	15	2010 and 2011	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
8	Breeding lines (mosaic of B-lines, R-lines, varieties and germplasm lines)	20	2007 and 2008	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
9	ICRISAT-bred established hybrid parents (B-lines) – Set I	250	2008 and 2009	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
10	ICRISAT-bred established hybrid parents (B-lines) – Set II	218	2010 and 2011	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
11	ICRISAT-bred established hybrid parents (B-lines) – Set III	55	2010 and 2011	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
12	ICRISAT-bred established hybrid parents (R-lines)	50	2008 and 2009	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
13	ICRISAT-bred established hybrid parents (R-lines)	50	2010 and 2011	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
14	Commercial sorghum cultivars (Set I)	20	2008 and 2009	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)
15	Commercial sorghum cultivars (Set II)	47	2009 and 2010	Replicated trials (RCBD with 3 replications; 2 rows of 2 m length plot size)

1. Source: <http://dataverse.icrisat.org/dvn/dv/sorghumbiofortification>

ICRISAT-developed trait based B-lines (523) were evaluated in three sets and R-lines (100) in two sets. The commercial cultivars were also evaluated in two sets. All these trials were organized in post-rainy seasons to get the best quality grain for assessing the grain Fe and Zn concentrations and agronomic traits.

In all years, the trials were planted in Randomized Complete Block Design (RCBD) with three replications using two controls at ICRISAT-Patancheru (altitude 545 m above mean sea level, latitude 17.53° N and longitude 78.27° E). The plot size was 2 rows of 2 m length with 75 cm spacing between rows and 15 cm spacing between plants. A good crop was raised with required irrigation under high fertility conditions (N:P:K 80:40:0). In each plot 3–4 panicles were selfed prior to flowering to avoid cross-pollination. The data were collected on time to 50% flower, plant height, grain yield and grain size. In each plot, three to five panicles were bagged with Kraft paper bags prior to flowering in each replication to avoid pollen contamination and to harvest pure seed for assessing grain Fe and Zn concentrations. The panicles were harvested at maturity and the grain was threshed carefully without any contact with metal or dust particles to avoid contamination. The remaining open-pollinated panicles in the plot were harvested and threshed to obtain per plot grain yield. Grain yield (g) from selfed and open-pollinated panicles was combined in each plot and extrapolated to get grain yield in t ha<sup>-1</sup>. The cleaned seeds from selfed panicles were collected in cloth bags and used for micronutrient analysis in the Charles Renard Analytical Laboratory (CRAL) at ICRISAT-Patancheru. The grain Fe and Zn concentrations were determined in the ground grain samples by using the triacid digestion method (Sahrawat et al. 2002). The data on agronomic traits along with grain Fe (mg kg<sup>-1</sup>) and Zn (mg kg<sup>-1</sup>) were statistically analyzed using the GENSTAT 9.1 package to assess the significant differences among the genotypes for mean performance for grain Fe and Zn concentrations and agronomic traits.

## Results and discussion

The Fe and Zn values of 2246 sorghum germplasm accessions from an unreplicated trial conducted in two separate years, viz, 2005 (1401 germplasm accessions) and 2006 (845 germplasm accessions) post-rainy season and mean values for Fe, Zn, time to 50% flower, plant height, grain yield and grain size for various trials: (1) micronutrient-dense landraces; (2) freely threshable micronutrient-dense landraces; (3) non-threshable micronutrient-dense landraces; (4) sorghum landraces (Set I, Set II and Set III); (5) micronutrient-dense breeding lines; (6) ICRISAT-bred sorghum B-lines (Set I, Set II and Set III); (7) ICRISAT-bred sorghum R-lines

(Set I and Set II); (8) commercial sorghum cultivars (Set I and Set II), conducted from 2007 to 2011 post-rainy season are presented in Annexures 1 to 15.

Annexure 1 contains Fe and Zn values for a total 2246 landraces evaluated in 2005 and 2006 post-rainy season with a range of 8 to 192 mg kg<sup>-1</sup> for Fe and 14 to 91 mg kg<sup>-1</sup> for Zn. The variability appeared to be very high for Fe and Zn concentrations. A total of 353 landraces showed Fe concentration above 50 mg kg<sup>-1</sup> with Zn concentration ranging from 51 to 192 mg kg<sup>-1</sup> which were selected for validation of results through replicated trials over years.

Annexure 2 contains results for 48 micronutrient-dense landraces evaluated with two controls in a trial during 2007 and 2008 post-rainy season. Among the 48 landraces evaluated, 29 micronutrient-dense landraces were similar for Fe concentration in two years and these were considered for mean estimations. The entries had average Fe content of 46 mg kg<sup>-1</sup> and average Zn content of 38 mg kg<sup>-1</sup> with the Fe content ranging from 26 to 60 ppm and Zn content from 21 to 57 mg kg<sup>-1</sup>. The controls ICSR 40 and 296B had same Fe and Zn concentrations with 40 mg kg<sup>-1</sup> Fe and 24 mg kg<sup>-1</sup> Zn. Four landraces (IS 5427, IS 5514, IS 55 and IS 3760) had significantly higher (by 8 to 23%) grain Fe concentration and all landraces except one (IS 22215) had significantly higher (by 14 to 116%) grain Zn concentrations than the control ICSR 40 (Fe 40 mg kg<sup>-1</sup> and Zn 24 mg kg<sup>-1</sup>). Four landraces IS 5427 (Fe 60 mg kg<sup>-1</sup> and Zn 57 mg kg<sup>-1</sup>), IS 5514 (Fe 56 mg kg<sup>-1</sup> and Zn 45 mg kg<sup>-1</sup>), IS 55 (Fe 54 mg kg<sup>-1</sup> and Zn 38 mg kg<sup>-1</sup>) and IS 3760 (Fe 53 mg kg<sup>-1</sup> and Zn 37 mg kg<sup>-1</sup>) were highly promising for grain Fe (8 to 23%) and for grain Zn (41 to 116%) concentrations. This variation is higher than what is generally observed in sorghum (Reddy et al. 2005, Ashok Kumar et al. 2009).

Annexure 3 contains results for 116 micronutrient-dense freely threshable landraces evaluated with two controls in a trial during 2007 and 2008 post-rainy season. The grain Fe content ranged from 27 to 71 mg kg<sup>-1</sup> and Zn content from 19 to 54 mg kg<sup>-1</sup>, with an average Fe content of 44 mg kg<sup>-1</sup> and an average Zn content of 32 mg kg<sup>-1</sup>. Sixty-five landraces showed significantly higher (by 5 to 76%) grain Fe concentration ranging from 42 to 71 mg kg<sup>-1</sup> and 83 landraces showed significantly higher (by 5 to 106%) grain Zn concentration ranging from 27 to 54 mg kg<sup>-1</sup> than the control ICSR 40 (Fe 38 mg kg<sup>-1</sup> and Zn 24 mg kg<sup>-1</sup>). Six landraces, IS 23680 (Fe 71 mg kg<sup>-1</sup> and Zn 44 mg kg<sup>-1</sup>), IS 5308 (Fe 63 mg kg<sup>-1</sup> and Zn 45 mg kg<sup>-1</sup>), IS 3790 (Fe 58 mg kg<sup>-1</sup> and Zn 54 mg kg<sup>-1</sup>), IS 12750 (Fe 58 mg kg<sup>-1</sup> and Zn 46 mg kg<sup>-1</sup>), IS 1222 (Fe 55 mg kg<sup>-1</sup> and Zn 41 mg kg<sup>-1</sup>) and IS 5299 (Fe 55 mg kg<sup>-1</sup> and Zn 40 mg kg<sup>-1</sup>), were found highly promising with 35 to 76% higher grain Fe concentration and 54 to 106% higher grain Zn concentration compared to the best control. This variation is quite interesting and two superior lines are

suitable for use as donors in crossing programs for enhancing grain Fe and Zn concentrations.

Annexure 4 contains results for 46 micronutrient-dense non-threshable landraces evaluated with six controls in a trial during 2008 postrainy season. They showed Fe concentration ranging from 27 to 57 mg kg<sup>-1</sup> and Zn concentration from 17 to 39 mg kg<sup>-1</sup> with an average Fe content of 39 mg kg<sup>-1</sup> and average Zn content of 28 mg kg<sup>-1</sup>. Twenty-four lines had significantly higher (by 5 to 52%) grain Fe content ranging from 39 to 57 mg kg<sup>-1</sup> and all lines except three (IS 186, IS 11 and IS 31683) showed significantly higher (by 7 to 80%) grain Zn concentration ranging from 23 to 39 mg kg<sup>-1</sup> than the control ICSR 40 (Fe 35 mg kg<sup>-1</sup> and Zn 20 mg kg<sup>-1</sup>). Four landraces IS 1563 (Fe 57 mg kg<sup>-1</sup> and Zn 39 mg kg<sup>-1</sup>), IS 12849 (Fe 46 mg kg<sup>-1</sup> and Zn 30 mg kg<sup>-1</sup>), IS 14108 (Fe 46 mg kg<sup>-1</sup> and Zn 30 mg kg<sup>-1</sup>) and IS 31680 (Fe 45 mg kg<sup>-1</sup> and Zn 30 mg kg<sup>-1</sup>) were promising with 21 to 52% for grain Fe and 40 to 80% for grain Zn concentrations.

Annexure 5 contains results for 41 landraces (best lines from Annexure 1) evaluated with two controls during 2008 and 2009 postrainy season. They showed an average Fe content of 42 mg kg<sup>-1</sup> and average Zn content of 29 mg kg<sup>-1</sup> with the Fe content ranging from 31 to 54 mg kg<sup>-1</sup> and Zn content from 21 to 42 mg kg<sup>-1</sup>. Twenty-eight germplasm accessions had significantly higher (by 6 to 43%) grain Fe content ranging from 40 to 54 mg kg<sup>-1</sup> and 34 landraces had significantly higher (by 10 to 75%) grain Zn content ranging from 26 to 42 mg kg<sup>-1</sup> than the control PVK 801 (Fe 36 mg kg<sup>-1</sup> and Zn 22 mg kg<sup>-1</sup>). Among them, IS 17307 (Fe 54 mg kg<sup>-1</sup> and Zn 38 mg kg<sup>-1</sup>), IS 3106 (Fe 54 mg kg<sup>-1</sup> and Zn 34 mg kg<sup>-1</sup>), IS 25699 (Fe 51 mg kg<sup>-1</sup> and Zn 33 mg kg<sup>-1</sup>) and IS 32 (Fe 50 mg kg<sup>-1</sup> and Zn 32 mg kg<sup>-1</sup>) were highly promising with 31 to 43% higher Fe content and 34 to 61% higher Zn content over the control PVK 801.

Annexure 6 contains results for 100 micronutrient-dense landraces (another best 100 lines from Annexure 1) evaluated with three controls in a trial during 2010 and 2011 postrainy season for validation of results. They showed an average Fe content of 44 mg kg<sup>-1</sup> and an average Zn content of 27 mg kg<sup>-1</sup> with Fe content ranging from 20 to 76 mg kg<sup>-1</sup> and Zn content from 16 to 40 mg kg<sup>-1</sup>. Forty-five lines had significantly higher (by 5 to 80%) grain Fe content ranging from 44 to 76 mg kg<sup>-1</sup> and 64 lines had significantly higher (by 5 to 68%) grain Zn content ranging from 25 to 40 mg kg<sup>-1</sup> than PVK 801 (Fe 40 mg kg<sup>-1</sup> and Zn 22 mg kg<sup>-1</sup>).

Annexure 7 contains results for 15 micronutrient-dense landraces (selected from Annexure 2 and Annexure 3) evaluated with two controls in a trial during 2010 and 2011 postrainy season for validation of results. They showed an average Fe content of 49 mg kg<sup>-1</sup> and an average Zn content of 31 mg kg<sup>-1</sup> with Fe content ranging

from 32 to 73 mg kg<sup>-1</sup> and Zn content from 19 to 41 mg kg<sup>-1</sup>. All the lines (except two) had significantly higher (by 11 to 84%) grain Fe content ranging from 44 to 73 mg kg<sup>-1</sup> and all the lines had significantly higher (by 16 to 95%) grain Zn content ranging from 24 to 41 mg kg<sup>-1</sup> than PVK 801 (Fe 37 mg kg<sup>-1</sup> and Zn 19 mg kg<sup>-1</sup>).

Annexure 8 contains results for 20 micronutrient-dense breeding lines evaluated with three controls in a trial during 2007 and 2008 postrainy season. They showed an average Fe content of 38 mg kg<sup>-1</sup> and an average Zn content of 30 mg kg<sup>-1</sup> with Fe content ranging from 30 to 45 mg kg<sup>-1</sup> and Zn content from 25 to 38 mg kg<sup>-1</sup>. The control 296B (a prominent B-line used as a female parent in the development of many sorghum hybrids released in India) had 34 mg kg<sup>-1</sup> Fe and 25 mg kg<sup>-1</sup> Zn content in the grain. Six lines (five breeding and one germplasm) had significantly higher (by 5 to 15%) grain Fe concentration ranging from 39 to 43 mg kg<sup>-1</sup> and 10 lines (five breeding and five germplasm) had significantly higher (by 5 to 30%) grain Zn concentration ranging from 30 to 38 mg kg<sup>-1</sup> over control 296B. The breeding line ICSV 25263 had significantly higher (12%) grain Fe (41 mg kg<sup>-1</sup>) and 10% higher Zn concentrations (32 mg kg<sup>-1</sup>). Another breeding line ICSV 93046 also recorded significantly higher (7%) grain Fe (40 mg kg<sup>-1</sup>) and higher (11%) grain Zn (32 mg kg<sup>-1</sup>) concentrations compared to 296 B. These two breeding lines can be used as parents in delivering new hybrids.

Annexure 9 contains results for 250 ICRISAT-bred sorghum B-lines (Set I) evaluated with two controls during 2008 and 2009 postrainy season. The mean performance for grain Fe content ranged from 28 to 48 mg kg<sup>-1</sup> with an average Fe content of 36 mg kg<sup>-1</sup> and for grain Zn content from 14 to 29 mg kg<sup>-1</sup> with an average Zn content of 21 ppm. The controls ICSB 52 and 296B had 35 and 37 mg kg<sup>-1</sup> grain Fe respectively and both had 19 mg kg<sup>-1</sup> grain Zn. Sixteen B-lines had significantly higher (by 5 to 19%) grain Fe concentration ranging from 42 to 48 mg kg<sup>-1</sup> and 93 B-lines had higher (by 5 to 40%) grain Zn concentration than the control 296 B, ranging from 22 to 29 mg kg<sup>-1</sup>. Six B-lines ICSB 10 (Fe 48 mg kg<sup>-1</sup> and Zn 24 mg kg<sup>-1</sup>), ICSB 263 (Fe 47 mg kg<sup>-1</sup> and Zn 25 mg kg<sup>-1</sup>), ICSB 399 (Fe 47 mg kg<sup>-1</sup> and Zn 27 mg kg<sup>-1</sup>), ICSB 17 (Fe 45 mg kg<sup>-1</sup> and Zn 22 mg kg<sup>-1</sup>), ICSB 354 (Fe 45 mg kg<sup>-1</sup> and Zn 27 mg kg<sup>-1</sup>), ICSB 50 (Fe 45 mg kg<sup>-1</sup> and Zn 26 mg kg<sup>-1</sup>) were found highly promising with 11 to 19% higher Fe content and 6 to 32% higher Zn content than the best control 296 B. This variability in B-lines is quite higher than that reported earlier in sorghum (Reddy et al. 2005).

Annexure 10 contains results for 218 ICRISAT-bred sorghum B-lines (Set II) evaluated with two controls during 2010 and 2011 postrainy season. The average Fe content was 38 mg kg<sup>-1</sup> and average Zn content was 22 mg

kg<sup>-1</sup> with the Fe content ranging from 27 to 50 mg kg<sup>-1</sup> and Zn content from 16 to 31 mg kg<sup>-1</sup>. Fifty-four B-lines had significantly higher (by 5 to 25%) grain Fe content ranging from 42 to 50 mg kg<sup>-1</sup> and 69 B-lines had significantly higher (by 5 to 43%) grain Zn content ranging from 23 to 31 mg kg<sup>-1</sup> than 296 B (Fe 38 mg kg<sup>-1</sup> and Zn 22 mg kg<sup>-1</sup>). Nine B-lines had significantly higher (by 5 to 11%) grain Fe content ranging from 47 to 50 mg kg<sup>-1</sup> and 68 B-lines had significantly higher (by 5 to 42%) grain Zn content ranging from 23 to 31 mg kg<sup>-1</sup> than PVK 801, a high Fe and Zn containing variety (Fe 43 mg kg<sup>-1</sup> and Zn 22 mg kg<sup>-1</sup>). Among them four B-lines ICSB 387 (Fe 48 mg kg<sup>-1</sup> and Zn 25 mg kg<sup>-1</sup>), ICSB 58 (Fe 47 mg kg<sup>-1</sup> and Zn 28 mg kg<sup>-1</sup>), ICSB 271 (Fe 47 mg kg<sup>-1</sup> and Zn 24 mg kg<sup>-1</sup>) and ICSB 306 (Fe 47 mg kg<sup>-1</sup> and Zn 24 mg kg<sup>-1</sup>) were highly promising with 5 to 6% higher Fe content and 7 to 27% higher Zn content than the control PVK 801. All these B-lines can be used as parents in delivering hybrids with high Fe and Zn concentrations.

Annexure 11 contains results for 55 ICRISAT-bred sorghum B-lines (Set III) evaluated with two controls during 2010 and 2011 post-rainy season. The average Fe content was 37 mg kg<sup>-1</sup> and average Zn content was 22 mg kg<sup>-1</sup> with the Fe content ranging from 27 to 47 mg kg<sup>-1</sup> and Zn content from 16 to 27 mg kg<sup>-1</sup>. Thirty-two B-lines had significantly higher (by 5 to 35%) grain Fe content ranging from 37 to 47 mg kg<sup>-1</sup> and 33 B-lines had significantly higher (by 5 to 32%) grain Zn content ranging from 21 to 27 mg kg<sup>-1</sup> than 296 B (Fe 33 mg kg<sup>-1</sup> and Zn 19 mg kg<sup>-1</sup>). Two B-lines had significantly higher (by 7% and 13%) grain Fe content (45 and 47 mg kg<sup>-1</sup>) and five B-lines had significantly higher (by 5 to 11%) grain Zn content ranging from 25 to 27 mg kg<sup>-1</sup> than PVK 801. Two B-lines ICSB 671 (Fe 47 mg kg<sup>-1</sup> and Zn 26 mg kg<sup>-1</sup>) and ICSB 29009 (Fe 45 mg kg<sup>-1</sup> and Zn 26 mg kg<sup>-1</sup>) were highly promising with 13% and 7% higher Fe content and 7% higher Zn content than the control PVK 801.

Annexure 12 contains results for 50 ICRISAT-bred sorghum R-lines (Set I) with two controls evaluated during 2008 and 2009 post-rainy season. The mean performance for grain Fe content varied from 25 to 39 mg kg<sup>-1</sup> with an average of 31 mg kg<sup>-1</sup> and grain Zn content from 16 to 28 mg kg<sup>-1</sup> with an average of 21 mg kg<sup>-1</sup>. The controls PVK 801 and RS 29 had 33 and 27 mg kg<sup>-1</sup> grain Fe and 21 and 16 mg kg<sup>-1</sup> grain Zn concentrations respectively. Two R-lines ICSR 89035 (Fe 39 mg kg<sup>-1</sup> and Zn 26 mg kg<sup>-1</sup>) and ICSR 113 (Fe 38 mg kg<sup>-1</sup> and Zn 28 mg kg<sup>-1</sup>) had significantly higher (by 9% and 7%) grain Fe and significantly higher (by 17% and 26%) grain Zn concentrations than the control PVK 801. Thirty-two R-lines had significantly higher (by 5 to 33%) grain Fe ranging from 30 to 39 mg kg<sup>-1</sup> and 45 R-lines had significantly higher (by 6 to 63%) grain Zn

concentrations ranging from 18 to 28 mg kg<sup>-1</sup> than the control RS 29. This variability in R-lines is higher than the variability reported earlier (Reddy et al. 2005) but compared to ICRISAT-bred B-lines, the grain Fe and Zn concentrations are low in R-lines. In ICRISAT sorghum program, the major focus all along was on genetic diversification for improving seed parents (A/B-pairs) (which are critical for developing heterotic hybrids), which resulted in higher variability for grain Fe and Zn concentrations also.

Annexure 13 contains results for 50 ICRISAT-bred sorghum R-lines (Set II) with two controls evaluated during 2010 and 2011 post-rainy season. The average Fe content was 36 mg kg<sup>-1</sup> and average Zn content was 21 mg kg<sup>-1</sup> with the Fe content ranging from 27 to 44 mg kg<sup>-1</sup> and Zn content from 18 to 29 mg kg<sup>-1</sup>. The controls PVK 801 and RS 29 had 38 and 35 mg kg<sup>-1</sup> grain Fe and 21 and 18 mg kg<sup>-1</sup> grain Zn respectively. Nine R-lines had significantly higher (by 5 to 17%) grain Fe ranging from 39 to 44 mg kg<sup>-1</sup> and 32 R-lines had significantly higher (by 5 to 47%) grain Zn concentrations ranging from 21 to 29 mg kg<sup>-1</sup> than the control RS 29. Two R-lines, ICSR 28 and ICSR 72, had significantly higher (by 7% and 8%) grain Fe content with 43 and 44 mg kg<sup>-1</sup> respectively. Ten R-lines had significantly higher (by 5 to 20%) grain Zn content ranging from 23 to 26 mg kg<sup>-1</sup> than the control PVK 801. The two R-lines ICSR 72 (Fe 44 mg kg<sup>-1</sup> and Zn 26 mg kg<sup>-1</sup>) and ICSR 28 (Fe 43 mg kg<sup>-1</sup> and Zn 25 mg kg<sup>-1</sup>) were highly promising with 8% and 7% higher Fe content and 20% and 14% higher Zn content respectively than the control PVK 801. They can be used as pollen pollinators in developing improved hybrids with high Fe and Zn concentrations.

Annexure 14 contains results for 20 commercial cultivars evaluated with two controls during 2008 and 2009 post-rainy season. The mean performance for grain Fe content varied from 30 to 44 mg kg<sup>-1</sup> with an average 39 mg kg<sup>-1</sup> and grain Zn content varied from 22 to 33 mg kg<sup>-1</sup> with an average 27 mg kg<sup>-1</sup>. The controls PVK 801 and CSH 16 (a popular commercial hybrid) had 43 and 41 mg kg<sup>-1</sup> grain Fe and 30 and 28 mg kg<sup>-1</sup> grain Zn concentrations respectively. Four hybrids GK 4035 (Fe 44 mg kg<sup>-1</sup> and Zn 33 mg kg<sup>-1</sup>), NSH 703 (Fe 44 mg kg<sup>-1</sup> and Zn 32 mg kg<sup>-1</sup>), Mahabeej 703 (Fe 43 mg kg<sup>-1</sup> and Zn 29 mg kg<sup>-1</sup>) and NSH 702 (Fe 43 mg kg<sup>-1</sup> and Zn 32 mg kg<sup>-1</sup>) were superior to the control CSH 16 for grain Fe (2 to 3 mg kg<sup>-1</sup>) and Zn concentrations (1 to 5 mg kg<sup>-1</sup>). The variability observed in commercial hybrids is 50% higher than that observed in post-rainy season adapted cultivars which are preferred for food but possess low Fe and Zn concentrations (Fe 30 mg kg<sup>-1</sup> and Zn 20 mg kg<sup>-1</sup>).

Annexure 15 contains results for 47 commercial cultivars evaluated with two controls during 2009 and 2010 post-rainy season. They showed an average Fe

content of 34 mg kg<sup>-1</sup> and an average Zn content of 22 mg kg<sup>-1</sup> with the Fe content ranging from 25 to 41 mg kg<sup>-1</sup> and Zn content from 17 to 28 mg kg<sup>-1</sup>. The controls PVK 801 and CSH 16 had 37 and 34 mg kg<sup>-1</sup> grain Fe and 22 and 21 mg kg<sup>-1</sup> grain Zn respectively. Five hybrids, Mahabeej 707 (Fe 41 mg kg<sup>-1</sup> and Zn 26 mg kg<sup>-1</sup>), HTJH 6290 (Fe 40 mg kg<sup>-1</sup> and Zn 27 mg kg<sup>-1</sup>), Mahabeej 706 (Fe 40 mg kg<sup>-1</sup> and Zn 27 mg kg<sup>-1</sup>), KSH 6363 (Fe 39 mg kg<sup>-1</sup> and Zn 27 mg kg<sup>-1</sup>) and KH 701 (Fe 39 mg kg<sup>-1</sup> and Zn 26 mg kg<sup>-1</sup>) had significantly higher (by 7 to 14%) grain Fe and and higher (by 13 to 17%) grain Zn content than CSH 16. The Fe and Zn concentrations in these hybrids are higher than poststray season adapted varieties used as food in India.

Annexure 16 contains results for all superior cultivars selected from all these evaluations to have a comparison of grain Fe and Zn concentrations. As expected the landraces showed higher Fe and Zn concentrations.

## Conclusion

Large genetic variability was observed for Fe and Zn concentrations in sorghum landraces and ICRISAT-bred hybrid seed parents. These landraces can be used in the crossing program as donors for grain Fe and Zn to develop improved lines and hybrid parents. The promising hybrid seed parents identified in these studies can be used to develop heterotic hybrids for grain yield and Fe and Zn concentrations. The high Fe and Zn containing commercial cultivars should be promoted for food use as they contain 50% higher Fe and Zn than the poststray season cultivars used for food in India.

**Acknowledgments.** The funding support for this study from HarvestPlus Challenge Program under the project "Identification of micronutrients (Fe and Zn) and Vitamin A precursor ( $\beta$  carotene) dense sorghum for better health in Western and Central Africa (WCA) and central India" is duly acknowledged. Thanks are also due to Dr Hari Upadhyaya for supplying the sorghum core germplasm accessions and the public and private sector NARS partners in India who contributed their cultivars for this study and Dr KL Sahrawat for assessing the grain Fe and Zn concentrations.

## References

**Ashok Kumar A, Reddy Belum VS, Ramaiah B, Sahrawat KL and Pfeiffer WH.** 2012. Genetic variability and character association for grain iron and zinc contents in sorghum germplasm accessions and commercial cultivars. *European Journal of Plant Science and Biotechnology* 6 (Special Issue 1):66–70.

**Ashok Kumar A, Reddy Belum VS, Ramaiah B, Sanjana Reddy P, Sahrawat KL and Upadhyaya HD.** 2009. Genetic variability and plant character association of grain Fe and Zn in selected core collections of sorghum germplasm and breeding lines. *Journal of SAT Agricultural Research* 7:1–4. ([ejournal.icrisat.org](http://ejournal.icrisat.org))

**Ashok Kumar A, Reddy Belum VS, Sahrawat KL and Ramaiah B.** 2010. Combating micronutrient malnutrition: Identification of commercial sorghum cultivars with high grain iron and zinc. *Journal of SAT Agricultural Research* 8(1). ([ejournal.icrisat.org](http://ejournal.icrisat.org))

**Ashok Kumar A, Reddy Belum VS, Sharma HC, Hash CT, Srinivasa Rao P, Ramaiah B and Sanjana Reddy P.** 2011. Recent advances in sorghum genetic enhancement research at ICRISAT. *American Journal of Plant Sciences* 2:589–600.

**Parthasarathy Rao P, Birthal BS, Reddy Belum VS, Rai KN and Ramesh S.** 2006. Diagnostics of sorghum and pearl millet grains-based nutrition in India. *International Sorghum and Millets Newsletter* 47:93–96.

**Pfeiffer WH and McClafferty B.** 2007. HarvestPlus: Breeding crops for better nutrition. *Crop Science* 47:S88–S105.

**Reddy BVS, Ashok Kumar A, Ramesh S and Sanjana Reddy P.** 2011. Breeding sorghum for coping with climate change. Pages 326–339 *in* Crop adaptation to climate change (Yadav SS, Redden B, Hatfield JL and Herman Lotze-Campen, eds.). Iowa, USA: John Wiley & Sons Inc.

**Reddy BVS, Ramesh S and Longvah T.** 2005. Prospects of breeding for micronutrients and carotene-dense sorghums. *International Sorghum and Millets Newsletter* 46:10–14.

**Reddy PS, Reddy BVS, Ashok Kumar A, Ramesh S, Sahrawat KL and Venkateswara Rao P.** 2010. Association of grain Fe and Zn contents with agronomic traits in sorghum. *Indian Journal of Plant Genetic Resources* 23(3):280–284.

**Sahrawat KL, Ravi Kumar G and Rao JK.** 2002. Evaluation of triacid and dry ashing procedures for determining potassium, calcium, magnesium, iron, zinc, manganese and copper in plant materials. *Communications in Soil Science and Plant Analysis* 33:95–102.

**Sharma AN.** 2003 Food security in India. New Delhi, India: Institute for Human Development. 27 pp. (Mimeo.)

**Underwood RA.** 2000. Overcoming micronutrient deficiencies in developing countries: Is there a role for agriculture? *Food and Nutrition Bulletin* 21(4):356–360.

**Welch RM and Graham RD.** 2004. Breeding for micronutrients in staple food crops from a human nutrition perspective. *Journal of Experimental Botany* 55:353–364.