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Grain iron density variability among new farmer-preferred experimental millet varieties from Niger

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ABSTRACT

Grain micronutrient content assessment is important in breeding pearl millet, in order to maintain or improve its high nutritional quality. Grain samples of 12 farmer-preferred pearl millet varieties produced in four representative environments in Niger during the 2013 rainy season were assessed for Fe, Zn, Al and P grain densities using energy dispersive X-ray fluorescence spectroscopy. Combined analysis of variance revealed significant ($P < 0.01$) variation among entries across environments only for Fe grain density, which had a broad-sense heritability of 89%. Fe grain density varied from 30.4 to 39.2 mg kg^{-1} among these varieties, with a mean of 32.4 mg kg^{-1}. Among the 12 varieties, ICRI-Tabi and ICMV-IS 13131 (reselected ICRI-Tabi) showed the highest Fe grain densities.

Keywords: Genetic variability, Grain iron, heritability, malnutrition, micronutrients, pearl millet.

INTRODUCTION

Micronutrient malnutrition, particularly zinc (Zn) and iron (Fe) deficiencies, afflicts over three billion people worldwide due to low dietary intake. In some Sahelian African countries, millets, and particularly pearl millet (*Pennisetum glaucum* (L.) R. Br.), can represent more than 75% of total cereal production (FAO, 2004) and thus represent an important proportion of total dietary intake for millions of people in this region.

Several reports indicate the existence of large variability for grain Fe and Zn concentrations in pearl millet. For example, a recent study by Pucher et al. (2014) of 72 pearl millet accessions from West and Central Africa (WCA) assessed in Niger showed moderate ranges in mineral density (24.2 to 48.7 mg kg^{-1} for Fe and 19.8 to 43.4 mg kg^{-1}

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for Zn). A study focusing on the grain mineral density of 225 Sudanese pearl millet accessions evaluated in Sudan also found wide variation for Fe and Zn ranging from 19.7 to 86.4 mg kg^{-1} for Fe and 13.5 to 82.4 mg kg^{-1} for Zn (Bashir et al., 2014). Rai et al. (2013) revealed two-fold variation for Fe density (31 to 61 mg kg^{-1}) and Zn density (32 to 54 mg kg^{-1}) among 122 commercial and pipeline hybrids of pearl millet developed in India.

Development of pearl millet varieties with high grain density and/or availability of Fe and/or Zn could contribute to the reduction of Fe and Zn deficiencies in millet-dependent populations in WCA (Hama et al., 2012; Pucher et al., 2014). Therefore, the objective of this study was to assess the genetic variability of Fe, Zn, Al and P grain concentrations among 12 pearl millet farmer-preferred varieties tested across representative sites in Niger.

MATERIALS AND METHODS

Field experiments were conducted during the 2013 rainy season at four sites in Niger (ISC-Sadoré Low-P, ISC-Sadoré Moderate-P, INRAN-Maradi and INRAN-Tara). The experimental materials consisted of 12 pearl millet entries open-pollinated varieties, including four pairs of experimental varieties undergoing farmer-participatory varietal improvement as well as appropriate local landrace and improved variety controls. These were arranged in randomized complete block designs with three replications per site. Plot size was 28 hills, arranged as four rows of 7 hills each, with 75 cm between rows and 80 cm between hills within rows. At ISC-Sadoré, two sets of the trial were conducted in a low-fertility field having Bray-1 P below 6 mg P kg^{-1} soil. The low-P treatment at ISC-Sadoré received 18 kg N ha^{-1} as basal fertilizer in the form of urea, while the moderate-P treatment there received 14 kg N ha^{-1}, 14 kg P_2O_5 ha^{-1} and 14 kg K_2O ha^{-1} in the form of NPK at the time of sowing. INRAN-Tara received 30 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} in the form of NPK as basal fertilizer, and 18 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} in the form of DAP were applied at sowing at INRAN-Maradi. At Maradi and Sadoré, the crops were subsequently side-dressed with urea in several splits, as and when rainfall permitted.

Open-pollinated grain samples were collected manually at maturity, directly from the panicles into paper envelopes to avoid grain sample contamination by soil or metal equipment. Grain samples were analyzed non-destructively for Fe, Zn, Al and P density at ICRISAT-Sadoré using energy dispersive X-ray fluorescence spectroscopy (EDXRF) with an Oxford Instrument X- Supreme 8000 (Jenkins, 1999). Statistical analysis was performed using SAS 8.1 software.

RESULTS AND DISCUSSION

The combined analysis of variance across environments (Table 1) showed significant environment effects on grain mineral concentration for all the studied micronutrients (Fe, Zn, Al and P), but showed no significant genotype × environment interaction. The genotype mean square was significant only for Fe, indicating the presence of significant variation among entries for grain Fe concentration. The extent of variation in the Fe, Zn and Al concentrations observed is presented in Table 2. The observed low levels of Al grain density indicated that the grain samples were essentially free from soil contamination. Grain Fe density ranged from 30.4 to 39.2 mg kg^{-1} with a mean of 32.4 mg kg^{-1} and grain Zn density from 32.8 to 38.7 mg kg^{-1} with a mean of 35.4 mg kg^{-1}. These ranges were substantially narrower than those recently reported for pearl millet (Hama et al., 2012; Rai et al., 2013; Bashir et al., 2014; Pucher et al., 2014), perhaps because the tested materials did not include any *Iniari* landrace-derivatives. Based on their mean performances across the four environments, the varieties ICRI-Tabi and ICMV-IS 13131 (reselected ICRI-Tabi) were identified as stable and more promising for grain Fe density. These two varieties have very compact panicles that confer some degree of resistance to millet head miner (*Heliocheilus albipunctella*), which in the Sahel can cause severe grain yield losses on early-flowering pearl millet varieties having less compact panicles, including most *Iniari* derivatives.

Broad-sense heritabilities were estimated across environments for Fe, Zn, Al and P grain densities. Highest heritabilities were recorded for grain Fe (89%) and Zn (49%), while that for grain Al was low (9%) and grain P was not heritable. The high heritability value for grain Fe content indicates it was less influenced by environment. High heritability estimates for grain Fe in pearl millet were previously reported by Bashir et al. (2014) and Govindaraj et al. (2011).

Table 1: Mean squares for studied micronutrients of the 12 pearl millet entries as obtained from combined ANOVA of the four environments (ISC-Sadoré Low- and Moderate-P, INRAN-Maradi and INRAN-Tara).

Source of variation	DF	Fe	Zn	Al	P
Environment (E)	3	95.78^{**}	419.6^{**}	293.67^{**}	9546.58^{**}
Genotype (G)	11	100.59^{**}	37.86^{ns}	14.48^{ns}	1704.05^{ns}
G × E	33	8.00^{ns}	14.97^{ns}	12.79^{ns}	2344.89^{ns}
Error	88	11.08	23.67	17.93	2146.83

** = significant at P <0.01, ns = not significant

Table 2: Combined means, standard errors, coefficients of variation and broad-sense heritabilities of Fe, Zn and Al grain densities (mgkg^{-1}) for the 12 pearl millet varieties evaluated at ISC-Sadoré Low- and Moderate-P, INRAN-Maradi and INRAN-Tara during the 2013 rainy season.

Entry name	Fe(mgkg^{-1})	Zn(mgkg^{-1})	Al(mgkg^{-1})
ICRI-Tabi	39.2a	38.7a	14.9b
ICMV-IS 13131(reselected ICRI-Tabi)	37.2a	37.7ab	14.7b
Tera PPBV C0	30.9c	37.6ab	14.1b
Tera PPBV C1	30.4c	34.6bc	13.8b
Falwel PPBV C0	31.2c	35.2bc	14.8b
Falwel PPBV C1	31.0c	35.5bc	15.9ab
Serkin Haoussa PPBV C0	31.0c	34.6bc	15.9ab
Serkin Haoussa PPBV C1	30.6c	32.8c	15.0b
Local check 1	31.5bc	33.2c	18.0a
Local check 2	31.2c	34.9bc	15.2ab
Improved check 1: SOSAT-C88	33.8b	35.4bc	15.4ab
Improved check 2: ICMV-IS 89305	30.5c	34.9bc	14.5b
Mean	32.4	35.4	15.2
Minimum	30.4	32.8	13.8
Maximum	39.2	38.7	18.0
CV (%)	10	14	28
SE (±)	0.96	1.4	1.2
h^2 (%)	89	49	9
lsd (*P*=0.05)	2.3	3.2	3.0

Means not sharing a common letter in a column differ significantly at 0.05% level of probability

Conclusion

The estimated high broad-sense heritability for grain Fe density (Table 2) indicates there is scope for genetic improvement of Fe concentration in pearl millet through selection.

The varieties ICRI-Tabi and ICMV-IS 13131 (reselected ICRI-Tabi) can be recommended to farmers in Niger for consumption to improve their nutrition.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

CTH conceived and designed the experiments; GDB and IK performed the experiments; GDB analyzed the data and drafted the paper. All authors read and approved the manuscript.

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