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Sorghum landrace germplasm: Genetic resources for demand lead product development and profiling in modern crop improvement

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Understanding genetic variation underlying adaptive traits responsible for sorghum's ability to tolerate challenging growing environments is of great importance. The present investigation was conducted to identify sources of genetic traits for utilization in product and hybrid parent development. Result showed that there exists variability for local names with Farafara and Kaura as most common types accounting for 30% and 40% respectively.SSR markers revealed opportunity to utilize these genetic resources for development of male sterility maintainer in hybrid parent program. Variation for days to 50% flowering ranged from 59-130 days with mean of 96 days, while plant height varied from 164 to 460 cm with mean of 343. There was variation for 100-seed weight (g) which ranged from 2.99 to 3.19g with mean value of 3.09g. Variation for grain yield (kg/ha) ranged from 2 649 to 3 566 kg/ha with mean of 3 108 kg/ha. Variation for grain colour were significant distributed into White (Farafara), Yellow (Kaura), Red or cream where Farafara with Yellow grain colour had equal share of 45% each. Highly significant variation exists for panicle shape classifying into 11 forms with compact elliptic accounting for 20%. Result from 2014 and 2015 landrace collections showed that Farafara types had the highest Fe concentration of 90.7ppm and 69.0pp while the Kaura types had the highest Zn concentration of 69.9ppm and 41,9ppm for 2014 and 2015 collections respectively. Diversity analysis for micronutrient concentration among the 2017 landrace collections for Iron (Fe) concentration ranged from 10.8 to 79.6ppm while Zinc (Zn) content ranged from 8.2 to 42.4ppm. In the present investigation, there exists wide genetic diversity among the sorghum accessions, providing scope for further genetic improvement.

Key words: Sorghum, Germplasm, Landraces, Diversity, Micronutrient, Genomics, male sterility, Genetics, Utilization

INTRODUCTION

The world's agricultural system is under strain from a growing world population, unpredictability in the environment, loss of vital farmland due to urban expansion, loss of natural resources, and constantly evolving consumer preferences related to food (Boyle et al., 2019). In the face of such dire climatic, demographic and environmental estimations, agriculture remain at the forefront to increase crop production and quality to satisfy the global food demand.

Sorghum [*Sorghum bicolor* (L.) Moench], an ancient resilient C4 grain and grass important for food and energy production, ranks fifth behind maize, rice, wheat and barley has broad adaptation throughout Africa, the Americas, Asia, Australia and Europe. It is grown in sub-Saharan Africa and particularly Nigeria as a staple to support an estimated half billion people (Bantilan et al., 2004; Mace et al., 2013).

Sorghum is not just grown for harvesting of grain, but also cultivated for syrup production (sweet sorghum), grazing (forage sorghum) and biomass production (Rooney et al., 2007). This broad adaptation and versatile end-use earlier reported by Tuinstra et al. (1997) as confirmed by Campbell-Staton et al. (2021) are connected to its natural genetic diversity and phenotypic plasticity. Although sorghum is a major subsistence staple worldwide and an important component of industrial agriculture, it has been relegated to the status of an orphan crop. The traditional paradigm with its primary focus on improving yield potential is not enough, and now must be paired with improving yield stability, nutritional quality and input-use efficiency.

With the recent development of genomic resources and high-throughput phenotyping platforms, the 21st century is primed for major breakthroughs in the discovery, understanding and utilization of plant genetic variation. In order to redefine the objectives of crop improvement, the most important tools are to understand the collection, curation and utilization of genetic and genomics resources to improve the rate of genetic gain in modern plant breeding (Boyles et al., 2019).

Development and use of climate-resilient crops and genotypes therein is critical to safeguard against global food scarcity and malnutrition (Mickelbart et al., 2015), thus the need to collect, preserve and explore landrace germplasms with genetic variation underlying adaptive traits. Diversity in plant genetic resources (PGR) provides opportunity for plant breeders to develop new and improved cultivars with desirable characteristics. Exploration of the genetic diversity of Nigeria sorghum landraces is aimed at identifying and defining "functional" heterotic parental-pools for utilization in product and hybrid parent development towards enhancing productivity to meet the increasing rural and industrial demand. The aim of this study therefore is to explore available sorghum landraces as genetic resources for developing OPVs and hybrid parents with enhanced food and micronutrient nutrition security.

MATERIALS AND METHODS

International crop Research Institute for Semi-Arid Tropics (ICRISAT), Nigeria Kano Office in collaboration with National Partners supported by Crop Diversity Trust through the ICRISAT Regional Genebank Niamey Niger, conducted exploratory sorghum landrace collections during 2014-2017 collection missions.

Capacity enhancement on germplasm passport data collection

Participant from the various partnering Institutions (Institute for Agricultural Research, Ahmadu Bello University Zaria; Federal University Wukari; Federal University Dutsinma; Lake Chad Research Institute, Maiduguri; Jigawa State Research Institute; University of Ilorin; and National Centre for Genetic Resources and Biotechnology Ibadan) were trained on expected protocols and features for germplasm digital passport data capture. For accuracy and reliable sources in different locations, android compatible off-line GPS installation and demonstration were conducted for georeferenced data collection in the location and delineation of collection areas by state.

Collection and curation

The heart of genetic and genomic research is the availability and accessibility of germplasm to link genotype to phenotype. To explore availability of economic traits, exploratory landrace sorghum collections were conducted across some states in Nigeria. 1,807 sorghum landrace samples were collected, desegregated as follows: 2014, 372 samples; 2015, 366 samples; while in 2017, 1069 samples (Table 1). Figure 1a and b shows collection map for 2015 and 2017, respectively.

Samples were collected on-farm per village, spaced 15 to 20 km apart. However, more than one sample was occasionally taken per site based on their distinct panicle features.

Germplasm evaluation and testcross generation

To assess the germplasm capacity for grain and seed qualities, 2014 collections were evaluated at Samaru-Zaria and Bagauda Kano on a 1-row plot of 5 m long spaced 0.75 m apart in 2 replications during 2015 cropping season for agronomic traits which include plant height, days to 50% flowering responses, panicle forms and grain colour.

Towards unveiling genotypes for male sterility maintenance for

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hybrid development, 2015 collections were evaluated for agronomic traits at both locations (Samaru-Zaria and Bagauda-Kano), where 388 testcrosses were generated at Samaru only from 40 randomly selected genotypes during 2016 cropping season.

While sourcing for more genetic materials for the ‘must have’ micronutrient traits for targeted product profiling, 2017 collections were evaluated at 4 locations (Samaru-Zaria, Dadinkowa-Gombe, Wukari-Taraba and Bagauda-Kano) during 2018 cropping seasons to identify trait specific lines to serve as genetic resource towards product development and testcrosses generated.

Testcross evaluation

During 2017 cropping season, the 388 testcrosses generated from 40 randomly selected landraces testcrossed on 2 male sterile lines (ICS38A and ICS24005A), along with their parents were evaluated on a 2-row plot of 5 m long spaced 0.75 m apart, using head-to-head cover at heading before anthesis to score for sterility maintainer at Bagauda-Kano Nigeria.

Micronutrient laboratory evaluation

To assess grains for micronutrient (Fe and Zn) content, grain samples from 723 sorghum landraces comprising 403 accessions from 2014 and 2015 collections, and 320 accessions from 2017 collections were collected at maturity, directly from panicles into sampling bags to avoid contact with any contaminants. Wooden pistil and mortar were used to thresh for grains. The grain samples were screened for Fe and Zn contents in 2018 using Energy-dispersive X-ray fluorescence spectrometry at ICRISAT Niamey Niger following Flinders University of Australia Laboratory Protocol based on the calibration from Waite Analytical Laboratories as presented in Figure 2a and b for Fe and Zn with R^2= 0.9946 and 0.9468, respectively.

Molecular screening

Two hundred and eighty-eight sorghum landrace materials studied were mainly selections from the following sources as follows: 70 lines from among the 2014 and 160 lines from the 2015 Nigeria collections, 44 diverse lines from ICRISAT-Mali (materials from Mali) and 14 common checks.

Using a single leaf sampling from a representative plant providing the DNA for each accession, DNA extraction was carried out following a protocol described by Mace et al. (2003). Extracted DNA samples were genotyped using 20 SSR markers, at the University of Hohenheim, Germany. Fragment analysis of PCR products was carried out using Gene Scan and Genotyper 3.7 software packages (Applied Biosystems, USA). PCR amplicon sizes were scored in base pairs (bp) based on migration relative to the internal ROX-400 size standard. SSR markers used in this study showed high reproducibility in PCR amplification and ABI/Licor runs based on the allele sizes produced by control panel entries that were included in every PCR run. To identify the pair-wise genetic relationships between the accessions of this sorghum germplasm collections a genetic dissimilarity matrix was calculated using simple matching with DARwin v6 software used by Perrier and Jacquemoud-Collet (2006) available at https://darwin.cirad.fr/. An overall representation of the diversity structure was obtained by a factorial analysis using the distance matrix, while individual relations were analyzed with a tree construction based on Neighbor Joining (NJ) method, as implemented in DARwin v6. The Euclidean dissimilarity matrix was used to cluster genotypes using the UPGMA algorithm to develop the dendrogram. The closer the matrix is to 0 the similar the genotypes, the farther the matrix get to 0.5 the more the distant the genotypes are.

Similarly, 1,427 sorghum lines from 3 West and Central Africa (WCA) countries {Nigeria (282), Mali (260) and Burkina-Faso (885)} were genotyped at ICRISAT Nairobi Kenya ILRI laboratory during which 25509 SNP markers were generated specially for genotypes from Nigeria out of which 4,112 SNPs for clustering accuracy were used for the analysis to develop the distance matrix.

RESULTS AND DISCUSSION

Diversity in local names

Sorghum landrace collections were desegregated and grouped into 26 local names with *Farafara* and *Kaura* as most common generic names accounting for 30 and 40%, respectively, as presented in Figure 3. This could be attributed to fact that sorghum is grown from Sahelian to Southern Guinea savannah agro-ecologies thus different localities naming their landrace varieties.

Morphological diversity for agronomic traits

Result showed that there exists variability within the collected sorghum landraces as presented in Table 2. Classifying the landraces into maturity groups, days to 50% flowering ranged from 59 to 130 days with mean value of 96 days, while plant height varied from 164 to 460 cm with mean value of 343 cm. There was variation for 100 seed weight (g) which ranged from 2.99 to 3.19 g with mean value of 3.09 g. Variation for grain yields (kg/ha) ranged from 2649 to 3566 kg/ha with mean value of 3108 kg/ha. Variation for grain colour was significant distributed into White grain (*Farafara*), Yellow grain (*Kaura*), Red or Cream where *Farafara* and Yellow grain colour had equal share of 45% each (Figure 4). Highly significant variation exists for panicle shape classifying into 11 forms with compact elliptic accounting for 20% (Figure 5).

Generally, materials from Sahelien and Sudanian agro-ecologies were early (70-89 days to 50% flowering) to medium (90-110 days to 50% flowering) maturing, associated with short (≤2 m) or medium (≥2.5 m) plant height, while collections from Northern and Southern Guinea savannah were generally late and tall which recorded more than 110 days to attain days to 50% flowering and plant heights greater than 3.5 m, respectively. This could be attributed to the fact that those in the Sudan which have relative low rains require early maturing varieties compared to those in the Guineanian ecologies with high rains.

Majority of those grown in the Sahel and some parts of Sudan Savannah were white grain (*Farafara*). Those from the Northern Guinea savannah were the yellow grain

Table 1. Sorghum germplasm collections across Nigeria.

Year	State	Collection areas	Number of accessions
	Kano	Garin-Mallam, Bebeji, Bichi, Tofa, Bagwai, Shanono, RiminGado	
2014	Jigawa	Gumel, Garki, Ringim	372
	Kaduna	Zaria, Ikara, Makarfi, Anchau, Jamaá, Kachia, Kajuru, Giwa, Soba,	
	Sokoto	Wamako, Gwaranyo, Sabon Birni, Isa, Tangaza, Wurno, Illela, Gada, Gwadabawa	
	Zamfara	Bakura, Zurmi, Marafa, Gusau, Maru, Bungudu,	
	Kebbi	Zuru, Argungu, Bunza, Arewa, Dandi, Suru, Bagudo	
	Niger	Meshegu, Mokwa	
2015	Kwara	Moro, Edu, Sarea	366
	Kaduna	Kajuru, Kachia, Giwa	
	Katsina	Ruma, Charanchi, Kasai, Sanuwa, Kunkumi	
	Jigawa	Ringim, Kiyawa, Taura, Dutse	
	Yobe	Fika, Nangere, Ngelzarma, Kayeri	
	Adamawa	Hong, Uba, MayaBelwa, Ganye, Numan, Song	
	Taraba	Karimlamido, Zing, Lau, Bali, Wukari, Takum	
	Plateau	Kanke, Barkinladi, Bokos, Mangu, Fulde-Jos, Shendam	
	Bauchi	Katagum, Zaki, TafawaBalewa, Ningi, Gajuwa, Dass	
	Borno	Benisheikh, Biu, Garkida, Guyuk, Bayo,	
	FCT	Keffi, lafiya, Bwari, Gwagwalada, Abaji, Taffa	
	Gombe	Yamaltu-Deba, Ako, Dukku, Bajoga, Biliri, Cham-Balanga	
	Kaduna	Giwa, Ikara, Makarfi, Jama'a, Zaria, BirninGwari	
2017	Kano	Sumaila, RiminGado, Kabo, Gwarzo, Bunkure, Kibiya	1069
	Jigawa	BirinKudu, Gwaram, Kiyawa, Kaugama, Babura, Gumel	
	Katsina	Bakori, Daura, Mashi, Danmusa, Dutsenma, Charanchi	
	Kebbi	Suru, Dandi, Zuru, Ngaski,Shanga, Arewa and Bagudo	
	Kogi	Ankpa, Dekina, Kabba, lokoja,Yagba, Itobe-Ofu and Ajaokuta	
	Kwara	Asa-Ilorin, Edu, Baruten, Moro, Kaiama, Pategi	
	Niger	Agaie, Gbako,Wushishi, Katcha, Lavun,Mokwa	
	Sokoto	Shagari, Tureta, Kebbe, Goronyo, Dange-Shuni, Rabah	
	Zamfara	Tsafe, T/mafara, Anka, Zurmi, Shinkafi and Gusau	
	Yobe	Gashua, Fika, Dabchi, Nangere, Fune-Damagum,	
Summary of collections			1,807

Figure 1. Exploratory Germplasm collection maps for 2015 and 2017, respectively.

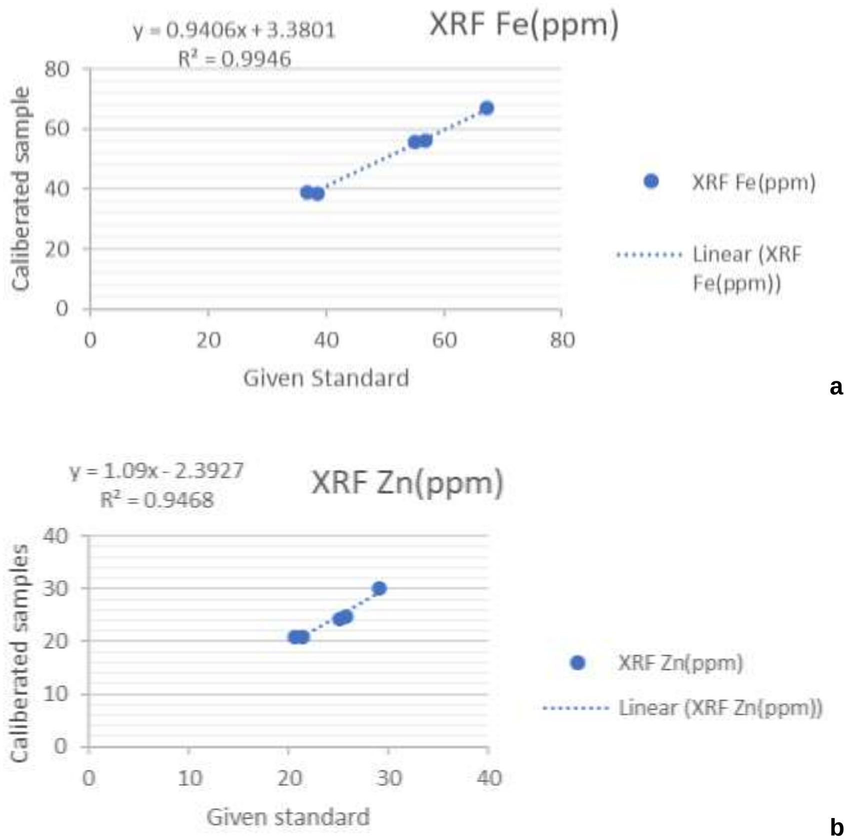

Figure 2. Calibration of XRF machine in Niamey for sorghum grains (a) Fe and (b) *Zn* assessment.

(Kaura) with compact elliptic panicle (caudatum type). In the Guinea Savannah area white or red grain types with loose dropping panicle forms (guinea type) are more commonly cultivated sorghum. Also, either the Farafara or Kaura types grown in the Sudan ecology with less insect pest is characterized with compact elliptic panicle forms (caudatum type) compared to those in Guinea Savannah cultivating white or red grain with loose dropping panicle forms (guinea type) thus avoiding grain mold and insect damage.

This implies that sorghum hybrid parent development should at present target, high yielding white or yellow grains with compact elliptic panicle forms, medium height (2 m) and medium maturity (100 days), for sustainable hybrid sorghum production.

Genetic diversity for male sterility maintenance

Result of the 288 genotypes from West African sorghum landraces studied at the University of Hohenheim Germany, using 20 SSR markers, revealed wide genetic diversity (Figure 6) especially among the Nigeria genotypes marked in blue and red for 2014 and 2015 collections, respectively distributed across the six clusters despite their year of collection. This indicates a good sign for heterotic groupings and be explored for crop improvement. In contrast, materials sourced from ICRISAT Mali clustering together marked in black (cluster 4) in Figure 4 were with little or no wide genetic distance and thus no much variability for use as sources for parental lines. It was evident among Nigerian collections however, testcross evaluations during 2017 cropping season, twenty-three (23) progenies were identified with sterile panicles as source for potential sterility maintainers were from diverse heterotic groups. Of these 23 progenies, landrace parents identified were mapped to clusters as follows: cluster 1= 3 parents, cluster 2= 13 parents, cluster 3= 4 parents and to cluster 5-1 parent presented in Figure 7, hence an opportunity to utilize these genetic resources for development of male sterility maintainer in hybrid parent program.

Similar pattern was observed from the 1,427 sorghum lines collected from the 3 the West and Central Africa (WCA) countries {Nigeria (282), Mali (260) and Burkina-Faso (885)} genotyped at ICRISAT Nairobi Kenya ILRI

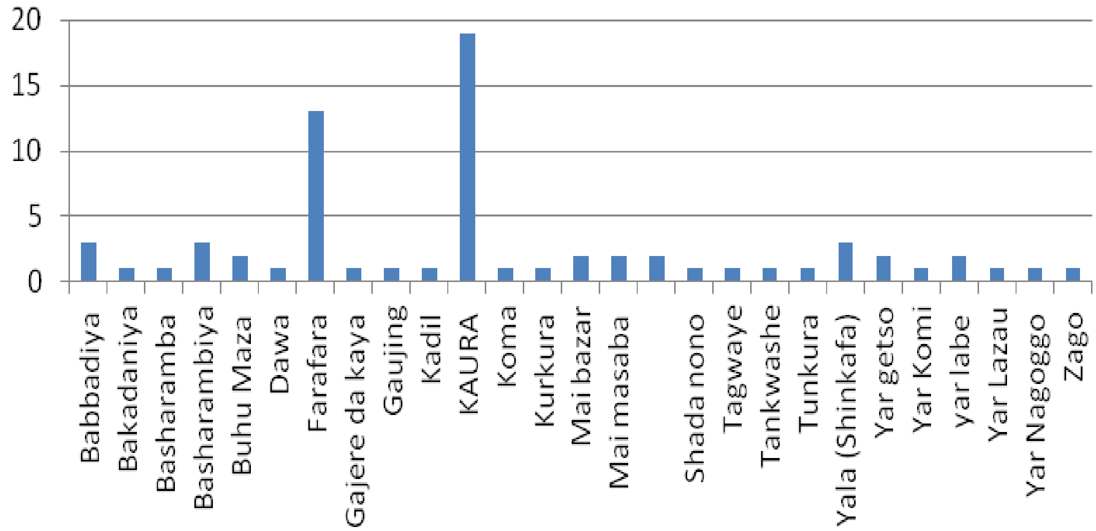

Figure 3. Diversity of local names for Nigeria landrace sorghum.

Table 2. Descriptive statistics of sorghum characters evaluated across combined locations (Bagauda, Samaru, Wukari, Dadinkowa) and cropping seasons (2015 - 2017).

Variable	Days to 50% flowering (days)	Plant height (cm)	100 seed weight (g)	Grain weight (kg/ha)	Grain colour	Panicle forms
Landrace (Min)	59	164.8	2.9925268	2649.622	0.6838269	15.57635
Landrace (Max)	130	460.7	3.1893737	3566.594	0.9364747	21.331212
Mean	96	343.4	3.0909502	3108.108	5.148265	17.44795
SED±	8.172	162.8	0.0499407	0.0232645	0.0644521	1.468104
P of F	<0.001	0.002	0.0025	0.001	<0.0001	<0.0001

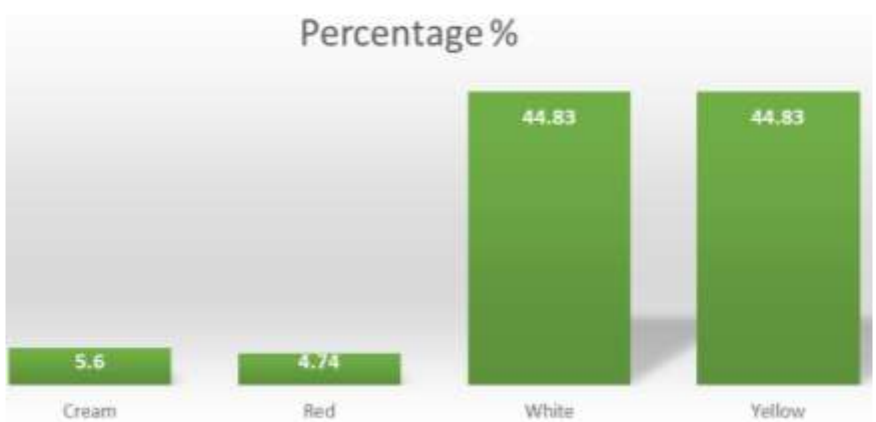

Figure 4. Frequency distribution for grain colour among sorghum landrace collections.

laboratory. Result from the genomic analysis for Nigerian landrace sorghums among others showed high genetic diversity, grouped into 7 major clusters marked green (Figure 8). This high level of genetic diversity as

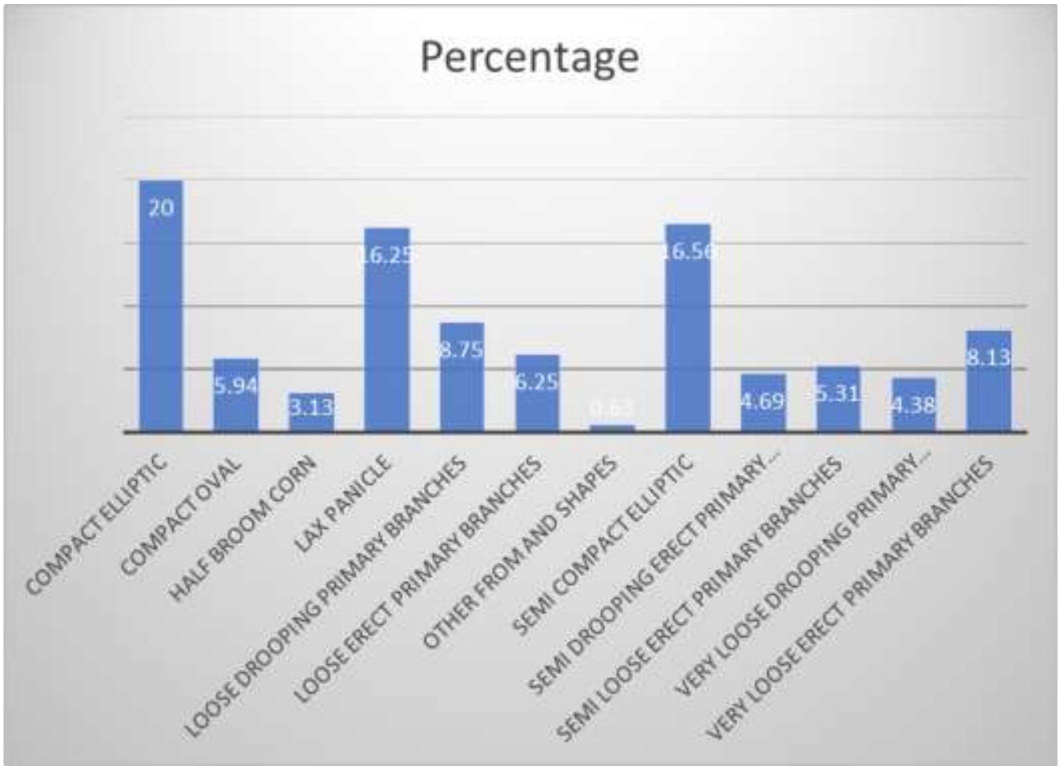

Figure 5. Panicle form frequency distribution among sorghum landraces.

expressed by Billot et al. (2013) and Upadhyaya et al. (2017), is thought to be due to multiple origins for domesticated sorghum, intermating between products of these independent domestication events, and continued gene flow between wild and cultivated sorghums. This is in conformity with the fact that, sorghum production in Nigeria is carried out across wide geographical distance of 1,173 km between longitude 3.5°E and 14.5°E within latitude 7.1°N and 13.0°N covering 635 km associated with also different rainfall pattern thus classifying the agro-ecology into Sahelien, Sudanian and Northern Guinea savannah which induces mutation for survival strategy and eventual variability.

Diversity for micronutrient content

2014 collections

Results of 403 sorghum landrace collections shown in Table 3 for Fe and Zn content indicated a significant variation among both the generic *Kaura* (yellow grain color) and the generic *Farafara* (white grain color) types for the 2 sets of collections (2014 and 2015). Within the 2014 landrace collections from Sudanian agro-ecology of Kano, Jigawa and Kaduna states of Nigeria, Fe concentration for *Kaura* types ranged from 45.8 to 88.1 ppm with a mean of 64.5 ppm while Zn ranged from 24.9 to 69.9 ppm. For the *Kaura* genotypes ICSL2014-14 was identified to have the highest Fe concentration of 88.1 ppm while ICSL2014-003-1 for high Zn concentration of 69.9 ppm. Variation within the *Farafara* types for Fe concentration ranged from 42.6 to 90.7 ppm with mean value of 61.8 ppm, while the Zn concentration ranged from 22.2 to 63.5 ppm with mean value of 38.9 ppm. Among the *Farafara* genotype ICSL2014-002-5 was identified as the genotype with high Fe concentration of 90.7 ppm, while IARSL/2014/0011 was identified to have high Zn grain concentration of 63.5 ppm.

2015 collections

In the same vein, result of the 2015 collections (Table 4) showed that the *Kaura* types for Fe concentration ranged from 35.3 to 64.4 ppm with mean value of 52.2 ppm and Zn value ranged from 22.8 to 38.7 ppm with mean of 30.6 ppm. Similarly, Fe concentrations among the Mori (early Farafara) varied from 35.1 to 69.9 ppm with mean value of 30.6 ppm while Zn concentration varied from 19.5 to 41.9 ppm with mean value of 27.5 ppm. CAPARLGSG2015-0158 among the 2015 collections was

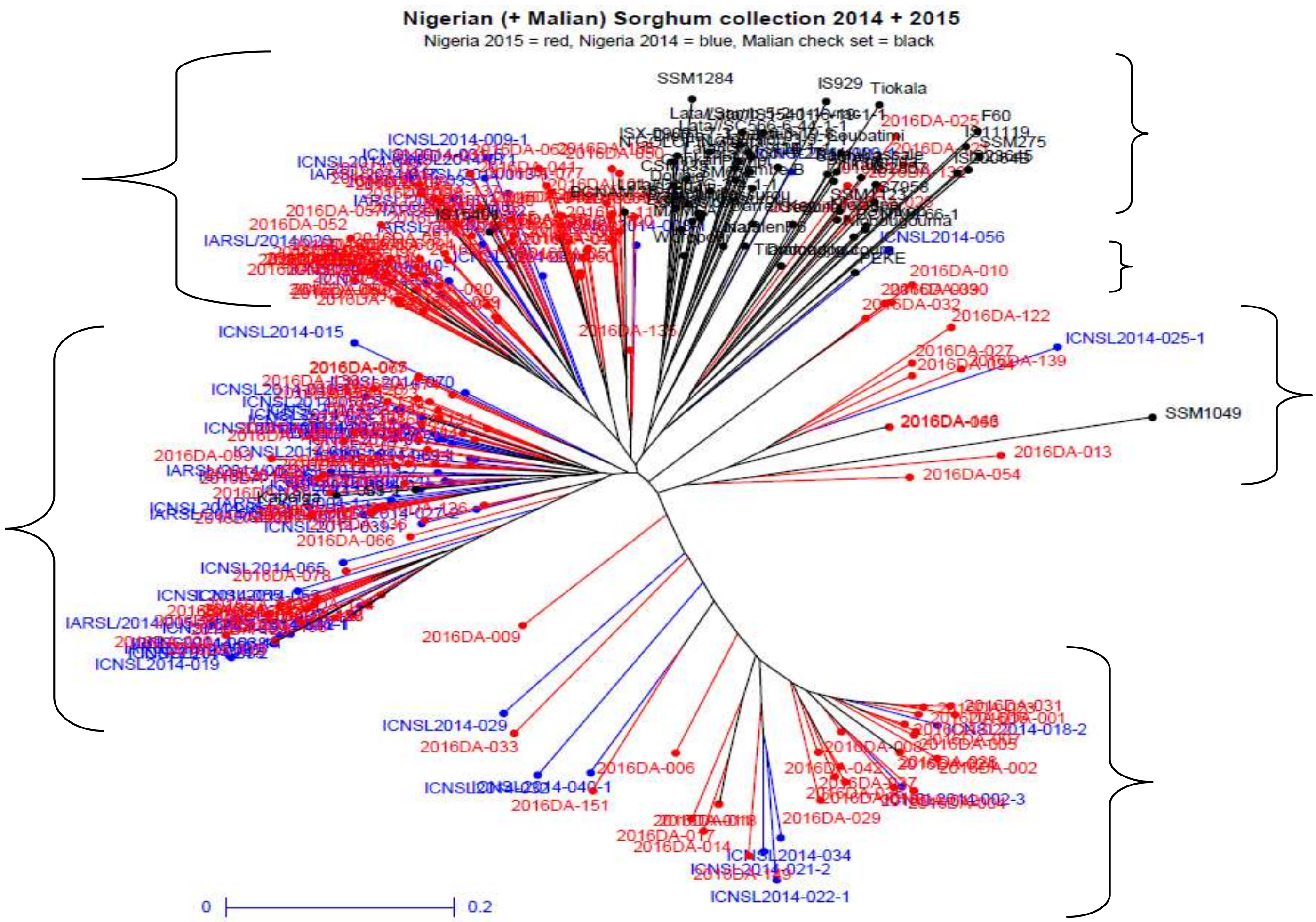

Figure 6. Genetic diversity of Nigeria sorghum in comparison to Mali.

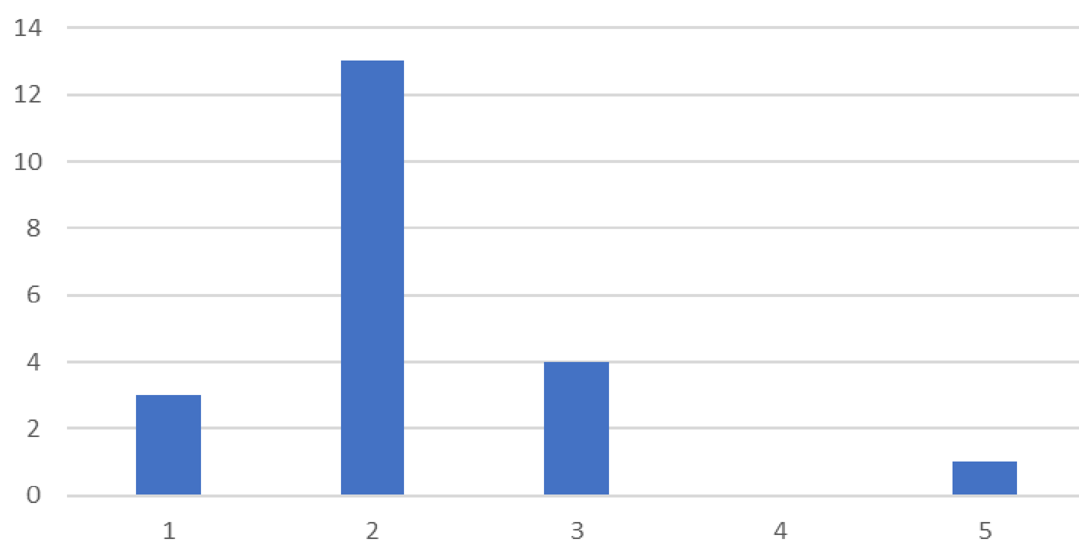

Figure 7. Number of landrace parents mapped to cluster/heterotic groups.

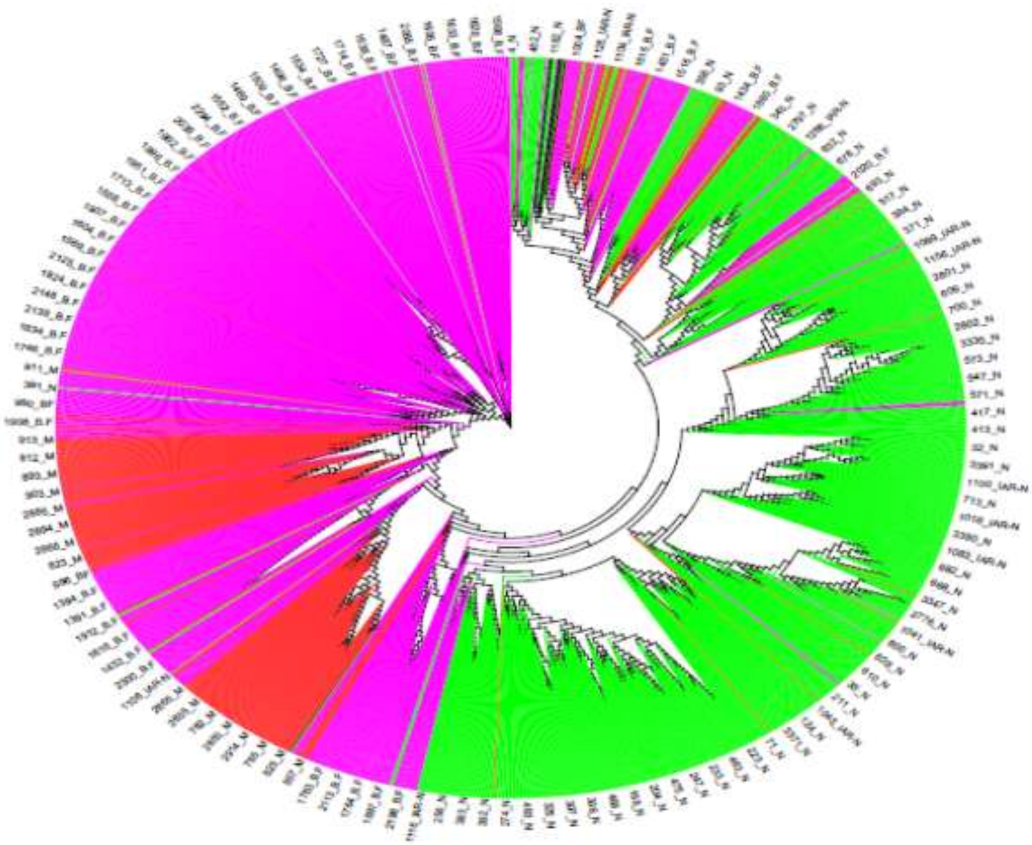

Figure 8. Genetic diversity of Nigeria sorghum in comparison. Green: Nigeria; Red: Mali and Magenta: Burkina Faso.

Table 3. Summary statistics of micronutrient concentration (Fe and Zn) for Farafara and *Kaura t*ype of Nigeria sorghum 2014 and 2015 landrace collections at Minjibir and Bagauda respectively during 2016 cropping season.

Sum Stat	2014 landrace collections				2015 landrace collections			
	Kaura		***Farafara***		***Kaura***		***Farafara***	
	Fe (ppm)	**Zn (ppm)**	**Fe (ppm)**	**Zn (ppm)**	**Fe (ppm)**	**Zn (ppm)**	**Fe (ppm)**	**Zn (ppm)**
Max	88.1	69.9	90.7	63.5	64.4	38.7	69.0	41.9
Min	45.8	24.9	42.6	22.2	35.3	22.2	35.1	19.5
Mean	64.5	41.2	61.8	38.9	52.2	30.6	49.4	27.5

Table 4. General Summary Statistics for micronutrient content for 2017 germplasm collection evaluation 2018 cropping season.

Variable	Fe (ppm)	Zn (ppm)
Mean	49.5	25.3
Median	50.1	25.4
Range	68.8	34.2
Min	10.8	8.2
Max	79.6	42.4
Std Dev	11.8	6.6

Table 5. Cluster Means for micronutrient (Fe and Zn) concentration.

Cluster	Count	Fe (ppm)	Zn (ppm)
1	38	36.42	22.37
2	25	28.45	14.85
3	63	52.65	18.73
4	**32**	**67.70**	**26.85**
5	**44**	**58.41**	**34.88**
6	80	51.09	26.63
7	34	41.72	31.89

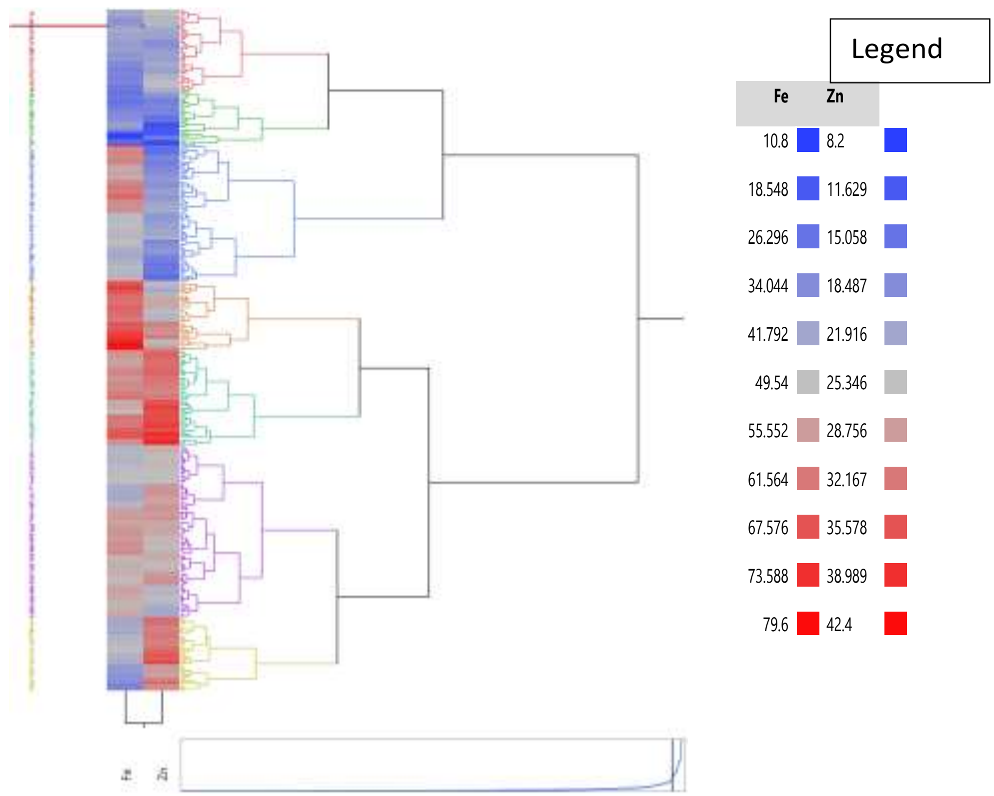

Figure 9. Dendrogram showing the clustering of sorghum genotypes for variability in Fe and Zn concentration.

identified to have appreciable Fe concentration of 64.4 ppm. CAPARLGSG20150300 among the *Farafara* types was identified to have appreciable Fe concentration of 69.9 ppm while CAPARLGSG20150043 among the landrace identified to have appreciable Zn concentration of 41.9 ppm.

2017 collections

Diversity analysis for micronutrient concentration showed that Iron (Fe) concentration ranged from 10.8 to 79.6 ppm while Zn content ranged from 8.2 to 42.4 ppm (Table 5). Based on micronutrient concentration, the sorghum genotypes grouped into 7 clusters (Table 5 and Figure 9) identified clusters 4 and 5 with 32 and 44 entries, respectively, to have higher mean values for Fe and Zn concentration. While genotypes in cluster 4 indicated high potential for Fe, those in cluster 5 indicated higher potential for Zn.

This study concurs with previous work carried out by Ashok et al. (2013); Karadi and Kajjidoni (2019), where variability exists for these traits and thus could be explored. Since the genotypes in clusters 4 and 5 (Figure 8) are crossable, materials from these 2 groups can be explored for population improvement to develop sorghum varieties with higher Fe and Zn concentration for better nutrition and health products.

CONCLUSION AND RECOMMENDATION

Considerable diversity was observed for all the characters studied in the Nigerian landrace sorghum. Result from all the various sources (2014, 2015 and 2017) showed high variability where days to 50% flowering ranged from 59 to 130 days with mean of 96 days, while plant height varied from 164 to 460 cm with mean of 343 cm. There was variation for 100 seed weight (g) which ranged from 2.99 to 3.19 g with mean of 3.09 g. Variation for grain yields (kg/ha) ranged from 2649 to 3566 kg/ha with mean of 3108 kg/ha. Variation for grain colour was significant distributed into White (*Farafara*), Yellow (Kaura), Red or Cream where *Farafara* and Yellow grain colour had equal share of 45% each. Highly significant variation exists for panicle shape classifying into 11 forms with compact elliptic accounting for 20%.

For the 2014 landrace collections, Fe concentration for *Kaura* types ranged from 45.8 to 88.1 ppm with a mean of 64.5 ppm while Zn ranged from 24.9 to 69.9 ppm. Variation within the *Farafara* types for Fe concentration ranged from 42.6 to 90.7 ppm with mean value of 61.8 ppm, while the Zn concentration ranged from 22.2 to 63.5 ppm with mean value of 38.9 ppm. Within 2015 landrace collections, variation for the *Kaura* types for Fe concentration ranged from 35.3 to 64.4 ppm with mean value of 52.2 ppm and Zn value ranged from 22.8 to 38.7 ppm with mean of 30.6 ppm. Similarly, Fe concentrations among the Mori (early *Farafara*) varied from 35.1 to 69.9 ppm with mean value of 30.6 ppm while Zn concentration varied from 19.5 to 41.9 ppm with mean value of 27.5 ppm. Diversity analysis for micronutrient concentration among the 2017 landrace collections for Iron (Fe) concentration ranged from 10.8 to 79.6 ppm while Zinc (Zn) content ranged from 8.2 to 42.4 ppm. The results from all sources showed that the landrace materials suggest huge resource for genetic improvement for these traits as evident in the cluster analysis of 2017 collections where in cluster 4 with high Iron (Fe) concentration and cluster 5 containing landraces with a corresponding high Zn content can be crossed.

Thus in the present investigation, quantitative data were able to identify heterotic parental-pools for both OPV and hybrid parent development, source for genetic product profiling in term of micronutrient and reveal the existence of a wide genetic diversity among the sorghum accessions used providing scope for further genetic improvement.

In view of the rapid genetic erosion in sorghum and new landraces evolving over a period of time, there is an urgent need to explore more landraces. Gaps in areas of collections should be identified and further clollections should be made.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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