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Evaluation Of Sorghum [*Sorghum Bicolor* L. (Moench)] For Adaptation And Nutritional Contents Of Grain Iron And Zinc In The Sudan And Northern Guinea Savannah Of Nigeria

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ABSTRACT
Thirty sorghum (*Sorghum bicolor* L.) accessions were evaluated for adaptation and grain iron (Fe) and zinc (Zn) contents in the Sudan Savannah (Minjibir) and Northern Guinea Savannah (Dadin-Kowa) of Nigeria. A 6 × 5 incomplete lattice design replicated three times was used. Data were collected on growth, yield, and grain Fe and Zn parameters. Significant differences were observed among accessions and locations for all traits. At Minjibir, top-yielding accessions were Sorg-Garki(3) (3,576 kg ha^{-1}), SAMSORG-46 (3,533 kg ha^{-1}), and KL2 (2,766 kg ha^{-1}), while SAMSORG-45 (3,532 kg ha^{-1}) and Zauna-Inuwa (2,804 kg ha^{-1}) led at Dadin-Kowa. IESV9024DL, SAMSORG-17, and Chan recorded the lowest yields across both locations. Grain Fe concentration was highest in SAMSORG-46 (61 mg kg^{-1}), while SAMSORG-45 recorded the highest grain Zn (35.2 mg kg^{-1}). Significant positive and negative correlations were observed among measured traits. SAMSORG-46, SAMSORG-45, Sorg-Garki, KL2, and 2155-1N showed consistent performance across both locations, indicating stability and adaptability. Agro-ecological differences significantly influenced growth, yield, and nutritional traits, underscoring the importance of environment-specific variety selection for sorghum production.
Keywords: Sorghum adaptation, nutritional content, grain Fe and Zn, agro-ecology.

INTRODUCTION

Sorghum is the world's fifth largest most important cereal grain, after wheat, maize, rice and barley. It is a highly reliable and resilient crop, and often called "climate change-ready". Sorghum is the dietary staple of more than 500 million people in more than 30 countries (El Naim *et al.*, 2012; Ahmed *et al.*, 2016). It contributes to food security and income for millions of resource-poor people living in arid and semi-arid dryland regions of Sub-Saharan Africa (SSA) and South Asia (Kumar *et al.*, 2013). Many subsistence farmers in Nigerian savannah regions cultivate sorghum as a staple food crop for consumption at home and sometimes as livestock feed (Ajeigbe *et al.*, 2010). Therefore, sorghum acts as a principal source of energy, protein, vitamins and minerals for millions of the poorest people living in rural areas of the Nigerian savannah, and it is used as an industrial raw material for the production of biscuits, confectionary, pop sorghum (Gurguru), noodles, baking flour, beverages, weaning food and beer (Ajeigbe *et al.*, 2010).

Sorghum generally behaves differently in response to different agro-ecological zones due to variations in annual rainfall, soil fertility, soil type, sunshine hours, temperature and several other factors. As such, sorghum farmers do not have the knowledge of suitable cultivar options that are most adaptable to their locality for improving their production and livelihoods (Beyene *et al.*, 2016). The improvement of sorghum nutrient availability is critical for food security and combating hidden hunger. Cereal scientists and sorghum food processors are thus faced with the challenge of identifying factors that adversely affect sorghum production and nutritional contents. Nutrient absorption can be increased by identifying dietary values that enhance nutrient uptake through the use of crop varieties with high grain iron and zinc content, or by increasing their dietary content through fortification. Thus, the aim of this study was to evaluate some sorghum collections for their adaptability and nutritional contents of grain Fe and Zn in two agro-ecological zones of Nigeria.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted in the Sudan Savannah (Minjibir, Kano State; Lat. 12°08'45.14" N, Long. 8°39'55.54" E, Alt. 429 m) and Northern Guinea Savannah (Dadin-Kowa, Gombe State; Lat. 10°17'43.13" N, Long. 11°31'23.12" E) agro-ecological zones of Nigeria during the 2017 rainy season. The experimental sites were selected to represent the range of agro-ecological characteristics of northern Nigeria.

Treatments and Experimental Design

Thirty (30) sorghum accessions were evaluated for their adaptability and grain Fe and Zn contents across the two agro-ecological zones in Northern Nigeria. The materials comprise a range of different agronomic traits such as plant height, grain colour, grain size, maturity group (early, medium, and late), and panicle form. The experimental materials include ten (10) released varieties, fifteen (15) breeding lines, and five (5) landrace collections. The experimental materials were laid out in a 6 × 5 incomplete block lattice design, replicated three (3) times. Each replication contained five blocks of six entries per block, giving a total of thirty entries per replication. Each entry was planted on a 4-row plot. The two middle rows (net plots) were used for data collection and grain sampling for nutrient analysis. The total gross plot size was 15 m², and the net plot size was 7.5 m².

Cultural Practices and Data Collection

The experimental site was cleared, harrowed, and made into ridges 75 cm apart. Five to eight seeds were sown at 30 cm intra-row spacing, and seedlings were thinned to two plants per hill two weeks after sowing. Weeds were controlled manually with a hoe. Pest and disease management addressed an outbreak of armyworm and stem borer, with Carbofuran and Cyper-Diforce. Sorghum panicles were covered with Kraft bags to prevent contamination. Panicles were harvested and threshed using a wooden mortar and pestle to avoid contamination for subsequent micronutrient analysis of grain Fe and Zn.

Data were collected on plant establishment count (EST #), seedling vigour (assessed on an arbitrary scale of 1–5, where 1 = poor and 5 = excellent), days to 50% heading and flowering, and plant height (cm) at physiological maturity. Panicle length (cm), panicle weight (g), panicle number, and number of harvested hills were recorded after harvest. Grain weight per plot (g) was recorded after threshing and winnowing. Grain yield (kg ha^{-1}) was estimated by converting the grain weight obtained per plot to a per-hectare basis following Hanumantharaju *et al.* (2017). Threshing percentage (%) was determined as the proportion of dry grain weight out of the total dry panicle weight. The 100-grain weight (g) was measured, and stalk weight per plot (kg) was assessed after bundling and sun-drying the stalks.

Nutritional Traits (Iron and Zinc)

Three grams of sorghum grain from each selected germplasm was cleaned and oven-dried at 75°C for 2 hours, then ground with a ceramic stone mill, sieved with a plastic sieve, and placed into sample holders. The grain nutrient content of iron and zinc was analysed using the NEX QC XRF Machine.

Data Analysis

All data collected from the experimental sites were subjected to analysis of variance (ANOVA) using JMP Pro 14 statistical software (SAS, 2018). Treatment means were compared using the Tukey HSD Test. Relationships between all measured parameters were established using correlation coefficient analysis.

RESULTS AND DISCUSSION

Grain yield among sorghum accessions exhibited significant variations. At Minjibir, top-performing accessions included Sorg-Garki(3) and SAMSORG-46 with the highest yields (3,576 kg ha^{-1} and 3,533 kg ha^{-1}, respectively). Dadin-Kowa results highlighted SAMSORG-45 as the leader with a yield of 3,532 kg ha^{-1}, closely followed by Zauna-Inuwa (2,804 kg ha^{-1}) and SAMSORG-46 (2,597 kg ha^{-1}). Notably lower yields were observed for several accessions such as IESV9024DL, KARIMtama1, SAMSORG-40, Chan, and Pato. No significant differences were found between the two locations in terms of grain yield. SAMSORG-46 and SAMSORG-45 stood out as top performers in combined yield analysis, while SAMSORG-17 and Chan displayed the lowest grain yields. The interaction between accessions and locations significantly influenced yield performance, highlighting the importance of selecting suitable varieties for specific agro-ecological zones.

The observed variations were attributed to the combined influence of environmental factors and the inherent attributes of individual sorghum accessions (Catherine, 2015). Certain accessions exhibited lower yields, primarily due to late flowering, resulting in suboptimal grain weight and overall yield across all environments. These late-flowering genotypes struggled to capitalise on periods of adequate moisture during the reproductive stage due to their inherent late-duration traits (Ullah *et al.*, 2007). Consequently, these accessions may not be well-suited for sorghum production in the studied locations.

Conversely, several accessions, such as Zauna-Inuwa, ICSV 111, ICSV 400, Kari Mtama, IESV9024DL, Pato, SAMSORG-14, SAMSORG-40, and SV4, displayed varied performances between the two agro-ecological zones, with superior grain yield outcomes in Dadin-Kowa. This divergence can be attributed to the timing and duration of precipitation during the critical reproductive stage. The extended rainy season in Dadin-Kowa, persisting until mid-October, likely favoured these accessions. In contrast, high-yielding accessions like SAMSORG-46, Sorg-Garki, 2155-1N, SAMSORG-45, and KL2 consistently excelled at both locations, underlining their stability and adaptability. The highly significant interaction between sorghum accessions and locations, with differences in phenology among accessions, aligns with previous research highlighting varying water stress levels during early or pre-flowering stages across different environments (Ana *et al.*, 2017).

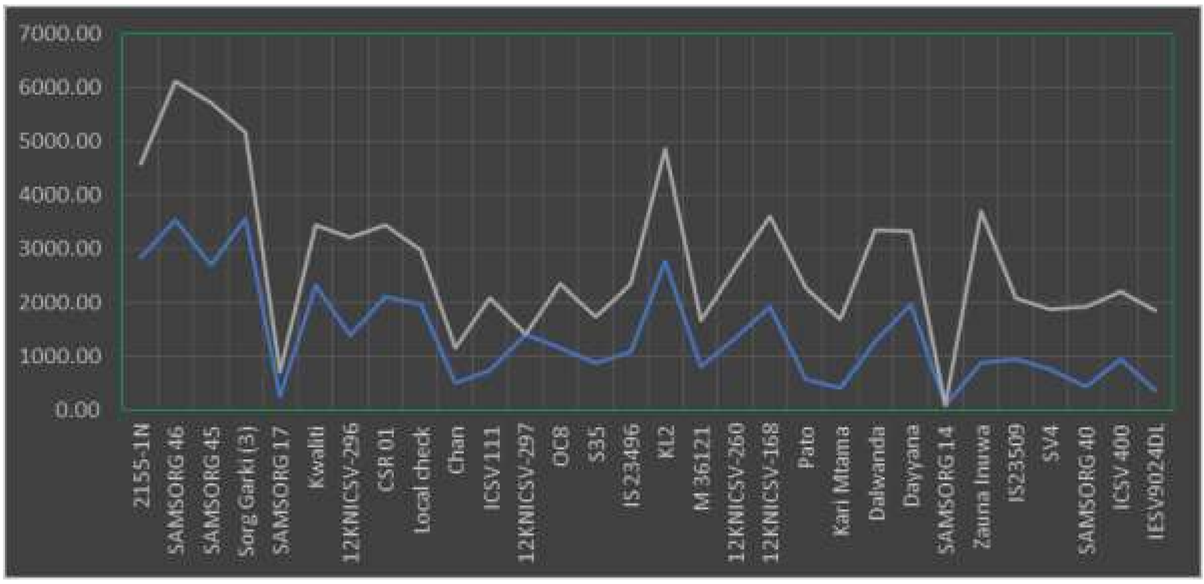

Figure 1: Graphical representation of the mean performance of grain yield in Minjibir and Dadin-Kowa

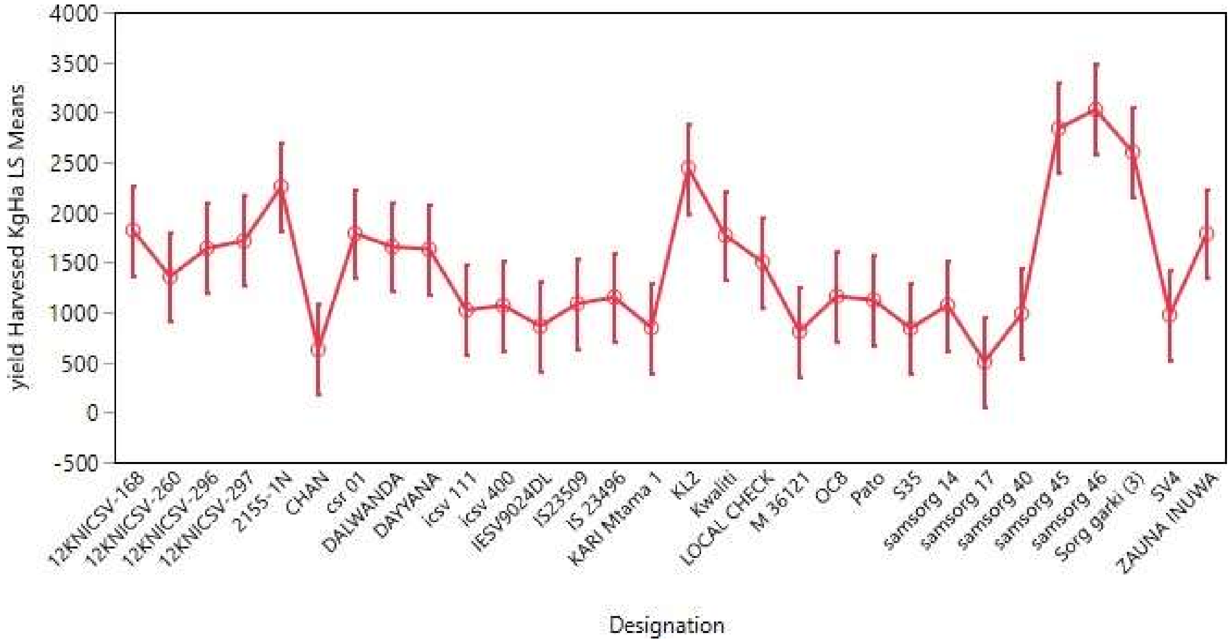

Figure 2: Least Square Mean Plot for Grain Yield (kg ha⁻¹)

Grain Iron and Zinc

Significant variations in grain Fe and Zn content were observed across the two agro-ecological zones. SAMSORG-45 displayed the highest mean grain Zn content at 35.2 mg kg^{-1}, followed by Zauna-Inuwa (33.9 mg kg^{-1}) and Kwaliti (33.3 mg kg^{-1}) (Table 1). Conversely, IS 23496 had the lowest mean grain Zn content at 14.8 mg kg^{-1} in Dadin-Kowa, while Zauna-Inuwa led with 33 mg kg^{-1} in Minjibir. SAMSORG-46 exhibited the highest mean grain Fe content at 61 mg kg^{-1}, closely followed by Zauna-Inuwa (55.5 mg kg^{-1}) and Kari Mtama (54.7 mg kg^{-1}), while M36121 had the lowest mean grain Fe content at 35.6 mg kg^{-1}. There were no significant differences in location means for grain Fe and Zn content. The observed variation in grain Fe and Zn concentrations between the two agro-ecological zones underscores the influence of environmental factors, including soil fertility and microclimate, on mineral accumulation in sorghum accessions. In general, grain Fe concentration exceeded grain Zn concentration in most sorghum accessions, aligning with previous findings by Polycarpe *et al.* (2006).

Table 1. Mean performance of sorghum at Minjibir and Dadin Kowa for grain Fe and Zn

Accessions	Fe ($mgkg^{-1}$)		Zn ($mgkg^{-1}$)	
	MJB	DKW	MJB	DKW
2155-1N	46.7	45.57 efg	29.4ab	25ab
SAMSORG 46	45.2	58.87 ab	26ab	35.2a
SAMSORG 45	45.8	61.5 a	25.8ab	30.9a
Sorg Garki (3)	46.2	44.93 fg	25.0ab	25.4ab
SAMSORG 17	52.7	48 b-g	28.3ab	22.3ab
Kwaliti	43.7	56.53 a-e	25.7ab	33.3a
12KNICSV-296	47.9	50.4 a-g	24.1ab	26.6ab
CSR 01	52.4	47.67 c-g	27.1ab	26.3ab
Local check	45.9	43.03 fg	27.4ab	25.8ab
Chan	43	47.93 b-g	25.7ab	25.6ab
ICSV 111	54.3	45.07 fg	23.9ab	25ab
12KNICSV-297	49	48.43 b-g	27.4ab	23.4ab
OC8	48.2	40.47 g	25.1ab	24.9ab
S35	42.5	50.03 b-g	23.5ab	25.1ab
IS 23496	46.6	44.47 fg	25.7ab	14.8b
KL2	42.3	50.33 b-g	26.2ab	24.8ab
M 36121	45	52.57 a-f	23.9ab	25.4ab
12KNICSV-260	45	44.27 fg	27.1ab	22ab
12KNICSV-168	43.8	47.47 d-g	23.6ab	25.8ab
Pato	45.5	50.33 b-g	25.2ab	24.5ab
Kari Mtama	50.9	58.63 abc	31ab	26.5ab
Dalwanda	41.4	53.2 a-f	22.8ab	28.9a
Dayyana	43.6	49.43 b-g	23.2ab	25.2ab
SAMSORG 14	30.7	44.4 fg	17.3b	24.9ab
Zauna Inuwa	53.6	57.03 a-d	33a	33.9a
IS23509	50.5	47 d-g	24.7ab	24.6ab
SV4	41.7	50.37 a-g	22ab	24.2ab
SAMSORG 40	52.1	47.7 c-g	21.8ab	27.4ab
ICSV 400	44.2	47.8 b-g	22.5ab	26.2ab
IESV9024DL	51.4	49.67 b-g	25.3ab	24ab

Means within a column having similar letter(s) are not statistically different at $p \leq 0.05$ using Tukey HSD Test. MJB= Minjibir, DKW= Dadin Kowa

Correlation

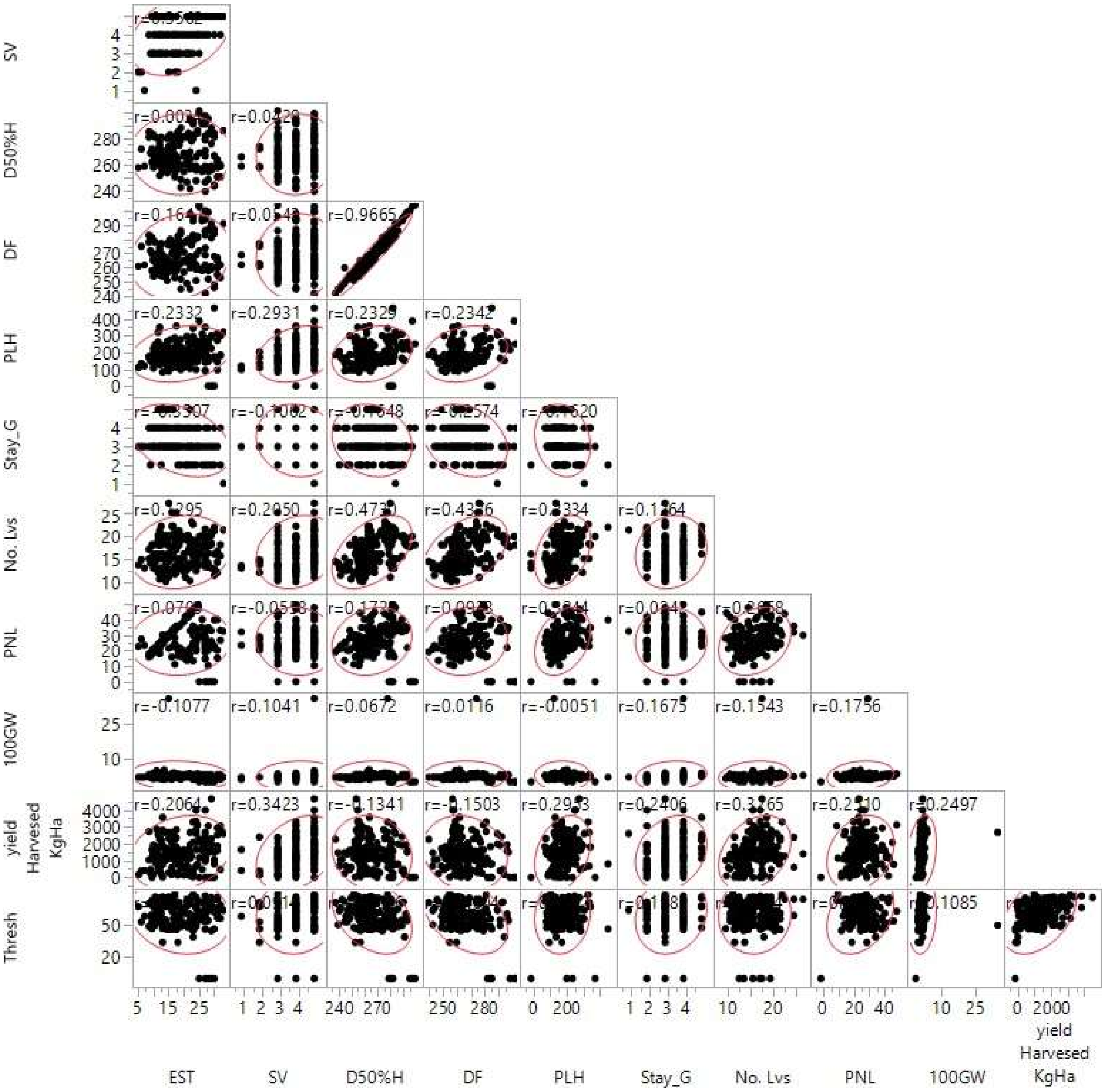

Figure 3: Scatterplot matrix of sorghum accessions showing the correlation coefficient of different attributing characters

The correlation analysis indicated significant positive and negative relationships among the measured parameters at different levels, which contributed to the general performance of the sorghum accessions across the two agro-ecological zones.

CONCLUSION

The study confirmed location as an important factor in sorghum production. The significant differences observed in growth, qualitative, and yield traits indicate that the two agro-ecological environments differ and exert distinct effects on sorghum germplasm performance. SAMSORG-46, SAMSORG-45, Sorg-Garki, KL2, and 2155-1N were the best sorghum materials for both locations in terms of optimum yield and high levels of grain Fe and Zn. Zauna-Inuwa, Kari Mtama, and SAMSORG-17 could be used as sources of Fe and Zn to improve sorghum cultivars. However, the implications of these findings for sorghum breeders are that selection for high Fe or Zn sorghum does not automatically translate into improved sorghum varieties; rather, it establishes a collection of germplasm for Fe and Zn concentrations.

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