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EVALUATION OF GENETIC VARIABILITY AND MINERAL COMPOSITION OF *Sorghum (Sorghum bicolor* L. Moench) IN TWO DIFFERENT LOCATIONS IN NASARAWA STATE

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ABSTRACT
Rice, wheat, maize and barley come second to *sorghum* (*Sorghum bicolor* L. Moench), which is the fifth most significant cereal crops. *Sorghum* is one of the most commonly grown cereal crops in the semiarid tropical region of Africa. Even though the mineral composition is an essential component in *sorghum* grains, there is little information on the variability in gene and the correlation between mineral composition and agronomic traits in *sorghum* germplasm. Field experiment was carried out during the raining season of the year in Duduguru and research farm College of Agriculture, Lafia. Twenty (20) genotypes of *sorghum* were used as the experiment materials and were randomly laid out in randomized complete block design (RCBD) with three replicates per genotype. Gross and net sizes of experimental plot were 2.4 m x 3 m (7.2 m^2) and 1.2 m x 3 m (3.6 m^2) respectively. Data on Agronomic variables such as Plant height, Leaf area (cm^2), Days to flower, Days to maturity, Grain yield (kg/ha and 100 seed weight) were recorded for each genotype. Analysis of variance results revealed that there were significant differences in the agronomic characteristics among genotypes. The genetic effect was highly significant ($p < 0.001$) for DF, DE, PH, LL. There was also a statistically significant difference at the 5 % probability level ($p < 0.05$) for 100-seed weight (100SW). This implies that there is a slight genotypic effect on the characteristic under study. The environmental effect was not statistically significant for all the variables, which indicates the uniformity of the effect of the two test environments on the expression of the characteristics. However, there was a significant block effect for DF ($p < 0.05$), PH ($p < 0.05$), LL ($p < 0.01$), 100SW ($p < 0.05$), and GY ($p < 0.05$). There was no statistically significant G × E interaction effect for all the variables Sorghum is the 5th most important cereal crop globally, after rice, wheat, maize, and barley, 2024 rainy season.

Keywords: Growth, Genetic variability, Mineral composition, *Sorghum* and Yield

INTRODUCTION

Sorghum global importance and food security. Sorghum, also known as Moench (Lee *et al*., 2021). Sorghum holds a crucial position in global food security due to its versatile usage as a staple food, bioenergy source, feed for livestock, and industrial products (Habyarimana *et al*., 2020). It is ranked as the fifth most important cereal crop globally in terms of production and cultivated area, after maize, wheat, rice and barley. Sorghum is cultivated in not less than 90 nations worldwide and serves as staple food for millions in developing countries where climatic conditions is limit the production. Approximately 90% of sorghum cultivation globally occurs in developing countries, particularly in sub-Saharan Africa and South Asia, where it is primarily grown by smallholder's famers under rain-fed conditions. Sorghum contributed very huge household food security by providing a dependable source of grain during periods of low rainfall when other cereals may fail (FAO 2011). Sorghum residues (stover) are widely used as livestock feed, fuel, fencing materials and thatching, thereby supporting mixed crop-livestock farming systems and rural livelihoods. Beyond human consumption, sorghum has numerous commercial values. Developed countries like Australia, United States and Argentina, a substantial proportion of sorghum production is utilized as livestock feed and the production of bioethanol, starch, porridges flatbreads, syrup, and alcoholic beverages. This versatility enhances its economic importance and creates additional income opportunities for farmers and agribusinesses. The importance of sorghum is achieving global food security is becoming increasingly recognized in the face of climate change. Expanding sorghum production, improving varieties through breeding, and promoting value addition can contribute significantly to reducing hunger, improving nutrition, and strengthening the resilience of farming communities in vulnerable regions. (AFO) 2026.

Sorghum considered as a hardy crop compared to other cereal crops, especially those of the C3 variety (Sunoj *et al*., 2020). In Nigeria, the cultivation of *sorghum* is of significant importance to the people living in the northern part because it serves as grains for human beings and fodder for the increasing ruminant's livestock animals. Its high-energy and drought-resilient characteristics make it an optimal crop choice in the face of climate change (Lee *et al*., 2021). Sorghum is among the most efficient crops in terms of converting solar energy and water use (Lee *et al*., 2022). Sorghum has comparative nutritional value to other cereals in terms of composition viz., protein, fat, carbohydrates, and non-starch polysaccharides, as well as bioactive components like vitamin B and fat-soluble vitamins (D, E, and K), micronutrients, macronutrients, and non-nutrients like carotenoids and polyphenols. These constituents contribute to the numerous health benefits of this grain, including anti-oxidative, anti-in flammatory, and anti-cancer effects, as well as free radical scavenging and high antioxidant activity (Chhikara *et al*., 2018).

In Nigeria, the cultivation of *sorghum* is of significant importance to the people living in the northern part because it serves as grains for human beings and fodder for the increasing ruminant's livestock animals. The cultivation of *sorghum* is expected to increase geometrically from 6.6 to 19.5 million tonnes in Africa between 2015 and 2050; this will result in the export of the crop to more than 2.5 million tones (Mwamahonje & Maseta 2021). However, the crop cannot be ranked as one of the most important crops compared to other crops like maize, rice, millet, and wheat (Macauley, 2019). Despite its resilience to drought and adaptation to marginal soils, sorghum production in Nigeria continues to face challenges such as low adoption of improved varieties, declining soil fertility, drought stress, striga infestation, and limited access to quality inputs and credit, highlighted the need for improved agricultural technology and supportive policies.

Sorghum is a highly valued cereal crop recognized for its high nutritional value. *Sorghum* contains 8–18 % protein, 70–80 % carbohydrates, 19 % dietary fiber, about 3 % fiber, and various minerals. The carbohydrates in sorghum grain, particularly starch, are crucial for determining the grain's nutritional value and functionality. Starch, the dominant carbohydrate in sorghum, is primarily located as granules in the grain's endosperm with some starch granules also found in the grain's pericarp. *Sorghum* is a rich source of carbohydrates, providing around 70–80 % of the daily recommended intake in one serving. These complex carbohydrates digest slowly, making *sorghum* a great source for steady, ongoing energy. *Sorghum* grain also contains fructosan, a trisaccharide that adds to its carbohydrate composition (Huang *et al.,* 2022). The grain is also rich in B-complex vitamins such as thiamine and riboflavin, essential for metabolic processes, and contains high levels of niacin, which supports digestion, skin health, and neurological function. In addition, sorghum supplies vital minerals including phosphorus, magnesium, iron, and copper, which contribute to bone strength, red blood cell production, and nerve health, along with trace amounts of zinc, calcium, and potassium that provide additional health benefits. A noteworthy feature of sorghum is its antioxidant profile, particularly the presence of 3-deoxy anthocyanins, which are associated with anti-inflammatory properties and potential cancer risk reduction. Its nutritional composition, however, varies depending on factors such as variety, cultivation practices, and processing methods. For example, grain sorghum generally contains higher protein and lipid levels but lower sugar content compared to sweet sorghum (Olawole et al., 2019).

Climate change is increasingly threatening agricultural production through rising temperatures, irregular rainfall, prolonged dry spells, and increased frequency and severity of drought. These challenges are particularly important in rain-fed agriculture, where crop productivity depends heavily on the availability and distribution of rainfall. Sorghum (*Sorghum bicolor* L. Moench) is considered an important crop for climate-change adaptation because of its relatively high tolerance to drought, heat, and low soil fertility compared with several other major cereals. Its ability to maintain production under water-limited conditions makes it particularly valuable in semi-arid and drought-prone environments of Africa and Asia (Yahaya & Shimelis, 2022; Mwamahonje *et al*., 2024). Despite its inherent drought tolerance, sorghum production is still negatively affected by water stress, particularly when drought occurs during critical developmental stages. Drought around panicle development, flowering, and grain filling can reduce floret fertility, grain formation, grain weight, and ultimately grain yield. In addition, high temperature frequently occurs simultaneously with water stress, creating combined stresses that can further reduce productivity. Therefore, the development and identification of sorghum genotypes capable of maintaining acceptable yield under drought and high-temperature conditions remains an important objective of contemporary sorghum breeding programmes (Prasad *et al*., 2019; Djanaguiraman *et al*., 2020). One of the important mechanisms associated with drought adaptation in sorghum is the stay-green trait, whereby plants maintain green leaf area for a longer period during grain filling under water-limited conditions. Other adaptive mechanisms include deep and extensive root systems, efficient stomatal regulation, osmotic adjustment, reduced transpiration, and early maturity. These mechanisms enable some sorghum genotypes to extract and conserve available soil moisture and continue grain production under drought conditions. Consequently, exploiting genetic variation for these traits within sorghum germplasm provides an important opportunity for developing varieties adapted to increasingly variable climatic conditions (Vadez *et a*l., 2011; Boyles *et al*., 2017).

The need for drought-resistant sorghum varieties is also connected to food and nutritional security. Sorghum is an important staple food in many parts of Africa, where it contributes substantially to household food supplies, particularly in areas where rainfall is insufficient or unreliable for crops such as maize. Developing varieties that combine drought resistance with high grain yield, desirable agronomic characteristics and improved nutritional quality could therefore provide a more sustainable response to climate change. Recent reviews emphasize that future sorghum improvement should not focus exclusively on yield under drought but should also consider grain quality and nutritional traits, including mineral density (Mwamahonje et al., 2024; Yahaya & Shimelis, 2022).

Furthermore, drought tolerance should be considered a complex quantitative trait because the expression of drought-response characteristics is influenced by genotype, environment and genotype × environment interaction. A genotype that performs well under drought in one environment may not necessarily exhibit the same performance under another environmental condition. Therefore, evaluation of diverse sorghum germplasm across contrasting environments and under controlled or naturally occurring water stress is essential for identifying stable and superior genotypes for breeding programmes. Such evaluations can contribute to the development of varieties that combine drought adaptation with acceptable yield and grain quality (Kapanigowda *et al*., 2013; Mwamahonje *et al*., 2024).

Sorghum grain is not only an important source of carbohydrates and energy but also contains nutritionally important minerals such as phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu) and sodium (Na). The concentration of these minerals varies considerably among sorghum genotypes, indicating the presence of useful genetic variability that can be exploited through plant breeding. A study involving sorghum genotypes reported significant differences in Ca, Fe, K, Mn, Na, P, Zn and Mg concentrations, demonstrating that sorghum germplasm represents a valuable source of genes for improving nutritional quality (Ndlovu *et al*., 2015). The mineral composition of sorghum can vary substantially among varieties. For example, Tasie *et al*. (2020), in an evaluation of 35 sorghum varieties, reported significant differences in mineral contents and recorded considerable variation in phosphorus, magnesium, potassium, calcium, iron and zinc. The authors demonstrated that some varieties possessed relatively high concentrations of specific minerals, suggesting that selection of superior germplasm could contribute to nutritional improvement of sorghum. Such variability is particularly important in regions where sorghum constitutes an important component of the human diet and may contribute to mineral intake. Iron and zinc deserve particular attention because deficiencies of these micronutrients are important nutritional concerns in many developing countries. Sorghum can serve as a dietary source of both minerals, and studies have demonstrated substantial genetic variation for Fe and Zn concentrations. Research on conventional and biofortified sorghum lines has also shown that Fe and Zn are distributed in specific tissues and cellular regions of the grain, with considerable potential for genetic improvement through biofortification. Therefore, identifying sorghum genotypes with high Fe and Zn concentrations could support breeding programmes aimed at improving the nutritional value of sorghum-based diets (Gaddameedi *et al.*, 2022).

This represents an important research opportunity because climate change may influence both grain yield and grain nutritional quality, and drought stress can alter grain composition and quality (Hassan *et al*., 2022; Yahaya & Shimelis, 2022). Another gap concerns the genotype × environment interaction for mineral composition under drought conditions. Although considerable

genetic variability for mineral concentration has been reported, the stability of mineral accumulation under water-limited environments remains insufficiently characterized for many sorghum germplasm collections. Understanding whether genotypes maintain desirable Fe, Zn, Ca, Mg, P and K concentrations under drought is important because a genotype with high mineral concentration under favourable conditions may not necessarily retain that nutritional advantage when exposed to water stress. Therefore, simultaneous evaluation of agronomic performance, drought-related traits and mineral composition could provide a more comprehensive basis for selecting climate-resilient and nutrient-dense sorghum genotypes (Kumar et al., 2018; Tasie *et al*., 2020).

Based on the available literature, there is considerable evidence for genetic variation in sorghum drought tolerance and mineral composition, but the two areas have often been investigated separately. There is therefore a need to evaluate sorghum germplasm for both drought adaptation and mineral nutritional quality, particularly under environments where water availability is limited. Such research would help identify genotypes capable of maintaining productivity while providing nutritionally valuable grain. This approach is consistent with recent calls for sorghum improvement strategies that integrate climate resilience with nutritional quality rather than treating these traits independently (Mwamahonje et al., 2024; Yahaya & Shimelis, 2022). The gap that this research hoped to fill is what level of genetic variation exists among selected sorghum germplasm for drought tolerance and mineral composition, and which genotypes combine superior drought adaptation with high concentrations of nutritionally important minerals such as iron, zinc, calcium, magnesium, phosphorus and potassium?

MATERIALS AND METHODS

Description of Experiment Site

Field experiment was done during the rainy season at two different locations in (Nasarawa State). This study was carried out at Duduguru in Obi Local Government Area with maximum rainfall of 8.3mm and relative humidity of 69.8 %, and on research farm in College of Agriculture, Science and Technology, Lafia with rainfall of about 11.4 mm, and maximum temperature of 32.7 ºC. Soil type is mostly sandy loam. (NMA 2024)

Physical and Chemical Properties of the soil at the Experimental Location in Lafia

Clay content of the soil was variable and ranged from 13.4 % before planning. The texture was determined as sandy loam. pH of the soils was 6.4 before planting which indicates that the soil was slightly acidic. Electrical Conductivity (EC) in the location was very low with the value of 0.65 dS/m before planting. Organic carbon content in the study area is 1.85 % before planting. The organic matter content in the study area was 3.18 % before planting indicates low organic matter content.

Total Nitrogen was low with the value of 0.49 % before planting. The available Phosphorus (P) is low in the location with the value of 3.78 ppm before planting. The status of the exchangeable bases in the soil under study indicated that Calcium (Ca) is moderate in both locations with least value of 1.08 C mol kg^{-1} before planting which are very low. Magnesium (Mg) is low with the value of 0.86 C mol kg^{-1} before planting. Potassium (K) is moderate with the value of 0.11 C mol kg^{-1} before planting. The Cation Exchange Capacity (CEC) in the study area is very low with the value of 2.71 C mol kg^{-}.

Table 1: Physical and Chemical Properties of Lafia Study Site

S/NO	PARAMETER	SOIL PROPERTIES
01	SAND (%)	81
02	SILT (%)	5.4
03	CLAY (%)	13.4
04	TEXTURAL CLASS	SANDY-LOAM
05	pH(H_2O)	6.3
06	EC(Dsm^{-1})	0.65
07	O.C (%)	1.85
08	O.M (%)	3.18
09	TOTAL N (%)	0.49
10	AVAIL. P (PPm)	3.78
11	Ca (C $molkg^{-1}$)	1.08
12	Mg (C $molkg^{-1}$)	0.86
13	K (C $molkg^{-1}$)	0.11
14	Na (C $molkg^{-1}$)	0.16
15	EX. ACIDITY	0.50
16	ECEC (C $molkg^{-1}$)	2.71

Physical and Chemical Properties of the Experimental Location in Duduguru

Clay content of the soil was variable and ranged from 14.1% before planning. The texture was determined as clay loam. pH of the soils was 7.1 before planting which indicates that the soil was slightly acidic. Electrical Conductivity (EC) in the location was very low with the value of 0.74 dS/m before planting. Organic carbon content in the study area is 1.92 % before planting. The organic matter content in the study area was 2.26 % before planting indicates low organic matter content.

Total Nitrogen was low with the value of 0.54 % before planting. The available Phosphorus (P) is low in the location with the value of 3.97 ppm before planting. The status of the exchangeable bases in the soil under study indicated that Calcium (Ca) is moderate in both locations with least value of 2.09 C mol kg^{-1} before planting which are very low. Magnesium (Mg) is low with the value of 0.99 C mol kg^{-1} before planting. Potassium (K) is moderate with the value of 0.19 C mol kg^{-1} before planting. The Cation Exchange Capacity (CEC) in the study area is very low with the value of 2.81 C mol kg^{-}.

Table 2: Physical and Chemical Properties of Duduguru Study Site

S/NO	PARAMETER	SOIL PROPERTIES
01	SAND (%)	67
02	SILT (%)	3.2
03	CLAY (%)	14.1
04	TEXTURAL CLASS	CLAY-LOAM
05	pH(H_2O)	7.1
06	EC(Dsm^{-1})	0.74
07	O.C (%)	1.92
08	O.M (%)	2.26
09	TOTAL N (%)	0.54
10	AVAIL. P (PPm)	3.97
11	Ca (C $molkg^{-1}$)	2.09
12	Mg (C $molkg^{-1}$)	0.99
13	K (C $molkg^{-1}$)	0.19
14	Na (C $molkg^{-1}$)	0.22
15	EX. ACIDITY	0.41
16	ECEC (C $molkg^{-1}$)	2.81

Collection of planting materials

A total of 14 varieties were collected from IAR, Samaru Zaria and 6 locals from Lafia farms.

Experimental Design

The experimental design for the research was carried out in a randomized complete block design (RCBD) having three replications.

Cultural Practices

The field preparation and manual ploughing was done using relevant farm implements. The planting was done in three rows with a total length of 3 meters, inter-row spacing of 75 cm, and intra-row spacing of 20 – 25 cm according to the findings by Munza, *et al*., (2018). Four seeds per hole were planted but reduced to two at 2 weeks after planting (WAP). NPK 20:10:10 fertilizer of 120 kg/ha was used as per the recommendations of Ashwini *et al*., (2017). The harvesting was done through manual cutting of the head of the plant (Tesema *et al*., 2022).

Mineral composition

The mineral composition of this experiment was performed according to the procedure of Abah *et al*. (2020) with slight modifications Using ICP-MS spectrometry following AOAC 999.11 method for micronutrient analysis. Samples (n=3) were dry-ashed at 550°C, then digested in 2M HCl. Standards were traceable to NIST. Quality control included recovery tests (95-105%) and duplicate analysis)

Data Collection

Days to seedling emergence, plant height, number of leaves, Leaf area, Days to flowering, Days to maturity, 100 seeds weight, Grain yield (Kg/ha) data were gathered.

Data Analysis

Data were analysed using R 4.5.1 and SPSS 20 versions. Normal distribution among groups was determined by Shapiro-Wilk test with p-value ≤ 0.05 considered significant. The G × E interaction was performed in R software, while ANOVA compared group mean with Least Significant Difference (LSD) and Tukey tests post-hoc analyses when applicable. Descriptive statistics of the data were performed R 4.3.1 for GxE interaction analysis, with ANOVA validation using SPSS 20 for cross-platform verification.

Table 3: Planting materials and genotypes code

No.	Genotype Name	Genotype Code
1	AREGE TUNANI	G1
2	CRS 01	G2
3	CRS 02	G3
4	FAIRE	G4
5	GBESEI	G5
6	GUJUNGU	G6
7	ICSG 1780608	G7
8	ICSG 1780846	G8
9	ICSG 1980091	G9
10	ICSG 1980169	G10
11	ICSG 1980447	G11
12	ICSG 1980854	G12
13	KAURA	G13
14	MADARA	G14
15	SAMSORG 46	G15
16	SAMSORG 48	G16
17	SAMSORG 49	G17
18	SAMSORG 52	G18
19	SAMSORG 53	G19
20	SAMSORG 54	G20

RESULTS

Table 4: Combined Analysis of Variance for Agronomic Traits of *Sorghum* Genotypes Evaluated in Two Locations, 2024.

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Source of variation		DF		DE		PH		NL		LL		100SW		GY	
	Df	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Genotype (G)	19	6444.37	339.18***	158.37	8.34***	1217.58	64.08***	11.53	0.61^{ns}	1560.83	82.15***	283.05	14.9*	117453.07	6181.74^{ns}
Environment (E)	1	19.20	19.20^{ns}	3.33	3.33^{ns}	33.08	33.07^{ns}	0.53	0.53^{ns}	283.67	283.67^{ns}	7.01	7.01^{ns}	3950.97	3950.97^{ns}
Block	4	253.87	63.47*	12.33	3.08^{ns}	394.23	98.56*	3.37	0.84^{ns}	744.06	186.01**	102.03	25.51*	46230.45	11557.61*
G × E	19	346.80	18.25^{ns}	20.67	1.09^{ns}	210.09	11.06^{ns}	15.80	0.83^{ns}	149.14	7.85^{ns}	124.12	6.53^{ns}	57767.87	3040.41^{ns}
E / G	20	366.00	18.30^{ns}	24	1.20^{ns}	243.17	12.16^{ns}	16.33	0.82^{ns}	432.81	21.64^{ns}	131.12	6.56^{ns}	61718.85	3085.94^{ns}
Residuals	76	1556.13	20.48	425.67	5.60	2447.84	32.21	67.97	0.89	3327.03	43.78	745.53	9.81	330655.50	4,350.73

Note: Df: Degrees of Freedom; SS: Sum of Squares; MS: Mean Squares; DF: Days to Flowering; DE: Days to Emergence; PH: Plant Height; NL: Number of Leaves; Leaf Length; 100SW: One Hundred Seed Weight; GY: Grain Yield. *, significant at 0.05 probability level; **, significant at 0.01 probability level; ***, significant at

Table 5: Mean Performance for Agronomic Traits in 20 *Sorghum* Genotypes Tested Across Two Locations, 2024.

Gene	DF	DE	PH	NL	LL	100SW	GY
G1	60.17^{a}	8.33^{ab}	80.00^{ab}	7.67^{a}	72.75^{a}	23.67^{a}	605.34^{a}
G2	82.83^{e}	6.50^{ab}	72.70^{ab}	8.00^{a}	72.13^{a}	26.83^{a}	536.86^{a}
G3	69.17^{abcd}	5.67^{ab}	74.77^{ab}	7.50^{a}	70.58^{a}	23.83^{a}	602.33^{a}
G4	83.00^{e}	6.00^{ab}	78.57^{ab}	8.33^{a}	76.60^{a}	26.67^{a}	537.78^{a}
G5	77.67^{cde}	7.33^{ab}	73.17^{ab}	7.67^{a}	66.68^{a}	28.83^{a}	516.03^{a}
G6	68.00^{abc}	8.33^{ab}	75.77^{ab}	7.67^{a}	77.28^{a}	25.17^{a}	569.95^{a}
G7	62.00^{ab}	6.67^{ab}	82.00^{ab}	7.33^{a}	72.93^{a}	25.00^{a}	573.47^{a}
G8	63.83^{ab}	7.50^{ab}	76.43^{ab}	7.67^{a}	76.75^{a}	25.48^{a}	565.32^{a}
G9	63.67^{ab}	9.33^{b}	74.03^{ab}	7.50^{a}	72.63^{a}	24.33^{a}	590.65^{a}
G10	63.67^{ab}	6.33^{ab}	74.47^{ab}	7.50^{a}	76.93^{a}	26.50^{a}	547.01^{a}
G11	63.00^{ab}	7.33^{ab}	78.73^{ab}	7.83^{a}	75.65^{a}	24.83^{a}	579.01^{a}
G12	64.33^{ab}	5.50^{ab}	77.37^{ab}	7.50^{a}	73.52^{a}	24.50^{a}	589.57^{a}
G13	83.00^{e}	6.50^{ab}	74.20^{ab}	7.83^{a}	75.63^{a}	26.00^{a}	560.45^{a}
G14	79.00^{de}	6.17^{ab}	77.53^{ab}	8.50^{a}	67.43^{a}	25.17^{a}	587.35^{a}
G15	67.83^{abc}	7.00^{ab}	78.50^{ab}	7.67^{a}	74.38^{a}	26.22^{a}	545.53^{a}
G16	68.33^{abc}	4.00^{a}	74.67^{ab}	7.17^{a}	67.23^{a}	24.50^{a}	595.55^{a}
G17	66.00^{ab}	7.17^{ab}	75.17^{ab}	7.67^{a}	71.87^{a}	28.17^{a}	510.71^{a}
G18	70.50^{bcd}	7.83^{ab}	79.00^{ab}	7.50^{a}	75.88^{a}	27.00^{a}	538.54^{a}
G19	64.83^{ab}	7.67^{ab}	69.93^{a}	7.50^{a}	65.00^{a}	27.67^{a}	524.98^{a}
G20	64.83^{ab}	6.50^{ab}	83.30^{b}	8.00^{a}	72.80^{a}	28.80^{a}	498.30^{a}
GM	68.79	6.39	72.39	7.64	76.28	25.76	554.55
CV	12.28	33.17	9.82	11.86	7.86	12.54	12.23
LSD	5.48	3.17	6.88	1.08	8.2	3.73	77.18

Note: Values that carry the same superscript letter within a column are not really significantly different from one another at a probability value of < 0.05. GM= Grand mean, CV= Coefficient of Variation, LSD= Least significant difference. DF= Days to flowering, DE= Days to emergence, PH= Plant height, NL= Number of leaves, Leaf length, 100 SW= One hundred seed weight. GY= Grain yield

Table 6: Mean Performance Across the Two Environment for Agronomic Traits of 20 genotypes of *sorghum* assessed in 2024.

Environment	DF	DE	PH	NL	LL	100SW	YD
Lafia	69.68^{a}	7.05^{a}	75.99^{a}	7.77^{a}	71.20^{a}	25.72^{a}	564.47^{a}
Duduguru	68.88^{a}	6.72^{a}	77.04^{a}	7.63^{a}	74.27^{b}	26.20^{a}	553.00^{a}
P Value	0.36	0.44	0.34	0.44	0.02	0.42	0.36

Days to flowering is indicated as DF, Days to emergence as DE, Plant height as PH, Number of leaves as NL, Leaf length as leaf length, One hundred-seed weight as 100 SW, and Grain yield as GY.

Table 7: Estimate of Variance of 20 *Sorghum* Genotypes Evaluated in Two Location, 2024.

Trait	DF	DE	PH	NL	LL	100SW	GY
GCV	20.17	5.57	31.65	0.88	46.71	10.16	4494.36
PCV	26.58	41.94	10.46	10.12	12.46	14.87	14.07
Heritability (%)	94.39	59.92	66.94	40.88	63.75	59.45	57.9
GA	51.69	51.64	14.4	8.52	16.36	18.23	16.76
GG	188.94	95.3	112.56	53.83	104.79	94.56	90.66

Note: PCV = Phenotypic Coefficient of Variation; GCV = Genotypic Coefficient of Variation; GA = Genetic Progress; GG = Genetic Gain; DF = Days to Flowering; DE = Days to Emergence; PH = Plant Height; NL = Number of Leaves; Leaf Length; 100SW = One Hundred Seed Weight; GY = Grain Yield.

Table 8: Pearson correlation analysis for morphological traits in the two environments

Traits	DF	DE	PH	NL	LL	100SW	GY
DF	1						
DE	-0.093	1					
PH	-0.120	-0.096	1				
NL	0.262**	0.031	-0.107	1			
LL	-0.093	0.090	0.452**	-0.200*	1		
100SW	0.062	0.112	-0.031	0.010	-0.111	1	
GY	-0.036	-0.125	0.022	-0.007	0.101	-0.988**	1

Note: N = 120, DF = Days to Flowering, DE = Days to Emergence, PH = Plant Height, NL = Number of Leaves, Leaf Length, 100SW = One Hundred Seed Weight, GY = Grain Yield. **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 9: Mineral and Protein Composition of Selected *Sorghum* Varieties

Variety	Zn	Pb	K	N	Na	Ca	Mg	Fe	Protein
1CSG 1780846	0.51 ± 0.52	0.24 ± 0.17	0.36 ± 0.09	0.66 ± 0.44	0.80 ± 0.47	0.52 ± 0.24	0.80 ± 0.59	0.30 ± 0.20	0.35 ± 0.05
Aregetunani LV	0.26 ± 0.14	0.27 ± 0.07	0.36 ± 0.11	0.52 ± 0.27	1.00 ± 0.66	0.46 ± 0.06	0.38 ± 0.18	0.40 ± 0.39	0.36 ± 0.06
CSR 01	0.36 ± 0.35	0.64 ± 0.43	0.37 ± 0.13	0.23 ± 0.17	0.46 ± 0.22	0.80 ± 0.60	0.29 ± 0.05	0.34 ± 0.34	0.44 ± 0.11
CSR 02	0.38 ± 0.13	0.67 ± 0.48	0.34 ± 0.15	0.83 ± 0.61	0.69 ± 0.42	0.41 ± 0.33	0.25 ± 0.08	0.47 ± 0.41	0.62 ± 0.55
Faire LV	0.70 ± 0.45	0.57 ± 0.47	0.44 ± 0.50	0.78 ± 0.63	0.20 ± 0.15	0.74 ± 0.47	0.28 ± 0.05	0.69 ± 0.43	0.22 ± 0.19
Gbesi LV	0.35 ± 0.10	0.94 ± 0.83	0.35 ± 0.09	0.68 ± 0.48	0.69 ± 0.37	0.89 ± 0.43	0.82 ± 0.47	0.41 ± 0.29	1.21 ± 0.68
Gujungu LV	0.33 ± 0.11	0.31 ± 0.11	0.88 ± 0.47	0.93 ± 0.66	0.27 ± 0.34	0.72 ± 0.47	0.27 ± 0.14	0.39 ± 0.03	0.42 ± 0.26
ICSG 1780608	0.44 ± 0.30	0.71 ± 0.51	0.34 ± 0.18	0.20 ± 0.08	0.26 ± 0.18	0.17 ± 0.10	0.29 ± 0.15	0.69 ± 0.38	0.99 ± 0.75
ICSG 1980091	0.33 ± 0.12	0.40 ± 0.43	0.50 ± 0.41	0.30 ± 0.25	0.31 ± 0.31	0.92 ± 0.67	0.76 ± 0.63	0.90 ± 0.60	0.40 ± 0.17
ICSG 1980169	0.35 ± 0.15	0.51 ± 0.47	0.45 ± 0.19	0.40 ± 0.27	0.36 ± 0.02	0.53 ± 0.37	0.52 ± 0.25	0.61 ± 0.26	0.61 ± 0.39
ICSG 1980447	0.31 ± 0.13	0.35 ± 0.12	0.84 ± 0.60	0.77 ± 0.51	0.58 ± 0.35	0.14 ± 0.17	0.52 ± 0.47	0.30 ± 0.15	0.52 ± 0.40
ICSG 1980854	0.28 ± 0.25	0.32 ± 0.27	0.34 ± 0.29	0.26 ± 0.28	0.16 ± 0.13	0.28 ± 0.09	0.50 ± 0.24	0.66 ± 0.46	1.03 ± 0.61
Kaura LV	0.41 ± 0.14	0.33 ± 0.43	0.77 ± 0.39	0.36 ± 0.16	0.31 ± 0.30	0.24 ± 0.13	0.59 ± 0.52	0.43 ± 0.14	0.37 ± 0.14
Madara LV	0.99 ± 0.62	0.34 ± 0.26	0.90 ± 0.54	0.22 ± 0.15	0.36 ± 0.13	0.31 ± 0.05	0.39 ± 0.36	1.02 ± 0.80	0.37 ± 0.27
Samsorg 46	0.36 ± 0.15	0.41 ± 0.33	0.37 ± 0.14	0.30 ± 0.21	0.64 ± 0.58	0.31 ± 0.03	0.43 ± 0.39	0.27 ± 0.13	0.54 ± 0.18
Samsorg 48	0.75 ± 0.49	0.77 ± 0.37	0.39 ± 0.25	0.33 ± 0.44	0.99 ± 0.72	1.17 ± 0.90	0.32 ± 0.23	0.29 ± 0.28	0.28 ± 0.15
Samsorg 49	0.34 ± 0.11	0.60 ± 0.41	1.08 ± 0.67	0.30 ± 0.19	0.62 ± 0.41	0.39 ± 0.15	0.39 ± 0.23	0.73 ± 0.54	1.04 ± 0.71
Samsorg 52	0.40 ± 0.43	0.40 ± 0.17	0.64 ± 0.25	0.46 ± 0.39	0.67 ± 0.41	1.07 ± 0.62	0.78 ± 0.53	0.30 ± 0.22	0.52 ± 0.14
Samsorg 53	0.67 ± 0.50	0.52 ± 0.51	0.28 ± 0.21	0.72 ± 0.63	0.34 ± 0.26	0.48 ± 0.21	0.39 ± 0.21	0.22 ± 0.04	0.42 ± 0.34
Samsorg 54	0.16 ± 0.06	0.49 ± 0.36	1.12 ± 0.84	0.34 ± 0.26	0.56 ± 0.44	0.30 ± 0.21	0.27 ± 0.16	0.69 ± 0.54	0.51 ± 0.26
p value	0.312	0.832	0.146	0.423	0.276	0.061	0.548	0.416	0.113

Note: Values indicate mean ± standard deviation; N=3. Values are significant with $p < 0.05$.

DISCUSSION

In the analysis of the average performance of 20 *sorghum* varieties studied in two locations in 2024 (Table 5), genotypic variation was observed for DF and PH; on the contrary, no statistically significant differences were found in other agronomic characters like GY. Days to flowering ranged from 60.17 days in G1 to 83.00 days in both G4 and G13, with genotypes G1, G7 to G12, G16, G17, G19, and G20 classified as early-flowering, making them suitable candidates for breeding programs targeting early maturity. In contrast, genotypes such as G2, G4, G13, and G14 exhibited significantly delayed flowering. Although variation was observed in days to emergence (DE), which ranged from 4.00 days in G16 to 9.33 days in G9, the differences were not statistically significant, likely due to high within-group variation (CV = 33.17 %), indicating potential environmental influence. For plant height, G20 recorded the tallest plants (83.30 cm), which was significantly different from the shortest genotype, G19 (69.93 cm), while the remaining genotypes were statistically similar. Other traits, including number of leaves (NL), leaf length (LL), and 100-seed weight (100SW), showed no significant genotypic differences despite numerical variability—100SW, for example, ranged from 23.67 g (G1) to 28.83 g (G5). Grain yield also did not differ significantly among genotypes, although G1 recorded the highest yield (605.34 kg/ha) and G20 the lowest (498.30 kg/ha), with a grand mean of 554.55 kg/ha and a coefficient of variation of 12.23%. The relatively high least

significant difference (LSD = 77.18) for yield suggests that the observed differences, though numerically apparent, were not statistically meaningful. Overall, the results indicate that while days to flowering and plant height revealed significant genotypic effects, most other traits, particularly grain yield, remained statistically indistinct across environments.

Growth performance is an attribute associated with the genotype and environment present in the period of growth. Some literature has shown evidence of the presence of GEI effect in different plants such as rice (Rahman and Shah, 2019; Calayugan *et al*., 2020), sweet potatoes (Ngailo *et al*., 2019), and *Sorghum* (Jiang *et al*., 2020). According to Yan and Kang (2003), the more the genotypes and environments, the greater the environmental variations. The authors further stated that the higher number of genotypes within the few environments will lead to less environmental variations and vice versa. However, Aremu *et al*. (2019) stated that the environment will always be the greatest source of variation in plant breeding. GEI obtained from the results of this experiment is different from the results of previous research where gene had an effect on the growth of this plant, weight of wet pods per stand, weight of dry pods per stand, and weight of 100 wet pods per stand showing that performance of groundnut varieties for this trait is dependent on the interaction of both the gene as well as the across which supports the findings of Olanrewaju *et al*., (2021) whose study was conducted on groundnut. Genotypic effects were highly significant ($p < 0.001$) for days to flowering (DF), days to emergence (DE), plant height (PH), and leaf length (LL). Furthermore, there was a statistically significant difference at the 5 % probability level ($p < 0.05$) for 100-seed weight (100SW) which contradicts the findings of Wakili *et al*., (2025) who conducted their experiments on groundnuts and found that performance of groundnut varieties for this trait is dependent on the interaction of both the gene which supports the findings of Olanrewaju *et al*., (2021).

Comparative mean agronomic performance of the crop in the two environments Lafia and Duduguru in 2024 (Table 6) demonstrated that effects of environment on all the variables except leaf length (LL) were not statistically significant. The values of days to flowering (DF) and days to emergence (DE) were comparable in the two environments. The mean values of DF and DE in Lafia environment were 69.68 days and 7.05 days, respectively. While in Duduguru environment, the mean values of DF and DE were 68.88 days and 6.72 days, respectively. The p-values of the above comparison were 0.36 and 0.44, respectively, which clearly indicated that there was no significant difference in the two locations with respect to these variables. The PH value was found to be 75.99 cm in Lafia and 77.04 cm in Duduguru ($p = 0.34$). The grain yield of the *sorghum* genotypes was slightly higher in Lafia (564.47 kg/ha) as compared to the Duduguru (553.00 kg/ha), but this result was not statistically significant ($p = 0.36$). However, the leaf length proved to be significantly different in the two environments, and the leaf length was found to be significantly higher in the Duduguru environment (74.27 cm) than Lafia (71.20 cm) at 5 % probability level ($p = 0.02$). It can be concluded from the results obtained that while both the environments have had more or less similar influence on the majority of the agronomic parameters, leaf expansion was favoured by the Duduguru environment.

Understanding the grain yield productivity of *sorghum* genotypes in the North-central region of Nigeria is very important in solving the problem of food security and breeding genotypes that could yield high grain yield and high stalk sugar content. Adeyemi *et al*., (2023) observed that there was a lot of genetic diversity for Plant Height (PH), Hundred Seed Grain Weight and other traits. In this current study, the genotypes used showed high genetic diversity for qualitative traits. Although there was no specific pattern observed in terms of Number of Leaves (NL), Leaf Length (LL) and 100-seed Weight (100SW) in the sense that all the

genotypes were statistically similar for the three traits in this current study, it is important to note that Madara genotype recorded the highest yield (629.06 kg/ha). This observation was in agreement with the study conducted by Mshelmbula *et al*., (2024) in their study on Bambara Groundnut where they observed that the local genotypes performed better than the improved genotypes. This might be due to the influence of the environment.

Table 7: presents important estimates for the genetic variability, heritability, and genetic gain for seven agronomic characteristics observed in 20 varieties of *sorghum* plants evaluated at two sites during the 2024 growing season. The highest genotypic coefficient of variation (GCV) values was observed for the yield of grains (4494.36), leaf length (46.71), and plant height (31.65), which suggests a high genetic variability of these characteristics. On the other hand, the phenotypic coefficient of variation (PCV) was much higher for days to emergence (41.94), followed by the yield of grains (14.07) and the 100-seeds weight (14.87). These results reflect significant effects of the environment on the trait manifestation and especially emergence. The close value of GCV and PCV for traits such as plant height and grain yield is indicative of genetic control with some environment effects, while wider gaps (days to emergence) point out the influence of the environment. Broad sense heritability values for various morphological traits of wheat ranged from medium to high. Days to flowering had the highest heritability value of 94.39 %, followed by plant height (66.94 %) and leaf length (63.75 %), which implies that selection of these traits will be highly effective. Traits such as number of leaves (40.88 %) and days to emergence (59.92 %) had medium heritability values, implying that the improvement of such traits might take much longer time or use of indirect selection methods. Consistently, GA and GG were highest in case of days to flowering (GA = 51.69; GG =188.94), plant height (GG = 112.56) and leaf length (GG =104.79). Thus, the result suggests that traits such as days to flowering, plant height and leaf length are under genetic control and have great potential for improvement through selection, while traits that have low heritability and are environment dependent, such as days to emergence and number of leaves, require specific breeding methods.

The significance of using variability in selected plant parameters and its variables in the breeding process allows breeders to understand how the environment affects such a parameter in plants. This is because the quantitative character is affected by the environment (Mshelmbula *et al*., 2024; Pranesh *et al*., 2007). Varietal differences in growth parameters have also been seen between different varieties of groundnut by Mshelmbula *et al*. (2022). All these findings match the results found in the current research done in Duduguru. It has been found that genotypic differences only existed in days to flowering (DF) that ranged between 62.00 days in G7 and 81.33 days in G4. Genotypes like G1, G3, G7, G8, G9, G10, G11, G12, G16, G17, G19, and G20 flowered significantly earlier and can prove to be valuable for developing early maturing *sorghum*, while G2, G4, and G13 flowered late. Trait of interest to farmers is another important aspect which serves as basis for breeding and socio-economic research. Significant differences observed among the genotypes in regard to their quantitative traits indicate that there exist significant differences in their genetic constitution and ability or inability to adapt to certain environmental conditions. Variability exists in most of the traits under consideration. For instance, the plant height of a crop, and indeed, all quantitative traits, is a function of both genotypic and environmental factors (Muniaz *et al.* 2001). Flowering is among the traits that can be used in selecting a variety. Early flowering *sorghum* is preferred in areas where there is short rainfall season, especially drought-prone regions where *sorghum* is predominantly grown (Belay & Meresa, 2017). Days to 50 % flowering & maturity of *sorghum* varieties are critical in identifying early and late grain production system (Mwamahonje & Maseta, 2018). *Sorghum* is considered quantitative short-day plants since some varieties show long day sensitivity delay floral initiation. Days to flowering will dictate the maturity, whereby early-flowering varieties

have the highest chances of maturing first. Samsorg 46 had fewer days to 50% flowering and maturity. It was observed that the medium-ripened varieties which had a longer growth period yielded more grains. For example, in this study, concerning days to flowering (DF) and plant height (PH), there were significant variations among the genotypes evaluated. This corroborates the findings by (Muhammad *et al*., 2022; Adamu and Dauda, 2008). It is in agreement with the findings of Omoregie *et al*. (2021); Mwamahonje & Maseta (2018), Belay & Meresa (2017) and Msongaleli *et al*. (2017), who reported that the medium maturing varieties have the longest growth period and play a major role in the grain yield. G1 had the highest grain yield (605.34 kg/ha) and had early flowering and high plant height. This is similar to the findings from the research conducted by Omoregie *et al*., (2021) where he found out that Samsorg 42 with the highest plant height produced the highest grain. Also, it should be noted that genotype G1 produced the highest grain yields compared to all other genotypes used in the experiment. Grain yield is one of the main factors considered when selecting varieties of crops. This study differs from the findings of Omoregie & Nwajei (2015) where they found out that there was a reduction in grain yield due to increase in height of the millet. Such results helped to understand the role of the plant height in determining plant growth and ensuring good yield for the crop. This study is consistent with the findings of Kotu & Admassie (2015); Staggenborg (2016); Msongaleli *et al*. (2017) and Mwamahonje & Maseta (2018).

There was no statistical difference in the mean performances of the crops in both environments except for LL. Similarities exist in DF and DE in both environments indicating that no specific environmental conditions affect the performance of the varieties. However, there are times when some varieties do not perform well in certain environments as compared to other varieties which contradicts results obtained by Ngailo *et al*. (2019) for sweet potato genotype and Masila and Langat (2020) for hybrid maize. From the above findings, it can be seen that even though there was no difference between the effects of both environments on the agro-morphological traits of the *sorghum*, Duduguru environment had a slight upper hand over the Lafia environment especially with regards to promoting leaf expansion. Number of leaves per plant-1 played an important role in increasing growth and productivity in *sorghum* (Abduselam *et al*., 2018). Regarding the number of leaves (NL), G4 and G14 had the highest NL, whereas concerning grain yield (GY), G14 was the highest yielder than other varieties in Lafia; however, G4 was considered as the highest flowering genotype, and it shows its early maturity nature. This means that there is an impact of the number of leaves on the grain yield in that variety. This is because the production of more leaves increased the photosynthesis process in the exponential growth stage of the crop. As stated by Staggenborg (2016), the increment in the number of leaves per plant-1 increased the photosynthetic biomass (Omoregie *et al*., 2021). With regards to 100-seed weight (100SW), G5 had the highest seed weight in Lafia, whereas G20 had the highest seed weight in Gunduguru because of sink potentiality. Contrarily, G14, G16, and G3 received the lowest ranks due to varietal features (Mshelmbula *et al*., 2024; Omoregie *et al*., 2021). Also, analogous results have been found by Staggenborg (2016) and Msongaleli *et al*. (2017), thereby showing that the presence of varietal features can make seed weight vary. It should be mentioned that none of the genotypes showed good performance in all traits, meaning that the genotype-trait interactions were complex.

Measurement of CV is yet another method of measuring the variations in a set of data that use different units, and where there is high CV, there is dispersion in the variable (Akatwijuka *et al*., 2016). From the findings, it can be noted that there are high genetic variations in inflorescence length, grain yield, and plant height (Akatwijuka *et al*., 2016). According to Singh *et al*. (1997), variations in the length of *sorghum* panicles were caused by variations in rachis length, branch length, and distance between whorls. Where there is a wide variation in

the values of the morphological traits, it shows the presence of genetic variation among the accessions tested (Wakili *et al*., 2025; Mshelmbula *et al*., 2024; Amare *et al*., 2015).

The variability level of GCV and PCV shows the extent of variability in each of the traits (Sami *et al*., 2013). The PCV and GCV of most of the traits observed in the study were very high and in agreement with the results obtained by Mshelmbula *et al*. (2024); Mengistu *et al*. (2020) and Andiku *et al*. (2022). Genotypic coefficient of variation (GCV) was higher for grain yield as compared to its PCV in the same parameter. It implies that genetic variance had greater impact on the performance of the trait than the environmental variance unlike in the findings of Gebregergs and Mekbib, 2020. This result does not agree with the results of Bello *et al*. (2007), Sami *et al*. (2013) and Amare *et al*. (2020). According to Bello *et al*. (2007), high GCV and PCV values show wide genetic background which will be positively reacting. The results show that the environment had minimum effects on the character traits (Hamidou *et al*., 2012). Thus, *sorghum* can freely grow in both the sites studied in Nasarawa state.

Broad-sense heritability is the proportion of phenotypic variation that is accounted for by genetic variation (Schmidt *et al*., 2019). Levels of heritability are categorized as follows: low (H2 ≤ 40 %), medium (40 < H2 ≤ 59 %), moderately high (60 ≤ H2 ≤ 79 %) and very high (H2 ≥ 80 %) (Mengistu *et al*.,2020). High heritability estimates indicate that the environment in which the test was carried out contributed little to the traits tested and thus, the traits were selected for directly during the seasons (Mengistu *et al*., 2020; Amare *et al*., 2015). Low heritability estimates, on the other hand, indicate that the environment made a great contribution to the trait. As per Singh (as cited in Amare *et al*. 2015), high heritability (≥ 80 % or 0.80) of a trait makes direct selection of the trait favourable due to the close association between variety and phenotype as a result of minimal effects of environment on phenotype. Considering the high heritability values of the aforementioned traits like flowering (highest value - 94.39 %), plant height (66.94 %) and leaf length (63.75 %), it may be concluded that the selection of these traits shall be quite successful. It suggests that the traits are controlled by the genes and not the environment. This is consistent with the observations of Murray *et al*. (2008).

The heritability of traits such as number of leaves (40.88 %) and days to emergence (59.92%) was observed to be moderate, hence the implication that the improvement of these traits would need a longer duration for selection or indirect selection methods. This further implies that it is easier to do effective selection when the variability from the environment is smaller than that from the genetics. Selection may however be very difficult if there is a low heritability (40% or 0.40), since the environment could mask the variability to the extent that a significantly large part of it comes from the environment (Amare *et al*., 2015). This finding agrees with the findings by Zou *et al*. (2011); Sami *et al*. (2013) and Naoura *et al*. (2019). Virtually all the traits in this study show a high broad sense heritability indicating a good chance of favourable selection response. Heritability is not enough for the genetic gain to be achieved since high heritability may not imply high genetic gain. Therefore, it is only under the use of heritability as a means to estimate genetic gains that its effectiveness is realized (Mulualem *et al*., 2018). This being the case, the greatest genetic advance (GA) and genetic gain (GG) was recorded in days to flowering (GA = 51.69; GG = 188.94), plant height (GG = 112.56), and leaf length (GG = 104.79), meaning that there was efficient selection. Since most of the yield components have high genetic advance and high heritability, promising gene lines can be selected and subjected to further analysis and used by farmers. Selection will be facilitated by high genetic advance and heritability in the number of pods per plot and number of seeds in a plot (Mshelmbula *et al*., 2024).

Table 8 shows the Pearson correlation coefficients of the morphological characteristics of the *sorghum* genotypes in different environments. From Table 5, it is clear that there is a highly significant positive correlation between days to flowering and number of leaves ($r = 0.262$, $p < 0.01$). This means that those genotypes which flowered after a longer time had greater number of leaves. However, there are low and non-significant correlations between days to flowering and plant height, leaf length, seed weight, and grain yield. Thus, days to flowering do not affect these variables significantly. There are no significant correlations between days to emergence and the morphological characteristics studied. However, there are slightly negative correlations between days to emergence and days to flowering ($r = –0.093$) and plant height ($r = –0.096$). This shows that there are minimal effects of days to emergence on days to flowering and plant height. There was a positive correlation between plant height and leaf length with high statistical significance ($r = 0.452$, $p < 0.01$). On the other hand, there was a highly significant negative correlation between number of leaves and leaf length ($r = -0.200$, $p < 0.05$). This might imply a trade-off between number and size of the leaves. Interestingly, the grain yield showed a very strong and highly significant negative correlation with seed weight ($r = -0.988$, $p < 0.01$), suggesting that any increment in the size of the seeds led to a marked reduction in yield. This is possibly because the plants would have had less energy for grain production due to the resource invested in seed formation. Other correlations between grain yield and days to flowering, days to emergence, plant height, number of leaves and leaf length were weak and statistically insignificant. From the findings, it is clear that although some plant morphological traits such as plant height and leaf length, or days to flowering and number of leaves, are correlated, grain yield is mostly influenced by seed weight.

2014; Singh *et al*., 1997). Yield traits were found to be positively correlated with each other with some degree of significance, similar results have been documented by Mshelmbula *et al*., (2024). According to Makanda, (Magar *et al*., 2021), late-flowering genotypes had higher leaf numbers. In our case, the only negative correlation that is significant in this study is days to emergence with no significant relationship with any trait and showed slight negative relationships with days to flowering ($r = -0.093$) and plant height ($r = -0.096$). A moderate but highly significant positive correlation also existed which indicated that tall plants tended to have bigger leaves. The most important relationship found was the highly significant and very high negative correlation that existed between grain yield and seed weight ($r = –0.988$, $p < 0.01$). This indicates that a rise in seed size is characterized by a marked decline in yield. This kind of inverse correlation might be due to some physiological constraints regarding resource utilization between seed and yield.

Table 9: Represents the mean concentrations (± standard deviation) of nine essential nutrients; zinc (Zn), lead (Pb), potassium (K), nitrogen (N), sodium (Na), calcium (Ca), magnesium (Mg), iron (Fe) and protein of twenty different *sorghum* genotypes, involving the improved genotypes (for example; ICSG 1780846, ICSG 1980091, Samsorg series) and the landraces (LV). The levels of Zn varied from 0.16 ± 0.06 mg/kg for Samsorg 54 to 0.99 ± 0.62 mg/kg in Madara LV and those of Pb from 0.24 ± 0.17 mg/kg in ICSG 1780846 to 0.94 ± 0.83 mg/kg in Gbesi LV. The maximum value of potassium was obtained in Samsorg 54 (1.12 ± 0.84 mg/kg) and the minimum in ICSG 1780608 (0.34 ± 0.18 mg/kg). The values of nitrogen showed moderate variation, with the minimum value for ICSG 1780608 (0.20 ± 0.08 mg/kg) and the highest in Gujungu LV (0.93 ± 0.66 mg/kg). Sodium ranged from 0.16 ± 0.13 mg/kg in ICSG 1980854 to 1.00 ± 0.66 mg/kg in Aregetunani LV. The concentration of calcium varied from 0.14 ± 0.17 mg/kg for ICSG 1980447 to 1.17 ± 0.90 mg/kg for Samsorg 48. The magnesium concentrations were fairly constant; however, there were some variations, with 0.25 ± 0.08 mg/kg (CSR 02) being the minimum and 0.82 ± 0.47 mg/kg (Gbesi LV) being the maximum. Iron content was

found to be highest in Madara LV (1.02 ± 0.80 mg/kg), while the minimum iron content was noted in Samsorg 53 (0.22 ± 0.04 mg/kg). The concentration of protein varied widely among the samples with 1.21 ± 0.68% for Gbesi LV being the highest and 0.22 ± 0.19% for Faire LV being the minimum. No statistically significant difference could be noted in any of the parameters tested among the varieties as all p-values exceeded 0.05-Zn (p=0.312), Pb (0.832), K (0.146), N (0.423), Na (0.276), Ca (0.061), Mg (0.548), Fe (0.416), and protein (0.113).

The lack of mineral elements and protein is a great challenge to the increasing number of humans. Mineral elements have been an important factor in the formation of the human body (Ng'uni *et al*. 2012). Genetic diversity among genotypes with respect to nutritional content will contribute to the improvement of crops that have high nutritional content through breeding using the available gene pool (Ng'uni *et al*. 2012; Shegro *et al*. 2012). Quantification of *sorghum* genotypes with respect to mineral elements and protein will help in identifying the genotypes that will be used as parents in the breeding of nutritionally improved *sorghum*. Lack of variation in mineral elements among the current genotypes of *sorghum* may be attributed to the genetic similarity among the genotypes, environmental factors and similar concentration of minerals in the soil. This is in contrast to (Shegro *et al*., 2012). Nevertheless, Significant similarities have different points of view in another research, where differences were found among the different cultivars, breeding lines and selected accessions of *sorghum* (Hariprasanna *et al*., 2014). The concentration of iron, zinc and copper in *sorghum* flour is estimated to be 2.24 mg/100g, 0.75 mg/100g and 0.61 mg/100 g (Mohammed *et al*., 2010).

Furthermore, the level of Fe and Zn in *sorghum* grain is higher than any other staple cereal such as wheat, rice, and maize, and even equals to that of pulses (Chan *et al*., 2007). Biofortification, which involves improving the density and availability of the micronutrients, is the most appropriate way of addressing nutritional problems (especially in developing countries) (Clemens, 2014). Consequently, the mineral elements found in the *sorghum* landraces can become a potential source of biofortification. The utilization of the landraces, such as Jamuye and Dagnew, which have very high amounts of Fe and Zn, may be recommended to individuals who lack these nutrients. Normally, the landraces with increased mineral elements may be consumed directly or used in breeding programs for producing new cultivars.

Conclusion

Results revealed that the genetic effect was very highly significant ($p < 0.001$) for days to flowering (DF), days to emergence (DE), plant height (PH), and leaf length (LL), indicating that the genetics was highly responsible for the variation in these traits. Moreover, there was a significant difference at 5 % probability level ($p < 0.05$) in 100-seed weight (100SW) which showed that there was significant genotypic effect in this trait. The environmental effect was not statistically significant in all traits studied, implying that there is no difference between the two testing locations regarding the influence of environment on trait expression.

Also, genotypic variation was observed for DF and PH; on the contrary, no statistically significant differences were found in other agronomic characters like GY. Days to flowering ranged from 60.17 days in G1 to 83.00 days in both G4 and G13, with genotypes G1, G7 to G12, G16, G17, G19, and G20 classified as early-flowering, making them suitable candidates for breeding programs targeting early maturity. In contrast, genotypes such as G2, G4, G13, and G14 exhibited significantly delayed flowering. Grain yield also did not differ significantly among genotypes, although G1 recorded the highest yield (605.34 kg/ha) and G20 the lowest (498.30 kg/ha), with a grand mean of 554.55 kg/ha and a coefficient of variation of 12.23%. Overall, the results indicate that while days to flowering and plant height revealed significant

genotypic effects, most other traits, particularly grain yield, remained statistically indistinct across environments.

Days to flowering had the highest heritability value of 94.39 %, followed by plant height (66.94 %) and leaf length (63.75 %), which implies that selection of these traits will be highly effective. No statistically significant difference could be noted in any of the parameters tested among the varieties as all p-values exceeded 0.05-Zn ($p=0.312$), Pb (0.832), K (0.146), N (0.423), Na (0.276), Ca (0.061), Mg (0.548), Fe (0.416), and protein (0.113).

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