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Single-Location Assessment of Growth Parameters of Sorghum [*Sorghum bicolor* (L.) Moench] as a Basis for Multi-location Assessments

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ABSTRACT

Sorghum is a globally important crop for food and nutrition security, feed, and industry. The crop meets the need of low-income populations that rely on resilient crops with minimal soil nutrient requirements. Therefore, programmes for improving the crop are important in alleviating malnutrition. Multi-location assessments of sorghum materials enable identification of stable accessions or genotypes in different agro-ecological conditions. However, such assessments are resource-intensive and time-consuming. Preliminary assessment of sorghum materials in a single location could allow for streamlining of multi-location trials to variable traits; thereby reducing the resources and time that otherwise would have been used in assessing the traits. In that note, the study reports a single-location assessment of sorghum accessions for variability in growth parameters. There were significant differences ($p < 0.05$), which signify variability, in plant height, leaf length, days to flowering, inflorescence length and width, days to grain maturity, vegetative seedling vigour, vegetative lodging susceptibility, vegetative overall plant aspect, inflorescence exsertion, inflorescence compactness shape, and grain covering. Therefore, the multi-location assessment of genetic variability in the sorghum accessions will include these parameters.

Keywords: Sorghum, morphological variability, genetic variability, single-location assessment, multi-location trial

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is a high-energy photosynthetic C4 crop with climate-resilient features including ability to thrive in nutrient-poor soils. The crop is a global staple being the fourth most important cereal crop worldwide. It provides the nutritional needs of many low-income populations in developing countries because of its ease of cultivation, climatic sturdiness, nutritional benefits, and genetic diversity (Tanwar et al., 2023).

Sorghum is a dryland crop whose genetic diversity is predominantly centred in Africa and especially in Ethiopia, which has a high concentration of landraces (Mamo et al., 2023). Substantial genetic diversity is also represented in Asia (Upadhyaya et al., 2016). Furthermore, the northern region of Nigeria is one of the hubs for cultivation and genetic diversity of sorghum (Yahaya et al., 2023). Nigeria is a major global producer of the crop albeit a large proportion of the yield comes from subsistence farming (Yahaya et al., 2022; Yahaya et al., 2023).

Some varieties of sorghum are also known to thrive in regions with high rainfall. For example, the early-maturing sorghum varieties, SAMSORG 17, CSR-01, and 121 CKSV-180 produced high yield gains and the late-maturing varieties, Improved Deko and SK 5912, produced high grain yields in the rainforest zone of Nigeria that is characterized by high rainfall (Agele et al., 2025). These varieties are generally resistant to grain mold, leaf diseases, and short-term waterlogging, which are predominant in areas with higher rainfall (Aruna et al., 2021; Müller et al., 2020). However, planting is usually done at the end of the period of heavy rainfall in order to attain better yield (Wolf et al., 2015). Therefore, the south of Nigeria with an annual rainfall of approximately 2,000 mm (Awode et al., 2025; Okoro & Ofordu, 2025) provides a favorable agro-ecological environment for sorghum cultivation. For this reason, the variability of morphological parameters of sorghum accessions was assessed in the South-South state of Bayelsa, Nigeria.

The study provides useful information for the assessment of variability of sorghum accessions and opens up avenues to explore environmental influence on morphological parameters in sorghum by assessing the parameters in different locations. This is crucial because environmental influences on growth parameters of crops create phenotypic variations in plant materials (VanDerZanden, 2024). Therefore, the subsequent multi-location assessment will enable clear determination of the genetic basis and environmental influence on the parameters.

Materials and methods

Plant material

Seeds of 50 accessions of sorghum were obtained from the National Centre for Genetic Resources and Biotechnology (NACGRAB) and are tabulated in Table 1.

Table 1: Sorghum accessions sourced from NACGRAB

S/N	ACCESSION	SOURCE	S/N	ACCESSION	SOURCE	S/N	ACCESSION	SOURCE
1	NGB01233	NACGRAB	21	NGB01410	NACGRAB	41	NGB01471	NACGRAB
2	NGB01237	NACGRAB	22	NGB01411	NACGRAB	42	NGB01473	NACGRAB
3	NGB01243	NACGRAB	23	NGB01413	NACGRAB	43	NGB01480	NACGRAB
4	NGB01246	NACGRAB	24	NGB01416	NACGRAB	44	NGB01482	NACGRAB
5	NGB01255	NACGRAB	25	NGB01417	NACGRAB	45	NGB01485	NACGRAB
6	NGB01256	NACGRAB	26	NGB01431	NACGRAB	46	NGB01493	NACGRAB
7	NGB01259	NACGRAB	27	NGB01432	NACGRAB	47	NGB01502	NACGRAB
8	NGB01260	NACGRAB	28	NGB01435	NACGRAB	48	NGB01503	NACGRAB
9	NGB01276	NACGRAB	29	NGB01437	NACGRAB	49	NGB01506	NACGRAB
10	NGB01301	NACGRAB	30	NGB01443	NACGRAB	50	NGB01512	NACGRAB

11	NGB01316	NACGRAB	31	NGB01444	NACGRAB
12	NGB01322	NACGRAB	32	NGB01445	NACGRAB
13	NGB01352	NACGRAB	33	NGB01449	NACGRAB
14	NGB01367	NACGRAB	34	NGB01456	NACGRAB
15	NGB01386	NACGRAB	35	NGB01457	NACGRAB
16	NGB01400	NACGRAB	36	NGB01459	NACGRAB
17	NGB01403	NACGRAB	37	NGB01465	NACGRAB
18	NGB01405	NACGRAB	38	NGB01468	NACGRAB
19	NGB01406	NACGRAB	39	NGB01469	NACGRAB
20	NGB01409	NACGRAB	40	NGB01470	NACGRAB

NACGRAB: National Centre for Genetic Resources and Biotechnology

Experimental site, design, and planting

The experiment was done in the Research Farm of the Department of Biological Sciences, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria. A completely randomized design (CRD) was used with triplicate for each accession. Three seeds were planted in each well of a 96-well seedling tray containing loamy soil. The seeds were nurtured to germinate and the seedlings were weaned to one plant per well after 2 weeks of sowing. Thereafter, the seedlings were transferred to the field with 5 cm spacing within accessions and 10 cm spacing between accessions.

The plants were nurtured to maturity under natural environmental conditions of rainfall, sun shine, temperature, wind, and humidity from December 2024 to July 2025. The estimated average rainfall during the period of the planting was 166 mm with average daylight hours of 13.9 hours and mean sunshine hours of 7.3. The average wind speed was 9 km/h and average humidity of 79.2 % (Weather Atlas, 2025). The soil was irrigated by sprinkling 20 Litres of water daily and weeding was done manually by hand-removing growing weeds in every 3 weeks.

Data collection and analysis

The parameters for which data were obtained at the reproductive stage of the plants included plant height, leaf length, leaf width, stem diameter, days to flowering, inflorescence length, inflorescence width, days to grain maturity, vegetative seedling vigour, vegetative lodging susceptibility, vegetative overall plant aspect, inflorescence exsertion, inflorescence compactness shape, grain covering, awns, grain colour, and grain form (IBPGR & ICRISAT, 1993). The data for days to emergence were obtained during the germinating stage of the plants.

Plant height, leaf length, leaf width, inflorescence length, and inflorescence width were measured with a metre rule. The days to flowering and days to grain maturity were obtained by noting the days it took for the plants to flower and the grain to mature. Data for vegetative seedling vigour, vegetative lodging susceptibility, vegetative overall plant aspect, inflorescence exsertion, inflorescence compactness shape, grain covering, awns, grain colour, and grain form were obtained by using the scales provided in the IBPGR and ICRISAT's Descriptors for Sorghum [*Sorghum bicolor* (L.) Moench].

The mean of plant height, leaf length, leaf width, stem diameter, days to flowering, inflorescence length, inflorescence width, and days to grain maturity were subjected to analysis of variance and post-hoc tests using Turkey's Honestly Significant Difference, HSD. The statistical analyses were done on version 4.5.1 of R (R Core Team, 2020) and rendered on R studio (RStudio Team, 2019), with which graphical representations of the results were produced.

Results

Quantitative growth parameters

The result for plant height of the sorghum accessions is presented in Figure 1. There were significant differences in plant height in the accessions. For example, NGB01233 is significantly different in height from NGB01237 (Figure 1). However, some accessions had no significant difference in plant height. For instance, there was no significant difference in plant height between NGB01260 and NGB01276 (Figure 1). Similarly, there were significant differences in leaf length in the accessions (Figure 2). However, some accessions had no significant difference in leaf length. In contrast, there were no significant differences in leaf width, stem diameter, and days to emergence among the sorghum accessions as shown in Figure 3, Figure 4, and Figure 5, respectively.

The results for days to flowering (Figure 6), inflorescence length (Figure 7), inflorescence width (Figure 8), days to grain maturity (Figure 9) of the sorghum accessions demonstrated that there were significant differences in the accessions as obtained from the post-hoc results and presented as bars with different letters above the bar. However, the post-hoc results also showed that some accessions had no significant difference in days to flowering, inflorescence length, inflorescence width, days to grain maturity.

The significant difference of the accessions in their plant height, leaf length, days to flowering, inflorescence length, inflorescence width, and days to grain maturity implies that the accessions have variability in these parameters.

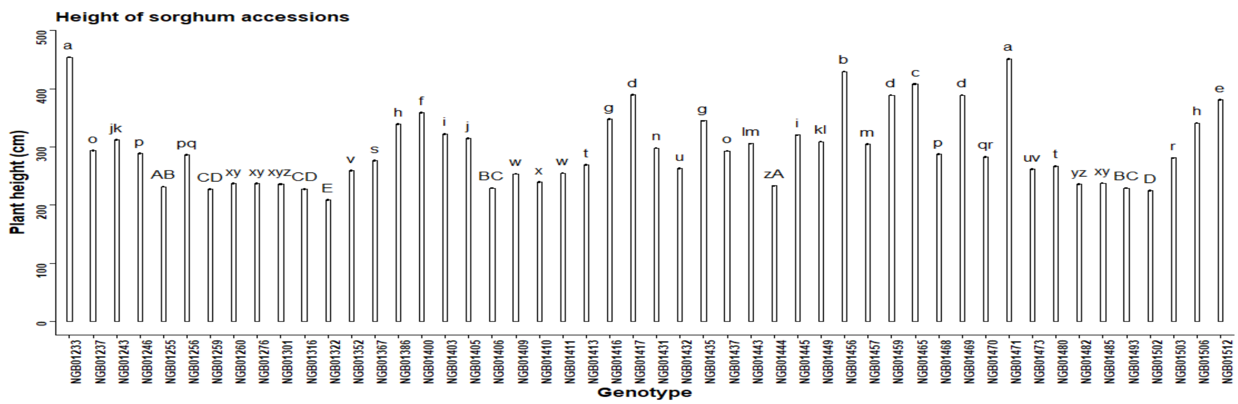

Figure 1: Plant height of sorghum accessions

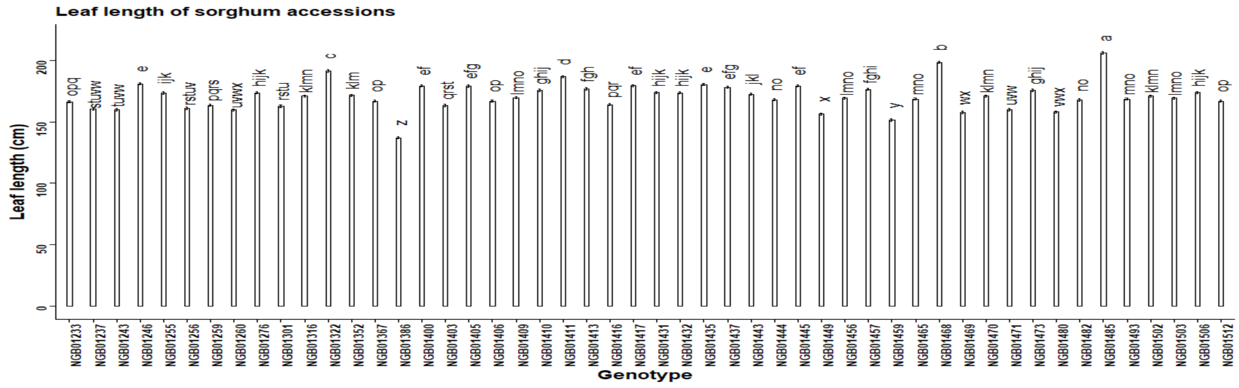

Figure 2: Leaf length of sorghum accessions

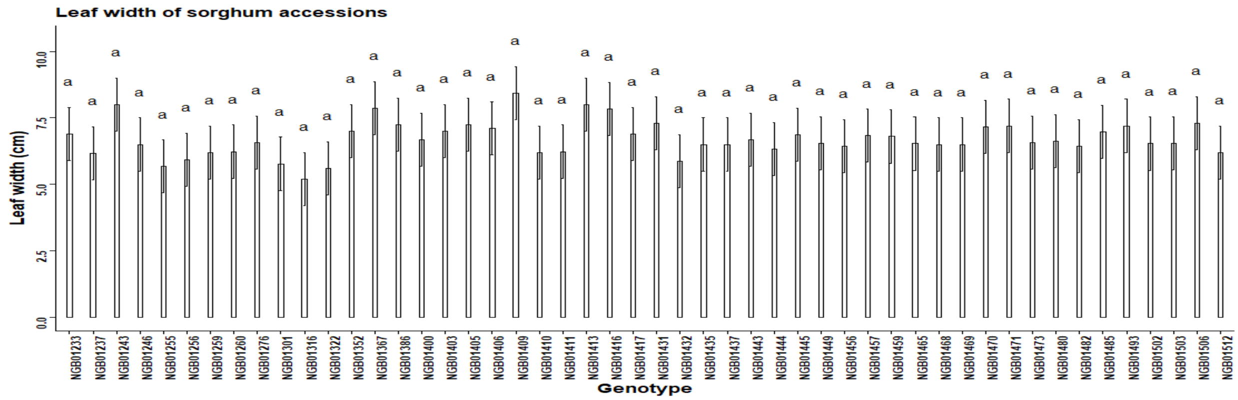

Figure 3: Leaf width of sorghum accessions

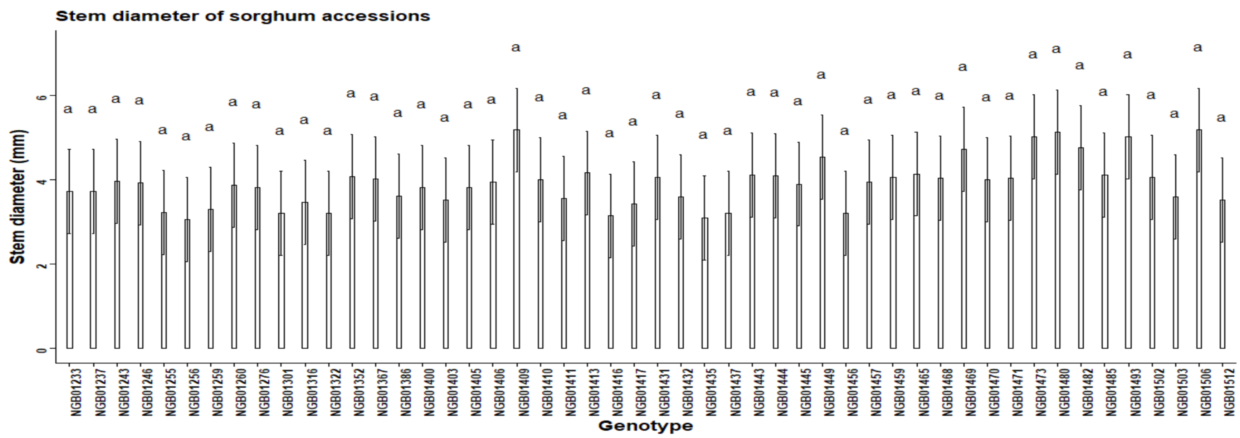

Figure 4: Stem diameter of sorghum accessions

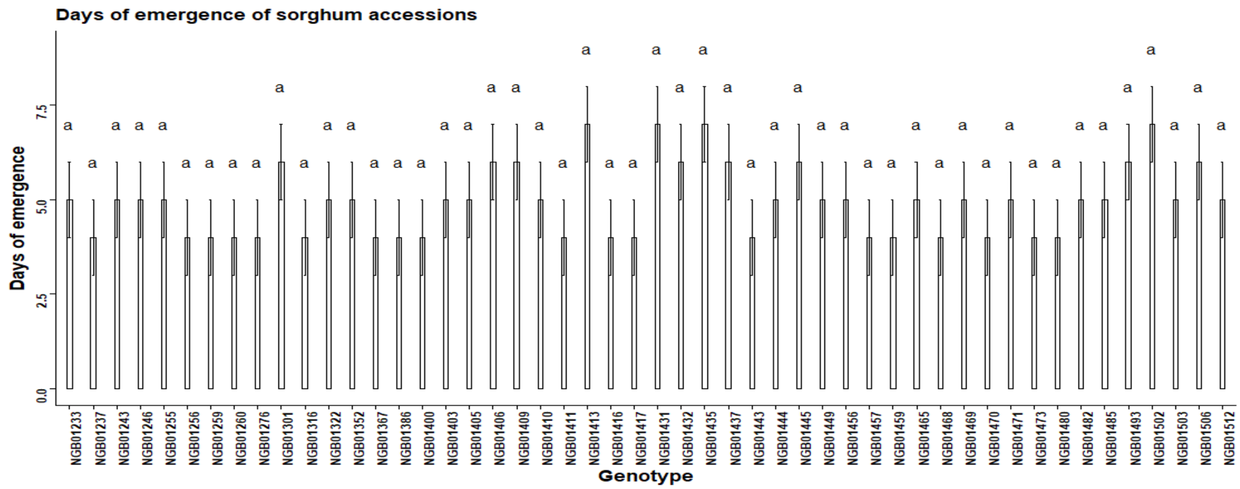

Figure 5: Days of emergence of sorghum accessions

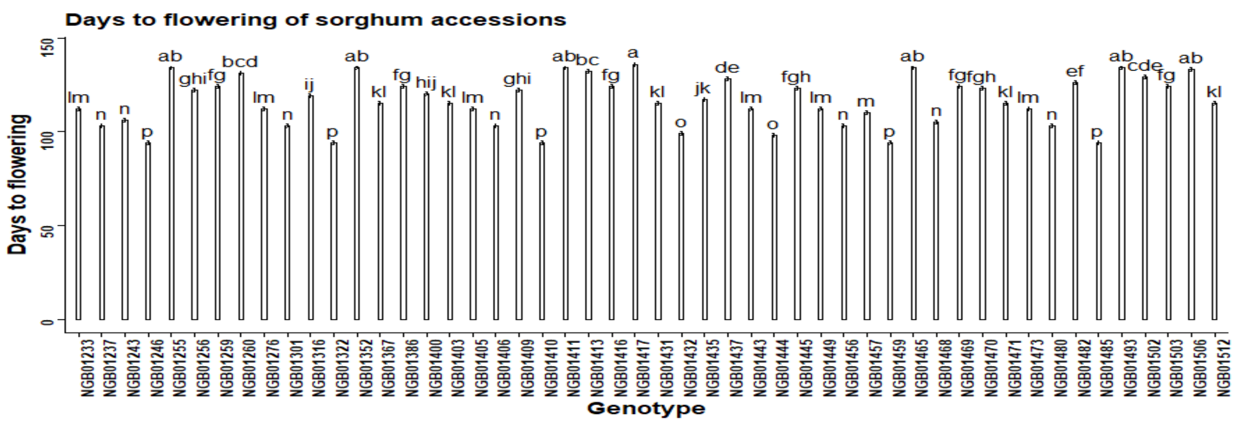

Figure 6: Days to flowering of sorghum accessions

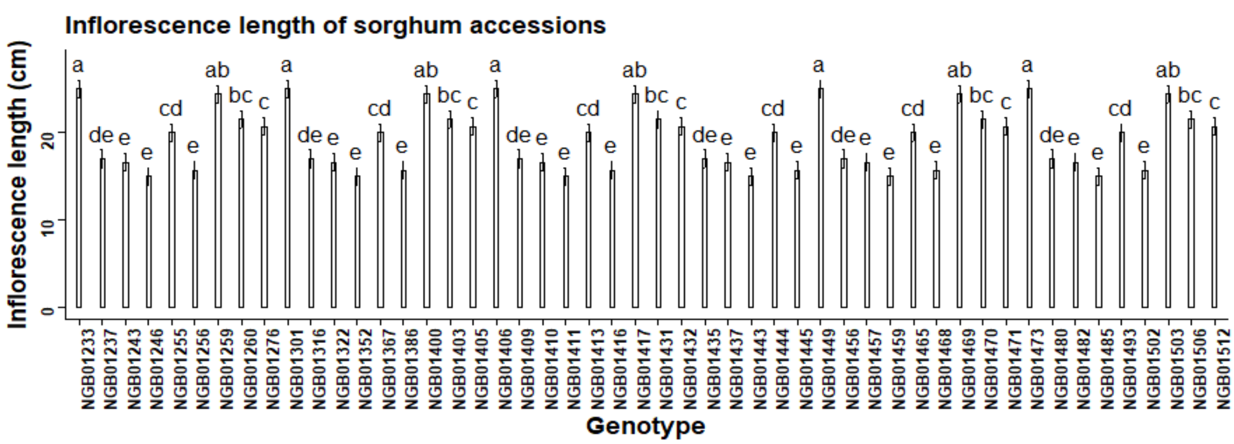

Figure 7: Inflorescence length of sorghum accessions

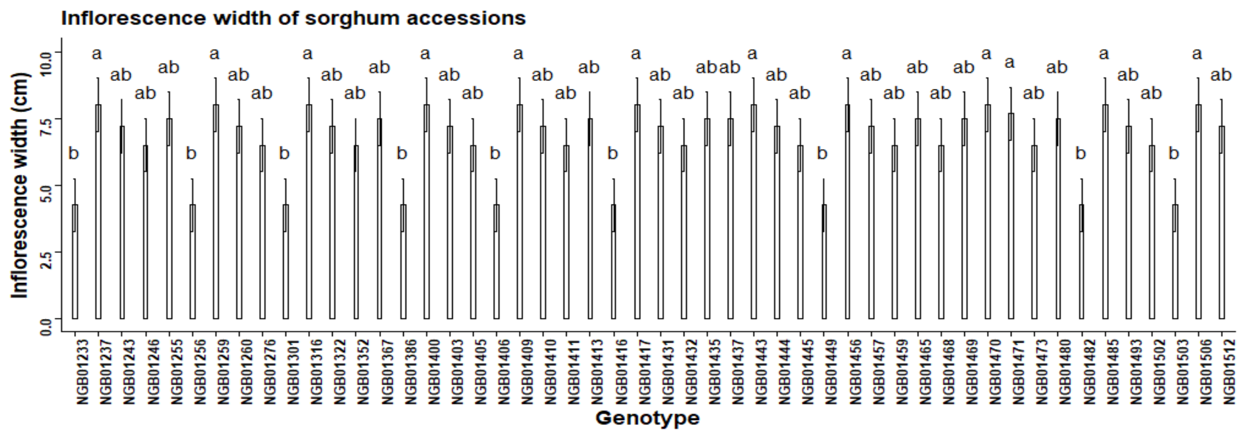

Figure 8: Inflorescence width of sorghum accessions

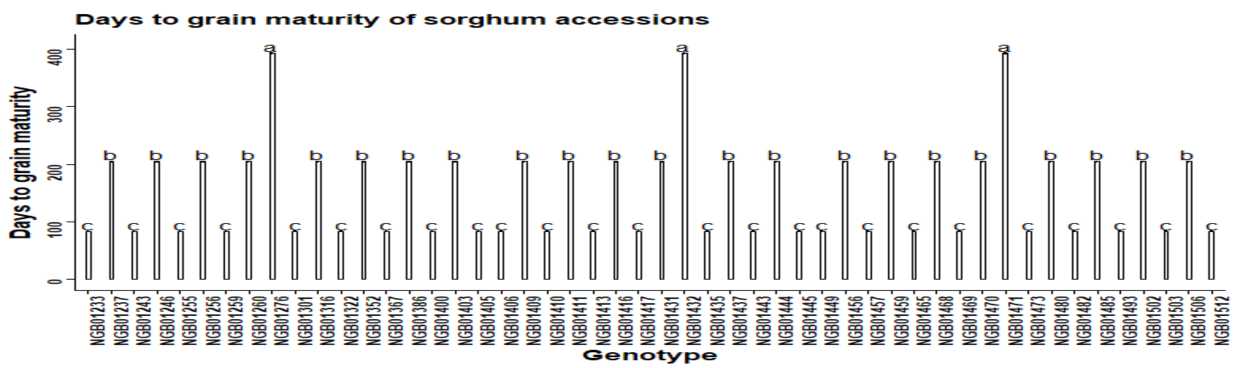

Figure 9: Days to grain maturity of sorghum accessions

Principal components of quantitative growth parameters

The principal component analysis grouped the data for the quantitative morphological parameters into three quadrants with two dimensions (Dim1 and Dim2) (Figure 10). Plant height, number of days to flowering, inflorescence length, and leaf width occupied one quadrant in Dim1, which accounted for 31.0% of the data. Diameter of stem, number of days to emergence, inflorescence width, and leaf length were found in another quadrant in Dim1. Days to grain maturity alone made a quadrant within the Dim2, which had 17.2% variance in the data. This indicates that the data centered around the parameters represented in the highest dimension of 31% in Dim1.

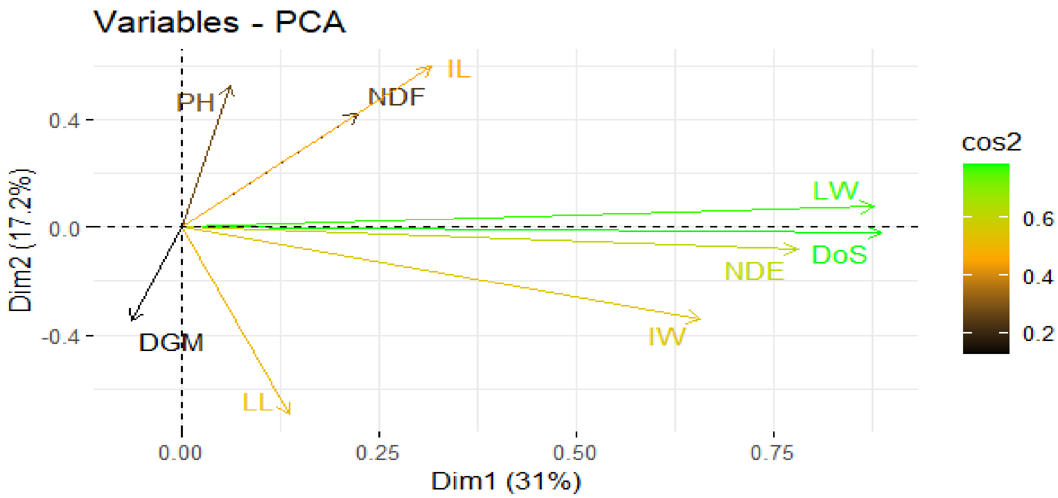

Figure 10: Principal components of morphological traits of sorghum accessions
*ns: non-significant, *: significant at 5% level of probability, PH: plant height, LL: leaf length, LW: leaf width, DOS: diameter of stem, DoS: diameter of stems, NDE: number of days to emerge, NDF: number of days to flowering, IL: inflorescence length, IW: inflorescence width, DGM: days to grain maturity*

Dendogram showing relatedness of sorghum accessions

Clustering of the accessions based on the data for quantitative morphological parameters produced three main clusters (Clusters I, II, and III) as presented in Figure 11. Each of the main clusters had subclusters that eventually branched into grouping of the accessions with similarity in morphology. Therefore, the following accessions clustered together; 9: NGB01276 and 27: NGB01432, 38: NGB01468 and 45: NGB01485, 4: NGB01246 and 21: NGB01410, 2: NGB01237 and 31: NGB01444, 23: NGB01413 and 26: NGB01431, 46: NGB01493 and 49: NGB01506, 16: NGB01400 and 25: NGB01417, 37: NGB01465 and 50: NGB01512, 42: NGB01473 and 43: NGB01480, 30: NGB01443 and 35: NGB01457, 18: NGB01405 and 32: NGB01445, 3: NGB01243 and 14: NGB01367, 17: NGB01403 and 40: NGB01470, 7: NGB01259 and 8: NGB01260, 5: NGB01255 and 11: NGB01316, 28: NGB01435 and 29: NGB01437, 13: NGB01352 and 22: NGB01411, 33: NGB01449 and 48: NGB01503, 15: NGB01386 and 24: NGB01416, 34: NGB01456 and 36: NGB01459. The clustering of these accessions shows that they are more closely related.

The following accessions did not cluster with any other accession; 12: NGB01322, 20: NGB01409, 39: NGB01469, 47: NGB01502, 1: NGB01233, 10: NGB01301, 19: NGB01406, 6: NGB01256, and 41: NGB01471. This means that these accessions are less related to the other accessions.

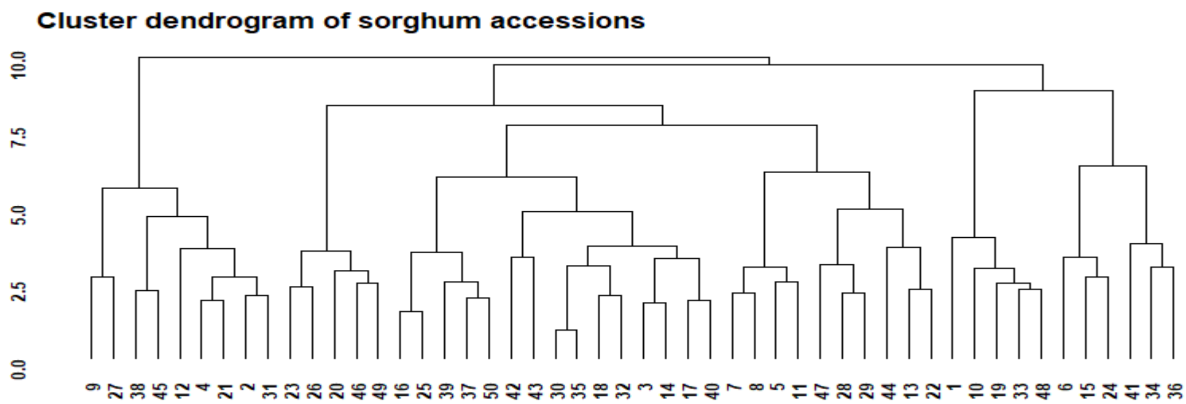

Figure 11: Cluster dendrogram showing relatedness among sorghum accessions

Similarity matrices were computed from quantitative data based on Ward's algorithm (Ward, 1963) Euclidean distance method among the 50 accessions. The similarity matrices were subjected to the hierarchical cluster analysis on the R software. 1: NGB01233; 2: NGB01237; 3: NGB01243; 4: NGB01246; 5: NGB01255; 6: NGB01256; 7: NGB01259; 8: NGB01260; 9: NGB01276; 10: NGB01301; 11: NGB01316; 12: NGB01322; 13: NGB01352; 14: NGB01367: 15: NGB01386; 16: NGB01400; 17: NGB01403; 18: NGB01405; 19: NGB01406; 20: NGB01409; 21: NGB01410; 22: NGB01411; 23: NGB01413; 24: NGB01416; 25: NGB01417; 26: NGB01431; 27: NGB01432; 28: NGB01435; 29: NGB01437; 30: NGB01443; 31: NGB01444; 32: NGB01445; 33: NGB01449; 34: NGB01456; 35: NGB01457; 36: NGB01459; 37: NGB01465; 38: NGB01468; 39: NGB01469; 40: NGB01470; 41: NGB01471; 42: NGB01473; 43: NGB01480; 44: NGB01482; 45: NGB01485; 46: NGB01493; 47: NGB01502; 48: NGB01503; 49: NGB01506; 50: NGB01512

Phenotypic frequency of qualitative characters in sorghum accessions

The data for the qualitative characters of the sorghum accessions are presented in Table 3. The accessions had high to low vegetative seedling vigour with high vegetative seedling vigour having the highest (64%) and low vegetative seedling vigour having the lowest (12%). There was also variation in vegetative lodging susceptibility and vegetative overall plant aspect. The inflorescence exsertion was mostly exserted (64%). The inflorescence compactness shape was majorly Loose erect primary branches (42%) and very loose erect primary branches (40%). The grain covering was 75% grain covered (60%) and 50% grain covered (40%). Awns were present in all the accessions (100%). There was variation in grain colour with some accessions having white (46%), sienna (26%), red (18%), and purple (10%).

The accessions showed variation in vegetative seedling vigour, vegetative lodging susceptibility, vegetative overall plant aspect, inflorescence exsertion, inflorescence compactness shape, grain covering, and grain colour.

Table 2: Phenotypic frequency of qualitative characters in sorghum accessions

Characters	Variation	Frequency count	Percent frequency (%)
Vegetative seedling vigour	Low	6	12.00
	Intermediate	12	24.00
	High	32	64.00
Vegetative lodging susceptibility	Low	10	18.18
	Intermediate	15	27.27
	High	30	54.55
Vegetative overall plant aspect	Poor		
	Medium	11	22.00
	Good	39	78.00
Inflorescence exsertion	Slightly exserted		
	Exserted	32	64.00
	Well-exserted	18	36.00
	Peduncle recurved		
Inflorescence compactness shape	Very lax panicle		
	Very loose erect primary branches	20	40.00
	Very loose drooping primary branches		
	Loose erect primary branches	21	42.00
	Loose drooping primary branches		
	Semi-loose erect primary branches	9	18.00
	Semi-loose drooping primary branches		
Grain covering	25% grain covered		
	50% grain covered	20	40.00
	75% grain covered	30	60.00
	Grain fully covered		
	Glumes longer than grain		
Awns	Absent		
	Present	50	100.00
Grain colour	White	23	46.00
	Sienna	13	26.00
	Mahogany		
	Red	9	18.00
	Purple	5	10.00
	Black		
	Grey		
	Other		
Grain form	Single	50	100.00
	Twin		

Discussion

The occurrence of significant differences in plant height, leaf length, days to flowering, days to grain maturity, inflorescence length, and inflorescence width showed that the sorghum accessions had variability in these growth parameters. These growth parameters are important factors in determining the preferences of stakeholders in sorghum breeding programs. For example, dwarf varieties are usually early-maturing varieties and could suitably be cultivated in areas with shorter growing seasons and intercropped-farming system (Yosef et al., 2009).

This also allows for avoidance of abiotic stressors like flooding and drought as well as biotic stressors within the shorter growing season. In contrast, tall varieties are usually late-maturing varieties and should ideally be bred to be sturdier to abiotic and biotic stressors. Consequently, early-maturing varieties would have shorter leaf length, days to flowering, days to grain maturity, inflorescence length, inflorescence width while late-maturing varieties would have longer leaf length, days to flowering, days to grain maturity, inflorescence length and inflorescence width. Therefore, these parameters will be focused on in the multi-location assessment of genetic variability in the accessions. Studies (for instance, Alade et al., 2022; Andiku et al., 2022; Bankole, et al., 2025) in which quantitative growth parameters have been assessed showed that sorghum accessions have variability in the growth parameters.

The centering of the data around the highest dimension of 31% in Dim1, which consisted of plant height, number of days to flowering, inflorescence length, leaf width, diameter of stem, number of days to emergence, inflorescence width and leaf length, connotes that these growth parameters accounted for a large portion of the variance in the data. Therefore, multi-location assessment of the genetic variability in the sorghum accessions would involve these parameters. Nevertheless, the days to grain maturity, which accounted for 17.2% variance in the data, could also be assessed because it is a yield-related trait.

The pattern of clustering of the sorghum accessions could be used as a basis for selection of accessions in the multi-location assessment of genetic variability. One accession out of each closely-clustered pair could be selected and used in the multi-location assessment. This is because the closely-clustered pair have closely similar growth parameters and they could be represented by one out of the two accessions. This would reduce the overall cost of the multi-location assessment of the genetic variability among the sorghum accessions. Going by this cost-reduction method occasioned by the clustering pattern observed in the dendrogram, 30 sorghum accessions will be used in the multi-location assessment of genetic variability instead of the 50 accessions. Other studies (Gebre et al., 2025; Santhiya et al., 2025) in which dendrogram has been produced have also shown clustering of sorghum accessions based on level of similarity and differences among the accessions.

The observation of variability in vegetative seedling vigour, vegetative lodging susceptibility, vegetative overall plant aspect, inflorescence exsertion, inflorescence compactness shape, grain covering, and grain colour means that the multi-location assessment would focus on these parameters because they might show variation in different locations. These parameters are important agronomic traits to farmers, traders, breeders, and consumers. For example, farmers would prefer varieties with high vegetative seedling vigour, low vegetative lodging susceptibility, and high overall plant aspect.

The observed variability in the qualitative characters of other sorghum accessions has also been reported in other studies (Andiku et al., 2022; Gebre et al., 2025). This affirms the variability in sorghum accessions from different regions. It also establishes that the crop exhibits adaptability to different climatic conditions.

Conclusion

Multi-location assessment of plant materials for level of environmental and genetic influence of traits is a crucial aspect in selecting parental materials for breeding. This task is however time-consuming, costly, and resource-demanding. Therefore, care is usually taken in planning and executing a multi-location assessment in order to minimise cost and resource-expenditure. One known means in which this is done is by carrying out a single-location assessment as a preliminary step in order to narrow down on variable traits. The growth parameters that showed variability in this study include plant height, leaf length, days to flowering, inflorescence length and width, days to grain maturity, vegetative seedling vigour, vegetative lodging susceptibility, vegetative overall plant aspect, inflorescence exsertion, inflorescence compactness shape, and grain covering. Therefore, the multi-location assessment of genetic variability in the sorghum accessions will include these parameters.

Conflict of interest

The authors declare that there was no conflict of interest during the conception of the project and experimentation. There was also no conflict of interest during the manuscript preparation.

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