

Agro-Morphological Diversity and Yield Performance of 21 Sorghum (*Sorghum bicolor* L. Moench) Varieties from Different Agro-Ecological Zones Evaluation in Maradi, Eastern Niger

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How to cite this paper: Mamadou, Y.A., Ousseini, A.A., Ali, H.M., Assane, F.M., Habiboulaye, A.K.M. and Ousmane, Z.M. (2026) Agro-Morphological Diversity and Yield Performance of 21 Sorghum (*Sorghum bicolor* L. Moench) Varieties from Different Agro-Ecological Zones Evaluation in Maradi, Eastern Niger. *Open Journal of Applied Sciences*, 16, 273-287. <https://doi.org/10.4236/ojapps.2026.161017>

Received: December 25, 2025

Accepted: January 18, 2026

Published: January 21, 2026

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Abstract

Sorghum (*Sorghum bicolor* L. Moench) is a major cereal crop well adapted to the harsh environmental conditions of arid and semi-arid regions. In Niger, it ranks as the second most important food crop after pearl millet and plays a crucial role in food security. This study was conducted at the CERRA Maradi Research Station (13°27'72" N latitude and 7°06'54" E longitude) to evaluate the agronomic performance of twenty-one (21) sorghum varieties originating from different agro-ecological zones. The experiment was laid out using a randomized incomplete block design with three replications. Analysis of variance (ANOVA) revealed significant differences among varieties for several agronomic traits, including number of plants emerged, days to 50% flowering, plant height, number of green leaves on the main stem, and biomass production. Both positive and negative correlations were observed among the measured parameters, notably between the number of panicles harvested per plot and panicle dry matter yield, panicle dry matter yield and 1000-grain weight, number of panicles and grain yield, grain yield and biomass weight, midge incidence and number of panicles, as well as between flowering cycle, plant height, and biomass. Ascending Hierarchical Classification (AHC) allowed the identification of high-performing varieties, namely ISRA-S-754-83, 016-SB-BC1F6-11, ISRA-S-754-12, Sepon82, 90SN7, and Témoin 1, characterized by good average yields, intermediate maturity cycles, and tolerance to diseases.

The Saba Nafante variety was identified as the most productive; however, it exhibited susceptibility to diseases. These results highlight the existence of significant genetic variability among sorghum varieties and provide valuable information for selecting adaptable and high-yielding genotypes for sorghum improvement programs in Niger.

Keywords

Sorghum, Adaptability, Agronomic Performance, Agro-Ecological Zones, Maradi

1. Introduction

In semi-arid tropical zones, such as the Sahel, addressing food security through improved agricultural productivity remains a top priority. The food security of populations in this region depends largely on cereal crops [1]. The Sahelian environment, of which Niger is a prime example, is characterized by generally poor soils and low, irregular, and poorly distributed rainfall. Under these challenging conditions, millet (*Pennisetum glaucum* (L.) R. Br.) and sorghum (*Sorghum bicolor* L. Moench) are the crops best adapted to marginal agricultural conditions. These two species account for approximately 95% of national cereal production and form the basis of the population's diet. The importance of sorghum is reflected in particular by the increase in cultivated areas, which rose from 3,564,858 ha in 2013 to over 3,896,900 ha in 2018 [2], although national production remains relatively modest at around one million tons per year. The main production areas are located in the south and west of the country, contiguous with the production zones of northern Nigeria [3]. However, despite its strategic importance, sorghum productivity remains very low in Niger, with average yields of 0.2 to 0.4 t/ha in smallholder farming areas, compared to 2.5 to 3.5 t/ha in research stations [4]. This situation shows that the increase in production observed over the last four decades is essentially linked to the expansion of cultivated areas and not to a real improvement in yields. This low productivity is all the more concerning given that Niger's population has grown from 2.4 million in 1950 to nearly 21 million in 2018, with an annual growth rate of 3.9%, one of the highest in the world [5]. Moreover, the majority of farmers continue to use traditional late-maturing varieties in a context of insufficient and irregular rainfall. However, having a longer growing cycle than millet, sorghum is more susceptible to climatic stresses and pest attacks, which further exacerbates yield losses. With this problem of low productivity, the adoption of resistant, early-maturing and better adapted varieties of sorghum to local agro-ecological conditions appears to be an essential solution to the crop production [4]. The present study was undertaken in order to contribute to the sustainable improvement of sorghum production through the evaluation of the agronomic performance of twenty-one (21) varieties from different agro-ecological zones, the identification of the best adapted varieties to the

edaphic conditions of Maradi, as well as the selection of early and high-yielding varieties.

2. Materials and Methods

2.1. Site Description

The trial was conducted at the CERRA research station in Maradi, located between 13°27'72" North latitude and 7°06'54" East longitude, characterized by annual rainfall between 300 and 500 mm. The experimental site is characterized by sandy to sandy-loam soils, slightly acidic to near neutral in pH, with low organic matter content and generally low inherent fertility.

2.2. Plant Material

This study includes twenty-one (21) lines of sorghum varieties with different maturity cycles and photoperiod sensitivity from different agro-ecological zones of the sub region and (Table 1). In this study, "Témoins 1" corresponds to the

Table 1. List of the 21 varieties evaluated.

Num	Country	Line	Maturity (days)	Photoperiod sensitivity
1	Burkina	ICSB 176003	105 - 110	Medium
2	Burkina	ICSB 176008	105 - 110	Medium
3	Burkina	Kouria	100 - 110	Medium
4	Togo	ABM18-47	105	Not sensitive
5	Togo	ABM18-300-2	105	Not sensitive
6	Togo	ABM18-104	105	Not sensitive
7	Mali	CSM63E	90	Weak
8	Niger	90SN7	95	Not sensitive
9	Sénégal	F2-20	110	Not sensitive
10	Togo	ABM18-300-1	100	Not sensitive
11	Sénégal	ISRA-S-621B	105	Not sensitive
12	Sénégal	ISRA-S-752-38	110	Not sensitive
13	Sénégal	ISRA-S-75-12	110	Not sensitive
14	Sénégal	ISRA-S-75-83	110	Not sensitive
15	Mali	016-SB-BC1F6-11	15 - 140	Weak
16	Mali	SABA NAFANTE	115	Weak
17	Mali	Grinkan	90	Not sensitive
18	Niger	Hakorin Karoua (check)	90	Sensitive
19	Niger	SSD-35	85 - 90	Sensitive
20	Niger	Sepon82	95	Sensitive
21	Niger	Mota Maradi	85 - 90	Sensitive

check variety “Hakorin Karoua”, as listed in **Table 1**. This variety was used as the reference control in all analyses and comparisons.

2.3. Experimental Design

The experimental design used is a randomized incomplete block design with three repetitions. Each repetition consists of comprised three blocks measuring 4 m × 3 m. Each block contained seven (7) varieties, planted in a row of 11 holes. The spacing was 1 m between rows and 0.4 m between holes. The blocks spaced 1 m apart, while replicates spacing between was 2 m.

2.4. Climatic Data of Maradi Region

The experimental season, climatic data recorded at the Maradi station indicate that total annual rainfall was approximately 512.7 mm, with the majority of precipitation received between June and September, Temperature conditions during the experiment period were characterized by high heat, with average daily maximum temperatures frequently exceeding 32°C and average nightly minimum temperatures above 15°C, reflecting the hot semi-arid conditions of Maradi.

2.5. Data Collect and Data Analysis

For data collection, five (5) plants were randomly tagged in the two central rows of each plot to minimize border effects. Plant height was measured at physiological maturity, while the number of green leaves was recorded at the flowering stage. The data obtained were analyzed by the GENSTAT software (version 17). An analysis of variance (ANOVA), followed by Fisher’s exact test at the 5% significance level, was performed to compare means. A principal component analysis (PCA) was then conducted on the mean values obtained from the ANOVA. Correlations between traits were also established. To assess the organization and diversity of the varieties, a hierarchical ascending classification (HAC) was performed based on Euclidean distance, using Ward’s clustering criterion. The groups resulting from the HAC were characterized using correspondence analysis (CA) to identify the most discriminating traits. Finally, a correlation circle was created to visualize the relative performance of each variety.

3. Results

3.1. Variability of Quantitative Parameters

Eleven (11) parameters were observed (**Table 2**) in this study. Traits, such as plant height, number of harvested panicles, panicle dry matter yield, grain mass per plot, grain yield, 100-grain weight, 1000-grain weight, and biomass weight, showed high variability among varieties. Plant height at maturity ranged from 120 to 340 cm with an average of 199.39 cm and a coefficient of variation (CV) of 24.78%.

Flowering dates of varieties were very significant and varied from 53 to 87 days from the earliest to the latest after sowing. The number of panicles harvested per plot, ranging from 5 to 60 panicles, with an average of 20 panicles is the most

variable parameter. The dry matter yield per panicle varies from 0.50 g to 3.50 g, with an average of 1.46 g. The grain mass per plot and the grain yield each have an average of 253.2 g and 843.9 kg/ha, respectively.

The number of emerged clusters and the number of green leaves on the main stem showed little variation between varieties. The average 1000-grain weight was 32.81 g, with a CV of 26.87%, while the average biomass weight was 4.73 g, with a high CV of 66.61%, reflecting considerable variability between varieties for this trait (**Table 2**).

Table 2. Variation of observed quantitative parameters.

Variable	Min	Mean	Max	Standard deviation	Coefficient of variation (%)
50% Flowering (days)	53.00	65.02	87.00	10.00	15.38
Plant height (cm)	120.00	199.39	340.00	49.40	24.78
Number of raised pockets	4.00	6.7895	7.00	0.5586	8.23
Number of panicles harvested/plot	5.00	20.19	60.00	9.78	48.41
Panicle dry matter yield (kg)	0.50	1.4649	3.50	0.6391	43.62
Grain mass/plot (g)	5.0	253.2	876.0	190.0	75.03
Yield (kg/ha)	16.7	843.9	2920.0	633.2	75.03
Weight of 100 grains (g)	2.00	3.281	5.00	0.881	2.687
Weight of 1000 grains (g)	20.00	32.81	50.00	8.81	26.87
Number of green leaves/main stem	6.00	8.49	12.00	1.32	15.60
Weight of biomass (kg)	0.50	4.737	12.40	3.155	66.61

Values in bold have a coefficient of variation > 20%.

3.2. Variability of Qualitative Parameters

The observed frequencies of the qualitative parameter categories are presented in **Table 3**. The varieties exhibited a tendency to lodging ranging from 70.2% to 26.3%. For gray spot disease and heterogeneity, very low frequencies were observed, at 86% and 87.7% respectively. Leaf anthracnose had a low frequency of 49.1% to a medium frequency of 15.8%. Gall midge had a very low frequency of 59.6% to a low frequency of 35.1%. The plant's ability to remain green at maturity was excellent at 38.6% and good at 49.1% (**Table 3**).

3.3. Correlation Analysis between Observed Parameters

A principal component analysis (PCA) was performed on the observed parameters. **Figure 1** shows the correlation between the parameters and dimensions 1 and 2 of the PCA. These dimensions represent 28.05% and 16.55% of the inertia, respectively.

Table 3. Frequencies of observed qualitative parameters.

Parameters	Terms	Frequency	Frequency (%)
LodgInc	Very weak	40	70.2
	Weak	15	26.3
	Medium	2	3.5
FAnthrRes	Very weak	20	31.1
	weak	28	49.1
	Medium	9	15.8
LeafCercos	Very weak	49	86
	Weak	8	14
GCeciInc	Very weak	34	59.6
	Weak	20	35.1
	Medium	3	5.3
StayGreen	Excellent	22	38.6
	Good	28	49.1
	Medium	6	10.5
	Weak	1	1.8
Heterogeneite_Plot	Very weak	50	87.7
	Weak	7	12.3

LodgInc: lodging, FAnthrRes: foliar anthracnose, LeafCercos: grey spot disease, GCeciInc: gall midge, StayGreen: plant's ability to stay green, Heterogeneite_Plot: plot homogeneity.

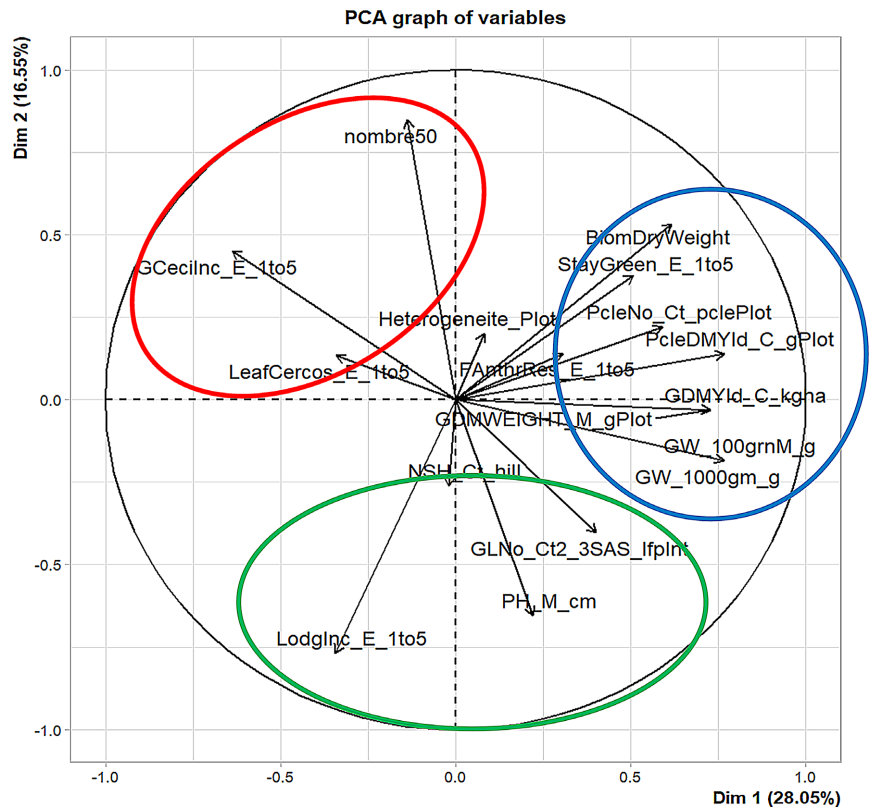


Figure 1. Correlation circle between observed parameters (PCA).

A positive correlation was observed in dimension 1 with the following parameters: biomass weight, number of harvested panicles, basic dry matter yield of panicles, basic dry matter yield of grains, 100-grain weight, 1000-grain weight, and stay green. This means that these parameters are correlated with each other.

The number of days from sowing to 50% flowering is positively correlated with dimension 2. Conversely, the number of green leaves on the main stem and plant height are negatively correlated with the same dimension (**Figure 1**).

Table 4 presents the correlations between the measured parameters and the first five dimensions of the PCA. For dimension 1, a correlation was observed with parameters such as: the number of panicles harvested per plot, basic dry matter yield of the panicle, grain mass, basic dry matter yield of the grains, 100-grain and

Table 4. Correlations between the observed parameters and the first 5 dimensions of PCA.

Parameters	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
NSH_Ct_hill	-0.019	-0.262	-0.773	0.079	-0.220
50% Flowering	-0.138	0.849	0.076	0.193	-0.292
PH_M_(cm)	0.219	-0.653	0.240	0.276	0.142
PcleNo_Ct_pclePlot	0.590	0.221	-0.363	0.201	0.256
PcleDMYld_C_gPlot	0.766	0.139	-0.252	-0.023	0.172
GDMWEIGHT_M_gPlot	0.726	-0.031	-0.065	-0.642	-0.050
GDMYld_C_(kg/ha)	0.727	-0.030	-0.065	-0.642	-0.050
GW_100grnM (g)	0.765	-0.185	0.118	0.312	-0.287
GW_1000gm (g)	0.765	-0.185	0.118	0.312	-0.287
LodgInc	-0.342	-0.769	-0.085	-0.017	0.075
GCeciInc	-0.637	0.451	-0.035	0.131	-0.255
FAnthrRes	0.307	0.140	-0.070	0.299	0.685
LeafCercos	-0.341	0.133	0.011	-0.092	0.453
StayGreen	0.507	0.376	0.301	0.223	0.264
GLNo_Ct2_3SAS_lfplnt	0.401	-0.403	0.382	0.285	-0.206
Heterogeneiye_Plot	0.081	0.201	0.780	-0.302	0.030
BiomDryWeight	0.616	0.532	-0.211	0.118	-0.149

NSH Ct hill: number of raised hills, 50% Flowering: number of days from sowing to 50% flowering, PH M cm: plant height, PcleNo Ct pclePlot: number of panicles harvested per plot, PcleDMYld C gPlot: basic dry matter yield of panicles in g, GDMWeight: grain mass per plot in g, GDMYld kgha: basic dry matter yield of grains in kg/ha, GW_100gmMg: weight of 100 grains in g, GW_1000gm: weight of 1000 grains in g, GLNo_ Ct2_3SAS_lfplnt: number of green leaves on the main stem, BiomDryWeight: dry biomass weight, Lodg-Inc: lodging tendency, FAnthrRes: foliar anthracnose, LeafCercos: gray leaf spot disease, GCeciInc: gall midge, StayGreen: capacity of The plant to remain green, Heterogeneite_Plot: homogeneity of the plots. Values in bold are significant at the 5% threshold.

1000-grain weights, biomass, wheat blossom midge infestation, and Stay Green disease. Similarly, the number of panicles harvested per plot is positively correlated with all other yield-related parameters. Wheat blossom midge infestation is negatively correlated with the number of panicles harvested per plot, basic dry matter yield of the panicle, grain mass, basic dry matter yield of the grains, 100-grain and 1000-grain weights, biomass, and Stay Green disease. This axis can be identified as a yield axis and its components.

For dimension 2, parameters such as the number of days at 50% flowering, plant height, biomass, and lodging tendency are correlated with lodging. However, plant height and lodging tendency are negatively correlated with the number of days at 50% flowering and with biomass. Dimension 3 is correlated with the number of emerged hills and plot heterogeneity. However, these two parameters are negatively correlated with each other. Regarding dimension 4, a negative correlation was observed with grain mass per plot and basic grain dry matter yield; these two parameters are positively correlated with each other. Dimension 5 is correlated only with foliar anthracnose.

Analysis of the Relationships between Varieties, Variety Groups, and Measured Parameters

Figure 2 presents in the factorial plane the relationships between varieties, variety groups and measured parameters. Analysis of this figure along two dimensions reveals following information: the varieties located in the negative part of dimension 1 (Saba Nafante, Sepon 82, ABM18-300-1, ABM18-104, Control 1, 90SN7, ISRA-S-754-12, ISRA-S-754-83, ISRA-S-621B, 016-SB-BC1F6-11) exhibit the highest performance in terms of grain mass per plot and grain yield. However, in the positive portion of dimension 1, there are varieties (CSM63E, Kouria, Mota Maradi, SSD-35) characterized by greater plant height, a higher number of green leaves on the main stem, and a greater tendency to lodging. Varieties such as ICSB 176008, ICSB 176003, Grinkan, F2-20, and ISRA-S-752-38, located in the positive portion of dimension 2, are distinguished by their late maturity, low yield, but good biomass.

Figure 3 presents the correlation circle between varieties and measured parameters. Analysis of **Figure 3** shows that for variety 016-SB-BC1F6-11, the predominant parameters are the 100- and 1000-grain weight and the number of green leaves on the main stem. Variety 90SN7 exhibits tolerance to foliar anthracnose and moderate susceptibility to lodging. Variety ABM18-104 has low biomass and susceptibility to foliar anthracnose. Variety ABM18-300-1 shows high heterogeneity and a very low number of emerged clusters. Variety CSM63E demonstrated good performance in terms of plant height, number of panicles harvested per plot, 1000-grain weight, and stay green. Variety F2-20 was distinguished by the number of green leaves on the main stem and by its biomass. The Grinkan and ICSB 176003 varieties are noted here for their late maturity and damage caused by gall midge. As for the ICSB 176008 variety, it has an acceptable number of panicles harvested per plot. The ISRA-S-621B variety exhibits low biomass and 1000-grain

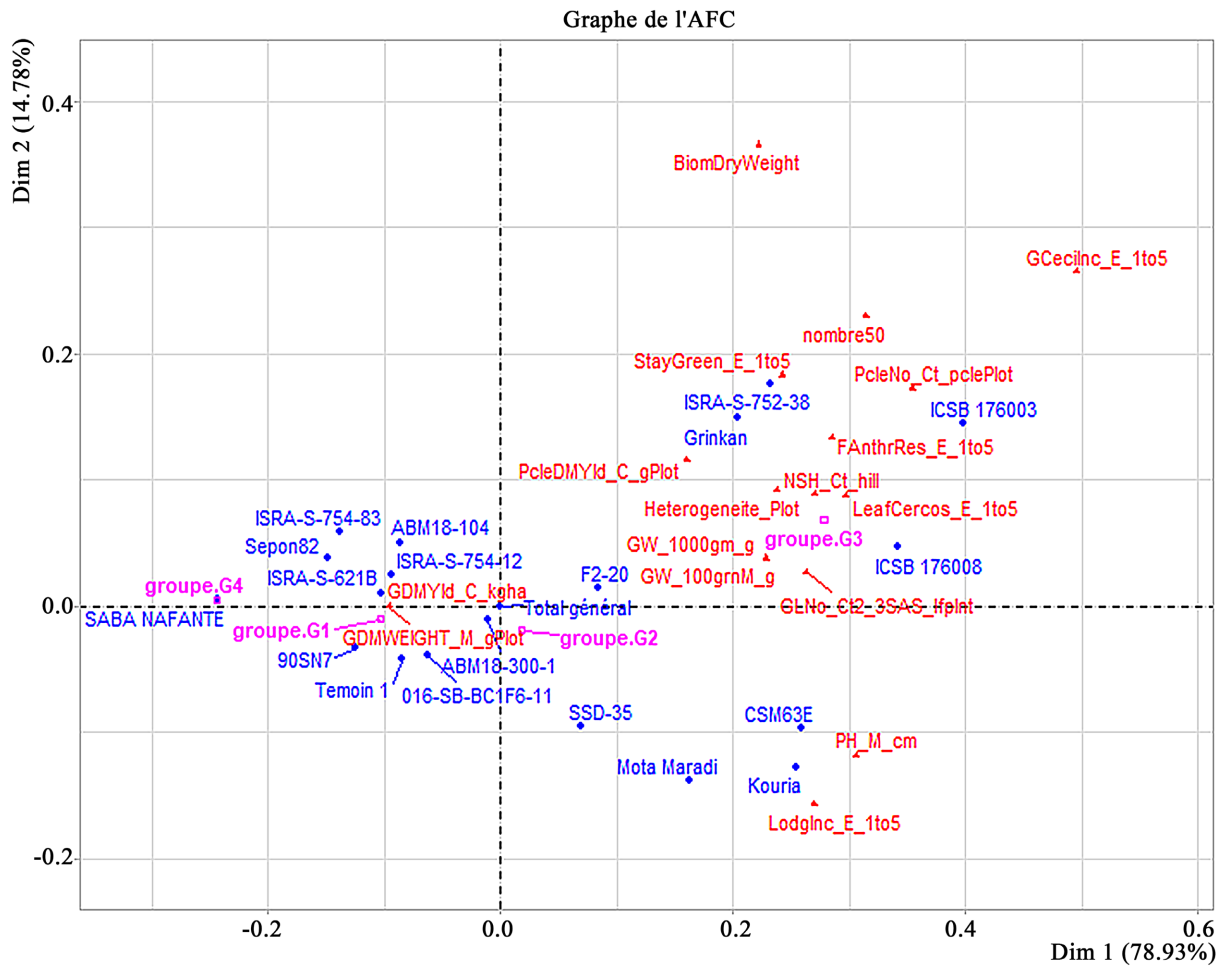


Figure 2. Factorial Correlation Plan (FCP) between varieties, groups of varieties and observed parameters.

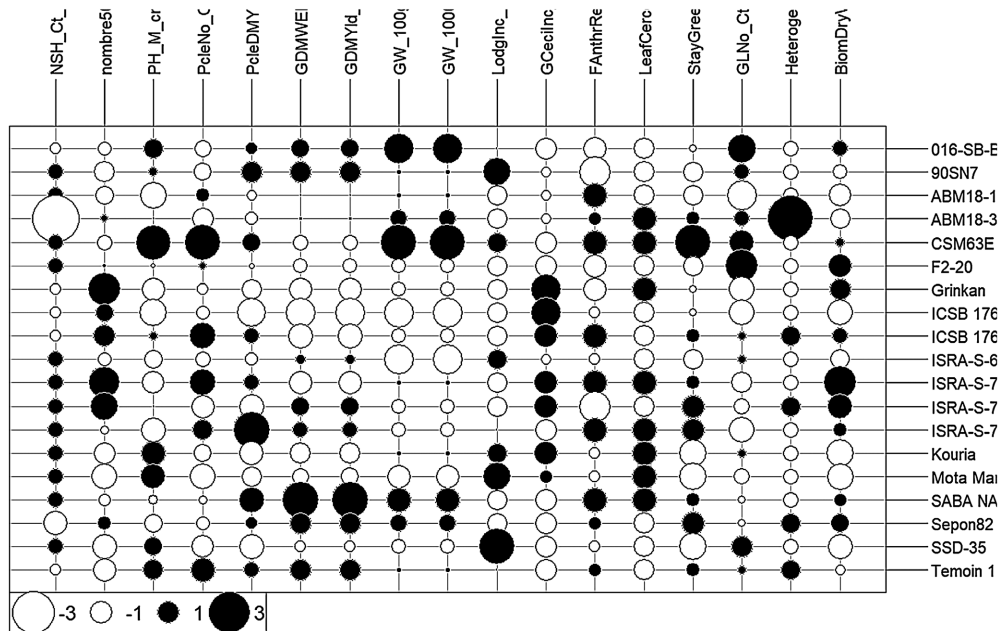


Figure 3. Correspondence circle between varieties and measured parameters.

weight values, but with an average yield. The ISRA-S-752-38 variety has good biomass and a high number of panicles harvested per plot, but is also susceptible to gray leaf spot, leaf anthracnose, and wheat blossom midge. The ISRA-S-754-12 variety is distinguished by a low number of panicles harvested per plot but is resistant to gray leaf spot and leaf anthracnose. The ISRA-S-754-83 variety is identified by its higher panicle dry matter yield. The Kouria and Mota Maradi varieties share the same characteristics. These varieties exhibit a good number of emerging clusters, early maturity, and tall plants, but also susceptibility to gray leaf spot disease and a tendency to lodging. The Saba Nafante variety is the most productive in terms of yield, with an intermediate height, but is susceptible to anthracnose and lodging. The Sepon 82 variety is characterized by an average yield, average biomass, and an average ability to retain its green leaves. The SSD-35 variety is characterized by its early maturity, a high tendency to lodging, and tolerance to gall midge. Finally, the control variety, check 1 (Temoin1), is characterized by early maturity and tolerance to gall midge and gray leaf spot disease.

3.4. Analysis of Variance

The combined analysis of variance in **Table 5** shows a significant difference between varieties for the following parameters: number of emerged seedlings, 50% flowering, plant height, number of green leaves on the main stem, and biomass weight. The other parameters are not statistically different between varieties.

Analysis of variance for the number of emerged hillocks showed a significant difference (**Table 5**). The lowest average number of hillocks was recorded for variety ABM18-300-1 (5.33 hillocks), while the remaining 18 varieties had an average between 6.33 and 7 hillocks.

The 50% flowering date, depending on the variety, was reached between 53 and 84.67 days after sowing (**Table 5**). The earliest variety was Mota Maradi with an average of 53 days, and the latest was Grinkan with an average of 84.67 days. The other varieties had averages between 53 and 84.67 days.

Plant height ranged from 136.67 to 303.30 cm (**Table 5**). The variety with the highest average height was CSM63E, followed by Mota Maradi, Kouria, Control 1, 016-SB-BC1F6-11, and SSD35. The lowest average was recorded for variety ICSB176003. The other varieties had intermediate values.

Regarding the number of green leaves on the main stem, variety F2-20 had the highest average (10.33), varieties 016-SB-BC1F6-11 and SSD35 had 10 and 9.33 leaves, respectively, while ICSB176003 (7.33 leaves) and ABM18-104 (7.00 leaves) had the lowest average (**Table 5**).

The average biomass weight varied between varieties from 1.70 to 9.23 kg (**Table 5**). Variety ISRA-S-752-38 produced the highest biomass (9.23 kg), while Kouria produced the lowest (1.70 kg). Similarly, varieties SABA NAFANTE, ISRA-S-754-12, F2-20, CSM63E, Grinkan, 016-SB-BC1F6-11, and Sepon82 also had lower biomass compared to ISRA-S-752-38. On the other hand, the varieties SSD-35, Mota Maradi, ISRA-S-621B, ABM18-104, 90SN7, Control 1, ICSB 176003, ABM18-300-1

Table 5. Variation of observed parameters according to varieties.

Variété	NSH	Nbr50	H-cm	PcleNo	PcleD	GDMW	GDMYld	GW_100	GW_1000	GLNo	Biom
SSD-35	7.00 ± 0.00 ^a	53.33 ± 0.57 ^j	233.33 ± 5.77 ^{abc}	14.00 ± 5.57 ^A	1.03 ± 0.47 ^a	223.30 ± 137.60 ^a	744.00 ± 459.00 ^A	3.00 ± 1.00 ^a	30.00 ± 10.00 ^a	9.33 ± 0.57 ^{abcd}	2.06 ± 0.46 ^{ef}
SABA NAFANTE	7.00 ± 0.00 ^a	61.66 ± 0.57 ^{ghij}	190.00 ± 17.30 ^{bcd}	19.00 ± 2.00 ^A	1.93 ± 0.51 ^a	498.00 ± 328.00 ^a	1659.00 ± 1093.00 ^a	4.00 ± 1.00 ^a	40.00 ± 10.00 ^a	8.33 ± 1.52 ^{bcdef}	5.70 ± 2.51 ^{abcdef}
Mota Maradi	7.00 ± 0.00 ^a	53.00 ± 0.00 ^j	255.00 ± 5.00 ^{ab}	12.00 ± 6.08 ^A	1.16 ± 0.28 ^a	192.30 ± 87.10 ^a	641.00 ± 290.00 ^A	2.67 ± 0.57 ^a	26.67 ± 5.77 ^a	8.00 ± 1.00 ^{cdef}	1.86 ± 0.80 ^f
Kouria	7.00 ± 0.00 ^a	56.00 ± 0.00 ^{ij}	253.30 ± 22.50 ^{ab}	16.00 ± 11.14 ^A	1.06 ± 0.98 ^a	166.00 ± 230.00 ^a	553.00 ± 766.00 ^A	3.33 ± 1.52 ^a	33.33 ± 15.28 ^a	8.67 ± 0.57 ^{abcdef}	1.70 ± 1.66 ^f
ISRA-S-754-83	7.00 ± 0.00 ^a	63.00 ± 1.73 ^{efghi}	146.67 ± 7.64 ^d	25.67 ± 5.03 ^A	2.33 ± 1.04 ^a	308.00 ± 223.00 ^a	1028.00 ± 743.00 ^A	3.00 ± 0.00 ^a	30.00 ± 0.00 ^a	7.33 ± 0.57 ^{ef}	5.73 ± 1.10 ^{abcdef}
ISRA-S-754-12	7.00 ± 0.00 ^a	80.00 ± 0.00 ^{abc}	200.00 ± 0.00 ^{bcd}	13.33 ± 4.93 ^A	1.03 ± 0.45 ^a	327.00 ± 391.00 ^a	1091.00 ± 1302.00 ^a	3.00 ± 1.00 ^a	30.00 ± 10.00 ^a	8.00 ± 1.73 ^{cdef}	7.53 ± 2.76 ^{ab}
ISRA-S-752-38	7.00 ± 0.00 ^a	83.00 ± 3.46 ^{ab}	155.00 ± 8.66 ^d	29.00 ± 7.94 ^A	1.66 ± 0.28 ^a	150.67 ± 13.65 ^a	502.20 ± 45.50 ^A	3.33 ± 1.15 ^a	33.33 ± 11.55 ^a	7.66 ± 1.15 ^{def}	9.23 ± 2.46 ^a
ISRA-S-621B	7.00 ± 0.00 ^a	61.00 ± 4.36 ^{efghi}	166.70 ± 25.70 ^{cd}	17.00 ± 8.89 ^A	1.33 ± 0.41 ^a	280.00 ± 168.00 ^a	933.00 ± 562.00 ^A	2.33 ± 0.57 ^a	23.33 ± 5.77 ^a	8.67 ± 0.57 ^{abcdef}	3.07 ± 2.35 ^{bcdef}
F2-20	7.00 ± 0.00 ^a	65.66 ± 0.57 ^{defgh}	196.67 ± 16.07 ^{bcd}	21.33 ± 0.57 ^A	1.43 ± 0.51 ^a	209.00 ± 153.00 ^a	697.00 ± 510.00 ^A	3.00 ± 0.00 ^a	30.00 ± 0.00 ^a	10.33 ± 1.52 ^a	7.27 ± 4.66 ^{abc}
CSM63E	7.00 ± 0.00 ^a	60.33 ± 1.15 ^{ghij}	303.30 ± 33.30 ^a	35.70 ± 21.00 ^a	1.73 ± 0.90 ^a	204.70 ± 118.40 ^a	682.00 ± 395.00 ^A	4.67 ± 0.57 ^a	46.67 ± 5.77 ^a	9.67 ± 1.15 ^{abc}	5.23 ± 4.58 ^{abcdef}
ABM18-104	7.00 ± 0.00 ^a	58.33 ± 0.57 ^{ghij}	140.00 ± 8.66 ^d	23.00 ± 6.08 ^A	1.36 ± 0.05 ^a	253.30 ± 80.80 ^a	844.00 ± 269.00 ^A	3.33 ± 0.57 ^a	33.33 ± 5.77 ^a	7.00 ± 1.00 ^f	2.60 ± 1.22 ^{def}
90SN7	7.00 ± 0.00 ^a	56.66 ± 1.15 ^{hij}	210.00 ± 13.23 ^{bcd}	16.00 ± 7.55 ^A	1.80 ± 1.05 ^a	344.00 ± 279.00 ^a	1148.00 ± 931.00 ^A	3.33 ± 0.57 ^a	33.33 ± 5.77 ^a	9.00 ± 2.00 ^{abcde}	3.77 ± 3.96 ^{bcdef}
Témoin 1	6.67 ± 0.57 ^{ab}	54.66 ± 1.15 ^{ij}	238.30 ± 51.10 ^{abc}	28.00 ± 15.52 ^a	1.66 ± 0.61 ^a	346.00 ± 208.00 ^a	1152.00 ± 695.00 ^A	3.33 ± 0.57 ^a	33.33 ± 5.77 ^a	8.67 ± 1.52 ^{abcdef}	4.20 ± 2.52 ^{bcdef}
ICSB 176008	6.67 ± 0.57 ^{ab}	74.67 ± 5.03 ^{bcd}	208.30 ± 63.30 ^{bcd}	29.33 ± 4.93 ^A	1.66 ± 0.28 ^a	138.00 ± 46.80 ^a	460.00 ± 155.90 ^A	3.00 ± 1.00 ^a	30.00 ± 10.00 ^a	8.67 ± 0.57 ^{abcdef}	5.93 ± 2.50 ^{abcdef}
ICSB 176003	6.67 ± 0.57 ^{ab}	72.00 ± 7.94 ^{cde}	136.67 ± 14.43 ^d	17.67 ± 12.50 ^a	0.90 ± 0.36 ^a	91.70 ± 117.20 ^a	307.00 ± 393.00 ^A	2.33 ± 0.57 ^a	23.33 ± 5.77 ^a	7.33 ± 1.52 ^{ef}	1.90 ± 1.15 ^f
Grinkan	6.67 ± 0.57 ^{ab}	84.67 ± 4.04 ^a	151.67 ± 5.77 ^d	18.33 ± 10.50 ^a	1.16 ± 0.76 ^a	149.00 ± 178.00 ^a	498.00 ± 595.00 ^A	3.00 ± 1.00 ^a	30.00 ± 10.00 ^a	7.33 ± 0.57 ^{ef}	6.87 ± 4.30 ^{abcd}
016-SB-BC1F6-11	6.67 ± 0.57 ^{ab}	61.00 ± 1.73 ^{efghi}	235.00 ± 13.23 ^{abc}	16.33 ± 6.03 ^A	1.60 ± 1.01 ^a	327.00 ± 226.00 ^a	1089.00 ± 754.00 ^A	4.33 ± 0.57 ^a	43.33 ± 5.77 ^a	10.00 ± 0.00 ^{ab}	5.97 ± 3.87 ^{abcdef}
Sepon82	6.33 ± 1.15 ^{ab}	69.67 ± 4.04 ^{def}	168.30 ± 27.50 ^{cd}	17.67 ± 4.73 ^A	1.60 ± 0.52 ^a	345.00 ± 223.00 ^a	1149.00 ± 742.00 ^A	3.67 ± 5.15 ^{ab}	36.67 ± 5.77	8.33 ± 1.52 ^{bcdef}	6.43 ± 1.76 ^{abcde}
ABM18-300-1	5.33 ± 1.15 ^b	66.67 ± 2.08 ^{defg}	200.00 ± 30.40 ^{bcd}	14.33 ± 2.08 ^A	1.33 ± 0.30 ^a	257.30 ± 116.70 ^a	858.00 ± 389.00 ^A	3.67 ± 0.57 ^a	36.67 ± 5.77 ^a	9.00 ± 0.00 ^{abcde}	2.93 ± 0.92 ^{cdef}
P-value	0.024 [*]	0.000 [*]	0.000 [*]	0.114 ^{ns}	0.516 ^{ns}	0.738 ^{ns}	0.739 ^{ns}	0.080 ^{ns}	0.080 ^{ns}	0.038 [*]	0.032 [*]

NSH: number of raised planting holes, Nbr50: number of days from sowing to 50% flowering, H-cm: plant height, PcleNo: number of panicles harvested per plot, PcleD: basic dry matter yield of panicles in kg, GDMW: mass of grains per plot in g, GDMYld: basic dry matter yield of grains in kg/ha, GW_100: weight of 100 grains in g, GW_1000: weight of 1000 grains in g, GLNo: number of green leaves on the main stem, Biom: weight of dry biomass.

gave average biomasses ranging from 1.86 to 4.20 kg (**Table 5**).

The number of panicles harvested per plot varied: the CSM63E variety yielded the highest average number of panicles (35.70 panicles), while the Mota Maradi (12 panicles), ISRA-S-754-12 (13.33 panicles), and ABM18-300-1 (14.33 panicles) varieties yielded the lowest number of panicles harvested (**Table 5**).

The ISRA-S-754-83 variety recorded the highest average (2.33 kg) and the ICSB 176003 variety the lowest (0.90 kg) (**Table 5**) of the basic dry matter yield of panicles.

Regarding grain mass per plot and grain yield in kg/ha, the Saba Nafante variety performed best with 498 g and 1659 kg/ha, respectively. Next came the varieties Témoin 1 (346 g and 1152 kg/ha), 90SN7 (344 g and 1148 kg/ha), and ISRA-S-752-12 (327 g and 1091 kg/ha). Meanwhile, the ICSB 176008 and ICSB 176003 varieties performed worst, with 91 g and 307 kg/ha, and 138 g and 460 kg/ha, respectively (**Table 5**).

4. Discussion

The descriptive analysis of the studied parameters revealed high variability (CV > 20%) for several major agronomic traits, including plant height, number of harvested panicles, panicle dry matter yield, grain mass per plot, grain yield, 100-grain weight, 1000-grain weight, and biomass weight. The significant differences observed between minimum and maximum values, together with the high coefficients of variation, indicate the existence of considerable morphological and agronomic diversity among the evaluated varieties. Similar levels of variability were reported by [6] in sweet grain sorghums from northern Burkina Faso. This variability may be related to farmers' seed management practices, where local seed production often occurs in fields hosting multiple cultivars, thereby favoring gene flow and the maintenance of genetic diversity.

Analysis of variance revealed significant differences among varieties for several parameters, including the number of emerged hills, days to 50% flowering, plant height, number of green leaves on the main stem, and biomass. Emergence is an important indicator of seed germination quality. In the present study, the average number of emerged hills ranged from 5.33 to 7, reflecting generally good emergence across all tested varieties.

Flowering time ranged from 53 to 87 days after sowing, indicating that the tested varieties belong to early to intermediate maturity groups. These results are comparable to those reported by [7], who observed flowering periods between 61 and 73 days, but differ from those of [8] who reported later flowering times ranging from 64 to 103 days. The varieties Mota Maradi, SSD35, and Control 1 were among the earliest flowering, while Grinkan and ISRA-S-752-38 were among the latest. These results indicate that certain improved varieties remain later than local cultivars under the conditions of Maradi.

Plant height varied significantly among varieties, ranging from 136.67 to 303.30 cm. ICSB 176003 and ABM18-104 were the shortest varieties, while CSM63E and

Mota Maradi were the tallest. Comparable plant heights were reported by [9]. A significant positive association was observed between plant height and lodging, suggesting that taller plants tend to be more prone to lodging, as also reported by [10] in sesame. Conversely, plant height showed a positive association with panicle size and biomass, which may partly explain the agronomic interest of tall genotypes in traditional production systems.

The number of green leaves on the main stem differed significantly among varieties, with mean values ranging from 7 to 10 leaves. Varieties 016-SB-BC1F6-11 and CSM63E exhibited the highest leaf numbers. These values are lower than those reported by [9], who observed between 17.6 and 18.9 leaves at maturity, possibly due to differences in genetic material or environmental conditions.

The number of panicles per plant, an important trait in sorghum breeding, is closely related to tillering capacity and overall plant architecture [11]. In this study, the average number of panicles per plot was 20.19, which is similar to the findings of [8]. However, despite high panicle numbers in some varieties, grain yield remained relatively low, which may be associated with incomplete panicle development or damage caused by granivorous insects and birds [12].

Panicle dry matter yield showed significant variation among varieties. The highest values were recorded for 016-SB-BC1F6-11, Sepon82, Saba Nafante, 90SN7, ISRA-S-754-83, ISRA-S-752-38, Control 1, CSM63E, and ICSB 176008. The mean panicle yield obtained in this study (1.46 kg) is comparable to that reported by [7] but higher than the value reported by [8].

Biomass yield also differed significantly among varieties, with ISRA-S-752-38, ISRA-S-754-12, and F2-20 exhibiting the highest values. These results are consistent with those reported by [8], who obtained high biomass yields for improved sorghum varieties under similar conditions.

Although no statistically significant differences were observed for grain yield, substantial variability was recorded among varieties. The highest grain yields were obtained with Saba Nafante and Control 1. These values are lower than those reported by Barro (2010) but higher than some results obtained by [8], reflecting the influence of both genetic and environmental factors.

Correlation analysis revealed several agronomically important relationships. A highly significant positive correlation was observed between the number of harvested panicles and panicle dry matter yield, indicating that these traits are positively associated. Panicle dry matter yield also showed a positive association with 1000-grain weight, suggesting that varieties with heavier panicles tend to have heavier grains. These associations are consistent with findings reported by [13] and [14].

In contrast, gall midge incidence exhibited significant negative correlations with several yield-related traits, including number of panicles, grain mass, grain yield, 100-grain weight, and 1000-grain weight, indicating that higher infestation levels are associated with reduced yield performance. A negative correlation between flowering duration and plant height suggests that earliness is not directly

associated with plant size, in contrast to observations reported by [8] and [15]. The positive correlation observed between flowering duration and biomass indicates that late-maturing varieties are generally associated with higher biomass production.

Cluster analysis based on agro-morphological traits grouped the varieties into four distinct categories. The first group, comprising ISRA-S-754-83, 016-SB-BC1F6-11, ISRA-S-754-12, Sepon82, 90SN7, and Control 1, included varieties with favorable agronomic performance. The second group consisted of ISRA-S-621B, ABM18-104, ABM18-300-1, F2-20, SSD35, CSM63E, and Mota Maradi, characterized mainly by strong vegetative vigor. The third group included ICSB176003, Kouria, ICSB176008, Grinkan, and ISRA-S-752-38. The fourth group consisted solely of Saba Nafante, which was distinguished by its high grain yield potential despite its susceptibility to lodging and diseases.

Saba Nafante exhibited the highest grain yield among the evaluated varieties (1659 kg/ha) but showed increased susceptibility to lodging and anthracnose. While its high yield offers potential for improved food security in Maradi, farmers may face yield losses under adverse weather or disease pressure. Adoption should therefore be accompanied by management practices, such as optimized planting density, disease monitoring, and pest control, to balance productivity with stability.

5. Conclusions

Sorghum, a self-pollinating species of great global importance, exhibits significant variability among cultivated varieties. In this context, the present study evaluated the performance of eighteen lines from different agro-ecological zones, as well as a control variety (HK). The results show that only one line stands out with higher productivity than the control and local varieties. Analysis of the measured traits reveals wide agro-morphological variability within the tested material, particularly for qualitative traits, variability attributable to the diverse agro-ecological origins of the lines.

The study also highlights a positive relationship between early growth cycle and biomass production. Significant differences were observed for several traits, including the number of emerged plant clusters, flowering date, plant height, number of green leaves on the main stem, and biomass. Classification based on these traits identified four groups, among which Group 4, consisting solely of the Saba Nafante line, stands out for its high yield potential, despite susceptibility to foliar anthracnose and gray spot disease. Conversely, the varieties in Group 1 (ISRA-S-754-83, 016-SB-BC1F6-11, ISRA-S-754-12, Sepon82, 90SN7, and Control 1) exhibit average yields, an intermediate growth cycle, and appreciable disease tolerance.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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