Genotype x environment Interaction and stability of heading time and grain yield of 12 open pollinated sorghum varieties across different agro-ecological zones in Burkina Faso

ABSTRACT

Sorghum is the most important crop grown in Burkina Faso and is a staple food for millions of people in rural areas. However, sorghum grain production is mainly from local varieties which are low yielding. Introduced exotic varieties were high yielding but low adopted due to bad grain quality for local dishes. Therefore, it is important to popularize new varieties that meet farmer's needs. We assessed the agronomic performance and stability of 12 sorghum varieties in different agro-ecological zones in Burkina Faso. Studies were conducted in one location (Kamboinse research station) during 2022 and in six locations (Farako-Bâ, Kamboinse, Fada, Sabou, Zoula and Andemtenga) during rainy season 2023. Twelve sorghum varieties including checks (Kapelga, ICSV 1049) were evaluated in a randomized complete block design with genotypes as studied factors. Agromorphological parameters along with midge damage and number of Striga plants were collected in all the sites. Genotypes, environments and genotype × environment interactions were significant for heading time and grain yield. The varieties had different heading times and different grain yields within environments and across the six environments. The GGE biplot discriminated the study areas into a unique mega-environment for heading time and three mega-environments for yield potential. The majority of varieties yielded more than the average sorghum yield in sub-Sahara Africa, however low yielding varieties were found in environments affected by biotic and abiotic constraints. Some high yielding varieties (Sariaso 43 = 3960.94 kg/ha, 014-SB-EPDU-1004 = 3681.64kg/ha, Sariaso 42 = 3478,52 kg/ha and Sariaso 39 = 3427.73 Kg/ha) were clearly identified in constraintless mega-environments of Kamboinse and Farako-Ba. In conclusion, the GGE biplot analysis revealed that Sariaso 43 was the best genotype that combined suitable heading time and high grain yield across environments. The best performing genotypes for heading time were Sariaso 39 and PR3009B for grain yield. Identified high yielding varieties will be submitted for released and cultivation in suitable agro climatic areas.

Keywords: Burkina Faso, sorghum, GGE biplot, mega-environment, stability, performance, grain yield

1. INTRODUCTION

Sorghum is the fifth most important crop in the world and is a staple food for millions of people living in the semi-arid tropics of Africa [1]. It ranks first in Burkina Faso in terms of growing area and production [2, 3] and is the main dietary constituent for rural populations [4].It is also used as source of forage for cattle, small ruminants and poultry. It is cultivated all the different climatic zones of the country and its production has been estimated to be 2 100 036 tons on about 2 007,650 ha in 2022 [3].

Despite its importance, its yield remains low in Sub-Saharan countries compared to yield in developed countries. In fact, in Burkina Faso, sorghum yield is less than 1 ton/ha because of some biotic and abiotic constraints that considerably limit sorghum production. Moreover, it has been reported by Zongo [5], Barro/Kodombo [6], Ouedraogo *et al.* [7] and Compaore *et al.* [8] that Sorghum production is mainly from landraces (around 70%) and only 30% is from improved varieties. Unfortunately, local landraces are low yielding compared to improved varieties [5,6].

To solve this problem, local NARS (INERA) along with CGIARs (ICRISAT and CIMMYT) have developed and released a number of improved Sorghum varieties that meet farmer's needs. Since 2017, INERA has evaluated 75 fixed lines provided by ICRISAT. Twenty lines were retained and evaluated across three sites (Farako-Ba, Fada, and Kamboinse) during two years (2019 and 2020)[9] and among them10 were chosen to conduct multi locations trials and participatory evaluations in research stations and in farmers field conditions. Three others sites (Andemtenga, Sabou, and Zoula) were added to the three research stations (Farako-Ba, Fada, and Kamboinse) for this purpose. The objectives of this study were to (i) evaluate grain yield performance across sites in Burkina Faso, (ii) assess the presence of GEI using GGE biplot analysis, and (iii) identify high yielding and stable sorghum varieties with potential for commercialization.

2. MATERIAL AND METHODS

2.1 Study locations

The field studies were conducted in one location (Kamboinse) in 2022 and in six locations: three research stations (Farako-Bâ, Kamboinse, and Fada) of the Institute of Environment and Agricultural research (INERA) and in three farmer's field (Sabou, Zoula, and Andemtenga) during 2023 rainy season. The research stations were chosen based on an increasing rainfall gradient from North to South. Farako-Bâ is located in the sudanian climatic zone; Kamboinse is located in the centre of the transition zone (sudano-sahelian), and fada is located in Eastern part of the transition zone. Farmers' fields were located in Sabou, Zoula, and Andemtenga in the Sudano-sahelian zones with rainfall ranging from 700 mm to 900 mm. These sites were used for participatory varieties selection. Details about sites are shown in table 1.

Table 1.Sites geographical coordinates, rainfall, and planting data

Site	Rainfall (mm)	Planting date	Longitude	Latitude	Post flowering drought	Biotic and /abiotic
Kamboinse	737.4	07/07/2023	1°32' E	12° 28' N	<10 days	-
Andemtenga	703.0	09/07/2023	0°31' E	12° 32' N	<10 days	Midge and striga
Sabou	677.6	11/07/2023	2°28' E	12° 06' N	>14 days	-
Zoula	785.0	15/07/2023	2°46' E	12° 25' N	<10 days	-
Fada	797.1	21/07/2023	0°17' E	11°56' N	<10 days	Midge
Farako-Ba	1165.0	25/07/2023	04°20'	11°06' N	<10 days	-

2.2 Plant materials

Twelve sorghum lines including checks (Kapelga and ICSV 1049) were evaluated in the six different locations. Most (8) of the lines where from guinea race except ICSV 1049 and PR3009B were Caudatum and 014-SB-EPDU-1004 and 12B were Caudatum-Guinea).Table 2 summarizes the lines status.

Table 2. List of genotypes involved in the evaluation

Genotypes	Line race	Line status
014-SB-EPDU-1004	Caudatum-Guinea	Tested line
12B	Caudatum-Guinea	Tested line
ICSV1049	Caudatum	Check
Kapelga	Guinea	Check
Kouria	Guinea	Tested line
PR3009B	Caudatum	Tested line
Sariaso 38	Guinea	Tested line
Sariaso 39	Guinea	Tested line
Sariaso 40	Guinea	Tested line
Sariaso 41	Guinea	Tested line
Sariaso 42	Guinea	Tested line
Sariaso 43	Guinea	Tested line

2.3 Experimental design

Experimental design was a randomized complete block with genotypes as studied factors, four replications with the twenty lines. At each location, plot area was 12.8 m^2, including four rows of 4 m length. Distance between rows was 0.8 m and 0.4 m between hills on each row with a total of 10 hills per row. Between 4 and 8 seeds were sown by hand in each hill, in 3-cm deep holes in all four locations. Seeds were sown only after receiving at least 20 mm rainfall. Two weeks after sowing, plants were thinned to two plants per hill.

2.4 Crop management

Fifteen days after planting, the field was hand weeded and NPK fertilizer was applied at a rate of 100 kg/ha. Fifteen days later, the field was hand weeded again and urea (46%) was applied at a rate of 25 kg/ha. The last dose of urea was applied 45 days after planting and trial was hilling to avoid lodging.

2.5 Data collection

Data collected included days to 50% heading (HD), plant height (PH),number of Striga per plant (N Striga), midge damage (MD), and grain yield (GY). Grain yield was measured in kilograms per hectare adjusted to grain moisture content at 12%. Days to 50% heading was recorded by counting the number of days from planting to when 50% of the plants in a plot headed. Striga number was counted within 50 cm radius around the sorghum plants of each genotype. Midge damage was a visual assessment (scoring from 1-9) as loss of grain yield in five panicles expressed as a percentage (1: 1-10% of yield loss; 2:11-20% of yield loss; 3: 21-30% of yield loss; 4: 31-40% of yield loss; 5: 41-50% of yield loss; 6: 51-60% of yield loss; 7: 61- 70% of yield loss; 8: 71-80% of yield loss; 9: > 80% of yield loss). Plant height (cm) was measured.

2.6 Data analysis

Analysis of the effect of location, genotypes, and their interactions on variables was computed with SAS 9.1 software. Means were calculated and GGE biplot analyses in GenStat version 12 were performed to identify high yielding and suitable lines for grain yield across three different environments.

3.RESULTS AND DISCUSSION

3.1 Result

3.1.1 Analysis of variance of studied parameters

Analysis of variance (ANOVA) across environments (sites) and genotypes by environments were highly significant ($P< 0.001$) for all traits [heading time (HD), plant height (PH), number of striga (N Striga), midge damage (MD) and grain yield (GY)]. For genotypes, the ANOVA was highly significant ($P< 0.001$) for heading time (HD), plant height (PH) and grain yield (GY), but significantly different at 5% level for two traits (number of Striga and midge damage (MD). Only midge damage was not significantly different across sites at 5% level. The results of factors interaction showed that genotypes by environment (sites) was highly significant ($P< 0.001$) for all traits except midge damage. The result also revealed coefficient of variation for number of Striga (CV=126.48), for midge damage (CV=74.50) and for grain yield (CV=42.59) (Table 3).

Table 3.Mean square of site, genotype, and genotype by site analysis for studied traits

Sources	df	HD	PH	N Striga	MD	GY
Env	5	1256.85***	84639.22***	5347492.60***	134.59***	25507485.70***
Rep	3	5.88ns	1203.82ns	176294.62ns	3.67ns	1596633.20*
Geno	11	511.34***	59441.09***	71659.32**	9.29**	1858325.00***
Geno*Env	55	62.32***	2773.19***	71677.96***	5.07ns	1253242.30***
Error		2481.88	262705.44	6344386.38	4.43	493400.70
Valeur F (Geno)		43.88	48.19	2.41	2.09	3.77
CV		4.64	16.80	12648	74.50	42.59
Pr > F (Geno)		<.0001	<.0001	0.01	0.02	<.0001

Env: Environment; ANDTGA: Andemtenga; FKB: Farako-Ba; KBS: Kamboinse; Rep: repetition; CV: Coefficient of variation; Geno: genotypes; HD: Heading time; PH: Plant height; MD: midge damage: GY: Grain yield; ns: non-significant; *: significant; ***: highly significant

3.1.2 Descriptive analysis of studied parameters

Heading time varied slightly from one site to another. Overall, genotypes headed around 75±3 days after sowing (DAS). At Andemtenga, 50% heading was observed in 75.40 das, but the early genotype headed at 63 das and the late one headed at 86 das. Genotypes headed earlier at Farako-Ba (63.38 das) and later at Kamboinse (77.40 das). In others sites (Fada, Zoula, and Sabou) varieties headedat almost the same time (around 75±1 das). The earlier material headed at 53 das at Farako-Ba and later ones headed at 90 das at Zoula. For Striga infestation, Andemtenga had the highest number of Striga counted per sorghum plant. The maximum of Striga number counted was 211.00 and the minimum counted was 125.00 with a mean of 117.77. In other sites, Striga weeds were almost not present. For biotic stress such as midge, damage was higherin three sites (Kamboinse, Andemtenga, and Fada) than the other sites. In those sites, damage ranged from 1 to 9 and ranged from 1 to 5 at Zoula. In contrast, there was no midge yield damage recorded at Saou and Farako-Ba. For grain yield, genotypes performed well in two sites, Kamboinse and Zoula, where grain yield reached 2636.39 kg/ha and 2251.24 kg/ha, respectively. In three sites, grain yield ranged between 1000 kg/ha and 2000 kg/ha. Only at Fada did genotypes recorded less than 1000 kg/ha. Individual genotype yielded 7007.81 kg/ha at Kamboinse, 4490.00 kg/ha Farako-Ba, 4087.89 kg/ha at Fada, 3984.38 kg/ha at Zoula. The lowest yield was observed at Andemtenga. Yield ranged from 78.13 kg/ha (Fada) to 610.00 kg/ha (Farako-Ba) (Table 4).

Table 4. Descriptive analysis of studied varieties

Var / Env	Trait	Mean	Standard D	Min	Max	CV	Heritability
ANDTGA	**HD**	75.40	7.94	63.00	86.00	0.82	1.00
	N Striga	117.77	96.88	125.00	211.00	41.54	0.74

	MD	4,96	3.88	0.00	9.00	78.30	0.10
	GY	887.04	603.46	78.13	2421.88	50.41	0.75
Fada	**HD**	74.31	6.26	59.00	85.00	7.41	0.59
	N Striga	0.96	0.20	0.00	1.00	20.60	0.00
	MD	4.08	2.14	1.00	9.00	46.47	0.57
	GY	1054.94	792.85	147.27	4087.89	69.49	0.46
FKB	**HD**	63.38	5.28	53.00	72.00	3.18	0.96
	GY	1956.04	938.40	610.00	4490.00	37.73	0.73
KBS	**HD**	77.40	7.94	65.00	88.00	0.80	1.00
	MD	3.73	2.80	0.00	9.00	70.81	0.24
	GY	2636.39	1299.61	304.69	7007.81	42.81	0.61
SABOU	**HD**	75.38	4.54	68.00	86.00	2.87	0.93
	GY	1108.97	379.50	222.66	1945.31	29.65	0.46
ZOULA	**HD**	75.85	5.67	64.00	90.00	7.07	0.39
	MD	2.19	1.00	1.00	5.00	44.22	0.31
	GY	2251.24	730.12	234.38	3984.38	26.55	0.68

Env: Environment; Var; Variable; ANDTGA: Andemtenga; FKB: Farako-Ba; KBS: Kamboinse; HD: Heading time; PH: Plant height; MD: midge damage: GY: Grain yield; Min: Minimum; Max: Maximum: CV: Coefficient of Variation;

3.1.3 Heading time and performances of Sorghum varieties across environments

Heading time and yield performances of varieties across six environments are presented in Table 5.The mean heading time ranged from 53.5 das (Kouria) to 87.75 das (Sariaso 43). Overall, varieties headed earlier at Farako-Ba than in other sites. For instance, 014-SB-EPDU-1004 headed 70.5 das at Farako-Ba while it headed 76.5 das at Fada, 77 das at Zoula, 83.75 das at Sabou, 85 das at Andemtenga et finally 87 das at Kamboinse. At Andemtenga, only two varieties (Kouria =63.75 das and PR3009B= 65 das) headed earlier than the checks (Kapelga =69 das and ICSV 1049=71 das). Sariaso 38 had the same heading time (69 das) with Kapelga and the remaining (12B, Sariaso 39, Sariaso 40, Sariaso 41, Sariaso 42, Sariaso 43) headed later. Kouria headed earlier than all varieties including the checks in all studied sites, in contrast,PR3009B that headed later at Farako-Ba (69.25 das) and Sabou (74.25 das) than the two checks.

Comparing heading time across sites, only three varieties, including one check, (Kapelga=69 das, PR3009B=65das, and Sariaso 38=69das) headed before 70 das, Three other varieties, including the second check,(12B=74.5 das; ICSV1049=71 das; Sariaso 39=72.25 das) headed between 70 das and 80 dasand the last group of five varieties (014-SB-EPDU-1004=85 das, Sariaso 40=83.5 das, Sariaso 41=83.25das, Sariaso 42=82.75 das and Sariaso 43=85.75 das) headed beyond 80 das at Andemtenga. At Fada, two varieties Kouria=67.75 das, PR3009B =68.75 das) headed before 70 das and only one (Sariaso 39=81.25 das) headed beyond 80 das while the majority (014-SB-EPDU-1004=76.5 das, 12B=78.25 das, ICSV1049=72.75 das, Kapelga=70.5 das, Sariaso 38=74.75 das, Sariaso 40=75.5 das, Sariaso 41= 71.25 das, Sariaso 42=75.25 das and Sariaso 43=79.25 das) headed between 70 das and 80 das. At Farako-Ba, except for 014-SB-EPDU-1004, which headed at 70.5 das, all the remaining varieties including the two checks headed before70 das.

At Sabou and Zoula, varieties varied by only a few days (das ±3) except for 014-SB-EPDU-1004, 12B and Kapelga which were considerably different, respectively, das ± 6, das ± 4 and das ± 5. At Kamboinse, all the varieties headed later thanin other sites.

Yield performance of the 12 varieties across six sites is presented in Table 5. The overall mean yield across the six (6) sites for the 12 varieties ranged from 175.78 kg/ha to 3960.94 kg/ha. The highest yield was obtained at Kamboinsé by Sariaso 43 with a yield of 3960.94 kg/ha and the lowest yield was obtained at Andemtenga by Sariaso 43 with a yield of 175.78 kg/ha. Overall, the varieties yielded better at Kamboinsé than the other sites and all varieties yielded more than 1kg/ha. The low yielding variety in this site was Kapelga with 1269.53kg/ha. Three other varieties (Kouria = 1929.69 kg/ha, PR3009B=1574.22 kg/ha, and Sariaso 38=1650.39 kg/ha) yielded below 2000 kg/ha. Four varieties including, one check, (12B=2615.23 kg/ha, ICSV1049=2513.67 kg/ha, Sariaso 40= 2792.97 kg/ha and Sariaso 41= 2742.19 kg/ha) yielded between 2000 kg/ha and 3000 kg/ha. Three varieties (014-SB-EPDU-1004=3681.64 kg/ha, Sariaso 39= 3427.73 kg/ha and Sariaso 43= 3960.94 kg/ha) yielded more than 3000 kg/ha with Sariaso 43 yielding 3960.94 kg/ha. The lowest yields (< 1000.00 kg/ha) were recorded at Andemtenga (seven varieties: 014-SB-EPDU-1004= 493.75 kg/ha, 12B= 937.5 kg/ha,PR3009B=742.19 kg/ha, Sariaso 40= 644.53 kg/ha, Sariaso 41= 488.28 kg/ha, Sariaso 42= 566.41k g/ha and Sariaso 43=175.78 kg/ha), at Sabou (six varieties: 014-SB-EPDU-1004= 927.73 kg/ha, 12B= 961.91 kg/ha, ICSV 1049= 923.83 kg/ha, PR3009B= 879.88 kg/ha , Sariaso 38= 940.43 kg/ha and Sariaso 43= 995.12 kg/ha) and at Fada (five varieties: 014-SB-EPDU-1004= 616.99 kg/ha, 12B= 503.75 kg/ha,Sariaso 38= 784.57 kg/ha, Sariaso39= 352.68 kg/ha and Sariaso 43= 619.28 kg/ha). Zoula was the second site after Kamboinse for varieties performing well following by Farako-Ba. The bold and underlined mean yields are for those varieties with higher or lower yield in the comments.

Table 5. Means of studied variables over different evaluation site

Env	ANDTGA		Fada		FKB		KBS		SABOU		ZOULA	
Genotypes	HD	GY	HD	GY	HD	GY	HD	GY	HD	GY	HD	GY
014-SB-EPDU-1004	85	**493.75**	76.5	**616.99**	70.5	2507.5	87	**3681.64**	83.75	**927.73**	77	2050.78
12B	74.5	**937.5**	78.25	**503.75**	68.25	**940**	76.5	2615.23	75	**961.91**	79.5	1972.66
ICSV1049	71	1166.41	72.75	1589.45	63.5	1775	73	2513.67	71.5	**923.83**	73.25	2421.88
Kapelga	69	1523.44	70.5	1106.78	56.25	1457.5	71	1269.53	71.75	1388.67	76	1972.66
Kouria	63.75	1347.66	67.75	1515.06	53.5	2215	65.75	1929.69	71.25	1261.72	71.25	2207.03
PR3009B	65	**742.19**	68.75	1170.25	69.25	1012.5	67	1574.22	74.25	**879.88**	71.5	1640.63
Sariaso 38	69	1035.16	74.75	**784.57**	60.75	2035	71	1650.39	72.75	**940.43**	72.5	2363.28
Sariaso 39	72.25	1523.44	81.25	**352.68**	65.75	1662.5	74.25	**3427.73**	76.25	1203.13	79.5	2519.53
Sariaso 40	83.5	**644.53**	75.5	1454.12	64.75	**3102.5**	85.5	2792.97	75.75	1591.80	76.25	**3066.41**
Sariaso 41	83.25	**488.28**	71.25	1925.88	59.25	2790	85.25	2742.19	74	1164.06	74	**3030.47**
Sariaso 42	82.75	**566.41**	75.25	1020.45	64	1422.5	84.75	**3478.52**	75.75	1069.34	78	1269.53
Sariaso 43	85.75	**175.78**	79.25	**619.28**	64.75	2552.5	87.75	**3960.94**	82.5	**995.12**	81.5	2500.00
Heritability	0.999	0.749	0.59	0.46	0.96	0.73	0.999	0.61	0.93	0.46	0.39	0.68
P value	0	0.001	0.02	0.08	0	0	0	0.02	0.00	0.08	0.13	0.00

Env: Environment; ANDTGA: Andemtenga; FKB: Farako-Ba; KBS: Kamboinse; HD: Heading time; GY: Grain yield

3.1.4 Identification of Mega-environments

The polygon view of the genotypes in the GGE biplot for 12 sorghum varieties is presented in Fig. 1. For heading time, primary (PC1) and secondary (PC2) scores were significant and explained 51.41% and 24.25% of the variation, respectively, and together they explained 75.66% of the genotype main effect and G × E interaction. For grain yield, primary (PC1) and secondary (PC2) scores were significant and explained 65.71% and 18.60% of the variation, respectively, and together they explained 84.31% of the genotype main effect and G × E interaction. The polygons view of a GGE biplot displayed the “which-won-where” pattern and mega environment differentiation from the genotype by environment interactions and gives a precise summary of the G × E pattern on a multi environment trial. The polygons in Fig. 1a and 1b are formed by the connection of genotypes that are far away from the biplot origin such that all the remaining genotypes are contained in the polygon.

For heading time, the biplot (Fig. 1a) was composed of one mega-environments and four sectors with the early, intermediate and late maturing genotypes (12B, Sariaso 39, Sariaso 42, and Kouria) located on the vertices of the polygon. This mega-environment contained all the locations (Andemtenga, kamboinse, Fada, Farako-Ba, Sabou, and Zoula) located in sudano-sahelian climatic zone with almost the same rainfall amount except Farako-Ba which is located in sudanian climatic area. Andemtenga was a sub-environment included in the mega-environment and was comprised of intermediate maturing genotypes. This sub-environment was characterized by serious drought at the end of rainy season.

For grain yield, the biplot (Fig. 1b) was divided into three mega-environments and six sectors with the poorest and/or best genotypes (12B, ICSV 1049, Sariaso 38, PR3009B, Sariaso 39 and 014-SB-EPDU-1004) located on the vertices of the polygon. The first mega-environment included only Zoula which is a medium yielding environment and where Sariaso 40 (3066.41 kg/ha) was the highest yielding genotype. The second mega-environment included Andemtenga and Sabou which are low yielding environments with Sariaso 43 (175.78 kg/ha) and 12B (352.68 kg/ha) as low yielding genotypes. The third mega-environment included Fada, Farako-Ba and Kamboinse which are all research stations. In these mega-environments, kamboinse was a high yielding location with Sariaso 43 (3960.94 kg/ha) as the highest yielding genotype, Farako-Ba was a medium yielding location with Sariaso 40 (3102.5 kg/ha) as highest yielding genotype whereas Fada was the low yielding environment with Kapelga (1523.44 kg/ha)and Sariaso 39 (1523.44 kg/ha). It is important to notice that Fada is a midge hotspot site.

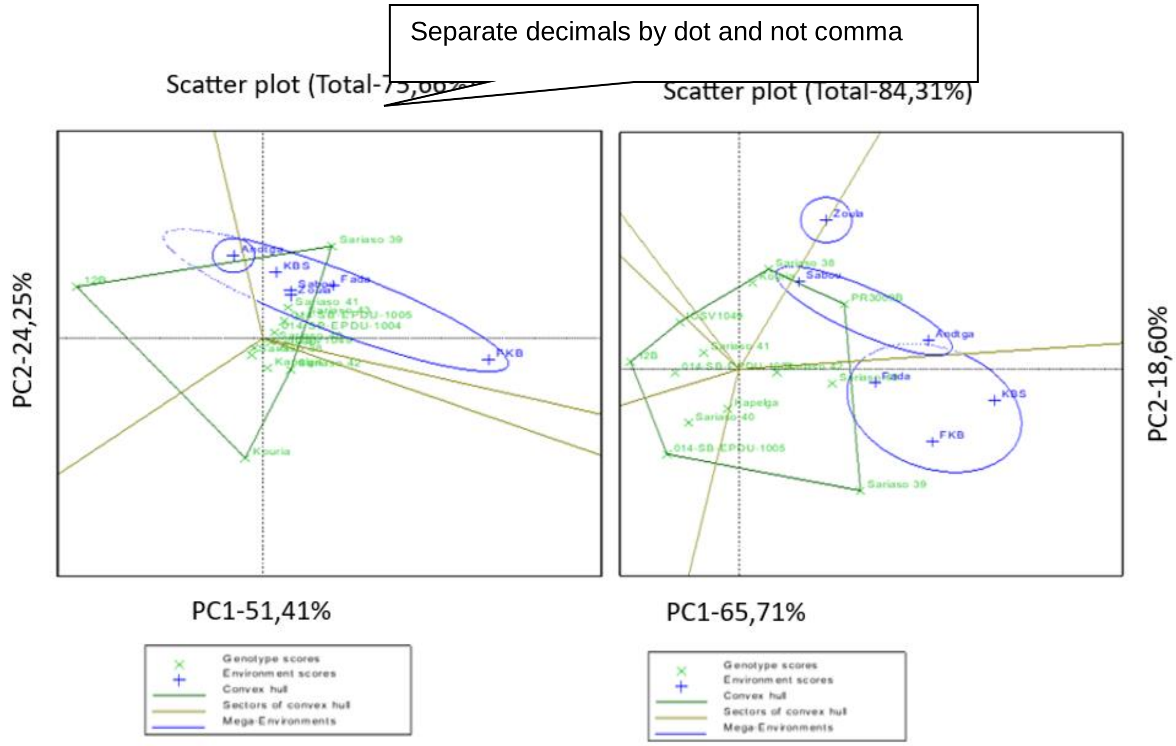

Fig. 1a. Polygon view of the GGE biplot showing mega-environment based on heading time

Fig. 1b. Polygon view of the GGE biplot showing mega-environment based on grain yield

Fig. 1. Polygon view of the GGE biplot showing mega-environment based on heading time (Fig.1a) and grain yield (Fig.1b)

3.1.5 Identification of highest yielding and stable Genotypes across sites

Grain yield and genotype stability were evaluated from the average environmental coordinate (AEC) which was achieved by drawing an AEC on the genotype-focused biplot represented by two axes facing in opposite directions from the biplot origin (Fig.2).The arrow headed line points to higher performing genotypes across environments while the crossing lines point to greater stability (poor variability) according to the direction, meaning that that the greater the genotype projection in the axis of the AEC ordinate, the greater the instability of the genotype.

For heading time, except for Sariaso 39 and Kouria, genotypes were stable across environments (Fig. 2a). For yield performance, the highest yielding genotypes were Sariaso 42, Sariaso 43, Sariaso 38, Sariaso 39, Kouria and PR3009B.Sariaso 42 and Sariaso 43 were more stable than Sariaso 38, Sariaso 39, Kouria and PR3009B. The lowest yielding varieties were 014-SB-EPDU-1004, 12B, ICSV1049, Kapelga, Sariaso 40, and Sariaso 41but 014-SB-EPDU-1004, 12B, ICSV1049, and Kapelga were more stable than the others.

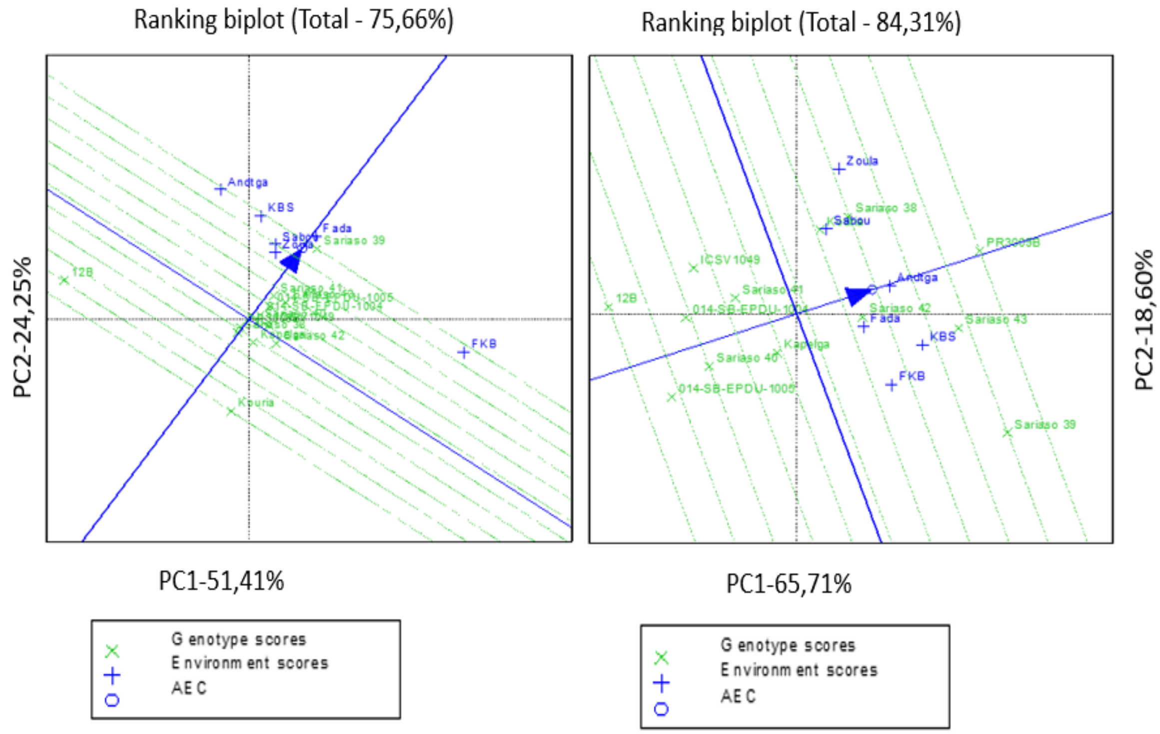

Fig. 2a. GGE-biplot showing ranking of 12 OP varieties based on heading time

Fig. 2b. GGE-biplot showing ranking of 12 OP varieties based on grain yield

Fig. 2. GGE-biplot showing ranking of 12 sorghum OP varieties based on heading time (Fig. 2a) and grain yield (Fig.2b)

3.1.6 Identification of Ideal Genotypes

Based on heading time, grain yield and stability of performance, the 12 best genotypes including checks for high yield and stable performance are presented in Fig. 3. The highest yielding and most stable genotype are located at the center of the concentric circles. For heading time, Sariaso 39 was superior and stable across environment since it was located on the first concentric circle. The second most stable and superior genotype was Sariaso 43 as it was located in third concentric circle. For grain yield, the biplot (Fig. 3b) identified PR3009B as superior since it is located in the concentric circle. The second most stable and superior genotype was again Sariaso 43 as it was located in third concentric circle.

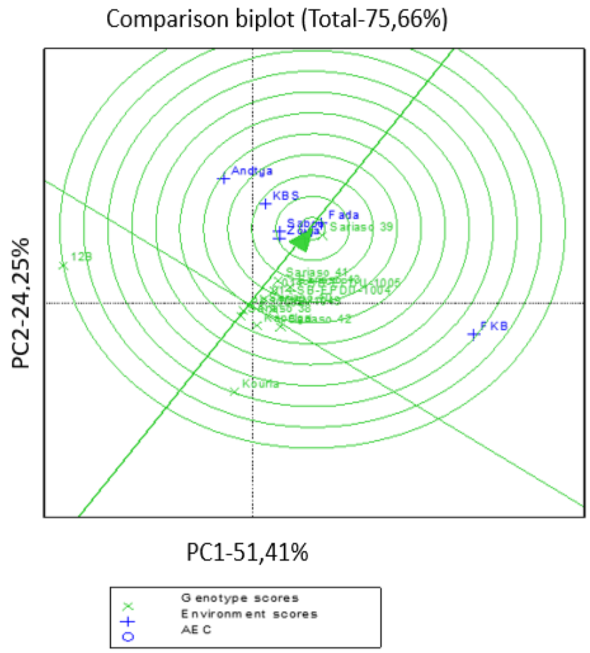

Fig 3a. GGE biplot based on genotypes scaling for comparing 12 OP varieties at heading time

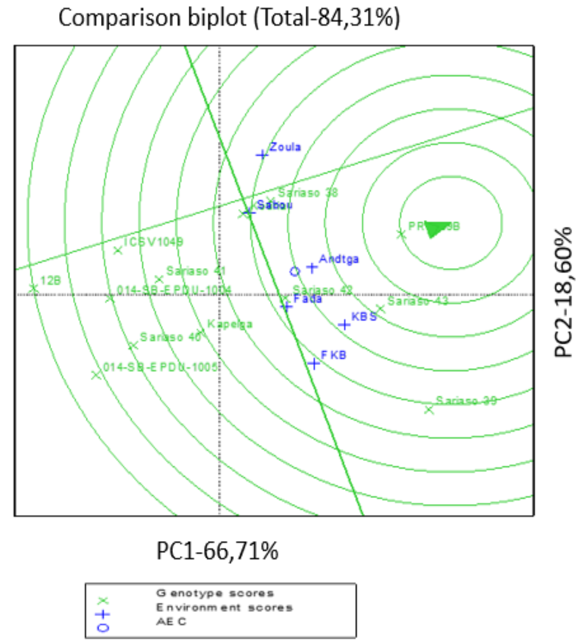

Fig 3b. GGE biplot based on genotypes scaling for comparing grain yield of 12 OP varieties

Fig. 3. GGE-biplot based on genotypes scaling for comparing 12 sorghum OP varieties at heading time (Fig. 3a) and yield performance (Fig. 3b)

3.2 Discussion

The wide variation of data around the mean with large coefficient of variation for most of traits including Striga number, midge damage and grain yield indicate that genotypes reacted differently from each other and differently across sites. The huge coefficient of variation for Striga number indicates that Striga infestation was different across sites. In fact, only one site (Andemtenga) over the six sites was a Striga infestation field. Midge damage variation across sites indicates that two sites (Fada and Andemtenga) were midge hotspots and four sites (Farako-Ba, kamboinse, Sabou, and Zoula) were not infested by midge. For grain yield, the large, variability among genotypes within sites and across sites is due to biotic factors such as midge and Striga or due to racial origin of material used. The lowest grain yields were found at Andemtenga followed by Fada. Andemtenga was infested by Striga and midge and Fada is recognized as a midge infestation hotspot [10,11]. Dakouo [11] and Ouedraogo *et al.* [12] reported that midge damage on sorghum grains was 33% to 81.51%. Difference of grain yield among genotypes may be also due to genetic potential as the genotypes were composed of guinea, caudatum and intermediate (guinea caudatum) varieties. Zongo *et al.* [5] reported that local guinea lines or lines derived from guinea race had low yield potential compared to other sorghum races.

The highly significant mean squares of environments, genotypes and genotypes by environments for the majority of traits, including grain yield, indicates that climatic conditions across environments were diverse and confirmed again that genotypes reacted differently from each other. Gezahegn *et al.* [13] reported similar results through on Napier grass. Five out of the six sites were located in the sudano-sahelian zone with rainfall ranging from 700 mm to 900 mm whereas Farako-ba was located in Sudanian zone with rainfall ranging from

900 mm to 1200 mm. The climate was harsh in areas due to rainfall shortage (confer table 1).

Differences between heading time among genotypes within sites and across sites are probably due to different planting dates across sites and to genetic characteristics linked to photoperiodism. Sorghum is a short-day plant within the tropics which may often show high sensitivity to photoperiod in normal growing seasons [14, 15].Heading times were shorter at Zoula, Fada, and Farako-Ba than Kamboinse, Andemtenga and Sabou due to late planting in those sites. This result is in agreement with Folliard *et al.* [16] reported that Sorghumcropping duration is shortened when planting is delayed during rainy season.
Agronomic performances of 12 varieties evaluated across sites was strongly impacted by biotic constraints (Striga and midge) and environmental factors (rainfall shortage at post-flowering growth stage). Varieties yield were low at Andemtenga compared to other sites due to both midge damage and Striga infestation. At Fada, the yields were lower due to midge damage. In opposite, low yields observed at Sabou were probably due to rain shortage in this site. In this site, rainfall quantities did not reach 700 mm and rainy season was characterized by rain shortage at post-flowering growth stage and, therefore, varieties were subjected to more than 14 days of water stress. Kamboinse, Farako-Ba, and Zoula were constraintless sites and varieties performed well for grain yield. Consequently, the highest yields were recorded in those sites with Sariaso 43 (3960.94 kg/ha), 014-SB-EPDU-1004 (3681.64kg/ha) Sariaso 42(3478,52 kg/ha), and Sariaso 39 (3427.73 Kg/ha). The yields obtained by these varieties were beyond the global sorghum average yield across the world from 2001 to 2020, but less than global average in North America (4.1t/ha) and the Middle East and North Africa (5.7t/ha). However, those yields were higher than yields obtained in Europe and Central Asia (3.1t/ha), Latin America and the Caribbean (2.6t/ha), and East Asia and Pacific (2.5t/ha), sorghum yield in South Asia (0.9t/ha) and sub-Saharan Africa (0.9t/ha)[3]. The maximum Sorghum yield of sub-Saharan Africa is 1.3 t/ha according to result reported by Muhammad and Elfatih [17] and FAOSTAT [3].
The GGE biplot has the ability to show the which-won-where pattern and identify mega environments from the genotype by environment interactions and can provide a precise summary of the G × E pattern on a multi locations trial. According to Yan and Rajcan[18], mega environment is a group of environments that shares almost the same and best genotypes. Concerning the heading time, varieties were grouped inside one mega-environment indicating that varieties heading times were not diverse enough across sites. The biplot of varieties performance analysis revealed three mega-environments linked to yield performance and environmental conditions. The first mega-environment was a medium yield environment and was characterized by low soil fertility. The second mega-environment was a low to medium yielding environment characterized by biotic constraints such as Striga and midge infested areas for Andemtenga and rain shortage at Sabou. The third mega-environment was constituted to research station sites characterized by adequate rainfall ranges and homogeneous soil that was suitable for experimental trials. This mega-environment grouped medium to high yielding environments with the exception of Fada where yields were low due to strong infestation of trial areas by midge. The which won-where-pattern revealed that Kamboinse, Fada, and Farako-Ba were almost similar and could be used for the cultivation of the same genotypes. Sabou and Andemtenga were different from the first three sites but similar enough for cultivation of genotype such as PR3009B. Earlier studies conducted byTeodoro *et al.* [19], Hamidou *et al.* [20], Ouedraogo *et al.* [9] reported two mega-environments in sorghum evaluation while De Figueirodo *et al.* [21] revealed several mega-environments for green mass yield and total soluble solids in sweet sorghum using GGE biplot analysis. The results revealed clearly that the mega-environment identified were associated with either high, medium, or low yield along environmental or biotic constraints. This statement is in agreement with result reported by Badu-Apraku *et al.* [22] about mega-environment in working on maize.

After mega-environment identification, it was important to identify the highest yield and stable genotypes across sites. According to Yang *et al.* [23] and Adediran *et al*., [27], the greater the genotype projection in the axis of the AEC ordinate, the greater the instability of genotypes inducing a greater interaction with environment. Consequently, the analysis revealed that Sariaso 42 and Sariaso 43 were genotypes with highest yield and were the most stables across sites. On the other hand, genotypes Sariaso 38, Sariaso 39, Kouria, PR3009B, Sariaso 40, and Sariaso 41 could be removed as having high instability and low average yield across environments.

The wish of each plant breeder is an ideal genotype, meaning a genotype that combines high adaptability, stability and high yield across environments [24]. According to Mafouasson *et al.* [25] and Chaudhary et al. [26], genotypes that are located at the center of the concentric circles are the ideal (highest yielding and stable). In this regard and from the GGE biplot graphs (Fig.3a and Fig.3b) and analysis, Sariaso 43 was the genotype that combined suitable heading time along with high grain yield. This is in agreement Yan and Tinker [24], who reported that genotypes displaying both high yield and stability across environments are considered as ideal genotypes. Sariaso 39 and PR3009B were the ideal genotypes for heading time and grain yield as they were located at the center of the concentric circles respectively in Fig.3a and in Fig.3b. This study was very useful in such that it allows to identify adequate genotypes for suitable environments and will contribute to reach food security in Burkina Faso.

4. CONCLUSION

Genotypes, environments, and genotype × environment interactions were significant for both heading time and grain yield. The varieties had different heading times and different grain yield performance within environments and across the six environments. The GGE biplot discriminated the study areas into a unique mega-environment for heading time and three mega-environments for yield potential. Overall, a majority of varieties performed better than the average sorghum yield in sub-Sahara Africa. Low yielding varieties were found in environments affected by biotic and abiotic constraints. However, high yielding varieties Sariaso 43 = 3960.94 kg/ha, 014-SB-EPDU-1004 = 3681.64kg/ha, Sariaso 42 = 3478.52 kg/ha and Sariaso 39 = 3427.73 Kg/ha were identified in constraintless mega-environments (Kamboinseand Farako-Ba). Finally, the GGE biplot analysis revealed that Sariaso 43 was the best genotype for heading time and high grain yield across sites. The most adapted genotype for heading time is Sariaso 39 and PR3009B is most adapted for grain yield.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

ICRISAT: International Crops Research Institute for the Semi-Arid Tropics

INERA : Institut de l’Environnement et de Recherches Agricoles
GGE : ???