



## Review article

# Assessing yield performance and stability of local sorghum genotypes: A methodological framework combining multi-environment trials and participatory multi-trait evaluation

Clarisse Pulchérie Kondombo<sup>a,\*</sup>, Pierre Kaboré<sup>b</sup>, David Kambou<sup>a</sup>,  
Issaka Ouédraogo<sup>a</sup>

<sup>a</sup> Institut de l'Environnement et de Recherches Agricoles (INERA), BP 10 Koudougou, Burkina Faso

<sup>b</sup> Office de Développement des Eglises Evangéliques (ODE), 01 BP 108 Ouagadougou 01, Burkina Faso

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## ABSTRACT

Sorghum grain is a vital staple cereal crop for food and nutritional security for rural households in Burkina Faso. However, its yields are regularly affected by environmental and socio-economic constraints. Here, we aim to assess the performance and grain yield stability of local sorghum genotypes, as well as their acceptability by smallholder farmers. Nine genotypes were assessed across five environments in the North-Sudanian zone (700–900 mm) in Burkina Faso during the 2019, 2020, and 2021 rainy seasons. A randomized complete block with three replications was used to establish the experiments, from which data were collected on five quantitative traits as well as five participatory assessment criteria chosen by sorghum farmers and users. Grain yield analysis for each environment revealed significant differences between genotypes. The combined analysis showed highly significant differences between genotypes, environments and years, as well as their interactions. Most of the variation in grain yield was explained by the environment effect (29.0%), followed by the environment-by-year interaction (20.3%). The GGE biplot analysis identified two mega-environments (ME) with ME1 consisting of one environment (E1) and ME2, represented by four environments (E2, E3, E4, and E5). The E1 is a non-discriminating and poor environment with the lowest grain yield (1506 kg ha<sup>-1</sup>). The E5 and E2 were respectively, the most discriminating and representative environments, with also the highest grain yields (2406 and 2102 kg ha<sup>-1</sup>). In terms of stability, genotypes G6, G3, G5, and G9 exhibited the highest stability but lower performance, while G4 was the most unstable. G2 and G8, which produced respectively 2240 and 2072 kg ha<sup>-1</sup>, were better adapted to ME2. G2 was identified as the closest to the "ideal genotype". The principal component analysis showed that genotypes G2, G8, G7, G4, and G9 were the most selected in both individual and group assessments, owing to the panicle productivity, the good grain quality for storability, the grain attractiveness, and grain heaviness. This study highlighted the potential of genotypes G2 and G8 as promising varieties that could broaden the range of improved varieties and offer income opportunities for sorghum smallholder farmers in Burkina Faso.

\* Corresponding author.

E-mail addresses: [clarissebk@yahoo.fr](mailto:clarissebk@yahoo.fr) (C.P. Kondombo), [kabsonp@yahoo.fr](mailto:kabsonp@yahoo.fr) (P. Kaboré), [david.kambou@gmail.com](mailto:david.kambou@gmail.com) (D. Kambou), [ouedraogoissaka80@yahoo.fr](mailto:ouedraogoissaka80@yahoo.fr) (I. Ouédraogo).

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**Table 1**  
Origin and characteristics of the studied genotypes.

Genotype	Code	Origin/province	Origin/village	GID (BMS)	Type	Botanical race	Pericarp colour	PanL <sup>m</sup> (cm)	HD <sup>m</sup> (days)	W1Gr <sup>m</sup> (g)	EndoT <sup>m</sup> (1–5)
Beleco	G1	Kourweogo	Sourgoubila	572	L. OPV	Gg	White	42.4	79	2.1	3.0
Gnougua	G2	Houet	Dibien	576	L. OPV	Gg	White	31.6	77	2.4	3.1
Kapèlga (Check)	G3	Boulkiemdé	Saria	579	L.I. OPV	Gg	White	33.4	68	2.2	2.0
Karemsambalidou	G4	Nayala	Mobgwentenga	578	L. OPV	Gg	White	43.7	80	2.3	3.0
Kongobana	G5	Nayala	Kossé	575	L. OPV	Gg	Red	30.1	68	2.5	3.4
Pagyelgpazalem	G6	Nayala	Nabonswendé	574	L. OPV	Gg	White	29.1	71	2.5	3.2
Pogyalambonko	G7	Kourweogo	Taonsgo	573	L. OPV	Gg	White	44.3	77	2.2	3.1
Samabolo	G8	Nayala	Labara	577	L. OPV	Gg	White	45.8	79	2.1	3.0
Wedzouré	G9	Nayala	Nabonswendé	571	L. OPV	Gg	White	48.4	77	2.3	3.0

**Legend.** GID = genotype identity in the Breeding Management System (BMS) INERA portal sorghum database, L. = local genotype, L.I. = local improved genotype, Gg = Guinea gambicum, OPV = open pollinating variety, PanL = panicle length, HD = number of days from sowing to 50% heading, W1Gr = weight of 100 grains, EndoT = endosperm texture [1 = completely corneous (100% vitreous), 2 = 75% corneous and 25% floury, 3 = 50% corneous and 50% floury, 4 = 75% floury and 25% corneous, 5 = completely floury (100% floury)].

<sup>m</sup> = average value of traits measured in 2019, 2020, and 2021 in environments E2 and E4.

**Table 2**  
Information on the trial environments.

Municipality	Trial location/environment	Code	Latitude	Longitude	Altitude (m)	Soil texture	Dates of sowing			Rainfall (mm)					
							2019	2020	2021	2019		2020		2021	
										T	Ut	T	U	T	U
Gassan	Gassan	E1	12°49' N	3°12' W	264	Sandy-clay	03-Jul	03-Jul	05-Jul	684	540	908	756	725	580
	Soroni	E2	12°43' N	3°12' W	265	Sandy-clay	02-Jul	03-Jul	05-Jul	821	670	823	702	827	706
Sourgoubila	Sandogo	E3	12°21' N	1°58' W	339	Sandy-clay	02-Jul	14-Jul	07-Jul	841	684	1117	906	786	548
	Song-naba	E4	12°57' N	2°20' W	327	Sandy-clay	03-Jul	17-Jul	07-Jul	841	684	1117	906	786	548
Koudougou	INERA Saria	E5	12°16' N	2°09' W	300	Sandy-clay	11-Jul	10-Jul	14-Jul	912	649	945	775	721	662

**Legend.** T = total rainfall, U = useful rainfall (from sowing to maturity).

## 1. Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most cultivated cereal crop in the world in terms of both acreage and grain production, after wheat, maize, rice, and barley. In 2021, the global area sown with sorghum was estimated at 40.9 million ha, with a production of 61.4 million tonnes. Sorghum is grown in different countries around the world on varying acreages ranging from 7 ha to 6.9 million ha [1].

In Burkina Faso, sorghum is the major food grain, followed by maize (*Zea mays* L.), pearl millet [*Pennisetum glaucum* (L.) R. Br.], rice (*Oryza sativa* L.), and fonio (*Digitaria exilis* Stapf). In 2020, about 1.84 million tonnes of sorghum was reported, produced from 1.73 million ha. In 2021, the total production was 1.69 million tonnes on 1.88 million ha, with the yield decreasing from 1060 kg ha<sup>-1</sup> to 900 kg ha<sup>-1</sup> [2].

Sorghum is a multi-purpose cereal (food, feed, fodder, fuel, alcohol, and fiber), drought-tolerant [3], with moderate water requirements [4]. As a “nutri-cereal” crop, the grain has several key traits (gluten-free, rich in bioactive phenolic compounds, etc.) [5,6] that are beneficial for human nutrition and health [7,8]. In Burkina Faso, the grain is mainly used for traditional dishes, and straw is used as fodder for livestock feed. However, similar to other countries in the semi-arid tropical zone of Africa and Asia, sorghum yields are low and variable [9–11]. This is attributable to a range of constraints, including but not limited to rainfall variability and other biotic and abiotic stresses, whose nature and extent vary across agro-ecological zones [12–14]. The resulting sorghum production instability repeatedly exposes a large proportion of households to food, nutritional, and economic insecurity.

During the decades (2000–2020), various new improved sorghum varieties were developed, released, and disseminated by the breeding programs in Burkina Faso, with, for most of the varieties, the inclusion of farmers in the creation and selection processes [15]. This approach led to successful varietal adoption, and contributed to increasing sorghum yields among farmers growing these varieties as well as increasing the demand for the improved varieties’ seed [16]. It is worth noting that local varieties remain important and are often preferred by farmers for diverse reasons: (i) easier availability of seed on the farm; (ii) more suitable to the usual local dishes, particularly for thick porridge; and (iii) good adaptation to the different cropping systems practised on farms [17,18]. Local sorghum varieties, particularly those from the guinea botanical race are often associated with specific adaptations to their production environments [19] and show farmers’ preferred traits such as sensitivity to photoperiod [20], resistance to grain molds [21], but present in general a low productivity compared to sorghum of other races (Caudatum and Durra). Notwithstanding, some varieties among the guinea botanical race are singular, with high yields, but not known beyond the village where they are cultivated [19,22]. As small-holder farmers continue to grow local varieties, there is therefore a need from the benefit from preferred traits, breeding programs need to support this group through farmers’ networks to (1) identify high-yielding local varieties with large adaptation potential among the local diversity from other villages and (2) facilitate their dissemination depending on targeted seed systems. Furthermore, dealing with complex quantitative traits such as grain yield would require multi-environment and multi-year field trials are necessary to consider genotype and environment factors [23–25] in order to better assess the performance of genotypes and their stability [26–28]. The present paper proposes a methodological framework based on multi-environmental testing and participatory multi-trait evaluations, aiming to examine the performance and stability of grain yield for local sorghum genotypes and their acceptability by farmers in the North-Sudanian zone of Burkina Faso.

## 2. Material and methods

### 2.1. Plant material

A total of nine sorghum genotypes (G1 to G9), including eight from farmers and one from research breeding programme were evaluated in five environments during the 2019, 2020, and 2021 rainy seasons. Kapèlga (G3), is an improved local variety registered in the national catalogue (SCHV 168) in 2014 and disseminated by INERA in Burkina Faso. It was used as a reference control for cycle length and grain vitreousness. It is grown by many farmers in different agroecological zones for its relatively short cycle length, its adaptability to different areas, and for its good grain vitreousness, which is suitable for processing in local dishes. The list of genotypes is given in Table 1.

### 2.2. Study sites

The study sites were located in five municipalities of the North-Sudanian zone in the 700–900 mm of rainfall isohyet in Burkina Faso: Gassan and Soroni in Nayala province (Boucle of Mouhoun region), Sandogo and Song-naba in Kourwéogo province (Plateau-central region), and the INERA Saria research station in Boulkiemde province (Centre-west region). In these environments, the dominant soils are leached tropical ferruginous soils (gravelly, sandy, and sandy-clay). The characteristics of the growing environments and the amounts of rainfall are given in Table 2.

### 2.3. Field experimental design

The nine genotypes were evaluated under a randomized complete block design (RCBD) using three replications/plots. The plot is composed of 4 rows of 6 m length, with the two central rows as useful plot. The sowing was done at a spacing of 80 cm between the rows and 40 cm between the hills on the row. To reduce edge effects, five additional rows were sown with improved variety seed at the beginning and end of each replication. The seedlings were thinned to three plants per hole 17–20 days after sowing. For each trial, the

ploughing was done with animal traction, as practised by farmers. These commonly agreed to apply compost exclusively as the sole fertiliser in all fields on-farm as well as on research station at a rate of  $2.5 \text{ t ha}^{-1}$  at the ploughing time. Two manual weedings were carried out before ridging 40–45 days after sowing. Subsequently, weeding by pulling was carried out to control weediness.

#### 2.4. Participatory assessment

In 2019 and 2020, in the Soroni (E2) and Song-naba (E4) trials, the genotypes were evaluated at maturity in the field by farmers and users of the two municipalities. The assessments were performed using five criteria collectively agreed by the evaluators during a workshop prior to sowing. These criteria include the (1) adaptation of the cycle to the growing area (earliness/coincidence of maturity with the end of the rains), (2) panicle productivity (visual estimation of panicle size, grain density on the panicle, and grain size), (3) grain hardness (grain that does not break easily between the teeth and can be stored for more than a year), (4) fodder productivity (many leaves on the stem, long and large leaves that do not fall at maturity), and (5) drought tolerance (in the case of early stopping of rains after flowering, the leaves do not dry out fast, and the genotype can reach maturity with a good filling of the grain on the panicle).

The genotypes were evaluated by 25–30 participants from three to four villages in each municipality. The evaluations consisted of individual (InV) and group (GrV) scores using coloured cards (red, yellow, blue, and white) representing a scale of 1–4, where 1 (red) = bad [the evaluator rejects the genotype (InV), or the characteristics of the assessed trait are unsatisfactory (GrV)], 2 (yellow) = passable, 3 (blue) = good, and 4 (white) = excellent [the evaluator desires the genotype (InV), or the genotype exhibits the desired level of the criterion being evaluated (GrV)]. Each participant (InV/GrV) takes as many colour cards as the number of genotypes ( $4 \times 9$ ) to be evaluated by replication. To differentiate gender, the cards were tagged with the letters M for men and W for women, followed by the replication number. Before the evaluation, a scoring training was carried out to ensure that all participants had the same understanding of the scoring criteria. A non-transparent bag attached to the first plant in each plot was used to collect the evaluators' choices. Some arrangements were made in each category (InV and GrV) of votes to make invisible the colour of the card assigned to each genotype and also to avoid overlaps between evaluators. The individual evaluations were carried out on the three replications, while the group evaluations were carried out on the two best replications per trial each time, with four groups of men and one group of women, due to their small number (5–6). For the group votes, the genotypes were scored on each of the five criteria, followed by a score on global acceptance (considering all criteria).

#### 2.5. Data collection and analysis

Data were collected on cycle length [number of days from sowing to 50% heading (HD)], panicle length (PanL), 100-grain weight (W1Gr), endosperm texture (EndoT) determined by visual assessment of the floury and corneous proportions of the grain, and grain yield (GrYLD). An analysis of variance (ANOVA) was performed with the grain yield data per environment and then with the combined data from the five environments to assess the different sources of variation: genotypes (G), environment (E), year (Y), and possible interactions. Another ANOVA was performed with the data from participatory group assessments. In the single-environment analysis as well as the group assessments, we used a two-way ANOVA (Eq. (1)), by considering all effects as random except  $\mu$ , which is considered as fixed. In the combined analysis, we applied a linear mixed-model using restricted maximum likelihood (REML) (Eq. (2)), following the approach presented by Yang [29]. In this analysis, all effects are considered random, except  $\mu$ , considered as fixed.

$$Y_{ink} = \mu + G_i + R_k + Y_n + GY_{in} + \varepsilon_{ink} \quad (\text{Eq. 1})$$

Where:  $Y_{ink}$  is the yield response of the  $i$ th genotype within the  $k$ th replication of the  $n$ th year.

$$Y_{ijnk} = \mu + G_i + R_k + E_j + Y_n + GE_{ij} + GY_{in} + EY_{jn} + GEY_{ijn} + \varepsilon_{ijnk} \quad (\text{Eq. 2})$$

Where:  $Y_{ijnk}$  is the yield response of the  $i$ th genotype within the  $k$ th replication of the  $n$ th year in the  $j$ th environment.  $\mu$  is the general mean,  $G_i$  the effect of the  $i$ th genotype,  $R_k$  is the effect of the  $k$ th replication,  $E_j$  the effect of the  $j$ th environment,  $Y_n$  the effect of the  $n$ th year,  $GE_{ij}$  is the interaction effect of the  $i$ th genotype of the  $j$ th environment,  $GY_{in}$  the interaction effect of the  $i$ th genotype in the  $n$ th year,  $EY_{jn}$  the interaction effect of the  $j$ th environment in the  $n$ th year,  $\varepsilon_{ijnk}$  the residual error.

A GGE biplot analysis [30] was performed to better investigate the effects of genotype (G) and genotype-by-environment (GE) interactions. This approach allowed to evaluate the similarity between environments and identify the most discriminating and representative environments, as well as the most-adapted genotypes in the mega-environments. Finlay-Wilkinson's joint regression was performed to assess the response of genotypes to environmental changes [31]. In this approach, a value of 1.0 indicates an average sensitivity to environmental changes. The genotype with a value greater than 1 exhibit higher than average sensitivity, and genotype with a value less than 1 exhibit less sensitive than average.

A principal component analysis (PCA) was carried out in order to have an overall structuring of individual choices on the one hand and group choices on the other. This was done with the individual assessment rates and the indexes of group scores for each criterion. The analyses of variance and the GGE biplot were performed with the Genstat software, v20.1.2.24528 [32], while the PCA was performed with the XLSTAT software, 2022.1.1 [33].

**Table 3**

Variance in grain yield (GrYLD) of nine sorghum genotypes tested in 2019, 2020 and 2021 in five environments.

		Gassan municipality				Sourgoubila municipality				INERA station	
		Gassan (E1)		Soroni (E2)		Sandogo (E3)		Song-naba (E4)		Saria (E5)	
Source of variation	D.F.	M.S.	V.R.	M.S.	V.R.	M.S.	V.R.	M.S.	V.R.	M.S.	V.R.
Genotype (G)	8	199780	2.74*	878972	14.38***	161154	4.16***	289072	4.82***	1393769	9.78***
Repetition	2	228286	3.13	6990	0.11	13867	0.38	272408	4.54	1088888	7.64
Year (Y)	2	1806400	24.74***	1565305	25.61***	13980267	360.7***	1077312	17.96***	1079957	7.58***
GxY interaction	16	149511	2.05*	490606	8.03***	264849	6.83***	178808	2.98***	225293	1.58
Residual	52	73026		61122		38758		59991		142462	
CV (%)		25.57		21.40		41.09		18.67		27.39	

D.F. = degree of freedom, M.S. = mean squares, V.R. = variance ratio # calculated F, CV = coefficient of variation.

\* and \*\*\* = significant at the 0.05 and 0.001 probability levels.

### 3. Results

#### 3.1. Effect of different factors on grain yield

The analysis of variance (ANOVA) on grain yield (GrYLD) by environment showed significant ( $P < 0.05$ ) to highly significant differences ( $P < 0.001$ ) between genotypes (G), between years (Y), as well as the genotype-by-year interaction (GY), (Table 3). The ANOVA on grain yield across the five environments showed a non-significant replication effect, but highly significant differences for all sources of variation (G, E, and Y) and their interactions (Table 4). Twenty-nine percent (29.0%) of the variation in grain yield is explained by the environment effect, followed by environment-by-year (20.3%), genotype-by-environment-by-year (11.7%), genotype-by-environment (9.1%) interactions, genotype effect (6.5%), year effect (5.8%), and genotype-by-year interaction (2.3%). The average grain yield was  $1924 \pm 608 \text{ kg ha}^{-1}$ . The environments E2 (Soroni), E4 (Song-naba), and E5 (Saria) gave above-average yield. The genotypes G2, G8, G4, and G7 also yielded above the trial average. The comparison of means by the Student-Newman-Keuls test showed that G2 was significantly higher than the other eight genotypes for grain yield (Table 5).

#### 3.2. Evaluation of trial environments based on the GGE biplot

The GGE biplot (Fig. 1) showed that the first two principal components (PC1 and PC2) explained 86.56% of the total variance in grain yield due to the genotype (G) effect and the genotype-by-environment (GE) interaction. The vectors of environments E2, E3, E4, and E5 connected to the origin of the biplot taken two by two present between them acute angles (inferior to  $90^\circ$ ), therefore, these four environments are positively correlated. Each vector of these environments displayed an obtuse angle ( $>90^\circ$ ) with that of environment E1, showing that they are negatively correlated to environment E1. The length of the vectors of the trial environments is an indicator of their ability to discriminate the genotypes. It is proportional to the standard deviation of each trial environment. E3, E1, and E4 respectively showed shorter vectors compared to E5 and E2, which presented the longest vectors. Thus, the environments E3, E1, and E4 have a low ability to discriminate the genotypes, while E5 and E2 were able to better discriminate the nine genotypes on grain yield performance. Analysis of Fig. 2 showed that E3, which presented the smallest angle with the average environment coordination (AEC) abscissa is more representative but not discriminating. E4 is closer to the average environment but, like E2, it showed a larger angle than E5 with the AEC. E5, the most discriminating environment is the closest to the centre of the concentric circles, which is the virtual position of the "ideal test environment". It is therefore the most desirable environment, followed by E2.

#### 3.3. Average performance of genotypes in the environments

Two mega-environments (ME1 and ME2) were identified on the GGE biplot (Fig. 3). ME1 consisting of E1, and ME2 consisting of E2, E3, E4, and E5. The polygon grouping all the tested genotypes is divided into six sectors. The vertices of the polygon present the genotypes (G2, G8, G5, G6, G3, and G4) located farthest from the biplot origin. These genotypes were either the best or the poorest performers in some or all environments. Environments in the same sector share in common the genotypes that responded best in those environments ("which-won-where"). Thus, in ME1 consisting of E1 and located in one sector, G4 performed the best. In ME2, the remaining four environments are located in the same sector, in which G2 and G8 were the best performing genotypes for grain yield with respectively,  $2240 \text{ kg ha}^{-1}$  and  $2072 \text{ kg ha}^{-1}$ . E2 is located at the limit of the sector on the perpendicular that connects the genotypes G2 and G4, meaning that G4 performs as well as G2 in environment E2. Genotypes G1, G3, G5, G6, and G9 are located in sectors that are not part of any environment, indicating that they performed poorly in most of the environments; therefore, for grain yield, they are less interesting in the five environments of the study.

#### 3.4. Stability of genotypes in trial environments and identification of the ideal genotype

The linear regression values allowed to distinguish genotypes (G3, G5, G6, G7, and G9) with a stability above or equal to the

**Table 4**

Variance in grain yield (GrYLD) of the nine (G1-G9) sorghum genotypes over the five environments.

Source of variation	D.F.	S.S.	M.S.	V.R.	Percentage of S.S.
Genotype (G)	8	9770843	1221355	14.56***	6.5
Environnement (E)	4	43238206	10809552	128.9***	29.0
Year (Y)	2	8695035	4347517	51.84***	5.8
Repetition (R)	2	265275	132637	1.58 ns	0.2
GxE	32	13611130	425348	5.07***	9.1
GxY	16	3417281	213580	2.55***	2.3
ExY	8	30323446	3790431	45.20***	20.3
GxExY	64	17527796	273872	3.27***	11.7
Residual	268	22474284	83859		15.1
Total	404	149323297			

Legend. D.F. = degree of freedom, S.S. = sums of squares, M.S. = mean squares, V.R. = variance ratio # calculated F. ns = non-significant, \*\*\* = significant at the 0.001 probability level.

**Table 5**

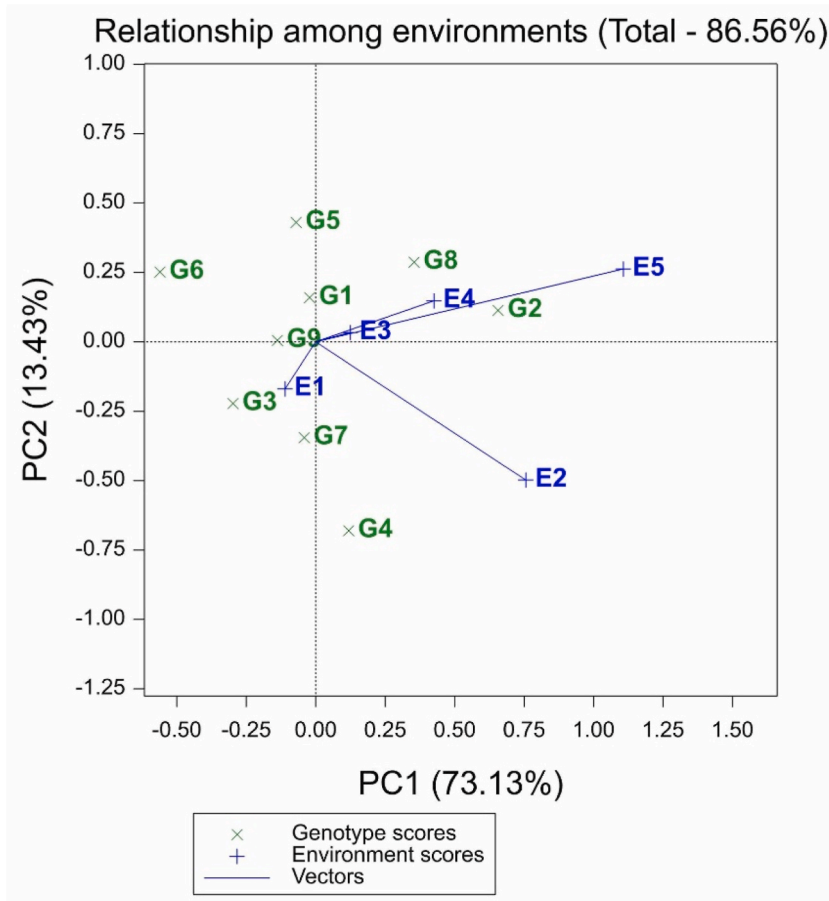
Average grain yield (kg.ha<sup>-1</sup>) of the nine sorghum genotypes tested in 2019, 2020 and 2021 and their sensitivity level to environmental effects.

Genotype	Code	Gassan (E1)	Soroni (E2)	Sandogo (E3)	Song-naba (E4)	Saria (E5)	Overall Mean	Newman-Keuls Test	Linear regression coefficient [31]
Gnougua	G2	1429 (7)	2839 (1)	1771 (2)	2367 (1)	2793 (1)	2240	a	1.6626 (9)
Samabolo	G8	1530 (4)	2500 (4)	1597 (5)	2118 (2)	2616 (2)	2072	b	1.2942 (8)
Karemsambalidou	G4	1693 (1)	2799 (2)	1545 (8)	1875 (7)	2112 (5)	2005	bc	1.2235 (7)
Pogyalambonko	G7	1474 (5)	2564 (3)	1836 (1)	1918 (5)	1920 (6)	1942	bcd	0.9556 (5)
Wedzouré	G9	1664 (3)	2283 (7)	1577 (6)	2104 (3)	1918 (7)	1909	bcde	0.7233 (2)
Beleco	G1	1267 (9)	2350 (5)	1654 (4)	1878 (6)	2116 (4)	1853	cde	1.1156 (6)
Kongobana	G5	1359 (8)	2159 (8)	1557 (7)	1962 (4)	2148 (3)	1837	cde	0.9531 (4)
Kapèlga (check)	G3	1458 (6)	2318 (6)	1381 (9)	1835 (8)	1717 (8)	1742	de	0.9215 (3)
Pagyelgpazalem	G6	1678 (2)	1842 (9)	1679 (3)	1817 (9)	1574 (9)	1718	e	0.1098 (1)
Mean ± s.e.d.		1506 ± 127	2406 ± 117	1622 ± 93	1986 ± 116	2102 ± 178	1924 ± 75		
H <sup>2</sup> (%)		52.5	82.1	44.3	67.8	86.5			

Legend. s.e.d. = standard errors of differences of means, H<sup>2</sup> = broad-sense heritability.

Newman & Keuls Test. Means with the same letter are not significantly different at the α risk level = 0.05, and the bolded values are the highest genotype grain yield at each trial environment.

(-) = in brackets, the rank of the variety in the test environment.



**Fig. 1.** GGE biplot showing the discriminating ability and representativeness of trial environments.

average (b = 0.1098–0.9556) and genotypes (G1, G2, G4, G8) with a stability below the average (b = 1.1156–1.6626) (Table 5). Fig. 4 showed that G6 is located almost on the abscissa of the AEC, thus reflecting a relatively constant performance across environments. G4 is the most distant with the AEC abscissa showing that it is unstable across environments. In terms of “ideal genotype”, with both high grain yield and high stability (general adaptability), G2 is the closest to the centre of the concentric circles, which is the virtual position of the ideal genotype, followed by G8.



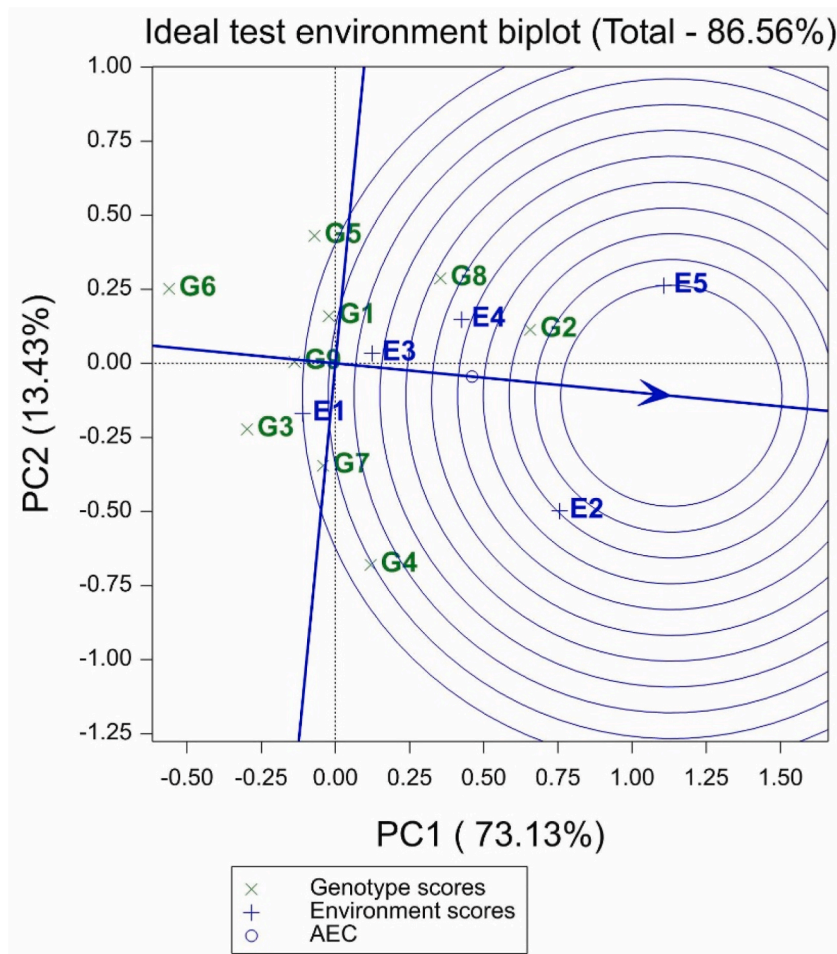


Fig. 2. Ranking the ideal environment based on the discriminating ability and representativeness of the trial environments.

### 3.5. Participatory assessment of genotypes by farmers and users

#### 3.5.1. Individual assessments

The individual preferences of women and men based on the five assessment criteria are presented in Fig. 5a–d. In the E2 trial conducted at Soroni, the women gave the highest scores of 3 (good) and 4 (excellent) to genotypes G7, G8, and G1 respectively (Fig. 5a), while the men gave the highest scores to genotypes G8, G7, and G2 (Fig. 5b). In the E4 trial conducted in Song-naba, G2, G6, and G8 were respectively chosen as the best genotypes by the women (Fig. 5c), while G2, G8, and G9 were the best genotypes for the men (Fig. 5d).

#### 3.5.2. Group assessments

The results of ANOVA on the different traits assessed by women and men groups' in the trials E2 and E4 (Table 6), showed for all groups [E2 (GsW and GsM) and E4 (SgW and SgM)] highly significant differences between the nine genotypes on grain productivity (GrP). The differences were significant ( $P < 0.05$ ) to highly significant ( $P < 0.001$ ) between the genotypes on cycle adaptability (CyA), grain hardness (GrH), and marketing (MrK), according to the group of men in trial E4 and both groups in trial E2. Concerning the year effect, only grain hardness (GrH) and Global acceptance (GIA) of the genotypes were not affected by the year effect in all groups.

The scores of the groups' assessments are presented in Table 7. In the trial E2, on average, the women's group gave the highest score to G2, which was better on almost all criteria. It is followed by G8 and G9, which were at the same level of rating, and then G4. Among these four genotypes, G8 was scored higher on grain productivity (GrP), G9 on fodder productivity (FPr), and G4 was rated less tolerant to drought (DrT). For the men's groups, G7, G8, and G9 were the best genotypes at the same level, followed by G2. However, G8 was rated higher for grain productivity (GrP), grain hardness (GrH), and drought tolerance (DrT). In terms of global acceptance of the genotypes by the groups for the different objectives of production and uses (home consumption, marketing, and processing), the choice of women was less clear-cut, and they chose G2, G4, G5, G7, and G8 at the same level of acceptance, while the men preferred G8, followed by G7 and G9 and then G4 and G2 at the same level of acceptance.

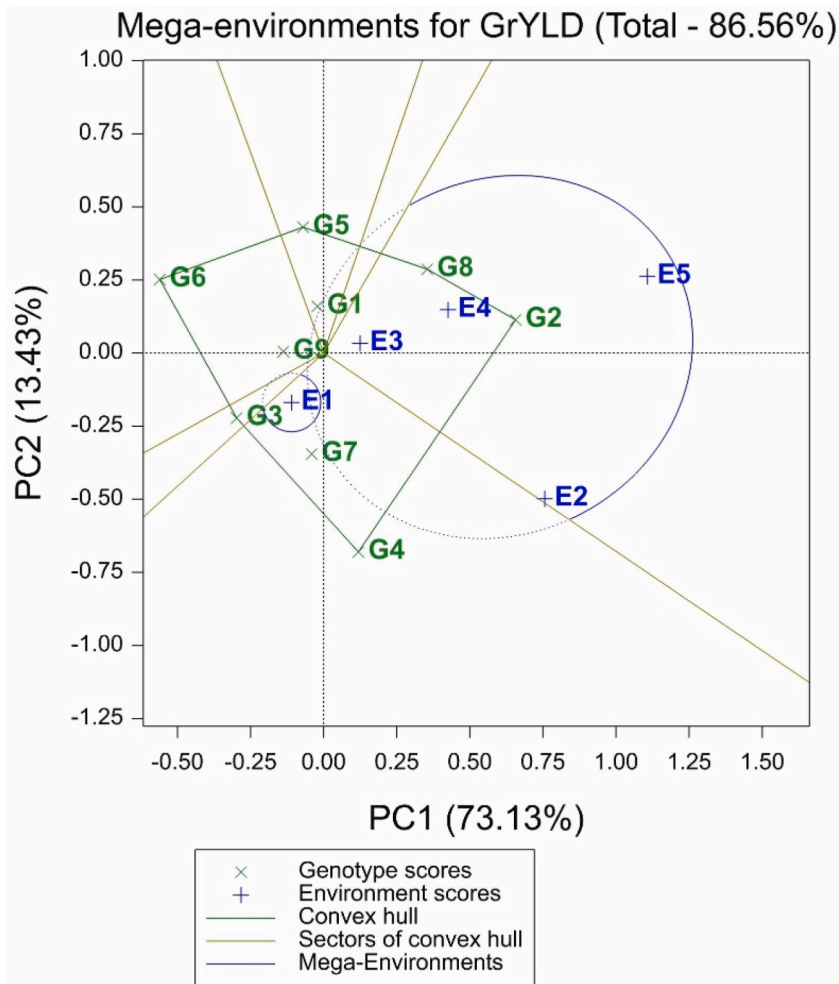


Fig. 3. GGE biplot showing mega environments, and polygon view of the best performing genotypes in each environment.

In the trial E4, on average across the five assessment criteria, the women gave the highest score to G2, followed by G3 (Check), G6, G5, and G7. G2 was superior to G3 only on fodder productivity (FPr), but also to the three other genotypes on grain productivity (GrP), fodder productivity (FPr), and drought tolerance (DrT). For the men, G2, G3, G8, and G9 were respectively the best genotypes. G2 was superior to G3 on the criteria of GrH, FPr, and DrT and to G8 and G9 on CyA, GrP, FPr, and DrT. In terms of global acceptance, the women preferred G2 at the same level as G3, followed by G4, then G6, and G7 at the same level. The men preferred G3, G2, G4, and G8, then G7 and G9 at the same level of acceptance.

### 3.6. Principal component analysis

The principal component analysis of the individual assessments of the genotypes in the E2 and E4 trials is shown in Fig. 6. The first two components (PC1 and PC2) explain 49.44 and 20.78% of the total variance, respectively. Three groups of genotypes were identified: groups one and two on PC1, and group three on PC2. Group one consisting of G5, G3, and G6, group two consisting of G8 and G7, and group three consisting of G2. PC1 is explained by the modalities BGsM, BGsW, PGsM, PSgM, BSgM, EGsM, and EGsW, which account for 68.1% of the total variance carried by the axis. BGsM, BGsW, PGsM, PSgM, and BSgM are positively and significantly correlated with the axis, while EGsM and EGsW are negatively correlated with the axis. PC2 is explained by the modalities PSgW, GSgM, GSgW, ESgW, and ESgM, which account for 71.92% of the total variance carried by the axis. PSgW, GSgM, and GSgW are positively and significantly correlated with the axis, while ESgW and ESgM are negatively correlated. Group one genotypes are characterised by a relatively shorter cycle, shorter panicle length, and lower yield compared to those of group two. Group three genotypes have a higher 100-grain weight. G2, G4, G7, G8, and G9 were ranked good or excellent, whereas G1, G3, G5, and G6 were ranked bad or passable by the evaluators.

The principal component analysis on group assessments of the nine genotypes in the E2 and E4 trials is shown in Fig. 7. The first two components (PC1 and PC2) explain 35.95% and 34.90% of the total variance, respectively. Four groups of genotypes were identified:

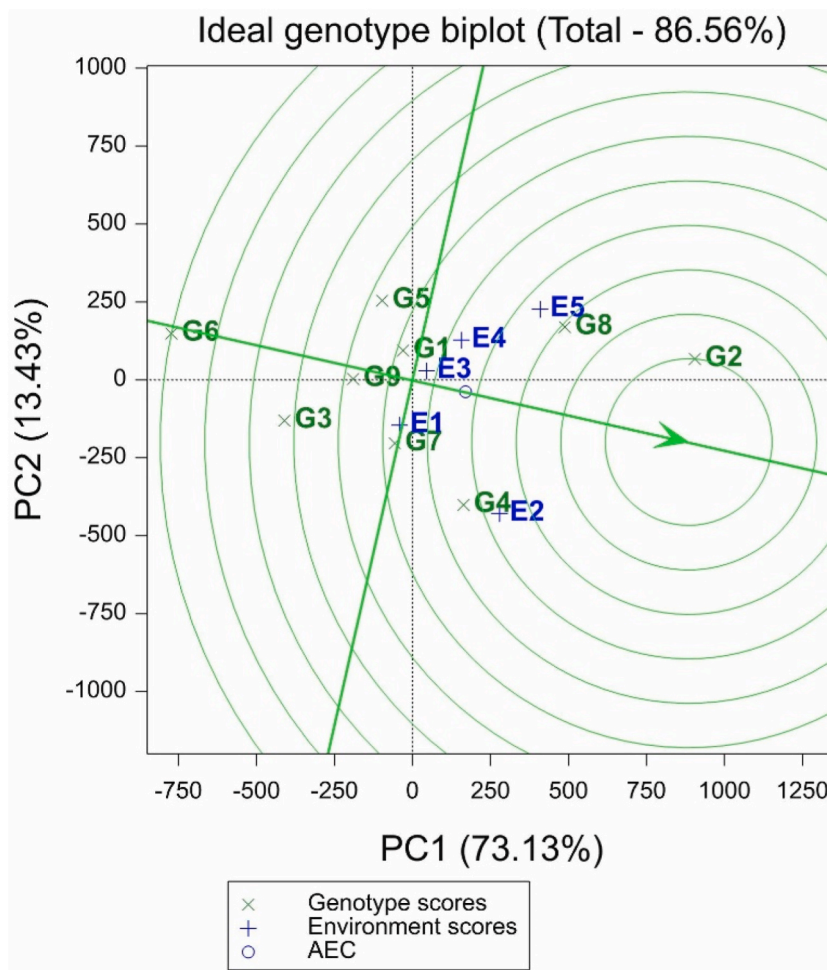


Fig. 4. GGE biplot of the nine sorghum genotypes showing the “ideal genotype” for grain yield.

groups one and two on PC1, and groups three and four on PC2. Group one consisting of G2, G9, and G7, group two consisting of G1 and G6, group three consisting of G3 and group four consists of G8 and G4. PC1 is explained by the variables SgMFPr, GsWFPr, GsWCyA, GsWGrP, GsWDrT, SgMDrT, SgMGrH, and GsMGIA, which account for 59.34% of the total variance carried by the axis. These variables are all positively and significantly correlated with the axis. PC2 is explained by the variables SgWGrP, SgWCyA, SgWGrH, SgWDrT, SgMGrP, SgMCyA, and SgWGIA, which account for 61.53% of the total variance carried by the axis. These variables are also positively and significantly correlated with the axis. G2, G4, G7, G8, and G9 obtained on average relatively higher scores across the five assessment criteria (CyA, GrP, GrH, DrT, and FPr) and global acceptance compared to the group consisting of genotypes G1, G3, G5, and G6.

## 4. Discussion

### 4.1. On-field performance of genotypes and environments qualities

In this study, the performance and adaptability of local sorghum varieties were investigated under five environments where both intra- and inter-environment variation were observed. The significant differences between genotypes for grain yield within the same environment could imply that the genotypes exhibit variation in their ability to adapt to the growing environmental conditions (water, nutrients, light, tolerance to various biotic and abiotic stresses encountered). Furthermore, results from the combined analysis of variance on grain yield across the five environments indicates that the environment effect (29%) had the greatest influence on genotype performance compared to all the sources of variation (Table 4). However, this variation remains relatively low compared to those reported by Rakshit et al. [34], Aruna et al. [35], Admas and Tesfaye [36] on sorghum, Ruswandi et al. [37] on maize, Yan et al. [30], Hagos and Abay [38] on wheat. While the trials were conducted in fields with the same soil texture (sandy-clay), these may differ in their natural fertility; also, the nutrient content of the compost used could differ from one farmer to another, thereby influencing the phenotypic response of the genotypes in the trials.

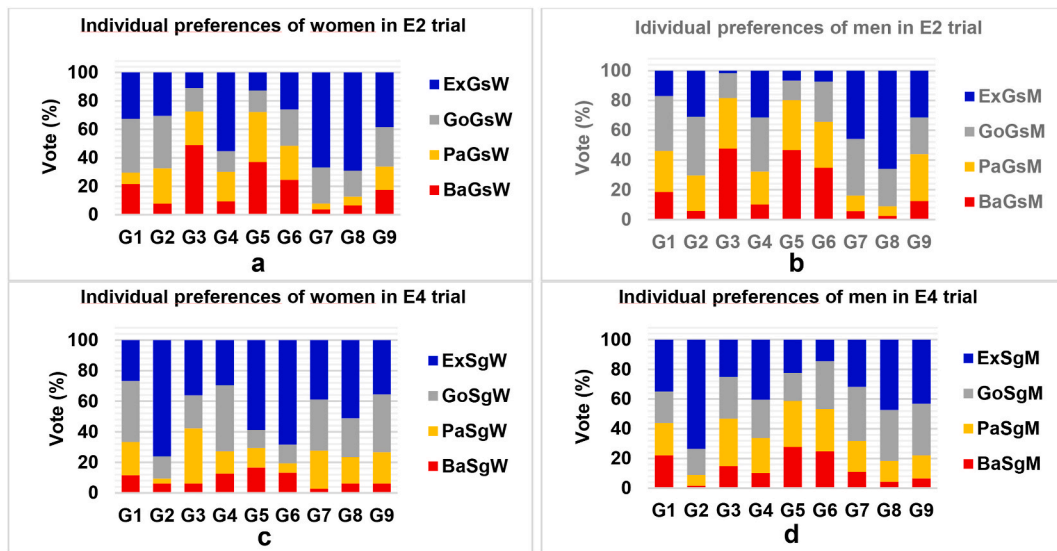


Fig. 5. a–d. Individual preferences of genotypes in the environments E2 and E4 in 2019 and 2020 participatory assessment.

Legend. Ba = bad, Pa = passable, Go = good, Ex = excellent.

GsW = Gassan women, GsM = Gassan men, SgW = Sourgoubila women, SgM = Sourgoubila men.

The presence of highly significant interactions (GE, GEY) indicated that the genotypes responded differently in the five environments and to the inter-annual variation of growing conditions of the environments. The results also showed inconsistent performance and rankings from one environment to another (Table 5), presuming the presence of “crossover-type GE” across some environments [23]. With regard to the inter-annual variation, the observed difference could be explained by changes in sowing dates (Supplementary material), the amounts of water received and their distribution during the growing season, and potentially to the stresses that occurring in one environment but not in another. In Burkina Faso, where sorghum is grown under rainfed conditions, water deficits are recurrent at the heading-flowering-grain filling stages and can affect yield parameters. The rainfall was less favourable in 2019 and 2021 compared to 2020 across the five environments. Tuinstra et al. [39] and Impa et al. [40] reported that post-flowering droughts induce a shorter grain-filling phase, resulting in reduced grain size and weight in sorghum. Genotypes that have physiological abilities to regulate their water demands or a root structure that gives them better accessibility to soil water may have been more favoured. Indeed, Singh et al. [41] and Mace et al. [42] reported that plants’ root system architecture determines their ability to access soil water and, therefore, their ability to tolerate water-limiting conditions in the soil.

The GGE biplot approach allowed good readability of the performance of environments (Figs. 1 and 2) as well as that of genotypes within environments (Figs. 3 and 4). In terms of “good trial environments”, Yan [43], Yan and Tinker [23], Yan et al. [44] reported that within the same mega-environment, the “ideal test environment” should be the most discriminating (informative) and also the most representative of the target environments to select genotypes with wide adaptability. In this study, E1 is the unique environment in the ME1, it is less informative and the least performing of all environments, therefore presenting a low agronomic interest. As well as the E3 environment (poor and not discriminating), it could be abandoned for yield trials. The E5 environment, owing to its location closest to the centre of the concentric circles (Fig. 2) is the most appropriate for selecting high-performing genotypes in terms of grain yield with a relatively wide adaptation potential. This result further validates its interest in varietal experimentation. E2 is a discriminating but not representative environment for grain yield. According to Yan and Tinker [23], this kind of environment is useful for selecting genotypes with specific adaptations. Mohammadi et al. [45], Akter et al. [46], and Worede et al. [47], in their respective studies on wheat, rice, and sorghum, also found discriminating and representative environments and discriminating but non-representative environments. If some authors suggest selection for general adaptation in environments [48], others [34,36,49] lean towards selection for the specific adaptation that would allow better valorization of different production areas. In the North-Sudanian zone, where this study was conducted, the variability between environments is relatively high, and selection for general adaptability is important not only to maintain yield stability in a wide range of environments but also to better valorize the research efforts in Burkina Faso.

As an important parameter, grain yield stability depends on yield components and other plant characteristics, such as pest resistance and tolerance to environmental stresses [50]. G6, with a regression coefficient of 0.1098 ( $b < 1$ ) (Table 5) was the least sensitive to environmental change. Fig. 4, which combines the information on stability and ideal genotype, G6 is located almost on the abscissa of the AEC, reflecting great stability in the environments, but it is positioned on the side of low yield values. Thus, G6 presents a great specificity of adaptation to poor environments, as well as G3 (check), G5, and G9. The genotype G7 has a regression value of almost 1, which means it has average stability; moreover, its yield ( $1942 \text{ kg ha}^{-1}$ ) is comparable to the average yield of environments ( $1924 \text{ kg ha}^{-1}$ ). Moreover, the groups’ (women vs. men) assessment scores showed that G7 has a good tolerance to water stress. This genotype could be grown in all five environments, but a significant improvement in grain yield should not be expected under the best environmental conditions. The stability results are in line with those reported by Rakshit et al. [34] and Enyew et al. [28]. These authors

**Table 6**

Variance of the traits assessed by the groups of women and men on the nine genotypes in the environments E2 and E4 trials in 2019 and 2020.

		Variance of the traits in the women's group assessment in trial E2							Variance of the traits in the women's group assessment in trial E4						
		CyA	GrP	GrH	FPr	DrT	GlA	MrK	CyA	GrP	GrH	FPr	DrT	GlA	MrK
Source of variation	D.F.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.
Genotype	8	0.04*	0.09**	0.09***	0.04ns	0.02ns	0.02ns	0.03*	0.09ns	0.10**	0.05ns	0.06ns	0.08ns	0.06ns	0.02ns
Year	1	0.01ns	0.04ns	0.01ns	0.01ns	0.00ns	0.00ns	0.00ns	0.25*	0.14**	0.00ns	0.25*	0.14ns	0.09ns	0.14*
Repetition	1	0.01ns	0.02ns	0.00ns	0.00ns	0.14*	0.02ns	0.02ns	0.03ns	0.02ns	0.02ns	0.00ns	0.09ns	0.04ns	0.04ns
Genotype.Year	8	0.04**	0.04ns	0.03ns	0.04ns	0.03ns	0.01ns	0.01ns	0.06ns	0.11**	0.05ns	0.02ns	0.07ns	0.09ns	0.05ns
Residual	17	0.01	0.02	0.02	0.03	0.02	0.02	0.01	0.04	0.02	0.04	0.04	0.04	0.04	0.03
s.e.d. (G)		0.07	0.10	0.09	0.11	0.11	0.09	0.06	0.14	0.09	0.14	0.14	0.14	0.13	0.11
s.e.d. (Y)		0.03	0.05	0.04	0.05	0.05	0.04	0.03	0.07	0.04	0.07	0.07	0.06	0.06	0.05
CV (%)		15.64	24.61	21.33	19.91	18.12	12.28	12.28	29.57	29.76	22.96	27.60	28.31	27.43	20.87
		Variance of the traits in the men groups assessment in trial E2							Variance of the traits in the men groups assessment in trial E4						
		CyA	GrP	GrH	FPr	DrT	GlA	MrK	CyA	GrP	GrH	FPr	DrT	GlA	MrK
Source of variation	D.F.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.
Genotype	8	0.07**	0.16***	0.12***	0.18***	0.04ns	0.30***	0.10***	0.19***	0.11***	0.13***	0.07ns	0.07ns	0.08**	0.37***
Year	1	0.06ns	0.03ns	0.00ns	0.21*	0.31***	0.19ns	0.30***	0.43***	0.00ns	0.06ns	0.25*	0.02ns	0.02ns	0.00ns
Repetition	1	0.03ns	0.08ns	0.00ns	0.00ns	0.01ns	0.01ns	0.01ns	0.05ns	0.00ns	0.00ns	0.04ns	0.00ns	0.07ns	0.00ns
Genotype.Year	8	0.13***	0.06*	0.08*	0.11*	0.05*	0.13*	0.05ns	0.10***	0.15***	0.11***	0.06ns	0.04ns	0.20***	0.03ns
Residual	107	0.02	0.02	0.03	0.04	0.02	0.06	0.03	0.02	0.02	0.02	0.05	0.04	0.03	0.03
s.e.d. (G)		0.06	0.06	0.07	0.08	0.06	0.09	0.06	0.03	0.03	0.06	0.09	0.07	0.04	0.05
s.e.d. (Y)		0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.02	0.02	0.03	0.04	0.03	0.02	0.02
CV (%)		20.95	22.45	24.01	32.94	20.32	35.50	22.42	21.35	20.35	21.57	30.33	22.43	23.02	25.60

Legend. D.F. = degree of freedom, M.S. = mean squares.

CyA (Cycle Adaptability), GrP (Grain Productivity), GrH (Grain Hardness), FPr (Fodder Productivity), DrT (Drought Tolerance), GlA (Global Acceptance), MrK (Marketing).

GsW = Gassan women, GsM = Gassan men, SgW = Sourgoubila women, SgM = Sourgoubila men, ns = non-significant, \*, \*\* and \*\*\* significant at the 0.05, 0.01 and 0.001 probability levels.

s.e.d. (G) = standard errors of differences of means for genotypes, s.e.d. (Y) = standard errors of differences of means for year, CV = coefficient of variation.

**Table 7**

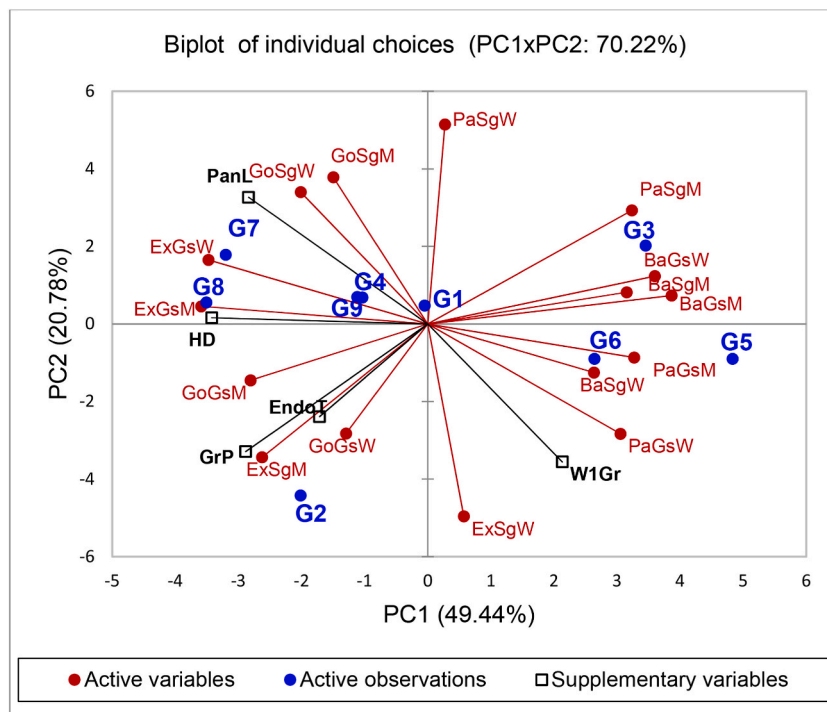
Average scores attributed to the genotypes by the groups of men and women in the environments E2 and E4 trials in 2019 and 2020.

Genotype Code	Cycle Adaptability		Grain Productivity		Grain Hardness		Fodder Productivity		Drought Tolerance		Mean of the five traits		Global Acceptance		Marketing	
	GsW	GsM	GsW	GsM	GsW	GsM	GsW	GsM	GsW	GsM	GsW	GsM	GsW	GsM	GsW	GsM
G1	3.00	2.86	2.75	3.21	3.00	3.00	3.00	2.71	3.25	3.00	3.00	2.96	3.75	2.64	4.00	3.07
G2	4.00	3.43	3.75	3.50	4.00	3.29	3.75	3.29	4.00	3.43	3.90	3.39	4.00	3.29	4.00	3.07
G3 (Check)	4.00	3.64	2.50	2.71	2.25	2.57	3.00	3.50	3.50	3.14	3.05	3.11	3.25	2.00	3.00	2.79
G4	3.75	3.29	3.75	3.50	4.00	3.57	3.75	2.86	3.25	3.00	3.70	3.24	4.00	3.43	4.00	3.43
G5	4.00	3.71	2.75	2.93	3.75	3.21	3.75	2.50	3.75	3.57	3.60	3.19	4.00	3.14	4.00	3.79
G6	3.50	3.57	2.50	2.79	3.00	3.14	3.00	2.07	3.25	3.14	3.05	2.94	3.50	2.57	3.75	3.57
G7	3.75	3.57	3.25	3.71	3.50	3.57	3.75	3.21	3.75	3.43	3.60	3.50	4.00	3.50	3.75	3.29
G8	4.00	3.79	4.00	3.86	3.75	3.79	3.50	2.57	3.75	3.50	3.80	3.50	4.00	3.86	4.00	3.71
G9	4.00	3.71	3.50	3.71	3.75	3.57	4.00	3.14	3.75	3.36	3.80	3.50	3.75	3.50	3.75	3.64
V.R. (G)	2.7*	3.1**	4.4**	7.0***	5.8***	3.9***	1.5ns	4.3***	0.9ns	1.8ns	6.4***	3.7***	1.1ns	5.5***	3.2*	3.7***
V.R. (Y)	0.7ns	2.53ns	2.25ns	1.12ns	0.47ns	0.03ns	0.27ns	4.95*	0.08ns	13.9***	0.21ns	6.45*	0.11ns	3.39ns	0.21ns	10.8***
s.e.d. (G)	0.29	0.23	0.39	0.23	0.34	0.27	0.45	0.31	0.43	0.23	0.20	0.17	0.35	0.35	0.26	0.25
	SgW	SgM	SgW	SgM	SgW	SgM	SgW	SgM	SgW	SgM	SgW	SgM	SgW	SgM	SgW	SgM
G1	2.50	2.57	2.25	2.93	2.75	3.14	3.00	2.71	3.00	2.79	2.70	2.83	2.50	3.00	3.00	3.57
G2	4.00	3.71	4.00	3.71	4.00	3.86	3.75	3.57	4.00	3.86	3.95	3.74	4.00	3.71	4.00	3.86
G3 (Check)	4.00	3.86	4.00	4.00	4.00	3.64	3.50	3.21	4.00	3.50	3.90	3.64	4.00	3.79	3.75	3.07
G4	3.25	3.14	3.00	3.41	3.50	3.86	2.50	3.14	3.25	3.43	3.10	3.34	3.75	3.64	3.75	4.00
G5	3.75	4.00	3.50	3.50	3.50	3.07	2.75	2.93	3.75	3.50	3.45	3.40	3.25	3.07	3.25	2.50
G6	3.75	4.00	3.75	3.64	4.00	2.93	2.75	2.93	3.75	3.50	3.60	3.40	3.50	3.14	3.50	2.43
G7	3.25	3.29	3.25	3.14	3.50	3.79	3.50	3.00	3.50	3.43	3.40	3.33	3.50	3.57	3.50	3.93
G8	2.50	3.50	2.50	3.64	3.25	3.86	2.50	3.36	2.25	3.57	2.60	3.59	3.00	3.64	3.50	4.00
G9	3.00	3.36	3.00	3.14	3.25	3.79	2.75	3.50	3.25	3.57	3.05	3.47	3.25	3.57	3.50	4.00
V.R. (G)	2.2ns	13.0***	602***	6.8***	1.1ns	5.3***	1.4ns	1.3ns	2.1ns	2.0ns	2.6*	5.4***	1.6ns	3.2**	0.9ns	13.4***
V.R. (Y)	6.44*	29.6***	9.0**	0.09ns	0.04ns	2.59ns	6.18*	4.65*	3.77ns	0.47ns	5.65*	8.09**	2.36ns	0.67ns	5.62*	0.05ns
s.e.d. (G)	0.56	0.18	0.35	0.19	0.58	0.24	0.57	0.35	0.55	0.29	0.43	0.16	0.54	0.24	0.45	0.25

Legend. GsW = Gassan women, GsM = Gassan men, SgW = Sourgoubila women, SgM = Sourgoubila men. V.R. (G) = variance ratio or calculated F for genotype, V.R. (Y) = variance ratio or calculated F for year, s.e.d. (Y) = standard errors of differences of means for year.

ns = non-significant, \*, \*\* and \*\*\* significant at the 0.05, 0.01 and 0.001 probability levels.





**Fig. 6.** Principal component analysis (PCA) showing the structuring of the nine sorghum genotypes based on individuals' preferences in the E2 and E4 trials.

Legend. Ba = bad, Pa = passable, Go = good, Ex = excellent.

GsW = Gassan women, GsM = Gassan men, SgW = Sourgoubila women, SgM = Sourgoubila men

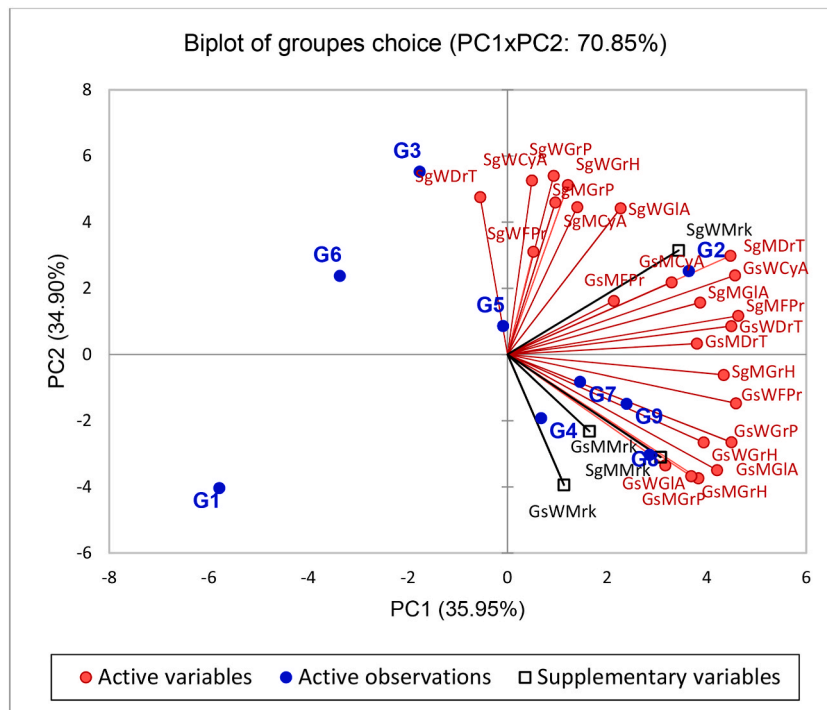
GrP = grain productivity, W1Gr = 100 grain weight, PanL = panicle length, EndoT = endosperm texture, HD = number of days from sowing to 50% heading.

found on sorghum (in India and Ethiopia, respectively) that the most stable genotypes were not the best performing for grain yield. Our results showed that there was no absolute "ideal genotype" as defined by Yan and Tinker [23], Akash et al. [51], and Teodoro et al. [52]. However, among all genotypes, G2 (Gnouga) was found to have the closest characteristics of the "ideal genotype" (Fig. 4), therefore foreseen to be the most desirable in ME2, followed by G8. In terms of performance, according to regression values, G2, G4, and G8 showed a good ability to exploit favourable and "non-limiting" environmental conditions (soil rich in nutrients, not deficient in water, etc.).

#### 4.2. Farmers' choices and preferences

The assessment of the phenotypic performance of the genotypes at the grain maturity stage by farmers and users (consumers, traders, and processors), based on the five criteria (cycle adaptation to the growing area, panicle productivity, grain hardness, fodder productivity, and drought tolerance) showed differences in individual and group choices for both women and men in the trials E2 and E4. The differences in individual choices (Fig. 5a–d) could be explained both by the personal interests of the evaluator and the weight that each evaluator gives to the criteria.

Despite the consensual choice of assessment traits, it is not excluded that each evaluator looks for genotypes that could best fit his/her growing context, production, and final use objectives. It is also likely that other criteria have been considered by evaluators. Indeed, in the group-based evaluations, before attributing the global acceptance score to each genotype, other criteria were discussed between the evaluators: for example, the women observed the non-adherence of the glumes, the characteristics of the pericarp to assess the ease of manual shelling, and the probability there is a significant part of bran or not. They also discussed the suitability of the grain for various local dishes and the flour yield by estimating the heaviness of the grain and checking the appearance of the endosperm after dissecting the grain between the teeth. Furthermore, they appreciated the market value of grain, which was more based on the appearance and attractiveness of the grain. As for the men, they discussed the ability of the genotype to adapt to different types of growing soils, the storability of the grain over a long period (more than one year), and the market value of the grain by examining the colour for different uses, the size and heaviness of the grain. A grain that is big and not heavy is less profitable to sell. In general, regardless of the criteria used, whether consensually defined or not, five genotypes emerged (G2, G8, G4, G7, and G9) with the highest scores and were highlighted by the PCA in both individual (Fig. 6) and group (Fig. 7) choices. These genotypes exhibited on average the highest grain yields. vom Brocke et al. [15] reported that in some areas of Burkina Faso, farmers prefer early-maturing varieties to their



**Fig. 7.** Principal component analysis (PCA) showing the structuring of the nine sorghum genotypes, based on groups' preferences for the five assessed criteria and on global acceptance in the E2 and E4 trials.

Legend. GsW = Gassan women, GsM = Gassan men, SgW = Sourgoubila women, SgM = Sourgoubila men.

Criteria: CyA = cycle adaptability, GrP = grain productivity, GrH = grain hardness, FoP = fodder productivity, DrT = drought tolerance, GIA = global acceptance, Mrk = market preferences.

local ones, probably owing to the rainfall variability and the recurrent post-flowering water deficits. In this study, the relatively early genotypes (G5 and G6) were generally well rated for cycle adaptation, but in the global acceptance, they appeared lowest in scoring. From the group assessments, these genotypes can be used to mitigate starvation, often observed at the end of the rainy season. However, when sown as earlier as the local varieties, they may be subjected to birds attack or damaged by molds in the event of prolonged rains at the end of maturity. Indeed, Diallo et al. [53] reported that for sorghum, grain loss in the field is an important parameter considered by farmers in Mali because sorghum is harvested late after other crops.

## 5. Conclusion

This study on the performance and grain yield stability of local sorghum genotypes showed that the performance of genotypes was influenced by both the quality of the growing environments and the inter-annual variation of the growing conditions in the environments. The results showed that E5 was an appropriate environment to identify performing genotypes with relatively large adaptations for grain yield, while E2 was a useful environment to identify genotypes with specific adaptations. Concerning the individual preferences of genotypes among farmers and users, the choices of men were slightly different from those of women. However, the genotype G8 was the most consistent among the best genotypes chosen in both environments (E2 and E4), followed by G2 and G7. In group preferences, G2 got the highest average score of all criteria as well as global acceptance for both women and men. For the most preferred genotypes (G2, G4, G7, and G8), additional studies are needed to better characterise them.

## Additional information

No additional information is available for this paper.

## Data availability statement

The data used for this article are available in Breeding Management System (BMS) through the "Institut de l'Environnement et de Recherches Agricoles (INERA)" portal.



## CRediT authorship contribution statement

**Clarisse Pulchérie Kondombo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Pierre Kaboré:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **David Kambou:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Issaka Ouédraogo:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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