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Phenotypical variability of four types of sorghum cultivated in intercropping conditions in two agroclimatic areas of Burkina Faso based on qualitative traits

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Sorghum (*Sorghum bicolor* (L.) Moench) is an indigenous crop in Africa, primarily cultivated to meet the food and commercial needs of rural communities. In Burkina Faso, various types of sorghum are cultivated together, potentially increasing gene flow and influencing the evolution of key morphological traits of interest. This study compared the morphological variability of four types of sorghum cultivated under intercropping conditions using qualitative morphological traits. The variability within and between sorghum types was estimated using 130 accessions in an incomplete Fisher block experimental design with three replications. Twenty-five qualitative traits (such as seedling colour, leaf spot colour, midrib colour, peduncle shape, grain shape, glume appearance, botanical breed, etc.) were observed during the study. The results indicated a morphological similarity between sorghum types for most traits. All types of sorghum had an erect stem, red leaf spots, positively exerted erect peduncle, and grains that were not sweet in the dry stage. This morphological similarity was very high between grain sorghum and sweet grain sorghum, varying according to the village and agroclimatic areas. The findings of this study could help establish a sustainable strategy for the management of sorghum genetic resources in Burkina Faso.

Key words: Sorghum, genetic resources, morphological variability, intercropping.

INTRODUCTION

In Sahelian countries such as Niger, Mali, Senegal, and Burkina Faso, cereals serve as the primary source of

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food (FAO, 2017). Sorghum (*Sorghum bicolor* (L.) Moench) is a commonly cultivated cereal crop used for human consumption in Burkina Faso. The prevalence of sorghum in the Sahel can be partly attributed to its varietal diversity, versatility, multiple uses, and adaptability to low rainfall, marginal soils, and high temperatures (Zongo, 1991; Chantereau et al., 2013). In Burkina Faso, sorghum ranks as the second most important cereal crop after maize (DGESS/MAAH, 2021).

Grain sorghum is the primary crop in the country, utilized in various local foods such as tô (prepared flour paste), couscous, and local beer (DGESS/MAAH, 2021). Besides regular grain sorghum, there are three other types: sweet grain sorghum, consumed at the soft dough stage; sweet sorghum, used similarly to sugarcane; and dyer sorghum, cultivated for artisanal purposes. These sorghum types play a crucial role in ensuring food self-sufficiency for the population (Nebié, 2014; Sawadogo, 2015), particularly in areas with low rainfall. They are often cultivated in overlapping areas, potentially leading to gene flow among them. According to Slatkin (1987), gene flow can give rise to new genotypes that may not always be well adapted to agricultural conditions. Previous studies have focused on the management methods and genetic diversity of grain sorghum (Zongo, 1991; Barro-Kondombo, 2010), sweet stalk sorghum (Nebié, 2014), and sweet grain sorghum (Sawadogo, 2015). Other studies have examined the genetic relationships between different types of sorghum.

These studies revealed low intra-type diversity of sorghum for qualitative characters (Sawadogo et al., 2022a) but high diversity for quantitative characters (Sawadogo et al., 2022b). On a molecular level, proximity was also observed between grain sorghum and sweet grain sorghum (Tuina, 2019; Tiendrebéogo et al., 2022). However, dyer sorghum was not included in these studies. Additionally, these studies utilized accessions already characterized and used in selection processes, which limits the assessment of the impact of co-cultivation of these sorghum types in a farming environment. To date, the impact of the coevolution of different types of sorghum on the organization of sorghum diversity in Burkina Faso remains partially described. An ethnobotanical survey was conducted, revealing flowering coincidences and significant phenotypic changes within sorghum types (Tuina et al., 2023). Describing the level of morphological variability of the different types of sorghum cultivated in intercropping conditions could help understand the impact of the farming system on sorghum genetic resources. Such knowledge is useful for developing a strategy for the conservation and improvement of each type of sorghum.

The aim of this research was, therefore, to describe the morphological variability of the types of sorghum. The purpose was to establish their morphological similarities or dissimilarities based on qualitative traits for better management of these types of sorghum.

MATERIALS AND METHODS

Plant

The plant materials consisted of 130 sorghum accessions, with ninety-seven accessions collected from farmers' fields in two agroclimatic areas of Burkina Faso and thirty-three control accessions (Table 1). The ninety-seven accessions from the collection were obtained from seven villages across two different agroclimatic zones: 67 from the North Sudanian zone and 30 from the sub-Sahelian zone.

The thirty-three control accessions, which are already used in the selection process, were included to compare their variability with the 97 collected accessions. Among these control accessions, five were sourced from the gene bank of the Biosciences Laboratory at Joseph KI-ZERBO University. These accessions were collected between 2008 and 2010, characterized, and preserved as part of the sorghum research program. The remaining twenty-eight control accessions were obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) gene bank in Mali collected between 2007 and 2008.

Experimental site

The agromorphological characterization was conducted from July 2021 to November 2021 at the Institute of Rural Development's experimental station in Gampèla, situated approximately 20 km from Ouagadougou (1°21’ W longitude and 12°24’ N latitude). The experimental plot had a predominantly sandy-loam texture. The pH of the water was 6.6. A total of 977 mm of rainfall was recorded over 45 days during the experimental period. The rainy season began in May and concluded in October, with June and August being the wettest months, receiving 196 and 378 mm of rainfall, respectively. Average daily temperatures during the rainy season (May to October) ranged from 27.1 to 33.5°C, with May and October being the hottest months.

Experimental design and data collection

An incomplete Fisher block experimental design with three replications was implemented on a total area of 1484.72 m² (53.6 × 27.7 m). Each block was subdivided into two sub-blocks, and each sub-block consisted of 68 lines. Each replication included 132 lines, with two border lines. Each line was 3.2 m long, with 0.8 m spacing between lines and 0.4 m between holes. The distances between replications and sub-blocks were 2 and 1.5 m, respectively. The plot was plowed with a tractor before planting. Two weeks after sowing, 100 kg/ha of NPK (14-23-14) fertilizer was applied to the plot. Urea was applied at a rate of 50 kg/ha during the panicle swelling stage. Data were collected throughout the entire plant growth cycle, recording twenty-four qualitative traits (Table 2).

Data analysis

The variants of qualitative traits for each type were summarized using Excel 2016 spreadsheet. Phenotypic frequency distributions of the traits were calculated for each sorghum type by village using SPSS 15.0 for Windows. To determine the morphological proximity and specific traits of each type of sorghum, a multiple component

Table 1. Origin of the accessions of different types of sorghum.

Agroclimatic areas	Provinces	Village	Types of sorghum	Number of accession
North sudanian	Kadiogo	Zambanega	Grain sorghum	13
			Sweet grain sorghum	5
		Sogué	Grain sorghum	2
			Sweet grain sorghum	2
			Dyer sorghum	3
	Boulkièmdé	Nakomtenga	Grain sorghum	16
			Sweet grain sorghum	10
			Dyer sorghum	2
	Bazèga	Lado	Grain sorghum	4
			Dyer sorghum	2
	Oubritenga	Loango	Grain sorghum	4
			Sweet grain sorghum	3
Sub-sahelian	Sanmatenga	Korsimoro	Grain sorghum	4
			Sweet grain sorghum	2
			Sweet sorghum	8
		Fulnakambogo	Grain sorghum	8
			Sweet grain sorghum	5
			Sweet sorghum	4
Gene bank		University Joseph KI-ZERBO (UJKZ)	Grain sorghum	2
			Sweet grain sorghum	2
			Sweet sorghum	1
		International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	Grain sorghum	10
			Sweet sorghum	18

Table 2. List of qualitative traits.

Stage	Trait	Abbreviation
Emergence	Seedling colour	SC
Flowering	Main stem status	MSS
Paste stage	Basal tiller status	BTS
	Leaf spot colour	LSC
	Presence or absence of aerial tillers	AT
	Midrib colour	MC
	Leaf sheath colour	LSCO
	Stem pith colour	SPC
	Exertion	EXE
	Peduncle shape	PS
	Panicle type	PT
	Botanical breed	BB

Table 2. Contd.

Maturity	Aristation	ARI
	Glume colour	GC
	Glume appearance	GA
	Stem succulence	SUC
	Grain coverage	GCO
	Type of ginning	TG
	Grain shape	GS
	Grain colour	GRC
	Fresh grain flavour	FGF
	Dry grain flavour	DGF
	Grain rotation	GRO
	grain endosperm texture	VIT

analysis (MCA) was carried out based on the most variable qualitative traits. This analysis was carried out using RStudio 4.1.3 software.

Shannon diversity was calculated according to the types of sorghum for each qualitative character according to the following formula: H'= $-\sum_{i=1}^{n} pi\ \ln(pi)$. Pi is the proportion of accessions in the i^{th} class of an n-class character and n is the number of phenotypic classes of traits. The average diversity index ($\bar{H'}$) over n traits by sorghum type was estimated as $\sum H'/n$.

RESULTS

Variation in qualitative traits related to stem and leaf

The qualitative traits related to stem and leaf (Figure 1) varied depending on the sorghum type and the surveyed villages (Table 3). All types of sorghum (grain sorghum, sweet grain sorghum, and dyer sorghum) from the village of Sogué exhibited erect stems, red leaf spots, aerial tillers, and no succulent stems. Discriminating traits included seedling colour (SC), midrib colour (MC), leaf sheath colour (LSCO), and pith colour (SPC). Grain sorghum and dyer sorghum displayed light red and light green seedlings, while sweet grain sorghum showed dark red seedlings. Additionally, grain sorghum and sweet grain sorghum had white midribs, green leaf sheaths, and white pith, whereas dyer sorghum had red midribs, reddish pith, and leaf sheaths.

The sorghum types from Sogué did not differ from those from the Joseph KI-ZERBO University gene bank in terms of stem status and the presence or absence of aerial tillers. Furthermore, grain sorghum and sweet grain sorghum from Sogué were similar to those from the Joseph KI-ZERBO University gene bank in midrib colour, leaf sheath colour, and stem succulence. Grain sorghum from Sogué was also similar to grain sorghum from the Joseph KI-ZERBO University gene bank in seedling colour and pith colour. However, dyer sorghum from Sogué differed from grain sorghum, sweet grain sorghum, and sweet sorghum from the Joseph KI-ZERBO University gene bank.

Comparison of the sorghum types from Sogué with grain sorghum and sweet sorghum from Mali revealed similarity in stem status and the presence or absence of aerial tillers. However, these sorghum types differed in other traits.

The two types of sorghum (grain sorghum and sweet grain sorghum) from the village of Zambanega exhibited erect stems and no succulent stems. Additionally, these sorghum types had red leaf spots, white midribs, red leaf sheaths, and white pith, and did not develop aerial tillers. Sweet grain sorghum typically had light green seedlings (80%), while grain sorghum displayed various seedling colors: light red (38.8%), dark red (7.7%), and light green (53.5%). Grain sorghum and sweet grain sorghum from Zambanega were similar to those from the Joseph KI-ZERBO University gene bank in terms of stem status and succulence; they both had erect stems and no succulent stems. However, these sorghum types differed in other traits.

The types of sorghum (grain sorghum, sweet grain sorghum, and dyer sorghum) from the village of Nakomtenga had erect stems, red leaf spots, and white midribs. These sorghum types did not develop aerial tillers, and their stems were not succulent. Additionally, grain sorghum and sweet grain sorghum mainly had white pith. Dyer sorghum differed from the others with its dark red seedlings and reddish pith. Some accessions of grain sorghum exhibited succulent stems (6.2%). Grain sorghum, sweet grain sorghum, and dyer sorghum from Nakomtenga were similar to those from the Joseph KI-ZERBO University gene bank in terms of stem status, midrib colour, and stem succulence. However, differences were observed in other traits. Dyer sorghum from Nakomtenga was also similar to grain sorghum from Mali in terms of the presence or absence of aerial tillers

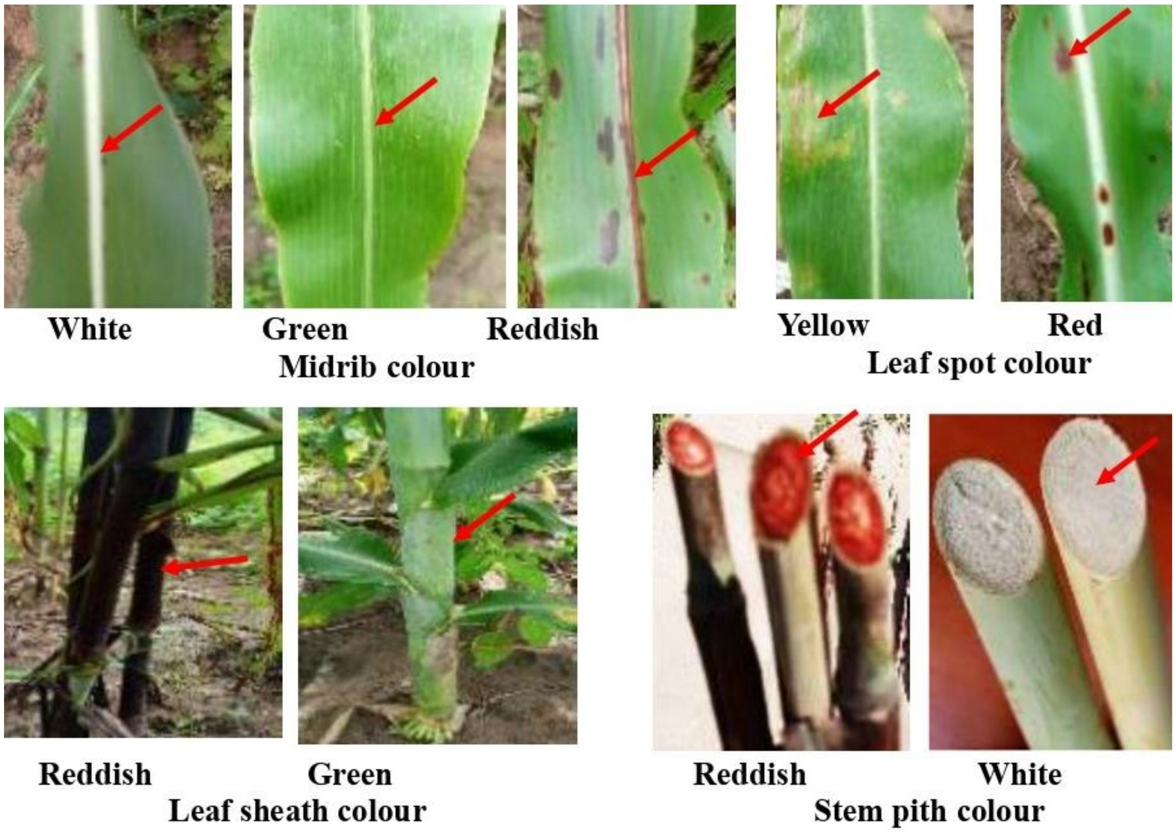

Figure 1. Variation in midrib colour, leaf spot colour, leaf sheath and pith colour.

and succulent stems, but differed in other traits.

There was only a minor difference between grain sorghum and dyer sorghum from the village of Lado. These sorghum types had light red and light green seedlings, erect stems, greenish leaf sheaths, white midribs, reddish pith, and succulent stems, but did not develop aerial tillers. Dyer sorghum differed from grain sorghum by the absence of yellow leaf spots. Grain sorghum and dyer sorghum from Lado were also similar to grain sorghum, sweet grain sorghum, and sweet sorghum from the Joseph KI-ZERBO University gene bank in terms of stem status, midrib colour, leaf sheath colour, and the presence or absence of aerial tillers. However, grain sorghum and dyer sorghum from Lado differed from grain sorghum and sweet sorghum from Mali in all traits except leaf sheath colour.

Both types of sorghum (grain sorghum and sweet grain sorghum) from the village of Loango exhibited erect stems, red leaf spots, green sheaths, white midribs, and no aerial tillers. Grain sorghum differed from sweet grain sorghum by its light red seedlings, absence of reddish pith, and the presence of succulent stems. Grain sorghum and sweet grain sorghum from Loango were similar to grain sorghum, sweet grain sorghum, and sweet sorghum from the Joseph KI-ZERBO University gene bank in terms of stem status, midrib colour, leaf sheath colour, and the presence or absence of aerial tillers. Comparison of grain sorghum and sweet grain sorghum from Loango with grain sorghum and sweet sorghum from Mali showed differences in all traits except leaf sheath colour.

The sorghum types from the village of Korsimoro (grain sorghum, sweet sorghum, and sweet grain sorghum) mostly exhibited erect stems with aerial tillers, reddish leaf spots, greenish leaf sheaths, and white pith. Grain sorghum and sweet grain sorghum had white midribs, non-succulent stems, and mostly green seedlings. Sweet sorghum predominantly had light red seedlings (88.9%), green midribs, and succulent stems. These sorghum types from Korsimoro did not differ from those in the Joseph KI-ZERBO University gene bank in terms of stem status. Additionally, grain sorghum and sweet grain sorghum from Korsimoro were similar to those from the Joseph KI-ZERBO University gene bank in midrib colour and the presence or absence of succulent stems. However, these types of sorghum differed from those from Mali in all traits.

The grain sorghum, sweet sorghum, and sweet grain

Table 3. Variation in qualitative traits related to vegetative development.

Agroclimatic areas	Villages	Type	SC			MSS		BTS		LSC		MC			LSCO		SPC		AT		SUC	
			Light red	Dark red	Light green	Erect	Drooping	Erect	Drooping	Red	Yellow	White	Green	Red	Reddish	Greenish	White	Reddish	Absence	Presence	No succulent	Succulent
North sudanian	Sogué	GS	50.0	0	50.0	100.0	0	100.0	0	100.0	0	100.0	0	0.0	0.0	100.0	100.0	0.0	100.0	0	100.0	0
		SGS	0.0	0	100.0	100.0	0	100.0	0	100.0	0	100.0	0	0.0	0.0	100.0	80.0	20.0	100.0	0	100.0	0
		DS	33.3	0	66.7	100.0	0	100.0	0	100.0	0	0.0	0	100.0	100.0	0.0	0.0	100.0	100.0	0	100.0	0
	Zambanega	GS	38.5	7.7	53.8	100.0	0	100.0	0	92.3	7.7	100.0	0	0.0	7.7	92.3	100.0	0.0	84.6	15.4	100.0	0
		SGS	20.0	0.0	80.0	100.0	0	100.0	0	100.0	0.0	80.0	0	20.0	20.0	80.0	80.0	20.0	80.0	20.0	100.0	0
	Nakomtenga	GS	37.5	18.8	43.8	100.0	0	100.0	0	100.0	0	100.0	0	0	31.2	68.7	100.0	0.0	87.5	12.5	93.8	6.2
		SGS	50.0	10.0	40.0	100.0	0	100.0	0	100.0	0	100.0	0	0	30.0	70.0	90.0	10.0	90.0	10.0	100.0	0.0
		DS	0.0	100.0	0.0	100.0	0	100.0	0	100.0	0	100.0	0	0	50.0	50.0	0.0	100.0	100.0	0.0	100.0	0.0
	Lado	GS	50.0	0	50.0	100.0	0	100.0	0	75.0	25.0	100.0	0	0.0	0	100.0	100.0	0.0	100.0	0	100.0	0
		DS	66.7	0	33.3	100.0	0	100.0	0	100.0	0.0	100.0	0	0.0	0	100.0	100.0	0.0	100.0	0	100.0	0
	Loango	GS	25.0	0	75.0	100.0	0	100.0	0	100.0	0	100.0	0	0	0	100.0	100.0	0.0	100.0	0	50.0	50.0
		SGS	0.0	0	100.0	100.0	0	100.0	0	100.0	0	100.0	0	0	0	100.0	66.7	33.3	100.0	0	100.0	0.0
Sub-sahelian	Korsimoro	GS	25.0	0	75.0	100.0	0	100.0	0	100.0	0	100.0	0.0	0	25.0	75.0	100.0	0.0	100.0	0.0	100.0	0.0
		SGS	0.0	0	100.0	100.0	0	100.0	0	100.0	0	100.0	0.0	0	0.0	100.0	100.0	0.0	60.0	40.0	100.0	0.0
		SS	88.9	0	11.1	100.0	0	100.0	0	100.0	0	22.2	77.8	0	11.1	88.8	86.7	13.3	77.8	22.2	0.0	100.0
	Fulnakambogo	GS	12.5	12.5	75.0	100.0	0.0	100.0	0.0	87.5	12.5	100.0	0.0	0	25.0	75	87.5	12.5	87.5	12.5	100.0	0.0
		SGS	0.0	33.3	66.7	66.7	33.3	66.7	33.3	100.0	0.0	100.0	0.0	0	33.3	66.7	66.7	33.3	66.7	33.3	100.0	0.0
		SS	75.5	24.5	0.0	100.0	0.0	100.0	0.0	75.0	25.0	75.0	25.0	0	0.0	100	75.0	25.0	100.0	0.0	20.0	70.0
Gene bank	Joseph KI-ZERBO University	GS	50.0	0.0	50.0	100	0	100	0	0.0	100.0	100.0	0.0	0.0	0.0	100.0	100.0	0.0	100.0	0.0	100.0	0.0
		SGS	0.0	0.0	100.0	100	0	100	0	100.0	0.0	100.0	0.0	0.0	0.0	100.0	90.0	10.0	100.0	0.0	100.0	0.0
		SS	0.0	100.0	0.0	100	0	100	0	100.0	0.0	100.0	0.0	0.0	0.0	100.0	100.0	0.0	100.0	0.0	0.0	100.0
Gene bank	ICRISAT (Mali)	GS	0.0	0.0	100.0	90.0	10.0	90.0	10.0	80.0	20.0	90.0	0	10.0	0	100.0	80.0	20.0	100.0	0.0	100	0
		SS	33.3	16.7	50.0	100.0	0.0	100.0	0.0	55.6	44.4	100.0	0	0.0	0	100.0	94.4	5.6	94.4	5.6	0	100

GS: Grain sorghum, SGS: Sweet grain sorghum, SS: Sweet sorghum, DS: Dyer sorghum, SC: Seedling colour, MSS: Main stalk status, BTS: Basal Tiller status, LSC: Leaf spot colour, MC: Midrib colour, LSCO: Leaf sheath colour, SPC: Stem pith colour, AT: Aerial tillers, SUC: Stem succulence.

sorghum from the village of Fulnakambogo exhibited erect stems, aerial tillers, reddish leaf spots, green midribs, greenish leaf sheaths, and white pith. Variability was observed among these sorghum types for other traits. Sweet sorghum predominantly had light red seedlings (75.5%), green midribs (25%), and succulent stems. Sweet grain sorghum and grain sorghum mostly had light green seedlings and non-succulent stems. Grain sorghum and sweet grain sorghum from Fulnakambogo were similar to those from the Joseph KI-ZERBO University gene bank in terms

Figure 2. Variation in panicle size according to sorghum type.

of stem status, midrib colour, and stem succulence. However, grain sorghum, sweet sorghum, and sweet grain sorghum from Fulnakambogo differed from types of sorghum from Mali in all traits.

Variation in traits related to panicle and glume

A high variation was observed in panicle and glume-related traits (Figure 2). From the village of Sogué, there were no differences among sorghum types in terms of exertion type (EXE) and peduncle shape (PS) (Table 4). All types of sorghum exhibited positive exertion and erect peduncles. Additionally, grain sorghum and sweet grain sorghum did not differ in panicle type and glume appearance; these types displayed loose panicles and either hairy glumes (50%) or hairless glumes (50%). Dyer sorghum, however, had compact panicles and hairless glumes. Nevertheless, the sorghum types from Sogué village differed in aristation, grain coverage, and glume colour. All types of sorghum from Sogué were similar to grain sorghum, sweet grain sorghum, and sweet sorghum from the Joseph KI-ZERBO University gene bank in terms of peduncle shape (erect peduncle). Sweet grain sorghum from Sogué did not differ from sweet grain sorghum from the Joseph KI-ZERBO University gene bank in terms of exertion type and aristation; all accessions exhibited positive exertion and lacked aristation. However, these sorghum types differed in other traits. The sorghum types from Sogué differed from grain sorghum and sweet sorghum from Mali in all qualitative traits.

The sorghum types (grain sorghum and sweet grain sorghum) from the village of Zambanega had erect peduncles and positive exertion. The majority (at least 84.6%) of accessions of these sorghum types had loose panicles. However, these two types of sorghum differed in all other traits. Grain sorghum exhibited various glume colours, including straw (7.7%), black (61.5%), light brown (7.7%), and dark brown (23.1%). The majority of this type of sorghum's accessions had hairless glumes and grain coverage at 25%. All accessions developed aristation. In contrast, sweet grain sorghum exhibited no aristation, hairy glumes, straw glumes (80%), and grain coverage at 50%. Grain sorghum and sweet grain sorghum from Zambanega were similar to grain sorghum, sweet grain sorghum, and sweet sorghum from the Joseph KI-ZERBO University gene bank in terms of peduncle shape; these types had erect peduncles. Additionally, sweet grain sorghum from Zambanega was similar to sweet grain sorghum from the Joseph KI-ZERBO University gene bank in terms of exertion type,

Table 4. Variation in qualitative traits related panicles and glumes.

Area	Village	Type	EXE		PS		PT			ARI		GC					GA		GCO			
			Positive	Negative	Erect	Curved	Loose	Semi-compact	Compact	Absence	Presence	Straw	Black	Red	Light brown	Dark brown	Hairly	Hairless	25 %	50 %	75 %	Fully
North Sudanian	Sogué	GS	100.0	0	100.0	0	100.0	0	0	0.0	100.0	50.0	50.0	0.0	0.0	0.0	50.0	50.0	56.0	0.0	44.0	0
		SGS	100.0	0	100.0	0	100.0	0	0	100.0	0.0	0.0	0.0	0.0	39.5	60.5	50.0	50.0	0.0	100.0	0.0	0
		DS	100.0	0	100.0	0	0.0	0	100.0	100.0	0.0	0.0	0.0	66.7	33.3	0.0	0.0	100.0	0.0	0.0	100.0	0
	Zambanega	GS	100.0	0	100.0	0	84.6	15.4	0	0.0	100.0	7.7	61.5	0	7.7	23.1	23.1	76.9	53.8	38.5	7.7	0
		SGS	100.0	0	100.0	0	100.0	0.0	0	100.0	0.0	80.0	0.0	0	20.0	0.0	100.0	0.0	0.0	100.0	0.0	0
	Nakomtenga	GS	100.0	0	100.0	0	81.2	6.2	12.5	12.5	87.5	6.2	75.0	6.2	0.0	12.5	18.8	81.2	62.5	37.5	0	0
		SGS	100.0	0	100.0	0	90.0	10.0	0.0	40.0	60.0	40.0	50.0	0.0	10.0	0.0	50.0	50.0	30.0	70.0	0	0
		DS	100.0	0	100.0	0	0.0	0.0	100.0	100.0	0.0	0.0	0.0	50.0	0.0	50.0	0.0	100.0	0.0	100.0	0	0
	Lado	GS	100.0	0	100.0	0	100.0	0.0	0	0	100.0	25.0	75.0	0	0	0.0	0.0	100.0	75.0	0.0	25.0	0
		DS	100.0	0	100.0	0	68.7	31.3	0	0	100.0	0.0	66.7	0	0	33.3	33.3	66.7	33.3	66.7	0.0	0
	Loango	GS	100.0	0	100.0	0	75.0	25.0	0	20.0	80.0	0	0	0	75.0	25.0	25.0	75.0	50.0	25.0	25.0	0
		SGS	100.0	0	100.0	0	100.0	0.0	0	76.7	23.3	0	0	0	33.3	66.7	69.7	30.3	53.3	33.4	13.3	0
Sub-Sahelian	Korsimoro	GS	100.0	0	100.0	0.0	100.0	0.0	0.0	0.0	100.0	0.0	50.0	0	50.0	0.0	0.0	100.0	75.0	25.0	0.0	0.0
		SGS	100.0	0	100.0	0.0	100.0	0.0	0.0	100.0	0.0	50.0	0.0	0	50.0	0.0	60.0	40.0	0.0	100.0	0.0	0.0
		SS	100.0	0	77.8	22.2	33.4	22.2	44.4	66.7	33.3	0.0	88.9	0	0.0	11.1	44.4	55.6	44.4	22.2	22.2	11.2
	Fulnakambogo	GS	100.0	0	100.0	0	87.5	12.5	0.0	12.5	87.5	0.0	37.5	0.0	25.0	37.5	25.0	75.0	62.5	37.5	0	0
		SGS	100.0	0	100.0	0	100.0	0.0	0.0	66.7	33.3	37.3	32.4	34.3	0.0	0.0	33.8	66.7	0.0	100.0	0	0
		SS	100.0	0	100.0	0	0.0	0.0	100.0	100.0	0.0	0.0	75.0	0.0	25.0	0.0	75.0	25.0	0.0	100.0	0	0
Gene Bank	Joseph KI-ZERBO University	GS	50.0	50.0	100.0	0	0.0	50.0	50.0	100.0	0	100.0	0	0	0	0	50.0	50.0	50.0	0	50.0	0
		SGS	100.0	0.0	100.0	0	100.0	0.0	0.0	100.0	0	100.0	0	0	0	0	100.0	0.0	0	100.0	0	0
		SS	100.0	0.0	100.0	0	0.0	100.0	0.0	100.0	0	0	100.0	0	0	0	0.0	100.0	0	0	0	100.0
	ICRISAT (Mali)	GS	100.0	0.0	100.0	0.0	90.0	10.0	0.0	10.0	90.0	20.0	40.0	20.0	10.0	10.0	0.0	100.0	30.0	40.0	30.0	0.0
		SS	88.9	11.1	100.0	0.0	22.2	50.0	27.8	77.8	22.2	44.4	38.9	11.1	0.0	5.6	72.2	27.8	16.7	27.8	50.0	5.6

GS: Grain sorghum, SGS: Sweet grain sorghum, SS: Sweet sorghum, DS: Dyer sorghum, EXE: Exertion, PS: Peduncle shape, PT: Panicle type, ARI: Aristation, GC: glume colour, GA: glume appearance GCO: Grain cover.

panicle type, and aristation; these accessions exhibited positive exertion, erect peduncles, and no aristation. However, these accessions differed in other traits. The sorghum types from Zambanega differed from Mali sorghum types in all traits except for peduncle shape.

There was no difference among grain sorghum, sweet grain sorghum, and dyer sorghum from Nakomtenga in terms of exertion type and peduncle shape; all accessions exhibited positive exertion and erect peduncles. However, these sorghum types differed in all other traits. Grain sorghum and sweet sorghum had loose panicles, black hairless glumes with aristation. The majority of grain sorghum accessions (62.5%) had covered grains at 25%, while sweet grain sorghum accessions (70%) had covered grains at 50%. Dyer sorghum had compact panicles with hairless glumes that were red (50%) or dark brown (50%) and covered grains at 50%. Grain sorghum, sweet grain sorghum, and dyer sorghum from Nakomtenga differed from those from the Joseph KI-ZERBO University gene bank in all traits except for peduncle shape. However, dyer sorghum from Nakomtenga and sweet sorghum from Joseph KI-ZERBO University were similar in exertion type, aristation, and glume appearance; these accessions exhibited positive exertion, hairless glumes, and no aerial tillers. The sorghum types from Nakomtenga differed from grain sorghum and sweet sorghum from Mali in all traits except peduncle shape.

Grain and dyer sorghums from Lado were similar in peduncle shape, exertion type, aristation, and glume color. Accessions of these sorghum types had erect peduncles, positive exertion, aristation, and mostly black glumes.

However, these sorghum types differed in other traits. Grain sorghum had loose panicles, hairless glumes covering 25% of the grain. Dyer sorghum had mostly loose panicles (68.7%), hairless glumes (66.7%), and covered grains at 50% (66.7%). Grain and dyer sorghums from Lado were not different from those from the Joseph KI-ZERBO University gene bank and from Mali in terms of peduncle shape; however, differences were observed in other traits.

There were no differences between grain sorghum and sweet grain sorghum from Loango in peduncle shape, exertion type, panicle type, and covered grains. Both types of sorghum had erect peduncles, positive exertion, loose panicles, and covered grains (25%). However, these sorghum types differed in other traits. Most grain sorghum exhibited aristation (80%), hairless (75%), and light brown (75%) glumes. Most (76.7%) of the sweet grain sorghum had no aristation, were hairy (69.7%), and had dark brown glumes (66.7%). Grain and sweet grain sorghums from Loango were not different from grain sorghum, sweet grain sorghum, and sweet sorghum from the Joseph KI-ZERBO University gene bank in terms of peduncle shape; however, these sorghum types differed in other traits. Similar observations were made with accessions from Mali.

Grain sorghum, sweet grain sorghum, and sweet sorghum from Korsimoro were not different in exertion type; all types exhibited positive exertion. Grain and sweet grain sorghums had erect peduncles and loose panicles, while sweet sorghum had erect (77.8%) or curved (22.2%) peduncles with variable panicle shapes: loose (33.4%), semi-compact (22.2%), and compact (44.4%). Grain sorghum had aristation, black or light brown hairless glumes covering 25% of the grains. Sweet grain sorghum had no aristation, mostly hairless straw or light brown glumes, with variable grain coverage: 25%, 50%, 75%, or completely covered. Grain and sweet grain sorghums from Korsimoro did not differ from those collected from the Joseph KI-ZERBO University gene bank in peduncle shape. Additionally, sweet grain sorghum from Korsimoro was similar to those from the Joseph KI-ZERBO University gene bank in panicle type, aristation, and exertion type; these accessions showed positive exertion, loose panicles, and no aristation. However, these sorghum types differed in other traits. The sorghum types from Korsimoro differed from grain sorghum and sweet sorghum from Mali in all traits except peduncle shape.

Grain and sweet grain sorghums from Fulnakambogo were not different in exertion type and panicle type; both types exhibited positive exertion and loose panicles. However, these types differed in other traits. Grain sorghum had aristation (87.5%), hairy glumes (75%) of varying colors: black (37.5%), light brown (25%), or dark brown (37.5%), and grain covered at 25% (62.5%). Sweet grain sorghum usually had no aristation (66.7%), hairless glumes (66.2%) of varying colors: straw (37.3%), black (32.4%), or red (34.3%), and covered grains at 50%. Sweet sorghum had compact panicles, no aristation, hairy black glumes (75%), and covered grains at 50%. These types of sorghum from Fulnakambogo differed from accessions collected from Mali and the Joseph KI-ZERBO University gene bank in all traits except peduncle shape.

Variation in qualitative traits related to grain

The comparative analysis of different types of sorghum revealed variations in most grain-related traits (Table 5). However, some similar traits were found among sorghum types. Grain sorghum, sweet grain sorghum, and dyer sorghum from Sogué did not differ in dry grain flavor; all types produced grains that were not sweet in the dry stage.

Grain sorghum and dyer sorghum had elliptical grains that were not sweet in the fresh stage, while dyer sorghum and sweet grain sorghum had non-rotating grains, whereas grain sorghum had low grain rotation. High variation among sorghum types was observed in other traits: grain sorghum mostly had grains that were easy to gin (69.5%), white (50%) or light red (50%) in color, with variable endosperm textures—mainly vitreous (50%), mainly floury (26.4%), and floury (23.6%) in the dry stage. Sweet grain sorghum had grains that were easy to gin, asymmetrical, light red, and 50% floury (33.6%) or fully floury (66.4%) in the dry stage. Dyer sorghum had grains that were difficult to gin, dark red, and mostly floury (66.7%) in the dry stage.

Grain sorghum, sweet grain sorghum, and dyer sorghum from Sogué were similar to grain sorghum, sweet grain sorghum, and sweet sorghum from the Joseph KI-

Table 5. Results of qualitative traits variation related grain.

Area	Village	Type	TG		GS		GRC						FGF		DGF		GRO			GET				
			Difficult	Easy	Elliptical	Disymmetrical	White spotted black	White	Light red	Dark red	Yellow	Grey	No sweet	Sweet	No sweet	Sweet	Absent	High	Low	Vitreous	Mainly vitreous	50% floury	Mainly floury	Floury
North Soudanian	Sogué	SG	30.5	69.5	100.0	0.0	0	50.0	0.0	50.0	0	0	100.0	0.0	100.0	0	30.0	0	70.0	0	50	0.0	26.4	23.6
		SGS	0.0	100.0	0.0	100.0	0	0.0	100.0	0.0	0	0	0.0	100.0	100.0	0	100.0	0	0.0	0	0	33.6	0.0	66.4
		ST	100.0	0.0	100.0	0.0	0	0.0	0.0	100.0	0	0	100.0	0.0	100.0	0	100.0	0	0.0	0	0	0.0	33.3	66.7
	Zambanega	SG	38.5	61.5	92.3	7.7	0	46.2	7.7	38.5	7.7	0	100.0	0.0	100.0	0	15.4	7.7	76.9	0	38.5	15.4	23.1	23.0
		SGS	0.0	100.0	0.0	100.0	0	0.0	80.0	20.0	0.0	0	0.0	100.0	100.0	0	40.0	60.0	0.0	0	0.0	0.0	20.0	80.0
	Lado	SG	0	100.0	100.0	0	0	50.0	25.0	25.0	0	0	100.0	0	100.0	0	0	25.0	75.0	0	55.6	19.4	25.0	0
		ST	0	100.0	100.0	0	0	0.0	33.3	66.7	0	0	100.0	0	100.0	0	0	0.0	100.0	0	0.0	0.0	100.0	0
	Loango	SG	30.0	70.0	100.0	0.0	0	50.0	0.0	25.0	0	25.0	100.0	0.0	100.0	0	19.5	80.5	0.0	20.0	30.0	0.0	25.6	24.4
		SGS	0.0	100.0	33.3	66.7	0	0.0	66.7	0.0	0	33.3	66.7	33.3	100.0	0	33.3	0.0	66.7	0.0	30.3	36.3	0.0	33.3
	Nakomtenga	SG	18.8	81.2	87.5	12.5	0.0	43.8	6.2	50.0	0	0.0	100.0	0.0	100.0	0	12.5	31.2	56.2	0	18.8	25.0	25.0	31.2
		SGS	0.0	100.0	60.0	40.0	10.0	0.0	30.0	40.0	0	20.0	60.0	40.0	100.0	0	30.0	10.0	60.0	0	0.0	0.0	10.0	90.0
		ST	24.5	75.5	0.0	100.0	0.0	0.0	0.0	100.0	0	0.0	100.0	0.0	100.0	0	100.0	0.0	0.0	0	0.0	0.0	30.0	70.0
Sub-sahelian	Fulnakambogo	SG	12.5	87.5	100.0	0.0	0.0	50.0	37.5	12.5	0.0	0	100.0	0.0	100.0	0	0.0	62.5	37.5	0	25.0	25.0	12.5	37.5
		SGS	33.3	66.7	33.3	66.7	0.0	0.0	30.3	69.7	0.0	0	68.7	31.3	100.0	0	0.0	66.7	33.3	0	0.0	0.0	23.3	76.7
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Korsimoro	SG	0.0	100.0	100.0	0.0	0.0	100.0	0.0	0	0.0	0	100.0	0.0	100.0	0.0	0.0	0	100.0	0	75.0	25.0	0.0	0.0
		SGS	0.0	100.0	0.0	100.0	0.0	0.0	100.0	0	0.0	0	0.0	100.0	74.5	25.5	30.0	0	70.0	0	0.0	0.0	0.0	100.0
		STS	88.9	11.1	33.3	66.7	22.2	11.1	33.3	0	33.3	0	100.0	0.0	100.0	0.0	88.9	0	11.1	0	11.1	22.2	22.2	44.4
Gene Bank	Joseph KI-ZERBO University	SG	50.0	50.0	0.0	100.0	0	100.0	0.0	0.0	0.0	0	100	0	100	0	100	0	0	0	100	0	0	0
		SGS	0.0	100.0	0.0	100.0	0	0.0	50.0	50.0	0.0	0	0	100	100	0	50.0	50	0	0	0	0	0	100
		STS	100.0	0.0	100.0	0.0	0	0.0	0.0	0.0	100.	0	100	0	100	0	100	0	0	0	0	0	100	0
	ICRISAT (Mali)	SG	50.0	50.0	100.0	0.0	10.0	80.0	0.0	10.0	0.0	0	100.0	0.0	100.0	0.0	20.0	0.0	80.0	30.0	50.0	0.0	10.0	10.0
		STS	50.0	50.0	61.1	38.9	0.0	50.0	33.3	0.0	16.7	0	100.0	0.0	100.0	0.0	50.0	27.8	22.2	0.0	16.7	27.8	38.9	16.7

GS: Grain sorghum, SGS: Sweet grain sorghum, SS: Sweet sorghum, DS: Dyer sorghum, TG: Type of ginning, GS: Grain shape, GRC: Grain colour, FGF: Fresh grain flavour, DGF: Dry grain flavour, GRO: Grain rotation, GET: Grain endosperm texture.

ZERBO University gene bank in dry grain flavor, all types having non-sweet grains in the dry stage. Additionally, sweet grain sorghum from Sogué was similar to sweet grain sorghum from the Joseph KI-ZERBO University gene bank in ginning type, grain shape, and fresh grain flavor; these accessions had asymmetrical grains that were easy to gin but lacked sweetness in the fresh stage. However, differences were observed in other traits. A comparison of grain sorghum, sweet grain sorghum, and dyer sorghum from Sogué with grain sorghum and sweet sorghum from Mali revealed similarity only in dry grain flavor. Grain sorghum from Sogué was similar to those from Mali in grain shape, fresh and dry grain flavor, but differences were noted in other traits.

Grain and sweet grain sorghums from Zambanega did not differ in traits except for dry grain flavor; both types had sweet grains in the dry stage. Grain sorghum had grains that were easy to gin (61.5%), had low rotation (76.9%), was elliptical (92.3%), not sweet in the fresh stage, and varied in color: white (46.2%), light red (7.7%), dark red (38.5%), or yellow (7.7%). Grain sorghum also exhibited variable endosperm textures: mainly vitreous (38.5%), 50% floury (15.4%), mainly floury (23.1%), and fully floury (23.0%). Sweet grain sorghum had asymmetrical grains that were easy to gin, with grains being light red (80%) or dark red (20%) and sweet-tasting in the fresh stage. Accessions had either high (60%) or no (40%) rotation and mainly floury (20%) or fully floury (80%) endosperm texture. Grain sorghum and sweet grain sorghum from Zambanega differed from grain sorghum, sweet grain sorghum, and sweet sorghum in the Joseph KI-ZERBO University gene bank in all traits except dry grain flavor. Similar variation was observed between sorghum from Zambanega and accessions collected in Mali.

Most traits of sorghum types (grain sorghum and dyer sorghum) from Lado did not differ. Both types of sorghum had elliptical grains that were easy to gin, with no sweetness in either the fresh or dry stages, and mostly exhibited low rotation. However, differences were observed in other traits. Grain sorghum exhibited variable grain colors: white (50%), light red (25%), and dark red (25%). This type of sorghum also displayed variable endosperm textures: mainly vitreous (55.6%), 50% floury (19.4%), and mainly floury (25%). Dyer sorghum had a floury endosperm texture and dark red (66.7%) or red (33%) coloration. Grain sorghum and dyer sorghum from Lado differed from grain sorghum, sweet grain sorghum, and sweet sorghum from the Joseph KI-ZERBO University gene bank in traits other than dry grain flavor. Grain sorghum and dyer sorghum from Lado were similar to grain sorghum and sweet sorghum from Mali in terms of fresh and dry grain flavor, but differed in other traits.

Grain and sweet grain sorghums from Loango did not differ in terms of ginning type and grain flavor. Both sorghum types produced grains that were mostly easy to gin and lacked sweetness in both fresh and dry stages. Grain sorghum produced elliptical grains with various colors: white (50%), dark red (25%), and grey (25%). Most accessions showed grain rotation (80.5%) and had a vitreous (20%), mainly vitreous (30%), mainly floury (25.6%), or floury (24.4%) endosperm texture. Sweet grain sorghum produced asymmetrical grains with light red (66.7%) or grey (33.3%) coloration, mostly low rotation, and variable endosperm texture: mainly vitreous (30.3%), 50% vitreous (36.4%), and floury (33.3%). Sorghum types from Loango differed from those collected in the Joseph KI-ZERBO University gene bank and Mali in traits other than dry grain flavor.

There was no difference among grain sorghum, sweet grain sorghum, and dyer sorghum from Nakomtenga in terms of dry grain flavor. All types of sorghum produced grains that were mostly easy to gin and lacked sweetness in both fresh and dry stages. Grain sorghum and sweet grain sorghum were similar in grain shape, grain color, and grain rotation. Both types had elliptical grains, dark red coloration, and low rotation. However, these sorghum types differed in other traits. Grain sorghum exhibited mainly vitreous (18.8%), 50% vitreous (25%), mainly floury (25%), and floury (31.2%) endosperm textures, while sweet grain sorghum had mainly floury (90%) endosperm texture. On the other hand, dyer sorghum grains were asymmetrical in shape, dark red, mostly floury (70%) without rotation. Sorghum types from Nakomtenga differed from those collected from the Joseph KI-ZERBO University gene bank and Mali in traits other than dry grain flavor.

Grain sorghum, sweet grain sorghum, and sweet sorghum from Fulnakambogo did not have sweet grains in either the fresh or dry stages. Additionally, grain sorghum and sweet grain sorghum had grains that were mostly easy to gin and had high rotation. However, there were differences in other traits. Grain sorghum had elliptical grains with variable colors: white (50%), light red (37.5%), and dark red (12.5%). It also exhibited variable endosperm textures: mainly vitreous (25%), 50% vitreous (25%), mainly floury (12.5%), and floury (37.5%). On the other hand, sweet grain sorghum had mainly asymmetrical grains (66.7%), with light red (30.3%) or dark red (69.7%) coloration, and floury (76.7%) endosperm texture. Sweet sorghum had grains that were difficult to gin (88.9%), asymmetrical in shape (66.7%), with low rotation, floury grain, and variable colors: white with black spots (50%), white (25%), red (33.6%), and yellow (33.1%). It also had variable endosperm textures: mainly vitreous (11.1%), 50% vitreous (22.2%), mainly floury (22.2%), and floury (44.4%). Grain sorghum, sweet grain sorghum, and sweet sorghum from Fulnakambogo differed from sorghum from Mali and the Joseph KI-ZERBO University gene bank in traits other than the flavor of the fresh and dry grain.

Grain sorghum and sweet sorghum from Korsimoro did

Figure 3.. Variation in grain colour according to sorghum type.

not produce sweet grains in either the fresh or dry stages. Furthermore, grain sorghum and sweet grain sorghum had grains that were easy to gin. However, there were differences between the two types of sorghum in other traits. Grain sorghum had elliptical grains with white coloration, low rotation, and mainly vitreous (75%) endosperm texture. On the other hand, sweet grain sorghum had asymmetrical grains with light red coloration, sweet in the fresh stage, mostly not sweet when dried (60%), and floury endosperm. Sweet sorghum had grains that were mostly difficult to gin (88.9%), asymmetrical in shape (66.7%), with no rotation (88.9%), and variable colors: white with black spots (22.2%), white (11.1%), red (33.6%), and yellow (33.1%). It also exhibited variable endosperm textures: mainly vitreous (11.1%), 50% vitreous (22.2%), mainly floury (22.2%), and floury (44.4%) (Figure 3). Comparison of grain sorghum from Korsimoro with that from the Joseph KI-ZERBO University gene bank revealed similarity in grain color and grain flavor. These sorghum types had white grains that were not sweet in either the fresh or dry stages. Additionally, sweet sorghum from Korsimoro and the Joseph KI-ZERBO University gene bank were similar in fresh and dry grain flavor. However, differences were observed in other traits. Apart from grain flavor, sorghum types from Korsimoro differed from those collected in Mali.

Botanical breed of types of sorghum

A total of four botanical races (guinea, bicolor, caudatum, and durra) and three intermediate races (caudatum-bicolor, guinea-bicolor, and guinea-caudatum) were identified based on sorghum type and village (Figure 4). The results showed that most grain sorghum belonged to the guinea race. Sweet sorghum and dyer sorghum belonged to the caudatum race, while sweet grain sorghum belonged to various races. Grain sorghum and sweet grain sorghum from Lado mainly belonged to the guinea race. The majority of grain sorghum and sweet grain sorghum from Nakomtenga also belonged to the guinea race, while dyer sorghum belonged to the caudatum race. Grain sorghum, sweet grain sorghum, and dyer sorghum from Sogué belonged to multiple botanical races. Half of the grain sorghum and sweet grain sorghum belonged to the guinea race, while all dyer sorghum accessions belonged to the caudatum race. Another portion of grain sorghum was intermediate between the guinea and bicolor races, whereas sweet grain sorghum belonged to the caudatum race.

The majority of grain sorghum from Zambanega belonged to the guinea race, while sweet grain sorghum belonged to the guinea-caudatum race. There was racial diversity among the sorghum types from Fulnakambogo. All grain sorghum accessions belonged to the guinea

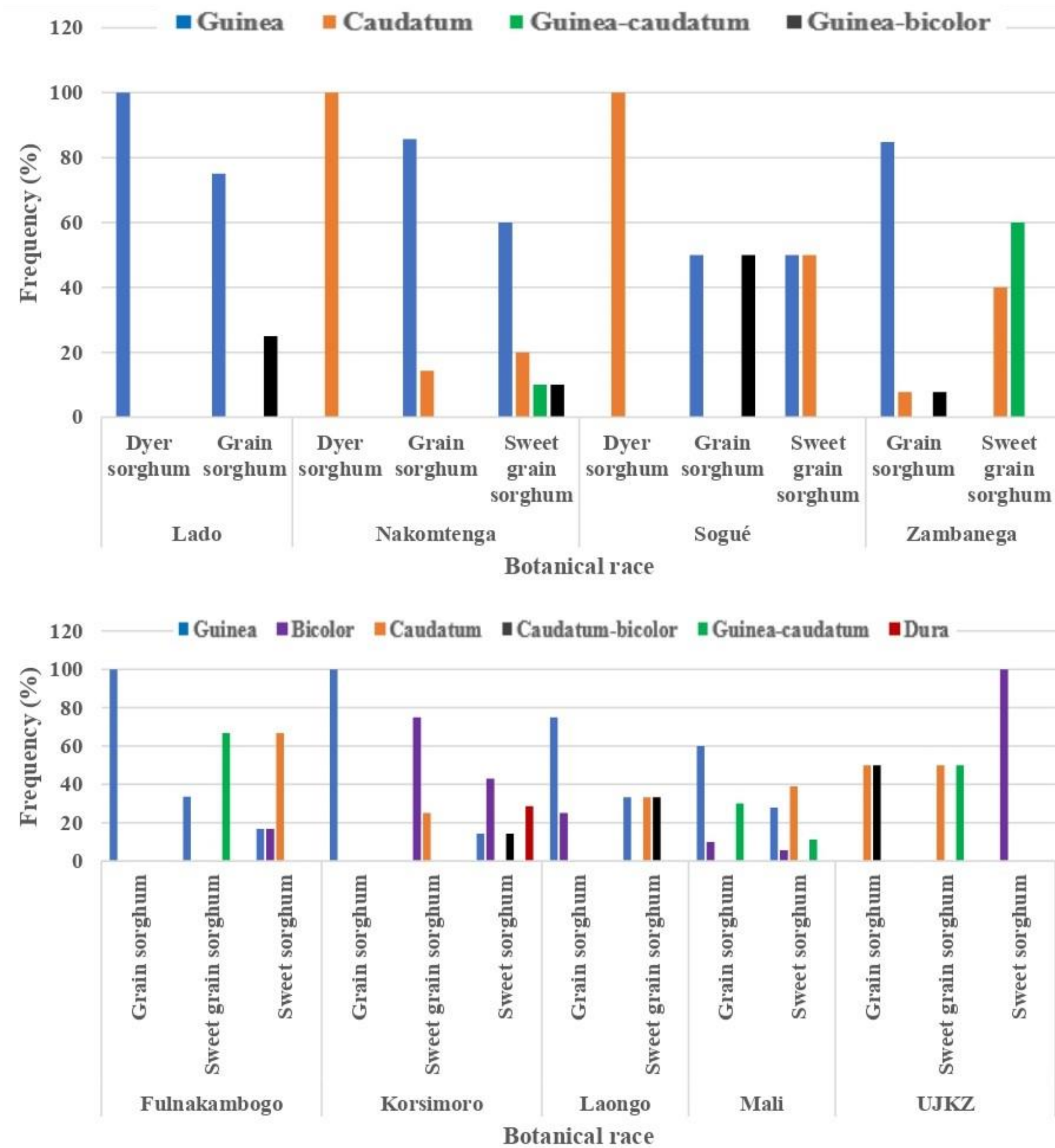

Figure 4. Distribution of botanical breed frequency according to sorghum type and villages.

race. Most sweet grain sorghum accessions were intermediate between the guinea and caudatum races, while sweet sorghum accessions belonged to the caudatum race. The majority of sweet grain sorghum and sweet sorghum from Korsimoro belonged to the bicolor race. In contrast, all grain sorghum accessions belonged to the guinea race. Most grain sorghum from Loango belonged to the guinea race, while sweet grain sorghum consisted of a variable botanical race distribution: 33.34% guinea, 33.33% caudatum, and 33.33% caudatum-bicolor.

Except for sweet grain sorghum accessions from Zambanega, the other accessions differed from those in the Joseph KI-ZERBO University gene bank. Racial diversity was observed among the accessions from Mali, with the majority of grain sorghum belonging to the guinea race and sweet sorghum to the caudatum race. Comparative analysis revealed differences between the sorghum types collected in each village and those from Mali.

Comparison of the Shannon diversity index of sorghum types according to villages

The results of this analysis revealed variation in the

Table 6. Estimates of Shannon-Weaver diversity index for each trait by sorghum type and village.

Character	Shannon-Weaver diversity index (H')																						
	Sogué			Zambanega		Nakomtenga			Lado		Loango		Korsimoro			Fulnakambogo			UKZ			Mali	
	GS	SGS	DS	GS	SGS	GS	SGS	DS	GS	DS	GS	SGS	GS	SGS	SS	GS	SGS	SS	GS	SGS	SS	GS	SS
Seedling colour	0.63	0.00	0.58	0.82	0.46	0.95	0.86	0.00	0.63	0.58	0.51	0.00	0.51	0.00	0.32	0.67	0.58	0.51	0.63	0.00	0.00	0.00	0.92
Main stem status	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.47	0.00
Basal tiller status	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.47	0.00
Leaf spot colour	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.81	0.00	0.00	0.00	0.72	0.99
Midrib colour	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.51	0.00	0.00	0.00	0.30	0.00
Leaf sheath colour	0.00	0.00	0.00	0.39	0.72	0.90	0.88	0.00	0.00	0.00	0.00	0.00	0.81	0.00	0.50	0.81	0.92	0.00	0.00	0.00	0.00	0.00	0.00
Stem pith colour	0.00	0.72	0.00	0.00	0.72	0.00	0.47	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.57	0.54	0.92	0.81	0.00	0.47	0.00	0.72	0.31
Aerial tillers	0.00	0.00	0.00	0.62	0.72	0.54	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.76	0.54	0.92	0.00	0.00	0.00	0.00	0.00	0.31
Stem succulence	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	0.00	0.00	0.00	0.00	0.00
Exertion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.50
Peduncle shape	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panicle type	0.00	0.00	0.00	0.39	0.00	0.55	0.30	0.00	0.00	0.57	0.51	0.00	0.00	0.00	0.97	0.34	0.00	0.00	0.63	0.00	0.00	0.30	0.94
Aristation	0.00	0.00	0.00	0.00	0.00	0.54	0.97	0.00	0.00	0.00	0.72	0.78	0.00	0.00	0.92	0.54	0.92	0.00	0.00	0.00	0.00	0.47	0.76
Glume colour	0.43	0.42	0.40	0.64	0.31	0.51	0.59	0.43	0.35	0.40	0.35	0.40	0.43	0.43	0.22	0.67	0.68	0.35	0.00	0.00	0.00	0.91	0.70
Glume appearance	1.00	1.00	0.00	0.78	0.00	0.70	1.00	0.00	0.00	0.92	0.81	0.88	0.00	0.97	0.99	0.81	0.92	0.81	1.00	0.00	0.00	0.00	0.85
Grain coverage	0.49	0.00	0.00	0.65	0.00	0.48	0.44	0.00	0.09	0.46	0.75	0.70	0.41	0.00	0.92	0.41	0.00	0.00	0.50	0.00	0.00	0.79	0.84
Type of ginning	0.89	0.00	0.00	0.96	0.00	0.70	0.00	0.80	0.00	0.00	0.88	0.00	0.00	0.00	0.50	0.54	0.92	0.81	1.00	0.00	0.00	1.00	1.00
Grain shape	0.00	0.00	0.00	0.39	0.00	0.54	0.97	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.92	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.96
Grain colour	0.39	0.00	0.00	0.62	0.28	0.49	0.71	0.00	0.58	0.36	0.58	0.36	0.00	0.00	0.73	0.54	0.34	0.58	0.00	0.39	0.00	0.36	0.56
Fresh grain flavour	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00
Dry grain flavour	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grain rotation	0.56	0.00	0.00	0.63	0.61	0.86	0.82	0.00	0.51	0.00	0.45	0.58	0.00	0.56	0.32	0.60	0.58	0.00	0.00	0.63	0.00	0.46	0.94
Endosperm texture	0.65	0.40	0.40	0.83	0.31	0.85	0.20	0.38	0.62	0.00	0.86	0.68	0.35	0.00	0.79	0.82	0.34	0.00	0.00	0.00	0.00	0.73	0.82
Botanical breed	0.43	0.43	0.00	0.33	0.42	0.25	0.68	0.00	0.35	0.00	0.35	0.68	0.00	0.35	0.79	0.00	0.40	0.54	0.43	0.42	0.00	0.56	0.80
$\overline{H'}$	0.23	0.12	0.06	0.35	0.15	0.38	0.43	0.07	0.16	0.14	0.32	0.33	0.10	0.17	0.48	0.35	0.50	0.27	0.22	0.08	0.00	0.34	0.51

$\overline{H'}$: Average diversity index, GS: grain sorghum, SGS: sweet grain sorghum, DS: dyer sorghum, SS: sweet sorghum.

Shannon diversity index according to the type of sorghum and villages (Table 6). Among the three types of sorghum from Sogué, grain sorghum showed a higher diversity index (0.23) compared to sweet grain sorghum (0.12) and dyer sorghum (0.06), indicating lower diversity in sweet grain and dyer sorghum. All three types of sorghum displayed a diversity index of zero for several characteristics, including main stem status (MSS), basal tiller status (BTS), leaf spots colour (LSC), midrib colour (MC), leaf sheath colour (LSCO), presence or absence of aerial tillers (AT), stem succulence (SUC), exertion (EXE), peduncle shape (PS), panicle type (PT), presence or absence of aristation (ARI), grain shape (GS), fresh grain flavour (FGF), and dry grain flavour (DGF).

Grain sorghum and sweet grain sorghum also exhibited identical diversity indices for glume colour (0.43), glume appearance (1.00), and botanical race (0.43). Similarly, sweet grain sorghum and dyer sorghum showed zero diversity indices for grain coverage (GCO), type of ginning (TG), grain colour (GRC), grain rotation (GRO), and grain endosperm texture (GET). However, variability was observed between the types of sorghum for other characteristics. The highest diversity indices were noted in grain sorghum for seedling colour (0.63), type of ginning (0.89), grain colour (0.39), grain rotation (0.56), and grain endosperm texture (0.65), while sweet grain sorghum showed the highest diversity index for pith colour (0.72).

These sorghum types exhibited similar Shannon diversity indices to those from the Joseph KI-ZERBO University gene bank for most characteristics. However, the diversity indices differed between these sorghum types and those from the Mali gene bank for most characteristics.

Grain sorghum and sweet grain sorghum from Zambanéga exhibited variable Shannon diversity indices. Grain sorghum had a higher value (0.35) compared to sweet grain sorghum (0.15). Both types of sorghum showed a zero diversity index for main stem status (MSS), basal tiller status (BTS), midrib colour (MC), stem succulence (SUC), exertion (EXE), peduncle shape (PS), presence or absence of aristation (ARI), fresh grain flavour (FGF), and dry grain flavour (DGF). However, they differed in other characteristics.

Grain sorghum recorded the highest diversity indices for seedling colour (0.63), leaf spot colour (0.39), leaf sheath colour (0.39), panicle type (0.39), glume colour (0.64), glume appearance (0.78), type of ginning (0.96), grain coverage (0.65), grain shape (0.39), grain colour (0.62), grain rotation (0.63), and grain endosperm texture (0.83). In contrast, sweet grain sorghum exhibited the highest indices for midrib colour (0.46), leaf sheath colour (0.72), stem pith colour (0.72), presence or absence of aerial tillers (0.72), and botanical race (0.42). These sorghum types showed diversity indices different from those of the Joseph KI-ZERBO University and Mali gene banks for most characters.

Grain sorghum, sweet grain sorghum, and dyer sorghum from Nakomtenga displayed higher diversity indices in sweet grain sorghum (0.43) and grain sorghum (0.38) compared to dyer sorghum (0.07). Similarly, these three types of sorghum had zero diversity indices for MSS, BTS, leaf spot colour (LSC), MC, EXE, PS, and DGF, while differing in other traits. Grain sorghum had the highest diversity indices for seedling colour (0.95), leaf sheath colour (0.90), aerial tillers (0.54), SUC (0.34), panicle type (0.55), grain coverage (0.48), grain rotation (0.86), and grain endosperm texture (0.85). Sweet grain sorghum recorded the highest diversity indices for stem pith colour (0.47), ARI (0.97), glume colour (0.59), grain shape (0.97), grain colour (0.71), FGF (0.97), and botanical race (0.68). Dyer sorghum exhibited the highest index for type of ginning (0.80) and lower indices for other characters. Apart from dyer sorghum, which showed indices close to those of the Joseph KI-ZERBO University gene bank, the other types differed in indices compared to those of the Joseph KI-ZERBO and Mali gene banks.

Grain sorghum and dyer sorghum from Lado exhibited low diversity indices, with grain sorghum showing a slightly higher value (0.16) compared to dyer sorghum (0.14). Both types of sorghum had a zero diversity index for most characters, including main stem status (MSS), basal tillers status (BTS), midrib colour (MC), leaf sheath colour (LSCO), stem pith colour (SPC), absence or presence of aerial tillers (AT), stem succulence (SUC), exertion (EXE), peduncle shape (PS), absence or presence of aristation (ARI), type of ginning (TG), grain shape (GS), fresh grain flavour (FGF), and dry grain flavour (DGF). However, they differed in other traits.

Grain sorghum had the highest diversity indices for seedling colour (0.63), leaf spot colour (0.81), grain colour (0.58), grain rotation (0.51), grain endosperm texture (0.62), and botanical race (0.35). On the other hand, dyer sorghum recorded the highest indices for panicle type (0.57), glume colour (0.40), glume appearance (0.92), and grain coverage (0.46). Both types of sorghum showed diversity indices that were similar to those of the Joseph KI-ZERBO University gene bank but different from those of the Mali gene bank.

Grain sorghum and sweet grain sorghum from Loango exhibited similar average diversity indices (0.33). These sorghum types also showed zero diversity indices for MSS, BTS, MC, LSCO, AT, EXE, PS, and FGF. However, they differed in other traits. Grain sorghum had the highest indices for seedling colour (0.51), stem succulence (1.00), panicle type (0.51), grain coverage (0.75), type of ginning (0.88), grain colour (0.58), and grain endosperm texture (0.86). On the other hand, sweet grain sorghum recorded the highest indices for pith colour (0.92), absence or presence of aristation (0.78), glume appearance (0.88), grain shape (0.92), fresh grain flavour (0.92), grain rotation (0.58), and botanical race (0.68). There was a similarity observed between the sorghum types from Loango and those from the Joseph KI-ZERBO University gene bank for most characters related to vegetative development, such as MSS, BTS, leaf spot colour (LSC), MC, LSCO, SUC, EXE, and PS. However, these sorghum types showed different indices compared to those from the Mali gene bank.

Grain sorghum, sweet grain sorghum, and sweet sorghum from Korsimoro showed variable diversity, with sweet sorghum having the highest value (0.48) compared

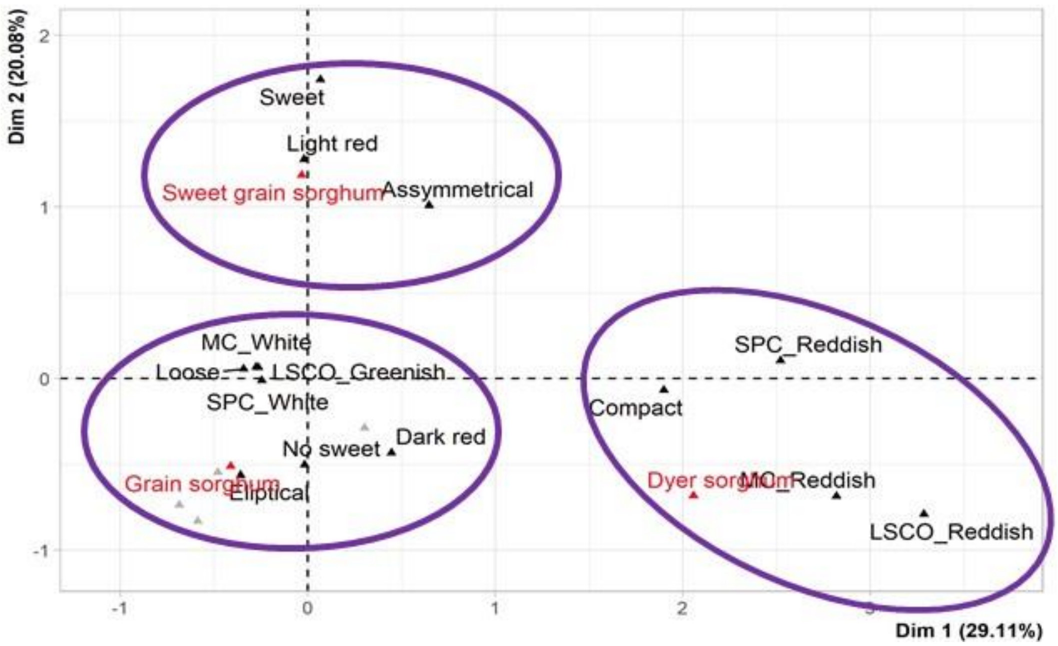

Figure 5. Phenotypical proximity of sorghum types in the north sudanian area.

to grain sorghum (0.10) and sweet grain sorghum (0.17). All types of sorghum recorded zero-diversity indices for main stem status (MSS), basal tiller status (BTS), leaf spot colour (LSC), stem succulence (SUC), exertion (EXE), and fresh grain flavour (SGF). Additionally, grain sorghum and sweet grain sorghum also showed zero-diversity indices for midrib colour (MC), pith colour (SPC), peduncle shape (PS), panicle type (PT), absence or presence of aristation (ARI), type of ginning (TG), grain shape (GS), and grain colour (GRC). These two types of sorghum also had the same diversity index for glume colour (0.43). However, these three types of sorghum differed in other traits. Grain sorghum showed the highest indices for seedling colour (0.51) and leaf sheath colour (0.81), while sweet grain sorghum recorded the highest indices for absence or presence of aerial tillers (0.97), dry grain flavour (0.82), and grain rotation (0.56). On the other hand, sweet sorghum showed the highest indices for midrib colour (0.48), pith colour (0.57), peduncle shape (0.76), panicle type (0.97), absence or presence of aristation (0.92), glume appearance (0.99), glume coverage (0.92), type of ginning (0.50), grain shape (0.92), and grain colour (0.73). Grain sorghum and sweet grain sorghum from Korsimoro also showed diversity indices close to those of the Joseph KI-ZERBO University gene bank for most characters but differed from those of the Mali gene bank. Sweet sorghum recorded diversity indices different from those of the Joseph KI-ZERBO University and Mali gene banks.

Grain sorghum, sweet grain sorghum, and sweet sorghum from Fulnakambogo showed high diversity, with sweet grain sorghum having a higher value (0.50) compared to grain sorghum (0.35) and sweet sorghum (0.27). All types of sorghum recorded zero-diversity indices for exertion (EXE), peduncle shape (PS), and dry grain flavour (DGF). For other characters, these sorghum types showed variable indices. Grain sorghum had the highest indices for seedling colour (0.67), grain coverage (0.41), panicle type (0.34), grain rotation (0.60), and grain endosperm texture (0.82). On the other hand, sweet grain sorghum recorded the highest indices for main stem status (0.92), basal tillers status (0.92), leaf sheath colour (0.92), stem pith colour (0.92), absence or presence of aerial tillers (0.92), absence or presence of aristation (0.92), glume colour (0.68), glume appearance (0.92), type of ginning (0.92), grain shape (0.92), and fresh grain flavour (0.90). Sweet sorghum recorded the highest indices for leaf spot colour (0.81), midrib colour (0.51), stem succulence (0.82), grain colour (0.58), and botanical breed (0.54). These sorghum types recorded diversity indices different from those of the Joseph KI-ZERBO University and Mali gene banks for the majority of characters.

Morphological variability of sorghum types based on agro-climatic zones

For sorghum types from north Sudanian area, multiple component analysis (MCA) of qualitative traits showed three groups (Figure 5) of traits association corresponding to different types of sorghum. Seven traits were

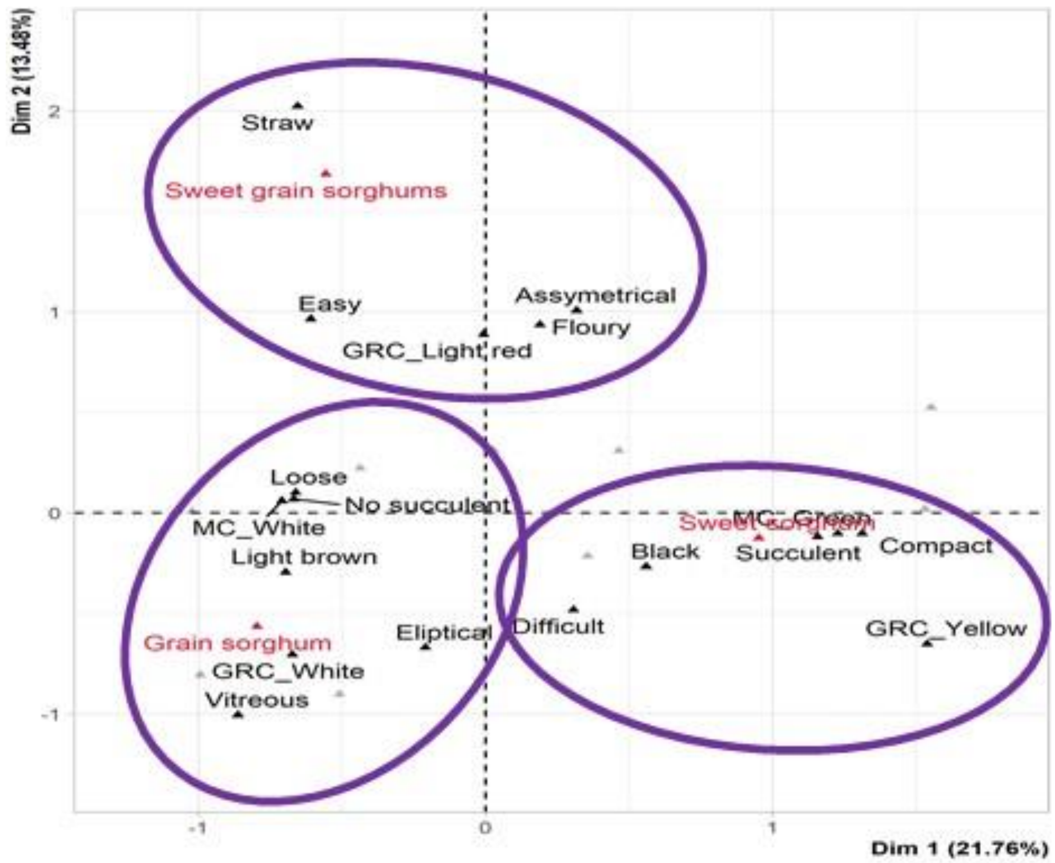

Figure 6. Phenotypical proximity of sorghum types in the sub-Sahelian area.

discriminant: midrib colour (MC), leaf sheath colour (LSCO), pith colour (SPC), panicle type (PT), grain shape (GS), grain colour (GRC) and the flavour of fresh grain (FGF). Grain sorghum had a greenish leaf sheath, white pith, white midrib, loose panicle, elliptical grain shape and no sweet grain in the fresh stage. Dyer sorghum, on the other hand, had a reddish leaf sheath and pith, a reddish midrib and a compact panicle. Sweet grain sorghum had light red grains, asymmetrical shape and sweet grains in the fresh stage.

The sorghum types from the sub-Sahelian area differed in midrib colour (MC), panicle type (PT), grain shape (GS), grain colour (GRC), glume colour (GC), grain endosperm texture (GET), succulence (SUS), and ginning type (TG). Three distinct groups (Figure 6) were observed based on these traits among the three types of sorghum.

Grain sorghum exhibited a white midrib colour, a loose panicle type, light brown glumes, elliptical grains that were white, easy to gin, vitreous endosperm texture, and no sweet stem.

Sweet sorghum, in contrast, showed a green midrib colour, a compact panicle type, yellow grains that were difficult to gin, black glumes, and a sweet stem.

Sweet grain sorghum displayed light red grains that were floury and easy to gin, asymmetrical grain shape, and straw-coloured glumes.

DISCUSSION

Comparative analysis of the variability among different types of sorghum revealed a morphological similarity in traits related to stem, leaf, and panicle characteristics. Most of these sorghum types exhibited an erect stem, red leaf spots, positive exertion, erect peduncle, absence of aerial tillers, and no sweet grains in the dry stage. This similarity is further supported by the similar Shannon diversity indices observed across these sorghum types, indicating low diversity in morphological traits.

Similar findings were reported by Sawadogo et al. (2022a, b), who observed monomorphism in several qualitative traits within sorghum genetic resources. This morphological proximity could be attributed to gene flow between different sorghum types. Despite sorghum's preference for self-pollination, it has an outcrossing rate that can range from 5 to over 40%, with an average around 6 when cultivated in the field (Djè et al., 2004; Schmidt and Bothma, 2006; Barnaud et al., 2008), which facilitates gene flow between varieties. Additionally, sorghum types are often cultivated in proximity or even in the same fields (Nebié et al., 2012), promoting cross-fertilization among different varieties.

This study highlighted that grain sorghum and sweet grain sorghum are very similar to sweet sorghum and dyer sorghum in most traits, as also noted by Sawadogo et al. (2022a) and Tiendrébéogo et al. (2022). These results were supported by the Shannon diversity indices, which showed comparable values across these types. This similarity may be explained by the prevalence of loose panicles in most grain sorghum and sweet grain sorghum, which typically belong to the guinea or intermediate guinea-caudatum race. In contrast, sweet sorghum and dyer sorghum tend to have more compact or semi-compact panicles. According to Djè et al. (2004), loose panicles, such as those in local Guinea races, are more conducive to cross-pollination, whereas very compact panicles, often found in local Durra races, inhibit cross-pollination. Previous studies have also indicated significant rates of allogamy in cultivated sorghum, ranging from 5 to 7% in Durra races (Doggett, 1988) and 10 to 30% in Guinea races (Ollitrault, 1987).

The results also revealed that the similarity among sorghum types varied significantly from one village to another. Sorghum types from Zambanega, Nakomtenga, Lado, and Loango exhibited greater similarity compared to those from other villages. This similarity was further supported by the Shannon diversity indices, which indicated zero-diversity for most characters in sorghum types from these villages. The consistency in similarity among different sorghum types within the same village could be attributed to shared farming practices. Similar crop husbandry methods used within a village might influence the genetic diversity of sorghum types, highlighting the importance of considering local agricultural practices in sorghum improvement programs in Burkina Faso.

Genetic studies often find higher similarities between sorghum types within the same village than between populations of the same types collected from different villages, echoing findings by Naino (2016). This phenomenon may be explained by the fact that sorghum types collected within the same areas or adjacent fields are more likely to experience cross-fertilization. According to Sagnard et al. (2008), the proximity of different sorghum varieties within the same or adjacent plots in agroecosystems of Burkina Faso, Mali, and Niger facilitates intervarietal gene flow. Such gene flow can lead to genetic introgression phenomena (Slatkin, 1987; Ronfort et al., 2005), potentially resulting in phenotypic changes within sorghum types or transitions between different types.

In millet, for instance, gene flow between domestic and wild millet has led to the emergence of plants with intermediate phenotypes that exhibit lower yield potential in agricultural environments (Mariac et al., 2006). Similarly, the appearance of intermediate traits such as intermediate races, mixed endosperm textures, and absence of sweet grains in fresh stages among sweet grain sorghum, as well as characteristics like green leaf sheaths and white pith in dyer sorghum, suggest significant gene flow between these sorghum types. These findings corroborate observations reported by farmers during the collection of sorghum accessions.

Farmers reported observing changes from one type of sorghum to another, along with decreases in yield potential, alterations in grain and stem succulence, and shifts in grain color even within the same sorghum types. These changes could potentially lead to the extinction of minor sorghum types such as sweet grain sorghum and dyer sorghum, despite their usefulness to local populations for consuming fresh grains and selling panicles during lean seasons (Nébié et al., 2012; Sawadogo, 2015), as well as the utilization of dyer sorghum for dyeing purposes (Nandkangré, 2009). According to Ellstrand (2003), gene flow can contribute to the disappearance of rare species.

The results of the multiple correspondence analyses indicated a close similarity between sweet grain sorghum and grain sorghum compared to sweet sorghum and dyer sorghum. This finding suggests a higher likelihood of intense gene flow between grain sorghum and sweet grain sorghum. The consequences of such gene flow could include a homogenization of allele frequencies (Busso et al., 2000), potentially leading to a decrease in genetic diversity within sorghum populations in Burkina Faso.

The significant differences observed between sorghum collected in this study and accessions from the Joseph KI-ZERBO University and Mali gene banks highlight the substantial impact of farming practices on the genetic diversity of cultivated sorghum in Burkina Faso. Similar findings were reported by Missihoun et al. (2012) in Benin regarding sorghum cultivated by the Lokpa community.

Conclusion

Comparative analysis based on qualitative traits revealed significant morphological proximity between sorghum types when grown in the same cultivation areas. These results indicated that sweet grain sorghum and grain sorghum are more similar than sweet sorghum and dyer sorghum in the same village and agroclimatic area. This study also highlighted that cropping practices significantly influence the genetic diversity organization of sorghum cultivated in Burkina Faso. The potential for gene flow between sorghum types could be beneficial for sorghum genetic improvement in Burkina Faso; however, this gene flow might lead to a reduction in sorghum genetic diversity and the potential disappearance of minor sorghum types such as sweet grain sorghum, sweet sorghum, and dyer sorghum cultivated in the region. Given that morphological markers are influenced by environmental factors, further investigation into the proximity of these sorghum types based on molecular markers would be valuable."

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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