Phenotypical characteristics and genetic diversity of three types of sorghum [*Sorghum bicolor* (L.) Moench] cultivated in Burkina Faso based on qualitative traits

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Abstract

The objective of this study is to compare the genetic diversity of sweet grain sorghum with grain sorghum and sweet sorghum using qualitative agro-morphological traits in order to identify its phenotypical specific traits. Forty-two genotypes of the three types of sorghum were evaluated using a three-repeat Incomplete Fisher Block device using 15 qualitative characters. The results showed a lack of variability in ten sweet grain sorghum traits that resulted in zero Shannon-Weaver diversity indices. However, the type of panicle, the colour of the grain, the cover of the grain, the appearance of the endosperm and the botanical race make it possible to clearly distinguish sweet grain sorghum from the other two cultivated sorghums. Indeed, sorghum sweet grain usually has a loose panicle, floury and red grains that are covered at most on 50% by glumes and often belongs to the *caudatum* breed. These results could be used in sorghum breeding program.

Keywords: Sorghum, genetic variability, genetic relationship, Burkina Faso

INTRODUCTION

Climatic hazards exacerbated by climate change, has particularly contributed to weakening the current food situation of peasant populations, thus compromising numerous development initiatives in the Sahelian countries (FAO, 2006). Solving these problems requires, among other things, the diversification of agriculture through the use of all resources and the development of new sustainable production systems (Assogbado *et al.*, 2009). One of the credible alternatives to respond effectively to the problem of food insecurity, is the use of underexploited plants (FAO, 2009). These plants are known and used by farming communities on a small scale and are not generally promoted or included in agricultural statistics (FAO, 2009). These minor species which are at risk of disappearing, include sweet grain sorghum and sweet sorghum (Nebié *et al.*, 2012; CIRAD, 2013).

In Burkina Faso, Sorghum [*Sorghum bicolor* (L.) Moench] is the second most important cereal crop after maize, with an estimated total production of 1,839,570 tonnes, including 1,425,103 tonnes of white sorghum and 414,467 tonnes of red sorghum (DGESS/MAAH, 2021). However, these statistics do not take into account all existing sorghum genetic resources. Indeed, next to grain sorghum, other types of sorghum with varying potential, such as sweet grain sorghum and sweet sorghum are also produced and used by farmers on a small scale (Nebié *et al.*, 2012).

Sweet grain sorghum [*Sorghum bicolor* (L.) Moench] is grown in hut fields mainly for family self-consumption and local sale of panicles at the doughy grain stage (Sawadogo *et al.*, 2014a; Sawadogo *et al.*, 2017). Harvesting generally occurs before the main food crops, hence its use as a bridging food in rural areas (Nebié *et al.*, 2012). Several previous studies on grain sorghum have highlighted farmers' management patterns (Sawadogo *et al.*, 2014a; Sawadogo, 2015), genetic diversity (Sawadogo *et al.*, 2014b; Sawadogo *et al.*, 2018) and genetic relationships with other cultivated sorghums based on molecular markers. Other studies focused on the biochemical composition of grain (Sawadogo *et al.*, 2017; Sawadogo *et al.*, 2020) and straw (Tiendrébéogo, 2020) as well as its response to mineral fertilization (Tiendrébéogo *et al.*, 2020). Compared to grain sorghum and sweet sorghum, work on sweet grain sorghum is relatively recent and very localised. Moreover, the phenotypic traits that can differentiate it from other cultivated sorghums are still poorly known, which could be a limitation to the rational exploitation of its genetic resources in the improvement of other cultivated sorghum types.

The objectives of this present study were (i) to compare the sweet grain sorghum genetic diversity to others cultivated sorghum (grain sorghum, sweet sorghum) and (ii) to identify the specific phenotypical traits of sweet grain sorghum using qualitative agro-morphological traits.

MATERIAL AND METHODS

Plant material

The plant material used consists of 42 sorghum genotypes (Table 1). The seeds of 22 sweet grain sorghum genotypes and 10 sweet sorghum genotypes were obtained from the germplasm of "Laboratoire Biosciences" of "Université Joseph KI-ZERBO". The 10 grain sorghum genotypes were obtained from "Institut de l'Environnement et de Recherche Agricole (INERA)".

Experimental site

The agro-morphological assessment was carried out under rainfed conditions in 2020 at the experimental station of Rural Development Institute situated in "Gampéla". This site is located in the northern Sudanese climatic zone with geographical coordinates of 12°25' North latitude and 1°21' West longitude. The soil is very heterogeneous, deep, of low chemical fertility and predominantly sandy loam texture with a pH of 5.69 (BUNASOL, 2019). In 2020, the station received 855 mm of rainfall over six months with a peak of 329 mm in August. During the July-October trial, the average monthly temperature ranged between 26°C and 28°C for a cumulative rainfall of 769 mm.

Experimental set-up

The experimental set-up was an incomplete Fisher block with three replications, each subdivided into three sub-blocks. Each sub-block consisted of 14 rows and 11 patches per row with row spacing of 0.8 m and patch spacing of 0.4 m. Each replication had 42 lines with one line per genotype and two border lines on either side. The distances between the replications and between the sub-blocks were respectively 2 m and 1 m for a total area of 504 m^2.

Cultivation techniques

The field was plowed with a tractor and leveled prior to planting, which took place on July 18, 2020. During the trial, one weeding and one stripping at a rate of one plant per bunch were performed 15 days after sowing, followed by two weeding on day 18 and day 35 after sowing, respectively. A ridging was then carried out towards the end of the vegetative development of the plants in order to counter the lodging caused by the violent winds. NPK fertilizer (14-23-14) was applied at each weeding at a rate of 50 kg/ha and urea at a rate of 50 kg/ha.

Data collection

A total of 15 qualitative characteristics were recorded. The observation of the qualitative characteristics was carried out in the field or in the laboratory, on all the individuals in the line. The characteristics observed were related to the grain, the panicle, the leaf and the stem. Thus, at the level of the leaf and stem, the colour of the seedlings at emergence, the colour of the leaf spots, the colour of the midrib and the succulence of the stem were noted. Panicle characteristics were the release of the panicle from the flag leaf (exertion), panicle type, peduncle shape, glume colour, glume appearance (hairy or hairless) and aristation (presence or absence of a black filament). For the grain, colour, glume coverage, dry grain flavour and grain endosperm texture (vitreous or floury) were determined. Panicle, grain and spikelet characteristics were used to determine the botanical race of the genotypes according to the key of Harlan and de Wet (1972).

Data analysis

Data processing, graph construction, calculation of frequencies and the Shannon-Weaver diversity index were carried out with the Excel 2016 spreadsheet. Phenotypic frequency distributions of the characters were worked out for each sorghum type. The Shannon-Weaver diversity index (H') was computed using the phenotypic frequencies to assess the phenotypic diversity for each trait for all accessions in each sorghum type. The Shannon-Weaver diversity index as described by Jain *et al.*, (1975), Gashaw *et al.*, (2016) and Ka *et al.*, (2020) is given as $H' = -\sum_{i=1}^{n} pi \ln(pi)$, *(1)* where 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.

Each H' value was divided by its maximum value ($\ln n$) and normalized in order to keep the values between 0 and 1. The average diversity index ($\overline{H}'$) over n traits by sorghum type was estimated as $\Sigma H'/n$.

RESULTS

Phenotypical characteristics of the three cultivated sorghum

Stem and leaf-related traits

The results of the comparative analysis of qualitative traits (Figure 1) reveal the presence in all sorghum types at different frequencies of light green and purple seedlings, leaves with red spots and white midribs. However, grain sorghum and sweet sorghum also express yellow leaf spots and green midribs. In terms of stem succulence, only sweet sorghum has juicy stems. Thus, sweet grain sorghum genotypes have mostly light green seedlings (95.5 %) and produce exclusively red leaf spots, white midribs and non-succulent stems.

Panicle-related traits

Figure 2 shows that of the three types of grown sorghums, only grain sorghum contains genotypes with negative or positive exertion of panicles and sweet sorghum contains genotypes with straight or curved stalks. For sweet grain sorghum, all genotypes have positive exertion of panicles

Table 1: Composition and genotypes origin

Sorghum type	Genotypes	Origin
Sweet sorghum	STS 79, STS 92, STS 97, STS 98, STS 104, STS 108, STS 124, STS 127, STS 129, STS 130	UJKZ
Sweet grain sorghum	Kapelga, Tiandougou, IRAT 204, Grinkan, ICSV1049, Kouria, Sariaso14, Soubatimi, Entrée03, Entrée 15	INERA
Grain sorghum	BZI1, BIP4, BKB2, BKB4, KBA1, KBZ4, MBO7, MTC2, PBO4, PBO5, PGO3, PLA1, SBR1, SBR5, SBR7, SKA3, SPI2, STO5, YOH3, YOH4, YOU4, YOU5	UJKZ

INERA: Institut de l'Environnement et de Recherches Agricoles; UJKZ: Université Joseph KI-ZERBO with straight stalks. The greatest variability is recorded in panicle type with the presence of loose, compact or semi-compact panicles (Figure 3). However, sweet grain sorghum had only loose panicles, unlike the other two types, which also had compact and semi-compact panicles.

***Glume*-related traits**

The results in figure 4 show that with the exception of aristation where all sweet grain sorghum genotypes do not have the black filament, a variability is observed in glume colour and glume appearance. Most of the sweet grain sorghum, sweet sorghum and grain sorghum

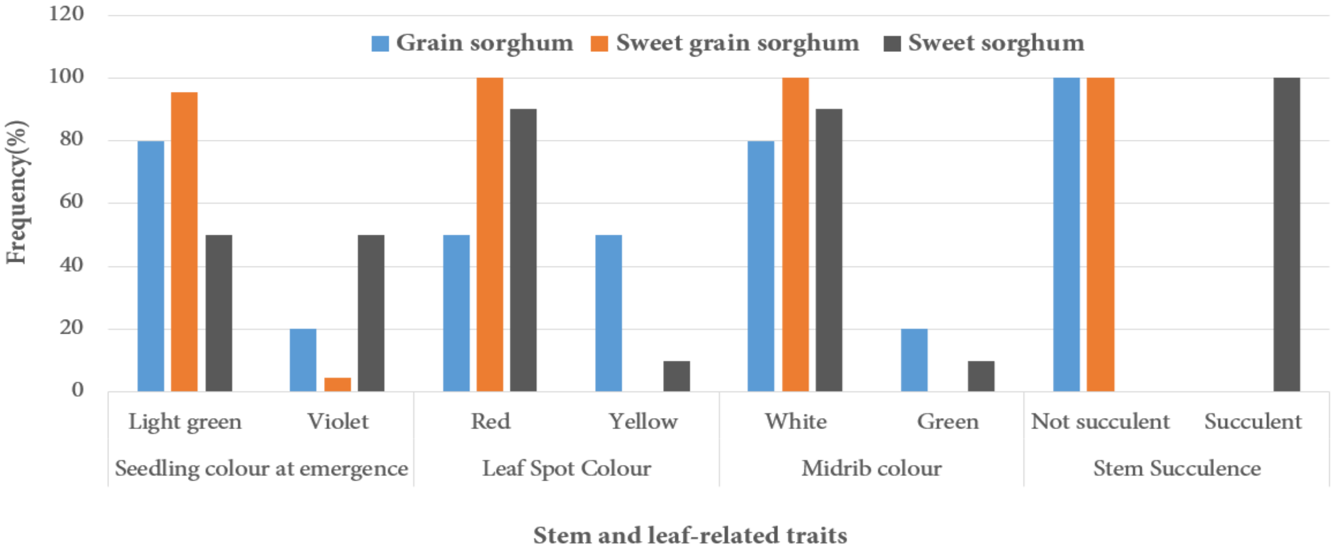

Figure 1*: *Frequency distribution of leaf and stem related traits for each sorghum type

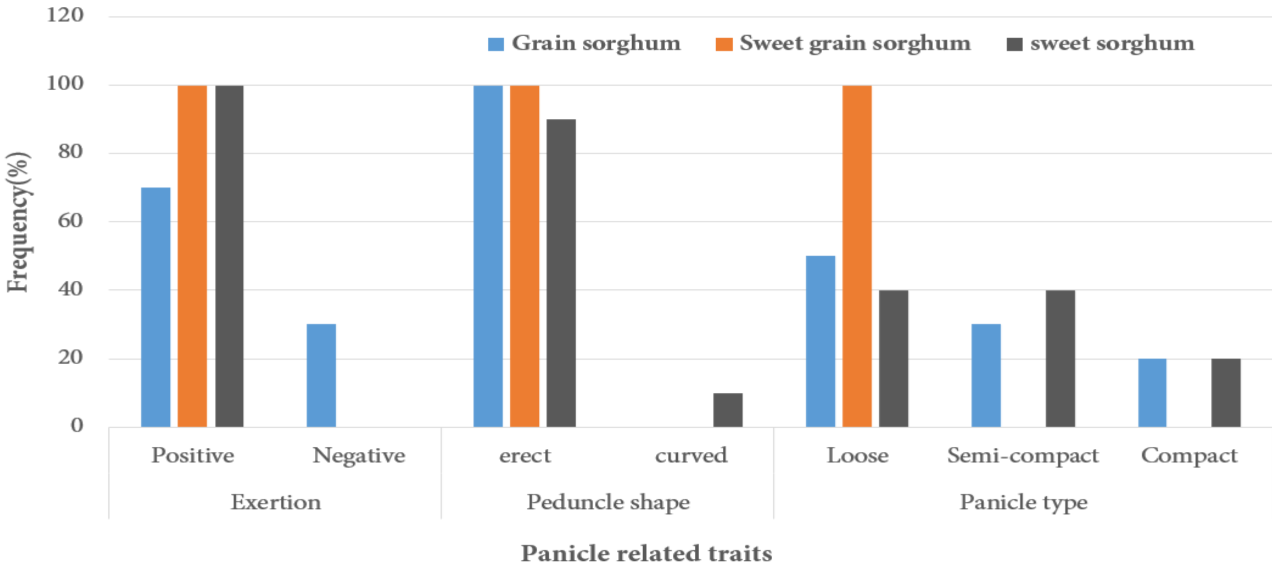

Figure 2: Frequency distribution of panicle related traits for each sorghum type

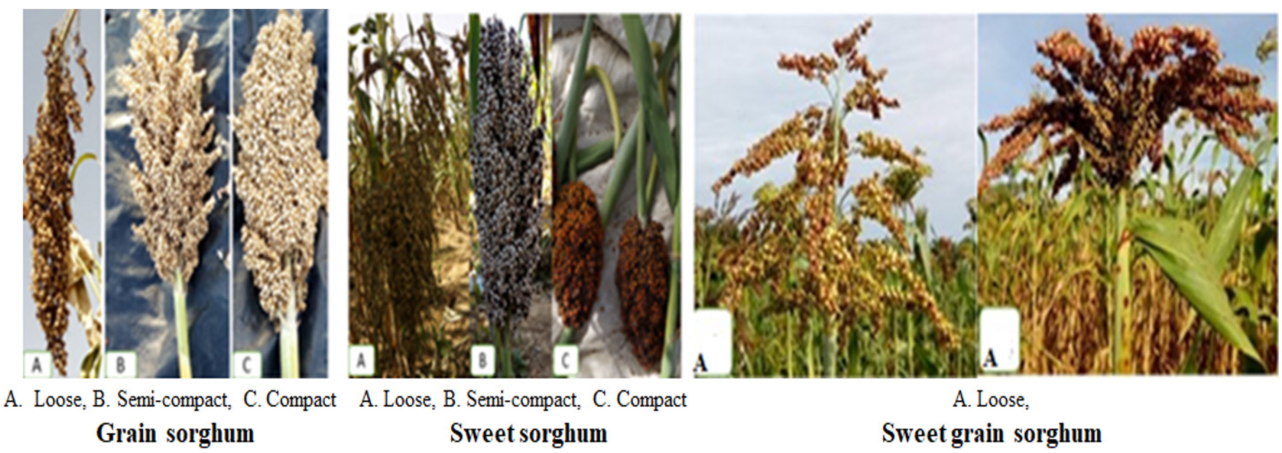

Figure 3: Different panicle types of the three sorghum types

genotypes have brown, black and straw colored glumes, respectively (Figure 5). In addition, the majority of sweet sorghum genotypes (70%) have hairy glumes while most grain sorghums (60%) and sweet grain sorghum (72.7%) genotypes have hairless glumes.

Botanical races

Low racial diversity is observed in sweet grain sorghum, which belongs to the race *caudatum* (95.5%) or the intermediate *caudatum-guinea* (Figure 6). The greatest racial diversity is found in sweet sorghum. It belongs to

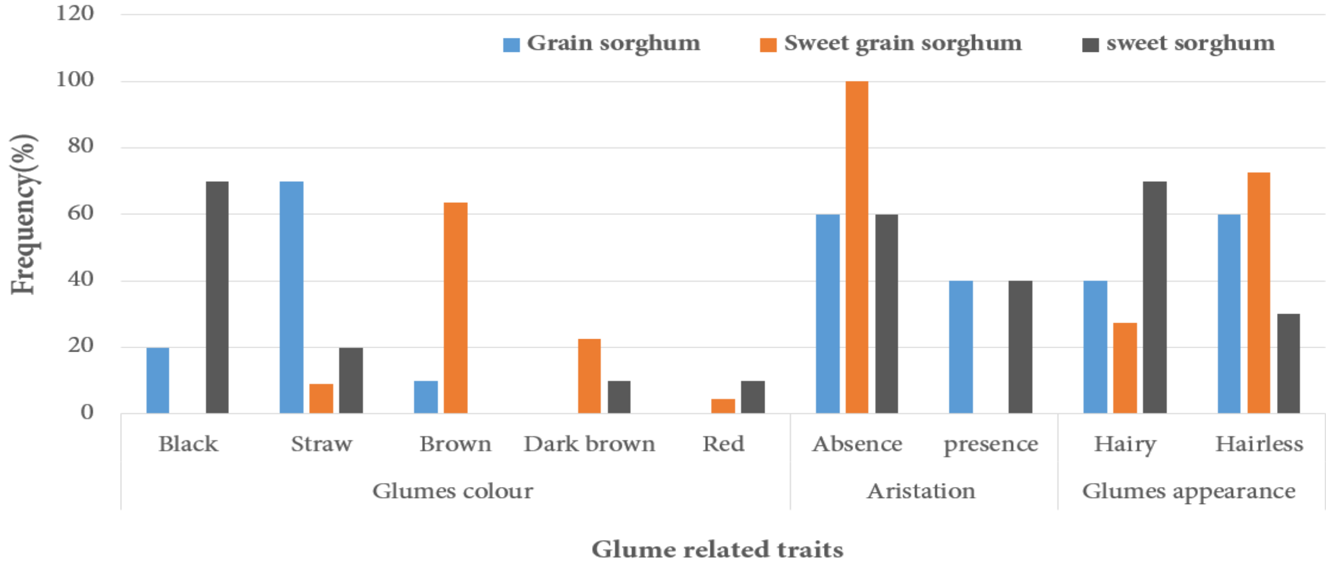

Figure 4: Frequency distribution of glume related traits for each sorghum type

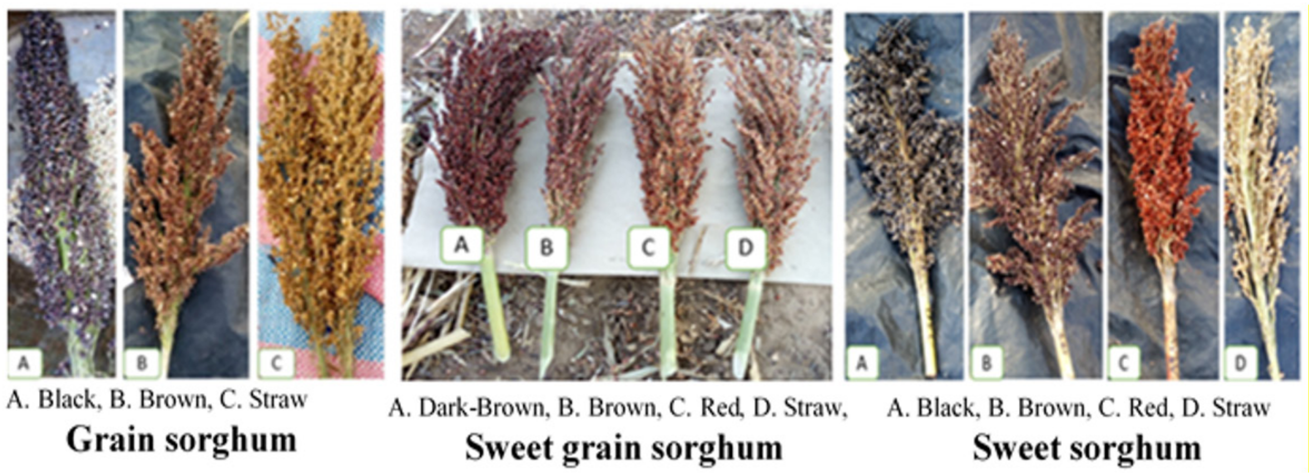

Figure 5: Different glumes colour of three sorghum types

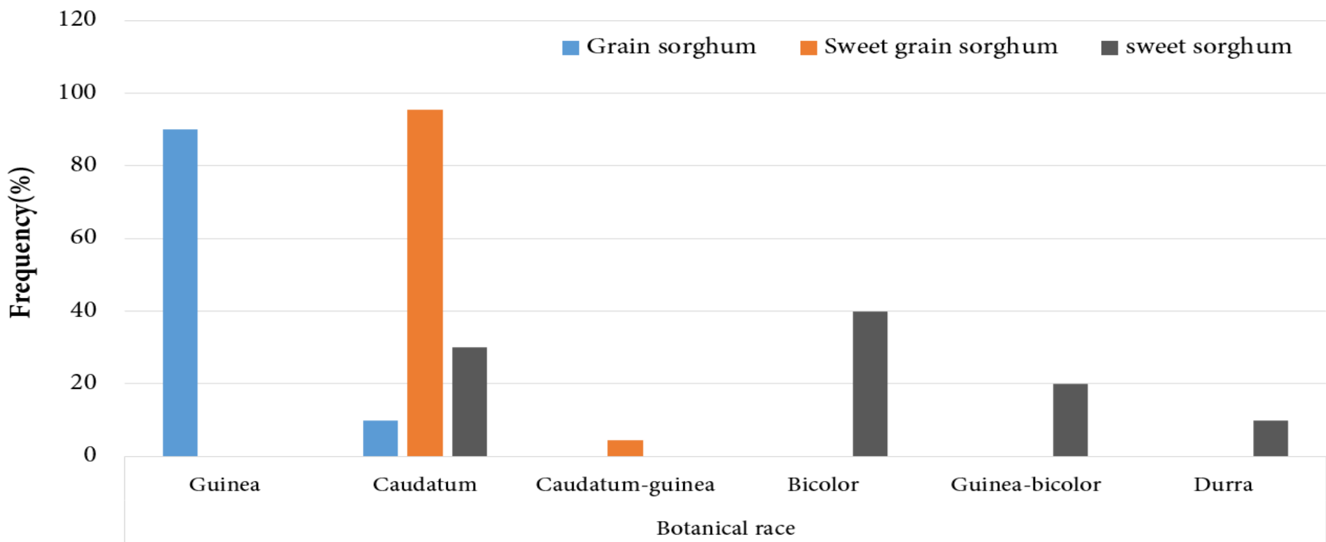

Figure 6: Frequency distribution of different botanical races for each sorghum type

the main races bicolor (40%), *caudatum* (30%), *durra* (10%) and the intermediate race *guinea-bicolor* (20%). As for grain sorghum, only the main races guinea (90%) and *caudatum* (10%) were encountered.

Grain-related traits

The results recorded in figure 7 reveal that for grain-related traits, except for grain coverage where sweet grain sorghum produced covered grains on 25% (90.9%) or 50% (9.1%), no variability was observed in this sorghum for the other three traits. Indeed, they have exclusively red colored grains that are floury and not sweet in the dry state. On the other hand, most of the grain sorghum genotypes (80%) and all of the sweet sorghum genotypes (100%) have grains covered on at least half by the glumes. In terms of grain colour, grain sorghum genotypes have grains that tend to be white, whereas sweet sorghum has white (50%) or red (50%) grains. Like sweet sorghum, the other two types of grown sorghum have grains that are not sweet in the dry state, but are more than 70% glassy.

Analysis of Shannon-Weaver diversity index of traits of the three cultivated sorghums

Stem and leaf-related traits diversity

The Shannon-Weaver index values recorded in table 2 for leaf and stem related traits show very low diversity in sweet grain sorghum (0.06) compared to grain sorghum (0.61) and sweet sorghum (0.45). Indeed, in sweet grain sorghum, except for seedling colour which showed diversity (0.22), the other three traits showed zero diversity indices. Apart from stem succulence which was non-variable in all sorghum types, the highest diversity indices of the other three traits were recorded in grain sorghum for leaf spot colour (1.0) and midrib colour (0.72) and in sweet sorghum for seedling colour (1.0) respectively.

Panicle and glume-related traits diversity

Analysis of Shannon-Weaver diversity index recorded in table 3 shows in sweet grain sorghum zero values for most traits except glume colour (0.71), glume appear-

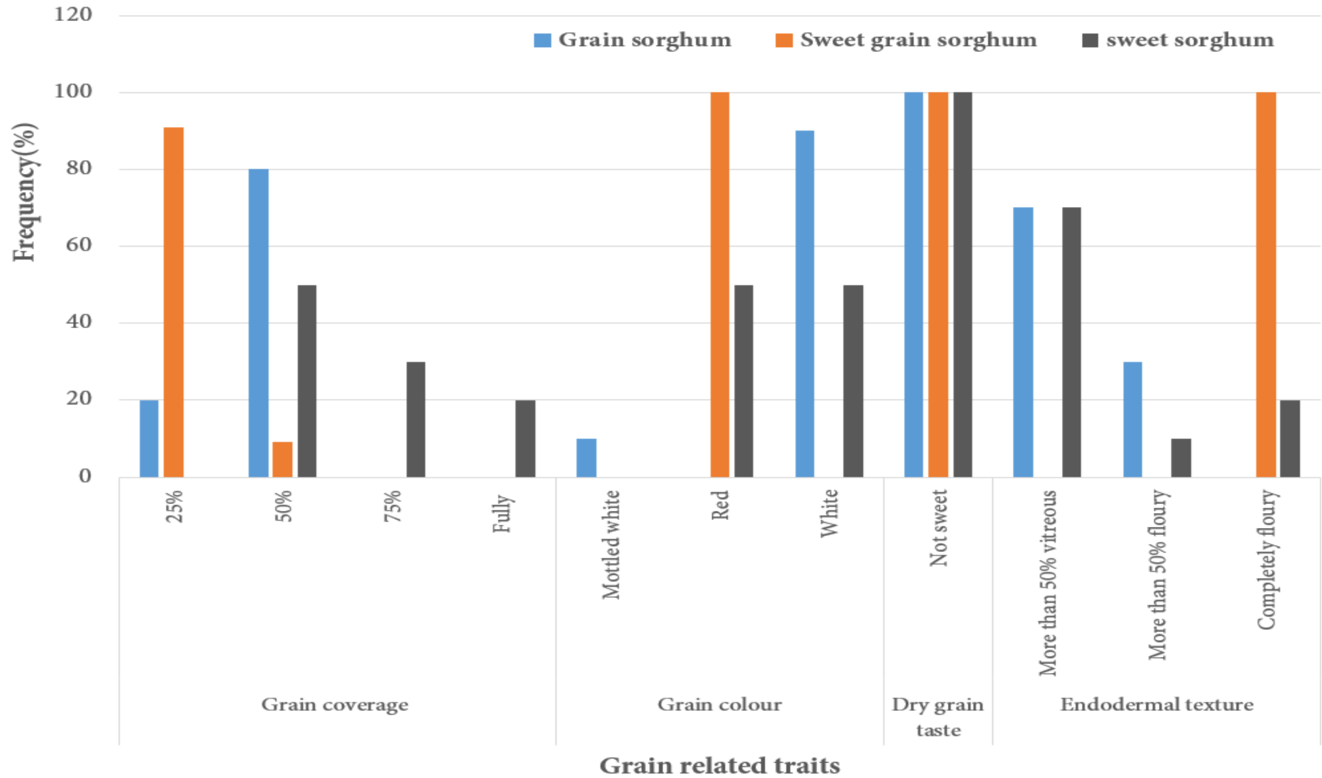

Figure 7: Frequency distribution of modalities of grain related traits for each sorghum type

Table 2: Estimates of Shannon-Weaver diversity index for leaf and stem related traits by sorghum type

		H'		
Traits	**Class number**	**Grain sorghum**	**Sweet grain sorghum**	**Sweet sorghum**
Seedling colour at emergence	2	0.72	0.22	1.00
Leaf spot colour	2	1.00	0.00	0.47
Colour of midrib	2	0.72	0.00	0.33
Stem succulence	1	0.00	0.00	0.00
$\overleftarrow{H}'$		0.61	0.06	0.45

H': *Diversity index per trait calculated from entire data set; Average* $\overleftarrow{H}'$ *by sorghum type for the considered traits* ance (0.83) and racial diversity (0.13). Sweet sorghum expressed the highest diversity indices for most panicle and glume traits as well as racial diversity except for exertion (0) and glume appearance (0.90). Thus, for all panicle and glume traits, sweet sorghum had the highest average diversity index (0.71) and sweet grain sorghum had the lowest average diversity index (0.22).

Grain-related traits diversity

All cultivated sorghum genotypes have zero diversity index for dry grain flavour (Table 4). However, sweet grain sorghum also has null Shannon-Weaver diversity index for grain colour and endosperm texture. Only grain coverage showed a non-zero diversity index (0.28) in this sorghum type. Sweet sorghum recorded the highest diversity index values for the other grain-related traits, namely grain cover (0.94), grain colour (1.0) and endosperm texture (0.73). Thus, the analysis of the average diversity index of grain-related traits shows that sweet grain sorghum is the least diverse (0.07) and sweet sorghum is the most diverse (0.67).

For all 15 quality traits, sweet sorghum (0.61) and grain sorghum (0.54) expressed the highest average diversity indices. Sweet grain sorghum, on the other hand, had the lowest average Shannon-Weaver diversity index value of 0.12.

DISCUSSION

A monomorphism was observed in several traits of sweet grain sorghum compared to grain sorghum and sweet sorghum where two and three traits respectively did not show variability. Indeed, the sweet grain sorghum genotypes are all anthocyaninized and have straight peduncles bearing well-cleared panicles that contain hairless glumes and mealy grains. Such monomorphism was also previously observed by Nebié *et al.* (2012) on sweet grain sorghum from north-central Burkina. However, these same characters were polymorphic in sweet sorghum (Nebié *et al.*, 2013) and grain sorghum (Barro-Kondombo, 2010). Yet, the positive exertion of sweet grain sorghum panicles, which is a much sought-after trait in breeding, exposes the panicle less to mold and thus contributes to good grain quality. According to Dicko *et al.* (2005), the anthocyanin character, which is due to the presence of the phenolic compound 3-deoxyanthocyanidins, could confer on the varieties forms of resistance to biotic stresses. These genotypes would therefore have been consciously or unconsciously selected by producers, as Barro-Kondombo (2010) also found in grain sorghum in west-central Burkina Faso.

The low diversity observed in sweet grain sorghum for several traits is confirmed by the very low Shannon-

Table 3: Shannon-Weaver diversity index for related panicle and glumes traits and botanical race

Traits	Class number	H'		
		Grain sorghum	Sweet grain sorghum	Sweet sorghum
Exertion	2	0.88	0.00	0.00
Peduncle shape	2	0.00	0.00	0.47
Panicle type	3	0.94	0.00	0.96
Glumes colour	4	0.58	0.71	0.75
Aristation	2	0.96	0.00	0.96
Glumes appearance	2	0.96	0.83	0.90
Botanical race	4	0.23	0.13	0.93
$\overline{H'}$		0.65	0.24	0.71

H': Diversity index per trait calculated from entire data set; Average $\overline{H'}$ by sorghum type for the considered traits

Table 4: Shannon-Weaver diversity index (H') for traits related grain traits and for all 15 qualitative traits

Traits	Class number	H'		
		Sorghum grain	Sweet grain sorghum	Sweet sorghum
Grain coverage	3	0.46	0.28	0.94
Grain colour	2	0.47	0.00	1.00
Dry grain taste	2	0.00	0.00	0.00
Endodermal texture	3	0.56	0.00	0.73
$\overline{H'}$		0.37	0.07	0.67
$\overline{H'}_F$		**0.54**	**0.12**	**0.61**

H': Diversity index per trait from entire data set; Average H' by sorghum type for the considered traits; $\overline{H'}_F$: Average H' by sorghum type for all 15 traits

Weaver diversity indices associated with them. Indeed, ten of the 15 traits showed zero diversity indices. However, in grain sorghum and sweet sorghum, it was two and three traits, respectively, that showed null diversity indices. Gashaw *et al.* (2016) reported for 16 studied qualitative traits of sugarcane, Shannon-Weaver diversity indices of 0.37 to 0.92. This low diversity recorded in sweet grain sorghum compared to grain sorghum and sweet stalk sorghum could be explained by a higher rate of allogamy within this type. Indeed, this sorghum, which is generally produced on a small scale in the hutches, has grains with little glume coverage and open (loose) panicles, which could then favor allogamy, resulting in a reduction in intra-type diversity. However, in sweet sorghum, Nebié (2014) reported the presence of sorghum with closed glumes, which would impose strict autogamy at the level of some genotypes.

The low phenotypic divergence observed between sweet grain sorghum and the other two types of sorghum grown in Burkina Faso in terms of certain quality traits (seedling colour, glume appearance and dry grain flavor) could be explained by the production method. These three types are sometimes grown in association in farmers' fields (Nebié *et al.,* 2012), which would have favored cross-fertilization between types. Djè *et al.* (2004) and Barnaud *et al. (*2007) reported allogamy rates of 7% to 40% in sorghum. These results could also confirm their genetic proximity as reported by Tiendrébéogo (2020).

The great phenotypic divergence observed between sweet grain sorghum and the other two cultivated sorghums in terms of grain colour, grain endosperm texture and botanical race could be related to their use. Sweet grain sorghum is a mouth sorghum and the grains are consumed directly fresh at the doughy stage (Sawadogo, 2015). Thus, the floury character facilitates chewing and would be well suited for this mode of consumption. However, sorghum grains are used in the preparation of several local dishes. Thus, the white colour and glassy appearance of the grains would be better suited to these uses. Indeed, Zongo (1991) and Barro-Kondombo (2010) have reported that white grain sorghum varieties are well suited to common dishes compared to red grain varieties that are more suitable for lean season and local beer. As for the sweet sorghum, it is cultivated mainly for the stem, hence the succulence of the stem of all the genotypes evaluated compared to the two grain sorghums (sweet grain sorghum, grain sorghum) whose stems are not juicy. In addition, racial classification could also be a criterion for distinguishing the different types of sorghum grown in Burkina. Indeed, the results showed a predominance of the guinea race in grain sorghum, the *caudatum* race in sweet grain sorghum and a more diversified racial composition in sweet sorghum (bicolor (40%), *caudatum* (30%), *guinea-bicolor* (20%), *durra* (10%)). The predominance of the *guinea* race in grain sorghum could be explained by Burkina Faso's biogeographic location at the heart of the breed's center of diversification, and also by the fact that the agronomic characteristics and technological qualities of their grains are perfectly suited to the food habits and preferences of rural populations (Zongo, 1991; Barro-Kondombo, 2010). As for sweet grain sorghum, the predominance of the *caudatum* race could be related to its exploitation as a food sorghum (Sawadogo *et al.*, 2017). The racial diversity in sweet sorghum would be due to the fact that producers are more interested in the stalk than the grains.

CONCLUSION

The study showed low phenotypic variability in several quality traits of sweet grain sorghum. The sweet grain sorghum is less diverse than grain sorghum and sweet sorghum. Qualitative traits such as panicle shape, grain endosperm texture, grain cover and botanical race discriminate sweet grain sorghum from the other two types of sorghum grown. Thus, sweet grain sorghum is generally of the *caudatum* botanical race and is characterized by sweet grains at the doughy stage, loosely shaped panicles and by grains that are entirely floury and poorly covered by glumes. The more diversified sweet sorghum is characterized by the succulence of its stem. As for grain sorghum, it belongs mainly to the *guinea* race and is characterized by glassy grains. These results offer possibilities for the development of multipurpose varieties through crosses between these types of sorghum.

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