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Agromorphological traits variation in local sorghum varieties from the North region of Burkina Faso and identification of some interest traits

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The aim of the study was to assess the agromorphological diversity of 150 local sorghum varieties collected from 13 villages of the North region of Burkina Faso, in order to understand the dynamics of diversity and to identify interest gene pools for varietal improvement. The varieties were characterized from 2017 to 2018 at INERA Saria Research Station in the North-Sudanian zone (700-900 mm of rainfall). The experimental design was an alpha lattice with three repetitions. Twenty-four qualitative and quantitative traits were used to assess the local sorghum. Seven qualitative traits of the panicle were allowed to identify four main botanical races and two intermediate races: guinea (86.0%), caudatum (6.7%), bicolor (0.7%), durra (0.7%), guinea-caudatum (2.0%) and durra-bicolor (4.0%). The anthocyanin varieties were predominant (99.3%) like those with white pericarp (62.7%). The highest variances were observed with cycle length and the weight of 100 grains as well between varieties as in each village; these two traits were the most heritable ($h^2 = 90$). The local sorghum varieties were structured into three groups by hierarchical cluster analysis on the basis of cycle length, grain weight, stem height, leaf length and 100-grains weight. The group of short cycle varieties (69 days) with short stem height and better 100-grains weight is the most productive. Therefore, this group is particularly interesting for varietal improvement.

Key words: Sorghum, local varieties, agromorphological variation, botanical race, cycle, heritability.

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth major cereal grown in the world after corn, rice, wheat and barley. On average, it takes up 42.8 million hectares with a grain production of 63.4 million tons (FAOSTAT, 2012-2016). The major part of cultivated areas (64.3%) is found in Africa, whereas the grain production represents only 42.2% of the world production. The average grain yield for Africa is low (970 kg/ha) compared with that of the other countries in the world (2399 kg/ha). Such differences in yield between Africa and the rest of the

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world are due to the technical and economic means used in the production. Bindraban et al. (2000) and Leiser et al. (2014) mentioned that the major constraints of sorghum production in Africa are the water availability and the deficiency of soil mineral nutrients, particularly in phosphorus. Ayana and Bekele (1998), Mujaju and Chakauya (2008), Ngugi and Maswili (2010), Dossou et al. (2015), Desmae et al. (2016) and Teshome et al. (2018) observed that the sorghum growing in Africa was still widely based on local varieties that remain an important component of traditional farming systems.

In Burkina Faso, sorghum is the first food crop, followed by millet, corn, rice and fonio. On average it takes up to 42.6% (1.7 million hectares) of cereal growing area with a grain production of 37.5% (1.7 million tons), (MARHASA, 2012-2016). The farming systems of sorghum are still extensive due to the low investment capacity of farmers (low level of agricultural equipment, the non-use or low use of mineral fertilizers, etc.); moreover, sorghum is often cultivated on marginal soils.

Studies have shown that local sorghum varieties were the most widely cultivated in Burkina Faso (Zongo, 1991; Barro-Kondombo et al., 2010; Nebié et al., 2009; Sawadogo et al., 2014). These local varieties mostly (93 to 96%) belong to the guinea botanical race (Harlan and De Wet, 1972). The varieties of this race (although their low agronomic performance) are preferred by farmers for their rusticity, their sensitiveness to photoperiod which better suit to the production conditions of traditional farming systems; their high stem and grain quality are preferred respectively for various domestic and culinary uses. Some improved sorghum varieties of caudatum botanical race have been developed and released by sorghum research program; despite their higher productivity, they are much less cultivated due to their weak adaptability to the extensive systems production.

The constraints of sorghum growing have always existed in Burkina Faso, but their nature and importance vary according to farming areas. In the North region, sorghum takes up on average 49.6% of cereal growing areas before millet (46.1%). The low agricultural potential of cultivated land (DGAT, 2006), shortening of the rainy season and the bad distribution of rainfall (Paturel et al., 2010), as well as bioagressors attacks, particularly striga (*Striga hermonthica*) are the major constraints which affect sorghum yields in the region. Some old low performing varieties have been given up and many new varieties were introduced in the villages by farmers (Kondombo et al., 2016). Thus, a collection of local sorghum varieties was carried out in 2009 in the four provinces of the region (Zondoma, Passoré, Yatenga and Lorum) and seed were stored in the gene bank of INERA Saria Research Station in Burkina Faso. Owing to the local differences between the villages and the interactions between genotypes and environments, the local sorghum varieties cultivated by farmers in the North region could show significant and useful biological traits.

This study was undertaken to assess the agromorphological diversity of local sorghum varieties from 13 villages of the North region of Burkina Faso to determine the structuration of the diversity and identify gene pools that could be of immediate use for the sorghum varietal improvement.

MATERIALS AND METHODS

Collection site

The plant material of this study was collected from 13 villages of the four provinces in the North region of Burkina Faso (Zondoma, Passoré, Yatenga and Lorum) according to the method described by Kondombo et al. (2016). The villages are situated between latitudes 12°38' and 14°18' north and between 1°55 and 2°95 longitudes west (Figure 1). The climate of the region is a Sudano-Sahelian type, with a rainfall of 500 to 700 mm. The prevailing types of soil are Ferric-lixisol (39.4%) and lithosols on hardpan with gravelus (33.3%). The average dates of the beginning and the end of rainy season in the region are around 28th June and 21st September (National Direction of Meteorology, 2011).

Plant material

The characterization of agromorphological diversity was carried out with 150 local sorghum varieties from 2017 to 2018 at INERA Saria Research Station, situated in the North-Sudanian zone, at 12°16' North latitude and 2°09' West longitude, at 300 m altitude. The list of sampled villages is reported in the Table 1.

METHODOLOGY

Experimental design and crop management

The experimental design was an alpha lattice with three repetitions. Each repetition includes 15 blocks of 10 varieties. The sowing was carried out on 12th July, 2017. By repetition, each variety was sown on one row of 6 m length with spaces of 80 cm between rows and 20 cm between seed holes. The thinning was carried out 14 days after sowing, leaving one plant per seed hole. Mineral fertilizers NPK (14N-23P-14K-6S-1B) were applied at 100 kg/ha and urea at 50 kg/ha (46% of nitrogen) respectively 14 and 40 days after sowing. The utile rainfall for the trial was 444.2 mm.

Assessed traits

Thirteen qualitative traits and eleven quantitative traits were used to describe sampled varieties (Tables 2a and 2b, respectively). Apart from the number of leaves recorded once a week from the thinning up to the appearance of the last leaf, the other traits were observed or measured at the stage of heading, milky grain stage, physiological maturity and after harvests (Table 2).

Data analysis

A Multiple Correspondence Analysis (MCA) was carried out with the average values of seven qualitative traits describing the panicle. Twenty five modalities of these traits were used in order to establish the structuration of the types of panicle and to identify the botanical races of the study according to the classification of Harlan and De

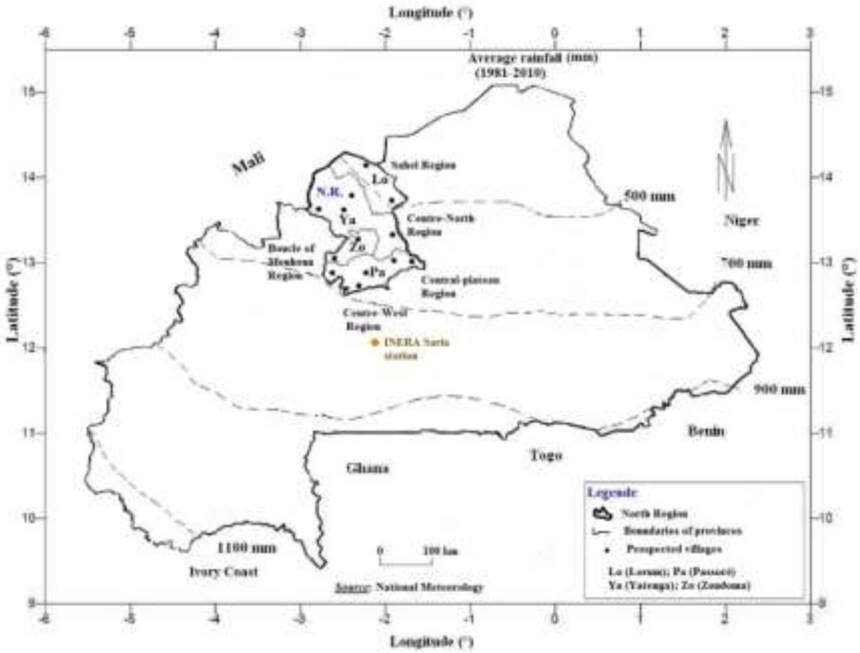

Figure 1. Geographic location of the surveyed villages in the North region of Burkina Faso (source: Ministry of Territorial Administration, 2010; National Direction of Meteorology, 2011). Lo (Lorum), Pa (Passoré), Ya (Yatenga), Zo (Zondoma).

Wet (1972). These traits are: the panicle compactness (PAC), the spikelet pedicellate persistence (SPP), the glumes length (GLL), the glumes opening (GLO), the grain rotation (GRR), the grain form (GRF) and the glumes adherence (GLA).

Regarding the quantitative traits, the variances analysis (ANOVA) were carried out at two levels to evaluate variety effect and the village effect on traits expression according to the following models: $Y_{ijk} = \mu + \tau_i + \gamma_j + \rho_{jk} + \varepsilon_{ijk}$ for the variety and $Y_{ij} = \mu + \alpha_i + \gamma_j + \varepsilon_{ij.}$ for the village; μ is general mean of the measured trait, τ_i mean of the variety i, γ_j effect of the repetition j, ρ_{jk} effect of block k in the repetition j, ε_{ijk} residual effect for variety; α_i variety effect within the village and ε_{ij} residual effect for village. The broad sense (H^2) and the narrow sense (h^2) heritabilities were calculated for each trait.

The structuration of agromorphological diversity was established by a Hierarchical Cluster Analysis (HCA) on the basis of the Euclidean distance according to Ward's aggregation criterion. The groups from the HCA were characterized by a Factorial Discriminant Analysis (FDA) in order to identify the most discriminating traits of the groups. The FDA was used to check if the varieties were different from one village to another.

The ANOVA was performed using GenStat software version 14.2, whereas the MCA, HCA and FDA were carried out with the XLSTAT software version 2018.2 (Addinsoft, 2018).

RESULTS

Evaluation of qualitative traits

Almost all the 150 varieties assessed had leaf anthocyanin pigmentation (99.3%). The varieties with white leaf midrib (94.7%) and black glumes (77.3%) were the most common. The most differentiated modalities were observed on the pericarp colour (six modalities): the white pericarp was predominant (62.7%), followed by red pericarp (18.7%), orange (7.3%), brown (4.0%), grey (2.7%) and yellow (1.3%); while 3.3% were mixtures. Seventy-eight percent of the varieties had grains without testa and 64.7% had presented good corneous to medium endosperm texture.

The modalities of the seven qualitative traits of the panicle have allowed identification for four main botanical races of sorghum and two intermediate races. The main races were: the guinea which represent 86.0% [two sub races: the gambicum (96.1%) and the margaritiferum (3.9%)], the caudatum (6.7%), the bicolor (0.7%) and the durra (0.7%). The intermediate races were: the guinea-caudatum (2.0%) and the durra-bicolor (4.0%). The structuration of the modalities of panicle traits is shown in the Figure 2, whereas the botanical races identified in the study is presented in the Figure 3.

Evaluation of quantitative traits

Effect of variety on the traits expression

The ANOVA (Table 3) showed very highly significant differences (P < α = 0.001) between the 150 local sorghum varieties for all the eleven quantitative assessed traits. The most important variations was observed with

Table 1. Geographic origin of the 150 local sorghum varieties assessed.

Province	Isohyet (mm)	Department	Village	Number of varieties per village
Loroum	400-500	Sollé	Sollé	7
		Ouindigui	Ouindigui	6
Yatenga	500-600	Koumbri	Pogoro Mossi	14
		Ouahigouya	Gourga	11
		Seguenega	Zomkalaga	7
		Tangaye	Tougué Mossi	10
Zondoma	500-600	Boussou	Toubyengo	13
		Léba	Léba	11
Passoré	600-700	Gomponsom	Zougoungou	17
		Kirsi	Koussaogo	12
		Latodin	Sissamba	14
		Pilmpikou	Sandia	15
		Yako	Douré	13
Total		13	13	150

Table 2. List of qualitative and quantitative traits.

Name of trait	Abbreviation	Modality
Leaf pigment colour	LPC	Tan (1), anthocyanin (2)
Leaf midrib colour	LMC	White (1), green (2), yellow (3), brown (4), mixed (5)
Glumes colour	GLC	Yellow (1), brown (2), red (3), black (4), mixed (5)
Pericarp colour	PEC	White (1), yellow (2), orange (3), grey (4), brown (5), red (6), mixed (7)
Seed subcoat	SSC	Present (1), absent (2), mixed (3)
Endosperm texture	ENT	1 to 5: 1 (completely corneous), 5 (completely starchy)
Panicle compactness	PAC	Very loose (1) loose (2), semi-loose (3), semi-compact (4), compact (5), very compact (6)
Spikelet pedicellate persistence	SPP	Absent (1), low (2), medium (3) persistent (4)
Glumes length	GLL	Shorter (1), equal (2), longer than grain (3)
Glumes opening	GLO	Completely closed (1), weak (2), medium (3), very open (4)
Grain rotation	GRR	Absent (1), weak (2), medium (3), full rotation (4)
Grain form	GRF	Globulous (1), elliptic(2)
Glume adherence	GLA	Absent (1), weak (2), medium (3), strong (4)
Cycle duration from sowing to 50% heading (days)	NDH	Whole plot
Leaves number	LVN	3 randomly main stem marked from the 5-6 leaves stage to the flag leaf
Plant height (cm)	PLH	3 main stem recorded from the base of the stalk to the tip of the panicle (cm)
Stem diameter (mm)	STD	3 main stem recorded at the third inter-node under panicle
Length of third leaf under panicle (cm)	LTL	3 main stem
Width of third leaf under panicle (cm)	WTL	3 main stem
Panicle length (cm)	PAL	3 main stem
Sugar content (% brix)	SUC	1 main stem using a refractometer
Panicle dry weight (g)	PAW	12 hills
Grain dry weight (g)	GRW	12 hills
100 grains weight (g)	1GW	Bulk of 12 hills

the cycle duration from sowing to 50% heading (NDH) and the average weight of 100 grains (1GW) with 28.2 and 27.9 values of F, respectively. The NHD varied from 54 to 82 days and the weight of 100 grains from 1.2 to

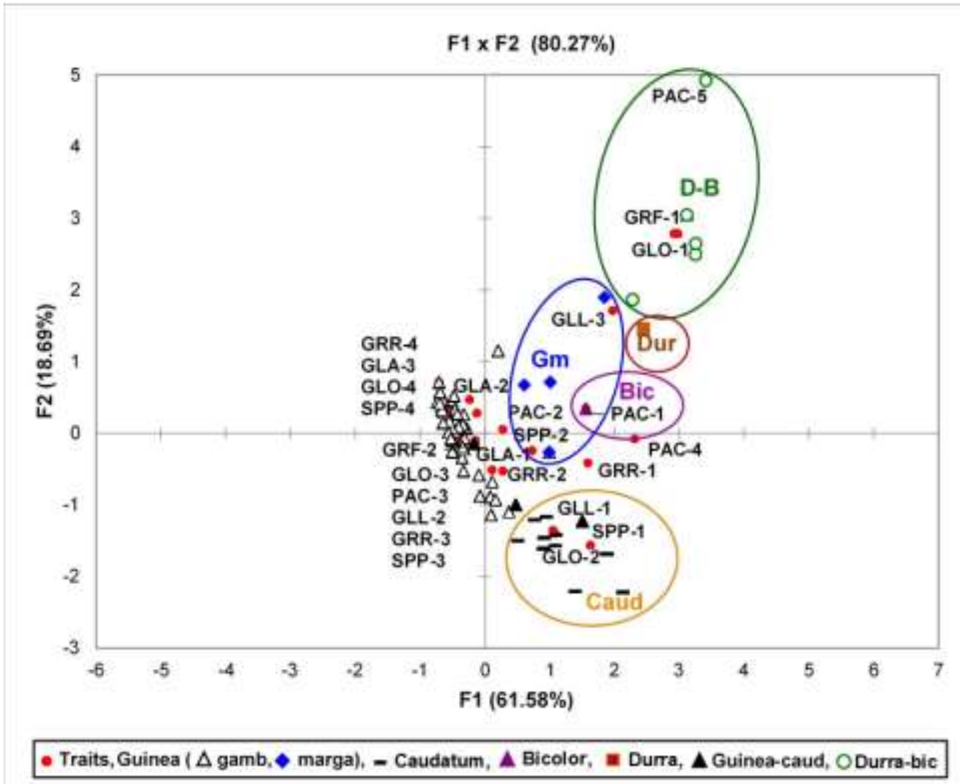

Figure 2. Racial structuration of the 150 local sorghum varieties of the North region of Burkina Faso determined by Multiple Correspondence Analysis (MCA) on the basis of seven qualitative traits.

4.1 g. The varieties with red pericarp were on average earlier cycle (67.4 days) compared to the varieties with white pericarp (72.1 days); their average weights of 100 grains were 2.3 g and 2.1 g, respectively. The earliest variety was Kapambga (Gg) (54 days) and the latest were Bobdo (Gg), Bininmênêm (Gg) and Kendezouanga (Db), who presented all 82 days of cycle duration (NDH). For the weight of 100 grains, Zonombdo (guinea-margaritiferum) (1.2 g) and Loumba (durra) (4.1 g) varieties had respectively the extreme values.

The broad sense heritability (H^2), including genetic effects as well as environmental effects varied from 0.55 to 0.97. It was particularly higher for the cycle duration (0.97) and the weight of 100 grains (0.96); as the number of leaves and length of leaves both showed a H^2 of 0.91. The narrow sense heritability (h^2) was higher for the cycle duration (0.90), the weight of 100 grains (0.90), the length of leaf (0.77), the number of leaves (0.76) and the Brix (0.66). The lowest heritability was observed for weight of panicles (0.28) followed by dry grains weight (0.32).

Effect of village on the traits expression

At the village level, the ANOVA revealed significant varietal differences in each village for cycle duration, the weight of 100 grains, the number of leaves and the length of leaves. The least differentiated traits in the most villages were the stem diameter, the leaf width, the panicles weight and the grains weight. The variability of varietal traits was more important within the varieties of the villages of Sissamba, Koussaogo, Léba, Porgo-mossi and Toubyango (Table 4).

Between villages, the most significant differences of traits were cycle duration and leaves length. The Lambda of Wilks test from Factorial Discriminant Analysis (FDA) gave a probability of 0.015 showing that the varieties are significantly different from one village to another. The differentiation was more important between the varieties of the village of Zougoungou and those of the villages of Gourga and Sollé; also, between the varieties of the village of Sollé and those of the villages of Douré, Koussaogo, Léba, Sandia, Sissamba and Zomkalaga.

Structuration of the diversity

The hierarchical cluster Analysis (HCA) discriminated the 150 local sorghum varieties into three groups (Figure 4). These are: i) Group 1 contains 58.7% of the varieties

Figure 3. Main botanical races identified in the 150 local sorghum varieties assessed.

from all the 13 villages. It has the earliest and most productive varieties, with a shorter plant height and a better weight of 100 grains; ii) Group 2 contains 30.7% of the varieties from 12 villages except the village Zomkalaga. This group includes varieties whose traits are intermediate between the first and third groups; iii) Group 3 includes 10.6% of the varieties from seven villages which are Sandia, Douré, Zougoungou, Sissamba, Tougué-mossi, Zomkalaga and Toubyango. This group is constituted by late maturing varieties characterized by lower productivity, taller plants and an average lower weight of 100 grains. The guinea-margaritiferum varieties are grouped into Group 1, while red pericarp varieties are classified into Groups 1 and 2. The description of the three groups is given in Table 5. The groups were discriminated in order by the cycle duration from sowing to heading, the weight of grain, the plant height, the leaves length and the average weight of 100 grains, with a probability $p < 0.0001$. The values of the proximity matrix established on the basis of the Euclidian distance showed that the 150 local sorghum varieties even those identified under the same names were all different from each another (sometimes weakly) for all eleven assessed traits.

DISCUSSION

Diversity of botanical races and variability of qualitative traits

Analysis of the seven descriptive traits of the panicle showed a predominance of the guinea botanical race varieties (86.0%) in the North region of Burkina Faso. This racial preference by farmers could be explained by four main reasons which are: i) the history of the domestication of botanical sorghum races, ii) the cultural heritage in terms of varieties, carried on from generation to generation by the local populations, iii) the adaptability of guinea to the extensive farming systems as practiced by most farmers in Burkina Faso, iv) their sensitivity to short days photoperiod and their good grain quality. The cultivation of the other races [caudatum (6.7%), durra (0.7%), bicolor (0.7%)] would meet the needs of specific uses. The caudatum varieties would serve as lain period sorghum, particularly those with sweet grain are consumed fresh before the harvests. The durra variety identified in this study is weakly used in human diet, but can be consumed in the form of porridge or mixed with cowpea in cooking; it would be used more specifically in traditional medicine for the treatment of goiter "hypothyroidism". The bicolor variety found in this study is called "Kankan-siido" in the region local language, and is cultivated for its sweet stem.

The racial composition of the local sorghum varieties of this study is similar to that reported by Zongo (1991) in Burkina Faso. However, the frequency of the guinea varieties is lower than those reported by Zongo (1991) and Barro-Kondombo et al. (2010) who found 93.1% across Burkina Faso and 94.4% at the level of three regions (Centre-North, Centre-West and the Boucle of Mouhoun), respectively.

The great presence of the anthocyanin varieties (99.3%) is noticeable in the local sorghum varieties. The reasons why farmers cultivate those varieties were not provided at the time of varieties collection. This strong

Table 3. Statistical parameters and heritabilities of the eleven quantitative traits of the 150 assessed varieties.

Source of variation	NDH (days)	PLH (cm)	STD (mm)	LVN	LTL (cm)	WTL (cm)	PAL (cm)	PAW (g)	GRW (g)	1GW (g)	SUC (% of brix)
Minimum	54.0	168.3	9.7	17.7	54.0	5.7	20.0	193.6	137.3	1.2	6.2
Maximum	82.0	435.0	15.0	25.0	85.3	10.7	43.7	811.8	641.6	4.1	18.6
Mean ± SD	71.0 ± 5.4	284.0 ± 48.3	12.4 ± 1.0	21.4 ± 1.3	68.0 ± 5.7	7.9 ± 0.8	30.3 ± 4.5	481.0 ± 137.0	349.0 ± 107.0	2.2 ± 0.4	12.6 ± 2.1
F repetition	0.4 ns	5.1*	4.2*	1.8 ns	4.5*	5.3*	6.1*	5.4*	5.2*	3.1*	0.6 ns
F block	15.2***	8.2***	3.1***	5.5***	4.3***	2.6***	3.5***	4.5***	4.6***	13.1***	3.6***
F variety	28.2***	5.0***	2.4***	10.6***	11.3***	3.7***	2.8***	2.2***	2.4***	27.9***	6.8***
CV (%)	2.3	9.8	6.2	2.8	3.9	7.1	10.9	21.4	22.5	5.2	9.4
H^2	0.97	0.80	0.58	0.91	0.91	0.73	0.65	0.55	0.60	0.96	0.85
h^2	0.90	0.57	0.31	0.76	0.77	0.48	0.38	0.28	0.32	0.90	0.66

ns (non significant)
* (significant effect of the factor at α = 0.05 level),
** (highly significant effect of the factor at α = 0.01),
*** (very highly significant effect of the factor at the α = 0.001).

Table 4. Results of ANOVA of the variety effect by village and between villages.

Villages	NDH (days)		PLH (cm)		STD (mm)		LVN		LTL (cm)		WTL (cm)		PAL (cm)		PAW (g)		GRW (g)		1GW (g)		SUC (% brix)	
	μ	F	μ	F	μ	F	μ	F	μ	F	μ	F	μ	F	μ	F	μ	F	μ	F	μ	F
Douré	72.6	22.6***	290	4.7***	12.3	0.9 ns	21.1	18.4***	67.2	11.2***	7.7	4.0**	29.3	1.4 ns	428	1.4 ns	297	1.5 ns	2.1	36.5***	13.2	2.0 ns
Gourga	69.2	35.4***	284	1.9 ns	12.9	2.4*	21.0	6.5***	72.0	5.8***	7.8	2.1 ns	32.0	2.7*	538	1.7 ns	382	1.7 ns	2.2	36.8***	12.4	2.1 ns
Koussaogo	70.6	17.8***	290	1.8 ns	12.3	3.4**	21.1	6.9***	68.7	6.2***	8.0	1.7 ns	31.0	3.3**	484	2.4*	360	2.4*	2.2	18.2***	12.1	2.8*
Léba	71.3	30.8***	270	5.4***	12.6	1.5 ns	21.2	21.8***	66.6	19.7***	8.2	3.4**	29.3	7.9***	481	2.3 ns	376	3.0*	2.4	43.0***	12.6	3.6**
Ouindigui	69.8	29.0***	271	2.6 ns	12.3	0.8 ns	21.3	14.8***	68.2	31.1***	7.8	1.9 ns	31.6	2.7 ns	547	5.7**	383	4.0*	2.3	51.6***	13.8	8.8**
Porgo-mossi	71.1	27.5***	277	3.9**	12.4	1.3 ns	21.3	17.7***	68.4	16.0***	7.8	2.1*	31.5	2.9*	461	2.5*	334	2.1 ns	2.1	49.4***	12.4	2.5*
Sandia	72.8	15.6***	296	1.7 ns	12.2	1.6 ns	21.8	14.5***	66.7	7.0***	7.8	1.2 ns	30.0	2.7*	477	1.1 ns	352	1.7 ns	2.2	19.1***	12.6	1.2 ns
Sissamba	72.4	23.8***	290	3.9**	12.4	3.2**	21.4	16.4***	68.0	9.6***	7.9	3.9**	30.0	2.9*	460	4.2***	340	3.7**	2.2	22.6***	11.7	1.9 ns
Sollé	69.5	33.3***	271	1.4 ns	12.8	0.4 ns	21.2	7.5**	72.6	11.4***	8.2	1.2 ns	32.3	2.1 ns	502	2.5 ns	333	4.7*	2.1	10.4***	12.8	6.3**
Toubyango	67.9	16.7***	273	8.3***	12.9	2.9*	21.3	5.7***	68.1	7.9***	8.1	5.6***	29.4	4.0**	504	2.0 ns	370	1.9 ns	2.1	37.4***	12.8	8.2***
Tougé-mossi	70.3	25.5***	278	2.6*	12.3	5.0**	21.2	8.1***	67.9	4.2**	7.5	0.9 ns	29.8	0.5 ns	465	1.7 ns	318	2.4 ns	2.2	8.4***	13.1	1.7 ns
Zomkalaka	73.1	25.1***	301	3.3*	12.5	2.2 ns	21.9	20.3***	67.9	3.2*	8.1	2.2 ns	30.1	4.3*	476	0.9 ns	354	1.2 ns	2.3	25.8***	12.2	4.1*
Zougougou	71.8	18.4***	287	6.6***	12.1	1.8 ns	21.7	2.9**	65.3	6.8***	7.8	1.9 ns	29.9	2.2*	484	1.9 ns	356	2.4*	2.2	17.4***	12.2	3.7***
Inter-villages		3.1***		1.4 ns		2.7**		1.8*		4.3***		2.1*		1.7 ns		1.7 ns		2.0*		1.6 ns		1.5 ns

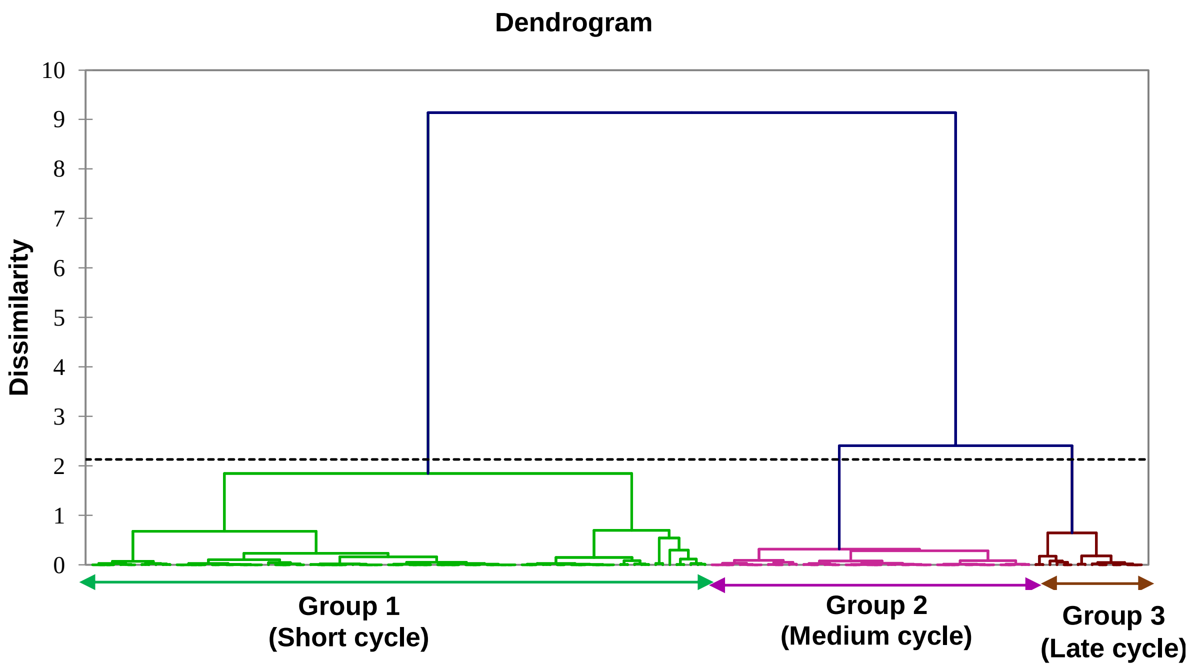

Figure 4. Agromorphological structuration of the 150 local sorghum varieties determined by HCA according to Ward's aggregation criterion.

Table 5. Description of the three groups of HCA with some discriminating traits.

HCA groups	NDH (days)	GRW (g)	PLH (cm)	LTL (cm)	1GW (g)
Group 1	69.2	388.5	276.8	68.9	2.3
Group 2	72.6	305.7	285.7	67.5	2.1
Group 3	76.6	258.8	316.3	64.4	2.0

adoption of the anthocyanin varieties would not be by fortuitous, but probably linked to the biotic and abiotic stresses. In fact, Etasse (1977) has found that the sorghums without anthocyanin would be more susceptible to foliar diseases especially to *Ramulispora sorghi*. Dicko et al. (2005) have emphasized that the sorghum varieties with high proanthocyanidins content showed better resistance to pre and post flowering drought. The importance of the phenolic compounds of sorghum has been reported by several authors who revealed that anthocyanins and other flavonoids have medicinal properties: antioxidants (Awika and Rooney, 2004), anti-inflammatory (Burdette et al., 2010) and anti-cancer (Wu et al., 2011). The presence of tannins in the grain would reduce the digestibility and fight obesity (Awika and Rooney, 2004; Wu et al., 2012).

The results of this study are similar to those reported by Barro-Kondombo et al. (2010) who found 98.4% of anthocyanin sorghum varieties. Multi-scale investigations could provide more information on the nature of phenolic compounds of the local sorghum varieties in Burkina Faso and the reasons why farmers prefer this trait. The results also showed a great presence of white pericarp varieties. Generally in Burkina Faso, white pericarp varieties are used in cooking to prepare thick porridge, a local dish widely consumed in rural families. On the other hand, red pericarp varieties are used in the preparation of local beer sold or served during traditional ceremonies. Some red pericarp varieties have a sweet grain and are sown to be consumed fresh during the lain period, as the earliest variety named Kapambga "sorghum whose grain is extracted fresh from the panicle".

Diversity and structuration of measured traits

The inter-varietal effect was very highly significant for all the eleven assessed traits, showing that the varietal diversity cultivated by the farmers was high. The greatest variations was observed with the cycle duration from sowing to heading and the average weight of 100 grains; these two traits strongly contribute to the differentiation of the local sorghum varieties assessed. At the village level in addition to the cycle duration and the weight of 100 grains, the number of leaves and the length of leaves were the traits which contributed to the varietal differentiation. The variability of the cycle within varieties was an expected result. In fact, the North region of Burkina Faso is an area more exposed to rainfall fluctuations. The beginning and the end of the rainy season is always uncertain, for that reason farmers integrate possible alternatives into their production strategies to maximize the chances of harvest. In case of an early beginning of rains the later-cycle varieties are the first to be sown and in the otherwise, short-cycle varieties are sown. Only farmers having farming areas around lowlands manage to sow late maturing sorghum varieties. Among the factors influencing crop diversity, climate effects are the most important Mercer and Perales (2010). Vom Brocke et al. (2010) also reported that the adaptability of the cycle was one of the criteria in sorghum growing areas in Burkina Faso.

The great variability of the weight of 100 grains is in relation to the various food uses. The guinea margaritiferum varieties, which have the smallest grains (1.2 g), dehulled and used alternative of rice. The sorghums with medium grain are used for the preparation of common dishes like “tôt”, local beer whereas the sorghums with big grain like the durra (4.1 g) are used in the preparation of porridges and couscous.

In term of traits heritability, our results are quite similar to those obtained by Tamini (2014) in a study on improved sorghum varieties of Burkina Faso. Tamini (2014) reported slightly higher values of heritability on the cycle ($h^2 = 0.98$), the weight of 1000 grains ($h^2 = 0.85$), the length of leaves ($h^2 = 0.81$) and the number of leaves ($h^2 = 0.94$). Some traits may not be selected intentionally, but owing to the phenotypic linkages they are inherited correlatively and therefore indirectly selected.

Concerning the sugar content of the stem, the high concentration in certain guinea sorghum varieties (up to 18.6% of brix) serves as interesting results to be exploited for varietal improvement. Nebié et al. (2009) found brix values up to 21.8 but specifically in sweet stem sorghums of Burkina Faso.

In general, the varietal diversity in this study was high, but it is difficult to compare it with that found in other countries like Ethiopia (Teshome et al., 1997) or in Kenya (Ngugi and Maswili, 2010) owing to the differences in the choice of the assessed traits and racial background.

The agromorphological diversity structuration of the 150 local sorghum varieties into three groups (Figure 4) was not based on village, botanical racial (except the sub-race guinea-margaritiferum varieties) or pericarp colour criteria. The structuration on the base of cycle duration (NHD) and grain productivity (GRW) shows clearly the importance of floral-biology on sorghum productivity, particularly under low rainfall conditions. Seven of the thirteen villages of this study have higher diversity representative in all the three groups structured by the HCA. Each one of these villages gives quite a good representation of the varietal diversity encountered in the North region of Burkina Faso and could constitute units of management for the preservation of varietal diversity on the scale of “terroirs”. Compared with other studies, Barro-Kondombo et al. (2010) reported that the cycle duration, plant height, 1000-grains weight and grain vitreousness were the principal structuring factor in local sorghum varieties from three regions of Burkina Faso. Koffi et al. (2011) reported in their study on the sorghums from the North of Côte d’Ivoire that the weight of 1000 grains, the cycle duration and the number of leaves were the first factors of the structuring of the diversity studied.

Conclusion

Assessment of the agromorphological diversity of the 150 local sorghum varieties from the North region of Burkina Faso showed that the varietal diversity cultivated by farmers was high and largely dominated by sorghums of the guinea botanical race, which indicates that racial configuration of sorghums remains unchanged in Burkina Faso. In terms of management, the three groups from the (HCA) are different entities based on phenology. However, for the North region, the Group 3 which contains late maturing varieties (76.6 days NDH) characterized by low productivity would be more exposed to the risks of abandonments, due to the rainfall constraints and probably parasitic attacks like midge (*Stenodiplosis sorghicola*). For this plant material, molecular analysis would be useful to confirm gene pools. Moreover, it is important to confirm the agronomic performance of the early maturing varieties, their tolerance to sorghum pests and other pathogens, their grain quality and even their biochemical composition with the aim of their use in the varietal improvement program.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Awika JM, Rooney LW (2004). Sorghum phytochemicals and their potential impact on human health. Phytochemistry 65: 1199-1221.

Ayana A, Bekele E (1998). Geographical patterns of morphological variation in sorghum [*Sorghum bicolor* (L.) Moench] germplasm from Ethiopia and Eritrea: qualitative characters. Hereditas 129:195-205.

Barro-Kondombo C, Sagnard F, Chantereau J, Deu M, vom Brocke K, Durand P, Gozé E, Zongo JD (2010). Genetic structure among sorghum landraces as revealed by morphological variation and microsatellite markers in three agroclimatic regions of Burkina Faso. Theoretical and Applied Genetics 120:1511-1523.

Bindraban PS, Stoorvogel JJ, Jansen DM, Vlaming J, Groot JJR (2000). Land quality indicators for sustainable land management: proposed method for yield gap and soil nutrient balance. Agriculture Ecosystems and Environment 81:103-112.

Burdette A, Garner PL, Mayer EP, Hargrove JL, Hartle DK, Greenspan P (2010). Anti-inflammatory activity of select sorghum (Sorghum bicolor) brans. Journal of Medicinal Food 13:879-887.

Desmae H, Jordan DR, Godwin ID (2016). Geographic patterns of phenotypic diversity in sorghum (*Sorghum bicolor* (L.) Moench) landraces from North Eastern Ethiopia. African Journal of Agricultural Research 11(33):3111-3122.

Direction Générale de l'Aménagement du Territoire (DGAT) (2006). Profil des régions du Burkina P. 290.

Dicko MH, Gruppen H, Barro C, Traoré AS, van Berkel WJH, Voragen AGJ (2005). Impact of phenolic compounds and related enzymes in sorghum varieties for resistance and susceptibility to biotic and abiotic stresses. Journal of Chemical Ecology 31:2671-2688.

Dossou AI, Loko LY, Adjatin A, Ewédjè BKE-E, Dansi A, Rakshit S, Cissé N, Patil VJ, Agbangla C, Sanni A, Akoègninou A, Kofi AK (2015). Genetic Divergence in Northern Benin Sorghum (*Sorghum bicolor* L. Moench) Landraces as Revealed by Agromorphological Traits and Selection of Candidate Genotypes. The Scientific World Journal pp. 1-10.

Etasse C (1977). Synthèse des travaux sur le sorgho. Agronomie Tropicale 33(3):311-317.

FAOSTAT. Food and agriculture data from 2012 to 2016. www.fao.org.

Harlan JR, De Wet JMJ (1972). A simplified classification of cultivated sorghum. Crop Science 12:172-176.

Koffi KGC, Akanvou L, Akanvou R, Zoro BTA, Kouakou CK, N'da HA (2011). Diversité morphologique du sorgho (*Sorghum bicolor* L. Moench) cultivé au nord de la Côte d'Ivoire. Ivoir. Science Technology 17:125-142.

Kondombo CP, Barro A, Kaboré B, Bazié JM (2016). On-Farm diversity of sorghum [*Sorghum bicolor* (L.) Moench] and risks of varietal erosion in four regions of Burkina Faso. Academicjournal, International Journal Biodiversity Conservation 8(8):171-179.

Leiser WL, Rattunde FW, Weltzien E, Haussmann BIG (2014). Phosphorus uptake and use efficiency of diverse West and Central African sorghum genotypes under field conditions in Mali. Plant Soil 337:383-394.

MARHASA (Ministère de l'Agriculture des Ressources Hydrauliques, de l'Assainissement et de la Sécurité Alimentaire). Résultats définitifs des campagnes agricoles 2012-2016 et des perspectives de la situation alimentaire et nutritionnelle, SG/DGESS.

Mercer KL, Perales HR (2010). Evolutionary response of landraces to climate change in centers of crop diversity. Blackwell Publishing Ltd 3:480-493.

Mujaju C, Ereck Chakauya E (2008). Morphological Variation of Sorghum Landrace Accessions On-Farm in Semi-Arid Areas of Zimbabwe. International Journal of Botany 4(4):376-382.

Nebié B (2009). Etude de la variabilité agromorphologique de quelques écotypes de sorghos sucres [*Sorghum bicolor* (L.) Moench] du Burkina Faso. Mémoire de DEA, Université de Ouagadougou P. 62.

Ngugi K, Maswili R (2010). Phenotypic diversity in sorghum landraces from Kenya. Africa Crop Science Journal 18(4):165-173.

Paturel JE, Boubacar I, L'Aour A, Mahé G (2010). Analyses de grilles pluviométriques et principaux traits des changements survenus au 20[è] siècle en Afrique de l'Ouest et Centrale. Hydrological Sciences Journal 55(8):1281-1288.

Sawadogo N, Nebié B, Kiébré M, Kando PB, Nanema RK, Traoré RE, Naoura G, Sawadogo M, Zongo JD (2014). Caractérisation agromorphologique des sorghos à grains sucrés (*Sorghum bicolor* (L.) Moench) du Burkina Faso. International Journal. Biology Chemistry. Science 8(5):2183-2197.

Tamini M (2014). Evaluation de l'effet de la densité de plantes sur la productivité de nouvelles variétés de sorgho [*Sorghum bicolor* (L.) Moench] du Burkina Faso. Université de Ouagadougou, Centre Universitaire Polytechnique de Dédougou 53 P.

Teshome A, Baum BR, Fahrig L, Torrance JK, Arnason TJ, Lambert JD (1997). Sorghum [*Sorghum bicolor* (L.) Moench] landrace variation and classification in North Shewa and South Welo, Ethiopia. Euphytica 97:255-263.

Teshome A, Torrance K, Breuer L (2018). Farmers' synergistic selection criteria and practices for livelihood security through the sustainable uses of on farm Sorghum landrace diversity, Ethiopia. African Journal of Agricultural Research 13(33):1674-1688.

Vom Brocke K, Trouche G, Weltzien E, Barro-Kondombo CP, Gozé E, Chantereau J (2010). Participatory variety development for sorghum in Burkina Faso: Farmers' selection and farmers' criteria. Field Crop Research 119:183-194.

Wu L, Huang Z, Qin P, Yao Y, Meng X, Zou J, Zhu K, Ren G (2011). Chemical characterization of a procyanidinrich extract from sorghum bran and its effect on oxidative stress and tumor inhibition in vivo. Journal Agricultural Food Chemistry 59:8609-8615.

Wu Y, Li X, Xiang W, Zhu C, Lin Z, Yun Wu Y, Li J, Pandravada S, Ridder DD, Bai G, Wang ML, Trick HN, Bean SR, Tuinstra MR, Tesso TT, Yu J (2012), Presence of tannins in sorghum grains is conditioned by different natural alleles of Tannin1. A. S. 109(26):10281-10286.

Zongo JD (1991). Ressources génétiques des sorghos (*Sorghum bicolor* L. Moench) du Burkina Faso : Evaluation agro-morphologique et génétique. Thèse de doctorat, Université d'Abidjan 175 p.