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Phenotypic variability and racial classification of landraces of sorghum (*Sorghum bicolor* (L.) Moench) collected in the Northwestern Benin

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Key words: Agro-morphological diversity, Botanical race, Quantitative descriptors, Qualitative descriptors, Benin.

Abstract

A morpho-botanical analysis of 76 sorghum accessions collected from the department of Donga, the northwestern part of Benin was carried out. An agro-morphological assessment of accessions was conducted based on 15 descriptors (10 quantitative traits and 5 qualitative traits). The experiment was laid at alpha lattice design with three repetitions. Four races (guinea, durra, caudatum and bicolor) were identified with high proportion of accessions of guinea race (86.84%) and low proportion of other races such as durra (5.26%), caudatum (2.63 %) and bicolor (1.32%). Kafir race was missed from the collection. The analysis of agro-morphological characters of accessions showed a significant phenotypic variability of sorghum local varieties kept and managed by farmers in Donga. The principal component analysis (PCA) performed on quantitative traits showed three axes accounted for nearly 70% of the total variation. The first axis represents plant height, diameter of third internodes, leaf length and leaf width of the third internodes; the second axis accounts for length of peduncle while the third one stands for the weight of 1,000 grains. On the basis of the quantitative and qualitative traits studied, ascending hierarchical classification according to Ward aggregation criteria differentiated four groups structured around key variables such as morpho-physiological characteristics of grains (color, size, degree of bitterness) and race.

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Introduction

Sorghum bicolor (L.) Moench, is a monocotyledon self-pollinating plant of tropical origin, belonging to the family of Poaceae. It is cultivated in many tropical regions of the world where it is used in human and animal food and also in industries (Djè *et al.*, 2007). Among the economically important cereals in the world, sorghum ranks fifth behind maize (*Zea mays*), rice (*Oryza* spp.), wheat (*Triticum* spp.) and barley (*Hordeum* spp.) (FAOSTAT, 2010). In the Sahelian and semi-arid zones of Africa, sorghum is one of the main resources of food (Djè *et al.*, 2007). Its grains are rich in carbohydrates and are appreciated for their high energy value.

In Benin, sorghum is a staple food and ranks second behind maize with an annual production of 168,090 tons in 2010 (FAOSTAT, 2010). Sorghum still remains a traditional and ancient crop in the northwest of the country despise its rank. Apart from its use as food, some landraces of sorghum are grown for their red pigment in the leaf sheaths and sometimes in adjacent parts of stem: tinctorial sorghum and coloring sorghum (Kayodé *et al.*, 2005) and others for their use in traditional medicine (for instance the bitter yellow sorghum) (Kayodé *et al.*, 2005; Missihoun *et al.*, 2012a).

The domestication of sorghum would probably began in the Northeast Africa in a region located between present-day Sudan and Ethiopia for about eight thousand years ago (Wendorf *et al.*, 1992). Sorghum domesticated shows high morphological diversity in terms of color and size of grains, color and length of glumes, length and shape of panicles, and vegetative cycle, etc. (Kayodé *et al.*, 2006; Barnaud, 2007 ; Djè *et al.,* 2007; Barro-Kondombo *et al.,* 2010), which contributes to its remarkable adaptation to varying climatic, soil and ecological conditions. The cultivated sorghums are generally classified botanically and based on the shape of the spikelet, grains and glumes in 5 basic races (guinea, caudatum, durra, kafir, bicolor) and 10 intermediate races gathering the characteristics of two or more basic races (Harlan and de Wet, 1972).

For better management, conservation and valorization through genetic improvement of its resources, the morphological diversity of cultivated sorghum was assessed worldwide. This evaluation prerequisite for any molecular genetics characterization allows to detect possible synonyms or homonyms of farmers' classification of varieties and also to make a reasoned and representative choice of samples for analysis at molecular level. In Africa, many studies of morphological diversity were carried out. In Ethiopia, a study on 10 qualitative traits and 54 fields showed the existence of significant morphological variability between fields and that observed from the enzyme data (Djè *et al.,* 1998). Many other studies assessing agro-morphological variability of landraces of cultivated sorghum were conducted. In West Africa, for instance, studies of genetic diversity of local varieties of cultivated sorghum were carried out by several researchers (Morden *et al.,* 1989; Zongo, 1991; Ollitrault *et al.,* 1997). Recently in Burkina Faso, a study of phenotypic variability of local sorghum varieties in two regions was performed (Barro-Kondombo *et al.*, 2008). It appears from this study that the racial diversity of cultivated sorghum in these regions is low and largely dominated by the guinea race representing 96.8% of cultivated varieties. This study confirmed that of Zongo (1991) also carried out in Burkina Faso by taking into consideration the whole country and estimated the proportion of accessions of guinea race at 93.1%. This preponderance of guinea race is not observed in other countries of the sub-region such as Nigeria (40.2% of guinea), Niger (10.5% of guinea) and Chad (7.0% of guinea) (Barro-Kondombo *et al.*, 2008, Deu *et al.*, 2008). In Benin, the agro-morphological characterization of sorghum local varieties remains in small portions and data on racial classification of cultivated accessions are almost non-existent. However, the preservation of genetic resources of cultivated species requires a thorough knowledge of their phenotypic and genetic diversity, for the purpose of better management and valorization through plant improvement.

The present work aims at:

(1) Assessing agro-morphological characteristics of accessions of cultivated sorghum in the northwestern parts of Benin;

(2) Identifying botanically different races of cultivated sorghum in the Northwestern Benin.

Materials and methods

Plant materials

The study was conducted on 76 accessions of local varieties (Table 1) surveyed in December 2010 in thirteen villages of Donga, the northwestern Benin (Missihoun *et al.*, 2012a) according to participatory research method described by Tuan *et al.* (2003) and Adoukonou-Sagbadja *et al.* (2006). Accessions were local varieties grown by farmers from different ethnic groups in the country.

Experimental site

The agro-morphological evaluation of accessions was conducted at the experimental site on the campus of University of Abomey-Calavi (6°24'57"N 2°20'31"E) in Benin. It is a tropical wet zone characterized by strong heat and high relative humidity ranging from 85-90%. The soil is ferralitic type dominated by sandy-clayey sediments of the continental terminal. Its pH is close to 6.2 and the organic matter content is 1.58%. The climate is of sub-equatorial type characterized by a rainfall of 800 mm to 1200 mm with four seasons: two rainy and two dry. The main rainy season is from April to July and early September to October. As for the dry season, the long one is from November to March and the short one from July to August (Table 2). The experiments were conducted from May 2011 to January 2012.

Table 1. Code of the accessions, vernacular name, racial group and some information's of grain and growing season.

N°	Code of the Accessions	Vernacular name	Racial group	Colour of grain	Colour of husk	Panicle shape	Growing season
1	SOD 1	Zomouara	G	Red	Black	Loose	Early-maturing
2	SOD 2	Zowémoha	G	Red	Black	Loose	Early-maturing
3	SOD 3	Zomooha	G	Red	Black	Loose	Early-maturing
4	SOD 4	Ano Eranan chinchin	G	Red	Red	Loose	Early-maturing
5	SOD 5	Moussema	G	Red	Black	Loose	Early-maturing
6	SOD 6	Zoténtérém	DK	Red	Red	Compact	Early-maturing
7	SOD 7	Zomoaha	G	Red	Black	Loose	Early-maturing
8	SOD 8	Zomooha 1	G	Red	Black	Loose	Early-maturing
9	SOD 9	Zomooha 2	G	Red	Purple	Loose	Early-maturing
10	SOD 10	M'ssema	G	Red	Black	Loose	Early-maturing
11	SOD 11	Koussem	G	Red	Black	Loose	Early-maturing
12	SOD 12	Zomoaha 1	G	Red	Black	Loose	Early-maturing
13	SOD 13	Anoro Kin'ka	G	Red	Black	Loose	Early-maturing
14	SOD 14	Zoténtérém	DK	Red	Red	Compact	Early-maturing
15	SOD 15	Zoumbouara	G	Red	Black	Loose	Early-maturing
16	SOD 16	Aka Kpankpan Kékéré	G	Red	Black	Loose	Early-maturing
17	SOD 17	Zopéra	G	White	Black	Loose	Late-maturing
18	SOD 18	Zopira	G	White	Black	Loose	Late-maturing
19	SOD 19	Zobeumdjoura rouge (à glumes rouges)	G	White	Red	Loose	Late-maturing
20	SOD 20	Kèmnin Piha	G	White	Black	Loose	Early-maturing
21	SOD 21	Agbani blanc	G	White	Black	Loose	Late-maturing

N°	Code of the Accessions	Vernacular name	Racial group	Colour of grain	Colour of husk	Panicle shape	Growing season
22	SOD 22	Zobomdjouha	G	White	Black	Compact	Late-maturing
23	SOD 23	Agbani 1	G	White	Red	Loose	Late-maturing
24	SOD 24	Tiam'la (blanc)	G	White	Black	Loose	Early-maturing
25	SOD 25	Zopiha 1 A	G	White	Black	Loose	Late-maturing
26	SOD 26	Zopiha 1 B	KG	White	Black	Compact	Late-maturing
27	SOD 27	Zopiha 2	G	White	Black	Loose	Late-maturing
28	SOD 28	Ano Efoonon	G	White	Black	Loose	Late-maturing
29	SOD 29	Koulom A	G	White	Purple	Loose	Late-maturing
30	SOD 30	Koulom B	G	White	Purple	Loose	Late-maturing
31	SOD 31	Aka Inodjo	G	Whitish	Whitish	Loose	Early-maturing
32	SOD 32	Aka foufou Kékéré	G	White	Black	Loose	Early-maturing
33	SOD 33	Agbani 2	G	White	Noirâtre	Loose	Late-maturing
34	SOD 34	Kouhloumè	G	White	Red	Loose	Late-maturing
35	SOD 35	Aka foufou Lako	G	Whitish	Black	Loose	Late-maturing
36	SOD 36	Sèmoutchè	G	White	blackish	Very loose	Early-maturing
37	SOD 37	Anoro Foonon 1	G	White speckled with crimson	blackish	Loose	Late-maturing
38	SOD 38	Anoro Foonon 2	G	Whitish	blackish	Loose	Late-maturing
39	SOD 39	Vèmah 1	DG	White	Purple	Compact	Early-maturing
40	SOD 40	Zomoala	D	Yellow	White	Compact	Intermediate-maturing
41	SOD 41	Ano chochomi	D	Yellow	White	Compact	Intermediate-maturing
42	SOD 42	Zomoila	D	Yellow	White	Compact	Intermediate-maturing
43	SOD 43	Zomoora	D	Yellow	White	Compact	Intermediate-maturing
44	SOD 44	Zotihou	D	Yellow	White	Compact	Intermediate-maturing
45	SOD 45	Sèmgin moaha	G	Whitish	Red/Black	Loose	Intermediate-maturing
46	SOD 46	Lam'za moaha	G	Whitish	Red/Black	Loose	Intermediate-maturing
47	SOD 47	Zogawa	G	Whitish	Crimson	Loose	Intermediate-maturing
48	SOD 48	Narabeunzo	B	blackish	Black	Loose	-
49	SOD 49	Zokaram nini 1	G	Reddish	Red	Loose	Late-maturing
50	SOD 50	Zokaram nini 2	G	Whitish	Black	Loose	Late-maturing
51	SOD 51	Lam néza	G	Reddish/ Whitish	Black	Loose	
52	SOD 52	Lamza	G	Whitish	Black	Loose	Intermediate-maturing
53	SOD 53	Sèmgnin Piha	G	Whitish	White-Black	Loose	Intermediate-maturing
54	SOD 54	Ano Kaki	G	Reddish	Black	Loose	Early-maturing
55	SOD 55	Ano Eranan	G	Reddish	Red	Loose	Intermediate-maturing
56	SOD 56	Za (moins rouge)	G	Whitish	Red	Loose	Late-maturing
57	SOD 57	Agbani (rouge)	G	Whitish	Crimson	Loose	Late-maturing
58	SOD 58	Za (rouge) ou Zaga	G	Whitish	Red	Loose	Late-maturing

N°	Code of the Accessions	Vernacular name	Racial group	Colour of grain	Colour of husk	Panicle shape	Growing season
59	SOD 59	B'mdjoura	G	Whitish	Red	Loose	Late-maturing
60	SOD 60	Zokpénaï	D	Yellowish	White	Compact	Early-maturing
61	SOD 61	Zooga	G	White/Red	Black	Loose	Late-maturing
62	SOD 62	Talèm'la	G	Whitish	Red	Loose	Late-maturing
63	SOD 63	Zoniniléti	G	Whitish	Black	Loose	Late-maturing
64	SOD 64	M'la Kssèmèè	G	Reddish	Red	Loose	Early-maturing
65	SOD 65	Anoro Kin'ka 2	G	Reddish	Red	Loose	Intermediate-maturing
66	SOD 66	Moukoulikouté	C	Reddish/ Yellowish	Whitish	Compact	Late-maturing
67	SOD 67	Zobeundjouha	G	White/Red	Red	Semi-loose	Late-maturing
68	SOD 68	Moussii	D	Yellowish	White	Compacte	Early-maturing
69	SOD 69	Zomoaha 2	G	Reddish	Red	Loose	Early-maturing
70	SOD 70	M'sséé	C	Yellowish	Crimson	Compact	Early-maturing
71	SOD 71	Vèmah 2	D	Whitish	Yellowish	Compact	Early-maturing
72	SOD 72	Talèm'la	G	Whitish	Black	Loose	Late-maturing
73	SOD 73	Zoumboua	G	Reddish	Black	Loose	Early-maturing
74	SOD 74	aka kpankpan Lako 1	G	Reddish	Red	Loose	Early-maturing
75	SOD 75	aka kpankpan Lako 2	G	Whitish	Reddish	Loose	Early-maturing
76	SOD 76	Zowémoha 2	G	Reddish	Black	Loose	Early-maturing

Table 2. Climatic characteristics of the sampled villages and experimental site.

Townships of department	Villages sampled	Climatic characteristics (adapted from WorldClim data base)	Other crops grown in addition to sorghum	Number of samples
Bassila	Guiguissou Salmanga	Climate : Sudano-Guinean rainfall: 1150-1183 mm with unimodal regime (May-October) Temperature: 20°C-33°C	Millet, maize, yam, groundnut, cassava, cowpea, pepper, tomato, okra, cashew	9
	Patargo	Climate : Sudanese rainfall : 1250 mm on average with unimodal regime (May-September) Temperature: 20°C-33°C	Millet, maize, yam, groundnut, cassava, pepper, tomato, okra, rice, cashew	6
Djougou	Danogou Onklou Darawinga Pélébina Serou Yoroussonga	Climate : Sudanese rainfall : 1130-1164 mm with unimodal regime (May-September) Temperature: 20°C-33°C	Millet, yam, rice, maize, groundnut, cassava, potato, cowpea, soya, bambara groundnut, pepper, tomato, okra, cashew	37
Copargo	Kpassabega Singre	Climate : Sudanese Rainfall : 1153-1164 mm with unimodal regime (May-September) Temperature: 20°C-33°C	Millet, yam, rice, maize, groundnut, cassava, potato, cowpea, tomato, okra, cashew	16

Townships of department	Villages sampled	Climatic characteristics (adapted from WorldClim data base)	Other crops grown in addition to sorghum	Number of samples
Ouaké	Kim-Kim Sonaholou	Climate: Sudanese Rainfall : 1227-1262 mm with unimodal regime (May-September) Temperature: 20°C-33°C	Millet, maize, yam, groundnut, cassava, cowpea, rice, bambara groundnut, pepper, tomato, okra, cashew	8
Abomey-Calavi (experimental site)	University of Abomey-Calavi (experimental site)	Climate : Guinean (sub-equatorial type) rainfall : 1160 mm on average with bimodal regime (April-July and from September-October) Temperature: 24°C-31°C	Non documented	76 (Total of samples)

Experimental design

The experimental design was laid at alpha lattice (Patterson and Williams, 1976) with three replicates, 11 blocks and 11 accessions per entry. Each accession was randomly sown in the three replicates. For each accession, the plot unit was 1.6 m long and 1 m wide with 0.80 m line spacing and 0.20 m row spacing. Each plot unit consisted of 10 plants. Only one plant was left in seed hole 10 days after emergence (Fig. 1a). The parameters were measured on five plants randomly selected from each primary plot. These plants were monitored until maturity (Fig. 1b and Fig. 1c) and various quantitative and qualitative parameters were recorded.

A total of 5 quantitative parameters and 5 qualitative parameters were measured during the experimentation. Quantitative parameters measured were: plant height (Hpl), length of the panicle (Lpa), peduncle length (Lpe), diameter of the third internodes (Dte), leaf length of the third internodes (Ltf), leaf width of the third internodes (LTF), the panicle exsertion (exp), number of leaves (NFE), the effective number of tillers (Nw) and the weight of 1000 grains (p ~ 1000). The qualitative parameters measured were the emergence vigor (Vem), grain color (Cgr), color of glumes (Cgl), panicle type (Ptp) and grain type (GTO). The various parameters were recorded according to the recommendations of the revised descriptors of sorghum (Bioversity International and ICRISAT, 1993).

As for racial classification, it was done according to the criteria defined by Harlan and de Wet (1972) in two stages: initially on panicles collected from farmers and secondly on panicles harvested in the end of the experiment carried out at the Laboratory of Genetics and Biotechnology, University of Abomey-Calavi.

Data analysis

In order to estimate the heterogeneity between the blocks, uni-variate statistical analysis of variance (ANOVA) with one factor was used with the aid of Statistica 7.1 software. A principal component analysis (PCA) was performed in order to estimate the overall diversity within the studied population and to describe the relationships between variables. This analysis was followed by a hierarchical cluster analysis (HCA). The grouping of accessions in phenotypic classes by the method of hierarchical cluster analysis was performed. From these results, the number of classes and the class of each composition were determined. Given that variables are coded, descriptive statistics of the classes in the table of frequencies allowed describing each of these classes.

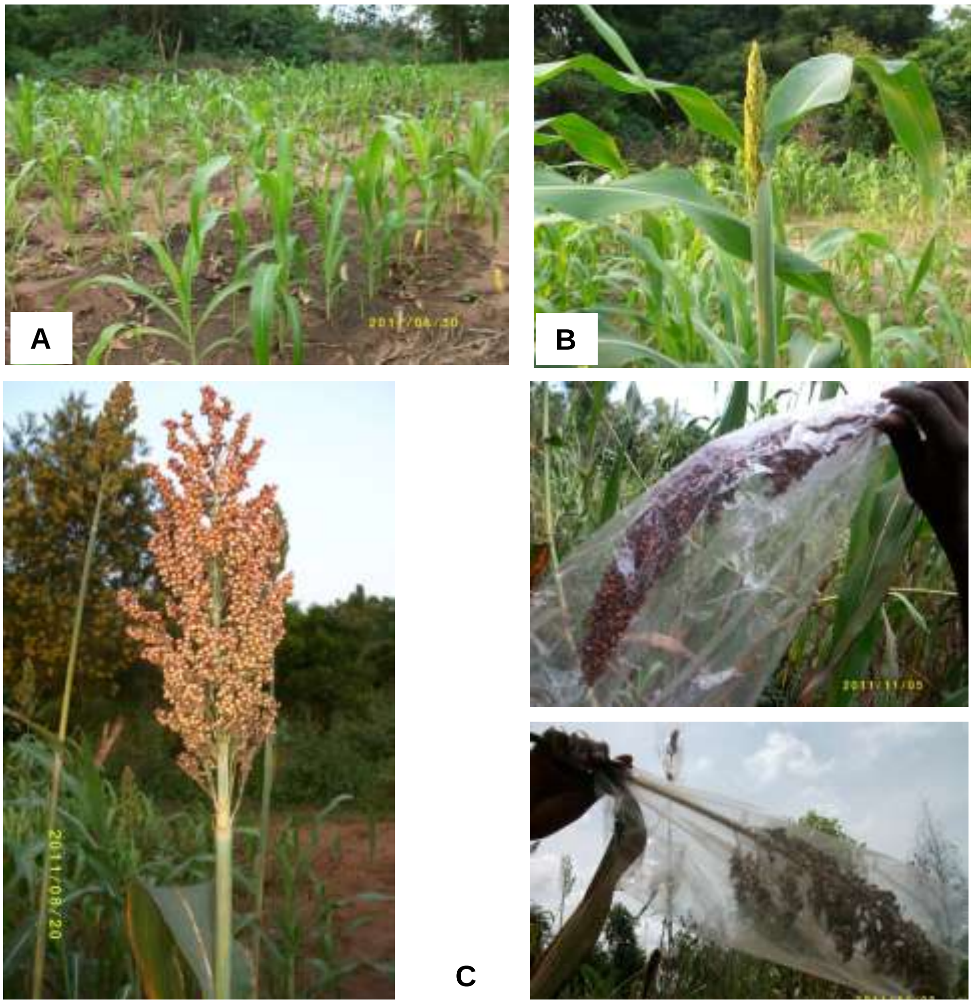

Fig. 1. Experimental site and some observations.

A: Overview of the experimental site after thinning to one plant per seed hole

B: early accessions with early flowering

C: Panicles of some accessions at maturity stage *Traits measured*

Results

Quantitative variation among accessions analyzed

The overall variability of traits is presented in Table 3. Plant height varies from 213.33 cm to 486.36 cm while the length of the panicle ranges from 17.63 cm to 48.60 cm. Peduncle length ranges from 18.00 cm to 78.50 cm and the diameter of the third internodes from 0.55 cm to 1.30 cm. As for the leaf length and leaf width of the third internodes they vary from 41.85 cm to 98.89 cm and from 3.55 cm to 8.83 cm respectively while the panicle exsertion ranges from 0.00 cm to 34.37 cm. The number of leaves per plant varies from 16 cm to 28 cm while the number of effective tillers was 1 or 2. The weight of 1000 grains accessions ranges from 7.50 g to 52.80 g. The variables with significant variation were panicle length, peduncle length, leaf length of the third internodes, panicle exsertion and weight of 1000 grains (Fig. 2).

Table 3. Performance of genotypes of sorghum accessions (*Sorghum bicolor* (L.) Moench) analyzed.

Quantitative traits	Mini-mum	Maxi-mum	Average	Standard deviation
Hpl (cm)	213.33	486.36	339.57	60.83
Lpa (cm)	17.63	48.60	33.43	6.83
Lpe (cm)	18.00	78.50	43.89	11.17
Dte (cm)	0.55	1.30	0.93	0.16
Ltf (cm)	41.85	98.89	74.82	9.91
ltf (cm)	3.55	8.83	5.59	1.05
Exp (cm)	0.00	34.37	10.08	6.59

Quantitative traits	Mini-mum	Maxi-mum	Average	Standard deviation
Nfe (Number)	16.00	27.67	20.47	2.35
Nte (Number)	1.00	1.75	1.08	0.17
p~1000 (g)	7.50	52.80	32.63	8.07

Hpl = plant height, Lpa = panicle length, Lpe = peduncle length, Dte = diameter of the third internodes, Ltf = leaf length of the third internodes, ltf = leaf width of the third internodes, Exp = panicle exsertion, Nfe = number of leaves, Nw = number of effective tillers and p = ~ 1000g weight of 1,000 grains.

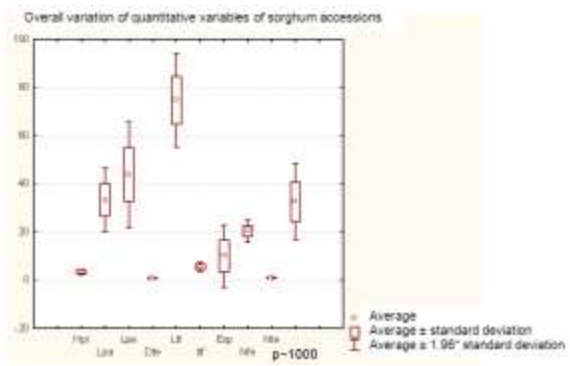

Fig. 2. Global Change in quantitative variables within accessions.

Correlation between quantitative variables

The correlation matrix between the measured variables is presented in Table 4. The analysis of this table shows that plant height was significantly and positively correlated with other variables except for panicle exsertion and number of effective tillers. The panicle length was positively correlated with the length of the peduncle, the leaf length and leaf width of the third internodes and the weight of 1000 grain (p ~ 1000). Peduncle length was negatively correlated to the diameter of the third internodes and number of leaves but was significantly and positively correlated with panicle exsertion.

The diameter of the third internodes was positively correlated with the leaf length and leaf width of the third internodes and the number of leaves but negatively correlated to the panicle exsertion. Leaf length of the third internodes was positively correlated with leaf width, number of leaves and weight of 1000 grains (p ~ 1000) and negatively correlated with panicle exsertion. Leaf width of the third internodes was positively correlated only to the number of leaves. With regard to the panicle exsertion and the effective number of tillers, they were negatively correlated to the number of leaves and the weight of 1000 grains (p ~ 1000) respectively and the positively correlated to the weight of 1000 grains (p ~ 1000).

Table 4. Correlation matrix of quantitative variables measured.

	Hpl	Lpa	Lpe	Dte	Ltf	ltf	Exp	Nfe	Nte	p~1000
Hpl	1.00									
Lpa	0.73*	1.00								
Lpe	0.31*	0.28*	1.00							
Dte	0.41*	0.20	-0.28*	1.00						
Ltf	0.53*	0.45*	-0.18	0.50*	1.00					
ltf	0.43*	0.23*	-0.11	0.73*	0.48*	1.00				
Exp	-0.02	-0.15	0.74*	-0.24*	-0.39*	-0.01	1.00			
Nfe	0.28*	0.09	-0.37*	0.44*	0.39*	0.47*	-0.27*	1.00		
Nte	-0.12	-0.14	-0.07	-0.02	0.01	-0.02	-0.02	0.07	1.00	
p~1000	0.34*	0.25*	-0.11	0.13	0.43*	-0.01	-0.32*	0.10	0.24*	1.00

* Significant correlation at 5%.

PCA analysis revealed variations within sorghum landraces

The principal component analysis (PCA) was used to explain the quantitative variations observed within the plant material used. The correlations between variables and the synthetic axes are showed in Fig. 3. Axes 1 and 2 put together account for 54.91% of the total variability in the sorghum accessions studied (Fig. 3). As for the factorial scheme (axis 1 and axis 3), it stands for 48.50% of the total variability. Overall, the first three axes account for nearly 70% of the total variation. These three axes were used to describe the variability within the collection.

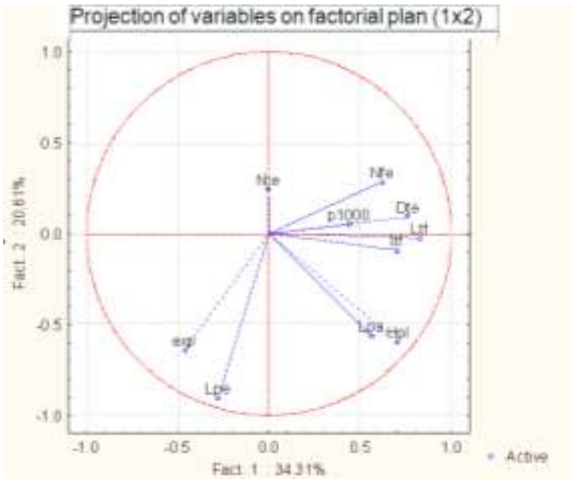

Fig. 3. Circle of correlation (ACP) in the plane 1-2.

Plant height, panicle length, diameter of the third internodes, length and width of the third leaf and the number of leaves were significantly and positively correlated with axis 1. On the other hand, axis 2 was significantly and negatively correlated with the length of the peduncle and panicle exsertion. As for the weight of 1000 grains, this variable was significantly and negatively correlated to the main axis 3 (Table 5). These variables were analyzed and interpreted respectively in accordance with their respective axis.

Table 5. Coordinates of variable on the first three axes.

Variables	axis 1	axis 2	axis 3
Hpl	0.700796*	-0.595646	-0.122998
Lpa	0.559952	-0.562835	-0.312229
Lpe	-0.278482	-0.904343*	-0.017289
Dte	0.762000*	0.091818	0.397449
Ltf	0.826384*	-0.024270	-0.168076
Ltf	0.702494*	-0.091277	0.555841
Exp	-0.464255	-0.642451	0.366395
Nfe	0.620137	0.283847	0.295721
Nte	-0.003610	0.241112	-0.281302
p~1000	0.437383	0.049252	-0.714529*

Grouping accessions on the basis of quantitative and qualitative variables

A hierarchical classification of sorghum accessions studied and performed with the aggregation criteria of Ward from adjusted mean values for 15 variables (10 quantitative and qualitative 5) from analysis of variance results in the dendrogram (Fig. 4). The Analysis of this dendrogram was able to differentiate four main groups by truncation at a distance of aggregation of 19. Group I contains 13 accessions that were mainly from durra race with bitter or no bitter yellow grains (SOD 40, SOD 41, SOD 42, SOD 44 and SOD 60), an accession with yellowish grains of caudatum race (SOD 71) and an accession of coloring sorghum of intermediate race durra-kafir (SOD 6). Group II composes of 24 accessions which were mainly sorghum accessions of guinea race with long and white grains of which vegetative cycle was long (SOD 21, SOD 22, SOD 33, SOD35, SOD 37, SOD 47, SOD 57 and SOD 62) and also contains some accessions with red grains as SOD 2, SOD 4 and SOD 65 (all belonging to guinea race). Group III consists of 20 accessions which were essentially guinea race with white or whitish grains and with medium growth cycle (SOD 24, SOD 29, SOD31, SOD 36, SOD54, SOD 56, SOD59, and SOD 61). The accession of the bicolor race (SOD 48) and an accession of caudatum race (SOD 66) were also found in this group. Finally, group VI consists of 17 accessions, mainly early guinea race with red grains of small size (SOD 7, SOD 10, SOD 13, SOD 15, SOD 16, and SOD 64) but also some accessions with white grains (SOD 17, SOD 26 and SOD 38).

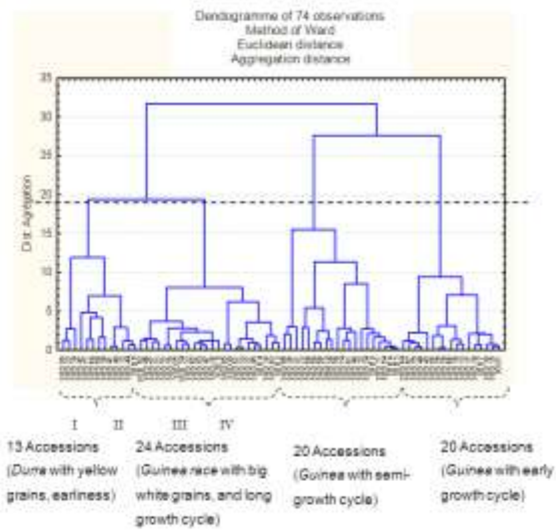

Fig. 4. Ascending hierarchical classification (AHC) of 74 sorghum accessions according to the Ward aggregation criteria.

Racial classification of sorghum accessions

76 sorghum accessions collected belong to four botanical races (guinea, Durra, caudatum and bicolor) out of the existing five races. The guinea race was predominant and represents 86.84% of the collection followed by durra race with 5.26%, caudatum race with 2.63% and bicolor race with 1.32%. The intermediaries represent 3.95% (Fig. 5, Table 1). In terms of grain color, 41.33% had an intermediate color (pink, reddish, whitish, yellowish, blackish, white-spotted purple or red, multicolored, etc.), 30.66% of the grains were white, 21.33% were red and 6.66% were yellow. Moreover, it should be noted that 53.95% of accessions had black glumes, 80.26% had loose panicles and 42.11% had a short vegetative cycle.

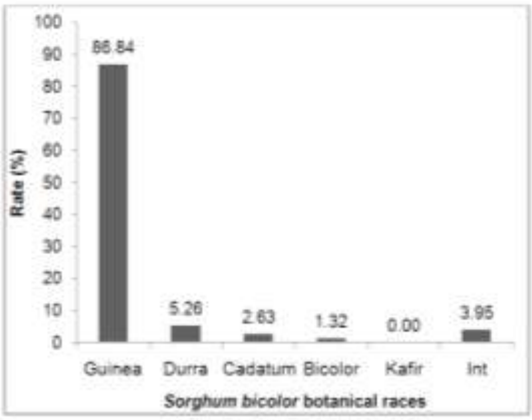

Fig. 5. Proportional distribution of different botanical races of accessions analyzed.

Discussion

Multivariate analysis of quantitative and qualitative data revealed a structuring in 4 distinct groups of sorghum accessions based mainly on racial factor, but also the duration of the vegetative cycle and morpho-physiological characteristics of grains (color, size, degree of bitterness). This structuring of Benin accessions according to botanical race confirms once again previous agro-morphological investigations on collections from countries of West Africa (Deu *et al.*, 2006; Barro-Kondombo *et al.*, 2008.). The structuring according to morpho-physiological characteristics of the grain was also reported in some studies such as those conducted by Barro-Kondombo *et al.* (2008) who identified, after agro-morphological characterization, an original group of accessions of local varieties of sorghum with red grains. In the present study, the group of accessions that appears more homogeneous on the basis of grain color is group I which consists of accessions with bitter or no bitter yellow grains. This phenotypic difference of this group of accessions appears extremely important for the judicious use in research because sorghum local varieties with bitter yellow grains are widely recommended for use in traditional medicine in Benin (Kayodé *et al.*, 2005; Missihoun *et al.*, 2012a). In addition, groups II, III, and IV compose of landraces of guinea race which differ in the duration of vegetative cycle and the nature of the grains. These two factors also seem to play an important role in agro-morphological structuring of accessions of cultivated sorghum in Burkina Faso (Barro-Kondombo *et al.*, 2008). However, in Benin, ethno-botanical investigations revealed the specific importance of each of these different groups of local varieties. Local varieties with red grains and short growth cycle (group IV) currently dominate Benin sorghum due to their relative tolerance to drought, their earliness (early maturity), their adaptability to relatively poor soils and their high market value. Local varieties with white grains or intermediate color, medium or long growth cycle (group II and group III) are often more profitable in terms of production of grains, more farinaceous and are used in the production of local dough (Wô, Dibou, Sifanou, Foura). They are sensitive to drought and require soil fertility. Finally, local varieties bitter yellow grains (group I) were mainly grown for use in traditional medicine. This structuring observed with the agro-morphological traits was globally confirmed by molecular analyzes with nuclear microsatellite markers used on the same collection (Missihoun *et al.*, 2015).

In terms of selection and/or varietal improvement, positive correlations observed between the different quantitative variables showed that the accessions with long panicles were of big size (big plant height) and those with the weight of 1000 grains had the largest diameter of the third internodes. On-farm, farmers had a preference for varieties of high size due to both the quality of their food grains and especially to their important role they play in the production of biomass for combustion and building materials (Kayodé *et al.*, 2006). The utilization of these results will be very important in plant breeding programs to improve the performance of local varieties in terms of grain and biomass production.

The racial diversity of cultivated sorghum in Donga department is very high (presence of 4 races out of the five existing races) with a predominance of guinea race. The dominant presence of guinea race in the regions of West Africa is known recognized and has been reported by many researchers from West African countries such as Burkina Faso (Ollitrault 1987; Zongo, 1991; Barro-Kondombo *et al.*, 2010), Mali (Sagnard *et al.*, 2008), Ghana (Kudadjie, 2006) and even in Central Africa with Cameroon (Barnaud, 2007). The present study is consistence with those reported above. The results of this work in Benin could be justified in terms of the geographical position of the country in relation to the history of diversification of sorghum. As a matter of fact, Benin is located in the central of West African countries where there is the diversification of guinea race and with high likelihood of plant materials (seeds) exchanges between farmers of the neighboring countries such as Burkina Faso and Niger. The predominance of guinea race could also be explained by climatic factor. Guinea race would be more suited to the higher rainfall areas (Barro-Kondombo *et al.*, 2010). Furthermore, the absence of kafir race among collected samples in Benin confirms all the previous work done in the regions of West Africa (Burkina Faso, Niger, and Ghana). Deu *et al.* (2008) observed the same racial diversity in Niger (all races except Kafir) with the difference that their proportion were not the same: durra (23.1%), caudatum (21.3%), guinea (10.5%) and bicolor (8.1%). Kafir race is reported to be found in southern Africa and is almost absent in the regions of West Africa, although more intermediate of this race with other races exist.

Conclusion

This study is one of the first evaluations which focused on agro-morphological characteristics of grown sorghum showed an important phenotypic variability of local varieties of sorghum kept and managed by farmers in Donga. Based on the traits studied four groups structured around factors such as morpho-physiological characteristics of the grains (color, size, taste) and race, were identified. Moreover, the results showed the presence of four pure races (guinea, Durra, caudatum bicolor) and the intermediaries such as guinea-durra, guinea-kafir, kafir-durra in the surveyed areas. Guinea race is predominant among the races. The use of molecular genetic markers in further work will allow thorough analysis of the evolution factors of genetic diversity for a better use of local resources of grown sorghum in breeding and conservation programs. The interest in the long run, is the sustainability of sorghum that will continue to play its role in food security and the diversification of cereal production country.

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