AGROMORPHOLOGICAL VARIABILITY OF PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.) CULTIVARS GROWN IN BENIN

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ABSTRACT

The agromorphological variability between various pearl millet cultivars was evaluated to examine the structure of millet in Benin Republic. Therefore, Forty-two (42) cultivars of pearl millet were collected from four agro-ecological areas viz North Extreme Zone (AEZ1), cotton Zone of northern (AEZ2), Food Zone of South-Borgou (AEZ3) and West-Atacora Zone (AEZ4) of Benin Republic. The experimentation was conducted on Ahossougbéta farm in the town Abomey-Calavi by using alpha lattice design in order to access thirty-three (33) agromorphological characters (seventeen (17) quantitative and sixteen (16) qualitative characters). The canonical discriminant analysis, principal component analysis and hierarchical ascendant classification has identified three morphological classes based on 16 quantitative traits and 8 qualitative discriminating Wilks' Lambda ($P < 0.0001$). According to vegetative cycle, agroecological zones and botanical race, the distribution of cultivars has regrouped the three classes in two great groups of importance for the improvement of the millet resources. The first one group established with the early cultivars (58.33%) to yellow grain (83.33%), long candle (58.23 cm Valeur test +5.23) with low seed production characteristics ($P1000 = 8.68 \text{ g Vt} - 4.64$). Its results from ZAE1 (83 %) and ZAE2 (17 %) and belong to globosum, typhoides and leonis races.

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The second group is trained of late cultivars (90% class 2 and 94.12% class 3) to grey and dark-grey grains (72.73%), short candle (21.12 cm Vt -2.33 and 22.38 cm Vt -2.77) offering the best vegetative development characteristics (Class2 and Class3) and the seed yield (Class 3). Results of the study revealed the trade routes between agroecological zones and millet producer ethnic groups of Benin. These results are significantly important for the definition of strategies for improvement and conservation of millet genetic resources in Benin.

1 Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br; Gramineae) is a cereal grown in the arid tropical region and semi-arid areas of Asia and Africa. It's a staple food of most of the countries in these two regions. According to Claessens et al. (2012) these two continents produced pearl millet crop in 29 million hectares areas for consumption of over 90 million peoples, it also serves as a forage crop in Europe and the United States (Beninga et al., 2011). Millet is highly cross-pollinated with outcrossing rate of over 85% (Rai et al., 2007). In Domesticated West Africa (3500 years BP), it was cultivated everywhere in the Sahelian and tropical countries (D'Andrea et al., 2001; D'Andrea & Casey, 2002). Due to its high ability to adapt in adverse environmental conditions and to survive in infertile soils where other grains can't resist this crop has very high importance in arid areas of African countries (Tostain, 1994). It is one of the cereals that provide high food security of Sahelian populations (Benzançon & Pham, 2004).

By understanding the importance of this crop in the Sahel, various international institutions such as Bioversity International (ex IPGRI) ; IRD (ex ORSTOM) and ICRISAT have developed pearl millet improvement and conservation programs in most of the West Africa countries (Niger, Mali, Togo, Burkina Faso, Senegal, Guinea, Cameroun), these programmes help to overcome the problem of food insecurity. Surveys were conducted in all these countries to make the program really perfect and happen. Millet collections were obtained and used as the base material in several studies. Many tests based on morphological traits were conducted to assess the genetic diversity of millet. Benzançon et al. (1994) classified it into two major groups (early and late) millets in West Africa and confirm that they may be structured differently in concerning descriptors and treatment methods used by a given author.

In Burkina Faso, Bono (1973) identified two groups of millet grown from morphological and botanical characteristics (the candle length and shape, number of high-yielding spikelet per involucre, spine diameter and bristle ornamentation). Furthermore, Brunken et al. (1977) identified four African races based on the ratio between the length and width of the seeds. Similarly, Marchais et al. (1993) were identified six geographic groups based on 14 botanical characters from Niger. Zangré et al. (2009) divided into two groups a population of seventy (70) ecotypes of millet collected in eight regions of Burkina Faso on the basis of the vegetative cycle,

yield and morphological traits. Similarly, In Cote d'Ivoire, Akanvou et al. (2012) has identified two groups based on 11 morphological characters.

In Benin, Niangado & Combes (1978) have revealed the existence of 126 cultivated forms and a significant phenotypic variability but until there are no significant studies have been made on millet genetic characterization. Its culture relegated at the second plan in research and development programs. Its production is very limited due to the constraints (irritation of the skin, weeding, excessive rain, soil quality, attacks by birds, termites and livestock havoc the abandoned thinning and lodging) and to the preference shown by the producers for maize and sorghum appears to be more productive and adapting better to the Beninese soil and climatic conditions. However, it subsists through tradition and customs both on cultural, religious and culinary (Clement, 1985; Dagba et al., 2015) but can cause the loss of diversity or lead to a genetic erosion. A new exploration and collection organized in 2013 and 2014 across the North of Benin helped save 42 accessions of cultivated form (Dagba et al., 2015). Under the effect of natural and human selection, local varieties or accessions involving these forms could accumulate genetic diversity that might be poorly exploited in the management of these resources. This study aimed to characterize the diversity in agro morphological plan of millet cultivars collected in Benin. It will specifically determine the level of morphological diversity of millet cultivars and also identify the structure into distinct groups and analyse the potential of cultivars productivity.

2 Materials & Methods

2.1 Materials

2.1.1 Study areas

The experimentations were conducted at Ahossougbéta farm in the town of Abomey-Calavi located between 7° 30'– 9° 45'N. The soil of this zone is mainly sandy and ferralitic (Assogbadjo et al., 2006). The rainfall is bimodal at two humid-seasons (April-July and October-November) and two dry-seasons (August-September and December-March) with an annual total rainfall varying between 800-1200 mm in the West and 1000-1400 mm in the East. The relative humidity varies between 69% and 97% and the temperature between 25° C and 29° C (MEPN, 2008).

Table 1 List of millet cultivars collected according to ethnic groups, localities, towns Departments AEZ and code.

Agroecological Zones	Covered districts	Localities	No	Name of the cultivars	Name of the accessions	Vegetative Cycle	Codes	Ethnic groups
ZAE4	Natitingou	Taghayè	1	Yèyo mata	Yèyo mata	Late (4-6months)	Ytag	Otamari
ZAE4	Natitingou	Tchoumi-Tchoumi			Yèyo mata		Ytt	Otamari
ZAE4	Boukombé	Koutchagou/Koutagou			Yèyo mata		Ykt	Otamari
ZAE4	Boukombé	Kounakokou			Yèyo mata		Ykn	Otamari
ZAE4	Boukombé	Kouponkou/Kouporgou			Yèyo mata		Ykp	Otamari
ZAE4	Boukombé	Tabouota			Yèyo mata		Ytab	Otamari
ZAE4	Toukountouna	Kokobrè/Kokoko			Yèyo mata		Yko	Otamari
ZAE3	Bembèrèkè	Dangbinikou/Dananzi			Yèyo mata		Yda	Otamari
ZAE3	Bembèrèkè	Saoré			Yèyo mata		Ysa	Otamari
ZAE3	Bembèrèkè	Travo/Ouenou			Yèyo mata		Ytr	Otamari
ZAE4	Matéri	Polohoun/Firihoun	2	Itoura	Itoura	Late (5 months)	Ipo	Berba
ZAE4	Matéri	Merhoun			Itoura		Ime	Berba
ZAE4	Toukountouna	Wabou	3	Sowawia	Sowawia	Late (4-5 months)	Swa	Wama
ZAE4	Toukountouna	Tchakalakou			Sowawia		Stc	Wama
ZAE4	Ouaké	Tchalinga	4	Amala	Amala	Late (4 months)	Atc	Lokpa
ZAE4	Djougou	Sosso			AmalaKoupètè		Akps	Lokpa
ZAE4	Djougou	Sosso			Amalakouhloumè		Akhs	Lokpa
ZAE4	Copargo	Karum	5	Naali	Na sowli	Early (3 months)	Nka	Tchila
ZAE4	Ouaké	Gnagbakabia	6	Mawoairi	Mawoairanéiri	Late (4 months)	Mgn	Peuhl
ZAE4	Cobly	Tapoga	7	Yotorika	Yotorika	Late (4-5 months)	Ytap	Kountèba
ZAE3	Bembèrèkè	Sakarou	8	Ayo	Ayoyantè	Late (5 months)	Asa	Niendé
ZAE3	Kouandé	Oroukayo	9	Yom mali	Yom mali	Late (4-5 months)	Yor	Natempa
ZAE1	Karimama	Birni-lafia	10	Haini	HainiKiré	Early (3 months)	Hbl	Dendi
ZAE1	Malanville	Toumboutou			HainiKiré		Hto	Dendi

ZAE1	Malanville	Madecali			HainiKiré		Hma	Dendi
ZAE1	Malanville	Garou-Tédji			HainiKiré		Hgt	Dendi
ZAE1	Malanville	Guéné			Hainikiré		Hgu	Dendi
ZAE1	Malanville	Garou-Tédji			HainiKiréDogo		Hdgt*	Dendi
ZAE1	Karimama	Birni-lafia	11	Bandadagou	Bandadagou	Early (2-3 months)	Ban	Dendi
ZAE1	Malanville	Toumboutou	12	Somna	Somna	Late (4-5 months)	Sto	Dendi
ZAE1	Malanville	Madecali			Somna		Sma	Dendi
ZAE1	Malanville	Garou-Tédji			Somna		Sgt	Dendi
ZAE1	Malanville	Guéné			Somna		Sgu	Dendi
ZAE2	Banikoara	Soroko	13	Gbè	GbèSk	Late (4-6 months)	Gso*	Bariba
ZAE2	Banikoara	Ouagou/Wagou			Gbè Ou		Gou	Bariba
ZAE3	N'Dali	Binansi			GbèKpika		Gbp	Bariba
ZAE3	N'Dali	Binansi			GbèWonka		Gbg	Bariba
ZAE2	Kandi	Pèdè	14	Iya	Iyakou	Late (4 months)	Ipe*	Mokolé
ZAE2	Kandi	Gogbèdè			Iyassè	Early (2 months)	Igo	Mokolé
ZAE2	Kandi	Bensékou	15	Wéa	Wéagban	Late (4months)	Wbb	Bo
ZAE2	Kandi	Bensékou			Wéaguézénou		Wgb	Bo
ZAE2	Kandi	Bensékou	16	Naa	Naaténou	Early (3 months)	Nbe	Bo

* Undeveloped Cultivars

Table 2 List of quantitative and qualitative traits selected (IBPGR & ICRISAT, 1981, revised in 1993)

N°	Quantitative variables	Codes	N°	Qualitative variables	Codes
1	Plant height (cm)	Hp	1	Candle shape	FCh
2	Stem diameter (cm)	Dt	2	Candle density	Dech
3	Number of leaves	Nf	3	Seed color	Cgr
4	Leaf length (cm)	Lf	4	Glumes color	Cgl
5	Leaf width (cm)	lf	5	Leaf color	Cf
6	Internode length (cm)	Len	6	Bristle color	Cs
7	Leaf sheath length (cm)	Lg	7	Seed shape	Fg
8	Leaf blade length (cm)	Ld	8	Node pigmentation	Pin
9	Leaf blade width (cm)	ld	9	Internodes pubescence	Puen
10	Total number of tillers	Ntt	10	Node pubescence	Pun
11	Number of productive tillers	Ntp	11	Bristle length	Ls
12	Number of secondary stem	Nts	12	Bristle density	Ds
13	Candle length (cm)	Lc	13	Bristle ornamentation	Os
14	Exsertion candle (cm)	Diec	14	Sensitivity to pour	Sverse
15	Candle diameter (cm)	Dc	15	Juice flavor	Sjt
16	Peduncle diameter	Dp			
17	1000-grain weight (g)	P1000			

2.1.2 Plant materials

Plant material consist 42 cultivars of millet which were collected during December 2012 – January 2013 and December 2013 - January 2014 from 32 localities in northern Benin with 13 different socio-cultural groups. As described by PANA-BENIN, these localities are situated in four different agro-ecological zones of Benin viz North Extreme Zone (AEZ1), cotton Zone of northern (AEZ2), Food Zone of South-Borgou (AEZ3) and West-Atacora Zone (AEZ4) (MEPN, 2008) (Table 1). The collection of plant material and its characteristics was made through group discussions based on a semi-structured interview guide.

2.2 Methods

2.2.1 Field experiments

The racial classification of millet candle collected from different was carried out according to Brunken et al. (1977) criteria at Laboratory of Genetics and Biotechnology of Faculty of Sciences and Technology of University of Abomey-Calavi (Benin).

The plant material was assessed using an alpha-lattice experimental design described by Patterson & Williams (1976) with three repetitions, 7 blocks with 7 landrace varieties per repetition. Each block has seven basic plots and each plot contains one cultivar randomly positioned. The last block of each repetition contains 7 repeated cultivars to offset blocks. The dimension of a basic plot is 0.2m on 0.6m, with a distance dimension of 0.2m and 0.4m for spacing. Each plot unit has 8 plants. Sowing was done by direct seeding (per hole). The

standard cultural and agronomic practices that included thinning and manual weeding at 15 days after sowing were followed. No chemical and organic contribution is brought on the soil.

2.2.2 Data collection

The observations on 17 quantitative and 16 qualitative traits selected in the millet descriptor were taken on four random plants in each plot (Table 2).

2.2.3 Statistical Analysis

Canonical discriminant analysis (CDA) was performed on the matrix of agromorphological data in order to select the most discriminated variables. An analysis of variance mixed model at two factors (random block and cultivar fixed) was evaluated to compare the selected parameters on cultivars. A multivariate analysis of variance was performed to confirm or refute the trends obtained by analysis of variance. These analyses are made with the R software by using packages "candisc" (Friendly & Fox, 2013), "lsmeans" (Russell et al., 2013) and "nlme" (Pinheiro et al., 2013).

The discriminating variables and qualitative data for each cultivar were joined and used to make a grouping into cultivars classes by ascending hierarchical classification method (CHA). Classes were reserved and described by a principal component analysis (PCA) using the quantitative variables. An association of qualitative variables was realized across each class using the Chi2 test. These statistical analyses were performed in the R v2.15 software, by using of package "Facto Mine R" (Husson et al., 2013).

Table 3 Summary variable selection discriminate

Stage	Variables	R ² partial	F Value	Pr>F	Lambda-Wilk	Pr <Lambda-Wilk	Averagesquared
1	P1000	1	33640.70	<0.0001	0.00023462	<0.0001	0.026
2	Nts	0.83	37.20	<0.0001	0.00004097	<0.0001	0.048
3	Lc	0.8	31.15	<0.0001	0.00000824	<0.0001	0.069
4	Nf	0.63	13.49	<0.0001	0.00000302	<0.0001	0.084
5	Dc	0.47	6.83	<0.0001	0.00000161	<0.0001	0.095
6	Hp	0.44	6.07	<0.0001	0.0000009	<0.0001	0.102
7	Lg	0.38	4.67	<0.0001	0.00000056	<0.0001	0.109
8	Ld	0.36	4.38	<0.0001	0.00000036	<0.0001	0.118
9	Ld	0.33	3.77	<0.0001	0.00000024	<0.0001	0.126
10	Len	0.31	3.50	<0.0001	0.00000017	<0.0001	0.134
11	Dp	0.25	2.51	<0.0001	0.00000012	<0.0001	0.139
12	Ntt	0.23	2.32	<0.0001	0.00000001	<0.0001	0.145
13	Diec	0.19	1.80	0.039	0.00000008	<0.0001	0.149
14	Lf	0.21	1.98	0.0009	0.00000006	<0.0001	0.153
15	Ntp	0.18	1.6	0.0182	0.00000005	<0.0001	0.156
16	Dt	0.16	1.45	0.0491	0.00000004	<0.0001	0.160

3 Results

3.1 Discriminant characters of millet cultivars

The canonical discriminant analysis (CDA) made step by step showed us that among the 17 selected quantitative variables, 16 are discriminating with relatively high F and R² values (Table 3). Only the variable leaf width (Lf) has little interest in separating cultivars. These results were confirmed by the statistical work of Wilks' Lambda (P < 0.0001).

As per the results of this study two canonical axes were selected and showed the high discrimination 99.8%. The first axis explains 99.6% of the total variance and the second axis totals 0.2%. Adjusted correlation coefficient 0.9997 is highly

significant (P < 0.001). The projection of variables on the two canonical axes shows that the variables that discriminate cultivars on the first axis are mainly the length of the candle (Lc), the length of the inter-node (Len), the length of the leaf sheath (Lg), the length of the leaf blade (Ld), stem diameter (Dt), the peduncle diameter (Dp), the number of productive tillers (Ntp), and the leaf blade width (Lf), which oppose to variable as number of leaves (Nf), the plant height (Hp), the number of second rods (Nts), the diameter of the candle (Dc), the number of Total tillers (Ntt) (Figure 1). The variable that contributes the most to the definition of the second axis is the weight of 1000 seeds (P1000). The multivariate analysis of variance in terms of the statistical test Wilks ($\lambda = 15.19$; P < 0.001) confirms the existence of a difference between the different cultivars.

Figure 1 Projection of discriminant quantitative variables in the canonical axis system.

Figure 2 Dendrogram resulting from the hierarchical Ascendant classification of millet cultivars from Benin.

[Legend: Hma : hainikiréMadécali ; Hbl : hainikiréBirni-lafia ; Sgt : somnaGarou-tédji ; Wbb : WéagbanBensékou ; Sma : SomnaMadécali ; Sto : SomnaToumboutou ; Nbe : NanténonBensékou ; Sgu : SomnaGuéné ; Ban : BandadabouBirni-lafia ; Hto : hainikiréToumboutou ; Hgt : hainikiréGarou-tédji ; Hgu : hainikiréGuéné ; Gbp : gbèBinansikpika, Ykp : yeyoKouponkou, Ime : itouraMerihoun ; Ytap : yeyoTapoga ; Ytr : yeyotravo ; Igo : IyassèGogbèdè ; Stc : SowawiaTchakalakou ; Yor : yotorikaOroukayo ; Atc : amalaTchalinga ; Swa : sowawiaWabou ; Nka : nasowliKarum ; Mgn : mawoairiGnangbakabia ; Gbg : gbèBinansiwonka ; Wgb : WéaguézenanBensékou ; Akhs : AmalakouhloumèSosso ; Akps : amalakoupètèSosso ; Gou : gbèOuagou ; Yda : yeyoDangbinikou ; Ykn : yeyoKounakokou ; Ytag : yeyoTaghayè ; Ysa : yeyoSaoré ; Ipo : itouraPolohoun ; Ytt : yeyoTchoumi-tchoumi ; Ytab : yeyoTabota ; Yko : yeyoKokobrè ; ayoyantéSakarou ; Ykt : yeyoKoutchagou]

Table 4 Main characteristics of the various classes formed by the HCA

Variables	Class 1		Class 2		Class 3	
	Mean	Value test	Mean	Value test	Mean	Value test
Dp	1.166	5.504	0.561	-2.881	0.634	-2.529
Lc	58.232	5.227	21.120	-2.330	22.381	-2.773
Lg	19.801	5.155	14.016	-2.512	14.492	-2.538
Lf	90.540	5.095	70.489	-2.465	72.057	-2.526
Dt	1.338	5.029	0.847	-3.146	-	-
Len	21.048	4.736	-	-	14.971	-2.663
Ld	58.396	3.575	44.445	-2.316		
ld	4.166	2.604	3.182	-3.623		
Diec	1.076	-2.561	-	-	3.718	2.702
Dc	2.137	-2.967	-	-	2.634	2.660
Ntp	1.309	-3.214	-	-	2.964	4.436
Hp	3.366	-4.124	-	-	4.625	2.556
P1000	8.686	-4.640	-	-	19.442	2.862
Nf	14.899	-4.795	-	-	30.031	3.268
Ntt	-	-	4.625	-2.125	6.161	3.682
Nts	-	-	-	-	2.949	2.533

Table 5 Test of Independence classes obtained with the variables

Variables	df	P.value
Cgr	8	<0.0001*
Ds	4	0.0004
Os	4	0.0015
Pun	2	0.0017
Sverse	4	0.0024
Fg	6	0.0229
Cs	6	0.0316
FCh	6	0.0338

Legend: Cgr : Seed color, Ds : bristle density ; Os : bristle ornamentation ; Pun : node pubescence ; Sverse : pour sensibility ; Fg : Seed shape ; Cs : bristle color ; Fch : candle shape.

3.2 Morphological characteristics of millet cultivars

The morphological diversity analyzed by the method of Hierarchical Ascendant classification has allowed structuring the variability of millet cultivars from Benin. The dendrogram produced from the 16 discriminant quantitative variables has helped to identify 3 classes that concentrate more than 50% of the total inertia (Figure 2). The main characteristics of classes are presented in the table 4.

The principal component analysis (PCA) showed that the first two axes explain 57.88% of the information of the starting matrix, which is sufficient to describe the cultivar characteristics of each class. The projection of quantitative variables in the axis system defined by the principal component (Figure 3) revealed that the first axis oppose the stem diameter (Dt), the leaf length (Lf), the internode length (Len), the candle length (Lc), the peduncle diameter (Dp), the leaf blade length (Ld) and leaf sheath length (Lg) at the plant height (Hp), the number of leaves (Nf) and the 1000-grain weight (P1000). The second axis reveals the positive linkage

Cultivars of the second class cover 10 cultivars (25.64%) which have the lowest values of the total number of tillers (Ntt), the leaf blade length (Ld), the candle length (Lc) (Figure 5b), the leaf length (Lf), the leaf sheath length (Lg), the peduncle diameter (Dp), the stem diameter (Dt), and the leaf blade width (ld). In this class 72.73% cultivars have a seed color (Cgr) Grey, 90.91% have a seed shape (Fg), globular and all cultivars has a hairy at the node (Pun).

As for Class 3, it consists of fifteen (17) cultivars (43.58%) with strong values for the number of productive tillers (Ntp), the total number of tillers (Ntt), the number of leaves (Nf), 1000- grain weight (P1000), the distance of the exertion (Diec), the diameter of the candle (Dc), the height of the plant (Hp) and number of secondary stems (Nts). 68.75% of these cultivars have a pour sensibility (Sverse) intermediate and a bristle density (Ds) of compact bristles.

between the total number of tillers (Ntt), the number of productive tillers (Ntp), the candle diameter (Dc), the candle exertion (Diec) and the blade width which move in the same direction. The independence test of Chi2 made on the qualitative variables allowed to note that the clusters obtained depends on 8 of the 16 variables in terms of probabilities which are all less than 0.05 (Table 5).

The projection of the classes in the axis system (Figure 4) showed that the first class consists of 12 cultivars i.e. 30.77% of total studied cultivars and is characterized by the highest values of stem diameter (Dp), the length of the candle (Lc) (Figure 5a), the length of the sheath (Lg), the Leaf length (Lf), diameter of the stem (Dt), the length of the internodes (Len), the flag length (Ld), and the flag width (ld). Among these cultivars, 83.33% have seed color (Cgr), a pour sensibility (Sverse) low. Similarly, all cultivars bristle ornamentation (Os) hairy. Also half of the class cultivars have a bristle color (Cs) green, a seed shape (Fg) obovate and bristles density (Ds) intermediate.

The distribution of cultivar from AEZ and their vegetative cycle through the three classes obtained show that all classes have early and late cultivars but only the first class contains 58.33% early cultivars while second and third classes have 90% and 94.12% late cultivars respectively. In the same way 83% cultivars of the first came from the AEZ1 while rest 17% came from the AEZ2. These cultivars are the "hainikiré, somna, bandadabou" (of Dendi) and Naatenon, wéagban" (of Bo). The cultivars of second and third classes gather in AEZ2, AEZ3 and AEZ4. 60% of cultivars (gbèkpika (Bariba), iyassè (Mokolé), sowawia (Wama), yomali (Natemba), yotorika (Koutemba) and itoura (Berba)) belonging to class 2 and 64.71% of those Na-sowli (Tchila), mawoairaneiri (Peulh), gbèwonka (Bariba), amala (Lokpa) and yeyo (Otamari) belonging to class 3 provide to AEZ4. According to Brunken et al. (1977) the distribution of racial diversity within the classes showed a predominance of globosum race in the three morphological classes, the existence of thypoides race in all classes and léonis and nigrarium race specifically in the first and third classes respectively (Figure 6).

Figure 3 Projection of quantitative variables in the 1 and 2 axis systems.

[Legend: Dt: stem diameter, Lf: leaf length, Len : internode length, Lc : candle length, Dp : peduncle diameter, Ld: leaf blade length, Lg: leaf sheath length, Hp : plant height, Nf : number of leaves, P1000: 1000-grain weight, Ntt: total number of tillers, Ntp: number of productive tillers, Dc: candle diameter, Diec : candle exertion, Id: leaf blade width.]

Figure 4 Projection of classes in the axes system. L'ACP result

Figure 5 Diversity of millet cultivars collected at Benin as revealed by candle morphology. *a*: type of the first class candle, *b*: type of the second and third class candles

Discussion

The high representativeness of the first two canonical axes demonstrates the existence of a strong phenotypical organization of millet cultivars in Benin. This strong phenotypical organization could be result from the expression

of a strong genotypical heterogeneity which will remain to be confirmed by the molecular analyses but also by the influence of the environmental factors. Likewise all selected quantitative variables showed a highly significant difference thus offering better phenotypical differentiation of cultivars confirming the work of Beninga et al., (2011).

Figure 6 Distribution of racial diversity within morphological classes

Many analyses through ACD, ACP and CHA associated with qualitative variables showed that the morphological variability of Benin millet cultivars is divided into three classes. These morphological structures uses the strong correlation between some characters like the candle length, the plant height, the number of leaves, the number of productive tillers, the number of secondary stems, the seed colour and the 1000-grain weight and also base itself on the vegetative cycle and agroecological zones.

Thus, the first class formed the group of early cultivars with yellow grain and weak seed yield in spite of the big size of the candles (58.24 cm). The second and third classes formed the group of the late cultivars, with grey and grey dark grain respectively and short candle (21.52–22.40 cm), offering the best characteristics of vegetative development. The cultivars of the third class present best characteristics of seed yield with an average of 6.10 total tillers, 2.96 productive tillers and 2.86 secondary productive stems. These results are in agreement with those obtained by Chaudhry et al. (2003). In contrast, Békoye et al. (2011) showed that more the vegetative cycle is long more low are the characteristics of vegetative development and seed yield.

This organization of three morphological classes in early and late groups is similar to that observed by Clement (1985) in Benin; Zongo et al. (1991) in Burkina Faso; Akanvou et al. (2012) in Côte d'Ivoire on the millet. Difference in the Benin cultivars is that the late cultivars group included the cultivar class which presents at the same time a high fodder potential but also seed yield. This difference of class can justify itself by the predominance of cultivars yeyomata at food and religious importance in the cultural area Otamari of AEZ4 (Dagba et al., 2015). The agronomic and ecological systems are susceptible to exercise very variable selective and anthropological pressures on genotypes (Sadiki & Jarvis, 2005; Robert et al., 2005).

The morphological dissimilarity observed between the phenotypical first class and the set second and third classes can be explained by the maintenance of cultivars under very different evolutionary processes according to agroecological zones studied. That observed between the second and third classes could be the result of an adaptive process which will be able to justify itself by the molecular analyses.

Besides, the structuring of the millet morphological variability based on agro-ecological zones was partially observed. It was reported by several authors on millet in Benin (Clement, 1985); in Côte d'Ivoire (Béninga, 1992; Akanvou et al., 2012), in Burkina Faso (Zangré et al., 2009); in the sub-region revealing similarities between millet of Senegal and Niger; Mali and Burkina Faso (Bono, 1973; Marchais, 1982); of Niger, Nigeria and Senegal (Ouendeba et al., 1995); contrary on Sudanese millet (Bashir et al., 2013) on other speculations as the Sorghum in Benin (Missihoun et al., 2012); the fonio in Togo (Adoukonou-Sagbadja et al., 2007) contrary on the fonio in Niger (Saidou et al., 2014).

This cultivars structuring according to the agroecological zones observed in this study might be due a high frequency of seed exchange of local cultivars among the producers across the zone but also shows the great ways of these exchanges and the bond between the ethnic groups producing of the millet in Benin. Such observations were described by certain authors on others species cultivated in West Africa (Bakasso, 2010; Missihoun et al., 2012; Saïdou et al., 2014). In the same way the racial diversity of the millet local cultivars collected through the classes comes to confirm not only the ways of exchanges between ZAE but also between the close countries like Nigeria, Burkina Faso, Niger and Togo. The predominance of globosum race was already reported by Bono (1973) which explained that it is most common of races to Benin, Ghana, Niger, Nigeria and Togo. It can be explained by the geographical situation of the agroecological zones close to certain countries, in relation to the history of the domestication of the millet. Findings of the present study also confirms by thework of Rai et al. (1997) and Syngenta, (2006) which found that it is the dominant race of the Western zones of the Sahel.

In conclusion, this study exploited the millet cultivars collected in four agroecological zones (North Extreme Zone (ZAE1), cotton Zone of North (ZAE2), food Zone of the South Borgou (ZAE3) and Zone of West-Atacora (ZAE4)) of Benin. It has allowed highlighting the great morphological variability and the rich racial diversity existent between the cultivars of millet of country. It showed also a structuring in three morphological classes being summarized in two great groups on the basis some morphological characters, the vegetative cycle and agroecological zone. These two group present very advantageous for improvement programs. Thus the first group is consisted of first class cultivars, early maturing with yellow grain, long candle, poor seed yield coming from the AEZ1 and AEZ2; the second group formed of second and third classes cultivars, late maturing with grey grain and grey-dark, short candle, high-output to forage (2 and 3 Class) and seed (class 3) coming from the 2, 3 and 4 ZAE. These results made it possible to define the large geographical areas of morphological diversity necessary for a better collection and a better in situ conservation of the genetic resources of the millet. The data analysed in this study being based on the agromorphological traits, the molecular markers with high density could be used for better concluding the genetic differentiation from local pearl millets cultivated in Benin.

Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

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