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RESEARCH ARTICLE

Participatory evaluation of Guinea yam (*Dioscorea cayenensis* Lam.–*D. rotundata* Poir. complex) landraces from Benin and agro-morphological characterization of cultivars tolerant to drought, high soil moisture and chips storage insects

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Abstract Guinea yam (*Dioscorea cayenensis* Lam.–*D. rotundata* Poir. complex) is an important tuber crop that highly contributes to food security and poverty alleviation in Benin. However, its production is seriously affected by many biotic and abiotic constraints which could be overcame by concentrating the production on resistant or tolerant cultivars. In order to identify such cultivars that are known to exist in Benin traditional agriculture, 51 villages were randomly selected throughout the production zones and surveyed. Out of the 426 cultivars (subject to synonymy) evaluated using participatory approach and 13 agronomic, culinary, and technological traits, 25, 47, 49, 64 and 64 cultivars respectively tolerant to poor soils, nematodes, high soil moisture (adaptability to lowland), drought and chips (peeled and dried tuber) storage insects were, among others, identified. These pools of cultivars could serve in breeding program or be directly used in varietal exchanges towards the zones of interests. The agromorphological characterisation conducted per pool of performing cultivars revealed the existence of many duplicates that should be clarified with the use of molecular markers. Flowering, sex and intensity of flowering of the different cultivars were analysed and revealed a low rate (11.68 %) of non-floriferous plants, a high rate (61.03 %) of plants with low intensity of flowering and five types of male inflorescences indicating a hypothetical evolution towards the suppression of flowering with the cultivated yams.

Keywords Agromorphological characterization · Benin · *Dioscorea cayenensis–D. rotundata* complex · Flowering · Participatory evaluation

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Introduction

Yam (*Dioscorea* spp.) is an important food crop, especially in sub-Saharan Africa (FAO 2012). According to Mengesha et al. (2013), it is the fourth largest cultivated tuber in the world after potato, cassava and sweet potato. Yam is rich in carbohydrates, minerals (calcium, copper, potassium, iron, manganese and phosphorus) and vitamins (A, B and especially those of the group C) that are important for human and animal health (Polycarp et al. 2012). Its production also generates income for producers and thus contributes to the reduction of poverty (Olorede and Alabi 2013). Yam also plays an important role in the socio-cultural life of the people as reflected in the many festivals held for the release of the new yams in West Africa (Osunde and Orhevba 2009).

In all the producing countries of West Africa and particularly in Benin, several species are cultivated. The most important are white yam (*Dioscorea alata*) and the African complex *D. cayenensis–D. rotundata*, also referred to as Guinea yam. In Benin traditional agriculture, the cultivated yams *D. cayenensis–D. rotundata* complex occupy more than 95 % of the sowing area with a national production estimated to 2.739.088 tonnes in 2012 (FAO 2012). Studies carried out in various production zones (Loko et al. 2013a) revealed that, unfortunately, the production of yams *D. cayenensis–D. rotundata* in Benin face many biotic (anthracnose, yam mosaic virus disease, nematodes, mealybugs, etc.) and abiotic constraints (poor soils, drought and effects of climate variability) that have negative impacts on its production and diversity (Dansi et al. 2013; Loko et al. 2013b). Climate change impacts are more perceptible in all the northern zone of Benin where the crop is also mostly produced. This situation is leading to the abandonment of numerous cultivars for susceptibility reasons and to the reduction from the total production (Loko et al. 2013a). To minimise the drought effects, farmers usually install their fields in the lowlands. Because not all landraces tolerate high soil moisture, losses due to tubers rotting in the mounds are often huge and a full field may be affected leading to famine in the corresponding household (Loko et al. 2013c).

Production of dried yam chips is well developed in Benin and is seen as an interesting alternative to the post-harvest storage difficulties of the fresh tubers and the brown paste made with yam chips powder known as "Amala" is highly appreciated throughout the country (Bricas and Vernier 2000). Here again, most of the single-harvest landraces (locally called Kokoro) available for use for the production of yam chips produce tubers that are easily and severely attacked (susceptibility) by the storage insects that reduce them in powder within a short time (Bricas and Vernier 2000; Loko et al. 2013d). To control insects and avoid drastic losses, some households use dangerous cotton insecticides and many deaths due to food poisoning have been recorded. According to Dansi et al. (2013), the use of tolerant/resistant yam varieties will be the only means of minimising in both economical and healthy way, the effects of the biotic and abiotic constraints related to yam production. The results of the participative agronomic evaluations recently carried out in Togo (Dansi et al. 2013) indicate that such cultivars would exist in the great Benin Guinea yam cultivar diversity estimated at more than 400 clones (Loko et al. 2013a) but need to be identified and characterized to clarify the many homonyms and synonyms that exist in the local nomenclature following Dansi et al. (2013) and Demuyakor et al. (2013).

We report in this paper the findings of a study carried out in Benin in order to:

1. Identify, by evaluation trait, the best Guinea yam cultivars produced in Benin
2. Classify, on the basis of agro-morphological traits, cultivars identified as tolerant to drought, high soil moisture and chips storage insects.

Materials and methods

Study area

The Republic of Benin is situated in West Africa and between the latitudes 6°10N and 12°25N and longitudes 0°45E and 3°55E. It covers a total land area of 112,622 km^2 with a population estimated at about 7 million (Akoégninou et al. 2006). The country is partitioned into 12 departments inhabited by 29 ethnic groups (Akoégninou et al. 2006). The south and the centre are relatively humid agroecological zones with two rainy seasons and mean annual rainfall varying from 1,100 to 1,400 mm/year (Akoégninou et al. 2006). The north is situated in arid and semi-arid agro-ecological zones characterized by unpredictable and irregular rainfall oscillating between 800 and 950 mm/year with only one rainy season. Mean annual temperatures range from 26 to 28 °C and may exceptionally reach 35–40 °C in the far northern localities. Vegetation types are semi-deciduous forest (south), woodland and savannah woodland (centre-east and northeast), dry semi deciduous forest (centre-west and south of northwest) and tree and shrub savannahs (far north). Yam is produced throughout all the country apart from the far north because of drought and the far south due to ignorance of cultural practices (Dansi et al. 1999).

Participatory evaluation

Fifty-one (51) villages (Fig. 1) were randomly selected following Gbaguidi et al. (2013) from the entire yam production and diversity zones of Benin and surveyed. The participative evaluation was carried out following the method described by Dansi et al. (2013) and Orobiyi et al. (2013). In each village, listed yam cultivars were individually evaluated in groups (30–40 producers of both sexes and different ages) and on the basis of a pre-established evaluation sheet (Dansi et al. 2013) with eleven agronomic traits (productivity; post-harvest storage suitability; resistance/tolerance to: mealybugs, nematodes, high soil moisture, drought, poor soils, chips storage insects), one technological trait (quality of the chips) and two culinary attributes (quality of pounded yam and quality of boiled yams). The two-levels scoring scale

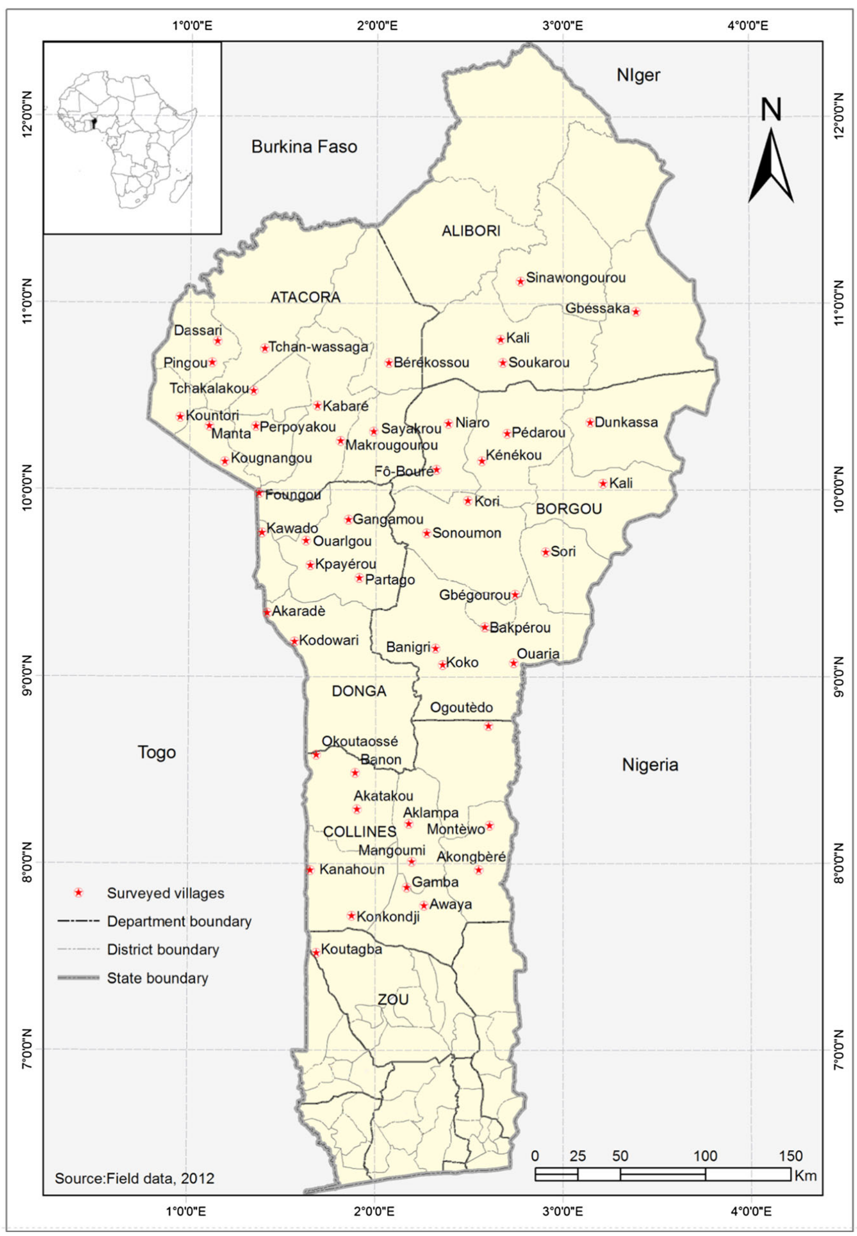

Fig. 1 Map of Benin showing the geographical locations of the villages surveyed

describe by Dansi et al. (2013) was used. In this approach, a cultivar is scored 1 when unanimously recognized by the farmers as efficient (very good/resistant/tolerant) and 0 otherwise. At total 426 cultivars initially inventoried in Benin were evaluated. To facilitate communication and guidance in each the villages, interpreters were locally recruited following Adjatin et al. (2012). At the end of the evaluation in each village, the results were immediately restituted to the producers for confirmation.

Table 1 Qualitative and quantitative morphological traits used

Traits	
Qualitative traits	
Leaves' characteristics	Cataphylls size
Colour of young leaves	Cataphylls colour
Position of leaves	
Opening state of the limb	Flowering
Relative space between lobes	Degree of flowering
Colour of mature leaves	Sex
Leaf shape	Inflorescence type
Undulation of leaf border	Average length of inflorescence
Relative leaf length	
Relative leaf width	Underground tubers
Tip length	Relative size of the head of the tuber
	Presence of corm
Stem characteristics	Shape of the tip
Colour of young stem	Hairiness of the tuber
Pruinescence	Tuber skin colour
Colour of mature stem	Presence of wounds on tuber surface
Thorniness of the stem	Presence of striations on the tuber surface
Spine shape	Skin colour at the head of the tuber
Spine colour	Colour of tuber flesh
Relative spine length	Presence of discontinuity nodes on the tuber
Presence of coalescent spines	Relative tuber length
Presence of coloured spot at the base of the spines	Relative tuber width
Shape of spot at spine base	Tuber shape
Colour of spot at spine base	Thickness of the tuber skin
Stem aspect	
Thorniness of the branches	*Quantitative traits*
Stem striation	Leaf width (cm)
Stem branching	Leaf length (cm)
Roughness of the stem	Leaf petiole length (cm)
Type of stem	Stem's internode length (cm)
Relative length of the stem internodes	Ramification's internode length (cm)
Relative length of the branches internodes	Leaf lobe length (cm)

Agromorphological characterization

The plant material used consisted of 177 accessions collected from the villages surveyed which represent respectively the 64 cultivars known as tolerant to drought, the 49 cultivars known as tolerant to high soil moisture (adaptability to lowlands) and the 64 cultivars known as "kokoro" cultivars (single-harvest cultivars of numerous small tubers) producing chips of good quality (high dry mater content; good dough) and resistant to chips storage insects. The 177 yams accessions to be characterized were planted on the experimental field of the Faculty of Science and Technology of Dassa (FAST-Dassa) in a completely randomized block design with three replications. The distance between rows and mounds was fixed at 2 m to avoid mixture of stems according to Dansi et al. (1999). The morphological features considered (55 on the whole) related to the morphological details of the stem (young and mature), the leaf (young and mature), the secondary branches, the flowers and the tubers (Dansi et al. 1999). The parameters of the aerial part of the plants were scored during the vegetative phase and the details of tubers during the harvest in December. The descriptors used included 49 qualitative and 6 quantitative (Table 1) parameters and are among those recommended by IPGRI/IITA (1997) as the most relevant for the identification and the description of the cultivated yams in West Africa.

Statistical Analysis

Data were analysed through descriptive statistics (mean, percentage, variance, etc.) and the results are presented in tables and figures. Correlations between quantitative variables were examined by Pearson correlation coefficient. To analyse the relationship between the cultivars identified by the participative evaluation with respect to their agronomic, technological and culinary performances, they have been considered according to Kombo et al. (2012), as individuals and the evaluation parameters as variables and noted 1 or 0 depending on whether the variable is applicable or not. By using this methodology, a complete binary matrix is defined and used to build a dendrogram with UPGMA (Unweighted Pair-Group Method with Arithmetic Average) method and NTSYS-PC 2.2 software (Rohlf 2009). The same statistical analysis approach (dendrogram) was used to classify cultivars tolerant to drought, high soil moisture and chips storage insects identified by considering the morphological features as variables. Principal component analysis (ACP) was also carried out with Minitab 14 (Minitab the version 14, Minitab Inc., State College, Pa in the USA) using only qualitative data.

Results

Performance of Benin's Guinea yam (*D. cayenensis–D. rotundata*) cultivars

Subject to synonymy, the participatory evaluation led to the identification of 25–269 performant cultivars (CVs) per evaluation criterion (Fig. 2). Culinary features (quality of both pounded and boiled yam) and the post-harvest storage aptitude were the parameters for which more performant cultivars were found. In contrast, only few elite cultivars were identified for

Fig. 2 Variability of the number of best performing yam cultivars identified through participatory evaluation per trait of economic importance in Benin

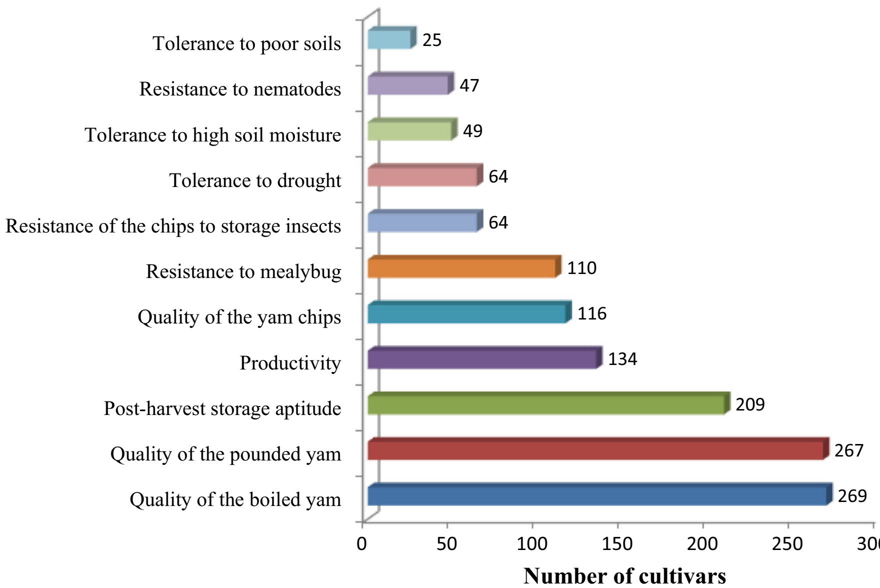

Table 2 Number of agronomic units of yam cultivars obtained by evaluation trait as revealed by the UPMGA clustering method (dendrogram)

Performance criteria	Number of cultivars	Number of agronomic unit and/or culinary
Tolerance to drought	64	28
Tolerance to high soil moisture	49	13
Résistance of the chips to storage insect	64	19
Tolerance to poor soils	25	11
Resistance to nematodes	47	22
Resistance to mealybugs	110	28
Productivity	134	60
Post-harvest storage aptitude	209	99
Quality of the yam chips	118	76
Quality of the pounded yam	267	121
Quality of the boiled yam	269	118

biotic and abiotic parameters such as tolerance to poor soils (25 CVs), resistance to nematodes (47 CVs), tolerance to high soil moisture (49 CVs) and to drought (64 CVs), resistance to chips storage insects (64 CVs). Productivity, quality of chips and resistance to mealybugs showed intermediate situation (Fig. 2). Several cultivars are good for more than one parameter. However, their numbers decrease as the number of parameters increases). Per evaluation parameter, the best performing cultivars identified (subject to synonymy and of tests of confirmation) constitutes an exploitable pool of genotypes by the scientific research (varietal creation) and development (exchanges of varieties) projects and programmes.

The dendrogram constructed on the basis of the parameters considered revealed within the 154 farmer-named cultivars (tolerant to drought, high soil moisture and chips storage insects) considered for agromorphological characterisation, 56 agronomic and culinary units (UA). The number of UA varies from a pool of genotypes to another (Table 2). Figure 3 for example shows, at 100 % of similarity, thirteen (13) different

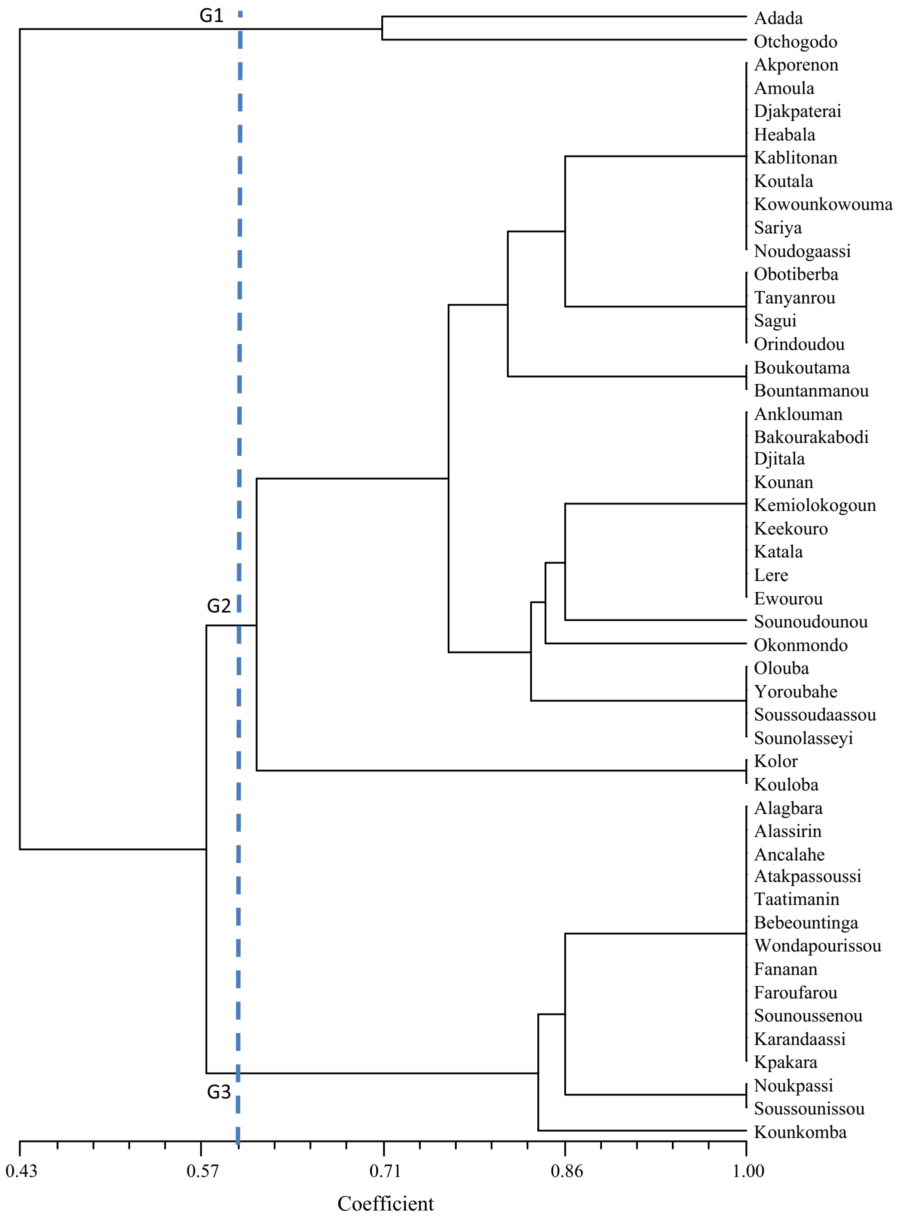

Fig. 3 UPGMA dendrogram showing the similarities between yam cultivars tolerant to high soil moisture in terms of agronomic and culinary performances

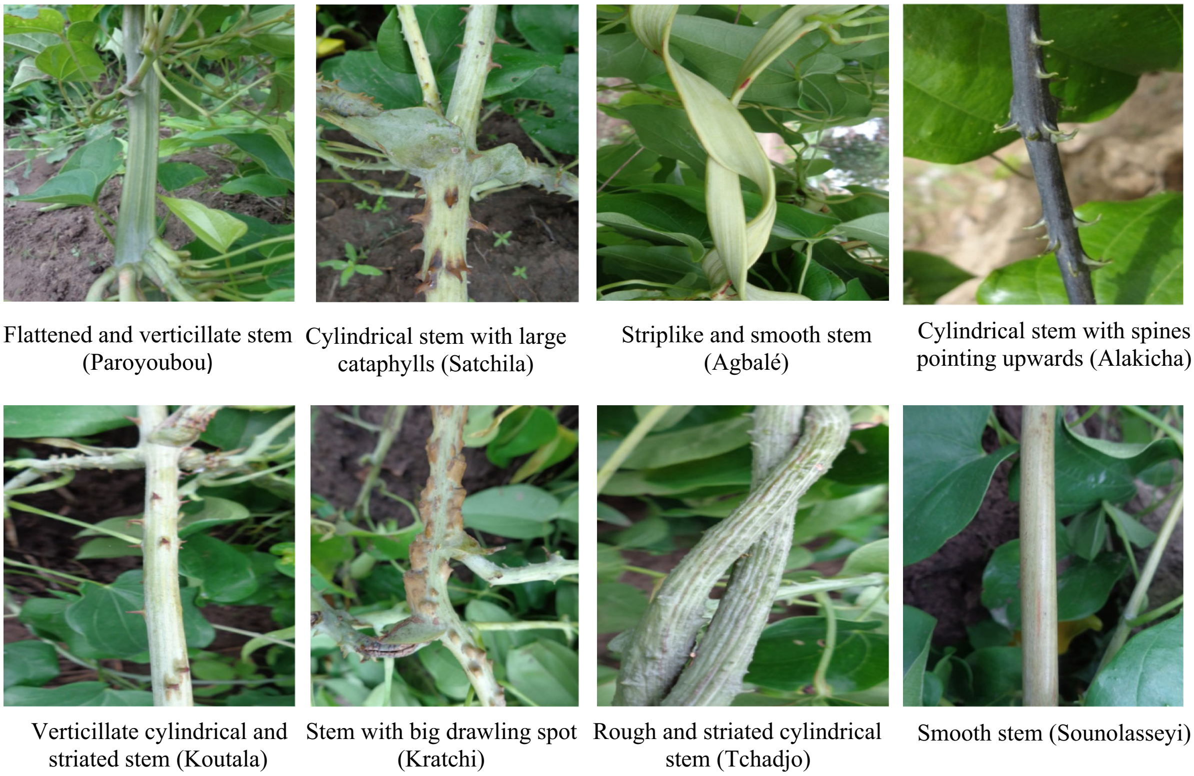

Fig. 4 Stems variability in the characterized yam cultivars

units (UA1 to UA13) within the pool of cultivars tolerant to high soil moisture. UA1, UA2, UA7, UA8 and UA13 consist each of a single cultivar while UA11 includes, subject to synonymy, 12 cultivars. At 62 % of similarity, the agronomic units (UA) appear, in this pool, structured in three groups (G1, G2 and G3) of various characteristics (Fig. 3). G1 includes two cultivars of poor cooking qualities (pounded and boiled) but having a good productivity, a good post-harvest storage aptitude of the tubers, a good quality of chips and produce chips resistant to storage insects; G2 includes 32 cultivars with a good quality of both pounded yam and boiled yam; G3 gathers 15 cultivars that are only tolerant to high soil moisture (Fig. 3).

Morphological variability within the studied cultivars

Base on the qualitative and quantitative variables considered (Table 1), an important morphological variability is noted within the studied yam collection. By considering the characteristics (shape, size, width, colour and opening state of the limb; tip length) of the leaves 15 types were observed. At stem level, eight morphological types are noted and differ primarily by the degree of thorniness, the size, the colour and the orientation of the spines, the roughness of the stem, the presence and the thickness of the spot at the base of the spines (Fig. 4). The size of the cataphylls, the arrangement of both branches and leaves along the stem and the degree of spinescense of the branches are also variable and even constitute key morphological identification traits for some cultivars (Fig. 4). A great diversity is also observed on the level of tubers. In total, 21 types of tubers were recorded throughout the germplasm analysed (Fig. 5).

Subject to synonymy, 136 cultivars are floriferous against 18 which are not. Among the floriferous cultivars, 111 (81.61 %) were male whereas 25 (18.39 %) were female. However, the flowering intensity varies with cultivars. Out of the 136 floriferous cultivars, 83 (61.03 %) have low flowering intensity and 53 (38.97 %) flower intensely. Base on the length and the ramification of the inflorescence axis, five different

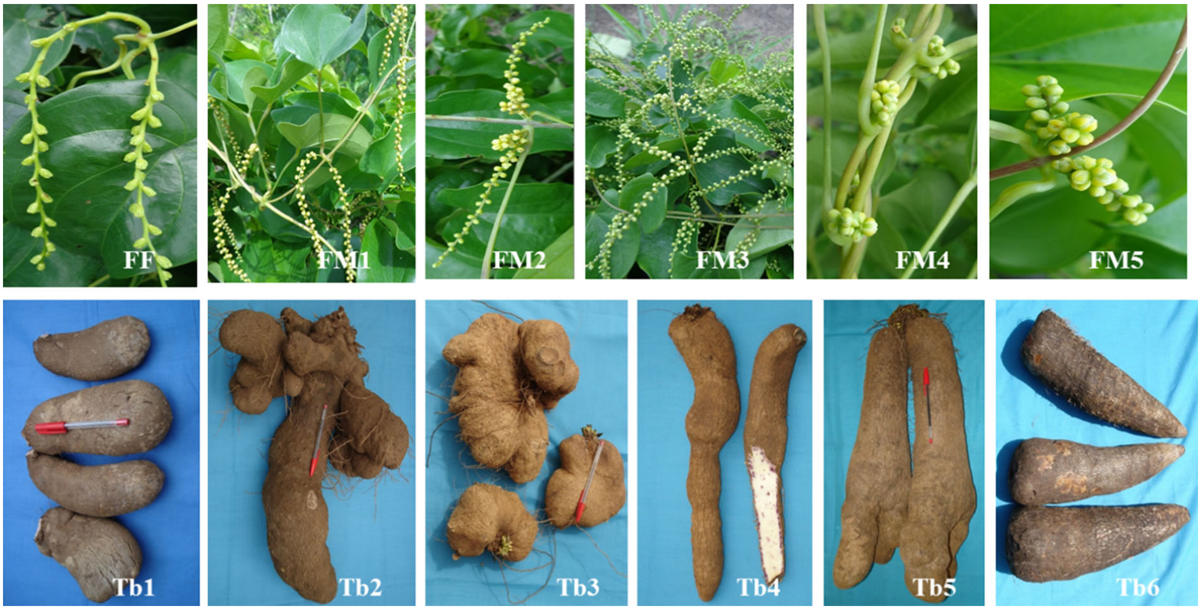

Fig. 5 Variability of inflorescences and some tubers in the characterized yam cultivars. FF: female flower; FM1: male flower with a long axis; FM2: male flower with combined long and short axis; FM3: male flower with a long ramified axis; FM4: male flower with almost nonexistent axis; FM5: male flower with a combination of short and almost nonexistent axis; Tb1: small tuber and flattened (Babétérou); Tb2: tuber in the shape of horn (Alakicha); Tb3: rounded tuber (Tchinguita); Tb4: tuber with small red spots inside the flesh (Banriouré gnintégué-rou); Tb5: large tuber (Katala); Tb6: tuber with a sharp tip (Kpouna)

Table 3 Descriptive statistics for the quantitative agronomic traits measured on the yam cultivars

Traits	Min	Max	Mean	Standard of deviation	Coefficient of variation
LOF	4.57	14.47	8.85 ± 0.11	1.53	17.34
LAF	1.97	8.83	6.34 ± 0.08	1.08	17.15
LOP	2.47	10.57	5.41 ± 0.08	1.14	21.14
LENT	2.67	32.13	13.80 ± 0.42	5.58	40.42
LENR	2.27	19.33	9.81 ± 0.26	3.45	35.19
LOL	0.23	3.17	1.40 ± 0.04	0.52	37.59

types of male flowers (FM1, FM2, FM3, FM4 and FM5) were observed (Fig. 5) and are sometimes characteristic of certain groups of cultivars. Males FM1 (32.43 %) have long inflorescence axes (Fig. 5), the FM5 (49.55 %) have mixed inflorescence with short and almost non-existent types (Fig. 5) whereas the FM2 (8.11 %) presents the short type combined with the long one. Males FM4 (6.31 %) bear only the inflorescence with almost non-existent axes type (Fig. 5) whereas the FM3 (3.6 %) have branched axes of inflorescence (Fig. 5). FM4 and FM5 were especially found among the single-harvest cultivars of the class kokoro with rough and striated stem like Deba, Kolor and Bodi but also among cultivars of the group Ahimon. FM3 exclusively characterizes the cultivars Tanyanrou, Otchogodo and Peremkouna of the varietal group Baridjo defined by Dansi et al. (1999).

The quantitative variables studied revealed significant differences between the minimum and maximum values, sometimes with high coefficients of variation (CV > 20 %) (Table 3). Positive and highly significant correlations were observed between the different variables except the length of internodes of the stem (LET) and ramifications (LER) which are not correlated with the length of the lobe (LOL) (Table 4). The highest correlations are those obtained between the

Table 4 Correlation between quantitative variables

Variables	LOF	LAF	LOP	LET	LER
LAF	0.64***				
LOP	0.65***	0.52***			
LET	0.31***	0.30***	0.24***		
LER	0.28***	0.25***	0.18***	0.23***	
LOL	0.27***	0.51***	0.30***	0.01 ns	−0.09 ns

*** $P < 0.001$; *ns* non significance

length of the leaf (LOF) and the length of the petiole (LOP) on the one hand (r = 0.65) and between the length and the width (LAF) of the limb (r = 0.64) on the other hand (Table 4).

A principal component analysis taking into account the 154 accessions analysed and the 49 qualitative variables released several components among which the two first explain 58.6 % of the total variability. These two first components were used to analyse the morphological variability of the yam cultivars assembled. Axis 1 which explains 54.9 % of the total variability is mostly characterised by the cultivars tolerant to high soil moisture (adaptation to lowlands) and the cultivars whose chips are resistant to storage insects (Fig. 6). Axis 2 with 3.7 % does not release any clear grouping although a prevalence of the cultivars resistant to drought in the negative part of this axis is noted (Fig. 6). By considering the two axes it is however difficult to conclude in a clear separation of cultivars from the three characterized pools because of many overlapping.

The classification based on UPGMA method generated a dendrogram showing the clustering of the 154 cultivars characterized in 47 morphotypes thus indicating the existence of many duplicates in the collection. With each of the three pools of performant cultivars considered, the hierarchical classification also revealed many duplicates. In the pool of the cultivars giving chips resistant to storage insects for instance, 24 morphotypes are obtained out of the 64 analysed (Fig. 7). In the pools of cultivars adapted to high soil moisture (49 cultivars) and cultivars resistant to drought (64 cultivars) respectively 23 and 27 morphotypes were identified.

Discussion

The results of the participatory evaluation revealed that many performing cultivars exist within guinea yams (*D. cayenensis–D. rotundata* complex) in Benin. The most provided evaluation parameters on efficient cultivars are those related to culinary qualities. This result was expected since taste and culinary qualities are, as rightly stated by Adjatin et al. (2013), the characters the most sought for in any food. It also mean that special attention would have been given to culinary qualities (especially pounded and/or boiled yam) during the wild yams domestication process that would generated all the existing cultivars as reported by Mignouna and Dansi (2003); Dumont et al. (2005); Chaïr et al. (2010). Biotic (nematodes and mealybugs) and abiotic (especially drought, poor soil, excess moisture soil) factors were the least provided evaluation parameters. Urgently, geneticists and breeders must made great efforts to develop new resistant/tolerant genotypes to strengthen the pools of cultivars corresponding to the biotic and abiotic stresses evaluated. The urgency of such action is justified by the impact of climate changes on traditional agriculture, which are increasingly felt throughout the country, especially in the northern regions (Gnanglè et al. 2012). Climate changes are characterized by the proliferation of insects (Nyman et al. 2012), degradation and poor soils (Usman et al. 2013), drought and sometimes the high moisture content in case of unexpected high rainfall (Schindlbacher et al. 2012). Before reinforcement, which could also result in tolerant cultivars developed in national and international institutions, well-structured research and development programs must be established to facilitate the

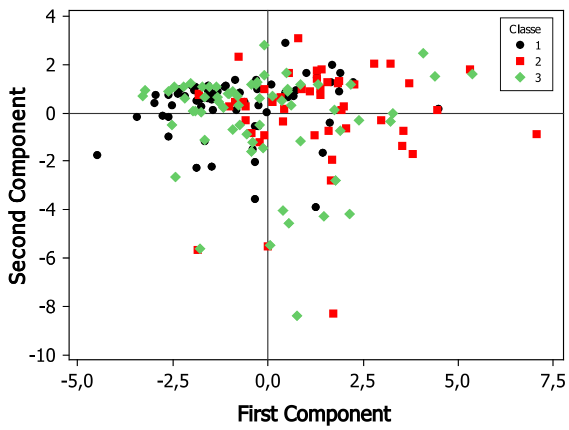

Fig. 6 Principal component analysis of qualitative and quantitative morphological variables showing the different grouping of yam cultivars. *1* resistance of the chips to storage insect, *2* adaptability to lowlands, *3* resistance to drought

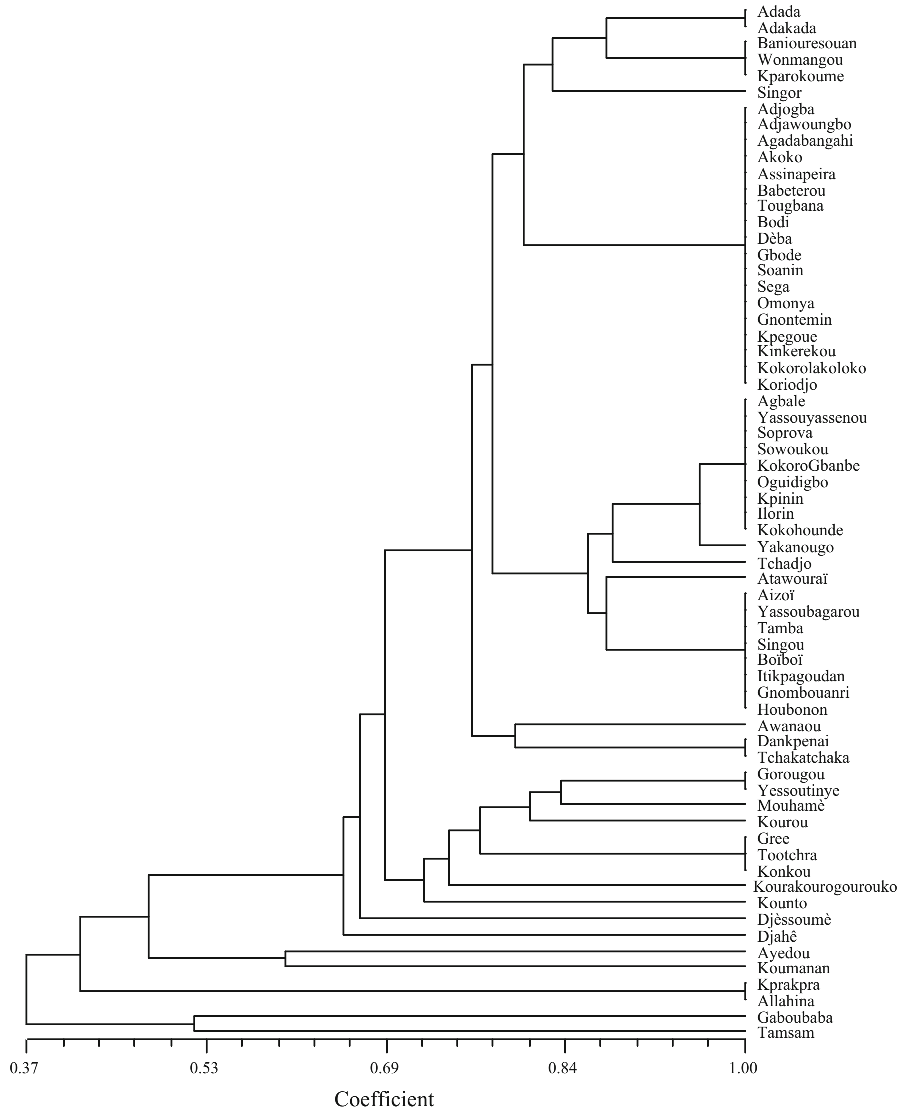

Fig. 7 Dendrogram showing the morphological similarity between yam cultivars giving chips resistant to storage insects

use of the available potential. This includes among others, molecular characterization for identifying duplicates and the clarification of synonymies, multilocal agronomic evaluation tests (performance and interaction genotype–environment) and the production of healthy seeds clones identified and their distribution to producers in areas of interest according Dansi et al. (2013).

The difficulties of flowering and fruiting have been the main constraints for genetic improvement in yams (Hamadina et al. 2009). The data obtained on flowering showed that, subject to synonymy, 11.11 % of the cultivars are non-floriferous. This value of non-floriferous plants is similar to that (12.25 %) obtained by Dansi et al. (1999) and is relatively low when considering the difficulties of flowering reported by various authors (Zoundjihekpon 1993; Hamadina et al. 2009) on cultivated guinea. The high rate of individuals with low-flowering is also well in agreement with the observations of the authors above. Zoundjihekpon (1993) and Hamadina et al. (2009) reported that with cultivated yam *D. cayenensis–D. rotundata* complex, flowering and intensity vary according to seasons and regions. Therefore it will be necessary to assess in the different agro-ecological zones and localities, the flowering and fruiting capacity of efficient cultivars identified for plant breeding purposes. To our knowledge and in the nature where the wild relatives of yam that are at the origin of cultivated yam evolve in natural populations, the types of inflorescence FM4, FM5 (Fig. 6) do not exist. In term of evolution, FM4 (axis almost non-existent) would be the result of an accumulation of mutations (domestication syndrome); due to the bringing into cultivation (initial phase of domestication) that led to a decline in the flowering ability (Parker et al. 2010; Sakuma et al. 2011). One can therefore establish the hypothetical evolutionary sequence FM1 (long axis), FM2 (long axis associated with short axis), FM5 (short axis and almost non-existent axis) and FM4 (non-existent axis).

The hierarchical clustering of cultivars based on performance criteria generated a relatively reduced number of different agronomic and culinary unit. Cultivars with different local names therefore have the same agronomic and culinary characteristics. This result indicates the existence of synonymies within cultivars assembled in each of the three considered pools. This result is not surprising since several studies on yam (Dansi et al. 1999; Tamiru et al. 2008; Otoo et al. 2009) showed that vernacular names given to cultivars often vary across ethnic zones and even between villages within ethnic areas. A great variability was obtained in the studied collection as it was the case in Ghana (Otoo et al. 2009) and in Kenya (Mwirigi et al. 2009). This morphological variability is the consequence of the evolutionary dynamics of guinea yams (*D. cayenensis–D. rotundata* complex) that integrates domestication (Mignouna and Dansi 2003; Dumont et al. 2005), gene flow between wild and cultivated forms, hybridizations between cultivated forms and cultivars newly introduced from neighbouring countries or elsewhere (Loko et al. 2013a). Morphological classifications gather together some cultivars that differ in terms of agronomic and culinary characteristics. As reported by Girma et al. (2012), this observation highlights the limitations of morphological characterization and call for the use of highly polymorphic molecular markers such as SSR and AFLP (Obidiegwu et al. 2009; Sartie et al. 2012) to refine the classification.

Conclusion

The present study revealed within Benin cultivated yams of *D. cayenensis–D. rotundata* complex the existence of many cultivars of yam with good agronomic and culinary performances although those resistant or tolerant to various biotic and abiotic factors affecting yam production are few. The pools of best performing cultivars hence identified can serve as sources of genes for breeding programs and also be directly exploited by the development programs and projects through varietal exchanges. For better conservation and use of these pools for climate change mitigation, the molecular characterization of the cultivars tolerant to drought, high soil moisture and chips storage insects is recommended.

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