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RESEARCH ARTICLE

Climate variability and status of the production and diversity of sorghum (*Sorghum bicolor* (L.) Moench) in the arid zone of northwest Benin

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Abstract Sorghum (*Sorghum bicolor* (L.) Moench) is an important staple food in semi-arid tropics which contribute to food security and poverty alleviation in Benin. However, its production is seriously facing enormous abiotic and biotic stresses including climate variability. To document its cultivar diversity, the impact of climate change on its production and diversity, the adaptation strategies developed by farmers and the performance of landraces, 22 villages were randomly selected and surveyed in the Department of Atakora in the northwest of Benin using participatory research appraisals (fields and granaries visit, individual and group survey using questionnaires, Four cells or distribution and extent analysis, etc.). Data were analysed through descriptive statistics (frequencies, percentages, means, etc.) to generate summaries and tables at different (villages, individuals) levels and also through multivariate analysis (cluster analysis) and the results figures. In total 8 constraints affecting sorghum production were recorded among which striga proliferation, soil poverty and climate change effects (drought; excess of rain; delay, insufficient and irregular rainfall, etc.) were the most important. Subject to synonyms, 89 sorghum landraces were inventoried and their number varied from 4 to 17 (7 on average) per village. The Shannon–Weaver diversity index (H) estimated at 3.02 indicated high sorghum diversity in the study area. Many landraces were threatened. The relatively high rates (16.7–88.2 %; 40.9 % on average) of

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cultivars loss recorded per village are proofs of menace of genetic erosion and necessity of developing conservation strategies. Inadaptability of cultivars to climate variability (39.6 % of abandoned landraces) was among others the most important reason justifying the loss of diversity. Crop rotations, growing of early maturing and/or drought tolerant landraces, establishment of fields in lowlands are the most important strategies developed by farmers to mitigate impacts of climate change (low productivity, increase of damages from storage insects, early drying of plant leaves etc.) on the crop. Participatory evaluation of the existing landraces led to the identification of some high-performing ones that are resistant/tolerant to diverse abiotic and biotic stresses. Farmers' cultivars preference criteria were identified and prioritized. Results of this study are useful to policy makers, agricultural extension services of the different districts, genetic resources specialists and breeders in order to improve sorghum production in Benin.

Keywords Climate change · Cultivar diversity · Northwest Benin · Participatory evaluation · *Sorghum bicolor*

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important cereal crop worldwide after maize, wheat, rice and barley in terms of production and area sown (FAO 2013). Sorghum is also the dietary staple of more than 500 million people in 30 countries (FAO 2013). Africa and India are the largest producers with more than 70 % of the word output (FAO 2013). Sorghum is able to grow with less water than the other cereals such as maize and wheat, and is well adapted to growing in many arid and semi-arid regions of the world (Nguyen et al. 2013).

In Benin, after maize sorghum is the second cereal in terms of production and is traditionally grown in the arid and semi-arid departments of the north under rainfed conditions (Missihoun et al. 2012). The crop plays a strategic role in households food security as the great majority of the production is consumed locally mainly in the forms of paste, porridge or tchoukoutou, a traditional opaque beer made with fermented sorghum grains (Kayodé et al. 2011). Sorghum also contributes substantially to households' income through commercialising in local markets (Adegbidi 2012). Its straw is used as animal feed and for fencing purpose as well as fuel for cooking (FAO 2013).

In spite of its cultural, nutritional and economic importance, sorghum in Benin has been for a long time neglected by scientific research and development programmes. Consequently, cultivated landraces are still unimproved and most of them have even been abandoned due to susceptibility to striga, pests, diseases and drought, soil selectivity (inadaptability to all types of soil), long cycle, competition by maize production in the area, etc. (Tidjani and Akponikpe 2012). The grain yields of the crop in the department of Atakora are relatively low and the annual production is highly variable from year to year. The major causes of low yields are mainly due to a range of factors involving both biotic and abiotic stresses including climate change (MacCarthy and Vlek 2012). Recent studies conducted in the study area have shown evidence of climate change and its impacts on yam and maize production and diversity (Tidjani and Akponikpe 2012; Loko et al. 2013) as well the adaptation strategies developed by farmers. For sorghum, there is a dearth/lack of information on such data.

In traditional agroecosystems in Africa and elsewhere, farmers generally grow a large diversity of landraces per crop species (Tidjani and Akponikpe 2012). This diversity needs to be conserved as its sustainable utilisation may help to lower the risk of crop failure owing to vagaries of climate, diseases, pests and soil limitations (MacCarthy and Vlek 2012; Gudu et al. 2012). Locally adapted landraces usually produce lower yields during optimal conditions than "improved" cultivars, but the relative stability of their yields provides food security to households (Mekbib 2012). However, designing strong conservation strategies for a crop species at a country level requires good knowledge of the existing diversity within this crop in the country and good understanding of the traditional seed system and of the factors that affect this diversity (Bisht et al. 2007).

In the actual context of climate change, the development of modern and well adapted varieties of sorghum that could meet the needs of both farmers and consumers also becomes an imperious challenge (Haussmann et al. 2012). The knowledge of existing landraces and farmers' selection criteria are a prerequisite to designing a concrete breeding programme and to hope that the improved varieties will be adopted (Haussmann et al. 2012). To preserve the existing landraces against genetic erosion, germplasm collection and conservation *ex situ* is a necessity (Mekbib 2012; Dansi et al. 2013a). Recently, an ethnobotanical investigation was carried out in the relatively humid department of Donga, fourth sorghum producing zone of Benin in term of area and annual production (Missihoun et al. 2012).

We report in this paper the results of a study conducted in the Department of Atakora in order to: (1) identify the constraints of sorghum production in the study area (2) document the impact of climate change on the production and the diversity of sorghum and the mitigation strategies developed by farmers, (3) assess the diversity of sorghum at both community and household levels, (4) identify farmers' preference criteria of sorghum landraces, (5) understand the traditional sorghum seed system and on farm seed maintenance and (6) collect sorghum germplasm for *ex situ* conservation and utilisation purposes.

Materials and methods

The study area and its potential in sorghum production

The study was conducted in the Department of Atakora in the far northwest of Benin (Fig. 1). This Department is located in an arid agroecological zone characterized by unpredictable and irregular rainfall (800–950 mm/year) with only one rainy season and a dry season lasting more than 5 months (Dansi et al. 2010). The area is mountainous with poor sandy, rocky and crusted soils and some shallow soils. The region is partitioned into six districts which are Boukoumbé, Cobli, Matéri, Natitingou, Tanguieta and Toukountouna. These districts are, respectively, inhabited by the ethnic groups Ditamari and Lamba, Bialli, Berba, Wama, Natimba, Wama and Natimba that have a very long tradition in sorghum cultivation (Tidjani and Akponikpe 2012). The annual production is about 27.698 million kg (MAEP 2011) but this is very variable from one season to another mainly because of climatic variation. At the national level, the department of Atakora is the second sorghum production zone after the department of Alibori (60.691 million kg per year) (MAEP 2011).

Site selection and data collection

Twenty-two villages were randomly selected throughout the six districts and the different ethnic zones for the survey (Fig. 1). Data were collected from the different sites during expeditions through the application of Participatory Research Appraisal tools and techniques, such as direct observation, group discussions, individual interviews, and field visits using a questionnaire following Kombo et al. (2012) and Orobiyi et al. (2013). Interviews were conducted with the help of translators from each area. In each site, local farmers' associations and the village chiefs were involved in the study to facilitate the organisation of the meetings and the collection of data. Prior to the meeting, farmers were requested in advance to bring samples of the sorghum landrace they produce or knew about. Information on the location (name of district, name of village, ethnic group) was first collected after a detailed presentation of the research objectives to the farmers. Then, farmers were asked to list (vernacular names) and display the different landraces of sorghum produced in their village. Through discussions, the production constraints, the folk nomenclature and the detailed traditional morphological descriptions of panicles were documented. Constraints listed in groups of 20–30 farmers were prioritized following Orobiyi et al. (2013) by identifying and gradually eliminating the most severe one.

The distribution and extent of the landraces were assessed using the Four Cells Analysis approach described by Dansi et al. (2013a) and Kombo et al. (2012). At the community level and based on two parameters ("number of households" and "cultivated area"), this participatory analysis method helps to classify existing landraces into four groups: landraces cultivated by many households on large areas; landraces cultivated by many households on small areas; landraces cultivated by few households on large areas, and landraces cultivated by few households on small areas. To do this, landraces were individually taken and evaluated by farmers using the first parameter (number of households). For this parameter, farmers were asked to indicate for each landrace whether it is produced by many or few households. The same evaluation process was repeated for all the landraces for the second parameter (cultivated area). By combining the results of the two parameters, landraces were classified in the different quadrants and the results were

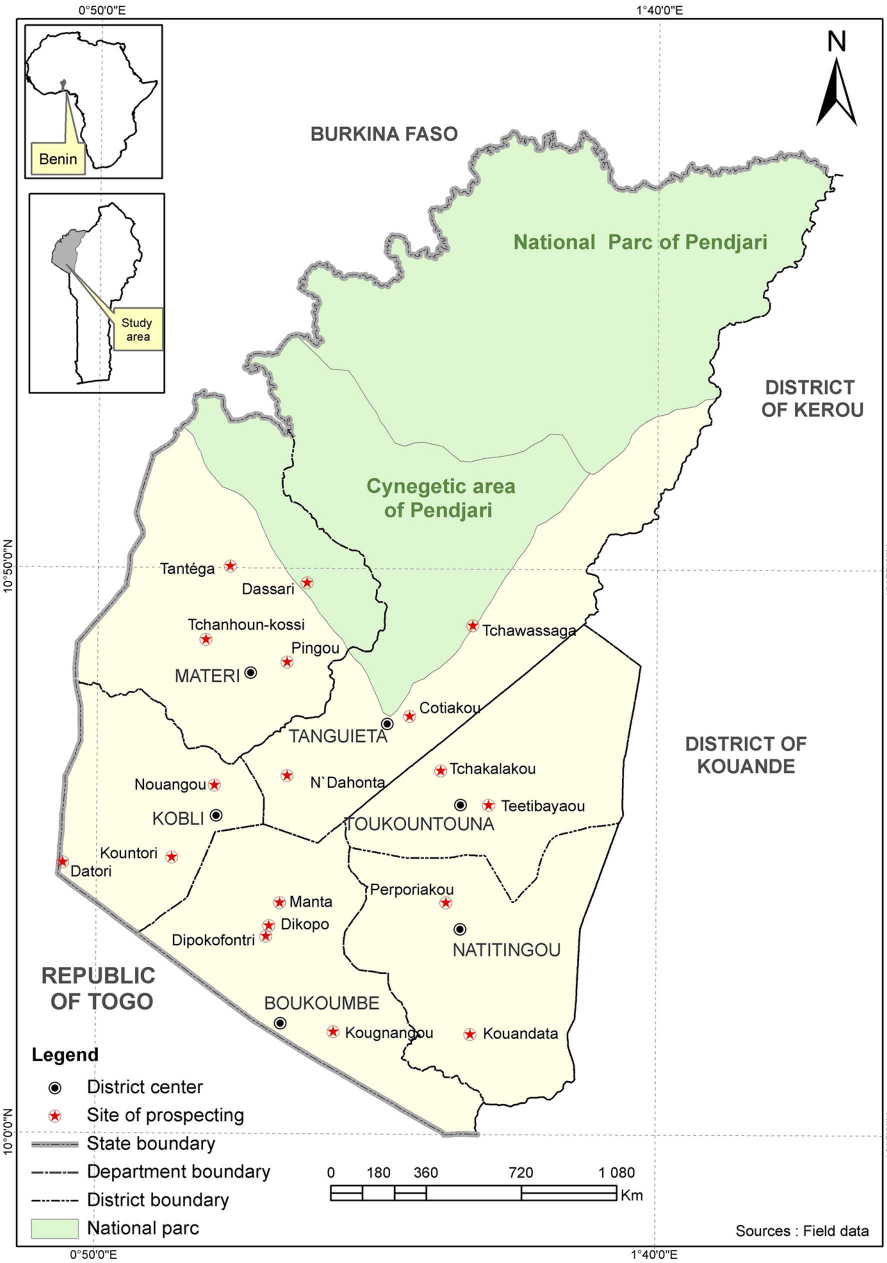


Fig. 1 Distribution map of the surveyed villages in the Department of Atakora

immediately presented to the farmers for eventual comments. After this, details of each landrace and the reasons for their status were discussed. Hence, reasons that justify the cultivation of each landrace by many or few households and on large or small areas were documented. The traditional seed system and its maintenance on farm were also discussed.

The participatory evaluation of the identified sorghum landraces was also carried out using the two-level evaluation method based on an agronomic and technological evaluation form described by Gbaguidi et al. (2013). In this method and for a given trait, a landrace is scored (in group of framers) 1 when it is performing and 0 when it is not. Parameters considered (13 in total) were productivity, resistance to striga, soil selectivity, tolerance to poor soil, resistance to birds, resistance to storage insect pests, earliness (time to maturity), drought resistance, tolerance to high soil moisture, threshability (ease of husking), suitability for beverages, good culinary quality (dough and porridge) and storage aptitude of the dough (liquefaction).

In each of the survey sites, 20 farmers (with at least 10 years of experiences in sorghum production) were randomly selected, after the group discussion, for individual interviews. Gender as well as age aspects were considered. In all, 440 men and women farmers from different ages were selected. Data collected were related to the impacts of climate changes (farmers' perception) on the production and the diversity of the crop, the adaptation strategies developed by farmers to mitigate the impacts of the climate changes and the varietal preference criteria. Three methods are generally used to identify and prioritize farmers' varietal preference criteria. These were: group survey (Gbaguidi et al. 2013; Kamara et al. 1996) and individual survey using the matrix comparison method (Dansi et al. 2010) or spontaneous reactions (Defoer et al. 1997). In this study, the matrix scoring technique (Dansi et al. 2010; Adoukonou-Sagbadja et al. 2006) was employed.

Within a village, seed samples of the identified landraces were independently collected, when possible, from two to three randomly selected farmers directly from their granaries or fields. In the field, samples were collected from panicles of at least 50 individual plants and at many sites (separated by 15–20 steps) following Brown and Marshall (1995). Each accession was packaged in a paper bag and documented, following Dansi et al. (2010). The descriptors used for data collection included: accession number, collection institution, date of collection, name of collector, type of material, scientific name, vernacular name and language, status of sample, sampling information and the location of the collection site. All collected samples were stored in the seed bank of the Faculty of Sciences and Technology of Dassa, Polytechnic University of Abomey.

Data analysis

Data were analysed through descriptive statistics (frequencies, percentages, means, etc.) to generate summaries and tables at different (villages, individuals) levels using SAS software (SAS 2011). Shannon–Weaver diversity index (H) was computed for the whole study area following Shannon and Weaver (1948) in order to assess the level of sorghum diversity in the study area. The rate of landraces menace or loss (RLL) at the village level was determined, according to Kombo et al. (2012), using the formula $RLL = (n - k)/N \times 100$ where n is the number of endangered landraces (cultivated by few households and small areas); k is the number of landraces newly introduced; N is the total number of landraces identified in the village.

For the direct utilisation of the existing diversity or for breeding purposes, the knowledge of the different groups of agronomic and technological performance of the sorghum landraces recorded is a prerequisite. To study the diversity of the landraces in terms of agronomic (biotic and abiotic traits) and technological performances, a dendrogram was constructed using Unweighted Pair-Group Method with Arithmetic Average (UPGMA) cluster analysis (Sneath 1973; Swofford and Olsen 1990) and NTSYS-pc 2.2 (Numerical Taxonomy and Statistical Analysis) software (Rohlf 2000). To do this, identified landraces were considered as individuals and evaluation parameters as variables and scored as a Bernoulli variable (0, 1) according to Kombo et al. (2012).

Results and discussion

Importance and production constraints of sorghum in the study area

Sorghum is a very important food crop for local populations in the Atakora region, the drought-prone marginal agricultural areas of northwest of Benin where it is traditionally grown exclusively under rain fed conditions. Many poor families grow and rely on sorghum for food security and only sold as the last resort in times of dire need. Apart from its importance for food security (consumption as paste and porridge made with the grain's flour), the crop also has social, economic (cash income through commercialisation of the grains and derived products), cultural (festivals, marriages, celebrations, traditional ceremonies, rituals), religious (sacrifices to pacify gods), nutritional (desserts, food for lactating mothers) and medicinal values (cure for diarrhoea, stomach pains, haemorrhoid and snake bites; stimulation of milk secretion with the lactating mothers with landrace Yèyopoto) in the farmers' lives. The stalks are used for fuel and for building and fencing material, the leaves and the stalks are used for animal feed. Another major utilisation of sorghum in the region is the production with malted, brewed and fermented grains of a traditional and largely consumed opaque beer named *Tchoukoutou* (Kayodé et al. 2011). This beer has a sour taste, a relatively high dry matter and low alcohol content (2–3 mL 100 mL^{-1}), which make it a suitable beverage for adults (Kayodé et al. 2011). Compared to other reports, the uses of sorghum as reported by farmers in the study are almost the same with those of the Department of Donga (Missihoun et al. 2012) and of other countries of West Africa. The socially, culturally and economically important beer *Tchoukoutou* for instance in Benin is the same local beer called *dolo* in Burkina-Faso, *pito* in Ghana, and *burukutu* or *otika* in Nigeria (Kayodé et al. 2011; Coulibaly et al. 2014).

Farmers reported 8 different constraints in sorghum production in their area (Table 1) among which five (proliferation of striga, soil poverty, climate change, insufficiency of performing landraces, introduction of maize, difficulty of postharvest storage) were the most important and accounted for 82.9 % of the total responses. Striga infestation was ranked first. This result was expected as the parasitic weed striga is known to pose a serious threat to cereal production in sub-Saharan Africa with infestation usually resulting in significant yield losses, quite often over 70 % hence keeping sorghum productivity below subsistence level (Gebretsadik et al. 2014; Kamara et al. 2014). Poor soils were a source of worry to all farmers as for any crop; productivity is function of the quality of the soil. Also, striga proliferation is, from farmers' observations, highly associated to infertile soils. In many parts of the world, climate change appears as one of the most important threats to the performance of agricultural systems. As the study area belongs to arid agroecological zone characterized by unpredictable and irregular rainfall (Dansi et al. 2010), it was expected that climate change should seriously impact sorghum production and may even rank first. Like with yam in this area (Loko et al. 2013), climate change ranked third within the production constraints (Table 1). Ali et al. (2011) reported that in sorghum water stress at critical stages like seedling establishment, tillering and reproductive stages (anthesis and postanthesis for instance) generally result in significant yield reduction and can even be lethal to the crops. One understands therefore why the erratic nature of rainfall is a major problem for farmers since their sorghum production is typically rainfed. More tolerant landraces are needed as the farmers even reported the lack of such varieties in the study area. According to the farmers, the introduction of a short-cycle maize landrace in the region in the past by the national agricultural extension service is contributing to the reduction of sorghum production and even to the loss of sorghum diversity for two reasons: more flour is obtained from maize than that from the same quantity of sorghum; the maize is early, high yielding, mature before the local sorghum and easy to thresh. The other constraints reported (pests and diseases) are well known in sorghum production (Gebretsadik et al. 2014; Sharma et al. 2014) and require practical, healthy and sustainable solutions.

Farmers' perceptions and mitigation strategies of climate change impacts on the production and the diversity of sorghum

According to the farmers, the weather was in the far past (more than 20 years ago) favourable for

Table 1 Sorghum production constraints and their ranking in the study area

Constraints	Percentage of responses (%)	Rank
Proliferation of striga	21.2	1
Soil poverty	19.3	2
Climate change (drought; excess of rain; delay, insufficient and irregular rainfall)	17.7	3
Insufficiency of performing varieties (high yielding, tolerant to biotic and abiotic stresses)	13.5	4
Introduction of high yield maize varieties	11.1	5
Difficulty of postharvest storage (infestation by storage insects)	9	6
Pests (stem borer, termites, panicles bug) and birds damages	6.2	7
Diseases damages (anthracnose, rust, grain mold)	1.9	8

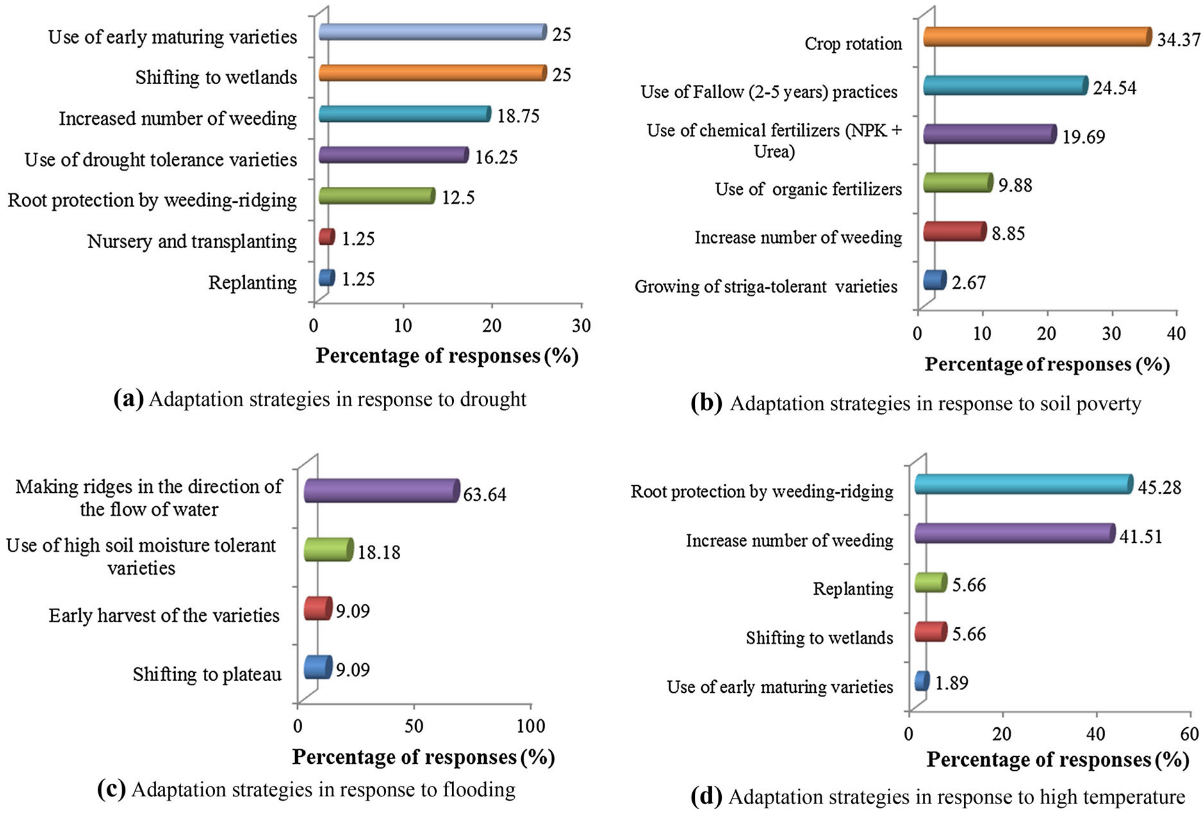


Fig. 2 Various adaptation strategies developed by farmers' to mitigate effects of climate change. **a** Adaptation strategies in response to drought, **b** adaptation strategies in response to soil poverty, **c** adaptation strategies in response to flooding, **d** adaptation strategies in response to high temperature

agriculture. Rain was regular with less blazing sun that resulted in high yields of cultivated crops. Unfortunately, agriculture in the study area is currently facing several environmental constraints that affect performances of crops especially sorghum. The evidences that farmers perceive climate change effects in the study area were recently reported by Loko et al. (2013), comparing farmers' perceptions with weather data of the last 40 years (1971–2010) as compiled for the study area by the Benin Department of Meteorology. For farmers, drought, flooding or high soil moisture, soil poverty, heat and gale force winds were the direct manifestations of climate change (Loko et al. 2013). According to the farmers, the impacts of climate change on sorghum production are perceived at four levels: reduction of productivity (30.7 %), loss or abandonment of landraces (22 %), proliferation of storage insect pests causing important damages mainly on the stocks (19.3 %), early drying of the sorghum plants (18.7 %) and rot of the seeds in the soil due to excess of heat (9.3 %). Similar results were reported on cowpea (Ajetomobi and Abiodun 2010), rice (Nwalieji and Uzuegbunam 2012), sesamum (Luka and Yahaya 2012), cassava (Jarvis et al. 2012), yam (Loko et al. 2013) and also on sorghum in Kenya (Bryan et al. 2013), Ghana (Etwire et al. 2013), Mali (Traore et al. 2013) and Burkina Faso (Lodoun et al. 2013). To mitigate the impact of climate change, farmers have developed or use (apart from the case of gale force winds) several strategies (Fig. 2) which varies depending on whether it is drought (Fig. 2a), soil poverty (Fig. 2b), soil moisture (Fig. 2c) or heat (Fig. 2d). Similar strategies were recorded and documented for maize (Tidjani and Akponikpe 2012) and yam (Loko et al. 2013) in the northern Benin and for corn in Nigeria (Tambo and Abdoulaye 2013). Interviewed farmers recognized that among the listed strategies, the shifting towards the relatively humid areas (peripheries of lowlands or watercourses) and the use of adapted landraces (early maturing; tolerant) were the most interesting. Shifting towards humid areas allows farmers to continue to grow many of their high yielding landraces of very good technological and culinary characteristics such as Kouala, Kouétifouénan and Tchanwoporika that are unfortunately late maturing and highly affected by the frequent precocious cuts of the rains. Otherwise these landraces would have been abandoned. Because sorghum has long been neglected by scientific research in Benin, farmers' access to performing local or improved varieties is very limited. Developing types of landrace with high degrees of heterozygosity and genetic heterogeneity for adaptation traits helps achieving better individual and population buffering capacity. Traits that will be considered include flooding tolerance, seedling heat tolerance, tolerance to soil poverty, striga, drought, storage insect pests and diseases. Farmer participatory dynamic genepool management using broad-based populations and diverse selection environments and larger-scale, on-farm participatory testing will enable assessments of genetical performance under evolving climatic variability, provide perspective on needs and opportunities, and enhance adoption (Haussmann et al. 2012).

Diversity, distribution and extent of sorghum landraces in the study area

In the northwest of Benin, sorghum is known under some generic names that vary according to the ethnic groups. The crop is called *Tiyoti* or *Eyoua* in Ditamari, *Soniya* in Wama, *Yoaga* in Natimba, *Ayo* in Bialli and *Kagou* in Berba. Diverse farmer-named landraces exist and are named according to the colour (Diyopéripèèka) and the hardness of their grains (Kpérimon), the flexibility of their sowing time (Koualaye), the ease of their cultivation (Taimpora), the rapidity of their growing (Tchanwoterika), the beauty of their panicle (Tchèriè) and their earliness (Atchontio), panicle type (Gnipidiaka), resistance to striga (Tchorôssoya), specific use (Kpankpansoya), medicinal value (Sotakaman) and resistance to birds (Kohounkohounbakalé). Their names vary from one ethnic area to another and sometime between villages within ethnic area with homonymy and synonymy scenarios. Each village seems to have its own series of vernacular names. These findings which are common in folk nomenclature have already been reported on many crops, including fonio (Dansi et al. 2010), cassava (Kombo et al. 2012), traditional leafy vegetables (Adjatin et al. 2012), yam (Dansi et al. 2013a), Chili (Orobiyi et al. 2013), cowpea (Gbaguidi et al. 2013) and also on sorghum (Missihoun et al. 2012; Mekbib 2007). In the entire study zone and subject to synonymy, 89 different local names (including synonymy, homonymy, deformation of names) of landraces were recorded. The meanings of the vernacular names of selected landraces are compiled in Table 2.

The number of landraces inventoried varied from 4 to 17 per village (Table 3) with 7 on average. The higher number of landraces were recorded in the villages Peporiyakou (11 landraces) and Tchanwassaga (17 landraces) of the Wama tribe (Table 3) while the lower (4 landraces) was found at Datori, Dipokor frontri, Matéri centre and Tectibayaou, all belonging to different tribes and districts (Table 3; Fig. 1). Subject to synonymy, 17, 11, 10 and 5 landraces were listed in only one village, 9 and 8 in three villages and 7, 6 and 4 in four villages.

With regard to the precocity of the landraces, no significant difference was found between the means of both early and late maturing landraces recorded per village throughout the study zone. This means that globally farmers produce approximately the same number of the two types of landraces across villages although some differences were notable in some areas such as Pouri, Pingou and Tantéga where the number of early sorghums outstrips the one of late sorghums (Table 3) and in some others like Nouangou, Kougnangou and Tchanwassaga where late sorghums were still predominant (Table 3). According to farmers and base on the ecological data of the study zone (Adam and Boko 1993), early sorghums mainly predominate in the very arid villages where drought is more severe (districts of Materi and Kobli) while late sorghums prevail mostly in the relatively humid villages or in the villages where lowlands are frequent as they help securing production by mitigating drought effects. Like in Mali (Kouressy et al. 2008), Burkina Faso (vom Brocke et al. 2010), Ethiopia (Gebretsadik et al. 2014) and Kenya (Ochieng et al. 2011), farmers in the study area also seem to be more attached to late sorghum than early sorghum and explained this by the fact that almost all of their best landraces in terms of productivity, culinary and technologically properties (including fermentation capacity to produce local alcoholic beer), post-harvest storage aptitude and market demand belong to this category. These results direct sorghum breeders to the necessity of developing early maturing sorghum landraces that will adequately

Table 2 Meaning of the names of selected sorghum landraces of the Department of Atakora

Vernacular names	Ethnic group	Meaning of the name and other characteristics
Bawidji/ Tchouangouhou	Wama	Lowlands' sorghum; resistant to birds; hard grain; susceptible to weeds
Bourkinasoya	Wama	Sorghum of Burkina Faso
Diyopéripeeka	Ditamari	Sorghum which is like the white rock. Grow well in the humid rocky areas
Kohounkohounbakalé	Bialli	Kohounkohoun means thorns and bakalé means surrounded. Glumes carry long eyelashes that prevent birds from pecking (resistant to birds)
Kontibaamou	Ditamari	Easy to produce; tolerant to weeds
Kouala	Berba	It has no time; reference to its sowing date not rigorous
Kpankpansoya	Wama	Kpankpan means Stake and Soya equals sorghum. Sorghum used to mark field boundaries; women variety, easily to grow (one weeding is enough)
Kpérimon	Wama	Kpéré equal hard. Hard grains difficult to grind; develop in full dry season new plants that flower and fruit as mother plants
Taimpora	Ditamari	Weak men sorghum. Does not require enough effort for it growing
Tchawonporika	Wama	Sorghum that grows fast; cultivated near houses as easily attacked by birds at maturity; very early maturing; Always sown in last position so that the maturity period coincides with the dry season
Tchorôssoya	Wama	Tchôrôma means striga and sooya equals sorghum; resist to striga; Susceptible to stem borers and to strong winds
Yèyopoto	Ditamari	Healer's sorghum; has medicinal properties and used to treat icterus and stomach aches
Yêtékonyoua	Ditamai	Twin sorghum, resistant to drought

respond to farmers' needs in the actual context of climate change. It is therefore urgent to develop and implement a national farmer's participatory breeding program that will help plant breeders to enhance adaptation of sorghum to climate variability and to other specific production constraints.

The distribution and extent of the diverse landraces in their production areas as revealed by the Four Square/cell analysis are variable (Table 4). At Kougnangou for instance (Table 3), out of the 7 landraces recorded, 2 (Tiyoperti, Tiyowonti) were cultivated by many households and on large area (quadrants Q1), one (Diyopéri) was found with many households but on small area (quadrants Q2), one (Taimpora) was cultivated by few households and on large area (quadrants Q3), and 3 (N'sara, Tiyowonti, Tapora) were found with few households and on small area (quadrants Q4). The distribution and extent of the cultivars also varied from one village to another. Variety Tchorossoya for example is cultivated by many households and on large areas at Perporiakou, Tectibayaou, Tchanwassaga while it is cultivated by few households and on small areas at Cotiakou.

The reasons underlying the positions of the landraces in the different quadrants (Fig. 3) indicated that farmers have good knowledge of their materials and confirmed the solidity of the four cell method used. Landraces in Q3, for example, are late maturing and drought sensitive. In a semi-arid agro-ecological zone, characterized by unpredictable, irregular and shorter rains added to climate change, only farmers who have their fields in a relatively humid areas (i.e., along watercourses, or around lowlands) can produce these landraces with a long duration growth as their yield in the ordinary fields is uncertain. Comparable results were reported on many crops including fonio (Dansi et al. 2010), cassava (Kombo et al. 2012), cowpea (Gbaguidi et al. 2013), chili (Orobiyi et al. 2013) and yam (Dansi et al. 2013a). In terms of genetic resources conservation, landraces in Q4 which were reported to be disappearing need to be preserved *ex situ*. For landraces in Q2 and Q3, complementary conservation strategies (*ex situ* and on farm) should be developed; while for landraces in Q1, no urgent action is required.

According to the producers interviewed and subject to synonyms, 83 landraces have been abandoned across villages surveyed (Table 5). Their number varies from 1 to 9 per village with 4 in average. Thirty landraces (Ayônio, Bouré, Kaaka, Kètèounpouèkè, Nagbélé, N'sara, Sotakaman, Taimpora, Tioniti, Yolata, etc.)

Table 3 Diversity, earliness, distribution and extent of sorghum landraces in the study area

Village	Ethnic group	TNV	Earliness (months)				Distribution and extent				NIV	NDV	RVL
			NVEV (2–3)	NEV (4)	NLV (5)	NVLV (≥6)	H+A+	H+A−	H−A+	H−A−			
Cotiakou	Wama	7	2	0	0	5	5	0	0	2	0	2	28.6
Dassari	Berba	8	4	0	0	4	3	0	0	5	0	5	62.5
N'Dahonta	Natimba	9	5	0	4	0	3	1	0	5	1	4	44.4
Dipokofontri	Ditamari	4	0	2	2	0	3	0	1	0	0	0	–
Kouandata	Ditamari	8	2	0	0	6	3	5	0	0	0	0	–
Kougnangou	Ditamari	7	0	0	3	4	2	1	0	4	4	0	–
Kountori	Bialli	6	2	0	1	3	3	1	0	2	2	0	–
Manta	Ditamari	6	0	0	5	1	4	1	0	1	0	1	16.7
Nouangou	Bialli	10	2	0	0	8	5	1	0	4	1	3	30
Peporiyakou	Wama	11	1	10	0	0	4	1	0	6	0	6	54.6
Pingou	Berba	7	1	4	0	2	5	0	1	1	1	0	–
Tantéga	Berba	7	3	2	2	0	2	1	0	4	2	2	28.6
Tectibayaou	Wama	4	2	0	0	2	2	2	0	0	0	0	–
Tchanhoun-kossi	Berba	5	2	0	0	3	2	0	3	0	0	0	–
Tchanwassaga	Wama	17	2	1	0	14	2	0	0	15	0	15	88.2
Datori	Bialli	4	1	1	2	0	2	2	0	0	0	0	–
Dipokô	Ditamari	9	3	6	0	0	4	0	1	4	0	4	44.4
Gouandé	Berba	6	2	2	2	0	2	0	1	3	0	3	50
Koukpankou	Ditamari	9	3	0	6	0	5	1	0	3	0	3	33.3
Matéri centre	Berba	4	1	1	2	0	2	1	0	1	0	1	25
Pouri	Berba	8	3	5	0	0	3	2	1	2	0	2	25
Tchakalakou	Wama	7	2	1	1	3	2	2	3	0	0	0	–
Mean		7	2	2	1	3	3	1	1	3	1	2	40.9

TNV total number of landraces, *NVEV* number of very early maturing, *NEV* number of early maturing, *NLV* number of late, *NVLV* number of very late, *M* month, *H+A+* many households and large area, *H+A−* many households and small area, *H−A+* few households and large area, *H−A−* few households and small area, *NIV* newly introduced landraces, *NDV* number of disappeared, *RVL* rate of loss

abandoned in certain villages are still cultivated in some others. The remaining ones (17 landraces in total) would have completely disappeared in the study area as they were not found during the survey (Table 5). The distribution and extent analysis also revealed that in spite of the existing diversity at village level, only 3 landraces on average were cultivated by many households and on large areas (Table 3). This simply means that there is an important gap in terms of performing landraces in this area that should be urgently filled by sorghum geneticists and breeders. The rate of cultivar loss (genetic erosion rates) varied from 16.7 % at Manta to 88.2 % at Tchanwassaga with 40.9 % on average (Table 3). The lack of diversity loss rate recorded in some villages is not an indication of a better preservation but rather a maximum threshold of varietal abandonment reached. On Fonio (Dansi et al. 2010), cassava (Kombo et al. 2012), cowpea (Gbaguidi et al. 2013) and yam (Dansi et al. 2013a) analogous results were reported. According to Gbaguidi et al. (2013), landraces revealed by the four square analysis as cultivated by many households and on large area in at least one village can be considered as elites. As plant genetic resources represent the inter and intraspecific reservoir of potentially useful genetic material, the 89 farmers-named varieties here recorded should be collected, fully characterised and evaluated for their sustainable utilisation as recommended by Djè et al. (2007), Rakshit et al. (2012) and Elangovan et al. (2013).

Table 4 Distribution and extent of some sorghum landraces grown in Atakora region selected from maturity groups

No.	Vernacular names	Earliness (month)	Village, distribution and extent
1	Inian	6–7	Dassari (− −); Pingou (− +); Tantéga (− +); Tchanhoun−kossi (− +)
2	Kalar	3	Tantéga (+ −) Tchanhoun−kossi (++)
3	Kouala	3–4	Gouandé (− −); Tantéga (+ +); Tchanhoun−kossi (++)
4	Kouétifouénan	4–5	Perporiakou (++); Tectibayaou (+ +)
5	Sonipoya	8	Cotiakou (++); Perporiakou (++); Tchanwassaga (− −)
6	Soniterya	8	Cotiakou (++); Perporiakou (++); Tchanwassaga (− −)
7	Sotakaman	6–8	Cotiakou (− −); Kouandata (+ −); Manta (− −); Nouangou (− −); N'Dahonta (− −); Perporiakou (− −); Tchakalakou (− −); Tchanwassaga (− −)
8	Soanikè	2	Pingou (− −); Tantéga (− −)
9	Tchorôssoya	6–7	Cotiakou (− −); Perporiakou (++); Tchakalakou (++); Tchanwassaga (+ +); Tectibayaou (++)
10	Tioniti	5	Manta (++); Nouangou (++)

++, Many households and large area; + −, many households and small area; − +, few households and large area; − −, few households and small area

Fig. 3 Summary of reasons for the position of the different genotypes in different squares

Many households and large area (Q1)

- High productivity
- Tolerance to environment stresses
- Tolerance to poor soil and to striga
- Resistance to storage insects pests
- Good culinary qualities
- Good suitability for beverage
- High market value

Example of landraces : Kouala ; Kapoué

Many households and small area (Q2)

- Early maturing

- Poor culinary and beverage qualities
- Difficult to dry (mature in rainy season)
- Lose culinary and beverage qualities after some storage time
- Susceptible to storage insects pests

Example of landraces : Kalar

Few households and large area (Q3)

- Soil selective (only farmers having the types of soil produce)
- Late maturing
- susceptible to drought
- susceptible to striga

- High productivity
- Good culinary qualities
- Good suitability for beverage
- High market value

Example of landraces : Inian

Few households and small area (Q4)

- Poor culinary and beverage qualities
- Low Productivity
- Susceptible to poor soil
- Susceptible to weeds
- Susceptibility to storage insects pests
- Late maturing
- grown just for specific uses (medicinal, sacrifice or feed)
- Newly introduced and seeds not yet sufficiently available

Example of landraces : Gnipidiaka, Sotakaman, Soanikè, Tchandoli

In all the study area, entire panicles of 113 accessions of sorghum corresponding to 89 clearly different variety names were collected. The number of accessions collected varied from 4 to 17 per village. Although landraces of the Q4 were rarely found for sampling, they have been all happily collected as a landrace that completely disappeared in one village was found with very rare farmers in another village. The accessions collected showed important variability with regard to the colour of the glumes and of the grains (Fig. 4) and could be classified into nine groups based on these two parameters. Each group contains a set of farmer-named varieties that are not necessary identical with regard to other morphological traits and agronomical characteristics. As recommended by Bioversity International (2010) (Ali et al. 2011; Rakshit et al. 2012; Elangovan et al. 2013) a sound agro-morphological characterisation is necessary and will help to better assess the diversity within the crop in the study area. In addition, a molecular analysis will be also required as it was the case for rice, maize and even sorghum (Chantereau et al. 2010; Missihoun et al. 2012; Rakshit et al. 2012; Adugna 2014; Kimani et al. 2014).

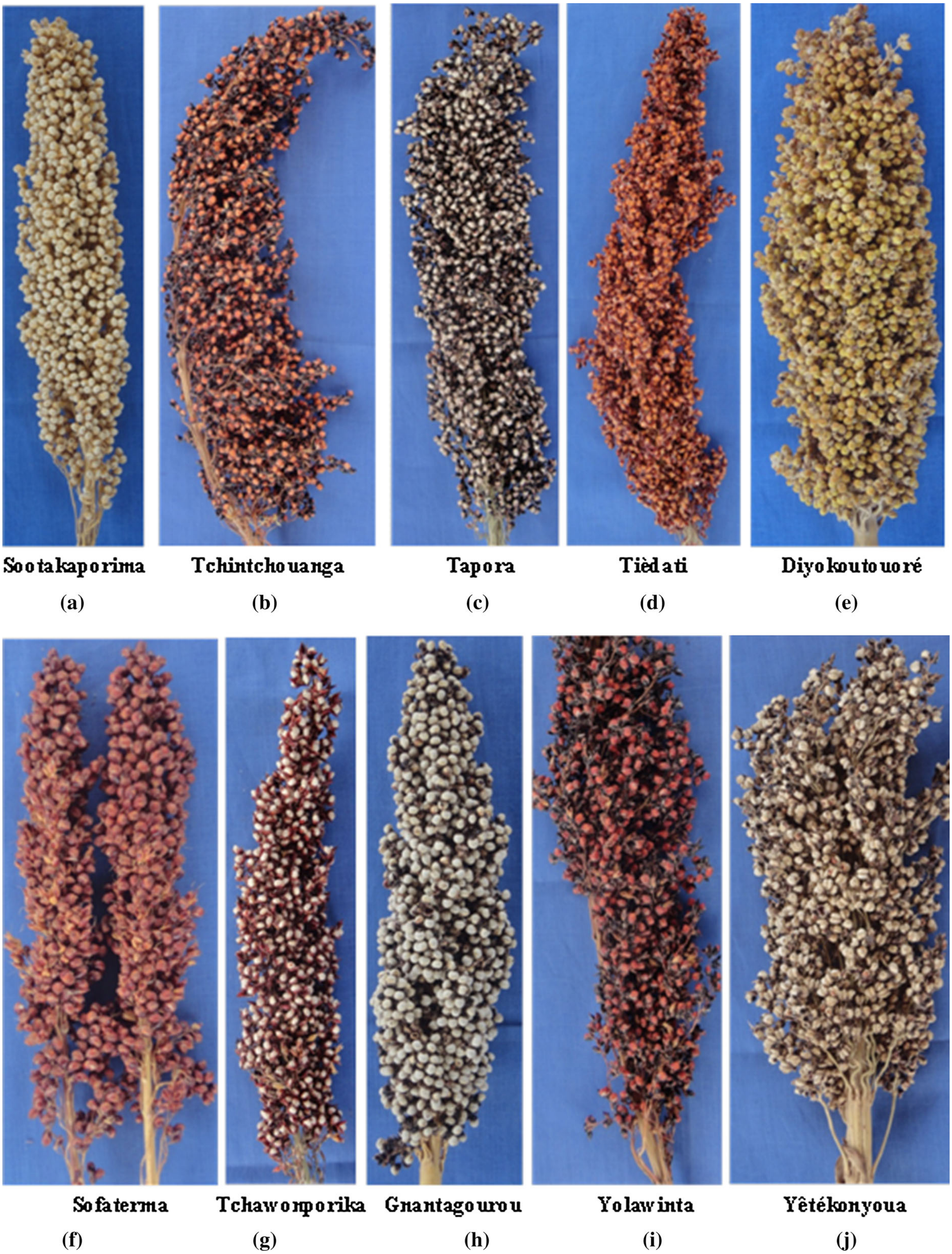
Fig. 4 Morphological variability (grains colour, glumes colour, panicle compactness, number of grains per glume) between different sorghum landraces of Atakora. **a** Compact panicle, white grain, beige glume, **b** orange grain, black glume, loose panicle, **c** white grain, black glume semi compact panicle, **d** orange grain, purple glume, semi loose panicle, **e** yellow grain, beige glume, compact panicle, **f** red grain, red glume, semi compact panicle, **g** white grain, purple glume semi compact panicle, **h** white grain, black glume compact panicle, **i** red grain, black glume loose panicle, **j** white grain, black glume semi compact panicle, two grains per glume

Factors affecting diversity

Reasons that underlie the abandonment of sorghum landraces as mentioned by the producers were mainly related to the susceptibility to striga (20.4 % of responses), drought (16.1 % of responses) and poor soils (15.1 % of responses), to the low fermentation capacity to produce local alcoholic beer (11.4 % of responses), the poor taste (bitter) and culinary qualities (11 % of responses), the low productivity (10.3 % of responses), the soil selectivity (7.4 % of responses) and the poor storability of the grains (5.9 % of responses). These principal reasons corroborate well with the constraints reported above and indicated, as reported on cowpea by Gbaguidi et al. (2013), appropriateness in farmers' decision making in abandoning landraces. Other reasons include low market demand and value and the introduction of early maturing maize varieties which have led farmers to the abandonment of the extra-precocious (2 months)

Table 5 List of abandoned landraces recorded across villages

Village	Number of missing landraces	Vernacular names
Cotiakou	2	Tchanworga; Tchorôssoya
Dassari	6	Inian; Itura; Koualawo; Koumbactor; Koukoumbali; Napoula
Datori	1	Outchètchaxowou
Dipokô	2	Diyopéri pèèkou; Diyopéri wonkou
Dipokofontri	3	Diyopéri; Taimpora; Yopéré
Kouandata	3	Eyoffouré; Eyouffôta; Tiotchanti
Kougnagou	4	N'sara; Taimpora; Tiyoperti; Tiyowonti
Koukpankou	3	Tapayorka; Titan'youanti; Yètouariyô
Kountori	5	Ayônio; Bouré; Kètèpouankè; Nénéwéné; Tchèriè
Manta	3	Tépouaga; Tiédati; Tioniti
Nouangou	8	Ata; Kaniwagou; Nagbélé; Tampouaka; Yolaata; Yolawinta; Yopouaga; Yoniwinkou
N'Dahonta	7	Bérisanbiéni; Darépoukanwoun; Kaniwagou; Sanipo; Siama; Terkata; Tchèpôrô
Peporiyakou	8	Koumbosoya; Kouwékifourna; Kpininkpininbou; Natisoya; Sabikouman; Sorporya; Sotakaman; Tchorôssissoya
Pingou	5	Fouannissanmou; Hilag miensiké; Inian; Kaniwagou; Koukoubari
Pouri	1	Ipowoun sibissi
Tantéga	5	Inian; Kalarou; Kaniwo; Kouala, Koumbari
Tchakalakou	2	Sotakaterima; Wawouré
Tchanhoun-kossi	4	Fouannissanmou; Inian; Ipoua; Kanian
Tchanwassaga	9	Kaaka; Kandouadaka; Kandouanika; Nontii; Sodaya; Soniterya; Soyabia; Winribaadassi, Gnimananmonrima
Tectibayaou	2	Natisoyapoya; Natisoyaterya


Sootakaporima
(a)
Tchintchouanga
(b)
Tapora
(c)
Tièdati
(d)
Diyokoutouoré
(e)
Sofaterma
(f)
Tchawonporika
(g)
Gnantagourou
(h)
Yolawinta
(i)
Yêtékonyoua
(j)

landraces Bapa, Nipièdéka, and Poukouakya. Out of the landraces reported across villages as completely disappeared, 39.58 % have been abandoned because of their susceptibility to the effects of climate change (drought, delay and precocious break of the rain, excess of humidity) described by Loko et al. (2013). These results are in agreement with Nkongolo et al. (2008) who reported that climate changes effects constrain farmers to abandon susceptible landraces in favour of the resistant or tolerant ones. It is widely recognised that disappearance of landraces is ineluctably accompanied by a set of genes that can be used in varietal improvement and breeding (Elangovan et al. 2013). Therefore it is necessary and urgent to develop for the study area a complementary (*in situ* and *ex situ*) and a participatory conservation programme following Fuentes et al. (2012) and Pautasso (2012).

Participatory evaluation of the landraces

Subject to synonymy and among the 89 sorghum landraces recorded and evaluated, 58 have good productivity and 50, 51, 26, 42, 12 and 15 were respectively reported to be tolerant or resistant to high soil moisture, poor soil, drought, storage insects pests, striga and birds (Fig. 5). For the other evaluation criteria (Storage aptitude of the dough, good culinary qualities, suitability for beverage, easiness of threshability, earliness, adaptability to all types of soil), highly variable numbers of landraces were obtained (Fig. 5). Many landraces (16 in total) are soils selective; among these 14 (Koniwaga, kouti kouti, Tiyoperti, etc.), prefer grit spreader soils three (N'sara, Taimpora, Taimpouorkoura) produce better on the mountainside and one (Kokem'po) is suitable for hard soils. The UPGMA dendrogram constructed based on the evaluation variables grouped the 89 landraces identified into 68 different agronomic and culinary sorghum types or units (Fig. 6). The composition of these different units and their key characteristic traits are summarized in Table 6. Among the 68 identified units, 53 were made of a single genotype and 15 were polyvarietal with 2–4 landraces of different characteristics (Table 6). Only 18 % of the identified landraces present 3–5 performance criteria (Table 6). Most of the landraces have six or more performance criteria and represent 80.9 % of the total diversity. At 62 % of similarity, the 68 units are clustered into 6 classes (C1–C6) of various characteristics (Fig. 6). This diversity observed in the evaluated landraces shows the existence of a good genetic basis that can be exploited for varietal improvement as genetic diversity is the basis of a plant improvement programme (Ghalmi et al. 2010; Elangovan et al. 2013). Landraces such as Kouala, Yowonga, Tépouaga, Tchorôssoya, and Yolawinta that present good performances for many criteria together could be directly used by NGOs and development projects in some seed exchange programmes between villages. The study revealed that few landraces are tolerant or resistant to excess of rain, drought, soil poverty and storage insects. In the present context of climate changes (Jalloh et al. 2013) that are now becoming more severe in the study area, efforts should be made towards strengthening the diversity in

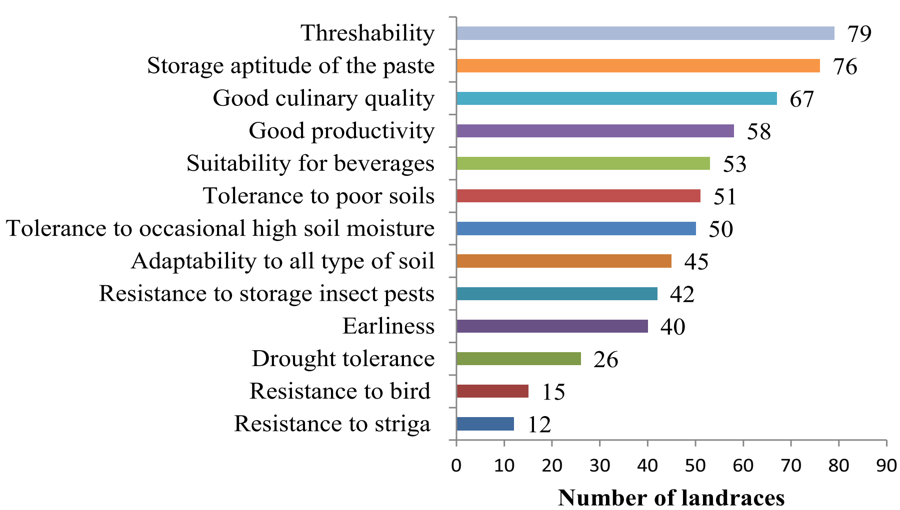


Fig. 5 Number of best performing sorghum varieties identified per trait of economic importance through participatory evaluation

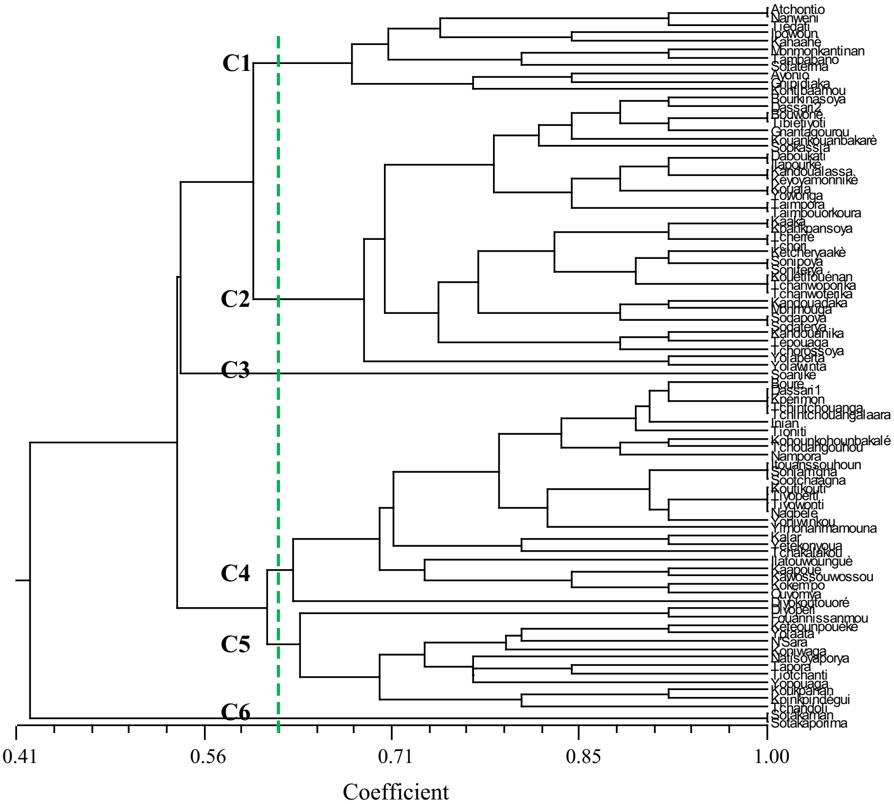


Fig. 6 Dendrogram constructed with the UPGMA method showing the clustering of the 89 landraces inventoried into 68 units and 6 groups based on their agronomic and culinary traits

the study zone with many more landraces tolerant to biotic and abiotic stresses for the benefit of both producers and consumers and for food security. As indicated by Dansi et al. (2013a, b) and Gbaguidi et al. (2013), the compilation in a single table of the distribution and extent data (Table 4) coupled with the agronomic characteristics of all the landraces identified in the study zone appears as a small database that will facilitate germplasm utilisation.

Traditional seed system and its maintenance on farm

No modern or formal sorghum seed production exists in Benin. Seeds used by farmers are obtained by retention on previous harvest (65 % of responses), donation within family circle (29 % of responses) and exchange between farmers (6 % of responses). At harvest time, interesting panicles are selected directly from the fields. The selection criteria used were plant robustness (24.9 % of responses), panicle width and length (24.9 % of responses), physiological maturity (23.5 % of responses), grain size (14.8 % of responses) and panicle richness in seeds (12 % of responses). Selected panicles are generally attached or weaved in a special way (Fig. 7) for drying and conservation in granaries (54.7 % of responses) and in kitchens by smoke (8.4 of responses). Some farmers removed dried seeds from panicles and conserve them in dried cans (15.8 of responses), jars (10.5 % of responses) and bags (10.5 % of responses). A similar seed management system is developed on farm for fonio (Dansi et al. 2010).

Farmers' landrace preference criteria

Fourteen criteria of three different natures (agronomic, culinary and technological, economic) underline the choice of the sorghum landraces to be cultivated at household level in the study zone (Table 7). Among them the most important were productivity (17 % of responses), suitability for beverage (16.6 % of responses) and the quality of the dough (15.9 % of responses). The importance that producers give to these parameters in choosing landraces is not surprising as beverage and dough are major forms of sorghum

Table 6 Agronomic and culinary characteristics of the 68 units of sorghum landraces identified in the study area

Units	NFNV	Vernacular names	NKC	Agronomic and culinary characteristics
U1	2	Atchontio, Nanwéni	6	Tas, Tps, Thsm, Ear, Rdr, Thr
U2	1	Tiédati	5	Tas, Tps, Thsm, Rdr, Thr
U3	1	Ipowoun	6	Tas, Tps, Thsm, Ear, Sbe, Sad
U4	1	Kahaahè	4	Tas, Tps, Thsm, Ear
U5	1	Monmonkantinan	6	Tas, Tps, Thsm, Thr, Rsip, Sad
U6	1	Tambabano	6	Tas, Tps, Thsm, Ear, Rsip, Sad
U7	1	Sofaterma	8	Tas, Tps, Thsm, Rdr, Rst, Rsip, Thr, Sad
U8	1	Ayônio	6	Pro, Tas, Tps, Thsm, Rst, Thr
U9	1	Gnipidiaka	6	Pro, Tas, Tps, Thsm, Ear, Thr
U10	1	Kontibaamou	7	Pro, Tas, Tps, Rst, Rsip, Ear, Thr
U11	1	Bourkinasoya	10	Pro, Tas, Tps, Rdr, Rsip, Ear, Thr, Sbe, Cuq, Sad
U12	1	Dassari 2	9	Pro, Tas, Tps, Rdr, Rsip, Thr, Sbe, Cuq, Sad
U13	2	Bouwoné, Tibiètiyoti	8	Pro, Tas, Tps, Rsip, Thr, Sbe, Cuq, Sad
U14	1	Gnantagourou	9	Pro, Tas, Tps, Rsip, Ear, Thr, Sbe, Cuq, Sad
U15	1	Kouankouanbakarè	8	Tas, Tps, Rsip, Ear, Thr, Sbe, Cuq, Sad
U16	1	Sookassia	9	Pro, Tas, Tps, Rdr, Rsip, Ear, Thr, Cuq, Sad
U17	2	Daboukati, Ilapourkè	10	Pro, Tas, Tps, Thsm, Rdr, Ear, Thr, Sbe, Cuq, Sad
U18	2	Kandoualassa, Kèyoyamonnikè	9	Pro, Tas, Tps, Rdr, Ear, Thr, Sbe, Cuq, Sad
U19	2	Kouala, Yowonga	11	Pro, Tas, Tps, Thsm, Rdr, Rsip, Ear, Thr, Sbe, Cuq, Sad
U20	2	Taimpora, Taimpouorkoura	8	Pro, Tps, Rdr, Ear, Thr, Sbe, Cuq, Sad
U21	2	Kaaka, Kpankpansoya	7	Tas, Tps, Thsm, Ear, Thr, Cuq, Sad
U22	2	Tchèriè, Tchori	8	Tas, Tps, Thsm, Ear, Thr, Sbe, Cuq, Sad
U23	1	Kètcheryaakè	7	Pro, Tas, Thsm, Thr, Sbe, Cuq, Sad
U24	2	Sonipoya, Soniterya	8	Pro, Tas, Tps, Thsm, Thr, Sbe, Cuq, Sad
U25	3	Kouétifouénan, Tchanwoporika, Tchanwoterika	9	Pro, Tas, Tps, Thsm, Ear, Thr, Sbe, Cuq, Sad
U26	1	Kandouadaka	6	Tas, Tps, Thsm, Thr, Cuq, Sad
U27	1	Monmouga	7	Tas, Tps, Thsm, Thr, Rsip, Cuq, Sad
U28	2	Sodapoya, Sodaterya	5	Tas, Tps, Thsm, Thr, Cuq
U29	1	Kandouanika	9	Pro, Tas, Tps, Thsm, Rsip, Thr, Sbe, Cuq, Sad
U30	1	Tépouaga	10	Pro, Tas, Tps, Thsm, Rst, Rsip, Thr, Sbe, Cuq, Sad
U31	1	Tchorôssoya	10	Pro, Tas, Tps, Thsm, Rst, Rsip, Ear, Thr, Cuq, Sad
U32	1	Yolaperta	9	Tas, Tps, Thsm, Rdr, Tst, Ear, Thr, Cuq, Sad
U33	1	Yolawinta	10	Tas, Tps, Thsm, Rdr, Rst, Ear, Thr, Sbe, Cuq, Sad
U34	1	Soanikè	5	Pro, Tps, Ear, Sbe, Cuq
U35	1	Bouré	7	Pro, Thsm, Rbi, Rsip, Thr, Cuq, Sad
U36	4	Dassari 1, Kpérimon, Tchintchouanga, Tchintchouanga laara	8	Pro, Thsm, Rbi, Rsip, Thr, Sbe, Cuq, Sad
U37	1	Inian	7	Pro, Thsm, Rbi, Rsip, Sbe, Cuq, Sad
U38	1	Tioniti	7	Pro, Thsm, Rbi, Rsip, Thr, Sbe, Sad
U39	1	Kohounkohounbakalé	8	Pro, Thsm, Rst, Rbi, Thr, Sbe, Cuq, Sad
U40	1	Tchouangouhou	7	Pro, Thsm, Rbi, Thr, Sbe, Cuq, Sad
U41	1	Nampora	8	Pro, Thsm, Rbi, Ear, Thr, Sbe, Cuq, Sad
U42	3	Itouanssouhoun, Sonia m'gna, Sootchaagna	7	Pro, Thsm, Rsip, Thr, Sbe, Cuq, Sad
U43	4	Kouti kouti, Tiyoperti, Tiyowonti, Nagbélé	6	Pro, Rsip, Thr, Sbe, Cuq, Sad

Table 6 continued

Units	NFNV	Vernacular names	NKC	Agronomic and culinary characteristics
U44	1	Yoniwinkou	7	Pro, Tps, Rsip, Thr, Sbe, Cuq, Sad
U45	1	Yimonanmamouna	6	Pro, Tps, Thr, Sbe, Cuq, Sad
U46	1	Kalar	9	Pro, Rdr, Rst, Rsip, Ear, Thr, Sbe, Cuq, Sad
U47	1	Yêtékonyoua	8	Pro, Rdr, Rst, Rsip, Thr, Sbe, Cuq, Sad
U48	1	Tchakalakou	9	Pro, Thsm, Rst, Rsip, Ear, Thr, Sbe, Cuq, Sad
U49	1	Ilatouwôunguè	7	Pro, Tas, Rsip, Ear, Thr, Sbe, Sad
U50	1	Kaapoué	6	Pro, Ear, Thr, Sbe, Cuq, Sad
U51	1	Kawossouwossou	7	Pro, Rsip, Ear, Thr, Sbe, Cuq, Sad
U52	1	Kokem'po	5	Ear, Thr, Sbe, Cuq, Sad
U53	1	Ouyômya	6	Tps, Ear, Thr, Sbe, Cuq, Sad
U54	1	Diyokoutouoré	6	Pro, Tps, Rbi, Rsip, Thr, Sad
U55	1	Diyopéri	5	Thsm, Rbi, Thr, Cuq, Sad
U56	1	Fouannissanmou	4	Thsm, Rbi, Cuq, Sad
U57	1	Kètèounpouèkè	3	Rdr, Thr, Sad
U58	1	Yolaata	4	Rdr, Ear, Thr, Sad
U59	1	N'Sara	3	Tps, Thr, Sad
U60	1	Koniwaga	4	Pro, Ear, Thr, Sad
U61	1	Natisoyaporya	4	Rdr, Ear, Cuq, Sad
U62	1	Tapora	6	Pro, Rdr, Rsip, Thr, Cuq, Sad
U63	1	Tiotchanti	6	Pro, Rdr, Ear, Thr, Cuq, Sad
U64	1	Yopouaga	5	Rdr, Thr, Sbe, Cuq, Sad
U65	1	Koukpanan	4	Rsip, Thr, Cuq, Sad
U66	1	Kpinkpindégui	3	Rsip, Cuq, Sad
U67	1	Tchandoli	2	Rsip, Thr
U68	2	Sotakaman, Sotakaporiman	8	Pro, Tas, Tps, Thsm, Rdr, Rbi, Rst, Sad

NB: U: unit, NFNV: Number of farmer-named landraces, NKC: Number of key characteristics, Pro: Productivity, Rst: Resistant to Striga, Tas: Tolerance to all type of soil, Tps: Tolerance to poor soil, Rbi: Resistance to birds, Rsip: Resistance to storage insect pests, Ear: Earliness, Rdr: Resistance to drought, Thsm: Tolerance to high soil moisture, Thr: Threshability, Sbe: Suitability for beverage, Cuq: Culinary quality, Sad: Storage aptitude of dough

consumption in the study area and good yield has been always the first objective of all producers. Similar results were already reported on sorghum in Ghana (MacCarthy and Vlek 2012) and Kenya (Ochieng et al. 2011) and also on many other crops such as maize (Tidjani and Akponikpe 2012), teff (Asfaw et al. 2012), acha (Dansi et al. 2010) and cassava (Kombo et al. 2012), cowpea (Gbaguidi et al. 2013) and pepper (Orobiyi et al. 2013).

The nature and importance of the preference criteria generally vary throughout ethnic groups (Dansi et al. 2013b). Except farmers of the Wama ethnic group for whom earliness was the first selection criterion, high productivity was the most important criterion for the ethnic groups Berba, Bialli, Ditamari and Natimba (Table 7). For dry land agriculture and adaptation to climate variability, early maturing and drought tolerant landraces are necessary as they may have the capacity to produce considerable yield even when the rains are not sufficient or late (Ejembi and Alfa 2012). Unfortunately, very few farmers have access to such landraces mainly when they are not available in the traditional agriculture. The example of a farmer from the village Tchakalakou who grows only three sorghum landraces (Tchorôssoya, Kpankpansoya and Bawidji) among the seven available in his village clearly indicates that farmers never select randomly the landraces to grow. Their choice depends on the objective of the production and the type of soil of the fields they have. This farmer reported to have one poor field invaded by striga where only Tchorôssoya (tolerant to poor soils and resistant

Fig. 7 Panicle's peduncles woven/bound together in this particular way for conservation in granaries for seed purpose

to striga) can be cultivated. He also has a field in a lowland along a watercourse which is a bird's sanctuary. In this area, only Bawidji which is tolerant to high soil moisture and resistant to birds can be produced. Panicle of Bawidji is u-turned in such a way that it doesn't allow birds to peck at the grains after landing (their neck is not long enough). Moreover the glumes carry long eyelashes that bite the eyes of the birds when they are approaching the grains. He produces Kpankpansoya (early maturing) to avoid food shortage after a long drying season. The preference criteria hence identified and prioritized will be considered by breeders in the various sorghum improvement programs and also by the NGOs and the national agricultural extension services during diversity exchanges (Dansi et al. 2010).

Conclusion

In the study area, sorghum is facing many agronomic and environmental constraints among which the most important are striga proliferation, soil poverty and climate variability. In spite of this, sorghum diversity (including high performing landraces) in the study zone is still not negligible and there is a hope for food security and poverty alleviation if appropriate actions are taken as, this unevenly distributed diversity is greatly threatened by the negative impacts of climate change. To reduce the risks associated with these impacts and improve sorghum production, farmers adopted several strategies among which the use of early maturing and/or tolerant (drought, high soil moisture, striga, etc.) landraces and the shifting to relatively humid fertile lands. Concerted efforts should be made with all the stakeholders to develop or introduce new varieties corresponding to farmers' needs and farmers' preference criteria. For this the morphological and genetic characterization and the evaluation of the accessions of sorghum collected in

Table 7 Farmers' preference criteria of sorghum landraces and their importance across ethnics groups

Preference criteria	% of percentage responses	Rank	Rank per ethnic group				
			Berba	Ditamari	Wama	Natimba	Bialli
High productivity	17.2	1	1	1	4	1	1
High suitability for beverage	16.6	2	2	5	8	5	9
Good quality of dough	15.9	3	3	6	6	11	2
High market value	10.2	4	7	8	5	4	7
Earliness	8.8	5	4	3	1	10	3
Good quality of the porridge	7.7	6	6	2	2	2	10
Tolerance to drought	6.4	7	5	7	7	6	13
Colour and grain size	4.1	8	8	4	3	8	6
High flour percentage	3.8	9	–	10	10	–	–
Resistance to striga	3	10	–	9	11	7	8
Tolerance to soil poverty	2.3	11	–	12	12	–	12
Medicinal value	1.4	12	10	11	–	12	11
Adaptability to all types of soil	1.4	13	–	13	13	9	5
Good post-harvest storage aptitude	1.1	14	9	14	9	3	4

the study area have used appropriate markers for their sustainable utilisation.

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