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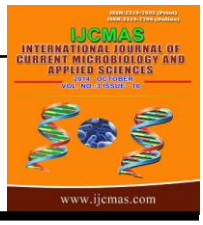

Original Research Article

Diversity, genetic erosion and farmer's preference of sorghum varieties [*Sorghum bicolor* (L.) Moench] in North-Eastern Benin

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Keywords

Preference criteria, varietal diversity, Participatory evaluation, North-East Benin, Sorghum

A B S T R A C T

Sorghum (*Sorghum bicolor* (L.) Moench) is an importance cereal crop which contributes 20 - 25% to food security and poverty alleviation in Benin. However, sorghum production is subject to various constraints. This paper aims to assess the varietal diversity, distribution and extent, the rate of diversity loss and farmers preferential criteria for adopting sorghum varieties in the North-eastern of Benin. Fifteen villages were randomly selected for the study and the data collected based on relevant questionnaire using the tools and methods of participatory research. The results showed maximum of 12 constraints in which climate change (76.34%) was rated by many farmers as the top most problem affecting the sorghum production. Based on vernacular names (local names) and subject to synonymy, medium diversity of sorghum (27 varieties) with a Shannon-Weaver diversity index (H) estimated at 2.46 bits was recorded. The number of varieties per village varied from 1 to 10 with an average of 4 varieties per village. The rate of varieties loss recorded per village varied from 0 to 100% (26.95% on average). At this rate of genetic erosion, local sorghum varieties might be vanished around 2030. There is an urgent need to conserve our valuable sorghum genetic resources through the establishment of National Genebank for Sorghum in Benin. The other reasons opined by the farmers for sorghum diversity loss are the varieties sensibility to poor soils, low productivity, bad quality of dough and *tchoukoutou* (local drink) and low market value. The most important sorghum varietal cultivation preferred by farmers' are high productivity, good culinary quality (dough and porridge) and the high market value among the 12 identified criteria. Participatory evaluation showed that few tolerant or resistant varieties for poor soils and striga were recognized. This requires the implementation of a national program for sorghum improvement and breeding to identify high-performance varieties adapted to soil and climatic conditions.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is a cereal plant member of the family of Poaceae (Adeyeye and Adesina, 2013). It is the fifth important cereal in the world after maize, rice, wheat and barley (Sher et al. 2013) with a worldwide production

estimated to 60 million tons per year on cultivated area of 46 million hectares (FAO, 2011). Sorghum is the main source of energy for millions of people (Adeyeye and Adesina, 2013; Sher et al. 2013) who grow it in arid and semi-arid environments where rainfall does not encourage economic production of maize or other crops that require almost twice as much water (Trouche et al. 2008). This cereal represents approximately 21% of cereal production in Benin after maize (FAO, 2011) and is principally grown in Northern Benin (Missihoun et al. 2012; Dossou-Aminon et al. 2014). In this region and in 2001, the ministry of Agriculture reported (MAEP, 2011) an annual production of 60,691 tons, 27,698 tons and 20,517 tons for the departments of Alibori, Atakora and Borgou. In the above mentioned areas, sorghum is one of the most important cereals that provide a variety of food and income to households (Trouche et al. 2008; Desobgo et al. 2013). It is used in the preparation of the dough and porridge (Kayodé et al. 2011), manufacture of infant flour (Sanoussi et al. 2013), production of traditional opaque beer (Kayodé et al. 2011) and soft drinks (Kayodé et al. 2011). Sorghum is also used for industrial malting and brewing purposes, feed manufacture and ethanol distillation (Kayodé et al. 2011; Desobgo et al. 2013; Kimani et al. 2014).

In spite of its food, economic and industrial importance, sorghum production in Benin is constrained by several, poorly documented, biotic and abiotic factors that are threatening its diversity and production (Dossou-Aminon et al. 2014). Notwithstanding sorghum constraints, very little studies had been conducted in Benin on the factors that influence sorghum production, the status of varietal diversity, the distribution and extent of the varieties and the rate of diversity loss. Recent studies revealed the existence of a certain number of sorghum varieties in the departments of Donga (fourth production zone) (Missihoun et al. 2012) and Atakora (Dossou-Aminon et al. 2014). While knowledge of sorghum diversity remains a prerequisite for effective implementation of on-farm conservation strategies and for development of new varieties no data is available on sorghum diversity and production constraints in the other departments of northern Benin (Dansi et al. 2013a; Loko et al. 2013a). Each variety of sorghum has its unique agronomic, culinary and technological traits that are intrinsic to it. Documentation and identification of high-performance varieties based on farmer's varietal preference criteria in this present study will provide strategies to overcome constraints affecting sorghum production and productivity.

The objectives of this study were fourfold:

1) Prioritize constraints associated with sorghum production in the north east of Benin;
2) Assess the diversity, distribution and extent of cultivated varieties;
3) Document farmers' varieties preference criteria for use in breeding and extension programs;
4) Evaluate, in participatory way, existing varieties for their agronomic, culinary and technological characteristics

Material and methods

Presentation of the study area

The study was conducted in the Departments of Borgou and Alibori located in the Northeast of Benin. The area is bounded at the North by the Republic of Niger, in the South by the Department of Collines, in the North-west by Burkina Faso and the Departments of Atakora and Donga and in the East by the Federal Republic of Nigeria

(Figure 1). Seven ethnic groups (*Bariba, Boo, Gando, Mokolés, Nago, Peulh* and *Dendi*) dominantly occupy this study area. The climate is tropical, characterized by a dry season and a rainy season with an annual rainfall varying from 805 to 1200 mm (Adomou, 2005; Vissin, 2007).

Site selection and data collection

Fifteen villages were randomly selected from different ethnic areas within the districts (Loko et al. 2013a). Data were collected using tools (questionnaires) and methods (group discussions, individual interviews and field visits) of participatory research appraisal following Dansi et al. (2013a). For the group discussions, 20 to 40 sorghum producers of both sexes (male and female) and different ages were identified and assembled per village, as described by Kombo et al. (2012). In each village, a local translator was selected to help and facilitate in data collection, interview and exchanges with producers according to Loko et al. (2013a). In group and after an exhaustive presentation of the research objectives to the farmers, information relative to the geographical situation (district, village and ethnic group) were first collected.

During the survey, farmers were asked to list, in local language, the major constraints that affect sorghum production in their village or locality. Reported constraints were prioritized in groups by identification and gradually elimination of the most severe one following Dansi et al. (2013b). Farmers were also asked to list (vernacular names) and display (panicles and/or seeds samples) the sorghum varieties they produce. Passport data as well as the meaning of the vernacular names, the origin and maturity cycle were collected on each variety following Sorghum descriptors (IBPGR/ICRISAT, 1993).

The distribution and extent of sorghum cultivar were evaluated using Four cell Analysis method (Kombo et al. 2012; Loko et al. 2013a). This technique helps to classify on participatory way and at the community level, existing varieties into four groups (varieties cultivated by many households on large areas; varieties cultivated by many households on small areas; varieties cultivated by few households on large areas and varieties cultivated by few households and small areas) and to document the reasons that justified the production of each variety by many or few households in one hand and on large or small areas in the other (Dansi et al. 2010; Loko et al. 2013a). The surveys provided names of varieties that have completely disappeared and reasons justifying their abandonment.

The agronomic, technological and culinary performance of the recorded varieties was carried out using participatory research appraisal described by Dansi et al. (2013a). On group basis, 9 agronomic (productivity, tolerance to striga, drought tolerance, adaptability to all types of soil, tolerance to poor soil, resistance to bird, tolerance to storage insect pests, tolerance to high soil moisture, earliness), 2 technological (threshability, suitability for beverages) and 3 culinary (porridge, dough quality and storability) characteristics were recorded using the two levels (0 and 1) scoring scale described by Gbaguidi et al. (2013). In this approach, varieties were given a score of 1 when it is unanimously recognized as high-performance (very good / resistant / tolerant) and 0 when not (Table 1).

In each surveyed village, 20 producers of sorghum (male and female) were randomly selected after group discussions for individual interviews. Pairwise comparison or Matrix scoring technique) were used, at

individual basis, to identify and prioritize farmers' preference criteria following (Teshome et al. 2007; Dansi et al. 2010; Kombo et al. 2012). To assess the morphological diversity among sorghum varieties base on panicles and seeds, panicles collected from farmers' granaries or fields according to Moss and Guarino (1995) were described with farmers before packaging. In this exercise, 8 key qualitative traits of panicle an grains (panicle density at maturity, glume colour, glume hairiness, threshability, glume length, grain shape, number of grains per glume, grain colour) commonly used by farmers to describe and classify their sorghum varieties were considered. Also, six quantitative traits (panicle length, length of principal raceme internodes, grain size, panicle width, panicle weight, and 100 seed weight were measured to search for significant correlations useful for breeding programs.

Statistical Analyses

Collected data were analyzed by descriptive statistics (frequencies, percentages, means, etc.) to generate tables and figures using SAS software (SAS Institute 2008 version 9.2). The rate of varietal loss (RVL) at village level was calculated using the formula described by Kombo et al. (2012) and Loko et al. (2013a). RVL = (n-k)/N x 100 where n is the number of varieties cultivated by few households on small areas; k is the number of newly introduced varieties among those cultivated by few households on small areas and N is the total number of varieties recorded in the village.

Shannon-Weaver diversity index (H) was calculated following Shannon and Weaver (1948). The level of sorghum diversity in the study area was assessed with the scale ($0.5 \leq H \leq 4.5$) used by Fanget et al. (2012).

To analyse the relationship between the identified varieties in terms of agronomic, culinary and technological performances, these were taken as individuals and the evaluation parameters used as variables and scored 1 where applicable and 0 if not. The binary matrix compiled was used to design through NTSYS-pc 2.2 (Rohlf, 2000) a dendrogram with UPGMA (Unweighted Pair-Group Method with Arithmetic Average) cluster analysis (Sokal and Sneath 1973; Swofford and Olsen 1990). The same statistical analysis approach (dendrogram) was used to classify varieties based on the morphological attributes of their panicles. Simple Pearson coefficients of correlation were computed between pairs of quantitative morphological variables using STATISTICA software, version 6.0 (Statsoft Inc., 2001).

Result and Discussion

Constraints related to sorghum production in Northeastern Benin

Twelve constraints were identified as affecting sorghum production in Northeastern Benin (Table 2). They were in majority (76.34%) directly or indirectly related to the effects of climate variability. Among these, the fluctuation of the rainy seasons (20.33% of responses) was the most important followed by drought (17.33% of responses), poor soils (16% of responses), proliferation of weeds (9.35% of responses) and low productivity (9.33% of responses). Low market value appeared as the less important constraint (0.98% of responses) in the study area (Table 2).

Diversity of sorghum varieties in North-eastern Benin

Throughout the 15 villages surveyed and subject to synonymy, a medium sorghum diversity was found (total of 27 varieties)

with a Shannon-Weaver diversity index (H) estimated at 2.46 bits. The number of varieties varied from 1 to 10 with an average of 4 per village. The number of early maturing varieties varied from 0 to 6 and the number of late maturing varieties varied from 0 to 5 with respectively 1 and 2 varieties on average (Table 3). The lowest diversity (1 variety) was observed at Agramarou, Djéga and Sékalé and the highest diversity of 10 and 9 varieties are observed in Binassi and Sompérékou respectively (Table 3).

In North-eastern Benin, an average of one variety is cultivated by many households on large areas (Table 3). According to the farmers, these varieties are characterized by high productivity, earliness, drought tolerance, poor soils tolerance, resistance to striga, good culinary quality and high market value. Varieties Dobi sinsou, Faribohounbo, Maliri, Sowoundobi and Tôkôgbéssénou are mainly cultivated to meet the market demand (Table 4). Very few varieties (average 2 varieties per village) are cultivated by few households on large areas. Their seeds are uncommon or newly introduced but with high productivity, good culinary quality, early maturing, resistant to stress and high market value. The example of Daniri gouda, Dinari, Essé wa téan, kantohounti and tanhounpouaga is given in Table 4. Finally only one variety on average is cultivated per village by few households on small areas (Table 3). These varieties showed low productivity, sensitive to drought, striga and poor soil, bad culinary and beverages quality, very little demand on the market, but cultivated for feed, fodder, medicinal use or are newly introduced (Table 4). Except those that are newly introduced, these varieties are threatened or being disappeared. Example of the variety Kloklorou binyirou "means two grains in a glume" also called "twin *sorghum"* cultivated for traditional ceremonies of twins' naming ceremony.

The generic name of sorghum varies according to the ethnic groups. Sorghum is called *Dobi* in Bariba, *Essé* in Boo, *Iya* in Mokole, *Ibaba* in Nago, *Gaouri* in Gando and Peulh. Each community used series of vernacular names to identify different varieties of sorghum. . Through the villages and subject to synonymy, 27 landraces varieties of sorghum have been recorded. The distribution and extent of these local varieties varies through villages. For example, the variety Dobi kpika that is cultivated by few households and on large areas in the village Guinagourou was found with few households and on small areas in the village Gokana. Maliri is cultivated by many households and on large areas at Sompérékou, but by few households and on small areas in the village Sékalé (Table 5).

In the 15 villages surveyed throughout the study area, the rate of the threatened varieties (genetic erosion) varied from 0% in the villages of Agramarou, Badou, Djéga, Guinangourou, Kokabo and Ouari to 100% in Sékalé with an average of 26.95% (Table 3). The number of completely abandoned varieties varied from 2 to 5 per village with, subject of synonymy, a total of 26 for the study area (Table 6). Varieties Dobi tobe, Bipimounou, Gbango, Kounouyirou and Kaanma were reported as completely disappeared in the villages Binassi, Sompérékou and Ouari (Table 6). The reasons listed by farmers as underlying the loss of sorghum varieties across villages were mainly agronomic (60.76% of responses), culinary (31.36% of responses) and economic (7.88% of responses). Susceptibility of varieties to poor soils (Kaanma), lower productivity (Dobi tobé), poor quality of the dough (Kounouyirou) and *tchoukoutou* (Bipimounou) and low

market value (Gnérégou) were the farmers reported main reasons of sorghum genetic erosion in the study area study (Table 7).

Morphological variability of accessions

Farmers use a set of key morphological traits (panicles shape, glume colour, hairiness and length, threshability, grain shape, colour, and number per glume, to identify the varieties. The dendrogram constructed with UPGMA method using the key morphological parameters of the panicles of 28 sorghum accessions collected from farmers revealed 24 morphological types (Figure 2) with some identities. Hence, accessions Dinari A and Dinari B in one hand Koussoubôkou and Daniritata in the other hand are for example identical (Figure 2) while the twin seeded variety Kloklorou binyirou was completely detached from all the other accessions due to the presence of two grains in its glume.

The correlation coefficients of the six quantitative traits of accessions showed significant positive correlations at $p < 0.05$ between the ear head width and panicle weight and the weight of 100 seed (Table 8).

Farmers' preference criteria of sorghum varieties

A total of twelve preference criteria were identified throughout the fifteen surveyed villages. The most important were high productivity (32.35% of responses), good quality of dough and porridge (29.11% of responses), high market value (12.67% of responses), resistance to storage insects (5.93% of responses) and resistance to drought (5.93% of responses). Precocity appears as the preference criterion of less importance in the study area (Table 9). The type and importance of varieties preference criteria varied among ethnic groups. In Bariba, Gando and Mokole ethnic area, the main criteria for varietal selection were high productivity and good quality of dough and porridge while with the Nago and Peulh, the high market value of varieties is their main preference criterion (Table 9). Whereas all the twelve criteria were listed in the Bariba ethnic area, only six were recorded with Mokole, five with Nago, four with Boo and Gando and two have with the Peulh ethnic group.

Farmers' participatory evaluation of sorghum varieties

Twenty-seven sorghum varieties (Subject to synonymy), were identified throughout the villages surveyed (table 5) and evaluated for fourteen agronomic, technological and culinary parameters. among them, 25, 24 and 23 varieties were found easy to thresh, 25,gives a good quality of tchoukoutou (local sorghum beer), 24 were highly productive and 23 were of good culinary qualities (Figure 4). Only few varieties were resistant to birds (3 varieties), tolerant to poor soils (5 varieties) and to striga (5 varieties).

At 68% of similarity, the different sorghum varieties appeared organized into four clusters C1, C2, C3 and C4 (Figure 5). Cluster C1 groups varieties that are highly productive, tolerant to all types of soil (gritter, clayey and grit spreader) but susceptible to poor soils and birds damage. Cluster C2, assembles varieties that are tolerant to high soil moisture and have good culinary and beverage qualities; its dough does not liquefy quickly and it is easily to thresh but very susceptible to striga and poor soils. C3 clusters together the early maturing varieties with good culinary and beverage qualities and easy to thresh but susceptible to striga, drought, high soil moisture and birds and cultivated on a specific soil. Cluster C4 contains the early maturing

varieties with a high productivity, resistant to striga and storage insects, good culinary qualities. However, they are sensitive to the high soil moisture and birds' damage and their dough get quickly liquefied (poor storability).

Gender role in sorghum production

In the Departments of Borgou and Alibori, the activities related to the production of sorghum are distributed by sex (Figure 3). Seed selecting is an exclusively male activity (100% of responses). Activities such as plowing and stem cutting that require a lot of energy are also of more men prerogative (88.24% of responses). On the other hand, activities such as sorting and processing are more women work (Figure 3).

In the north east of Benin, sorghum ensures food security and constitutes an important source of income for rural populations. Unfortunately, many factors negatively affect its production. The main constraints affecting sorghum productions in the study area were related to climatic, as was the case in the Department of Atacora (Dossou-Aminon et al. 2014). The variation of rainfall, drought, poor soil and unexpected rain excess reported by producers indicates a strong impact of climate change on sorghum production. Similar observations were made on corn (Tidjani and Akponikpe, 2012), yam (Loko et al. 2013b) and sorghum (Dossou-Aminon et al. 2014) in Benin. Soil impoverishment may be associated with the sole crop practice on the same soil for many years. In addition, abusive use of fertilizer to improve soil yield decrease considerably the performance of the land when the fertilizer was not used the next crop year for the same land. Proliferation of weeds such as striga is also a major constraint. The unpredictability of rainy season completely disturbs mass production of sorghum and contributes to the abandonment of the crop in favor of other more suited to rain disturbance (Bertrand et al. 2011). The poor post-harvest storability of the grains is closely related to the lack of effective conservation systems against storage insects. To face agronomic, biotic and environmental constraints, research for development must investigate the improvement of farming practices and promote the use of adapted varieties (Dansi et al. 2013b).

The diversity study revealed (subject of synonymy) 27 sorghum varieties throughout the fifteen surveyed villages. This showed that the area has a medium diversity of sorghum by reference to the value of the diversity index of Shannon-Weaver observed. However, this diversity is very low compared to that observed in the Department of Atakora (second production zone) by Dossou-Aminon et al. (2014). In Agramarou, Djéga and Sékalé villages only one variety of sorghum was under cultivation. According to the producers of Sékalé, sorghum varieties were late maturing than maize and cotton and thus economically less profitable for farmers. Therefore it is very urgent to strengthen sorghum diversity in these regions through the introduction of very early maturing and high yield varieties. On the other hand, for the producers of Agramarou and Djéga, the only one variety under cropping is that has the best market value and are very expensive and not expected in market. According to the farmers, red grains sorghum is more demanded in the market than white grains. So the production in this study area is oriented to the external request (red grain) and this could explain the state of cultivated diversity which tends to standardize or to reduce (Barnaud et al. 2007). The high varietal diversity of sorghum observed at Binassi and Sompérékou is not surprising

given their localization in relation to both the Federal Republic of Nigeria and the Department of Atakora which has large potential in terms of sorghum diversity (Dossou-Aminon et al. 2014, Vange et al. 2014). This proximity favors the introduction of new varieties or facilitates varietal exchanges. According to Baco et al. (2004), the production of varieties with different maturity cycles (early to late maturing) allows farmers to space the harvest in the time and thus have food available until the new harvest.

Generally in North easte of Benin, varieties cultivated by many households and on large areas are those having high market value, high productivity and good culinary and beverage qualities. In agreement with Mbabwine et al. (2008), the race for high yields using varieties with good agronomic performances leads to the abandonment and extinction of varieties with low agronomic performance. This has been proven by several studies on the diversity of yam in Benin showing that a small number of varieties occupy most of the cultivated area (Vernier and Dansi, 2006; Loko et al. 2013a). Most farmers prefer and favor varieties with high productivity and adapted to the food processing and eating habits as well as current soil and climatic conditions of their areas. In some villages, many varieties of sorghum are cultivated by few households because they are inefficient. The rate of varietal diversity loss recorded showed that many varieties are disappearing in the study area hence indicating a need to establish *in situ* and *ex situ* conservation program for both present and future generations. The rate of 100% diversity loss observed in the village of Sékalé doesn't means that no variety exist but indicates that that are all being disappeared and this could also be the reason of the advancement of the desert from Republic of Niger to Northern of Benin. The rate of diversity loss zero per cent recorded in some villages doesn't also mean better diversity conservation. According to the farmers, this represents the final result of selection of the few varieties that are really suitable or adapted to their actual agroecological conditions. Similar results were obtained on yam (Dansi et al. 2013, Loko et al. 2013), cowpea (Gbaguidi et al. 2013), cassava (Kombo et al. 2012), and chili (Orobiyi et al. 2013). The preliminary morphologically characterization of panicles yielded 24 different types of sorghum varieties with some identities. This indicates as expected, that some duplicates do exist in the diversity recorded based on local names and therefore sound morphological and molecular characterizations are required for clarification. Knowledge of the correlations between traits is important in breeding programs. However, the results here obtained should be considered as preliminary as they need to be confirmed by more complete agro-morphological characterization through the use of recommended qualitative and quantitative descriptors of sorghum as reported by many authors (Djè et al. 2007; Mujaju and Chakauya, 2008; Chantereau et al. 2010; Ali et al. 2011; Rakshit et al. 2012; Elangovan et al. 2013).

High productivity as the main criterion of sorghum varieties preference is not surprising as it is for all farmers the first key criterion sought-after. In the specific context and according to the explanations of producers, the market demand for food consumption stands first followed by good culinary quality as second criterion. This clearly explained the fact that sorghum is primarily grown for food and the adoption of a new variety will depend mainly on it culinary quality, which was appraised by the dough and beverage quality.

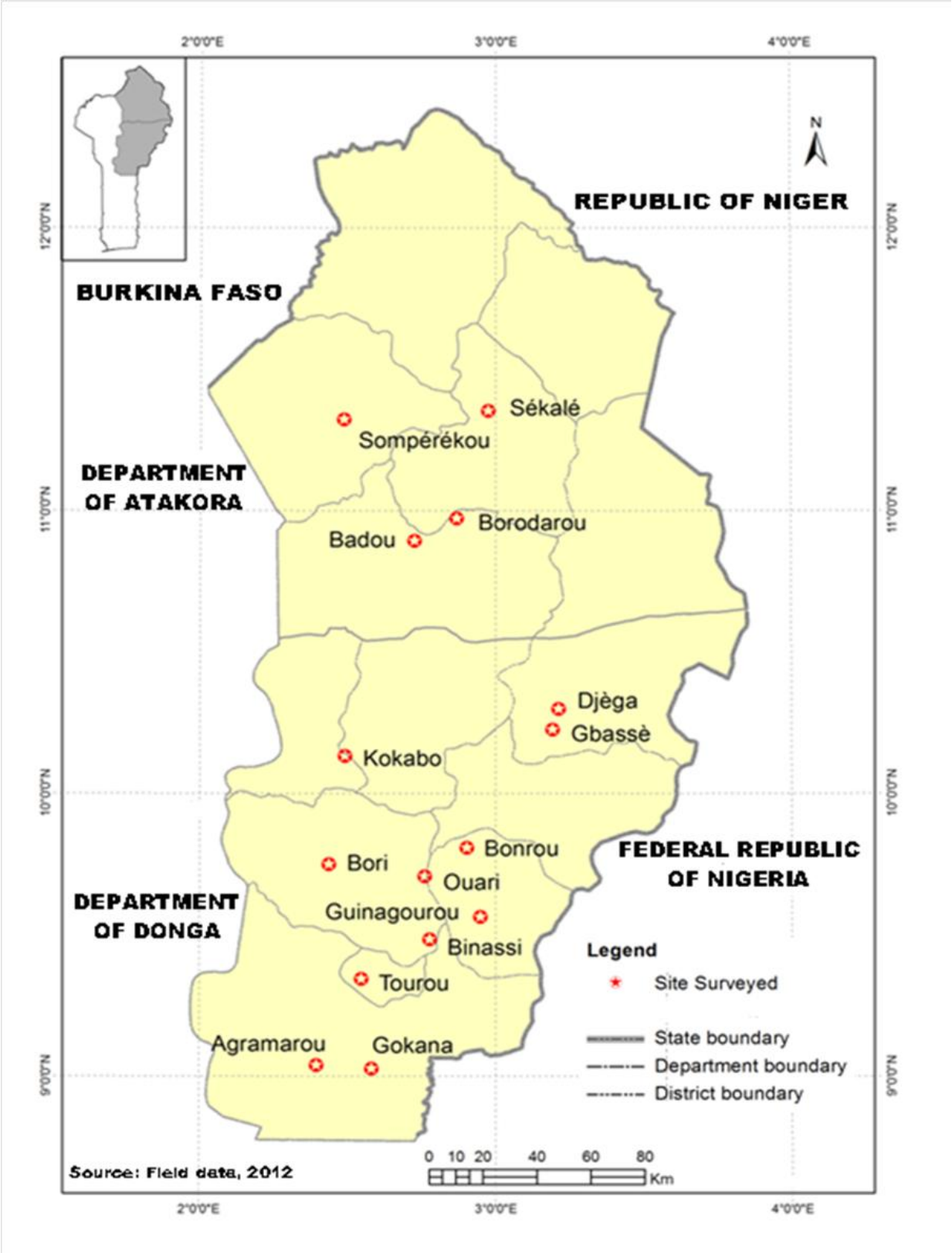

Figure.1 Map of Departments of Borgou and Alibori showing the villages surveyed

Table.1 Parameters used for the participatory evaluation of sorghum varieties

Categories of variable	Evaluation parameters	Scoring level
Agronomic	Productivity	High (1) – Low (0)
	Resistance to striga	Resistant (1) – Susceptible (0)
	Drought resistance	Tolerant (1) – Susceptible (0)
	Tolerance to all type of soil	No selective (1) – Selective (0)
	Tolerance to poor soils	Tolerant (1) – Susceptible (0)
	Resistance to Bird	Resistant (1) – Susceptible (0)
	Resistance to storage insect pests	Resistant (1) – Susceptible (0)
	Earliness	Early (1) – Late (0)
	Tolerance to high soil moisture	Tolerant (1) – Susceptible (0)
Technological and Culinary	Threshability	Easy (1) – Difficult (0)
	Storage aptitude of the dough (liquefaction)	High (1) – Low (0)
	Suitability for beverage	Good (1) – Bad (0)
	Culinary quality (dough and porridge)	Good (1) – Bad (0)

Table.2 List and importance of sorghum production constraints in the North-East Benin

Constraints	Percentage of responses (%)	Rang
rainfall variability	20.33	1
Drought	17 .33	2
Soil poverty	16	3
Proliferation of weeds (Striga)	9.35	4
Low productivity	9.33	5
Unexpected excess of rain	6.67	6
Pests and diseases damages (stem borers, termites, bacterial blight, etc.)	6.66	7
Poor post-harvest storage aptitude	5.33	8
Lack of arable land	4	9
Birds damages	3.02	10
Compactness of soil	1.33	11
Lack of organized market and low of the market value	0.98	12

Table.3 Diversity, earliness, distribution, extent and rate of diversity loss of sorghum varieties in the study area

Villages	TNV	NEV (4 Months)	NLV (5 Months)	NVLV (≥6 Months)	Distribution and extent			NNV	RVL (%)
					H+ A+	H- A+	H- A-		
Agramarou	1	1	0	0	1	0	0	0	0.00
Badou	2	1	1	0	1	1	0	0	0.00
Binassi	10	7	1	2	2	3	5	1	40.00
Bonrou	2	2	0	0	1	0	1	0	50.00
Bori	4	3	1	0	1	2	1	0	25.00
Borodarou	4	2	2	0	2	1	1	0	25.00
Djéga	1	0	1	0	1	0	0	0	0.00
Gbassè	7	2	0	5	1	5	1	0	14.29
Gokana	2	2	0	0	1	0	1	0	50.00
Guinagourou	4	3	1	0	1	3	0	0	0.00
Kokabo	2	1	1	0	1	0	1	1	0.00
Ouari	3	1	2	0	2	1	0	0	0.00
Sékalé	1	0	1	0	0	0	1	0	100.00
Sompérékou	8	4	3	1	2	4	2	0	25.00
Tourou 4	4	4	0	0	1	0	3	0	75.00
Mean	**3.66± 2.71**	**2.20±1.82**	**0.93±0.88**	**0.53±1.35**	**1.20± 0.56**	**1.33±1.67**	**1.13± 1.35**	**0.13± 0.35**	**26.95± 30.94**

TNV, Total number of varieties; NEV, Number of early maturing varieties; NLV, number of late varieties; NVLV, Number of very late varieties; 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; NNV, Number of Newly varieties; RVL, Rate of varieties loss.

Table.4 Justification of the distribution and extent of selected varieties

Distribution and extent	Landraces varieties names	Justification
Many households and large area	Dobi sinsou	High productivity
	Dobi souin faa	Earliness
	Dobi wonka	Tolerant to drought
	Essé téan gban	Resistant to Striga and poor soil
	Faribohounbo	Adaptability to all type of soil
	Sowoundobi	High economic value
	Koussoubôkou	Good culinary and beverage quality (dough,
	Maliri	porridge and *tchoukoutou*)
	Tôkôgbéssénou	Resistant to birds damages
		Good post-harvest conservation
Few households and large area	Daniri gouda	Rare variety
	Daniri tata	Newly introduce (Lack of seeds)
	Dinari	high productivity
	Essé wa sia	Good culinary and beverage quality High
	Essé wa téan	market value
	Kantohounti	Earliness
	Lélémouannin	Tolerant to drought
	Tanhounpouaga	Resistant to Striga and poor soil
Few households and small area	Dobi pkika	Low productivity
	Essé sia	Susceptible to drought
	Ibadi	Very susceptible to soil poverty and Striga
	Kloklorou	Bad culinary quality
	binyirou	Bad quality of beverage
	Kohounkohoun	Low market value
	bakalé	Difficult to thresh
	Lidjoali	Medicinal utilisation
	Soara	Good for feed
		Newly introduce

Table.5 Distribution and extent of sorghum varieties recorded in the North-East Benin

N°	Vernacular names	Earliness (Month)	Collected site, distribution and extent
1	Daniri gouda	4	Gbassè (- +)
2	Daniri tata	4	Gbassè (- +)
3	Dinari	6	Sompérékou (- +)
4	Dobi pkika	4	Badou (- +) ; Bonrou (- -) ; Bori (- -) ; Gokana (- -) ; Guinagourou (- +) ; Ouari (- +) ; Tourou 4 (- -) ; Sompérékou (- -)
5	Dobi sinsou	4	Binassi (- -); Guinagourou (+ +) ; Gokana (+ +) ; Tourou 4 (- -)
6	Dobi souin faa	6 to 7	Guinagourou (- +) ; Binassi (+ +) ; Bori (+ +) ; Tourou 4 (+ +) ; Bonrou (+ +) ; kokabo (- -)
7	Dobi souin sako wonkoussou	6	Binassi (- +)
8	Dobi wonka	4	Agramarou (+ +) ; Binassi (- -)
9	Essé poua guéssénan	7	Gbassè (- +)
10	Essé sia	6	Gbassè (- -)
11	Essé téan gban	7	Gbassè (+ +)
12	Essé wa sia	6	Gbassè (- +)
13	Essé wa téan	6	Gbassè (- +)
14	Sowoundobi	4	Binassi (+ +) ; Bori (- +)
15	Faribohounbo	4	Sompérékou (+ +)
16	Ibadi	6	Binassi (- -)
17	Kantohounti	4	Binassi (- +)
18	Kloklorou binyirou	5	Sompérékou (- -)
19	Kohounkohoun bakalé	5	Binassi (- -)
20	Koussoubôkou	4	Borodarou (+ +); Sompérékou (- +)
21	Kpika guia	4	Binassi (- +) ; Sompérékou (- +)
22	Lélémouannin	5	Guinagourou (- +)
23	Lidjoali	4	Binassi (- -)
24	Maliri	5	Djéga (+ +) ; Borodarou (+ +) ; Ouari (+ +) ; Kokabo (+ +) ; Sompérékou (+ +) ; Bori (- +) ; Sékalé (- -)
25	Soara	4	Tourou 4 (- -)
26	Tanhounpouaga	4	Borodarou (- +)
27	Tôkôgbéssénou	5	Sompérékou (- +) ; Badou (+ +) ; Borodarou (- -) ; Ouari (+ +)

Table.6 Number and vernacular names of the disappeared varieties in selected villages surveyed

Village	Number of disappeared varieties	Vernacular names of varieties
Binaasi and Guinangourou	4	Dobi tobé; Dobi pkiki; Yéroukou dobi; Bipimounou
Sompérékou	5	Gnérégou ; Gbango ; Biêdàwou ; Ibérèyinsi ; Kounouyirou
Ouari	2	Kaanma ; Maré dobi
Bori	2	Dobi pkiki, Dobi sourérou
Bonrou	2	Sakourago ; Gounkôbourou
Gokana	2	Dobi pkéssa ; Dobi kpikikira
Kokabo	2	Dobi sourérou ; Orougosindé
Agramarou	2	Babafounfoun ; Edjêêfàn
Sékalé	3	Angbodoundoun ; Angbofounfoun ; Angbounpka
Djéga	2	Kôwônlaari ; Poura
Badou	2	Maanisouanrou ; Yigouyinm

Table.7 Principal reasons for loss of varietal diversity throughout villages

Categories of reasons	Reasons	Percentage of responses (%)
Agronomic (60.76%)	Susceptibility to soil poverty	15.68
	Low productivity	13.72
	Bad post-harvest conservation	7.84
	Susceptibility to the drought	7.84
	Susceptibility to Striga	7.84
	Difficulty to thresh	3.92
	Susceptibility to birds	3.92
Culinary and technological (31.36%)	Bad quality of the dough	14.68
	Bad quality of the *tchoukoutou (local beer)*	10.80
	Dough bitterness	5.88
Economic (7.88%)	Low market value	7.88

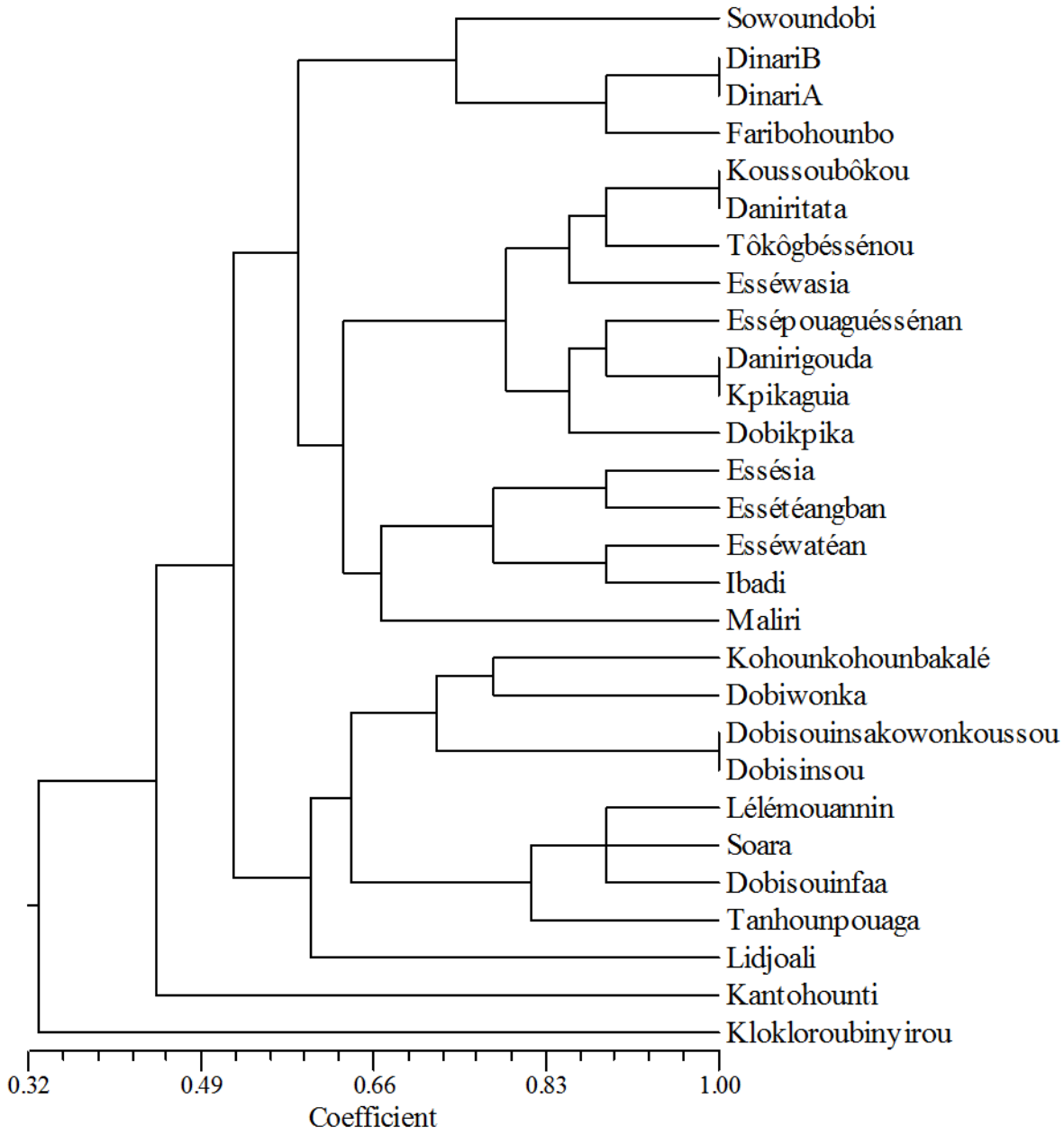

Figure 2: Dendrogram showing 24 morphotypes constructed with UPGMA method in basis of nine morphological key traits used by farmers to identify panicles of sorghum varieties in the study area

Table.8 Correlation between six quantitative key traits of panicles of sorghum accessions collected through the survey

	Panicle length	Length of raceme internodes	Grain size	Panicle width	Panicle weight	100 seed weight
Panicle length	1.00					
Length of raceme internodes	**0.62**	1.00				
Grain size	**0.47**	0.25	1.00			
Panicle width	**0.55**	0.20	0.31	1.00		
Panicle weight	**0.50**	0.08	0.21	**0.64**	1.00	
100 seed weight	0.26	0.20	0.28	0.34	**0.43**	1.00

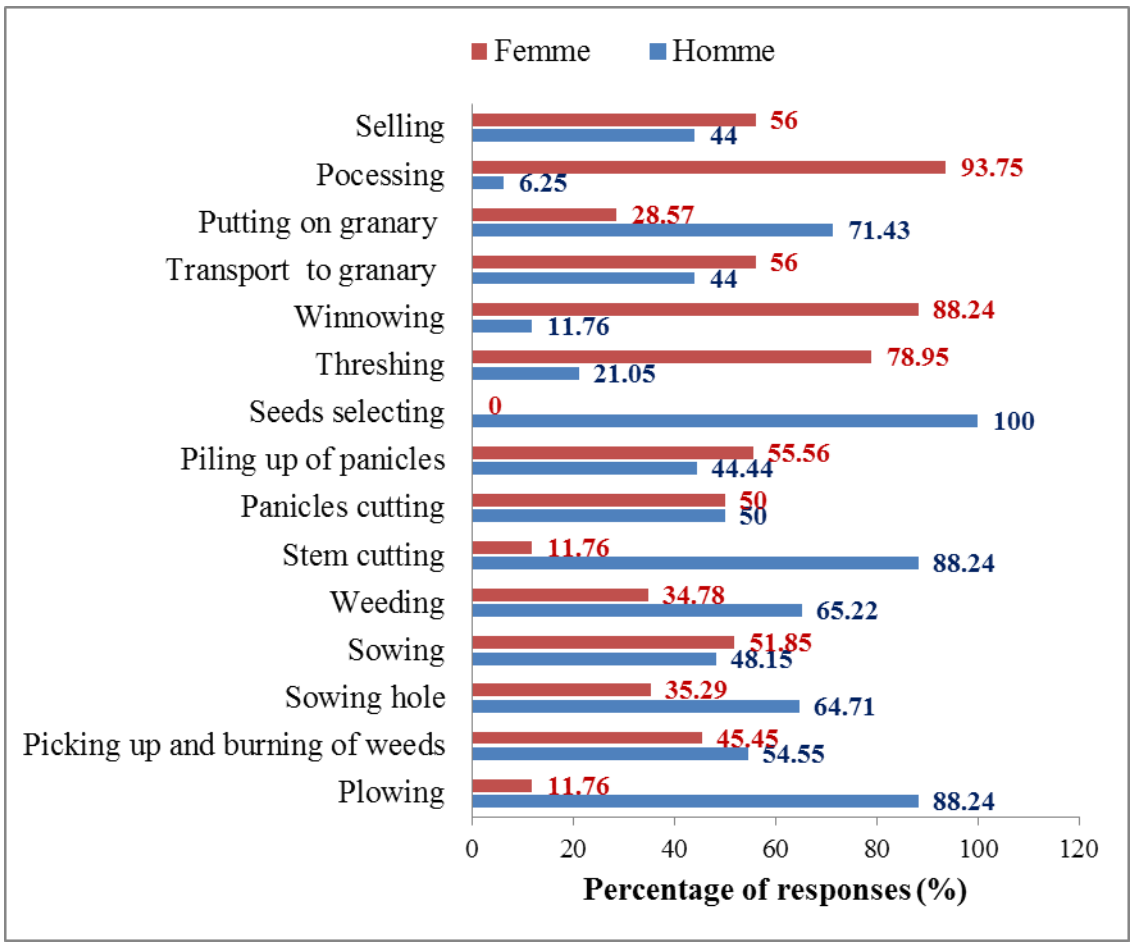

Figure.3 Gender role in sorghum production in the study area

Table.9 Farmers' sorghum varieties preference criteria and their importance across ethnic groups

Preference criteria	Percentage of responses (%)	Rank	Rang per ethnic groups					
			Bariba	Boo	Gando	Mokolé	Nago	Peulh
High productivity	32.35	1	1	-	1	2	3	-
Good quality of the dough and porridge	29.11	2	2	-	2	1	2	2
High market value	12.67	3	3	-	-	6	1	1
Resistant to the storage insects	5.93	4	4	-	3	-	-	-
Resistant to the drought	5.93	5	5	-	-	5	-	-
Adaptability to poor soils	4.32	6	9	1	-	4	4	-
Resistant to Striga	3.5	7	6	4	4	-	-	-
High suitability for beverage	2.43	8	7	-	-	3	-	-
High flour yield of grain	1.89	9	10	3	-	-	-	-
Facility of thresh	0.81	10	8	-	-	-	5	-
Adaptability to all type of soil	0.54	11	11	-	-	-	-	-
Earliness	0.52	12	12	2	-	-	-	-

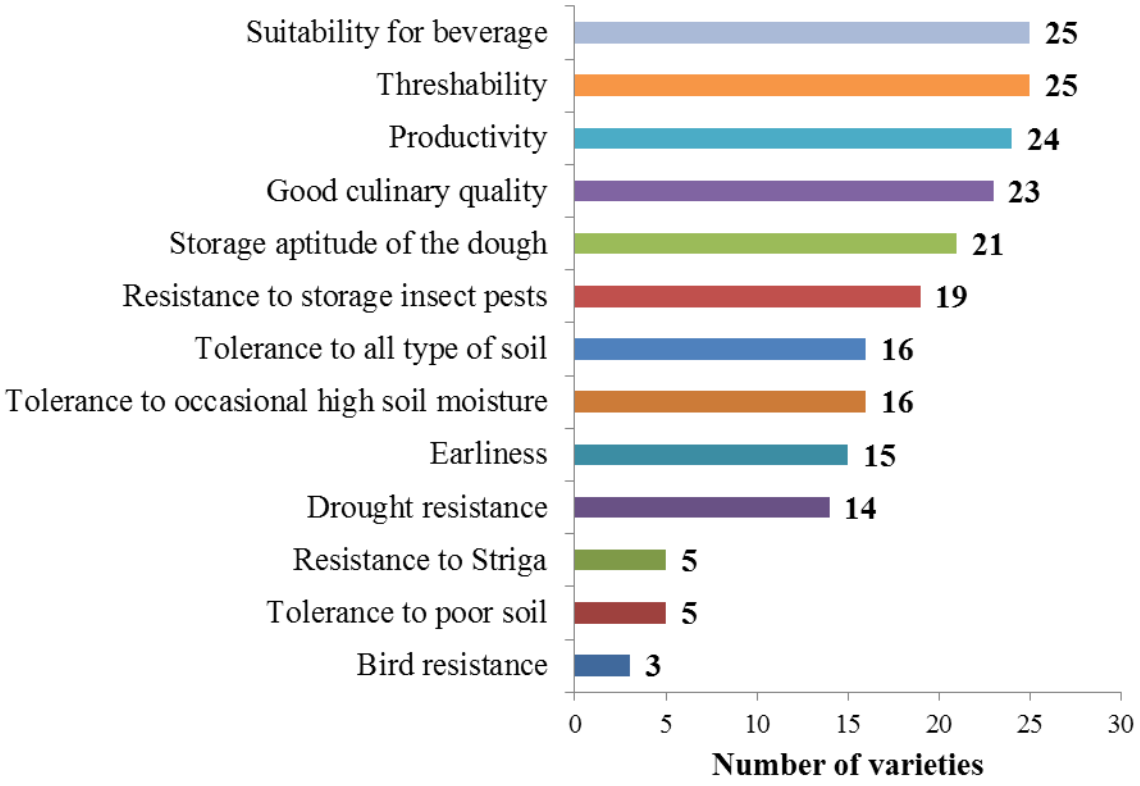

Figure 4: Number of high performing sorghum varieties identified per parameters of agronomic and economic importance through participatory evaluation

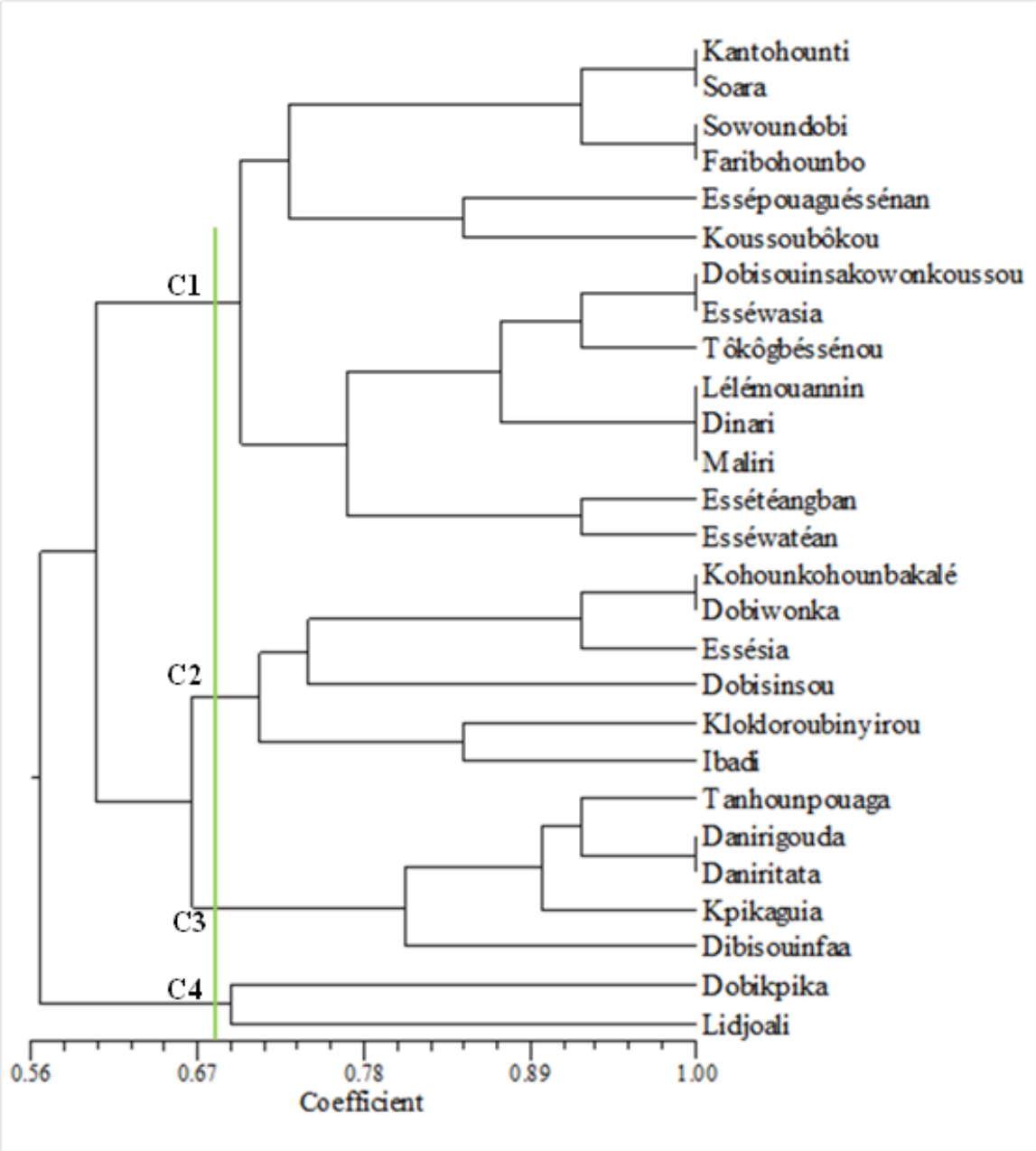

Figure 5: Classification of sorghum varieties with UPGMA method using agronomic, technological and culinary traits identified by participatory evaluation

The high market value as third criterion in the study area and first in Nago and Peulh ethnic groups showed how often the market influences sorghum production and diversity in these two Departments. Although the position (fifth criterion) of the resistance to drought was not expected due to the importance of climate variability in this area, it represents a strong indication of the necessity to develop and popularize sorghum varieties resistant to drought (early maturing or physiological resistance) and adapted to actual soil and climatic conditions (Dugue,

2012). Farmers interviewed were not aware of the existence of early maturing varieties of 2 to 3 months as observed throughout participatory evaluation in the Department of Atakora (Dossou-Aminon et al. 2014) but they have some of 4 months. The Pools of high-performance varieties identified throughout the participatory evaluation can be directly used in a varietal exchange programs to enhance diversity in many villages of the study area. Taking into account farmer's preferential criteria as it was the case for yam in Benin (Dansi et al. 2013b).

In North-eastern of Benin, sorghum is subject to many biotic and abiotic stresses which were mainly related to climate change. These constraints led to low productivity and loss of several varieties. Subject to synonymy, 27 varieties of sorghum were documented in the Departments of Borgou and Alibori. Sorghum varieties inventoried are not produced at the same scale. Some varieties are cultivated on a large scale and others are marginal. Most varieties are endangered and the reasons for these losses are varietal susceptibility to poor soils, low productivity, sensitivity to drought and striga, poor culinary quality and low market value. In the selection of new varieties, the main criteria used by producers in the study area are high productivity, the dough quality and economic value of the variety. These criteria according to their importance and type vary across ethnic areas. Participatory evaluation identified pools of high-performance varieties that can be used in strengthening programs of varietal diversity in the different villages of the study area. Given that the majority of constraints are related to climate change, we recommend documentation of farmer's perceptions on climate change, its impacts on sorghum production and diversity and strategies used by farmers to mitigate the effects of climate change. This will define best strategies to ensure sustainable production of sorghum in the north east of Benin.

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