Local Taxonomy and Diversity of Chadian Sorghum [*Sorghum bicolor* (L.) Moench] Accessions

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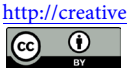

Abstract

The integration of local plant genetic resources into the breeding program is an asset for research. The objective of this study is to assess the diversity and analyze the management practices of cultivated sorghum. A questionnaire following a participatory approach was submitted to 675 producers in 45 villages. The cultivars collected were characterized using 9 qualitative descriptors. In total, 151 accessions and 191 names were inventoried. On average, 25.17 accessions per department and 3.36 accessions per village. Local taxonomy is based on many criteria expressed in different local languages. The most common method of naming is that to the word sorghum is added either the color of the grain, the precocity, or any element deemed relevant by the farmers. Significant variability in grain and panicle traits was observed within the collection, except the color of the endosperm. The rate of diversity loss is 11.52% and red grain sorghums are the most threatened with extinction. Five accessions groups are differentiated by the presence or absence of awns, the color of glumes, and amount of grain covered by glumes, grain plumpness, and form. Based on productivity, precocity, plant size, seed shape, and color, the farmers identified seven promising accessions. This potential will be preserved and developed in the sorghum varietal improvement program in Chad.

Keywords

Chad, Prospecting, Collection, Varietal Diversity, Local Taxonomy, Accession, Sorghum

1. Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] was domesticated around 6000 years

BC. It is one of the most widely used grains for human consumption in the tropical and subtropical regions of Africa and Asia [1]. At the World level, the areas sown to sorghum are estimated at 40,074,667 ha for production of 57,893,378 t. About 50% of this quantity is produced in Africa [2].

In Chad, cereals and particularly millet and sorghum constitute the staple foods of the population. For sorghum, there are two types, sorghum cultivated in strict rain-fed conditions and recession sorghum. Their production areas are relatively different. Recession sorghum is grown in humid areas after the water recedes. In this study, only rain-fed sorghum is concerned. During the last two years, sorghum production has fallen from 987,581 t to 972,516 t [3].

Given the importance of sorghum in Chad, partial surveys and cultivar collection in the Sudanian zone [4] [5] [6] and many research through regional projects have been done. However, no prospecting on sorghum has been done on all the national territory, except those did partly in the 1980s. These partial works, revealed the methods of attributing local names to the accessions and a high level of varietal diversity. The importance of this local taxonomy, in the management of the diversity of plant genetic resources, has been pointed out by many authors and on different crops [7] [8] [9].

In the south of Chad, the variability and genetic diversity of cultivated sorghum were analyzed. Yagoua [4] showed that this zone appears as a pole of sorghum diversification in Africa with the 4 main cultivated sorghum races and 3 identified hybrid races. High variability on the basis of qualitative and quantitative traits was also revealed within accessions from two regions [10].

In general, after the prospection and collection phase, it is mainly the morphological descriptors that are often used in the preliminary characterization work. Many descriptors have made it possible to identify sorghum races from Burkina Faso [11], to classify voandzou morphotypes [12], and to characterize cassava cultivars [13]. Likewise, the qualitative aspects of panicles and grains have been used very often in the study of diversity. In the case of cultivated sorghum, 5 main and 10 intermediate races resulting from hybridizations were identified by Harlan and de Wet [14] on the basis of the structure of the grain shape and the type of inflorescence. These traits were then used by other authors to make a racial classification of sorghum grown in two regions of Burkina [11] and Niger [8]. In Chad, previous works using grains morphological traits as criteria for classifying accessions were carried out on sorghum [4] [5] and on cowpea [15] [16].

Despite the importance of the accessions identified, the collections available do not represent the variability over the entire extent of the territory. In order to have a representative genetic base, surveys and collections should be carried out in other sorghum production areas. Indeed, these areas have not been studied and the accessions maintained *in situ* by farmers have not been documented. The objective of the present study is to evaluate the diversity and analyze the management practices of accessions of cultivated sorghum in the region of

Guéra and the departments of Dababa and Fitri.

2. Material and Methods

2.1. Study Area

The study was carried out in 6 departments in the South Center region of Chad: Guéra rural, Mangalmé, Abtouyour and Barh Signaka in the Guéra region (11˚30'N and 18˚30'E); Dababa (12˚23'N and 17˚03'E) in the Hadjer Lamis and Fitri (12˚52'N and 17˚35'E) in the Batha. The study area is largely located in the Sahelian zone except Barh Signaka which is in a Sahelo-Sudanese transition zone. It has an area of approximately 91,000 km^2 for an estimated population of 877,202 inhabitants [17]. The entire site is between 300 and 800 mm isohyets. The Guéra region is located in the Sudano-Sahelian zone between the 600 and 800 mm isohyets while Dababa and Fitri are in the 300 and 600 mm isohyets of Sahelian zone. Temperatures vary from 16˚C to 25˚C for minimum values, and from 38˚C to 45˚C during periods of high heat. Rainfall is very highly irregular and often characterized by extreme weather events, floods, periods of drought and severe thunderstorms. The soils are mostly sandy tropical ferruginous. The vegetation is characterized in its northern part by grassy savannah and pseudo steppe dominated by Mimosaceae and in the south by shrub savannah where acacias dominate with Combretaceae [18].

2.2. Sites Identification

In the study area, sorghum production basins were identified. Villages to be prospected have been identified in each of the departments, taking into account their distance from each other and their agricultural potential in order to collect the maximum number of accessions during the harvest period and from 24th November to 23th December 2016. The activities were planned and the questionnaire consolidated. The prospecting and collection of accessions took place in 45 villages spread over 17 sub-prefectures belonging to 6 departments. The geographic coordinates of the villages were recorded with a GPS and plotted on a map using ArcGIS 10.2 software (**Figure 1**).

2.3. Data Collection

Accessions were collected in a participatory manner, and on the basis of a two part questionnaire. General information on the village (names of village, department, ethnic groups, languages), main crops, sorghum-based production systems, list of accessions of sorghum in the village, their origin, names and meaning, names and number of disappeared accessions and the reasons of these disappearances, modes of consumption and other uses, the promising accessions and the seeds management practices. For each accession, observations on the agromorphological traits and organoleptic abilities were also collected. In each village, a focus group made up of 15 farmers on average was formed. The interview is conducted by a researcher assisted by an extension agent and a translator.

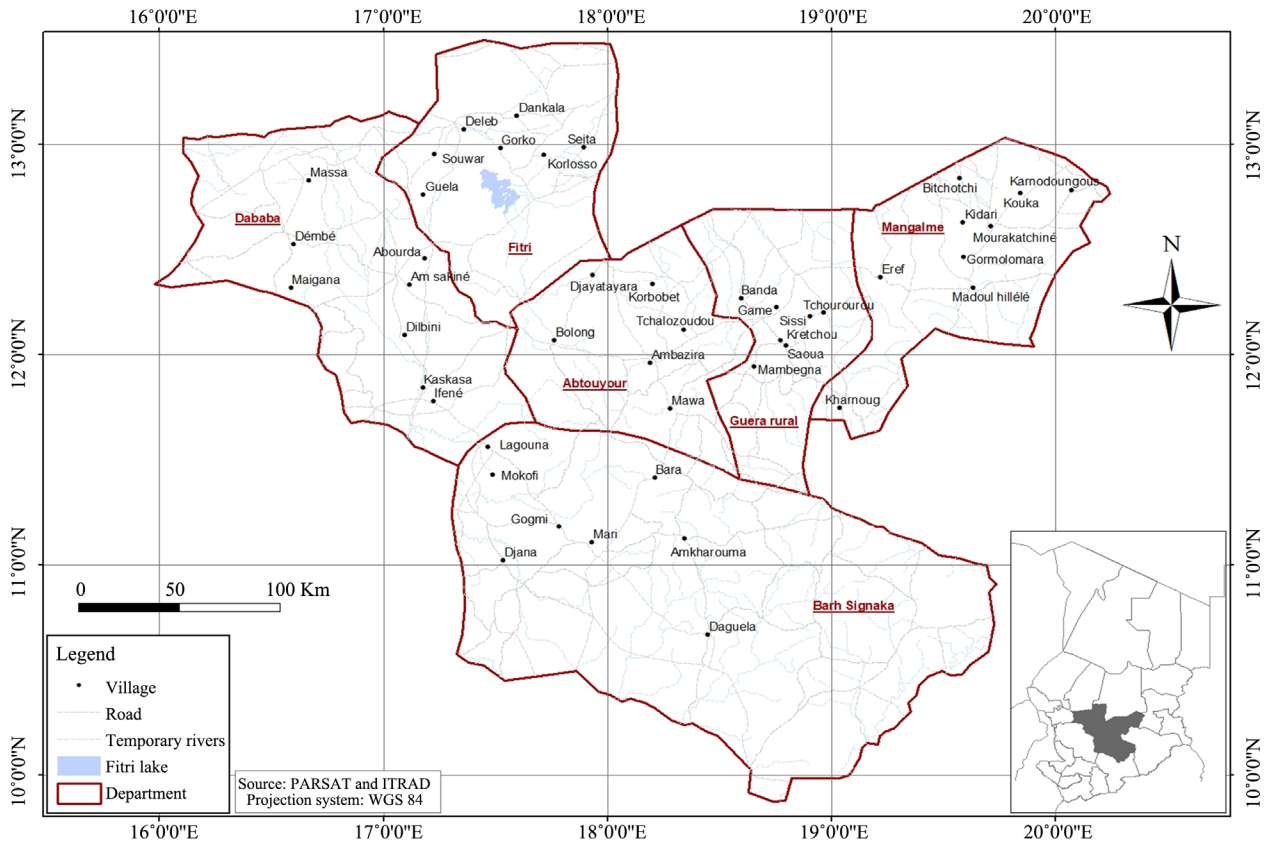

Figure 1. Villages surveyed in the region of Guéra and the departments of Dababa and Fitri.

On average, the interview took two hours. In the beginning, after the usual greetings and presentations, the survey objectives and protocols are outlined. The interview will continue with the recording of the geographical coordinates of the village and the information of the questionnaire. Then, a collect of sorghum accessions is made and for each, all the information is gathered. Panicles of the accessions are also collected. After that, if necessary, details will be provided by the farmer who gave each accession. At the research station, the panicles and the grains were evaluated by the principal investigator and technicians using 9 qualitative traits with modalities varying between 2 and 5 (**Table 1**). For the analysis of the inflorescence, these are the compactness and shape (ICS), the glume color (GCO), the grain covered by glumes (GCG), the presence or the absence of the awns (AW), the color (COG), form (GFO) and grain plumpness (GPP). For the endosperm, texture (ENT) and color (ENC) will be evaluated.

2.4. Statistical Analysis

Survey data was analyzed using Sphinx Plus2-Edition LexicaV5 software. The descriptors list for *Sorghum bicolour* (L.) Moench [19] was used to assess the morphological traits of panicles and seeds. The distribution percentages of the different modalities of the qualitative traits were determined. The relations between the accessions on the basis of qualitative traits were done according to the

Table 1. Qualitative traits and their different modalities.

Traits	Codes	Modalities
Inflorescence Compactness and Shape	ICS	1. Very loose; 2. Loose; 8. Semi-compact elliptic; 9. Compact elliptic; 10. Compact oval
Glume color	GCO	1. White; 4. Red; 6. Black; 7. Gray
Grain covering	GCG	1. 25% grain covered; 3. 50% grain covered; 5. 75% grain covered
Awns	AW	0. Absent 1.Present
Grain color	COG	1. White; 2. Yellow; 3. Red; 4. Brown; 5. Buff; 6. Gray
Grain plumpness	GPP	3. Dimple; 7. Plump
Grain form	GFO	1. Single; 2. Twin
Endosperm texture	ENT	1. Completely corneous; 3. Mostly corneous; 7. Mostly starchy; 9. Completely starchy
Endosperm color	ENC	1. White; 2. Yellow

method of [20] which was taken over by [21]. These authors considered the accessions as individuals and qualitative morphological traits as variables and coded by numbers. The similarity matrix obtained was used to build a dendrogram by Ward method. The organization and structure of morphological variability were analyzed using XLSTAT-2021 version 23.1.1085 software.

3. Results

3.1. Analysis of the Study Area

The survey using a participatory approach was conducted with 675 farmers from 45 villages belonging to 17 sub-prefectures and 6 departments. The majority are men (87%) and women (13%). Compared to the departments, the proportion of women in Guéra is more significant (20%) because women are very involved in field work. In the 32 cantons where the survey was carried out, the current languages are *Dadjo*, *Kengua*, *Djonkor*, *Bilala*, *Kouka* and *Arabic*.

3.2. Importance of Sorghum Cultivation

Sorghum is one of the main cereals grown in the Guéra region but in second rank after millet in Dababa and Fitri. During the 2019-2020 season, total sorghum production in the study area is estimated at 140,288 t of which 93,544 t in the Guéra region, 29,354 t from Dababa and 17,390 t from Fitri. The sown areas are estimated at 167,675 ha. The sorghum culture is practiced by family farms and on small and medium plots varying from 1 to 3 ha. Sowing is from June to July and harvests from September to October for early accessions or even in November for late ones. Sorghum crops are cultivated in pure form in 77% of cases against 30% in combination. About 44% of the sorghum fields are located near the huts and 55% of them are further away and located in the bush. The early accessions (2 to 3 months of cycle) called *Nadjada* are generally cultivated

around the huts and are intended for family consumption. As for late accessions (4 to 5 months of cycle) which are sown further from homes, are reserved for family consumption and for sale. Indeed, the harvested products are mainly used either for feeding the family (100%), or for sale (52%) and others (5%). In terms of consumption, very varied uses of sorghum are reported by the farmers. The flour from the seeds is used in the preparation of many dishes. The *boule*, which is a kind of dough, is the main dish of the people of Chad. Sorghum flour porridge is also popular. Some accessions are suitable for the production of local beers, *Bili bili* and *Gondonrong*. The stems are used in animal feed and also in the construction of habitats as thatch. The methods and places of seed conservation are identified. The main criteria for seed selection by farmers are the best panicles in the fields, productivity and organoleptic characteristics. Thus 73% of seeds are essentially collected in the form of panicles and 27% in the form of grain. The places where these seeds are stored vary from one area to another, but in general, 47% of the seeds of the accessions are placed on racks. The other types of storage, such as attics, bags, canaries, stores, roofs of huts and sheds, account for 53%.

3.3. Local Taxonomy

The survey revealed that for 151 accessions collected, 191 names were inventoried (Table 2). There are 50 names of sorghum in Mangalmé for 40 in Guéra rural. Only Fitri has 16 names. On the entire study area, there is an average of 4.24 names per village. The averages recorded in Guéra rural and Mangalmé respectively 5.71 and 5.56 are the highest. On the other hand, Fitri and Guéra rural, which have the same number of villages, have a big difference in terms of the number of names, 16 and 40 respectively. For the other localities, the averages per village are 3.50 in Dababa but 4.00 in Barh Signaka and 4.17 in Abtouyour. Several languages have been identified and Arabic is spoken in all these localities.

Table 3 shows the most frequent names of which the occurrence is greater than 4 within the collection. The most representative names of the accessions are

Table 2. Number of vernacular names inventoried.

Department	Vernacular names number	Number of villages	Average number of names by village	Language
Guéra rural	40	7	5.71	Bidiyo, Dadjo, Migama
Mangalmé	50	9	5.56	Moubi
Abtouyour	25	6	4.17	Dangleat, Djonkor, Kengua
Barh Signaka	32	8	4.00	Sokoro, Baguirmien
Dababa	28	8	3.50	Boulala, Korbo, Borno
Fitri	16	7	2.29	Bilala
Total	**191**	**45**	**4.24**	

Table 3. Most frequent common local names of sorghum accessions.

Local name	Synonymy	Occurrence	Ethnic group	Meaning
Kourgnagna	-	45	Local Arabic	Sorghum
Kordofan	Kourdoufan	16	-	From Kordofan
Tchangala	-	8	Bilala	Sorghum
Mera	Meiré, Merita	7	Bilala	Sorghum
Nadjada	-	6	Arabic	Precocity
Djorto	-	6	Sokoro	Sorghum
Akoulmout	Okoulmout	5	Local Arabic	You eat and die
Mara guisseïré	Gassariyé	5	Local Arabic	Short woman
Mourigana	Mouridabna	4		Sorghum
Amhalib	-	4	Arabic	White as milk
Ngaouli	-	4	Bornou	

Kourgnagna, *Kordofan*, *Tchangala*, *Mera*, *Nadjada*, *Djorto*, *Akoulmout* and *Mara guisséïré*. The most common method of naming is that to the word sorghum which is first translated into the local language, one adds either the color of the seed, the precocity, or whatever element the farmers deem necessary for the identification. Compared to the color, sorghum with red grains is the most cultivated in the surveyed departments. The coloring of the grain is often translated into the vernacular language according to the localities. Thus, the white color is translated by the word *Abiatt*, *Rafa*, *Rapo*, *Beida* or *Boul* depending on the language. The terms *Acth*é, *Kimêh*, *Ferêt*, *Ahmar*, correspond to the red color of the seeds while *Akhabach*, *Khibech* and *Souloum* are intended for the gray color.

3.4. Diversity of Accessions at the Department and Village Level

The study was conducted in 45 villages in 6 departments. The number of villages surveyed per department varies from 6 to 9 with an average of 7.6 villages. Nine is the largest number of villages which was recorded in Mangalmé while 6 villages, were surveyed in Abtouyour. In total, 151 accessions were collected and at the departmental level, the number of accessions varies from 14 to 35. The highest number, 35 accessions, was observed in Guéra rural and Mangalmé. On the other hand, Fitri with 14 accessions collected have the lowest number. On average, 25.17 accessions per department were recorded with a proportion of 3.36 accessions per village. There is a clear difference between the departments. The greatest diversity was observed in Guéra with an average of 5.00 accessions per village. The departments of Fitri, Dababa and Abtouyour with respectively: 2.00; 2.63 and 2.83 accessions per village show a fair low amount of diversity. This number is medium in Barh Signaka and Mangalmé (**Table 4**).

Table 4. Variation in sorghum diversity in the study area.

Site	Number of villages	Number of accessions	Average number of accessions by village
Guéra rural	7	35	5.00
Mangalmé	9	35	3.89
Abtouyour	6	17	2.83
Barh Signaka	8	29	3.63
Dababa	8	21	2.63
Fitri	7	14	2.00
Study area	**45**	**151**	**3.36**

3.5. Farmers' Promising Accessions

The collection data made it possible to collect from the farmers, information concerning the cycle, the productivity and the cultivar behaviour during periods of drought, pests and diseases. The color, the size of the grain and vitreousness, the market value as well as the organoleptic characteristics such as appearance of the flour, the taste, the aptitudes for preparation of local dishes, are criteria of appreciation and selection of these sorghum accessions. Therefore, based on these traits and according to their perception, the farmers have selected a number of local accessions that they consider promising. In this choice, the 3 improved varieties are not concerned (S35 renamed 45, ONU1 and ONU2). The names are in Arabic except for the *Goursoumboula* accession which was identified in Mangalmé. The Arabic language allows the different ethnic groups in the study area to communicate with each other even if in their village they have their own dialect (Table 5).

In Figure 2, some of these promising accessions are shown. The improved variety S35 was renamed 45 by the farmers. This name may be due to a hearing problem or to poor pronunciation on the part of extension agents. In relation to their place of collection, *Sabaguelmassar* was listed in Barh Signaka and *Goursoumboula* in Mangalmé. Likewise, the inventory identified at least 3 variants of *Mara guisseïré*. The method of assigning the names is based on a wide variety of criteria. For the height of the plants, there is *Mara guisséïré*. Precocity is highlighted with *Kordofan Nadjada* and *Sabaguelmassar*. As for the criteria related to the grain, there is *Amhalip* for coloring. On the other hand, the names *Goursoumboula* and *Guelbadaré* refer to the appearance of the grains.

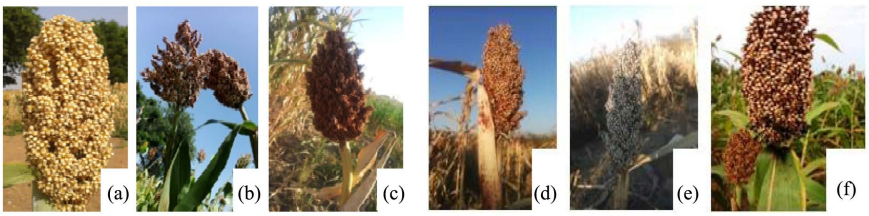

Figure 2. Promising sorghum accessions and some morphotypes. ((a): S35 or "45"; (b): Sabaguelmassar; (c): Goursoumboula). (Morphotypes of Mara guisseïré: (d): Mara guisseïré 1; (e): Mara guisseïré 2; (f): Mara guisseïré 3).

Table 5. Promising sorghum according to farmers' perception.

N°	Vernacular name	Meaning	Geographical extend
1	Mara guisseïré	Short woman	Guéra rural, Mangalmé, Abtouyour
2	Akoulmout	Eat and die	Guéra rural, Mangalmé, Abtouyour
3	Kordofan Nadjada	Kordofan early	Barh Signaka, Dababa, Fitri
4	Amhalip	White as milk	Guéra rural, Mangalmé, Barh Signaka
5	Guelbadaré	The heart of my rival	Mangalmé
6	Sabaguelmassar	Faster than corn	Barh Signaka
7	Goursoumboula	Coarse grains	Mangalmé

3.6. Endangered Accessions

The phenomenon of accessions disappears or abandonment is very pronounced in two villages. Red grain sorghum accessions are most threatened. In the rural Guéra department, 13 disappearances were reported in Saoua village alone and 9 others in Gamé. Out of all the names of the identified accessions, approximately 11.52% of the accessions disappeared in these two villages. The evaluation of this loss does not take into account the synonymies or duplicates that may exist within the accessions. Likewise, accessions that have disappeared from one locality can be available in another village. Many reasons can explain this loss: extreme climatic phenomena (drought, flooding), crop enemies and the length of cycles. However, it should be noted that this disappearance is less in the other departments. This could be explained by the good management of cultivar diversity by farmers but also by the fact that very few improved varieties have been identified. Indeed, the improved varieties identified in this study are those which retained their denomination at the time of introduction. These are two accessions of red-grained sorghum (ONU1 and ONU2) and one white-grained (S35). Improved varieties with local names are difficult to identify at this stage of the study.

3.7. Qualitative Traits of Panicles and Grains

The morphological traits of the panicles and grains of the collected accessions were evaluated on the basis of 30 modalities (Table 6). Some variations were observed between 70% and 100% on all accessions. It's the presence of the dimples on the grains (70.20%), which are awnless (96.69%), simple (98.01%) and whose endosperm is completely white (100%). In terms of the compactness and shape of the panicle, 4 types have been identified. Elliptical shapes are divided into 2 groups. Those which are compact represent 34.44% of the accessions collected against 39.07% for the semi-compact forms. In addition, 17.88% of the inventoried accessions are oval and compact. The results also show that 6.62% of accessions have loose panicles. On the other hand, the proportion of very loose forms which

Table 6. Variability of the qualitative panicle and grain traits of the accessions.

Traits observed	Code	Variants	Rate (%)
Inflorescence Compactness and Shape	ICS	Very loose	1.99
		Loose	6.62
		Semi-compact elliptic	39.07
		Compact elliptic	34.44
		Oval compact	17.88
Awns	AW	Absent	96.69
		Present	3.31
Glume color	GCO	White	7.95
		Red	39.07
		Gray	5.30
		Black	47.68
Grain color	COG	White	30.46
		Yellow	1.32
		Red	56.95
		Brown	5.30
		Buff	3.97
		Gray	2.00
Grain plumpness	GPP	Dimple	70.20
		Plump	29.80
Grain covering	GCG	25%	63.58
		50%	30.46
		75%	5.96
Grain form	GFO	Single	98.01
		Twin	1.99
Endosperm texture	ENT	Completely starchy	37.09
		Mostly starchy	47.02
		Mostly corneous	15.89
Endosperm color	ENC	White	100

is only 1.99% is very low. The concerned accessions are *Lodé*, *Filé grégnette* and *Djiro* respectively from the departments of Mangalmé, Barh Signaka and Guéra rural. The study shows also that the grains have glumes of various colors. These glumes are black (47.68%), red (39.07%), white (7.95%) or gray (5.30%) and mostly not awned (96.69%). Over the entire study area, there are a predominance of red (56.95%) and white (30.46%) grains. Small proportions are observed for the color brown (5.30%), buff (3.97%), gray (2.00%) and yellow (1.32%). A large number of these grains have dimples (70.20%) in contrast to those which

are regularly convex (29.80%). They are covered by glumes at 25% for 63.58% of them, 50% for 30.46% and 75% for only 5.96%. All the accessions studied have single grain (98.01%), except *Hierité beida*, *Hierité hamra* and *Djiro*, which have twin grains (1.99%). Their endosperm is white (100%) with a mostly starchy (47.02%), completely starchy (37.09%) or mostly corneous (15.89%) texture.

3.8. Structuring Morphological Variability

The analysis of **Figure 3** from the ascending hierarchical classification carried out on the basis of the qualitative morphological characters, shows a distribution of accessions (Ac) into five groups. Group I is the largest because it consists of 84 accessions divided into two sub-groups. This group is characterized by seeds that are not awned, have dimples and are simple. Group II counts 47 accessions divided into 2 subgroups all are awnless and have simple grains. In addition to these characters, among the 2 subgroups, there are 21.28% of accessions whose seeds have dimples and 74.47% having their grains regularly convex. In Group IV, there are 11 accessions divided into 2 sub-groups. All accessions have simple and awnless grains. Groups V and III are groups with a reduced number of accessions, respectively 3 and 6. The grains of Group V, are awnless, twinned and covered at 25% by black glumes. On the other hand, in Group III, all the accessions have awned and simple grains.

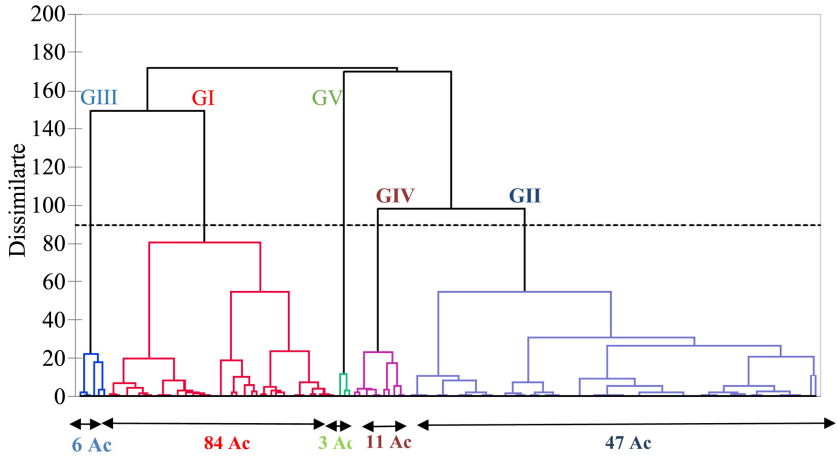

Figure 3. Classification of accessions based on morphological traits and Ward method.

4. Discussion

The study area is characterized by a significant production of rain-fed sorghum. But this production varies greatly from year to year. Many constraints can explain these variations, but the most important are the climatic variability and grain-eating birds. During the year 2019-2020, the production obtained in the study area represents 14.43% of the national production of sorghum [3]. Many products derived from sorghum were reported by the farmers. In addition to the grains which are consumed in different forms, the stems are most often used as

livestock feed. In Chad, sorghum and millet constitute the staple food of the populations. Red grain sorghum is a sacred crop and among the Massa populations it is even considered as a more nutritious food than rice [22]. Due to the importance of its production and the existence of different types of dishes, the chosen area is suitable for assessing the level of sorghum diversity.

The study reveals a high number of local names attributed to sorghum and which are certainly due, to the ethnic diversity and to the many languages spoken in this space between the Sahelian zone and the Sahelo-Sudanian transition zone. *Kourgnagna* is the most common name of sorghum in local Arabic language. Synonymies are frequent and often identical accessions have different names from one village to another in the same department. Likewise, different accessions may have identical names. These names are often translated into the local language. They are essentially based on the traits, the origin of the accession, the name of the person who introduced it to the village and the organoleptic characteristics. These results are similar to those of Sawadogo *et al.* [23] who assert that this farmer's nomenclature is mainly based on visible phenotypic characters. According to Mekbib [24], farmers name their varieties taking into account morphological traits, different uses, and their aptitudes. Likewise, Poncet *et al.* [25] have shown that the classification of plants is mainly guided by morphological traits, their habitat, and uses to which must be added their chemical properties as well as the different types of perception such as vision, taste, and smell. As for Nedelcheva and Dogan [26] in a study conducted on several families and plant species, they reported that most of the names are symbols that are linked to beliefs, legends, customs, and traditions.

The majority of the accessions inventoried are local. Only 3 improved varieties were formally identified during the prospecting phase. However, it is not excluded that improved varieties will remain within the collection because farmers usually rename them. However, this significant number of local accessions is due to the fact that farmers conserve and use them for their well adaptation to local climatic and environmental conditions, for their uses, or for cultural reasons. Many studies have pointed out this farmer specificity in terms of the conservation of local genetic material [9] [27] [28]. Likewise, Chantereau *et al.* [8] reported in a study on sorghum and millet in Niger, that there is a strong attachment of farmers to their local varieties.

Significant variability was observed across the departments and villages studied. For the average number of sorghum accessions prospected per village, the results obtained are low compared to those reported in the South of Chad [5] and in North-West of Benin [29] but similar to those in Niger [8]. The varietal diversity observed in the study area may have benefited from gene flow due to its proximity to Sudan. According to Shadia *et al.* [30], Sudan has a high level of diversity compared to other countries in Eastern and Central Africa. Also the local variety, *Kordofan*, which bears the name of a city in Sudan, has been identified in the collection. In addition, the name *Kordofan* is very common and his occurrence like *Kourgnagna* is also the highest in the study area. Genetic ana-

lyzes may confirm this hypothesis or even reveal other similar varieties.

The study shows also a significant percentage of loss of diversity, about 11.52%, which can be a source of genetic erosion. This disappearance was observed in two villages in the same department. This rate is low compared to the average rate of loss of diversity observed (54.31%) on sorghum [5] and on local cultivars (18.20%) of cassava [9] in the South of Chad. Red grain sorghums represent 56.95% of the accessions inventoried and they are the most threatened with extinction. In fact, they are very popular and are also used in the making of local beers.

The analysis of the qualitative traits of the seeds and panicles showed an important variation within the accessions, except for the color of the endosperm. This variability is quite pronounced for the shape and compactness of the panicles. Contrary to the work of Sawadogo *et al.* [23] on sweet-grained sorghum, where there is a predominance of loose-shaped panicles (78.40%), this type of panicle is very little represented in this study. Almost half of the accessions are black glumes against the Sudanian zone which only 30% are reported by Naoura *et al.* [10]. Likewise, there are a predominance of red (56.95%) and white (30.46%) grains in the inventoried accessions. On the other hand, the local varieties of two regions of Burkina Faso which have black glumes are nearly 80% and 67.90% are white-grained [11]. The results also show that a tiny fraction of the sorghum grown in this part of Chad has very loose panicles. Some traits like awn, yellow color and twin grains are poorly represented in the collection. However, more than 60% of accessions have their grains covered at 25% by glumes, which is high compared to the results on sweet grain sorghum from Burkina [23]. In addition, the texture of the endosperm of nearly 84% of accessions is starchy, unlike those in southern Chad which are predominantly vitreous [10]. The variability of accessions revealed in this study supports the idea that panicles and grains of sorghum, or other speculations, are quite relevant traits for this assessment. In previous work on sorghum, Mekbib [24] showed that the qualitative aspects of panicles and grains are important and the percentage of farmers who used them in the taxonomic classification varies between 90 and 100%. The color of the grains, the compactness, and the shape of the panicles, have also been associated with other specific characters such as resistance or tolerance to striga, resistance to birds, cooking skills and uses, for the selection of local sorghum accessions [31].

The dendrogram obtained on the basis of the morphological characters studied reveals 5 groups of accessions. This allows observing the structuring of this diversity. Accessions can be distinguished by the presence or absence of awns, glume coloration, percent cover, shape, and type of grain. Group I accessions, unlike Group II, have grains that are awnless, simple but all of them have dimples. In Group III, only accessions with awned grains are included. Within this group, *Manmouro* and *Kordofan* show a high number of similarities between them except the texture of their endosperm. Group IV, divided into 2 sub-groups, is characterized by accessions with awnless and simple grains. The first subgroup

includes in addition grains whose endosperm is mostly starchy and in the second subgroup, there are grains with a completely starchy endosperm. In one of the subgroups, *Dilema* and *Philé* differ only in the compactness and shape of their panicle and the color of their grain. These two accessions are characterized by grains covered by 50% gray colored glumes, regularly convex with a mostly starchy texture. In Group V, in addition to the lack of awns, the grains are twined type, 25% covered by black glumes. In addition, *Hierité hamra* has red grains while *Djiro* and *Hierité beida* have white grains. The analysis of the dendrogram also shows that there are accessions within the collection with a high number of similarities. After this preliminary work, other duplicates will then be detected by field tests and especially by molecular biology techniques. By comparing the varietal diversity between this zone and that obtained in southern Chad by Gapili and Djinodji [5], there is a significant varietal difference between the two agro-ecological zones. These results, based on morphological analysis, are contrary to those reported by Ouedraogo *et al.* [32], who after a genetic evaluation of local accessions using microsatellite markers, assert that regional diversity is not very different between two distinct agro-ecological regions. According to these authors, the little differentiation is due to the significant exchanges of local plant material between the farmers.

5. Conclusion

The importance of the production and varietal diversity of sorghum shows that the study area is indeed part of the production basins. Sorghum cultivation is practiced by family farms and in small areas. In terms of consumption, many products are derived from sorghum grain. The seeds are mainly kept in the form of panicles. The early accessions are cultivated around the huts, and those which are late are sown far from the dwellings. The methods of assigning names to accessions depend on many criteria expressed in the languages used by the different ethnic groups. Significant diversity was observed at the department and village levels. The analysis of the qualitative traits of the grains and panicles showed a fairly significant variation within the accessions. Promising accessions were identified by farmers. Compared to Southern Chad, relevant traits and 5 groups of accessions have been identified and will be used in the national improvement program. The varietal diversity observed, shows the importance of the role played by farmers in the conservation of sorghum plant genetic resources and in reducing genetic erosion. In perspective, the study should continue in order to have a representative genetic base at the national level.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Doggett, H. (1988) Sorghum. 2nd Edition, Longman Scientific and Technical, Harlow, 512 p.

[2] FAOSTAT (2019) Base de données statistiques agricoles. Organisation des Nations Unies pour l'Agriculture et l'Alimentation (FAO), Rome. http://www.fao.org/faostat/en/#data/QC

[3] DSA/ANADER (2020) Rapport de Campagne agricole 2019-2020. Direction de la Statistique Agricoles et l'Agence Nationale d'Appui au Développement Rural. Ministère de l'Agriculture, N'Djamena Tchad.

[4] Yagoua, N.D. (1994) Caractérisation du sorgho pluvial, (*Sorghum bicolor* (L.) Moench), de la zone soudanienne du Tchad. *Actes de l'atelier de formation sur les variétés locales de sorgho du*, Samanko, 10-14 octobre 1994, 44-59.

[5] Gapili, N. and Djinodji, R. (2016) Farmer's Management Practices to Maintain the Genetic Diversity of Sorghum (*Sorghum bicolor* L. Moench) in South of Chad. *Journal of Experimental Biology and Agricultural Sciences*, **4**, 625-630. https://doi.org/10.18006/2016.4(Issue6).625.630

[6] Naoura, G., Djinodji, R., Doyam, N.A. and Djondang, K. (2016) Ethno-Botanic Study and Characterization of the Farming System of Dry Season Sorghum's Accessions in South of Chad. *Journal of Applied Environmental and Biological Sciences*, **6**, 109-114.

[7] Manusset, S. (2006) Proposition pour une clé d'identification des variétés de manioc chez différents groupes culturels en Guyane française. *Antropo*, **11**, 61-73.

[8] Chantereau, J., Deu, M., Pham, J.L., Kapran, I., Vigouroux, Y. and Bezançon, G. (2010) Evolution des diversités phénotypique et génétique des sorghos et mils cultivés au Niger de 1976 à 2003. *Le Sélectionneur Français*, **61**, 33-45.

[9] Nadjiam, D., Diallo, M., Mbaïguinam, J.M.M. and Guissé, A. (2016) Pratiques paysannes de gestion des cultivars de manioc (*Manihot esculenta* Crantz) au Sud du Tchad. *International Journal of Biological and Chemical Sciences*, **10**, 1098-1113. https://doi.org/10.4314/ijbcs.v10i3.16

[10] Naoura, G., Mahamat, A.H., Djinodji, R., Serferbe, S. and Weltzien-Rattunde, E. (2019) Genetic Diversity of South Chadian Sorghum Landraces Assessed through Quantitative and Qualitative Traits. *International Journal of Applied Sciences and Biotechnology*, **7**, 395-406. https://doi.org/10.3126/ijasbt.v7i4.26920

[11] Barro-Kondombo, C.P., Vom Brocke, K., Chantereau, J., Sagnard, F. and Zongo,

J.D. (2008) Variabilité phénotypique des sorghos locaux de deux régions du Burkina Faso: La Boucle du Mouhoun et le Centre-Ouest. *Cahiers Agricultures*, **17**, 107-113. https://doi.org/10.1684/agr.2008.0175

[12] Touré, Y., Koné, M., Silué, S. and Kouadio, Y.J. (2013) Prospection, collecte et caractérisation agromorphologique des morphotypes de voandzou [*Vigna subterranea* (L.) VERDC. (FABACEAE)] de la zone savanicole en Côte d'Ivoire. *European Scientific Journal*, **9**, 1857-7881.

[13] Nadjiam, D., Sarr, P.S., Naïtormbaïdé, M., Mbaïguinam, J.M.M. and Guissé, A. (2016) Agro-Morphological Characterization of Cassava (*Manihot esculenta* Crantz) Cultivars from Chad. *Agricultural Sciences*, **7**, 479-492. https://doi.org/10.4236/as.2016.77049

[14] Harlan, J.R. and de Wet, J.M.J. (1972) A Simplified Classification of Cultivated Sorghum. *Crop Sciences*, **12**, 172-176. https://doi.org/10.2135/cropsci1972.0011183X001200020005x

[15] Nadjiam, D., Doyam, A.N. and LeDiambo, B. (2015) Etude de la variabilité agromorphologique de quarante-cinq cultivars locaux de niébé (*Vigna unguiculata* (L.) Walp.) de la zone soudanienne du Tchad. *Afrique Science*, **11**, 138-151.

[16] Gapili, N., Bemadjita, A., Nadjiam, D., Mbaïguinam, M. and Bolni, M.N. (2020) Ethnobotany and Genetic Diversity of South Chadian Cowpea Landraces as a Novel Source of Early Grain Production. *International Journal of Agricultural Science*, **5**, 85-100.

[17] INSEED (2012) Deuxième recensement général de la population et de l'habitat, RGPH-2, 2009. Institut National de la Statistique, des Etudes Economiques et Démographiques, Tchad, 121 p.

[18] DREM (1998) Carte climatique et formations végétales du Tchad. Direction des Ressources en Eau et de la Météorologie, N'Djaména, Tchad, 1 p.

[19] IBPGRI and ICRISAT (1993) Descriptors for Sorghum [*Sorghum bicolor* (L.) Moench]. International Board for Plant Genetic Resources, Rome, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, 38 p.

[20] Kombo, G.R., Dansi, A., Loko, L.Y., Orkwor, G.C., Vodouhe, R., Assogba, P. and Magema, J.M. (2012) Diversity of Cassava (*Manihot esculenta* Crantz) Cultivars and Its Management in the Department of Bouenza in the Republic of Congo. *Genetic Resources and Crop Evolution*, **59**, 1789-1803. https://doi.org/10.1007/s10722-012-9803-0

[21] Gbaguidi, A.A., Assogba, P., Dansi, M., Yedomonhan, H. and Dansi, A. (2015) Caractérisation agromorphologique des variétés de niébé cultivées au Bénin. *International Journal of Biological and Chemical Sciences*, **9**, 1050-1066. https://doi.org/10.4314/ijbcs.v9i2.40

[22] Arditi, C. (1998) Pourquoi les Massa préfèrent-ils le sorgho? Heurs et malheurs de la riziculture irriguée au Nord-Cameroun. *Journal des Anthropologues*, **74**, 117-131. https://doi.org/10.4000/jda.2674

[23] Sawadogo, N., Baloua Nebie, B., Kiebre, M., Kando, P.B., Nanema, R.K., Renan Ernest Traoré, R.E., Naoura, G., Sawadogo, M. and Zongo, J.D. (2014) Caractérisation agromorphologique des sorghos à grains sucrés (*Sorghum bicolor* (L.) Moench) du Burkina Faso. *International Journal of Biological and Chemical Sciences*, **8**, 2183-2197. https://doi.org/10.4314/ijbcs.v8i5.22

[24] Mekbib, F. (2007) Infra-Specific Folk Taxonomy in Sorghum (*Sorghum bicolor* (L.) Moench) in Ethiopia: Folk Nomenclature, Classification, and Criteria. *Journal of*

Ethnobiology and Ethnomedicine, **3**, Article No. 38.
https://doi.org/10.1186/1746-4269-3-38

[25] Poncet, A., Vogl, C.R. and Weckerle, C.S. (2015) Folk Botanical Classification: Morphological, Ecological and Utilitarian Characterization of Plants in the Napf Region, Switzerland. *Journal of Ethnobiology and Ethnomedicine*, **11**, 37 p.
https://doi.org/10.1186/1746-4269-11-13

[26] Nedelcheva, A. and Dogan, Y. (2009) Folk Botanical Nomenclature and Classification in Bulgarian Traditional Knowledge. In: Morel, J.P. and Mercuri, A.M., Eds., *Plants and Culture*: *Seeds of the Cultural Heritage of Europe*, Edipuglia S.R.L., Bari, 169-173.

[27] Willemen, L., Scheldeman, X., Cabellos, V.S., Salazar, S.R. and Guarino, L. (2007) Spatial Patterns of Diversity and Genetic Erosion of Traditional Cassava (*Manihot esculenta* Crantz) in the Peruvian Amazon: An Evaluation of Socio Economic and Environmental Indicators. *Genetic Resources and Crop Evolution*, **54**, 1599-1612.
https://doi.org/10.1007/s10722-006-9172-7

[28] Vaksmann, M., Kouressey, M., Chantereau, J., Bazile, D., Sangard, F., Toure, A., Sanogo, O., Diawara, G. and Dante, A. (2008) Utilisation de la diversité génétique des sorghos locaux du Mali. *Cahiers Agricultures*, **17**, 140-145.
https://doi.org/10.1684/agr.2008.0190

[29] Missihoun, A.A., Agbangla, C., Adoukonou-Sagbadja, H., Ahanhanzo, C. and Vodouhe, R. (2012) Gestion traditionnelle et statut des ressources génétiques du sorgho (*Sorghum bicolor* L. Moench) au Nord-Ouest du Bénin. *International Journal of Biological and Chemical Sciences*, **6**, 1003-1018.
https://doi.org/10.4314/ijbcs.v6i3.8

[30] Shadia, A.S., Herslman, L., Labuschange, M.T. and Mohammed, A.H. (2016) Assessment of Genetic Diversity of Sorghum [*Sorghum bicolor* (L.) Moench] Germplasm in East and Central Africa. *World Journal of Biotechnology*, **1**, 113-120.
https://doi.org/10.33865/wjb.001.03.0010

[31] Benor, S. and Sisay, L. (2003) Folk Classification of Sorghum (*Sorghum bicolour* (L) Moench) Landraces and Its Ethnobotanical Implication: A Case Study in Northeastern Ethiopia. *Etnobiología*, **3**, 29-41.

[32] Ouedraogo, N., Sanou, J., Traoré, H., Gracen, V., Tongoona, P. and Danquah, E.Y. (2017) Genetic Diversity among Sorghum Landraces and Polymorphism Assessment of Local Improved Varieties for Stay-Green Trait. *International Journal of Biological and Chemical Sciences*, **11**, 1-14. https://doi.org/10.4314/ijbcs.v11i1.1