Genet Resour Crop Evol (2009) 56:223–236
DOI 10.1007/s10722-008-9357-3

RESEARCH ARTICLE

Changes in the diversity and geographic distribution of cultivated millet (*Pennisetum glaucum* (L.) R. Br.) and sorghum (*Sorghum bicolor* (L.) Moench) varieties in Niger between 1976 and 2003

Gilles Bezançon · Jean-Louis Pham · Monique Deu · Yves Vigouroux · Fabrice Sagnard · Cédric Mariac · Issoufou Kapran · Aïssata Mamadou · Bruno Gérard · Jupiter Ndjeunga · Jacques Chantereau

Received: 1 February 2008 / Accepted: 23 June 2008 / Published online: 15 July 2008

Abstract Changes in the diversity of landraces in centres of diversity of cultivated plants need to be assessed in order to monitor and conserve agrobiodiversity—a key-element of sustainable agriculture. This notably applies in tropical areas where factors such as increased populations, climate change and shifts in cropping systems are hypothesized to cause varietal erosion. To assess varietal erosion of staple crops in a country subjected to various anthropogenic and natural environmental changes, we carried out a study based on a comparison of the diversity of pearl millet and sorghum varieties collected in 79 villages spanning the entire cereal-growing zone of Niger over a 26 year period (1976–2003). For these two crops, the number, name and type of varieties according to important traits for farmers were considered at different spatial scales (country, region, village) at the two collection dates. The results confirmed the high diversity of millet and sorghum varieties in Niger. No erosion of varietal diversity was noted on a national scale during the period covered. Some changes were observed but were limited to the geographical distribution of certain varieties. This highlights that farmers' management can preserve the diversity of millet and sorghum varieties in Niger despite recurrent and severe drought periods and major social changes. It also indicates that rainfed cereal cropping systems in Niger should remain to be based on millet and sorghum, while reinforcing farmers' seed systems.

Keywords Agrobiodiversity · Genetic erosion · Genetic resources · Germplasm collections · Landraces · Niger · Pearl millet · *Pennisetum glaucum* · Sorghum · Sub-Saharan Africa

G. Bezançon · Y. Vigouroux · C. Mariac
Institut de Recherche pour le Développement (IRD), UMR DIAPC Diversité et Adaptation des Plantes Cultivées, BP 11416, Niamey, Niger

J.-L. Pham (✉)
Institut de Recherche pour le Développement (IRD), UMR DIAPC Diversité et Adaptation des Plantes Cultivées, 911, Avenue Agropolis, BP 64501, 34394 Montpellier Cedex 5, France
e-mail: jean-louis.pham@ird.fr

M. Deu · F. Sagnard
CIRAD, UMR DAP Développement et Amélioration des Plantes, Montpellier 34398, France

F. Sagnard
International Center of Research for the Semi-Arid Tropics (ICRISAT), P.O. Box 39063, Nairobi, Kenya

I. Kapran · A. Mamadou
Institut National de la Recherche Agronomique du Niger (INRAN), BP 429, Niamey, Niger

B. Gérard · J. Ndjeunga
International Center of Research for the Semi-Arid Tropics (ICRISAT), BP 12404, Niamey, Niger

J. Chantereau
CIRAD, UPR Agrobiodiversité des plantes de savanes, Montpellier 34398, France

Introduction

The international community has set the objective "to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level" (United Nations Environment Programme 2002). Among the indicators proposed in the Convention on Biological Diversity for monitoring progress towards the so-called "2010 Biodiversity targets" are "trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance" (United Nations Environment Programme 2004).

Similar to other biodiversity components (Balmford et al. 2005), the need to make data available is crucial to be able to properly assess these trends in agricultural biological diversity. The overall consensus that crop diversity has been declining over the last decades needs to be supported or challenged with empirical evidence. Despite the need for global indicators to boost the awareness of the general public and decision-makers on the status of biodiversity on earth, it is obvious that the trends and intensity of biodiversity change might differ depending on the agroecological, cultural and economical environment.

Several studies on varietal erosion have focused on limited spatial or temporal scales. For example, Morin et al. (2002) concluded that there was a rapid decrease in the cultivation of traditional rice varieties in Cagayan Valley in the northern Philippines following climatic catastrophes. At a similar geographical scale but over a broader timespan, a diachronic (1979–2003) analysis of Asian rice molecular genetic diversity in six villages of Maritime Guinea did not reveal genetic erosion (Barry et al. 2008). Mekbib (2008) reached a similar conclusion when studying names of sorghum landraces in eastern Ethiopia.

Detailed studies on large temporal and geographical scales are relatively scarce. Gai et al. (2005) quantified changes over 10 years in the number of soybean landraces grown in different regions of China and concluded that there was an overall decrease of this number. Loss of cassava varieties over a 30-year period was reported by Peroni and Hanazaki (2002) in the Brazilian Atlantic forest, but the authors did not mention what varieties were introduced or created over this period. Both studies used a survey approach, i.e. information on varieties cultivated in the past was culled from farmers' interviews. Assessment of changes in cultivated diversity based on farmers' knowledge was also done on cassava in Peruvian Amazon (Willemen et al. 2007) and sorghum in Ethiopia (Mekbib 2008).

A study on a large geographical and temporal scale was conducted in Albania and southern Italy by Hammer et al. (1996), who showed a decrease over several decades in the occurrence of landraces for many crops. Teklu and Hammer (2006) assessed the genetic erosion of tetraploid wheats landraces in Ethiopia. These studies were based on a comparison of the content of genebank collections with surveys and collections made for the purposes of the study.

A similar approach was adopted for the research project described in this paper. In the 1970s, extensive collecting missions of crop genetic resources were conducted by French research institutions in West Africa, in partnership with national institutions and the International Board for Plant Genetic Resources. These collections and related information provided the most informative picture on the status of landrace distributions by that time. Such a collection was built in Niger for two staple crops in the sub-Sahelian region, i.e. sorghum and pearl millet, in 1976 (Clément 1985) with samples maintained in cold storage facilities at the genebank of the Institute of Research for Development (IRD, France).

Since then, there have been dramatic human and environmental changes in Sahelian countries in recent decades. In Niger, the cultivated area and human population (12 million in 2003) have increased more than twofold since 1980 (Food and Agriculture Organization 2006a). Moreover, the 400 mm isohyets have moved southward by about 100–200 km. Severe droughts affected the country in 1971, 1972, 1973, 1983, 1984 and 1985, and more recently in 2004. Social changes are under way that potentially affect the way farming households manage crop diversity, such as a lower authority of village chiefs and a weaker collective management of land use (Roussel 1999).

All of these factors and their interactions are potential causes of changes in the diversity of pearl millet and sorghum varieties in Niger, where these staple crops account for about 50% of the 14.5 million ha of arable land (Food and Agriculture Organization 2006b, c).

A project was initiated to characterise changes in cultivated pearl millet and sorghum diversity in Niger over 25 years, while using the 1976 sorghum and pearl millet collection as a reference. A new pearl millet and sorghum germplasm collection survey was thus carried out in 2003, covering the same regions as in 1976. In this paper, we present the results of the survey conducted in 2003 to study the varietal distribution of these crops in their cultivation areas. The results are compared with those obtained from an analysis of the genebank collections of the IRD assembled in 1976. We characterised changes in the distribution of landraces at the village and country level and studied whether the distribution of major landraces in the country was stable or evolving. The reasons underlying the results obtained are discussed. The present study is a component of the project, which will also involve diversity studies at the morphological, phenological and molecular level.

Material and methods

Data collection and sampling strategy

Diverse reports (FAO-ORSTOM 1977; Clément 1985) and passport data regarding the 1976 collection survey in Niger provided the information for describing the pearl millet and sorghum collection assembled at that time. They also provided information for planning the new collection of millet and sorghum accessions that was conducted over a 2 month period at the end of 2003 by a team of seven persons from different national and international institutes involved in agronomical research in Niger. This involved a trip to 79 villages in Niger, representing about half of the 183 villages from which samples had been collected in 1976, while still covering (in longitude and latitude) the entire agricultural area in Niger visited in 1976 but with more distance between villages. In each village the collection survey was organized in a participatory way with its chief and farmers and generally two villages were visited per day.

Care was taken to ensure that the sampling strategies for pearl millet and sorghum implemented in 2003 were similar to that of 1976. Thus a "minimum" sampling approach was applied, i.e. one sample per variety name and village provided by one farmer. Consequently, for a given village, the number of collected accessions was equal to the number of encountered variety names. The only difference between the 1976 and 2003 collections was that modern varieties (i.e. selected by researchers and released by the government services) were collected in 2003 but not in 1976. For each accession, spikes (millet) or panicles (sorghum) were collected.

For each sample, we filled out a "passport file" with the farmer donor, recording the main information concerning the geographical origin and situation of the sample, the social context of the farmer producing the variety, the vernacular name of the variety and the main agro-morphological characteristics.

Classification of varieties

Pearl millet and sorghum varieties identified through their local names indicated by the farmers were classified in larger taxonomic groups, as usually done by millet and sorghum breeders. Thus, based on the studies carried out in Niger by Bono (1973), FAO-ORSTOM (1977), Clément (1985) and Tostain (1994), we considered the following twelve varietal groups for pearl millet: Haïni Kiré, Maewa (also named Somno, the only late-maturing varietal group in Niger), Guerguéra, Zongo, Ba Angouré, Tamangagi, Boudouma, Ankoutess, Zanfaroua, Bazaomé, Gnieye and Moro. For sorghum, we used the botanical classification of Harlan and de Wet (1972). This classification recognises five basic races (bicolor, guinea, caudatum, durra, kafir) and 10 intermediate forms obtained by the combination of any two of these races. In addition, the taxonomic characterisation proposed by Snowden (1936) to distinguish margaritiferum from the other guinea landraces was also used. Indeed, margaritiferum sorghums deserve special attention because of their unique characteristics (small and corneous grain) and their genetic isolation from other guinea races, as discussed by Deu et al. (1995).

We used information obtained from farmers, laboratory observations of spikes and panicles by the plant breeders involved in the study and complementary field characterisations of accessions collected in Niger during the 2004 crop season to distinguish modern varieties from landraces. Modern sorghum varieties are rather short, not very photoperiod sensitive, and generally have a tan (brown) plant colour and a caudatum panicle. The name of the varieties and farmers' knowledge on their history were essential to identify modern pearl millet varieties as those grown in Niger do not have strong distinctive traits, although they are usually more homogeneous for phenological and spike traits than landraces when recently introduced.

Geographic distribution

The spatial distribution of the accessions was based on the geographical position of 79 villages common to the 2003 and 1976 collections. The villages were distributed within three regions defined by the 4 °E and 8 °E, i.e. western, central and eastern regions (Fig. 1).

Comparison of collections

The comparison between the two collections used data obtained during the collection surveys, such as number and name of the collected varieties. Taxonomic classifications and other important characteristics were also considered, such as precocity groups according to the farmers' information concerning millets and types of grain colour for sorghum. The results enabled us to describe the differences observed between the two collections with qualitative classes and compare the distributions by χ^2 tests.

Results

Number of collected pearl millet and sorghum accessions

Data on the number of pearl millet and sorghum accessions collected throughout Niger in 1976 and 2003 in the same 79 villages are presented in Table 1. On a national scale, about twice as many accessions were collected in 2003 as compared to 1976. For millet, an average of 5.3 accessions per village were collected in 2003 as compared to 2.4 accessions per village collected for the 1976 survey, whereas the results were 6.1 and 3.3, respectively, for sorghum.

On a regional scale, most of the millet accessions were collected in the western region in 1976 and 2003. For sorghum, the central region was where most accessions were collected during the two surveys. Between 1976 and 2003, the number of millet or sorghum accessions collected increased about twofold in each region, except in the central region for millet, where the 2003/1976 ratio in the number of accessions collected was 2.6 (high increase), and this ratio was 1.2 (low increase) in the eastern region for sorghum.

Pearl millet: characterization and geographical distribution

Varietal groups

Without taking modern varieties and unclassified varieties into account, the 12 groups of pearl millet varieties represented in 1976 were also found in 2003 (Table 2).

The same set of varieties predominated both in 1976 and 2003. Varieties Haïni Kiré, Maewa, Zongo, Guerguéra, and Ba Angouré were strongly represented (from 25.0% to 9.4% in 1976 and from 24.0% to 9.5% in 2003). Varieties Ankoutess, Bazaomé,

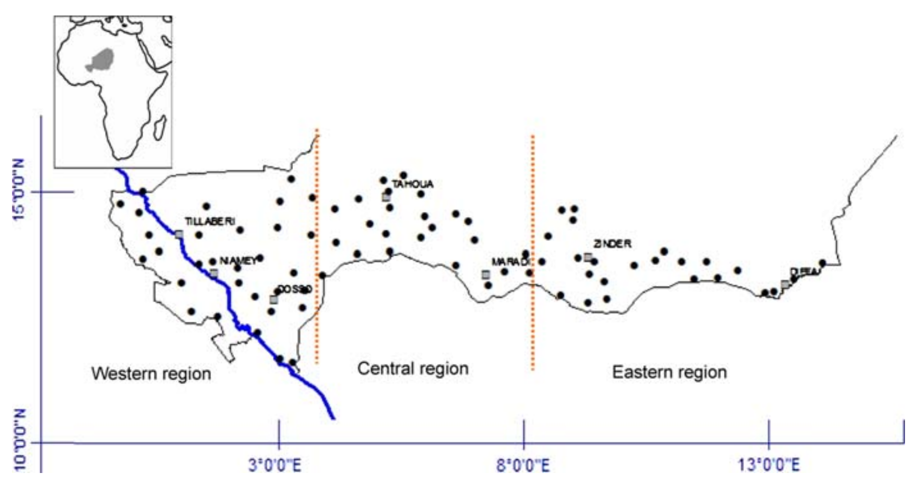

Fig. 1 Villages where samples were collected in 1976 and in 2003

Table 1 Number of pearl millet and sorghum accessions collected during the 1976 and 2003 surveys in Niger

Region	No. of accessions			
	Pearl millet		Sorghum	
	1976	2003	1976	2003
Western (31 villages)	90 (2.9)	173 (5.6)	87 (2.8)	193 (6.2)
Central (24 villages)	62 (2.6)	164 (6.8)	94 (3.9)	198 (8.3)
Eastern (24 villages)	40 (1.7)	83 (3.5)	76 (3.2)	93 (3.9)
Total Niger (79 villages)	192 (2.4)	420 (5.3)	257 (3.3)	484 (6.1)

The average number of accessions collected per village is given in brackets

Moro, Tamangagi, Gnieye, Boudouma and Zanfaroua were found at much lower frequency (from 4.7% to 0.5% in 1976 and from 5.0% to 0.9% in 2003). The Haïni Kiré group ("red millet" in Zarma) was found at the highest frequency, representing 25.0% and 24.0% of the varieties collected in 1976 and 2003, respectively. No significant differences between the frequencies of the fifth most frequent groups in 1976 and 2003 were found (Table 2).

While the overall ranking of these groups showed no great change between 1976 and 2003, the marked decrease in the frequency of the Maewa group (the latest-ripening varietal group in Niger) should be noted, i.e. from 18.2% in 1976 to 10.2% in 2003. The frequency of the Bazaomé, Moro and Gnieye groups also decreased, but this trend should be considered cautiously given the low number of occurrences of these varietal groups. Boudouma and Zanfaroua are also rare groups, but data suggest that these groups are emerging since the 2003/1976 ratios in the number of accessions were 3.6 and 7.0, respectively. Finally, a high relative frequency (10.9%) of modern varieties was noted in 2003.

Variety names

The number of different names of pearl millet varieties increased by 2.5-fold from 55 in 1976 to 137 in 2003. An average of 3.49 and 3.06 accessions

Table 2 Comparison of the importance of the main variety groups of pearl millet in 1976 and 2003

Groups of varieties	1976 Collection			2003 Collection			Length of cycle (No. of days to harvest)**
	No. of accessions	%	Rank	No. of accessions	%	Rank	
Haïni Kiré	48	25.0	1	101	24.0	1	90–120
Maewa	35	18.2	2	43	10.2	4	120–200
Zongo	27	14.1	3	60	14.3	2	80–90
Guerguéra	23	12.0	4	57	13.6	3	90–100
Ba Angouré	18	9.4	5	40	9.5	5	70–90
Ankoutess	9	4.7	6	21	5.0	6	60–80
Bazaomé	8	4.2	7	10	2.4	9	90
Moro	6	3.1	8	4	0.9	12	90
Tamangagi	5	2.6	9	11	2.6	7	70–80
Gnieye	5	2.6	9	5	1.2	11	90–100
Boudouma	3	1.6	11	11	2.6	7	50–70
Zanfaroua	1	0.5	12	7	1.7	10	70
Modern var.*	2	1.0	–	46	10.9	–	70–90
Indeterminate varieties	2	1.0	–	4	0.9	–	–
Whole collections	192	100		420	100		

Ranks are based on percentages. The cycle length is indicated and was obtained from farmers' interviews. No significant differences between the frequencies of the fifth most frequent groups (italics) in 1976 and 2003 were found ($\chi^2 = 5.85$, P-value $= 0.211$ for df 4)

* Modern varieties were systematically collected in 2003 but not in 1976. No comparisons between the two collections can therefore be made

** According to farmers' interviews

per variety name was found in 1976 and 2003, respectively. Of the 55 names existing in 1976, more than 70% (40) were found in 2003.

The most frequent groups (Haïni Kiré, Maewa, Zongo, Guerguéra, Ba Angouré, Ankoutess) showed the greatest enrichment in variety names. Rarer groups (Bazaomé, Tamangagi, Zanfaroua, Moro) were stable, except for the Gnieye and Boudouma groups for which more names were noted.

Some group names were very representative, i.e. borne by a large proportion of the accessions belonging to the group: 81% for Zongo, 74% for Guerguéra, 67% for Ba Angouré and Ankoutess in 1976. These percentages decreased in 2003 (except for Ankoutess, 67%): 65%, 47% and 45%, which means that most of the names of the new varieties inventoried in these groups were not based on the name of the group.

Figure 2 shows that the geographical distribution of large groups such as Haïni Kiré (early) and Maewa (semi-late) remained stable between 1976 and 2003. In contrast, other groups that were very sparsely represented in 1976, such as the very early typical variety Ankoutess (in Keïta region), showed an extension in their distribution range.

Figure 2 also illustrates the variety diversity in each village visited in 1976 and 2003. The following geographical differences were noted: the eastern and western regions were the least diversified as only one to four variety groups were found per village, while in the central region up to seven variety groups were represented in the same village.

Cycle duration

During the village surveys in 1976 and 2003, information was gathered from farmers on the growth duration of their varieties (data missing or not provided for less than 5% of varieties, Table 3). Overall, the frequencies of early, semi-late and late millet varieties observed in 2003 did not significantly differ from that noted in 1976 despite the appearance of a very low number of so-called "late" varieties in the 2003 collection, which had a cycle of up to 150 days according to interviewed farmers.

In contrast, at the regional level, the relative frequency of early varieties increased in the central region (+10.0%) and decreased in the western and eastern regions (respectively −7.4% and −3.2%) (χ^2 test, P-value = .042). Concerning "semi-late" varieties, no significant changes were detected.

The climatic trend observed over the last 30 years, especially the decrease in rainfall, has led to predictions that crops with high water requirements would disappear, such as the cultivated millet varieties with a long cycle (Tostain 1990). This predicted disappearance was actually not observed, even in cultivated millets with the longest cycle in Niger. Of course, we did not obtain data on the percentage areas sown in 1976 and 2003 with such varieties, but

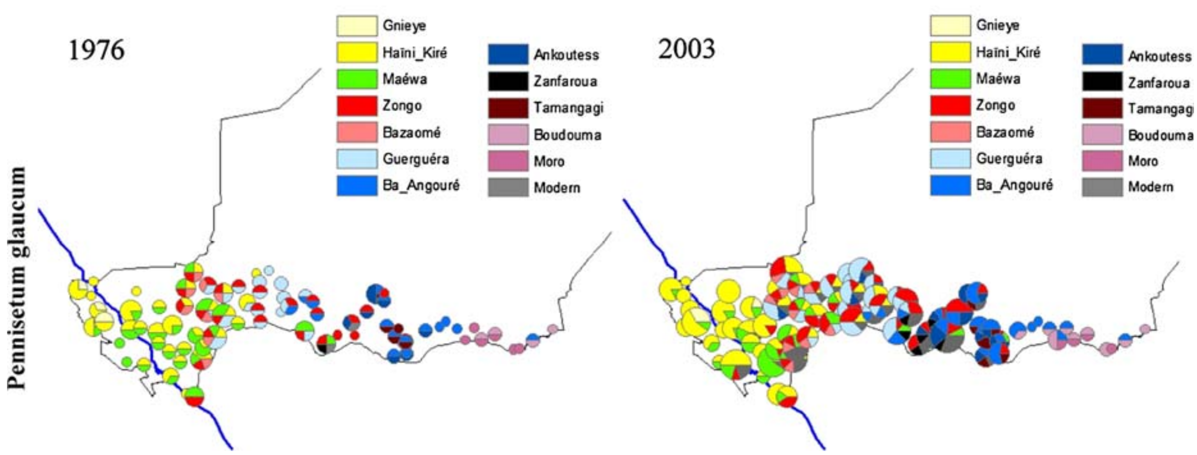

Fig. 2 Geographical distribution of pearl millet varietal groups per village in Niger. The size of the circles is proportional to the number of variety names per village

the surveys conducted during our study showed that these varieties are still well established in some regions of the country. Certain Somno varieties of Maewa group in the southernmost regions of the country (Burkina Faso, Benin and Nigeria border areas) were reported by farmers to have a cycle of up to 200 days under favourable rainfall conditions. The qualities attributed to these varieties by local farmers and their efforts to ensure their maintenance would account for their conservation.

Sorghum: characterization and geographical distribution

Racial groups

The results of the racial characterization of accessions collected in 1976 and 2003 in Niger are presented in Table 4. To simplify the data presentation, all intermediate forms were pooled in one complex class mainly composed of the same four intermediate forms found in the two collections (durra-bicolor, durra-caudatum, bicolor-caudatum and guinea-caudatum), with the durra-bicolor always being the most important intermediate form. This complex class also integrated some accessions presenting combinations of traits from more than two races. In both collections, no accessions of the kafir race and intermediate forms with kafir were found. Apart from the bicolor class, whose percentage increased in 2003 compared to 1976, and the guinea class, whose percentage decreased in 2003, most racial classes showed little change in percentage. This stability was confirmed by testing the homogeneity of the distributions of sorghum accessions in each racial class in the 1976 and 2003 collections (non-significant χ^2 test, Table 4).

The racial pattern was also determined per village and the geographical distribution is illustrated in Fig. 3. Two clear trends were noted for 1976 and 2003: the racial pattern per village was rather poor and mainly consisted of durra in the eastern zone, whereas there was more racial diversity per village in the western zone. The border latitude between the two zones appeared to be situated between Maradi and Tanout.

On the other hand, the racial distribution was generally the same for both collection years. The durra race had the widest distribution, i.e. found in almost all cropping areas of Niger and the predominant race in eastern Niger. The caudatum race was uncommon in eastern Niger but common in central

Table 3 Frequencies and regional distribution of pearl millet varieties according to the length of the cycle (farmers' information): number of varieties and relative frequency (in brackets)

	Number and frequencies (%) of pearl millet varieties									Total
	Early*			Semi-late*			Late*			
1976 Collection	139 (81.8)			31 (18.2)			0 (0.0)			170
2003 Collection	305 (81.1)			66 (17.6)			5 (1.3)			376
Regions	W	C	E	W	C	E	W	C	E	
1976	61 (35.9)	44 (25.9)	34 (20.0)	26 (15.3)	4 (2.4)	1 (0.6)	0 (0.0)	0 (0.0)	0 (0.0)	170
2003	107 (28.5)	135 (35.9)	63 (16.8)	45 (12.0)	16 (4.2)	5 (1.3)	5 (1.3)	0 (0.0)	0 (0.0)	376
Difference 2003 − 1976	+46 (−7.4)	+91 (+10.0)	+29 (−3.2)	+21 (−3.3)	+12 (+1.9)	+4 (+0.3)	+5 (+1.3)	0 (0.0)	0 (0.0)	
Total	444			97			5			546

No significant change was observed at the Niger scale in the proportions of early and semi-late or late varieties ($\chi^2 = 0.032$, df = 1, *P*-value = 0.857). Categories "semi-late" and "late" were pooled for the χ^2 test because of the null frequency of late varieties in the 1976 collection

The regional distribution of early varieties displayed a significant change between 1976 and 2003 ($\chi^2 = 6.353$, df = 2, *P*-value = 0.042). No significant change was observed in the regional distribution of semi-late varieties ($\chi^2 = 2.646$, df = 1, *P*-value = 0.104). Categories "Central" and "Eastern" regions were pooled for this χ^2 test on semi-late varieties because of low frequencies in the 1976 observations. The χ^2 test made without pooling these categories was not significant either ($\chi^2 = 0.270$, df = 2, *P*-value = 0.263)

W = Western region, C = Central region and E = Eastern region

* According to farmers' interviews

Table 4 Number of sorghum accessions in each racial class in the 1976 and 2003 collections

	1976 Collection			2003 Collection		
	No. of accessions	%	Rank	No. of accessions	%	Rank
Durra	55	24.0	2	112	23.7	2
Caudatum	49	21.4	3	103	21.8	3
Guinea margaritiferum	17	7.4	5	22	4.6	6
Others guinea	20	8.7	4	29	6.1	5
Bicolor	9	3.9	6	39	8.2	4
Intermediate forms	79	34.5	1	168	35.5	1
Indeterminate (missing or inappropriate samples)	28			11		
Total	257			484		

Percentages were computed without considering the indeterminate class. Ranks are based on percentages

The χ^2 test, which was performed without including the indeterminate class, showed no significant difference between 1976 and 2003 ($\chi^2 = 7.94$, *P*-value = 0.160 for df 5)

Niger. The guinea race, found mainly in the south of western Niger, had a limited distribution range and was totally absent from eastern Niger. The only notable change concerned the bicolor race, which considerably increased its growing area in western and central Niger between 1976 and 2003, as illustrated in Fig. 3.

Overall, we identified 23 modern varieties that correspond to 4.8% of all accessions. Modern varieties were found in 17 villages (16 located in western and central Niger and one in eastern Niger). The most frequent modern varieties were identified as Sepon 82, Irat 204 and L. 30.

Variety names

According to farmers' information, we distinguished 102 different names designating the 257 accessions of the 1976 collection. On average, the same name was used for 2.5 accessions. Concerning the 484 accessions of the 2003 collection, we noted a slightly higher number of names, with 2.1 accessions bearing the same name (corresponding to 232 different names identified). A total of 54% of the accession names used for the 1976 collection were identically used for the 2003 collection.

In both collections, some names were more frequently used in reference to the varieties. Table 5 presents the names whose occurrence was higher than five in each collection. Some popular names were common in both collections, i.e. Mota, Jan Jari, Hamo Kirey, Socomba and Fara Dawa. This name stability was generally associated with stability in the geographical distribution, e.g. the Jan Jari accessions were collected in the same area in both collections. There were also some changes, like the popular names Lala or Gaouri Boul in the 1976 collection which became rare in the 2003 collection, while other

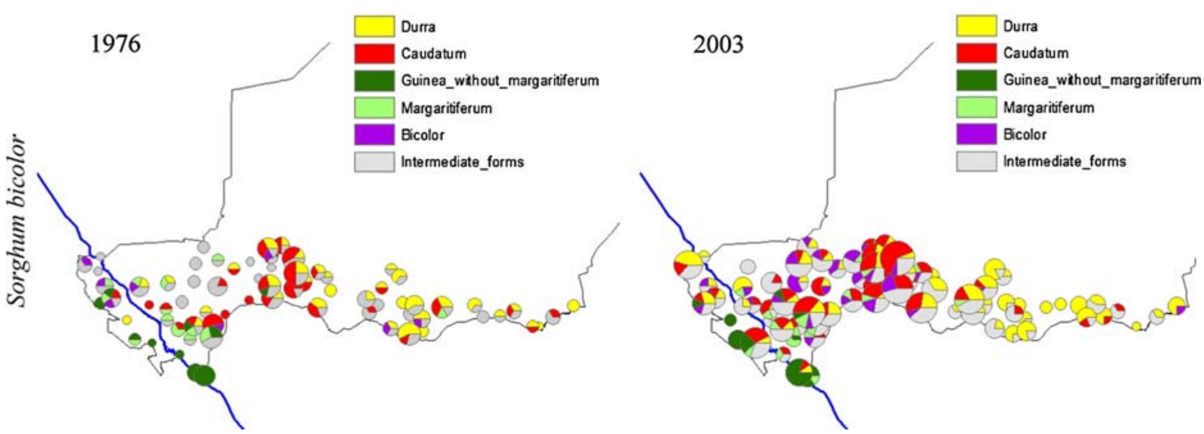

Fig. 3 Geographical distribution of sorghum races per village in Niger. The size of the circles is proportional to the number of sorghum variety names per village

names that were rare in the 1976 collection, like Takanda (one occurrence) or Matché Da Koumniya (two occurrences), were more frequent in the 2003 collection.

Sorghum grain colour

We characterised the two collections for grain colour, considering accessions with non-coloured or light coloured grain (white or yellow grain) and accessions with coloured grain (orange, red or brown grain). The results presented in Table 6 show no significant between 1976 and 2003 for the frequencies of the two types of sorghum (46.1% and 40.1% of varieties with coloured grain, respectively, in 1976 and 2003).

For each collection, the same percentage of accessions with non- or light coloured grain and with coloured grain was also noted at the village scale, considering villages that provided more than one sorghum variety (57/79 villages in 1976 and 65/79 in 2003). The results highlighted a stable equilibrium between the two types of accessions cultivated in the villages. Indeed, in the 1976 collection, 54.0% of accessions had non-or light coloured grain and 46.0% of accessions had coloured grain per village, whereas these proportions were 58.1% and 41.9%, respectively, in the 2003 collection.

Discussion

This study compared changes in the nature and distribution of pearl millet and sorghum varieties in Niger over a quarter of a century, with germplasm collected in 1976 used as reference. The overall hypothesis when we initiated the project was that climatic events and changes in agro-economic conditions in Niger during this period had likely led to a decline in the varietal diversity of this crop, but this was refuted by our results.

Number of collected varieties

A striking result of the study was that about twofold more sorghum and pearl millet accessions were collected in 2003 than in 1976 when using as similar as possible collection methods. In each village, one accession per variety was collected, so twofold more varieties per village were found on average in 2003 than in 1976.

Table 5 Most popular names of sorghum accessions in the 1976 and 2003 collections ranked by number of occurrences

1976 Collection		2003 Collection	
Variety names	Number of occurrences	Variety names	Number of occurrences
Mota	19	Takanda	21
Jan Jari	18	Hamo Kwarey	19
Hamo Kirey	18	Ja Dawa	17
Socomba	13	Fara Dawa	16
Baba Diya	8	Jan Jari	16
Lala	8	Hamo Kirey	15
Gouari Boul	7	Hamo Kana	14
Fara Dawa	6	Matché Da Koumniya	10
		Bagoba	9
		Mota	9
		Kaoura	8
		Makaho Da wayo	8
		Kor Biyu	7
		Mallé	7
		Socomba	7
		Darza	6
		Tallabani	6

Table 6 Frequencies of sorghum varieties in the 1976 and 2003 collections according to grain colour

	No. of sorghum varieties	
	1976 Collection	2003 Collection
Non or light coloured grain	132 (53.9)	282 (59.9)
Coloured grain	113 (46.1)	189 (40.1)
Indeterminate (missing or inappropriate samples)	12	13
Total	257	484

The percentages (in brackets) were calculated without taking the indeterminate class into account

The χ^2 test, which was performed without including the indeterminate class, showed no significant difference ($\chi^2 = 2.37$, P-value $= 0.124$ for df 1)

Several reasons could explain this result:

i. The level of diversity in 1976 might have been underestimated. The 1976 collection was carried out 3 years after the great drought of 1971–73, so it was a post-crisis period. It is unknown whether farmers had recovered their local varieties by that time, or whether farmers relied on external seed sources (e.g. emergency seeds).
ii. Repeated crisis periods favour exchanges at various geographical scales. This could generate "new" varieties simply on the basis of the name. Indeed, a variety is often renamed when it originates from another person or village. This process could have increased the number of variety names in villages.
iii. The 1976 and 2003 collection surveys were not carried out by the same people and thus may not have been carried out in the same way, even though maximum care was taken to reduce this bias. In 1976, the survey/collection staff spent less time in each of the villages visited (3.0 and 1.7 villages visited per day in 1976 and 2003, respectively).

However, a study conducted by Costis (2005) on agronomic and social aspects of millet and sorghum genetic diversity in several villages in Niger concluded that farmers clearly perceived an increase in the number of varieties managed per village between the 1970s and the 2000s. A similar result was obtained on the changes in rice varietal diversity in Maritime Guinea over a similar timespan (Barry et al. 2008). An increase in the number of sorghum landrace names between 1960 and 2000 was also noted by Mekbib (2008) in eastern Ethiopia.

Varietal groups

Niger has numerous pearl millet varietal groups some of which, e.g. the Zongo group, are specific to and emblematic of this country. These groups were maintained between 1976 and 2003 even though a modification in their relative importance or distribution range was noted for some of them.

No change was observed for the major (Haïni Kiré, Zongo, Guerguéra, Ba Angouré) and some minor (Ankoutess and Tamangagi) groups. Maewa, Bazaomé, Moro and Gnieye groups were less cultivated than before even though their geographical distribution had undergone no change. Finally, we observed an increase in the cultivation of Boudouma and Zanfaroua, likely as a result of their early ripening, high production or capacity to adapt to new geographical zones.

With regards to sorghum, Niger as a whole appears to have considerably high racial diversity. In 1976 as in 2003, four of the five basic races and four of the ten intermediate forms were significantly represented among the collected accessions. In other West African countries such as Senegal, Burkina Faso, Mali or Nigeria, this racial diversity is dominated by the guinea race (Viguier 1947; Scheuring et al. 1980; Zongo 1991; Zongo et al. 1993).

In this context, the only significant change in racial diversity between 1976 and 2003 collections concerned the bicolor accessions whose importance in terms of the number of accessions and racial percentages increased in the 2003 collection to the detriment of guinea sorghums. According to farmers interviewed during the collection surveys, these sorghums were mainly sweet sorghums used for direct consumption of the pitch. The bicolor race is known to be the major source of sweet sorghums (Harlan and de Wet 1972). In Niger, their stems are currently sold at the market as a substitute for sugarcane. Their increasing importance as a cash crop may explain the larger geographical distribution and greater importance of this race noted in the 2003 collection survey. Further studies are needed to confirm this trend in terms of the extent of cropping area.

The rate of farmer adoption of modern varieties (4.8% for sorghum and 10.9% for pearl millet) found in the 2003 collection is close to the estimation of Matlon (1985) and Yapi and Debrah (1998) in West Africa (respectively 5 and 8%). Since modern varieties were not collected in 1976, we could not conclude on the evolution of the occurrence of modern varieties between 1976 and 2003. The varieties genetically improved through research exist but they have not been substantially disseminated among farmers as a result of a certain extent of inefficiency in the formal seed distribution system and rather poor farmer acceptance. We can only suspect that their frequency is increasing—a phenomenon that has amplified as a result of the series of difficult years (droughts and low harvests) and has led to relatively massive but not always rational dissemination of improved seeds.

For sorghum, it is noteworthy that modern varieties were almost totally absent from eastern Niger, which appeared to be less affected by rural development as compared to western and central Niger. For millet, it should be noted that the region with the greatest number of modern varieties is the central region, which was revealed to be the most diversified in terms of varieties and the most advanced in terms of agricultural practices.

Regarding coloured and non-coloured grain sorghum, few changes were noted between 1976 and 2003. In West Africa, red and white grain sorghums are grown to meet various production objectives. In Burkina Faso, a neighbouring country of Niger, red sorghums generally mature earlier than white sorghums (Barro-Kondombo et al. 2008). Due to their grain pigmentation, red sorghums are less attractive to birds than white sorghums and this colouring also provides them with some grain mold resistance (Stenhouse et al. 1997). Farmers are thus inclined to accept the lower grain quality of red sorghums (because of the tannin content) compared to that of white sorghum for traditional food preparations. When white sorghums are ripened, red sorghums cease to be used for food and instead serve as basis for traditional beer production or animal feed. In our study, the equilibrium maintained between the two kinds of accessions at the village scale could result from permanent security strategies of variety management and from the diversity of production objectives.

The accession name is another criterion that we considered to analyse the diversity and evolution of the millet and sorghum collections. In this study it was found that the local name of a variety is very frequently related to a remarkable morphological feature of its vegetative parts, inflorescence or seeds, to certain qualities or to a special use by local people (e.g. millet beer). In Niger, grain colour is the main trait considered in naming millet or sorghum varieties. Hence, for millet, Somno Bi means white Somno, Haïni Kiré means red millet in Haussa, while for sorghum, Hamo Kwarey and Hamo Kirey mean white and red sorghum in Zarma, Fara Dawa and Ja Dawa mean white and red sorghum in Haussa, Gaouri Boul and Gaouri Kimé mean white and red sorghum in Kanouri.

This naming system results in distinct genetic unities receiving the same name because they have a specific common trait (e.g. same grain colour). Moreover, over the last 30 years, the relatively widespread series of droughts throughout the country have certainly favoured the dissemination (Allinne et al. 2008) and exchange of seeds of both local and improved varieties. A "new variety" could thus be renamed for ethnic reasons or because the new name is associated with that of the original donor or village, a known personality or current historical event, despite the fact that the "new variety" does not fundamentally differ from the "original variety".

There is consequently very little consistency in naming landraces. Caution should thus be taken when using variety names as a tool for investigating millet and sorghum genetic diversity, as mentioned by Busso et al. (2000) and Chakauya et al. (2006) in studies on pearl millet in Nigeria and sorghum in Zimbabwe, respectively. The difficulties can be clearly illustrated, e.g. there are popular names like Hamo Kwarey or Hamo Kirey, Ja Dawa or Fara Dawa, Mota that each encompass varieties belonging to different sorghum races.

Anthropogenic and climatic factors of importance, and distribution and evolution of variety diversity

The extent of pearl millet diversity in Niger is historically related to the Sahelian domestication of this cereal (Bezançon et al. 2001). In contrast, the extent of sorghum diversity is related to the marked cultural and ethnic influences in this country which, in the past, was an important crossroads for trading between Arab/white and black Africa and between the Niger River and Lake Chad basins. This country is thus marked by the presence of sorghums domesticated in humid regions of West Africa, caudatum sorghums originating from Sudan and Chad and durra sorghums from dry Islamic countries (Harlan and de Wet 1972). On the other hand, from a climatic standpoint, millet and sorghum diversity is higher in more humid areas with often richer soils (southern and central Niger) in comparison to drier areas (western and eastern Niger).

Varietal diversity is also affected by regional differences in the level of agricultural development and the state of advancement of agricultural techniques. For example, in the Nigerian border area (Birni N'Konni-Maradi), the use of agricultural inputs, intercropping, animal traction and ridging are highly developed. Trade with Nigeria is very high, with all positive and negative impacts that can be imagined on seed exchange, production and markets. Moreover, zones where large-scale rural and environmental development projects have been carried out have greatly profited, such as Keïta, with its broad land-recuperation initiatives in spite of a climate that is sometimes unfavourable for rainfed agriculture. Another example is Gaya region in the south of the country, where very high agricultural diversification, favored by richer soils and a more favourable rainfall (higher national yields for millet) can be noted.

Population and rural development changes have contributed to make the central region, in particular the department of Maradi, the zone with the maximum diversity for both crops and for both collections (1976 and 2003). This zone, where agricultural development is the most advanced, has a high population density (52.7 inhabitants per km^2). Agricultural development in Maradi region is mainly based on the improvement of traditional crop systems. It is not based on cash crops, release of plant breeding products nor high intensification practices. Moreover the industrialization remains very limited and agricultural lands continue to increase due to the availability of fallow space. Sorghum benefits from very numerous active development projects in this area. Actually, it was formerly an experimental zone for development projects, particularly those implemented by the World Bank (Guengant and Banoin 2003).

On the other hand, particular agricultural development strategies certainly have a different impact on millet and sorghum varietal diversity, as suggested by the situation in the eastern region (Diffa). This region, which has been markedly affected by an overall decrease in rainfall over the last 30 years, has made a strategic decision to develop irrigated agriculture (which nevertheless represents only 1% of the irrigable land potential in this department). This has involved opting to grow crops such as peppers, which are more productive and better exploited than cereal crops, to the detriment of millet and sorghum crops (only 1% of the area devoted to cropping on a national scale). This could explain the low varietal diversity and yields for these two cereals in this region (in the 1990s, 365 kg/ha for the millet and 107 kg/ha for sorghum (Guengant and Banoin 2003).

Conclusions

Between 1976 and 2003, changes were observed in the geographical distribution of certain varieties, which could be explained by modifications in climatic and agronomic constraints, or by the emergence of new uses (e.g. sweet sorghum) and/or the development of new agricultural practices. Nevertheless, there was very little change in diversity in terms of sorghum races and the main millet varietal groups. For the period covered, climatic and social changes affecting Niger therefore do not seem to have caused the feared varietal erosion of millet and sorghum, and traditional varieties as a whole have been preserved. The variety resilience that could be related to the diversity of accession morphotypes and traditional seed production systems highlights the ability of millet and sorghum to adapt to climatic changes, thus indicating that rainfed cultivation of these crops should be the focus of development in Sahelian countries.

Another reason accounting for the maintenance of a broad millet and sorghum diversity in Niger could be that no cash crops such as cotton, peanut or maize can compete with traditional cereal crops, as is the case in Mali and Burkina Faso where the genetic diversity of sorghums is particularly threatened.

Overall, our results suggest that the attention paid to conservation strategies of the diversity of cultivated plants based upon the continuous cultivation of crops in agroecosystems (Brush 1991) is deserved, as a complementary approach to centralized *ex situ* conservation in genebanks (Tsehaye et al. 2006). Indeed, the diversity resilience observed for millet and sorghum in Niger suggests that erosion is not the only possible fate of crop diversity in agroecosystems located in centers of diversity, even those submitted to multiple changes. Barry et al. (2008) and Mekbib (2008) concluded to the lack of evidence for genetic erosion in local scale studies of rice in Guinea and sorghum in Ethiopia.

The need for a long-term monitoring is obvious, however. In this paper, we have only analyzed data on the variety distribution of pearl millet and sorghum in Niger. Neutral markers and adaptive traits now need to be studied in order to conclude as to whether there have been changes or an absence of changes in the diversity of these crops in Niger over the past three decades. All of these data should constitute a benchmark in terms of existing diversity and methodology for new studies that will be conducted on different spatiotemporal scales.

Acknowledgements Hundreds of Nigerian farmers contributed to this study by providing seed samples and information on their millet and sorghum varieties. The success of surveys and collecting trips would not have been possible without the active participation of Moussa Tidjani (IRD), Djibo Moussa (IRD) and Hassane Yahaya Bissala (ICRISAT), and our drivers Hamza Guire (IRD) and Ousséïni Bouzou (ICRISAT). This research was carried out for the project "Changes in the diversity of cultivated millet and sorghum in Niger between 1976 and 2003: influence of natural and anthropogenic factors", a response to the call for proposals "Biodiversity and global change" of the French Institute of Biodiversity (IFB). The financial grant was provided by the French Ministry of Foreign Affairs (MAE) and the Ministry of Ecology and Sustainable Development (MEDD).

References

Allinne C, Mariac C, Vigouroux Y, Bezançon G, Emmanuel Couturon E, Moussa D et al (2008) Role of seed flow on the pattern and dynamics of pearl millet (*Pennisetum glaucum* [L.] R. Br.) genetic diversity assessed by AFLP markers: a study in south-western Niger. Genetica 133:167–178

Balmford A, Crane P, Dobson A, Green RE, Mace GM (2005) The 2010 challenge: data availability, information needs and extraterrestrial insights. Philos Trans R Soc Lond B Biol Sci 360:221–228

Barro-Kondombo CP, vom Brocke K, Chantereau J, Sagnard F, Zongo JD (2008) Variabilité phénotypiques des sorghos locaux de deux régions du Burkina Faso : la Boucle du Mouhoun et le Centre Ouest. Cah Agricultures 17:107–113

Barry MB, Pham JL, Béavogui S, Ghesquière A, Ahmadi N (2008) Diachronic (1979–2003) analysis of rice genetic diversity in Guinea did not reveal genetic erosion. Genet Resour Crop Evol 55:723–733

Bezançon G, Renno JF, Kumar AK (2001) Millet. In: Charrier A, Jacquot M, Hamon S, Nicolas D (eds) Tropical plant breeding. Cirad, Science Publishers Inc, pp 314–337

Bono M (1973) Contribution à la morpho-systématique des *Pennisetum* annuels cultivés pour leur grain en Afrique occidentale francophone. Agronomie Trop 28:229–356

Brush SB (1991) A farmer-based approach to conserving crop germplasm. Econ Bot 45:153–165

Busso CS, Devos KM, Ross G, Mortimore M, Adams WM, Ambrose MJ et al (2000) Genetic diversity within and among landraces of pearl millet (*Pennisetum glaucum*) under farmer management in West-Africa. Genet Resour Crop Evol 47:561–568

Chakauya E, Tongoona P, Matibiri EA, Grum M (2006) Genetic diversity assessment of *Sorghum* landraces in Zimbabwe using microsatellites and indigenous local names. Int J Bot 2:29–35

Clément JC (1985) Les mils pénicillaires de l'Afrique de l'Ouest : prospections et collectes. International Board for Plant Genetic Resources, Rome, Italy

Costis C (2005) Diversité des mils et sorghos cultivés au Niger: facteurs agro-économiques, socio-économiques et les modes de gestion des variétés. Mémoire de DESS « Gestion des systèmes agro-sylvo-pastoraux en zones tropicales » Université Paris XII

Deu M, Hamon P, Chantereau J, Dufour P, D'Hont A, Lanaud C (1995) Mitochondrial DNA diversity in wild and cultivated sorghum. Genome 38:635–645

FAO-ORSTOM (1977) Prospections des mils pénicillaires et sorgho en Afrique de l'Ouest—Niger-Campagne 1976. Report

Food and Agriculture Organization (2006a) FAOSTAT. Available at http://faostat.fao.org/site/429/default.aspx. Accessed on 06 March 2007

Food and Agriculture Organization (2006b) FAOSTAT. Available at http://faostat.fao.org/site/418/default.aspx. Accessed on 06 March 2007

Food and Agriculture Organization (2006c) FAOSTAT. Available at http://faostat.fao.org/site/408/default.aspx. Accessed on 06 March 2007

Gai J, Zhao T, Xiong D, Li H, Qian Y (2005) A sample survey on genetic erosion of soybean landraces in China. Paper presented at the expert consultation on genetic erosion, methodologies and indicators. ICRISAT Patancheru, India, pp 19–21

Guengant JP, Banoin M (2003) Dynamique des populations, disponibilités en terres et adaptation des régimes fonciers: le cas du Niger. In: Gendreau F, Mumpasi Lututala M (eds) FAO-CICRED

Hammer K, Knüpffer H, Xhuveli L, Perrino P (1996) Estimating genetic erosion in landraces – two cases studies. Genet Resour Crop Evol 43:329–336

Harlan JR, de Wet JMJ (1972) A simplified classification of cultivated sorghum. Crop Sci 12:127–176

Matlon PJ (1985) Analyse critique des objectifs, méthodes et progrès accomplis a ce jour dans l'amélioration du sorgho et du mil: une étude de cas de l'Icrisat/Burkina Faso. In: Technologies appropriées pour les paysans des zones semi-arides de l'Afrique de l'Ouest. Université de Purdue, USA

Mekbib F (2008) Genetic erosion of sorghum (*Sorghum bicolor* (L.) Moench) in the centre of diversity, Ethiopia. Genet Resour Crop Evol 55:351–364

Morin SR, Calibo M, Garcia-Belen M, Pham JL, Palis F (2002) Natural hazards and genetic diversity in rice. Agric Human Values 19:133–149

Peroni N, Hanazaki N (2002) Current and lost diversity of cultivated varieties, especially cassava, under swidden cultivation systems in the Brazilian Atlantic Forest. Agric Ecosyst Environ 92:171–183

Roussel B (1999) Déforestation des bas-fonds sahélo-soudaniens du Niger central : de la « brousse noire » aux cultures maraîchères. Autrepart 9:17–32

Scheuring JF, Konate IM, Toure S (1980) The Malian sorghum collection. Sorghums Newsl 23:33635

Snowden JD (1936) The cultivated races of sorghum. Adlard, London

Stenhouse JW, Bandyopadhyay R, Singh SD, Subramanian V (1997) Breeding for grain mold resistance in sorghum. In: International conference on genetic improvement of sorghum and pearl millet, September 22–27, 1996, Lubbock, (USA), Insortmil and Icrisat

Teklu Y, Hammer K (2006) Farmers' perception and genetic erosion of tetraploid wheats landraces in Ethiopia. Genet Resour Crop Evol 53:1099–1113

Tostain S (1990) Rapport de mission ICRISAT/ORSTOM. Octobre-novembre 1990. Rapport multigraphié, ORSTOM, Paris

Tostain S (1994) Evaluation de la diversité génétique des mils pénicillaires diploïdes (*Pennisetum glaucum* (L.) R. Br.) au moyen de marqueurs enzymatiques. Etude des relations entre formes sauvages et cultivées. Thèse de doctorat de l'Université de Paris-Sud, TDM No. 124, 331 pp. ORSTOM Editions, Paris, France

Tsehaye Y, Berg T, Tsegaye B, Tanto T (2006) Farmers' management of finger millet (*Eleusine coracana* L.) diversity in Tigray Ethiopia and implications for on-farm conservation. Biodivers Conserv 15(13):4289–4308

United Nations Environment Programme (2002) Report on the sixth meeting of the conference of the parties to the convention on biological diversity (UNEP/CBD/ COP/6/20/Part 2) strategic plan for the convention on biological diversity, decision VI/26 (Convention on Biological Diversity, 2002). Available at http://www.biodiv.org/decisions/default.aspx?m=COP-06&id=7200&lg=0 (accessed 06 March 2007)

United Nations Environment Programme (2004) Conference of the Parties to the Convention on Biological Diversity. Strategic plan : future evaluation of progress, Decision VII/30 (Convention on Biological Diversity 2004). Available at http://www.biodiv.org/decisions/default.aspx?m=COP-07&id=7767&lg=0 (accessed 06 March 2007)

Viguier P (1947) Les sorghos et leur culture au Soudan français. Grande Imprimerie Dakar

Willemen L, Scheldeman X, Soto Cabellos V, Rafael Salazar S, 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. Genet Resour Crop Evol 54:1599–1612

Yapi AM, Debrah SK (1998) Evaluation de l'impact des recherches variétales de sorgho et de mil en Afrique de l'Ouest et du Centre. In: Ratnadass A, Chantereau J, Gigou J (eds) Amélioration du sorgho et de sa culture en Afrique de l'Ouest et du Centre. Atelier de Restitution du Programme Conjoint sur le Sorgho, 17–20 mars 1997, Bamako, Mali. Colloques—CIRAD

Zongo JD (1991) Ressources génétiques des sorghos (*Sorghum bicolor* (L.) Moench) du Burkina Faso : Evaluation agromorphologique et génétique. Thèse de docteur ès sciences naturelles. Université d'Abidjan, Côte d'Ivoire

Zongo JD, Gouyon PH, Sandmeier M (1993) Genetic variability among sorghum accessions from the Sahelian agroecological region of Burkina Faso. Biodivers Conserv 2:627–636