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Proceedings of the National Academy of Sciences, India Section B: Biological Sciences

ISSN 0369-8211

Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci.
DOI 10.1007/s40011-020-01183-1



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RESEARCH ARTICLE

Assessment of Agro-morphological Performances of 56 Accessions of *Pennisetum glaucum* with Grain and Fodder Potentials in Niger

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Received: 17 November 2019/Revised: 13 January 2020/Accepted: 2 March 2020
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Abstract Morphological characterization is the first step in studying the genetic diversity of cultivated plants. The present study examined agro-morphological performance of the pearl millet local accessions collected across the Niger country, aimed to: (a) characterize, (b) discriminate morphologically the pearl millet accessions groups and (c) identify the pearl millet genotypes with promising grain and fodder potential. Fifty-six pearl millet accessions collected in the eight Niger regions (Agadez, Diffa, Dosso, Niamey, Tahoua, Tillabéry and Zinder) were evaluated in an Alpha lattice design with 3 replicates in Djirataoua and Kollo localities. Twenty-five specific agro-morphological descriptors were used for this purpose. The data set was

submitted to descriptive analyses and indicated wide significant accessions diversity. Hierarchical cluster analysis revealed 5 phenotypic groups, and principal component analysis showed 3 components representing 60.45% of total variability. Canonical discriminant analysis indicated 20 major traits of the discriminated phenotypic groups. Group G₁ holds early accessions, with average performances in grain production and low performances in biomass production. Group G₂ holds early accessions, with good performances for grain production and fodder biomass. Group G₃ holds early–late accessions with good grain performances and low fodder performances. G₄ holds both early and late accessions with good fodder performance and good grain performance. Finally, G₅ includes both late accessions with better fodder performances and bad grain performances. These groups can be used as parents in the creation of improved varieties for better grain and fodder production performance. Otherwise, Djirataoua would be ideal for the tested accessions to express their agro-morphological potentials.

Significance Statement Pearl millet is the main food cereal in Niger Republic. However, increasingly, after the grain harvest, the straw from pearl millet is collected to make up for the chronic forage deficit. However, straw is supposed to remain in the fields to improve fertility and prevent soil erosion. This agro-morphological characterization study of pearl millet accessions will eventually help farmers identify and select pearl millet varieties that are better adapted to their production objectives (grain and/or fodder).

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Keywords Agro-morphological traits · Diversity · Fodder · Grain · Accessions · Millet · Niger

Introduction

Climatic hazards and population growth in Sahelian areas are nowadays reflected in the extension of cultivated areas, overgrazing, erosion and the decline in soil fertility [1]. As a result, livestock breeders are becoming more and more sedentary. Moreover, the livestock partial transfer from the pastoral zone to agricultural land, synchronous with the drought, highly encourages farmers engagement in animal husbandry [2]. Competition between nomadic herders and farmers for space and the increasing recovery of crop residues by farmers and agro-pastoralists threaten transhumance which is the bedrock of Sahelian pastoral livestock systems [3, 4]. The Sahel region is now in prey to deep changes, and, with the drought that has been affecting it for more than a decade, ecosystems are gradually degrading and pastoral areas are reduced drastically [5]. Fodder production is greatly reduced in the dry season, forcing herbivore livestock to migrate or size reduced by mortality [6].

This fodder deficit context supported by natural scourges and anthropic actions clearly calls for strong alternatives for meeting the domestic livestock needs. Fodder production from local resources, among the existing solutions, includes pearl millet (*Pennisetum glaucum* (L.) R. Br) being a preferential species. Indeed, pearl millet is one of the most cultivated and consumed plants in the Sahel such as Niger [7, 8]. This status of pearl millet is due to its large-scale production and its remarkable and particular tolerance for drought. This cereal species originated from Africa and is grown in various parts of the continent and the world. Forevermore, the genetic diversity of millet in Africa also depends on the great diversity of African agro-ecological zones [8–10]. The millets variability appeared to be more important because it is mainly reflected in multiplicity of sociolinguistics or local names [11, 12]. Wide-scale surveys at the level of the Niger country have generated a significant number of samples stored in gene banks at the National Institute for Agricultural Researches of Niger (INRAN) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) [13] or used by breeding programmes [14]. Problems resulted from large number of samples to be kept have required strategies for limiting sampling sizes which was found by reducing the number of samples collected in a participatory way [15]. Participatory approach offers the way to reduce samples to be collected without damaging the conserved genetic diversity [14]. Surveys that have been carried out during

collections resulted in general knowledge on the genetic material built from farmers' perceptions [14]. But this knowledge from surveys lacks specific and objective ideas of the diversity of the material collected. Thus, a better use of the collection might require an evaluation and characterization of the germplasm. Indeed, previous works have shown that describing and structuring this genetic diversity for its better conservation and utilization wisely require agro-morphological assessment [14, 16–19]. Such an assessment in the context of agro-morphological variability of millet accessions is based on more appropriate multivariate analyses (some references to show use of multivariate to assess morphological variability). Thus, the perspective of efficient use of millet germplasm in Niger and its preservation from any genetic erosion can bring to the following concerns:

- What agronomic and morphological traits could better separate accessions?
- What is the agro-morphological variability of the 56 accessions collected across the Niger Republic?
- Which accessions are efficient and which features are interesting for the future selection and varietal improvement work for better grain and fodder production of millet?

This study, which seeks the agro-morphological performances of collected pearl millet accessions, is specifically concerned with (a) characterizing agro-morphological traits of collected millet accessions, (b) determining the agro-morphological diversity structure of collected millet accessions, and (c) identifying promising millet genotypes for their grain and fodder potentials for use in future breeding programmes in Niger.

Material and Methods

Test Installation Sites

The experiment took place during the 2016 rainy season. Tests were installed at two of INRAN stations, such as:

- (I) The N'Dounga Experimental Station located at Kollo (02°18'28" E; 13°25'00" N), 25 km south-eastern Niamey. Its climate is Sahelian with irregular and unevenly distributed rainfall over time and space which averages 500 mm per year [20]. Soils are typical tropical ferruginous with a silty–sandy texture and a good depth [21]. Prevailing winds are the Harmattan, i.e. a hot and dry wind blowing from the west to the east and the monsoon, i.e. a hot and humid wind blowing from the east to the west.

(II) Djirataoua irrigated area (13°20'0" N, 7°7'60" E), located 7 km south-eastern Maradi [22]. The climate is Sahelo-Sudanese with a rainfall averaging 600 mm, between June and September. Average temperatures range from 22 to 32 °C. Soils are developed on alluvial deposits of great texture diversity ranging from fine texture (clay) to coarse texture (sand, sandy-silt) with moderately low soil fertility [22, 23]. Two types of winds annually blow in Djirataoua as in the whole Niger [24]:

- (a) The Boreal or Harmattan trade wind (dry wind, cool at night and relatively hot during the day) blowing from October to April in a north-east to east directions. It usually generates the drying out of herbaceous plants and the loss of leaves in many woody plants;
- (b) From May, the Harmattan is relayed by the monsoon, a wind direction south-west, hot and humid favouring the rains establishment or arrival. The windiest months are January, February and December which average wind speeds ranges from 2.9 to 3.1 m/s. The lowest values of wind speed (< 2 m/s) are observed from August to October which correspond to the rainy period [24].

Plant Material

The plant material used consists of 56 accessions of pearl millet (*Pennisetum glaucum* (L.) R. Br.) which were collected from January to February 2016. It is composed of 49 accessions collected in 32 villages known as the best pearl millet producers of the Niger Republic (Fig. 1) and 7 hybrid accessions from the Regional Centre for Agricultural Research (CERRA) in Kollo (Table 1).

Experimental Design and Cropping Conditions

The test was conducted in an 8 * 7 alpha lattice device with 3 replicates, i.e. 8 incomplete blocks containing 7 experimental units each and each unit receiving a *P. glaucum* accession. The blocks are 2 m apart, with a 3 m wide driveway separating the repetitions. Each elementary plot covers 12.8 m² (6.4 m × 2 m) and is one meter separate from the other.

The extreme plots are 1 m from the edge. Each elementary plot has been labelled: name, origin of accession, code and serial number. The tests were carried out on 11 and 18 July 2016, respectively, on the Kollo and Maradi sites after ploughing followed by levelling of the experimental plot. The harvests are carried out on 23 and 10 November 2016, respectively, at the Kollo and Djirataoua

sites. Sowings were carried out in seed holes with spacings of 0.8 m between seed holes on the line and 1 m between the lines (1 m × 0.8 m), i.e. a sowing density of 12500 seed holes/ha. A demarcation to three plants per bunch was done 2 weeks after emergence. The entire test covers 3600 m² (80 m × 45 m).

The seeds have been previously treated with the fungicide Calthio C 50 WS [thiram (250 g/kg), chlorpyrifos ethyl (250 g/kg)], produced by ARYSTA LIFESCIENCE (France). The fertilizers used were mainly NPK mineral fertilizers (15–15–15) and 46% N urea applied at 100 kg/ha in micro-doses. While NPK was applied at seeding alone, urea was applied at 14 days after seeding (DAS) for the first time and at 42 DAS for the second time. Thinning was done at 3 plants, and the missed seed holes were reseeded or transplanted. Two weeding took place at Kollo and three at Djirataoua with regard to the speed of weeding.

Traits and Measurement Methods

The majority of the traits studied were those described by IBPGR and ICRISAT [26]. A total of 25 characters were used to describe the 56 accessions of *P. glaucum*. Observations and measurements were made on 3 plants randomly selected on the central lines for each elementary plot, representing a number of 9 individuals per accession.

Statistical Data Analysis

The accessions performances were evaluated by determining for each trait, the minimum and maximum values, as well as the values of mean, standard deviation and the coefficient of variation. A three-way ANOVA followed by the means comparison was performed to determine the traits that discriminate the accessions. A three-way ANOVA was also performed to test, respectively, how the pure effects of the factors such as “Block”, “Site”, “Accession”, as well as the interactive effects such as “Block * Site”, “Block * Accession”, “Site * Accession” and “Block * Site * Accession” affected the whole agro-morphological traits measured and to isolate significant differences among accessions, sites and experimental blocks. Pearson correlations were examined between traits followed by the comparison of averages by the Tukey's test at the 5% probability threshold. The most representative traits were searched throughout the principal component analysis (PCA). The hierarchical cluster analysis (HCA) using the Ward's method specifies the degree of divergence between discriminated groups. The isolated groups were characterized by canonical discriminant analysis (CDA). The whole data set was analysed using XLSTAT Software Version 2015.4.01 [27].

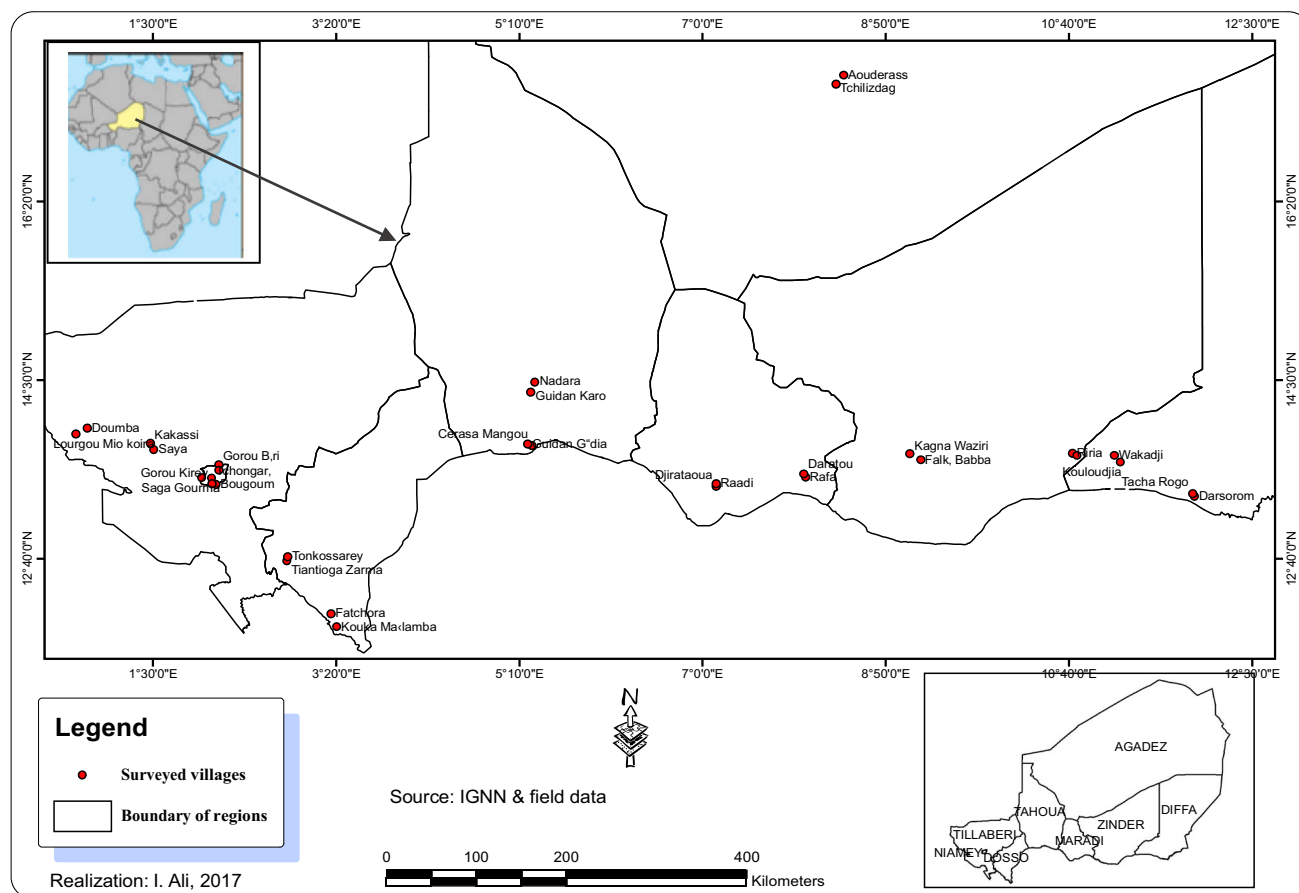


Fig. 1 Location of collection sites of pearl millet accessions

Results and Discussion

Variability of Agro-morphological Traits of the Millet Collection

Morphological characterization is essential in describing and classifying the germplasm of cultivated plants [18]. Indeed, since knowing genetic variability is essential in varietal selection [19, 28, 29], highlighting this variability is essential in describing genetic resources [18]. Thus, the results from the descriptive analysis indicated significant differences between the minimum and maximum for many traits such as number of days sowing-maturity, plant height, spikes weight, number of grains per spike and fodder biomass (Table 2).

The growth cycle averages 93.48 ± 1.08 days, with the earliest maturing from 60 days after sowing and the latest at 140 days. Plants can reach 400 cm for large varieties, with an average of 254.18 ± 2.19 cm. The spikes weight reaches 1037.5 g per m^2 with an average of 350.08 ± 9.43 g per m^2 . There are up to 8550.72 grains per spike with an average of 2889.49 ± 69.00 grains per

spike. The fodder biomass averages 1233.60 ± 67.45 g, up to 9782.44 g per m^2 .

The analysis of variance highlighted highly significant differences between accessions for all the studied traits, with the exception of number of productive tillers (NTfP), number of unproductive tillers (NTuP), 1000-grain weight (PMG), harvest index (IR), yield at threshing (RdtBat), number of days sowing-maturity (cycle) and appearance of foliage at maturity (SG).

Therefore, the sites differed significantly for all variables analysed except leaf width (LaF), number of internodes (NETRN), downy mildew incidence (DM), 1000-grain weight (PMG), yield at threshing (RdtBat), grain weight per spike (PDGEpi), number of grains per spike (NGEpi) and number of days sowing-maturity (Cycle). On the other hand, the “Block” effect is significant for 7 out of 25 variables: fresh mass, dry mass, grains weight, fodder biomass, weight of grains per spike, number of grains per spike and appearance of foliage at maturity.

The effect of the “Block * Site” interaction is significant for 4 out of 25 variables: spike circumference, fresh mass, weight and number of grains per spike.

Table 1 List of pearl millet accessions by collection area, number and code. *Source:* Collection data and missing contact information from ReNaLoc [25]

No.	Accessions local names	Codes	Regions	Villages	Latitude	Longitude
1	Mixte	Mix	Maradi	Djirataoua	N13°24',450	E007°08',376
2	Hatchi	Hat	Zinder	Kilakinna Manga	N13°43',356	E010°44',995
3	Dan-Arba'in	DanRir	Zinder	Riria	N13°44',651	E010°42',271
4	Guéro-A	GuéA	Niamey	Gorou Béri	N13°37',614	E002°09',605
5	Bondâbia	Bon	Tillabéry	Lourgou	N13°56',658	E000°43',808
6	Gamoji	Gam	Zinder	Falki Babba	N13°40',502	E009°11',022
7	Ouyan-bijini	Ouybij	Maradi	Darâtou	N13°32',011	E008°00',805
8	Goudourbia	Gou	Tillabéry	Doumba	N14°00',249	E000°50',760
9	Bâ-Angouré	BâA	Zinder	Falki Babba	N13°40',502	E009°11',022
10	Guéro-B	GuéB	Niamey	Gorou Béri	N13°37',614	E002°09',605
11	HKP	HKPDji	Maradi	Djirataoua	N13°24',450	E007°08',376
12	Ankoutess	AnkDar	Maradi	Darâtou	N13°32',011	E008°00',805
13	Ankoutess	AnkAwd	Agadez	Awderass	N17°37',679	E008°24',760
14	HKP	HKPGor	Niamey	Gorou Kirey	N13°25',964	E002°05',466
15	Bâ-Danji	BâD	Zinder	Riria	N13°44',651	E010°42',271
16	Zongo	ZonDar	Maradi	Darâtou	N13°32',011	E008°00',805
17	Guerguéra	GueGui	Tahoua	Guidan Karo	N14°22',282	E005°16',898
18	Goudiss-B	GouB	Diffa	Darsarom	N13°18',208	E011°55',512
19	Haïnikirey	HaïLou	Tillabéry	Lourgou	N13°56',658	E000°43',808
20	Haïnikirey	HaïFot	Dosso	Fotchorâ	N12°05',763	E003°17',032
21	Chanono	Cha	Agadez	Awderass	N17°37',679	E008°24',760
22	Somnobia	SomFot	Dosso	Fotchorâ	N12°05',763	E003°17',032
23	Somnokoirey	SomKoi	Dosso	Fotchorâ	N12°05',763	E003°17',032
24	Haïnikirey	HaïSay	Tillabéry	Saya	N13°47',032	E001°30',705
25	Haïnikirey	HaïDou	Tillabéry	Doumba	N14°00',249	E000°50',760
26	Idon-hawaynia	IdoHaw	Maradi	Djirataoua	N13°24',450	E007°08',376
27	Niaye	Nia	Tillabéry	Lourgou	N13°56',658	E000°43',808
28	Maiwa	Maï	Maradi	Darâtou	N13°32',011	E008°00',805
29	Goudiss-A	GouA	Diffa	Darsarom	N13°18',208	E011°55',512
30	Haïni-bi	Haï	Niamey	Gorou Kaina	N13°34',186	E002°09',725
31	Nassounga	Nas	Dosso	Tiantioga	N12°38',464	E002°50',594
32	Môro	Môr	Diffa	Darsarom	N13°18',208	E011°55',512
33	Gassama	Gas	Diffa	Kouloudjia	N13°39',157	E011°11',001
34	Guerguéra	GueDji	Maradi	Djirataoua	N13°24',450	E007°08',376
35	Tchinguel	Tch	Tillabéry	Lourgou	N13°56',658	E000°43',808
36	Dan-Arba'in	DanKil	Zinder	Kilakinna Manga	N13°43',356	E010°44',995
37	Tamatagna	Tam	Maradi	Darâtou	N13°32',011	E008°00',805
38	Fêreh	Fêr	Zinder	Riria	N13°44',651	E010°42',271
39	Bâ-Angouré Baki	BâABak	Zinder	Falki Babba	N13°40',502	E009°11',022
40	Darankôba	Dar	Dosso	Tiantioga	N12°38',464	E002°50',594
41	MBounga	MBo	Dosso	Tiantioga	N12°38',464	E002°50',594
42	Kôlâla	Kôl	Tillabéry	Lourgou	N13°56',658	E000°43',808
43	Haïnikirey	HaïSag	Niamey	Saga Gourma	N13°29',729	E001°59',396
44	Batoukouché	Bat	Zinder	Falki Babba	N13°40',502	E009°11',022
45	Zongo	ZonAwd	Agadez	Awderass	N17°37',679	E008°24',760
46	Zongo	ZonDji	Maradi	Djirataoua	N13°24',450	E007°08',376
47	Somno Bio	SomTia	Dosso	Tiantioga	N12°38',464	E002°50',594
48	Zongo	ZonWak	Diffa	Wakadji	N13°43',224	E011°07',440

Table 1 continued

No.	Accessions local names	Codes	Regions	Villages	Latitude	Longitude
49	Dan-Arba'in	DanWak	Diffa	Wakadji	N13°43',224	E011°07',440
50	GamojixHKB	V1	Tillabéry	CERRA Kollo	N13°20',144	E002°19',088
51	GamojixpEO	V2	Tillabéry	CERRA Kollo	N13°20',144	E002°19',088
52	GamojixMoro	V3	Tillabéry	CERRA Kollo	N13°20',144	E002°19',088
53	3/4 HKxGamoji	V4	Tillabéry	CERRA Kollo	N13°20',144	E002°19',088
54	3/4 SouanaxGamoji	V5	Tillabéry	CERRA Kollo	N13°20',144	E002°19',088
55	CMVis94206xGamoji	V7	Tillabéry	CERRA Kollo	N13°20',144	E002°19',088
56	MoroxHKpGMS	V8	Tillabéry	CERRA Kollo	N13°20',144	E002°19',088

Table 2 Averages, minima, maxima and coefficient of variation of the agro-morphological analysed traits

Traits	Units	Codes	Min	Max	Average	StDev	CV (%)
Plant height	cm	HTR	0.00	400.00	254.18	2.19	15.76
Stem diameter	cm	DTIG	2.83	7.33	5.17	0.05	16.64
Plant base diameter	cm	Dbase	21.00	146.00	63.25	1.24	35.80
Spike circumference	cm	CIRE	0.00	14.13	7.98	0.11	25.13
Spike length	cm	LEP	0.00	110.67	53.11	1.18	40.61
Number of productive tillers per plant	–	NTfP	0.00	47.00	8.42	0.30	65.24
Number of unproductive tillers per plant	–	NTuP	0.00	19.50	6.43	0.15	43.25
Leaf length	cm	LoF	36.00	110.00	73.06	0.63	15.69
Leaf width	cm	LaF	0.00	9.00	4.82	0.05	20.54
Number of internodes per stem	–	NETRN	2.00	15.00	9.60	0.09	16.91
Downy mildew incidence	%	DM	0.00	92.86	10.97	0.64	106.65
Number of seed holes harvested	–	NPR	0.00	12.00	10.01	0.15	27.68
Number of spikes harvested per plot	–	NEP	0.00	24.00	8.67	0.23	47.66
Fresh mass produced per square meter	g/m ²	PMF	0.00	7650.00	1791.31	71.86	73.43
Dry mass produced per square meter	g/m ²	PMS	0.00	9454.94	1100.12	65.17	108.42
Weight of harvested spikes per square meter	g/m ²	PDE	0.00	1037.50	350.08	9.43	49.29
Grain weight per square meter	g/m ²	PDG	0.00	721.25	216.59	6.69	56.57
Fodder biomass per square meter	g/m ²	PBF	0.00	9782.44	1233.60	67.45	100.08
Grain weight per spike	g	PMG	5.33	13.90	9.37	0.11	21.07
Number of grains per spike	–	IR	0.00	250.25	33.26	1.42	77.40
1000-Grain weight	g	RdtBat	0.00	314.29	62.10	1.13	33.15
Harvest index	%	PDGEpi	0.00	78.67	26.31	0.60	41.66
Yield at threshing	%	NGEpi	0.00	8550.72	2889.49	69.00	43.64
Number of days from sowing-maturity	day	Cycle	60.00	140.00	93.48	1.08	21.22
Stay green (appearance of foliage at maturity)	Scale 1–3	SG	1.00	3.00	1.60	0.04	44.65

StDev standard deviation, *CV* coefficient of variation, *Min* minimum, *Max* maximum

The “Block and Accession” interaction was significant for 4 out of 25 variables: plant base diameter, spike circumference, downy mildew incidence and fresh mass. Finally, the “Accession * Site” interaction was significant for 8 out of 25 variables, in particular: downy mildew incidence, fresh mass, dry mass, weight of spikes, weight of grains, fodder biomass, weight of grains per spike and number of grains per spike (Table 3).

Covariations Between Studied Traits

Table 4 shows the total correlation coefficients between agro-morphological traits. The positive and significant correlations observed highlighted the following features: height and stem diameter ($R^2 = 0.25$; $P < 0.0001$); spike length and fresh mass ($R^2 = 0.04$; $P = 0.0001$); number of seed holes harvested and number of spikes ($R^2 = 0.41$;

Table 3 Results of the three-way analysis of variance (three-way ANOVA) on the 25 agro-morphological traits of the 56 accessions of pearl millet cultivated in Niger

	Block F	SITE F	Accession F	Block * SITE F	Block * Accession F	SITE * Accession F	Block * SITE * Accession F
HTR	0.64ns	54.27***	5.09***	0.59ns	1.16ns	1.03ns	0.81ns
DTIG	1.07ns	193.64***	3.93***	0.87ns	1.32ns	0.54ns	0.85ns
Dbase	1.41ns	377.72***	2.57***	0.43ns	1.57*	1.20ns	0.62ns
CIRE	1.67ns	83.40***	2.74***	4.87***	1.40*	1.06ns	1.74**
LEP	0.74ns	10.82**	11.22***	0.94ns	0.94ns	0.72ns	0.38ns
NTfP	1.01ns	5.22*	0.96ns	1.50ns	0.71ns	1.04ns	1.13ns
NTuP	1.50ns	6.00*	0.74ns	0.64ns	0.80ns	1.14ns	0.86ns
LoF	0.46ns	21.07***	3.33***	0.24ns	0.90ns	0.82ns	1.37*
LaF	0.79ns	0.87ns	1.90**	0.96ns	0.85ns	0.78ns	1.17ns
NETRN	1.63ns	0.00ns	3.17***	0.34ns	1.13ns	0.96ns	1.01ns
DM	1.05ns	0.29ns	2.59***	1.49ns	1.40*	1.83**	1.82**
NPR	0.71ns	173.52***	2.56***	0.42ns	0.98ns	1.33ns	0.40ns
NEP	1.01ns	363.33***	3.16***	1.96ns	1.22ns	1.14ns	1.03ns
PMF	4.39**	624.47***	7.29***	4.45**	1.51*	3.93***	2.13***
PMS	2.28*	329.40***	3.19***	1.88ns	1.13ns	2.87***	14.07***
PDE	1.93ns	316.49***	3.36***	1.23ns	1.32ns	1.66*	1.31ns
PDG	3.08**	277.40***	4.15***	1.23ns	1.22ns	2.63***	1.64**
PBF	2.38*	358.71***	3.44***	1.79ns	1.15ns	2.95***	12.68***
PMG	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns
IR	2.06ns	69.04***	1.37ns	0.62ns	0.82ns	1.25ns	0.81ns
RdtBat	1.00ns	0.06ns	1.08ns	0.51ns	0.50ns	0.81ns	0.72ns
PDGEpi	2.74*	2.07ns	4.51***	2.71*	1.30ns	2.01**	0.90ns
NGEpi	3.07*	1.31ns	5.36***	2.79*	1.33ns	1.90**	0.90ns
Cycle	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns
SG	3.66**	60.44***	1.28ns	0.88ns	1.11ns	0.95ns	0.62ns

HTR plant height, *DTG* stem diameter, *Dbase* plant base diameter, *CIRE* spike circumference, *LEP* spike length, *NTfP* number of productive tillers per plant, *NTuP* number of unproductive tillers per plant, *LoF* leaf length, *LaF* leaf width, *NETRN* number of internodes per stem, *DM* downy mildew incidence, *NPR* number of seed holes harvested, *NEP* number of spikes harvested per plot, *PMF* fresh mass, *PMS* dry mass, *PDE* spikes weight, *PDG* grains weight, *PBF* fodder biomass, *PGEpi* grain weight per spike, *NGEpi* number of grains per spike, *PMG* 1000-grain weight, *IR* harvest index, *RdtBat* yield at threshing, *Cycle* number of days sowing-maturity, *SG* stay green

*(0.05): significant; **(0.005): highly significant; ***(0.0001): very highly significant

$P < 0.0001$), spikes and grains weights ($R^2 = 0.84$; $P < 0.0001$). In addition, the dry mass is positively correlated with fodder biomass ($R^2 = 0.99$; $P < 0.0001$) but negatively with the harvest index ($R^2 = 0.24$; $P < 0.0001$). The weight of grains per spike is positively correlated to the number of grains per spike ($R^2 = 0.74$; $P < 0.0001$).

The high agro-morphological diversity observed is attributable to the farmers' seed management practices, genotypic differences or agro-ecological factors [9, 17, 30]. Indeed, many authors had mentioned variety exchanges between farmers as a source of significant diversity between cultivated plant populations [31, 32]. In addition, the predominance of poly-variety culture in the cropping system could also be accused. This diversity would be even more accentuated by the strong allogamy characteristic of

millet in reproduction [33, 34]. McKey et al. [35] had shown that the presence of several varieties of cassava, each well differentiated from the others, in the same field would produce highly heterozygous individuals. In fact, it was a practice of Native American farmers to maintain a high varietal and genetic diversity of this plant. Therefore, what would be the structure of this genetic diversity of pearl millet accessions throughout the Niger Republic?

Structuring of Agro-morphological Diversity

The hierarchical cluster analysis (HCA) based on averages values of the 25 variables draws the dendrogram on the Ward aggregation method (Fig. 2). Five phenotypic groups

Table 4 Covariations analysis of agro-morphological traits measured within 56 accessions of pearl millet grown in the Niger Republic

	HTR	DTIG	Dbase	CIRE	LEP	NTIP	NTIP	LoF	LaF	NETRN	DM	NPR	NEP	PMF	PMS	PDE	PDG	PBF	PMG	IR	RdtBat	PDGEpi	NGEpi	Cycle	SG	
HTR	1																									
DTIG	0.50**	1																								
Dbase	0.06	-0.14*	1																							
CIRE	-0.17*	-0.1	0.23**	1																						
LEP	0.56**	0.35**	0.31**	-0.09	1																					
NTIP	0.01	-0.02	-0.09	-0.15*	-0.11*	1																				
NTIP	0.14*	0.24**	0.05	0.01	0.11*	0.03	1																			
LoF	0.49**	0.41**	0.07	-0.07	0.39**	-0.03	0.20*	1																		
LaF	0.29**	0.27**	0.1	0.07	0.29**	-0.05	0.13*	0.48**	1																	
NETRN	0.38**	0.34**	0.17*	0.03	0.26**	0.01	0.13*	0.42**	0.29**	1																
DM	-0.08	-0.06	-0.04	-0.14*	-0.14*	0.09	-0.04	-0.06	0.03	0.03	1															
NPR	0.34**	0.31**	-0.39**	-0.20*	0.08	0.1	0.01	0.13*	0.03	0.02	-0.11*	1														
NEP	0.26**	0.28**	-0.40**	-0.36**	-0.14*	0.21**	0.05	0.07	-0.08	0.01	-0.1	0.64**	1													
PMF	0.55**	0.57**	-0.22**	-0.32**	0.21*	0.17*	0.15*	0.40**	0.17*	0.31**	-0.08	0.46**	0.60**	1												
PMS	0.37**	0.45**	-0.29**	-0.18*	0.08	0.16*	0.05	0.28**	0.07	0.1	-0.08	0.41**	0.48**	0.64**	1											
PDE	0.39**	0.45**	-0.26**	-0.30**	0.20*	0.17*	0.13*	0.20*	0.06	0.12*	-0.12*	0.59**	0.72**	0.65**	0.47**	1										
PDG	0.28**	0.35**	-0.29**	-0.26**	0.13*	0.19*	0.14*	0.12*	0.03	0.02	-0.12*	0.53**	0.62**	0.45**	0.33**	0.92**	1									
PBF	0.38**	0.47**	-0.29**	-0.19*	0.1	0.16*	0.05	0.29**	0.08	0.11*	-0.09	0.42**	0.50**	0.66**	0.99**	0.50**	0.35**	1								
PMG	0.12*	0.13*	0.13*	-0.03	0.16*	-0.09	0.03	0.11*	-0.02	0.03	-0.05	-0.05	-0.12*	0.13*	0.09	0.08	0.04	0.1	1							
IR	-0.21**	-0.31**	0.29**	0.14*	-0.03	-0.04	0.07	-0.21*	-0.14*	-0.02	-0.11	-0.18*	-0.20*	-0.34**	-0.49**	-0.08	0.05	-0.49**	0.02	1						
RdtBat	-0.17*	-0.14*	-0.1	0.06	-0.12*	0.02	0.03	-0.17*	-0.02	-0.13*	-0.04	-0.11*	-0.1	-0.23**	-0.17*	-0.02	0.25**	-0.19*	-0.03	0.26**	1					
PDGEpi	0.1	0.15*	0.13*	0.1	0.31**	-0.03	0.12*	0.09	0.12*	0.05	-0.05	-0.08	-0.25**	-0.05	-0.07	0.31**	0.49**	-0.08	0.17*	0.32**	0.41**	1				
NGEpi	0.08	0.11*	0.07	0.1	0.26**	0	0.1	0.06	0.14*	0.06	-0.04	-0.03	-0.18*	-0.07	-0.08	0.28**	0.45**	-0.08	-0.31**	0.28**	0.38**	0.86**	1			
Cycle	0.28**	0.24**	0.20*	-0.02	0.26**	-0.03	-0.03	0.38**	0.22**	0.35**	-0.04	-0.03	-0.06	0.29**	0.14*	-0.02	-0.14*	0.15*	0.26**	-0.17*	-0.22**	-0.07	-0.19*	1		
SG	0.05	-0.19*	0.24**	0.14*	0.18*	-0.03	-0.09	-0.11*	-0.04	0	-0.04	-0.11*	-0.24*	-0.25**	-0.19*	-0.20*	-0.18*	-0.19*	-0.02	0.11*	0.05	-0.01	0.01	-0.06	1	

HTR plant height, DTIG stem diameter, Dbase plant base diameter, CIRE spike circumference, LEP spike length, NTIP number of productive tillers per plant, NTUP number of unproductive tillers per plant, LoF leaf length, LaF leaf width, NETRN number of internodes per stem, DM downy mildew incidence, NPR number of seed holes harvested, NEP number of harvested spikes, PMF fresh mass, PMS dry mass, PDE weight of spikes harvested, PDG grains weight, PBF fodder biomass, PGEpi weight of grains per spike, NGEpi number of grains per spike, PMG 1000-grain weight, IR harvest index, RdtBat yield at threshing, Cycle number of days sowing-maturity, SG stay green

**:(0.01): highly significant; *(0.05): significant

occurred which were also distinguished by the main traits out of a subservient analysis of variance (Table 5).

Table 5 shows 24 out of 25 characters significantly discriminating the 5 groups. Twenty characters (HTR, DTG, Dbase, CIRE, LEP, LoF, NETRN, NPR, NEP, PMF, PMS, PDE, PDG, PBF, IR, RdtBat, PDGEpi, NGEpis, Cycle and SG) allow a complete distinction, while the remaining four characters (NTfP, NTuP, LaF and DM) only allows a partial distinction. The Group 1 (G_1) included 22 accessions which are genotypically different or not (indeed, some accessions offered the same genotype but different by their experimental site locations). The Group G_1 consisted of the pearl millet accessions with higher values of yield at threshing, harvest index and downy mildew incidence. These accessions stand out on their lower fodder production. The Group 2 (G_2) contained 30 accessions highlighted by producing higher values for their number of productive and unproductive tillers per plant, number of spike and yield at threshing. These accessions are zoomed otherwise, for their average performances for traits such as grains and spikes weight, weight and number of grains per spike. The Group 3 (G_3) which is composed of 38 accessions showed higher values for plant base diameter, spike circumference, spike length, harvest index, yield at threshing, weight and number of grains per spike. These accessions belong to genotypes with higher values for grain production. The Group 4 (G_4) contained 19 accessions marked with individuals of higher spike length, grains and spike weight, plant height, stem diameter and higher number and weight of grains per spike. These accessions also showed average values for the following traits: fresh matter, dry matter, fodder biomass and leaf length. Obviously, these accessions belong to genotypes with intermediate values of fodder and grain production. Finally, the Group 5 (G_5) holding 3 accessions showed higher values for the fresh matter, the dry matter and the fodder biomass. These three accessions more profile the biomass production than the grain production. In addition, the accessions distribution in groups indicates a structured diversity also according to the experimental sites, exempting three accessions (AnkAwd_Dj, Cha_Dj, ZonAwd_Dj) and one accession (Bon_Dj) tested in Djirataoua, but included, respectively, in group G_1 and G_3 composed almost of accessions tested in Kollo. Thus, G_2 , G_4 and G_5 are composed exclusively of accessions tested in Djirataoua (Fig. 2).

The principal component analysis revealed three first axes which are explaining about 60.45% of the information (Fig. 3). Table 6 provides an estimated variability that is represented by each axis.

The Axis 1 (F_1) expresses 32.99% of the total variability. It is positively correlated with the following traits: plant height, stem diameter, number of seed holes

harvested, number of spikes per plant, fresh mass, dry mass, spikes weight and fodder biomass while negatively with the harvest index. In fact, F_1 characterizes the pearl millet accessions of larger sizes, higher straw yield and lower harvest index.

The Axis 2 (F_2) expresses 14.88% of the total variability. It is positively correlated with 5 following traits: plant base diameter, spike length, leaf length, leaf width and number of internodes. F_2 characterizes the pearl millet accessions with higher plant base diameter, longer spikes and higher number of internodes.

The Axis 3 (F_3) expresses 12.58% of the total variability and is positively correlated with 4 essential traits, i.e. grains weight, yield at threshing, grain weight per spike and number of grains per spike. F_3 characterizes the pearl millet accessions with higher yields to threshing, weight and number of grains per spike (Table 6).

The results, which also indicate significant differences between experimental sites, show by the way, a certainly significant variability. Indeed, the principal component analysis, confirming this variability, classifies the accessions into two distinct groups: accessions tested in Djirataoua and those tested in Kollo. This dichotomy, which is based on agro-ecological differences, is the potential essence of interactions between accessions and the environments of the respective sites. In fact, Djirataoua has a relatively high average rainfall (600 mm per year) on productive land (the land being a lowland, therefore floodable during the rainy season, thus benefiting from alluvial deposits) with good water retention capacity (linked to the silty and clayey texture of the land) [22, 23]. On the other hand, Kollo only receives an average of 500 mm of rain per year on sandy and poor soils [20]. The agro-ecological factor therefore plays an important role in structuring morphological diversity. These results corroborate those of Sanou [36], who stipulated a close relationship between the cycle length and the water availability. The structuring of morphological diversity according to agro-ecological zones was also mentioned for various plants [8, 9, 37]. This structure had also significantly discriminated against two groups of millet in Côte d'Ivoire [17]: (a) medium-sized early millet group grown in the centre-north and (b) large late millet group grown in the north-east. Our results are in line with the structure established by Mémento de l'Agronome [38] which indicates West African millet varieties as classified into two groups: (i) early varieties, including Guéro (Niger, Nigeria) and Souna (Senegal, Mali), grown under low rainfall and with 75–100 days of cycle; (ii) late varieties, namely Maiwa (Niger, Nigeria) and Sanio (Senegal, Mali), grown in the wettest regions and with a cycle of 110–150 days [39]. Ouendeba et al. [30] also suggested a close status or reconciliation between the pearl millet from Niger, Nigeria

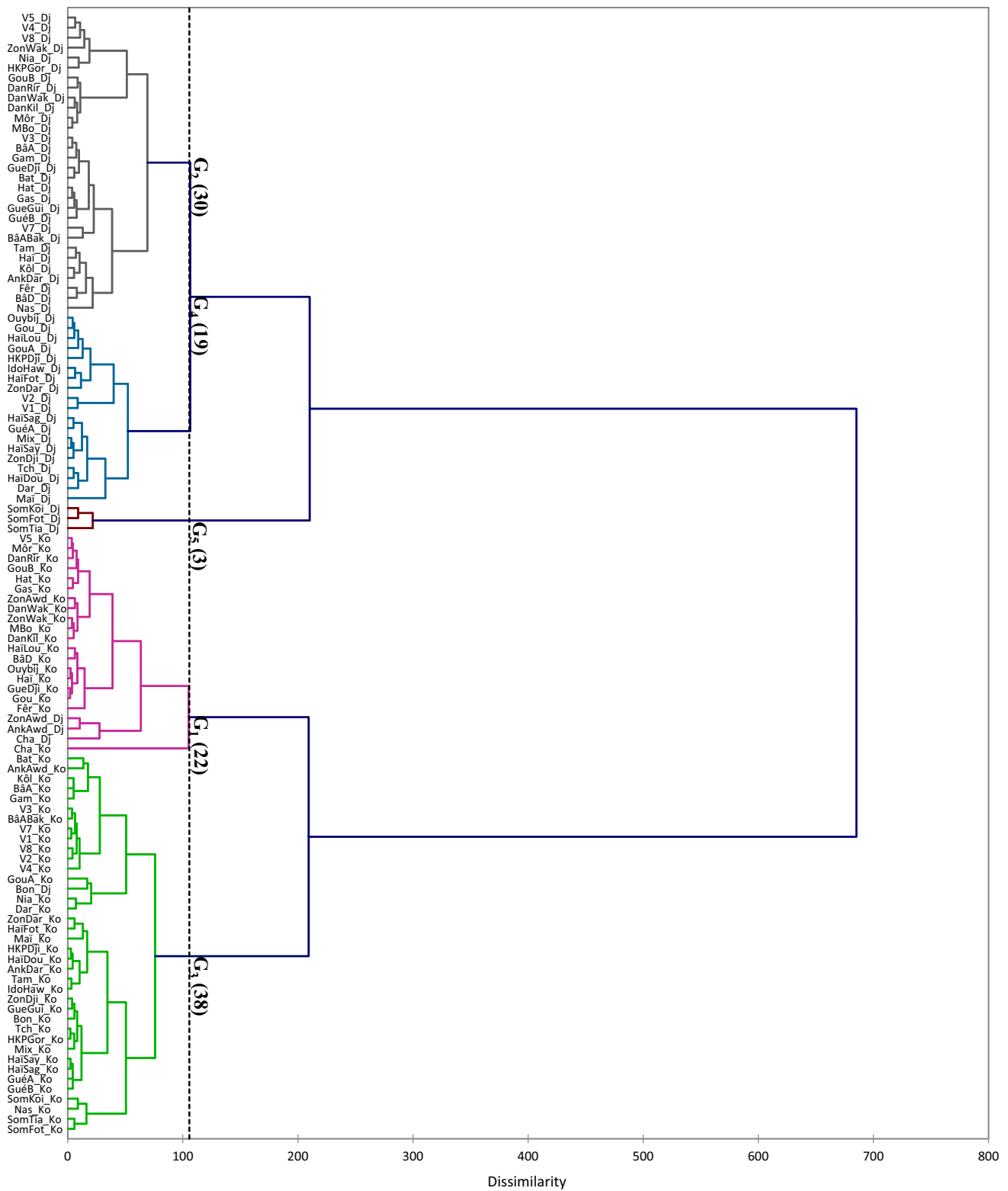


Fig. 2 Dendrogram from the HCA of the 56 pearl millet accessions considered per test site

and Senegal. In fact, according to these authors, this diversity of early, semi-late or late varieties would

correspond to farmer reality and the choice or preference of one type over another.

Table 5 Traits of groups from the hierarchical cluster analysis

	G ₁	G ₂	G ₃	G ₄	G ₅	Pr > F
HTR	219.36 ^c	256.70 ^b	254.48b	285.14 ^a	308.89 ^a	0.0000
DTG	4.32 ^d	5.48 ^b	4.99 ^c	5.86 ^a	6.33 ^a	0.0000
Dbase	65.49 ^b	45.92 ^d	81.78 ^a	50.79 ^{cd}	64.52 ^{bc}	0.0000
CIRE	8.13 ^{ab}	7.36 ^b	8.94 ^a	7.04 ^b	6.84 ^b	0.0000
LEP	37.53 ^b	44.82 ^b	62.18 ^a	66.22 ^a	52.52 ^{ab}	0.0000
NTfP	8.73 ^a	9.36 ^a	6.97 ^a	9.15 ^a	10.33 ^a	0.0153
NTuP	5.40 ^b	6.61 ^a	6.54 ^{ab}	7.11 ^a	6.61 ^a	0.0098
LoF	63.63 ^d	71.94 ^c	74.26 ^c	80.05 ^b	93.22 ^a	0.0000
LaF	4.33 ^b	4.70 ^{ab}	5.03 ^{ab}	5.12 ^a	5.22 ^a	0.0001
NETRN	8.83 ^d	9.21 ^{cd}	9.9 ^{8b}	9.83 ^{bc}	12.78 ^a	0.0000
DM	15.06 ^a	12.11 ^{ab}	10.17 ^{ab}	6.53 ^b	8.00 ^{ab}	0.0109
NPR	8.47 ^b	11.60 ^a	8.61 ^b	11.86 ^a	11.56 ^a	0.0000
NEP	6.58 ^b	11.67 ^a	5.78 ^b	11.40 ^a	13.14 ^a	0.0000
PMF	704.08 ^e	2256.42 ^c	1121.93 ^d	3018.29 ^b	5821.11 ^a	0.0000
PMS	347.06 ^d	1579.85 ^c	424.19 ^d	2069.02 ^b	4250.57 ^a	0.0000
PDE	185.09 ^d	438.86 ^b	278.93 ^c	544.25 ^a	343.47 ^{bc}	0.0000
PDG	112.05 ^d	279.60 ^b	169.66 ^c	355.90 ^a	65.28 ^d	0.0000
PBF	420.10 ^d	1739.11 ^c	533.46 ^d	2257.37 ^b	4528.76 ^a	0.0000
PMG	9.23 ^a	9.21 ^a	9.32 ^a	9.73 ^a	10.450 ^a	0.7587
IR	37.01 ^a	23.65 ^b	47.14 ^a	21.80 ^b	2.47 ^b	0.0000
RdtBat	66.03 ^a	64.15 ^a	60.84 ^a	65.91 ^a	17.94 ^b	0.0000
PDGEpi	19.14 ^c	25.02 ^b	30.47 ^a	31.60 ^a	4.87 ^d	0.0000
NGEpi	2077.33 ^b	2802.42 ^{ab}	3365.07 ^a	3385.35 ^a	473.45 ^c	0.0000
Cycle	87.05 ^b	86.50 ^b	97.24 ^b	97.11 ^b	140.00 ^a	0.0000
SG	1.91 ^a	1.13 ^b	1.84 ^a	1.74 ^a	1.00 ^b	0.0000

Mean values of same line followed by same letter indicate no significant differences ($P \geq 0.05$), while different letters inform on significant differences ($P < 0.05$) of trait values

Analysis of Agro-morphological Diversity

The diversity analysis by the hierarchical cluster analysis (HCA) structures the accessions variability into 5 phenotypic groups. Canonical discriminant analysis (CDA) aims to extract variables capable of discriminating groups defined above from the initial variables. This analysis profiles a reclassification of some accessions analysed during the upward hierarchical clustering. Thus, only variables such as the spike length fodder biomass, the 1000-grain weight and factors such as region—Niamey, region—Tahoua and site—Kollo appeared not so relevant to separate accessions. According to the λ -Wilk test ($P < 0.0001$), 23 out of 25 variables are well discriminated accessions. These are plant height, stem diameter, plant base diameter, spike circumference, spike length, leaf length, number of internodes, downy mildew incidence, number of seed holes harvested, number of spikes, fresh mass, dry mass, spike weight, grain weight, harvest index, yield at threshing, grain weight per spike, number of grains

per spike, number of days sowing-maturity, appearance of foliage at maturity, number of productive tillers, leaf width and 1000-grain weight. About 20 out of 23 descriptors mostly and significantly contribute to the observed morphological variability, while the last 3 others allow only a partial discrimination ($P < 0.0001$).

The Wilk test distinguishes a highly discriminating factorial design. The first axis explains 61.22% of the total variability and the second one about 32.21%. This will give a cumulative percentage of inertia of 93.43%. The accessions were mainly discriminated on Axis 1 based on following traits: plant height, stem diameter, spike circumference, leaf length, number of seed holes harvested, number of spikes, fresh mass, dry mass, spike weight, harvest index and leaf appearance at maturity. Specifically, the following plant base diameter, number of internodes yield at threshing, grain weight per spike, number of grains per spike, number of days sowing-maturity and grain weight mostly contribute in defining Axis 2. Accessions

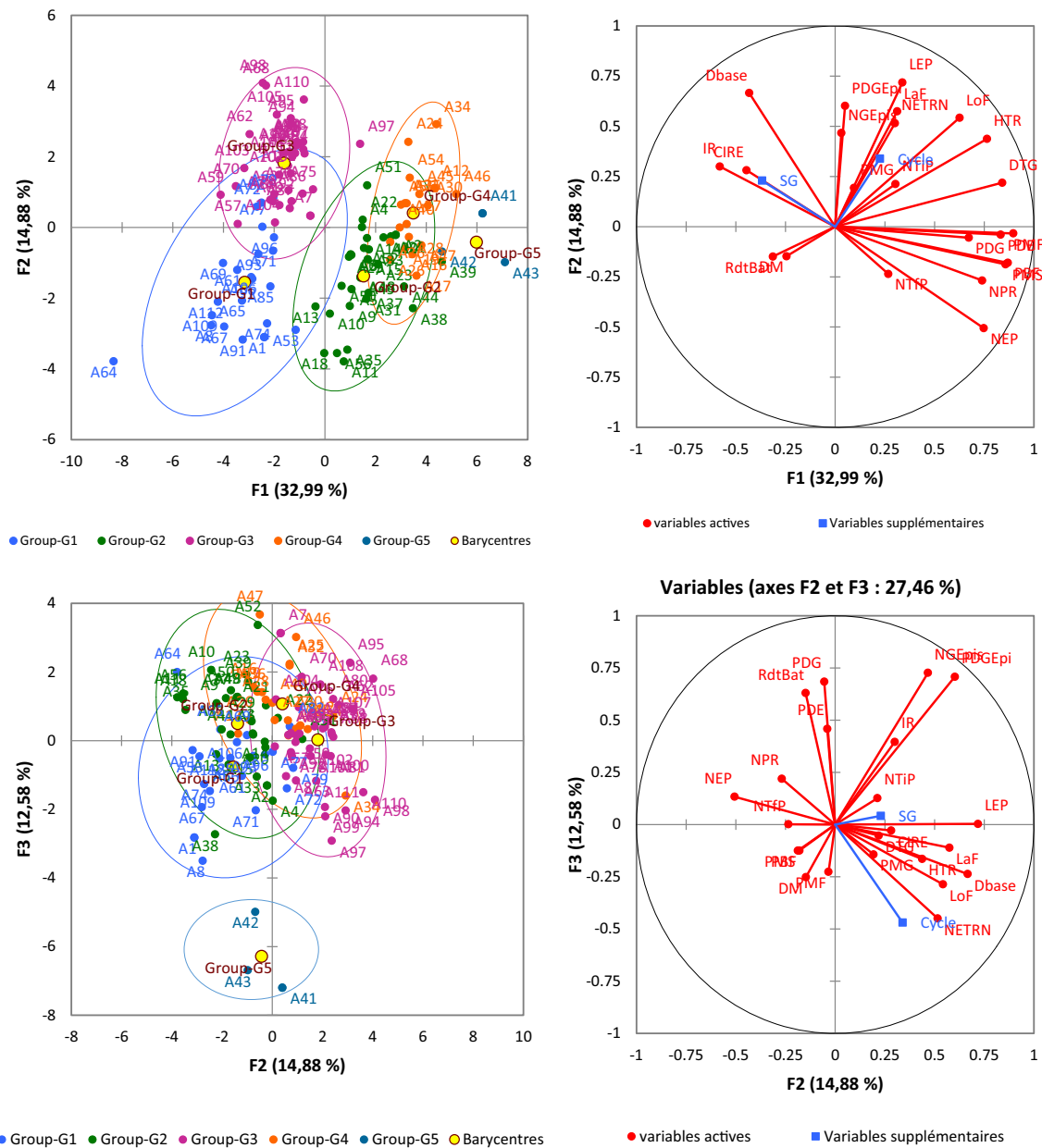


Fig. 3 Factor maps of accessions and traits from the PCA. A1: AnkAwd_Dj, A2: AnkDar_Dj, A3: BâA_Dj, A4: BâABak_Dj, A5: BâD_Dj, A6: Bat_Dj, A7: Bon_Dj, A8: Cha_Dj, A9: DanKil_Dj, A10: DanRir_Dj, A11: DanWak_Dj, A12: Dar_Dj, A13: Fêr_Dj, A14: Gam_Dj, A15: Gas_Dj, A16: Gou_Dj, A17: GouA_Dj, A18: GouB_Dj, A19: GuéA_Dj, A20: GuéB_Dj, A21: GueDji_Dj, A22: GueGui_Dj, A23: Hai_Dj, A24: HaiDou_Dj, A25: HaiFot_Dj, A26: HaiLou_Dj, A27: HaiSag_Dj, A28: HaiSay_Dj, A29: Hat_Dj, A30: HKPDji_Dj, A31: HKPGor_Dj, A32: IdoHaw_Dj, A33: Kôl_Dj, A34: Mai_Dj, A35: MBo_Dj, A36: Mix_Dj, A37: Môr_Dj, A38: Nas_Dj, A39: Nia_Dj, A40: Ouybij_Dj, A41: SomFot_Dj, A42: SomKoi_Dj, A43: SomTia_Dj, A44: Tam_Dj, A45: Tch_Dj, A46: V1_Dj, A47: V2_Dj, A48: V3_Dj, A49: V4_Dj, A50: V5_Dj, A51: V7_Dj, A52: V8_Dj, A53: ZonAwd_Dj, A54: ZonDar_Dj, A55: ZonDji_Dj, A56: ZonWak_Dj, A57: AnkAwd_Ko, A58: AnkDar_Ko, A59: BâA_Ko, A60: BâABak_Ko, A61: BâD_Ko,

A62: Bat_Ko, A63: Bon_Ko, A64: Cha_Ko, A65: DanKil_Ko, A66: DanRir_Ko, A67: DanWak_Ko, A68: Dar_Ko, A69: Fêr_Ko, A70: Gam_Ko, A71: Gas_Ko, A72: Gou_Ko, A73: GouA_Ko, A74: GouB_Ko, A75: GuéA_Ko, A76: GuéB_Ko, A77: GueDji_Ko, A78: GueGui_Ko, A79: Hai_Ko, A80: HaiDou_Ko, A81: HaiFot_Ko, A82: HaiLou_Ko, A83: HaiSag_Ko, A84: HaiSay_Ko, A85: Hat_Ko, A86: HKPDji_Ko, A87: HKPGor_Ko, A88: IdoHaw_Ko, A89: Kôl_Ko, A90: Mai_Ko, A91: MBo_Ko, A92: Mix_Ko, A93: Môr_Ko, A94: Nas_Ko, A95: Nia_Ko, A96: Ouybij_Ko, A97: SomFot_Ko, A98: SomKoi_Ko, A99: SomTia_Ko, A100: Tam_Ko, A101: Tch_Ko, A102: V1_Ko, A103: V2_Ko, A104: V3_Ko, A105: V4_Ko, A106: V5_Ko, A107: V7_Ko, A108: V8_Ko, A109: ZonAwd_Ko, A110: ZonDar_Ko, A111: ZonDji_Ko, A112: ZonWak_Ko

Table 6 Eigenvalues and percentage expressed by the first three axes

	F ₁	F ₂	F ₃
Eigenvalue	7.59	3.42	2.89
Total variance (%)	32.99	14.88	12.58
Cumulative variance (%)	32.99	47.87	60.45
HTR	0.76	0.44	- 0.16
DTG	0.84	0.22	- 0.05
Dbase	- 0.43	0.67	- 0.24
CIRE	- 0.45	0.28	- 0.03
LEP	0.34	0.72	0.00
NTfP	0.27	- 0.24	0.00
NTuP	0.30	0.21	0.13
LoF	0.63	0.54	- 0.29
LaF	0.31	0.57	- 0.11
NETRN	0.30	0.52	- 0.45
DM	- 0.24	- 0.15	- 0.25
NPR	0.74	- 0.27	0.22
NEP	0.75	- 0.51	0.13
PMF	0.90	- 0.03	- 0.23
PMS	0.86	- 0.19	- 0.12
PDE	0.83	- 0.04	0.46
PDG	0.67	- 0.06	0.68
PBF	0.87	- 0.18	- 0.12
PMG	0.09	0.19	- 0.14
IR	- 0.58	0.30	0.40
RdtBat	- 0.31	- 0.15	0.63
PDGEpi	0.05	0.60	0.71
NGEpi	0.03	0.47	0.73
Cycle	0.23	0.34	- 0.47
SG	- 0.37	0.23	0.04

Bold values indicate the significant values of correlation coefficient

differed significantly as shown by the result of the Wilk statistical test ($\lambda = 0.0003$; $P < 0.0001$).

The hierarchical cluster analysis of the basic data on initial agro-morphological traits generates five phenotypic groups G₁, G₂, G₃, G₄ and G₅ (Fig. 2). The canonical discriminant analysis clearly confirms the distribution of accessions in these groups. Thus, among the traits that mostly contributed to discriminating against accessions were: plant height, stem diameter, plant base diameter, spike circumference, spike length, leaf length, leaf width, number of internodes, number of seed holes harvested, number of spikes, fresh mass, dry mass, spike weight, grains weight, harvest index, yield at threshing, grains weight per spike, number of grains per spike, aspect of foliage at maturity and number of days sowing-maturity. These descriptors, which appear to be the most relevant for better explaining the observed agro-morphological variability, discriminate pearl millet accessions into five

homogeneous groups: (i) A first group (G₁) composed of early accessions, with agro-morphological traits more oriented towards the grain production. Indeed, individuals in this group have average performances in the grain production (PDG = 112.05 g/m²; NGEpi = 2077.33; IR = 37.01%) and low performances in the biomass production (PMF = 704.08 g/m²; PMS = 347.06 g/m²; PBF = 420.10 g/m²). As a result, G₁ may well serve as parents for programmes intended to create the pearl millet varieties with obvious grain potential. (ii) A second group (G₂) composed of early accessions, with mixed agro-morphological traits for the production of grains and fodder biomass. This group holds individuals with good performances for the grain production (PDG = 279.60 g/m²; NGEpi = 2802.42; IR = 23.65%) as well as for the fodder biomass (PMF = 2256.42 g/m²; PMS = 1579.85 g/m²; PBF = 1739.11 g/m²). In view of these excellent mixed performances combined, it is therefore not excluded that the corresponding accessions may contribute to the generation of new, more efficient varieties. As a result, G₂ may well serve as good parents for multiple-use pearl millet variety development programmes: grain and fodder production, but with a more fodder focus. (iii) A third group (G₃) composed of both early and late accessions, with agro-morphological traits more oriented towards the grain production. Indeed, individuals in this group have good performance in the grain production (PDG = 169.66 g/m²; NGEpi = 3365.07; IR = 47.14%) and low performance in the biomass production (PMF = 1121.93 g/m²; PMS = 424.19 g/m²; PBF = 533.46 g/m²). As a result, G₃ may well provide good parents for programmes to create millet varieties with high grain potential. (iv) A fourth group (G₄) of both early and late accessions with mixed agro-morphological traits for the production of grains and fodder biomass. This group offers claims with good fodder performances (PMF = 3018.29 g/m²; PMS = 2069.02 g/m²; PBF = 2257.37 g/m²) and good grain performance (PDG = 355.90 g/m²; NGEpi = 3385.35; IR = 21.80%). As a result, G₄ may well serve as good parents for multiple-use pearl millet variety development programmes: grain and fodder production, but with a more grainer accent. (v) A fifth group (G₅) of late accessions with agro-morphological traits more oriented towards the biomass production. This group offers claims with the best fodder performances (PMF = 5821.11 g/m²; PMS = 4250.57 g/m²; PBF = 4528.76 g/m²) as well as the bad grain performance (PDG = 65.28 g/m²; NGEpi = 473.45; IR = 2.47%). Like G₁ and G₂, G₃, G₄ and G₅ can also be used as a breeding ground for programmes to create millet varieties with high fodder potentials. In fact, this structuring of the morphological diversity of cultivated pearl millet accessions described in this study clearly confirms the fact that morphological differentiation is often based on agronomic traits [40].

The structuring of the morphological diversity observed could result from genotypic traits of the accessions but also from phenotypic selection made by farmers which mainly integrates the traits of the spike and flowering [29]. Phenotypic selection by farmers based on perceptible traits (phenological, vegetative, spike) could explain the contribution of these variables to the structuring of variability. According to Louette [37], vegetative traits, i.e. plant height and insertion height of the spike, cycle length and spike diameter are the main criteria for identifying maize varieties by farmers in Cuzalapa (Mexico). Farmers choose to grow their crops annually, seeds from the largest and most beautiful spikes of maize [41]. This mass selection would have favoured a differentiation of varieties into several groups highlighted in this study.

Groups G₁, G₂, G₃, G₄ and G₅ offer a choice of parents for the creation of pearl millet varieties with high grain and fodder yield potential and adapted to the agro-ecological conditions of the Niger Republic. The organization of millet morphological diversity according to agro-ecological zones has been reported [8, 29, 42]. In addition, 72 accessions of millet collected in the northern Côte d'Ivoire in 1979 had generated two groups which were well discriminated: north-eastern millet, long cycle, resistant to downy mildew, with good vigour but less grain production [43], and north-western millet, which is characterized by early maturity, abundant tillering with longer and thinner candles [29].

Moreover, the distribution of accessions in the five phenotypic groups is not entirely irreproachable. Indeed, this structure reveals two new unexpected cases whose clarification requires the use of the probable causes of their appearance. First, it can be noted that all Somno accessions tested at Kollo (SomFot_Ko, SomKoi_Ko and SomTia_Ko, IdoHaw_Ko, Mai_Ko) fall within the G₃ group of early accessions with grain production potential, while they are expected in the G₅ group. Because these are the same accessions (i.e. those from the same seed sample) tested both on the two experimental sites (Djirataoua–Kollo) at the same time with the same technical processes. The Somno tested in Djirataoua (SomFot_Dj, SomKoi_Dj, SomTia_Dj) are, however, the only individuals in the G₅ group, i.e. those with the best fodder performances. However, the timid expression of the fodder potential of Somno accessions tested at Kollo may well be the cause of high performances of certain agro-morphological traits (plant height, plant base diameter, spike length and number of productive and unproductive tillers) observed in the G₃ group. As a result, it can be said that the quantities of rainfall recorded at the Kollo site would have been insufficient for the growth and development of Somno accessions, so that this situation would not have allowed the optimal expression of their performances (especially fodder). This would partially justify the unclear structuring of

the individuals composing the G₃ group. Moreover, from the analysis of the folk farming systems in the Kollo area, the use of Somno accessions on farms is not observed. The cultivation of Somno accessions now seems to be limited exclusively to the southern parts of Niger, i.e. areas with the highest rainfall, as evidenced by the rainfall records of the collection sites. Thus, during the surveys, (1) Somno sample (*Somno Biyo* corresponding to the grey Somno in *Djerma-Sonhrai* language, thus referring to the grains colour) was collected in Tantioga (Commune of Falmey) with an annual rainfall averaging 657.1 mm [44], and (2) other samples from Somno (*Somno Biyo* and *Somno Koirey* which correspond, respectively, to the grey and white variants of Somno in *Djerma-Sonhrai* language) in Fotchorâ (Commune of Tanda) where the rainfall over 15 years averaged 807 ± 121 mm [45].

Secondly, the “Maiwa” and “Idonhawaynia” accessions tested in Djirataoua (IdoHaw_Dj, Mai_Dj) are found in the G₄ group, while they are also expected in the G₅ Group. In reality, the accessions “Maiwa” and “Idonhawaynia” (*Hausa* terroir name) are nothing more than variants of the Somno accession (*Djerma-Sonhrai* terroir name). On the one hand, the behaviour (the fact that they appeared in a group where they were less expected) of the Somno accessions tested in Kollo (SomFot_Ko, SomKoi_Ko, SomTia_Ko, IdoHaw_Ko, Mai_Ko) that are found in G₃ group would also be induced by agro-ecological factors (low rainfall–low soil fertility–low soil water retention capacity) above mentioned. Indeed, the Kollo experimental site, marked by low rainfall, fertility and soil water retention capacity (linked to the soil sandy texture), would not have helped the late accessions to better express their production potential. Admittedly, the accessions “Maiwa” and “Idonhawaynia” are distributed in G₄ group but, the reasons for such evidence, although complex, may well be related to sampling errors, erosion of the original genetic material, etc. Indeed, farmers who own the seeds could be mistaken in giving them to the investigators during collection or offer genetic material of unsecured or dubious reliability. Finally, it should also be noted that in either case, the late accessions (Somno, Maiwa and Idonhawaynia), which are sensitive to photoperiodism, certainly could not complete their reproduction cycle at harvest time, which would have been detrimental to their grain yields. Therefore, the use of molecular analyses would be most appropriate to characterize and determine more accurately the true identity of these genetic resources.

Conclusion

The results of the diversity analysis and morphological structuring of the 56 pearl millet accessions grown in Niger clearly show a variation in the traits used. This genetic variability between accessions is an asset for selection work. Multivariate analyses discriminate 5 groups of accessions: G₁ and G₃ of medium-sized individuals with the best performance for the following traits: harvest index, grains weight per spike, number of grains per spike and yield at threshing. This group can provide parents for grain yield improvement programmes. On the other hand, groups G₂ and G₄ of accessions with mixed agro-morphological traits (grain and fodder potential) would be better suited for adoption programmes for multiple-use millet accessions. Finally, the G₅ group of accessions with the best vegetative traits (fresh mass, dry mass and fodder biomass) can provide parents to improve fodder yield. In view of the poorly standardized boundaries between these groups discriminated on the basis of agro-morphological traits, the use of molecular marking by microsatellites would be appropriate, in order to better characterize and accurately evaluate accessions within the constituted phenotypic groups. Finally, it is worth highlighting the suitable and recommendable ability of the Djirataoua (Maradi) site to express the agro-morphological potential of pearl millet accessions in Niger.

Acknowledgements The West African Agricultural Productivity Programme (WAAPP/Niger; the Award number PPAAO/WAAPP-IC, Crédit 4877 NE) had funded this work. Regional Centre for Agricultural Research, CERRA-Kollo, CERRA-Maradi and the Laboratory of Applied Ecology (FSA-UAC) provided technical support for conducting the experimental trials.

Compliance with Ethical Standards

Conflict of interest The authors have no conflict of interest to publish this manuscript.

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