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## Research article

Farmers' perceptions of fodder performances of pearl millet (*Pennisetum glaucum* (L.) R. Br) accessions in NigerHamadou Moussa<sup>a,b,\*</sup>, Valentin Kindomihou<sup>b</sup>, Thierry D. Houehanou<sup>b,c</sup>, Mahamadou Chaibou<sup>d</sup>, Oumarou Souleymane<sup>a</sup>, Idrissa Soumana<sup>a</sup>, Joseph Dossou<sup>e</sup>, Brice Sinsin<sup>b</sup><sup>a</sup> National Agricultural Research Institute of Niger, Niamey, Niger<sup>b</sup> Laboratory of Applied Ecology, Faculty of Agronomic Sciences, University of Abomey-Calavi, Calavi, Benin<sup>c</sup> Laboratory of Ecology, Botany and Plant Biology, Faculty of Agronomy, University of Parakou, Parakou, Benin<sup>d</sup> Department of Animal Production, Faculty of Agronomy, Abdou Moumouni University of Niamey, Niamey, Niger<sup>e</sup> Laboratory of Bioengineering of Food Processes, Faculty of Agronomic Sciences, University of Abomey-Calavi, Calavi, Benin

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## ABSTRACT

Little is known about folk perception of pearl millet livestock fodder status across the Niger republic. Thus, this work assesses farmers' perceptions of the main pearl millet accessions fodder performance features in Niger. To that end, we: (i) Identify farmers' criteria for choosing pearl millet accessions fodder-profile, (ii) Analyze the farmer preferences for pearl millet accessions adapted to local cropping systems, and (iii) Analyze current cropping systems. Data have been derived from semi-structured surveys based on individual and focus group interviews of 508 stakeholders which were sampled from seven major ethnic groups across the eight country regions. Generated database was submitted to multivariate analysis in XLSTAT software. As results, the farmers' perception of a fodder profile may combine long and wide leaves, abundant tillers, slender stems, coupled to a large biomass and a plant capacity to regrow after grazing or mowing. Height accessions were agro-ecologically and socio-culturally chosen and valued by Farmers across the country, i.e. *Haini Kirey* at Tillabéry, Niamey and Dosso, *HKP* and *Guerguéra* at Tahoua, *Ankoutess* at Agadez, *Goudiss* and *Môro* at Diffa, *Batoukouché* at Zinder, and *HKP* and *Zongo* at Maradi. Distinctive producers' groups occur despite wider similarities in crop management practices. The prominent cropping system associated pearl millet to cowpea or groundnut. Therefore, identifying, characterizing or improving pearl millet accessions with a grain or fodder profile requires significant involvement of the farmers across Niger.

## 1. Introduction

Pearl millet is the most grown cereal in the Sahel region because of its difficult growing conditions. In The Niger Republic, climate hazards limit the sowing to just 12% of the country's land (Ouendeba and Sogoba, 2004). Pearl millet, which tolerates drought, poor soils conditions, can grow well in favorable conditions (Ouendeba and Sogoba, 2004; Sankar et al., 2014). Pearl millet provides about 90% of the entire grain production, as 54% of rainfed crops and will longer fight hunger (Ouendeba and Sogoba, 2004). The Pearl millet potential to ensure the human food security has been documented (Halilou and Karimou, 2019; Moussa et al., 2019; Ndjeunga and Nelson, 2005), with a significant impact on the daily diet of about 85% of the population in Niger (Ndjeunga and Nelson, 2005; Saidou, 2011). The use of pearl millet for feeding animal is

still secondary although its post-harvest residues are essential in the Sahelian cattle breeding systems. Whether pearl millet grain, as an energy and protein ingredient, might boost poultry, pig, cattle and sheep production systems in the same way as maize and sorghum (FAO, 1997; Moussa et al., 2019; Kindomihou, 2020), we are interested to know the drivers of fodder use of the pearl millet underutilized in Niger?

The pearl millet grown on marginal lands yields a crop that is barely sufficient for household food needs, and thus is fairly available for animals. Its production varies significantly from one year to another due to rainfall fluctuation and pernicious drought. Therefore, integrating pearl millet production with intensive livestock activities remains problematic. Moreover, the pearl millet cropping systems is still marked by lower yields. Production and transportation costs are often excessive compared to other feed grains.

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However, the situation in arid ecosystems is expected to change with food insecurity induced by droughts, persistent global warming context and higher population growth. In Africa, for example, despite the increasing use of pearl millet in cattle breeding systems, its production for animal feed is still underdeveloped especially in the Niger Republic. Nevertheless, the poultry farming development point out that it as a promising new initiative (Issa et al., 2016; Ouendeba and Sogoba, 2004).

Large amounts of pearl millet dry matters left on the farm after crop harvesting are systematically collected nowadays (Ouendeba and Sogoba, 2004). This statement is further enhanced by the chronic and recurrent fodder deficit, the increasing and faster deterioration of agricultural soils, and the depletion or outright extinction of pastoral areas (Fall-Touré et al., 1997; Gonin et Tallet, 2012; Moussa et al., 2017).

However, the Niger's rangelands are showing lower productivities because of farming systems and climate change effects (Bello, 2016; Boureima et al., 2017; Garraud and Mahamane, 2012; Hamadou et al., 2005). So far, the alternatives to the chronic fodder deficit advocate the proper use of crop residues, mowing, and conservation of natural fodder although they fail to cover the animals feed needs (Abdou et al., 2017a; Chaibou et al., 2019).

Moreover, the landscape in Niger is marked by pearl millet based farming systems. Hardiness and adaptation to hard edaphic and climate conditions as well as its proven fodder potentialities have been somehow less documented (Amodu et al., 2007; Govindaraj et al., 2011; Moussa et al., 2017, 2019; Newman et al., 2010). Thenceforth, how could pearl millet compensate for seasonal fodder deficits, despite its multifunctional status? Which adaptive strategies would be most suitable to integrate farmers' knowledge and practices?

Indeed, little information is available both on farmers' perceptions of pearl millet's fodder performance features in the farming environment or on criteria choice accessions across the Niger country.

Effective approaches identifying farmers' preferences might include involving them in the evaluation of the varieties to be tested (Witcombe and Joshi, 1996). For example, Witcombe and Joshi (1996) used Participatory Varietal Evaluation, to determine which varieties are better

adapted to farming conditions and mostly valued by farmers. Participatory Varietal Evaluation has also been used by ICRISAT in Rajasthan, India, and has shown farmers' preference for a wide range of pearl millet genetic types (Vom Brocke et al., 2001). Farmers have clearly expressed the will for having pearl millet accessions which are well adaptive to the poorly sandy soils, characteristic of the region.

The current study assesses farmers' perceptions of the pearl millet fodder descriptors as well as the accessions diversity of cropping systems in Niger. Specifically, we seek to (i) Identify the farmers' criteria in choosing pearl millet for fodder purposes, (ii) Assess farmers' preferences for pearl millet varieties that are adapted to their cropping systems in Niger, and (iii) Analyze the cropping systems that occur in the surveyed areas.

## 2. Materials and methods

### 2.1. Description of the study area

This study was carried out in the eight regions of Niger country (Figure 1). Nine sociocultural groups reside in Niger (INS, 2011). The landscape is characterized by a broad peneplain of an average 500-meter altitude, troughs and elevations especially in the northern part. The altitude rises from South to North, where mountains areas appear, i.e Air, Termit higher than 900 m and mounts Taroudji (900 m), Bagzan (2200 m), Tamgak (1900 m), Greboun (2300 m). Soils are sandy or sandy-clay, poor in organic matter and nutrients. Farm lands are 80% with dunes and 15–20% hydromorphic moderately clayey (I3N, 2012). About nine distinct agrarian systems occur, namely: pastoral in the north, transitional in the Center with cultures or dunes, plains in the East, plateaus in the West, valley systems, oases, hydro-agricultural developments and peri-urban areas (I3N, 2012). Climate is semi-tropical arid, marked by a dry season from October to May and a rainy season from June to September. Average temperatures range from 18.1 to 33.1 °C during the dry season and between 28.1 to 31.7 °C during the rainy season (PANA, 2006).

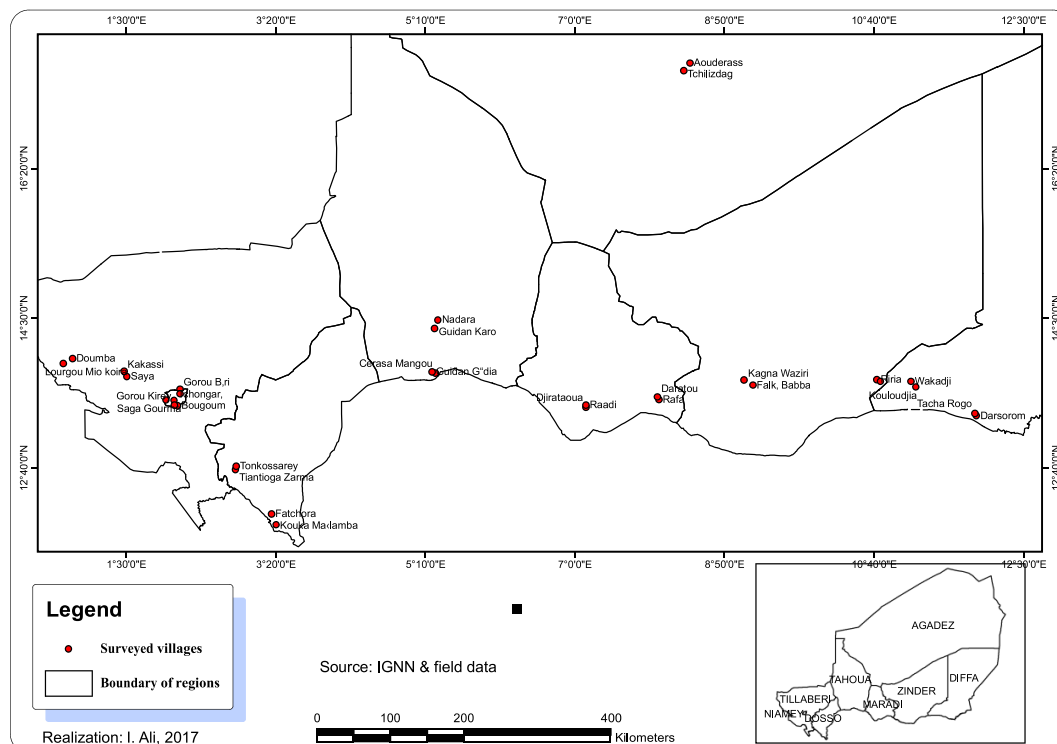


Figure 1. Map showing the location of surveyed sites.

2.2. Data collection

Semi-structured interviews were carried out using individual and focus groups (from two to sixty persons) with 508 stakeholders from the eight country regions in the selected locations based on a stratified sampling. Three levels of stratification were set: sociocultural groups (level one), the counties of better pearl millet production (level two), and the villages (level three) based on advising from the technical services of agriculture. The sampling was random at the village level. Globally, 32 villages were selected for investigating the farming system and the choice of pearl millet accessions. Questionnaires required prior agreement of local administrative and traditional authorities. Interviews were conducted in the most spoken local languages in Niger (*Hausa* and *Zarma*) but translators' services were systematically requested as soon as a participant did not speak one of these two languages.

2.3. Respondents socio-economic profile

We surveyed seven most represented socio-cultural groups: *Fulani*, *Gurmantche*, *Hausa*, *Kanuri*, *Tuareg*, *Tubu*, *Zarma-Sonhrai*, and two minority ones: *Gurmantche* and *Tubu*. Main socio-professional categories were farmers (90.37%), agro-pastoralists, dressmakers and traders (Figure 2).

2.4. Data analysis

Descriptive statistics (frequency, contingency tables, averages and standard deviations) were used to analyze the farmers' preferences of pearl millet accessions of their farming systems. The constituted matrices were subjected to one-way analyses of variance. The spatial distribution patterns of variables were explored using Principal Component Analysis (PCA) for quantitative traits matrices and Multiple Correspondence Analysis (MCA) for qualitative traits matrices. The analyses were performed using XLSTAT 2016.02 software (Addinsoft, 2016).

3. Results

3.1. Pearl millet accessions with fodder profile based on the farmers' criteria

3.1.1. Identification of pearl millet accessions with fodder profile

The farmers defined the fodder profile through the following features: tillering capacity (5.71%), capacity of regrow after grazing (2.36%), presence of large leaves (5.71%), aptitude of forming tufts of tillers at the

base (32.28%), presence of thin stems (4.33%), and production of significant amount of biomass (12.99%) (Table 1).

3.1.2. Characterization of fodder pearl millet accessions

The two first axes of the multiple correspondence analysis (MCA) concentrated 80% of the total variability and the Figure 3 showed the

Table 1. Farmers' criteria for accessions with fodder profile.

Villages	Latitudes	Longitudes	Accessions	Criteria
Bougoum	N13°25'.484	E002°07'.790	<i>Somno</i>	Tillering and regrowth capacity after grazing
Gorou Beri	N13°37'.614	E002°09'.605	Varieties	Large leaves
Gorou Keyna	N13°34'.186	E002°09'.725	<i>Daran Kôba</i>	Heavy tillering, 10–15 tillers per plant
Saga Gourma	N13°29'.729	E001°59'.396	Varieties	Profuse Tillers
Lourgou	N13°56'.658	E000°43'.808	<i>Kô Lâla</i>	Tufts of tillers at the base, more biomass, less grain
Doumba	N14°00'.249	E000°50'.760	<i>Somno Kouka</i>	More biomass, less grain
Doumba	N14°00'.249	E000°50'.760	<i>Somno Doungouriya</i>	More biomass, less grain
Awderass	N17°37'.679	E008°24'.760	<i>Chânôno</i>	High tillering capacity
Kouloudjia	N13°39'.157	E011°11'.001	<i>Maiwa</i>	More biomass, less grain
Saya	N13°47'.032	E001°30'.705	Varieties	Profuse Tillers
Tiantioga	N12°38'.464	E002°50'.594	<i>Tchouma</i>	Profuse Tillers
Kouka Mlamba	N11°57'.841	E003°20'.334	<i>Somno Bio</i>	Profuse Tillers
Daratou	N13°32'.011	E008°00'.805	<i>Zongo</i>	Profuse Tillers
Rafa	N13°29'.777	E008°01'.953	<i>Zongo</i>	Profuse Tillers
Fotchora	N12°05'.763	E003°17'.032	<i>Somno</i>	Producing large leaves
Riria	N13°44'.651	E010°42'.271	<i>Maiwa</i>	More biomass, less grain
Falki Babba	N13°40'.502	E009°11'.022	<i>Shibra*</i>	Thin stems, high amount of biomass

\* Hausa denomination (*Soun* in *Zarma-Songhay*) of wild/grown pearl millet varieties found in wastelands, near pearl millet fields or too often within plots or sometimes sharing the same base as the cultivated pearl millet varieties.

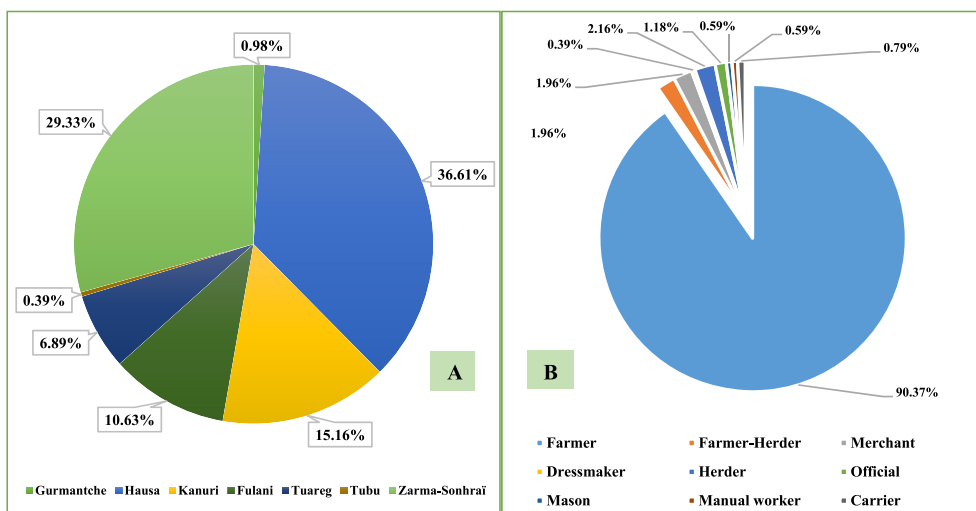


Figure 2. Proportions of socio-cultural (A) and socio-professional (B) groups surveyed.

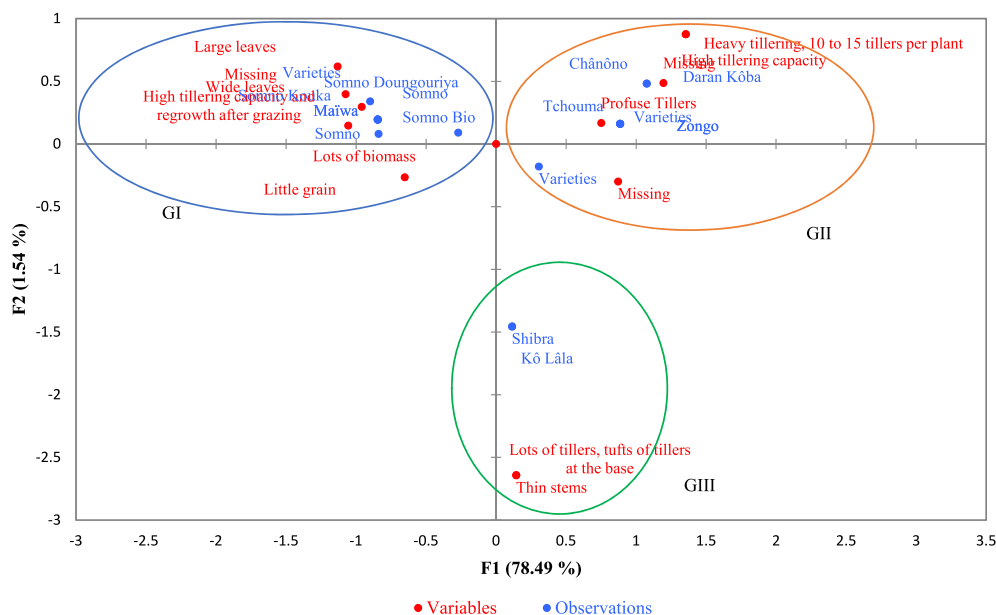


Figure 3. Factor map of pearl millet fodder profile accessions (Observations) and their features (Variables) based on the multiple correspondence analysis (MCA).

distinct groups formed. Axis 1 expressed 78.49% of the variability and contrasted two groups of accessions (GI and GII) with different fodder profiles: (i) Group GI holds a late cycle accessions (*Somno/Maïwa*) and those accessions easily regenerate after grazing and mowing of their aerial parts; (ii) Group GII holds early-cycle accessions (*Daran Kôba, Chânôno, Tchouma, Zongo*) with a large tillering capacity, some of which can produce up to 15 tillers per plant. Axis 2 expressing 1.54% of the total variability, isolated the Group GIII as early accessions (*Shibra, Kô Lâla*), producing profuse stalks which make the plant base very thick with very thin stems.

### 3.2. Analysis of farmers' preferences for pearl millet accessions within cropping systems

#### 3.2.1. Characterization of producers' groups

Results from Principal Component Analysis (PCA) revealed four first axes, both expressing 88.88% of the total variability (Table 2), which is presented on the Figure 4.

Axis 1 (F<sub>1</sub>) expressing 37.29% of the total variability and is positively correlated by the pearl millet grains production (*Grn\_Mil*), cowpea grains and haulms (*Grn\_Niéb* and *Fne\_Niéb*) and negatively by sorghum straw production (*Plle\_Sorgho*). This axis characterizes the producers of pearl millet grains larger amounts, cowpea grains and haulms, with weaker sorghum straw production.

Table 2. Eigenvalues and correlations between variables and PCA axes.

	F1	F2	F3	F4
Eigenvalues	2.98	1.97	1.26	0.90
Variability (%)	37.29	24.58	15.71	11.30
Cumulative %	37.29	61.86	77.58	88.88
Grn_Mil	0.74	-0.25	0.34	0.20
Grn_Sorgho	-0.55	0.23	0.64	0.26
Grn_Achide	0.33	0.94	-0.12	0.00
Grn_Niéb	0.88	-0.06	0.29	0.20
Plle_Mil	-0.09	-0.09	-0.57	0.81
Plle_Sorgho	-0.63	0.29	0.50	0.29
Fne_Achide	0.33	0.93	-0.12	-0.01
Fne_Niéb	0.85	-0.10	0.23	0.09

Axis 2 (F<sub>2</sub>) expresses 24.58% of the total variability, mainly characterized by the groundnut producers i.e. grains and haulms (*Grn\_Achid* and *Fne\_Achid*), all of which are positively correlated to this axis. Axis 3 (F<sub>3</sub>) expresses 15.71% of the total variability and characterizes the sorghum grains producers (*Grn\_Sorgho*), which are positively correlated to the axis3. Axis 4 (F<sub>4</sub>), expressing 11.30% of the total variability, is positively correlated by the pearl millet straw or post-grains harvesters (*Plle\_Mil*).

Furthermore, the results from PCA confirm the existence of three groups (G<sub>1</sub>, G<sub>2</sub> and G<sub>3</sub>) identified by the Hierarchical Cluster Analysis.

#### 3.2.2. Diversity and distribution of pearl millet accessions across in Niger

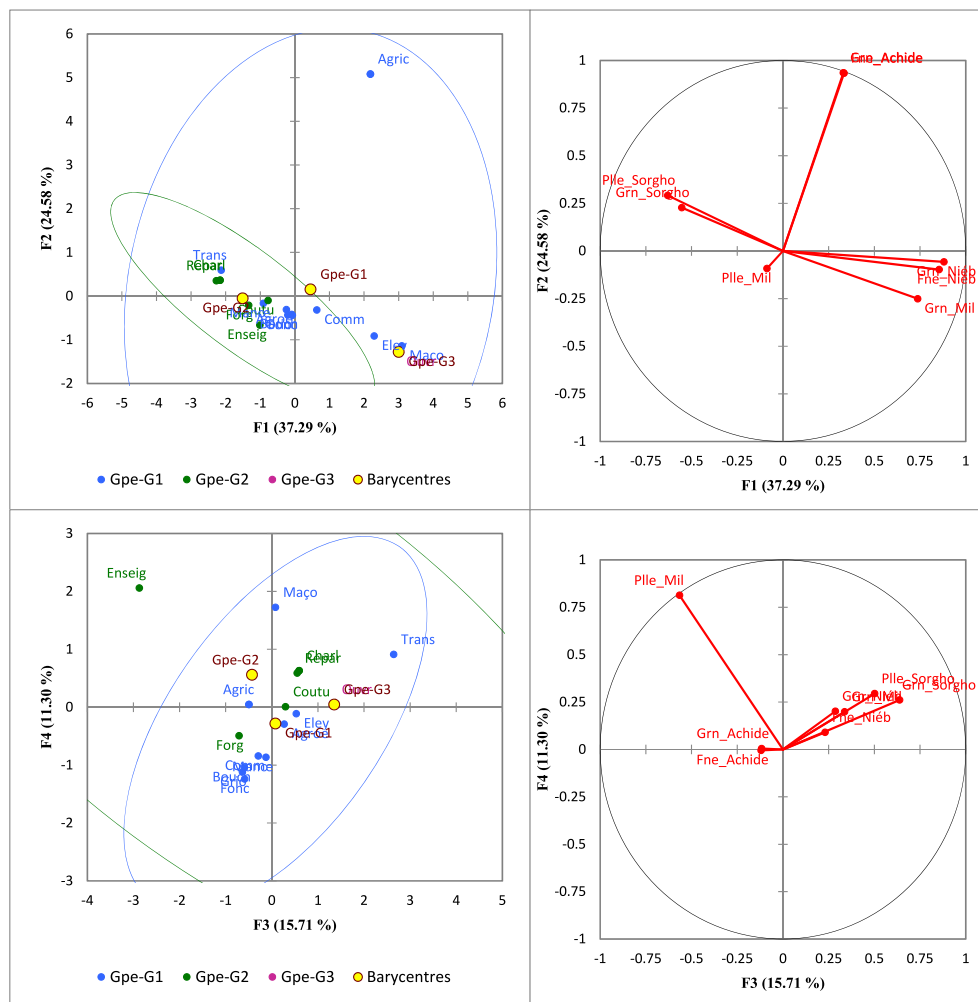
Farmers' preferences for pearl millet accessions throughout this study focus on the following criteria: duration of the production cycle, size and shape of stems, capacity to produce several tillers per plant, organoleptic quality of grains, and grains' colour.

Overall, 47 farmers' preferred-pearl millet accessions have been pointed up to 494 times across the eight Niger regions. For instance, *Haini Kirey* was mentioned for 70 times (28.54%), while *HKP* for 57 times (11.54%), and *Dan arba'in* for 32 times (6.48%). There is also a significant spatial variation in the farmers' choice of pearl millet accessions for cropping. This is the case of predominant accessions i.e. *Haini Kirey* at Tillabéry, Niamey and Dosso, *HKP* and *Guerguéra* at Tahoua, *Ankoutess* at Agadez, *Goudiss* and *Môro* at Diffa, *Batoukouché* at Zinder and *HKP* and *Zongo* at Maradi (Figure 5).

#### 3.2.3. Characterization of farmers' preferred accessions

Farmers' preferred pearl millet accessions have been collected as well as other bio-morphological and organoleptic traits. Figure 6 indicates the discriminated groups within a two-dimensional factorial plan of the multiple correspondence analysis (MCA).

The first two axes express 56.26% of the total variability. Axis 1 reflects 34.39% of the variability and contrasts the Group G<sub>a</sub> from positive section to Group G<sub>d</sub> located on negative part. Group G<sub>a</sub> holds pearl millet accessions that have shorter stems and spikes and smoother leaves than the other ones. These are generally short-cycle accessions. Group G<sub>d</sub> consists of pearl millet accessions that have longer stems and spikes and hairier leaves than the other ones. The accessions of this group are also of short-cycle but less early than those of Group G<sub>a</sub>. Axis 2, which expresses 21.87% of the variability, highlights G<sub>b</sub> and G<sub>c</sub> group accessions. G<sub>b</sub> group consists of early-cycle accessions and has larger stems, longer spikes and smoother leaves, while G<sub>c</sub> group gathers accessions with



**Figure 4.** Factor map describing the relationships between individual producers and their main productions. **Legend:** Enseig: Teacher, Maço: Builder, Trans: Carrier, Coutu: Dressmaker, Agric: Farmer, Forg: Blacksmith, Repar: Repairman, Charl: Charlatan, Bouch: Butcher, Fonc: Civil servant, Comm: Merchant, Manoe: Workman, Elev: Herder, Agroël: Farmer-Herder, Ouvr: Manual worker, Grio: Griot, Gn\_Mil: Pearl millet grain, Gn\_Sorg: Sorghum grain, Gn\_Achi: Groundnut grain, Gn\_Niéb: Cowpea grain, Plle\_Mil: Pearl millet straw, Plle\_Sorg: Sorghum straw, Fne\_Achi: Groundnut haulm, Fne\_Niéb: Cowpea haulm.

longer stems, wider and longer spikes comparatively to the other accessions. This group of accessions has a late cycle.

### 3.3. Cropping systems areas across the Niger regions

The cropping systems investigated favoured cereal (sorghum, pearl millet) and legume (groundnut, cowpea) as well as straw and haulms from sorghum, pearl millet, groundnut and cowpea productions respectively used for various purposes. The Pearson correlation analysis (Table 3) indicates respective associations between groundnut and sorghum grains production, pearl millet and sorghum grains production, cowpea grains production, and pearl millet straws production. Positive and significant correlations occur between productions of straws (pearl millet and sorghum) and grains (pearl millet). Quantitative cereal grains productions discriminate significantly farmers (Table 4).

## 4. Discussion

### 4.1. Farmers' perceptions of pearl millet accessions fodder features

At the scale of Niger Republic, accessions of pearl millet can be of fodder interest to farmers when meeting the following six main criteria: (a) producing abundant fertile or infertile tillers, (b) having a big height ( $\geq 3m$ ), (c) having leaves that are both long and wide, (d) having slender stems but with a lot of leaves, (e) having the capacity to quickly regenerate after grazing, and (f) producing more biomass than grains. These farmers' choices are well supported by the results of Multiple

Correspondence Analyses (accessions x morphological features) and the factorial map that discriminated three morphologically distinct accessions groups (GI, GII and GIII).

Nevertheless, Pasternak et al. (2012) felt that important characteristics expected from a fodder pearl millet variety include: (i) shorter production cycle: (ii) longer production cycle (iii) capacity to regenerate after mowing.

Indeed, during their study, Pasternak et al. (2012) evaluated the dry matter yield and quality of fodder at the boot, anthesis and at the soft dough stages. Thus, they found for this trial, that the highest seeding density gave a higher dry matter (and grain) yield compared to the lowest density (Pasternak et al., 2012). So, the dough stage was therefore the most suitable for harvesting, as the dry matter was at its maximum (Pasternak et al., 2012). However, the digestibility of organic matter and crude protein is higher at the boot stage than at the dough stage (Pasternak et al., 2012). The Malgorou variety gave the highest dry matter yield at the pasty stage. The high fodder productivity of this pearl millet variety was attributed to the longer growing period before anthesis and the higher number of tillers (Pasternak et al., 2012). These results demonstrated how long lasting pearl millet varieties can become an important source of fodder in the Sahel under rainfed growing conditions (Pasternak et al., 2012).

The breeding study undertaken by Loumerem (2004) in the Tunisian arid farming environment enabled selection of 20 pearl millet fodder lines. These lines included the most homogeneous plants for different target features, including: high number of leaves and tillers, length and width of leaves, high fodder yield potential and slow senescence at

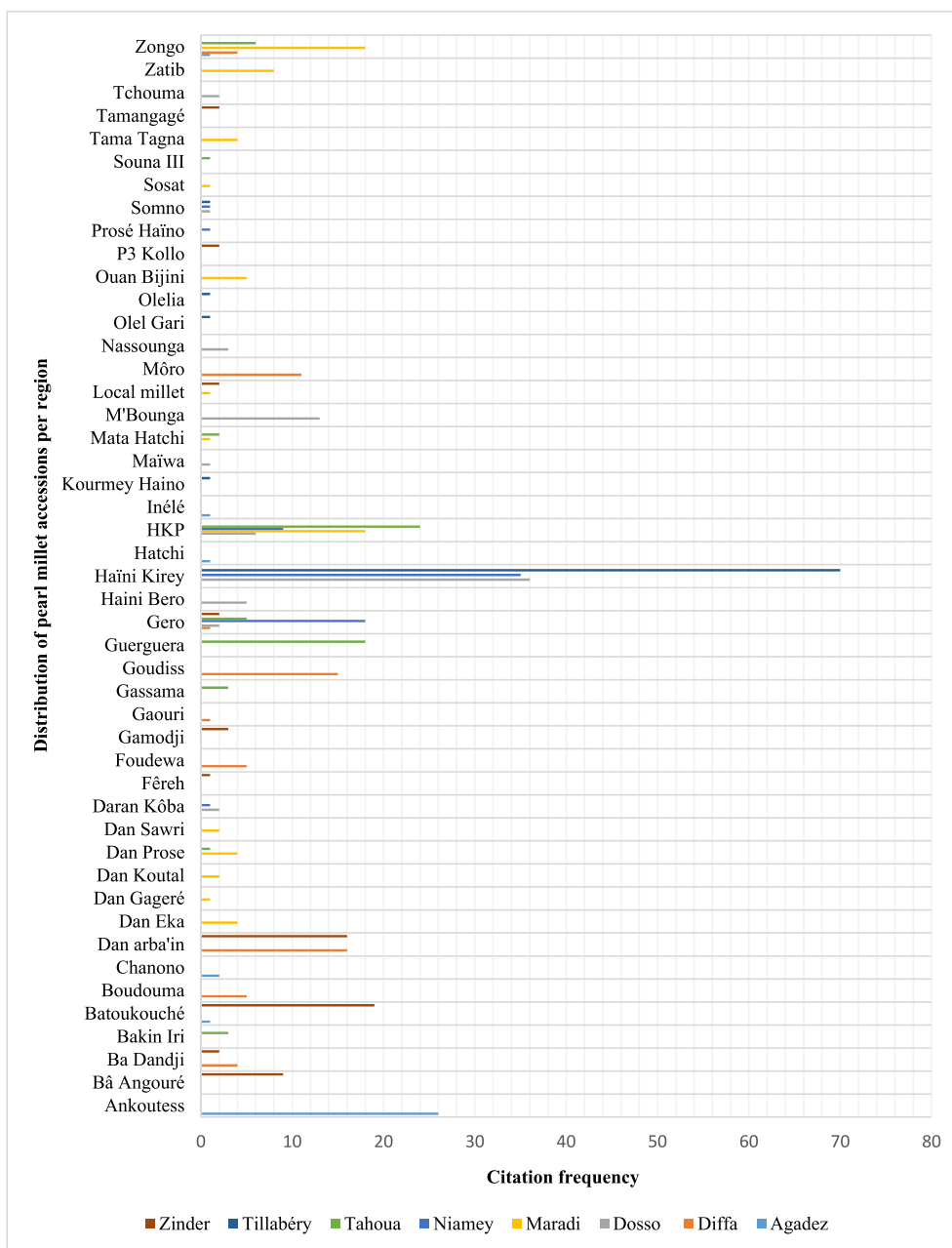


Figure 5. Preferred pearl millet accessions per region based on the citation frequency.

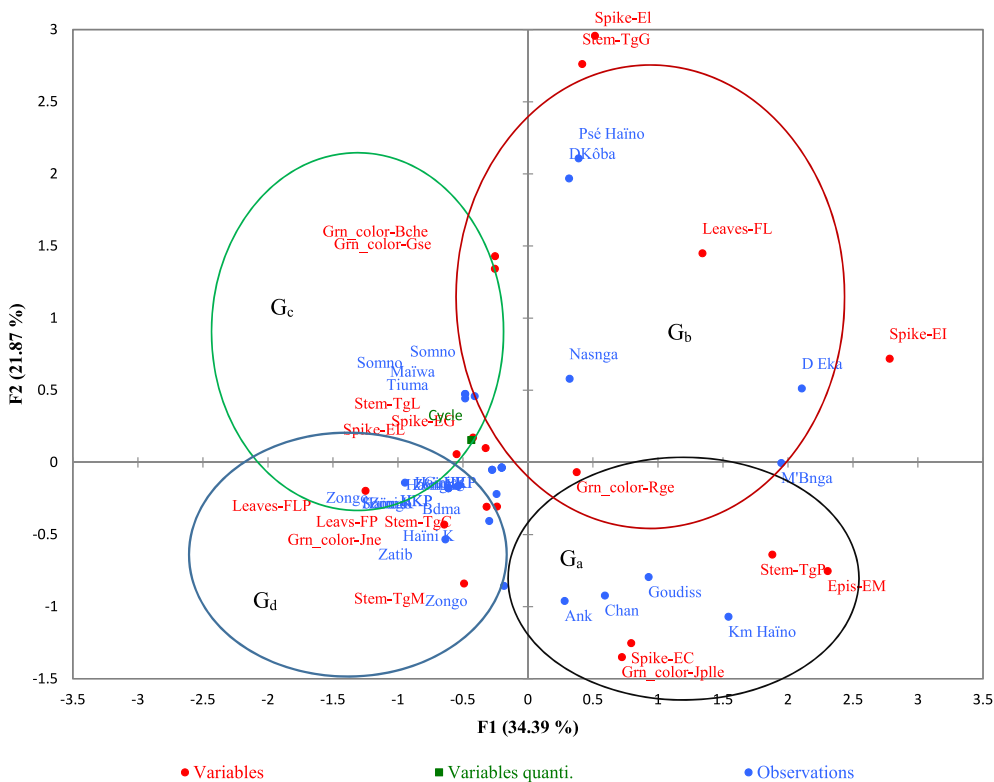
panicle maturity. Similarly, [Makeri and Ugherughe \(1992\)](#) reported from Northern Nigerian, 20 pearl millet varieties discriminated by dry matter production ranging from 7.2 to 9.92 tons ha<sup>-1</sup>. Thus, occurrence of several wild, intermediate forms and local pearl millet ecotypes would make the Niger an important pearl millet diversity center ([Ouendeba and Sogoba, 2004](#)). This variability may offer a strong genetic reservoir for developing high-performance pearl millet varieties that can withstand biotic and abiotic constraints ([Ouendeba and Sogoba, 2004](#)).

#### 4.2. Farmers' preferences for pearl millet accessions

Results showed significant changes between the regions of Niger following the choice of pearl millet accessions. These choices depend mainly on production objectives, agro-climatic and soil conditions and the people dietary habits ([Baidu-Forson, 1997](#); [Ndjeunga and Nelson, 2005](#)). Also, a spatial predominance of an accession appears to be linked to an agro-ecological or socio-cultural distributive pattern. This is the

case of either the *Haini kirey* accession at Tillabéry, Niamey and Dosso, *HKP* at Tahoua, *Ankoutess* at Agadez or *Goudiss* accession at Diffa. This finding is suggesting that farmers have succeeded in developing accessions adapted to their own tastes and socio-cultural behavior.

Thus, Diffa is already noteworthy for the *Môro* and *Boudouma* accessions with hard and glassy grains for making couscous (called "*Bourabousco*" in Kanuri). The Northern Zinder and North-Eastern Maradi are marked by the *Bâ Angouré* or *Ankoutess* accessions used for couscous or a local pearl millet-based drink (called "*Fura*" in Hausa). In contrast, in the Central and Western regions, the *Haini Kirey* or *Guéro* accessions with floury grains are more suitable for the pearl millet-based drink ("*Fura*" and "*Doonu*" in Zarma-Songhay) or for dough ([Jika, 2016](#)). The choices of pearl millet accessions by farmers are indeed driven by features including grains yield, grain colour, grain taste, stem height, duration of production cycle. According to [Ouendeba et al. \(1995\)](#), traditional cultivars are mainly discriminating by flowering date, plant height, stem diameter, length of first stalk and the production of spikes



**Figure 6.** Factor map of farmers' preferred pearl millet accessions in Niger. **Legend:** Dkôba: Daran Kôba, Psé Haïno: Prosé Haïno, Ank: Ankoutess, Km Haïno: Kourmey Haïno, Chan: Chanono, M'Bnga: M'Bounga, D Eka: Dan Eka, Nsnga: Nassounga, Tiuma: Tchouma, Haïni K: Haïni Kirey, Grn: grain, EC: Short spike, Jpille: Straw yellow, TgM: Medium stem, TgL: Long stem, TgC: Short stem, TgG: Large stem, TgP: Small stem, FP: Hairy leaves, Jne: Yellow, FLP: Long and Hairy leaves, EL: Long spike, Bdma: Boudouma, Rge: Red, EG: Large spike, Gse: Grey, Bche: White.

**Table 3.** Pearson correlation coefficients between the cropping systems descriptors.

Variables	Grn_Mil	Grn_Sorgh	Grn_Achide	Grn_Niéb	Plle_Mil	Plle_Sorgh	Fne_Achide	Fne_Niéb
Grn_Mil	1							
Grn_Sorgh	0.07 <sup>ns</sup>	1						
Grn_Achide	0.06 <sup>ns</sup>	0.11*	1					
Grn_Niéb	0.02 <sup>ns</sup>	-0.00 <sup>ns</sup>	-0.00 <sup>ns</sup>	1				
Plle_Mil	0.24***	0.20***	0.08 <sup>ns</sup>	0.09*	1			
Plle_Sorgh	0.01 <sup>ns</sup>	0.51***	0.13*	-0.01 <sup>ns</sup>	0.14**	1		
Fne_Achide	0.09*	0.13*	0.67***	-0.00 <sup>ns</sup>	0.10*	0.07 <sup>ns</sup>	1	
Fne_Niéb	0.30***	-0.02 <sup>ns</sup>	-0.02 <sup>ns</sup>	0.11*	0.06 <sup>ns</sup>	0.02 <sup>ns</sup>	-0.03 <sup>ns</sup>	1

Grn\_Mil: Pearl millet grain, Grn\_Sorgh: Sorghum grain, Grn\_Achide: Groundnut grain, Grn\_Niéb: Cowpea grain, Plle\_Mil: Pearl millet straw, Plle\_Sorgh: Sorghum straw, Fne\_Achide: Groundnut haulm, Fne\_Niéb: Cowpea haulm.

\* (P ≤ 0.05): Significant; \*\* (P ≤ 0,001): Highly significant; \*\*\* (P<0.0001): Very highly significant.

**Table 4.** Comparative grains and straws productions of main crop species grown by socio-professionals in Niger.

	Maço	Agric	Elev	Coutu	Agroé	Ouv	Trans	Comm	Fonc	Pr > F
Gn_Mil	1928.57 <sup>a</sup>	934.28 <sup>abc</sup>	1741.56 <sup>ab</sup>	535.71 <sup>c</sup>	1018.57 <sup>abc</sup>	1714.29 <sup>ab</sup>	728.57 <sup>bc</sup>	1062.86 <sup>abc</sup>	314.29 <sup>c</sup>	0.019
Gn_Sorgh	0.00 <sup>b</sup>	56.86 <sup>b</sup>	0.00 <sup>b</sup>	125.00 <sup>b</sup>	72.50 <sup>b</sup>	58.33 <sup>b</sup>	468.75 <sup>a</sup>	0.00 <sup>b</sup>	0.00 <sup>b</sup>	0.004
Gn_Achi	58.45 <sup>a</sup>	96.37 <sup>a</sup>	7.97 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	3.00 <sup>a</sup>	0.00 <sup>a</sup>	0.997
Gn_Niéb	621.33 <sup>a</sup>	328.19 <sup>a</sup>	418.73 <sup>a</sup>	240.00 <sup>a</sup>	127.20 <sup>a</sup>	183.33 <sup>a</sup>	115.00 <sup>a</sup>	171.50 <sup>a</sup>	51.00 <sup>a</sup>	1.000
Plle_Mil	4433.33 <sup>a</sup>	1295.62 <sup>b</sup>	817.73 <sup>b</sup>	1365.00 <sup>b</sup>	906.50 <sup>b</sup>	816.67 <sup>b</sup>	840.00 <sup>b</sup>	448.00 <sup>b</sup>	1587.83 <sup>b</sup>	0.169
Plle_Sorgh	0.00 <sup>a</sup>	232.18 <sup>a</sup>	0.00 <sup>a</sup>	315.00 <sup>a</sup>	279.00 <sup>a</sup>	390.00 <sup>a</sup>	675.00 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	0.992
Fne_Achi	0.00 <sup>a</sup>	58.77 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	4.12 <sup>a</sup>	0.00 <sup>a</sup>	0.993
FneNiéb	1991.33 <sup>a</sup>	934.61 <sup>a</sup>	1722.91 <sup>a</sup>	180.25 <sup>a</sup>	703.49 <sup>a</sup>	480.67 <sup>a</sup>	515.00 <sup>a</sup>	754.99 <sup>a</sup>	739.03 <sup>a</sup>	0.994

**Legend:** Gn\_Mil: Pearl millet grain, Gn\_Sorgh: Sorghum grain, Gn\_Achi: Groundnut grain, Gn\_Niéb: Cowpea grain, Plle\_Mil: Pearl millet straw, Plle\_Sorgh: Sorghum straw, Fne\_Achi: Groundnut haulm, Fne\_Niéb: Cowpea haulm, Maço: Bricklayer, Agric: Farmer, Elev: Herder, Coutu: Dressmaker, Agroé: Farmer-Herder, Ouv: Manual worker, Trans: Carrier, Comm: Trader, Fonc: Civil servant.

**NB:** On a same line, the numbers with different letters are statistically different at the threshold of 5%.

and grains. All these authors rather imply how traditional cultivars correspond to a farming reality and intentional type choice. In Niger, *Haiini Kiré*, *Guerguéra* and *Zongo* (early accessions) are mostly used in the West, the *Bâ Angouré*, *Ankoutess* and *Boudouma* groups (early accessions) predominate in the East, while the *Maiwa/Somno* group (late accessions) are more widely cultivated in the Western and Central parts. Additionally to the above list of accessions, there are the so-called oases pearl millet types grown in the Air Mountains (Bezançon et al., 1997; Halilou and Karimou, 2019; Moussa et al., 2019).

We have identified four groups of pearl millet accessions: Groups G<sub>1</sub>, G<sub>2</sub> and G<sub>4</sub> all of early pearl millet accessions ( $\leq 110$  days) while group G<sub>3</sub> corresponded to the late pearl millet accessions ( $\geq 120$  days). These various groups of closely related pearl millet accessions are indicative of agro-morphological and genetic diversity of Niger's agrarian systems.

Beyond being the second largest producer, the Republic of Niger offers the widest range of pearl millet morphologies in West Africa (Mariac et al., 2006; Tostain, 1994). This singularity is further emphasized by the spikes morphology which shows a wide variability, ranging from very short spikes in the Eastern part to very long spikes in the South-Central Niger (Mariac et al., 2006).

#### 4.3. Analysis of cropping systems

The cropping system deserves attention to understanding the specificities and scale of spatial investigation. Sebillotte (1990) defined it as "the range of technical procedures modalities that are implemented on the plots identically processed. Thus, every cropping system is defined by: i) the types of farms and their succession order; ii) the technical procedures implemented on farms types".

In lack of technical itinerary data, we addressed the cropping systems through respective species and levels of production. Agriculture in the Sahel tends to prefer the cereal/legume associations, which are diversified and variable along agronomical, nutritional, socio-cultural, socio-economical, demographical and political factors. For instance, farms associations or dissociations can be driven by seasons, socio-cultural practices, geographical area, agricultural policy guidelines, regional market issues (Gaillard and Sourisseau, 2009; Hamadou, 2000) or local demographical pressure, social and climate change adaptive strategies (Abdou et al., 2017b, 2019; Bello, 2016).

Additionally, other associations are developed between legumes (cowpea-sorrel, groundnut-sorrel), or between cereals (pearl millet-sorghum, pearl millet-maize, sorghum-maize). Cereal associations are made by rotation with the most fertile and/or water-demanding crops (sorghum or maize) being placed at the bottom of plots, in lowlands, along edges of ponds or basins (Karimou and Atikou, 2002; Adam et al., 1997; Bodo et al., 2019).

In contrast, most dominant cereal/legume associations across the Niger combine pearl millet with cowpea (*Vigna unguiculata*) or groundnut (*Arachis hypogea*) (Abdou et al., 2019; Bello, 2016; Bodo et al., 2019; Hamidou et al., 2016; Karim et al., 2016; Lawane et al., 2009; Mamoudou et al., 2015). It is also easier to find multilevel associations, such as pearl millet-sorghum-cowpea, pearl millet-sorghum-cowpea-sorrel, pearl millet-sorghum-cowpea-groundnut, pearl millet-sorghum-cowpea-sesame, pearl millet-sorghum-sorrel-sesame or pearl millet-sorghum-groundnut-sorrel (Abdou et al., 2019; Djibo et al., 2016; Karimou and Atikou, 2002).

Cereal-legume is indeed the most common association in West and Central Africa, where legumes are mostly often grown with pearl millet or sorghum (Bationo et al., 2011; Hamidou et al., 2016). According to Bationo et al. (2003), intercropping covers over 75% of West Africa Sudano-Sahelian croplands. Therefore, associated crop is more productive than monoculture because maize/legume reduces failure risk, improves productivity and incomes, and increases food security in vulnerable production systems (Rusinamhodzi et al., 2012).

However, the pearl millet mono-cropping, reduces fertility, rapidly degrades soil structure, enhances the invasion of diseases (mildew,

anthrax), insects (stem borers, grain-sucking borers) and weeds such as *striga* (Beninga 2014).

Cereal/legume is also an ecological intensification pathway (Olufajo and Singh, 2002). Arranging two lines cereals with two lines cowpea or two lines cereals with four lines cowpea was found more appropriate than the traditional practice of one cereal line with one cowpea line, which occurs in the Sahel (Rusinamhodzi et al., 2012). Alternating rows of pearl millet/cowpea promotes the light rays entrance into the pearl millet basal leaves which improves the foliar chlorophyll assimilation (Beninga, 2014). The legume covering highly reduces evapotranspiration while improving the soil nitrogen status. Similarly, interspecific competition for soil nutrients and water is greatly reduced (Beninga, 2014).

Moreover, it has been suggested that farming residues might be left for protecting soils against wind and water erosion, whose microbial activity offers higher structural stability of soil in no-till and ridge-cropping practices (Bationo et al., 2003; Bodo et al., 2019; Hamidou et al., 2016). Productivity and sustainability of these systems require optimizing crop residue management for soils protection (Beninga, 2014).

We found positive and highly significant correlations between cereal straws and grains productions. Indeed, these strong correlations may result from mutual tolerance. Indeed, a good grain production generally indicates good development of stems and leaves. However, the weak correlations between the cereal straw and legume grains production can be explained by multiple cereal/legume associations, i.e., pearl millet-sorghum-cowpea or pearl millet-sorghum-groundnut, which are more supportive of the legume vegetative development.

These findings are close to those of Beninga (2014) who reported from Nigeria, Niger and Burkina Faso, that 90% of pearl millet cropland is planted with crop associations including pearl millet and cowpea, sorghum, maize, groundnut or both sorghum and cowpea.

In addition, the positive correlation between cowpea haulms and pearl millet grains productions might be the result of the predominance of pearl millet-cowpea association and the potential competition induced by cowpea plants.

There is positive but weak correlation between the cowpea grain and haulms productions. Generally, a good grain yield is not well compatible with a good haulms yield. Indeed, the cowpea grains harvest is staggered, which implies significant foliage losses after several harvests. Nevertheless, the strong positive correlation between the groundnut haulms and grains productions can also be explained by the peanut harvest singleness, both for grains and haulms. The harvest will never favour a crop. Hence, good haulms yield could be the same with good grain yields in peanuts cropping.

The results on cropping systems showed significant variability among farmers across the Niger, even though they all cultivated more or less same plant species in the same cropping associations. Thus, the variations between pearl millet and sorghum grains productions and the socio-professional groups could be attributed to the reality that both cereals are main food crops. In addition, as agriculture is essentially for livelihood purposes in Niger, therefore, the main goal remains mostly the grains production.

However, the potential production discrepancies are likely to reveal distinctive objectives, agroecological strengths, socio-economical and socio-cultural features. For example, the group G<sub>1</sub> of typical professional individuals (Farmers, Farmer-Herders, Butchers, Merchants, Herders, Civil servants, Griots, Builders, Manual workers, Carriers), produced the most consistent quantities of pearl millet grains and straws and cowpea haulms. This group at higher incomes was likely to be significant agricultural investors in order to produce significant amounts of grains. In view of the large quantities of pearl millet that they had to borrow, it is well likely that the grains are used for household consumption while the straw and cowpea haulms would either be devolved for feeding livestock or trading on the market.

These results are closed to those of Beninga (2014) who argued that certain types of cropping associations were originated from agro-climate,

ethology and diet. Indeed, this author performed an ethnic discrimination using cropping associations and indigenous dietary habits in Côte d'Ivoire. For instance, while *Malinke* were linked to pearl millet and other cereals in the North-West, *Senoufo* were clustered around pearl millet and other cereals or pearl millet and legumes in the North-Central region, and *Koulango* and *Lobi* in the North-East were more attached to pearl millet and tubers.

Individuals of group G<sub>2</sub>, are efficient in straw production. As multi-functional stakeholders, they are also able to increase incomes by fattening large ruminants for market or to gain additional income by raising cattle. This somehow requires greater production or substantial purchases to offset feed needs.

Finally, the group G<sub>3</sub> of manual workers produces the best volumes of pearl millet, cowpea grains, and haulms. These wealthy actors invest heavily in inputs for large grains harvests of pearl millet, cowpeas and cereals. This reflects current reality of ambitious wage earners investing in agriculture. Pearl millet and cowpea grains could feed household while cowpea haulms, the animals or be sold. In any case, significant output would be used for feeding animals. The production of legumes associated to cereals is known as an approach integrating traditional crop-livestock production systems, guaranteeing new urban and peri-urban outlets or as a response to the scarcity of spontaneous forage plants (Saidou et al., 2018).

## 5. Conclusion

This study describes farmers' perceptions of pearl millet accessions with a forage profile. The forage profile combines long and/or large sheets, abundance of non-fertile tillers, fine stems, higher biomass and proven abilities or capacities to regenerate after mowing. There is variability in farmers' choice of pearl millet accessions, motivated by agro-ecological and socio-cultural factors. Producers differ from each other although their crop management practices are still similar. The most dominant cropping system combines pearl millet with cowpeas or groundnuts. Therefore, any identification, characterization and/or sustainable improvement of pearl millet accessions with a grain or fodder profile needs involvement of farmers across Niger.

## Declarations

### Author contribution statement

Hamadou Moussa; Valentin Kindomihou; Thierry D. Houehanou; Mahamadou Chaibou; Oumarou Souleymane; Idrissa Soumana; Joseph Dossou; Brice Sinsin: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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### Data availability statement

Data will be made available on request.

### Declaration of interests statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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