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Assessment of genetic diversity among pearl millet landraces (*pennisetum glaucum* (L.) R. Br.) from Algerian Sahara using qualitative traits

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Abstract

Genetic diversity is an asset for successful genetic improvement but also for food security. The aim of this work was to evaluate the variability of some millet landraces through qualitative traits using the Shannon diversity index (H'). Results showed existence of a high diversity for: green fodder yield potential (0.977), flag leaf attitude (0.736), bristle colour (0.625) and seed shape (0.632). Intermediate diversity index was found in the majority of the traits studied with the highest value for the anther colour (0.594), the tillering attitude (0.591), the number of nodal tillers (0.526), the spikelet shattering/threshing (0.468) and the seed colour (0.415). The same value of intermediate diversity index (0.497) was registered for the plant aspect, the bristle length and the seed covering. The lowest values of diversity index concerned the spikelet glume colour (0.403) and the spike shape (0.377). In vegetative traits, these classes were dominant: erect growth habit (64.71 %), intermediate green fodder yield potential (41.18 %), good plant aspect (76.47), few numbers of nodal tillers (82.35 %) and intermediate flag leaf attitude (64.71 %). In inflorescence traits, the greatest proportions were registered for: cylindrical spike shape (52.94 %), non-shattering and free threshing (64.71 %), tan tips for bristle colour (64.71 %), medium bristle length (76.47 %), brown group for anther colour (52.94 %) and yellow green group for spikelet glume colour (64.71 %). In seeds, intermediate seed covering class dominated with 76.47 %, followed by the gray brown group in seed colour (64.71 %) and finally by oblanceolate seed shape class (52.94 %).

Key words: Local ecotypes, Pearl millet, Shannon diversity index, Variability.

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1. Introduction

Pearl millet (*Pennisetum glaucum*) is a major warm-season cereal grown on 26 million ha in the arid and semi-arid tropical regions of Asia (› 10 million ha) and Africa (15-16 million ha), with India being the largest producer (› 9 million ha) of this crop in the world (Rai et al., 2009). In these regions, pearl millet is grown for food, feed and fodder, where increased and stable production of this crop is essential for well-being of millions of people living in these marginal regions (ICRISAT, 2015).

Genetic diversity is an important aspect in the exploration of plant genetic resources (McBenedict et al., 2016) and is defined as a variety of genes in a given species, which are important for adaptation and conservation of desired traits and drives survival during natural selection (Holden and Peacock, 1993).

According to Kumar and Andrews (1993), information on the genetics of different traits of a crop is important for its systematic breeding and long-term improvement. Lule et al. (2012) reported that species with greater genetic diversity are more likely to be able to evolve in response to a changing environment than those with low genetic diversity.

Pearl millet has wide genetic diversity, which is of little value unless it is characterized, evaluated and documented properly to enhance its utilization in crop improvement (Singh et al., 2016). On their side, Khairwal et al. (2007) indicated that pearl millet is a highly cross-pollinated crop and possesses enormous natural variability for quantitative, qualitative and quality traits.

The success in crop improvement programs depends largely on the extent of genetic variability available to the researchers (Upadhyaya et al., 2007).

Scientists to distinguish between varieties of different crops used seed traits. In other hand, as indicated by several authors (Weltzien et al., 1998; Basavaraj et al., 2015; Drabo et al., 2018) certain pearl millet qualitative traits related to grains and spikes are crucial for varietal choice by farmers.

To enhance adoption, Drabo et al. (2018) concluded that new varieties must correspond to farmer’s preferences and respond to the constraints prevailing in the production environments.

The green forage yield of pearl millet for livestock is also an important trait. As indicated by Chohan et al. (2006), it is important to develop pearl millet cultivars having high yield to meet the growing forage demand.

In Algeria, rural communities, like those of Adrar oases shelter great species diversity, are going through rapid changes (modernization, abandon of old culinary dishes, decline of the old oases ...) making plant diversity in danger.

Therefore, the assessment of variability for the economically important traits and identification of promising germplasm in unexploited landraces of pearl millet is essential to generate knowledge useful for germplasm conservation and breeding programs. Phenotypic information based on descriptors usually is the first step for the assessment, description and classification of germplasm collections to enhance pearl millet utilization in breeding.

This study aimed to evaluate the genetic diversity of some landraces of pearl millet through qualitative traits related to plant, spike and grain characteristics.

Materials and methods

Plant materials and experimental design

Pearl millet studied germplasm (Table 1) consisted of seventeen landraces collected from Algerian Sahara. The sampling sites were divided into western (Adrar) and central (Ain Salah, Hoggar, Tamanrasset) regions. The collected plant samples were grown at the National Institute of Agricultural Research of Algeria of Baraki (Algiers) situated in the plain of Mitidja (sub-humid zone with an average annual rainfall exceeding 500 mm).

A completely randomized design was adopted with three plots.

Experimental plot was one single row 6.3 m long, with 0.70 m inter rows spacing. Ten seeds, 0.70 m spaced, were sown per plot. The trial was irrigated twice per week at the beginning of cycle (up to the dough stage) and once per week at the end of cycle. 50 kg/ha of fertilizer (18 units N, 18 units P, 18 units K) were applied before sowing. The texture of the soil was a sandy clay loam.

Table 1. List of the investigated pearl millet landraces

Order	Sampling site
1	Tamanrasset
2	Tagrambait (Tamanrasset)
3	Tamanrasset
4	Tagrambait (Tamanrasset)
5	Tagrambait (Tamanrasset)
6	Tagrambait (tamanrasset)
7	Tagrambait (tamanrasset)
8	Tagrambait (tamanrasset)
9	Tagrambait (tamanrasset)
10	Tagrambait (tamanrasset)
11 (control)	Tagrambait (tamanrasset)
12	KsarOuled Ali
13	Adrar
14	KsarOuled Ali
15	KsarOuled Ali
16	Adrar
17	Adrar

Measurements

The observations were recorded for 14 agro-morphological descriptors including biotic stresses downy mildew, blast and rust diseases following guidelines of IBPGR and ICRISAT (IBPGR and ICRISAT 1993).

Traits measured were: plant aspect, number of nodal tillers, tillering attitude, flag leaf attitude, green fodder yield, spike shape, anther colour, spikelet glume colour, bristle colour, bristle length, spikelet shattering/threshing, seed shape, seed colour and seed covering. Measurements were based at 3, 5 and 7 scale, according to IBPGR/ICRISAT (1993); and made at different growth stages. Observations have been done on 10 randomly selected plants for every qualitative trait studied. Observations on grain characters such as seed shape, seed colour and seed covering were recorded after harvesting and threshing.

- Tillering and flag leaf attitudes were taken at heading
- Anther colour was measured before anther dehiscence
- Green fodder yield potential was evaluated at flowering
- Plant aspect, number of nodal tillers, spike shape (or panicle shape); spikelet glume colour, bristle colour and bristle length were measured at dough growth stage.
- Spikelet shattering/threshing taken at crop maturity
- Seed shape, colour and seed covering were evaluated at crop maturity after threshing.

Data analysis

- Collected data were analyzed using the Shannon diversity index (H'), calculated by the following formulae equation reported in Hennink and Zeven (1991).

$$H = -\sum_{i=1}^{n} pi \ln pi$$

where n is the number of phenotypic classes for a trait and *pi* is the proportion of the total number of entries consisting of the i^{th} class. To express the values of H' in the range of 0-1, each value of H' was divided by Ln n (where Ln n represents the natural logarithm of (n).

$$H' = \frac{H}{Hmax}$$

H max= $\ln(N)$

Results

1. Percentage of classes

For vegetative traits (table 2)**,** dominate classes were registered for: erect tillering attitude or growth habit (64.71 %), intermediate green fodder yield potential (41.18 %), good plant aspect (76.47), few numbers of nodal tillers (82.35 %) and intermediate flag leaf attitude (64.71 %).

In inflorescence traits, the greatest proportions were registered for: cylindrical spike shape (52.94 %), non-shattering and free threshing (64.71 %), tan tips for bristle colour (64.71 %), medium bristle length (76.47 %), brown group for anther colour (52.94 %) and yellow green group for spikelet glume colour (64.71 %).

In seeds, intermediate seed covering class dominated with 76.47 %, followed by the gray brown group in seed colour (64.71 %) and by oblanceolate seed shape class (52.94 %).

2. Diversity among landraces

Concerning the diversity in the germplasm and basing in the Shannon diversity index (table 2), results showed existence of a high diversity for the following traits: green fodder yield potential (0.977), flag leaf attitude (0.736), bristle colour (0.625) and seed shape (0.632). Intermediate diversity index was found in the majority of the traits studied. The highest values concerned the anther colour (0.594), the tillering attitude (0.591), and the number of nodal tillers (0.526). Plant aspect, bristle length and seed covering have the same value (0,497) followed by spikelet shattering/threshing (0.468) and seed colour (0.415). The lowest values of diversity index concerned the spikelet glume colour (0.403) and the spike shape (0.377).

Table 2. Phenotypic classes found, their numbers compared to those of IBPGR/ICRISAT (1993), percentage of classes and H' diversity index of the qualitative traits on 17 pearl millet landraces

Morphological traits	Phenotypic class observed	Class found/class by IBPGR and ICRISAT	Proportion (%)	Diversity index (H')
		Vegetative traits		
Tillering attitude	Erect	2/3	64.71	0.591
	Intermediate		35.29	
Plant aspect	Good	2/3	76.47	0.497
	Intermediate		23.53	
Green fodder yield potential	Poor	3/3	23.53	0.997
	Intermediate		41.18	
	Good		35.29	
Number of nodal tillers	Few	3/3	82.35	0.526
	Intermediate		11.76	
	Many		5.88	
Flag leaf attitude	Erect	3/3	29.41	0.736
	Intermediate		64.71	
	Pendant		5.88	
		Inflorescence traits		
Spike shape	Cylindrical	3/9	52.94	0.377
	Conical		41.18	
	Spindle		5.88	
Bristle colour	Grey	4/5	5.88	0.625
	Tan tips		64.71	
	Purple		17.65	
	Yellow-green		11.76	
Bristle length	Medium	2/3	76.47	0.497
	Long		23.53	
Spikelet glume colour	Yellow-green	2/5	64.71	0.403
	Tips purple		35.29	
Spikelet shattering/threshing	Non-shattering and free threshing	2/4	64.71	0.468
	Non-shattering and difficult to thresh		6	
Anther colour	Yellow	3/5	11.76	0.594
	Brown-yellow		35.29	
	Brown		52.94	
		Grain traits		
Seed shape	Globular	3/5	23.53	0.632
	Oblanceolate		52.94	
	Obovate		23.53	
Seed colour	Cream	4/10	5.88	0.415
	Yellow		5.88	
	Brown		23.53	
	Grey brown		64.71	
Seed covering	Intermediate	2/3	76.47	0.497
	Exposed		23.53	

Discussion

Majority of traits studied have high and intermediate diversity index indicating the existence of an interesting diversity among the pearl millet landraces studied. According to Kumar et al. (2012), success in crop improvement depends mainly on the extent of desirable genetic variability available for selection.

Diversity and dominant classes for traits

I. Vegetative traits

I.1. Tillering attitude or growth habit

Plant habit, also known as plant life form, is the characteristic shape, appearance, or growth form of a plant species. It develops from specific genetic patterns of growth in combination with environmental factors and is part of the organization of every plant (Plant life, 2011).

Our results showed that class of erect growth habit was dominant (64.71 %) with an intermediate diversity index (0.591). Erect and dense growth habits evolved to resist wind effects and other mechanical damages (Plant life, 2011).

In the study taken by Rai et al. (2009) on hybrid parental lines of pearl millet of ICRISAT, majority of lines (90 %) were also erect in their growth habit but with not considerable variation found for this trait as well as for other qualitative traits. In finger millet landraces from eastern and south eastern Africa, erect type growth habit was predominant in all countries (Lule et al., 2012). On the contrary, the study taken by Gupta *et al.* (2011) revealed that majority of lines (78 %) of pearl millet from ICRISAT, were intermediate in their growth habit.

I.2. Green fodder yield potential and plant aspect

Green fodder yield determines the fodder yield potential of landraces (Upadhyaya et al., 2014). According to Uno (2005), the characteristics of the local varieties, the possibility of high yields, late maturity, long and strong stalks and greater biomass were important to the traditional homestead and multi-subsistence strategies of farmers in Northern Namibia.

In our case, the highest diversity index was registered for fodder green yield potential (0.977) with domination of intermediate green fodder yield potential class (41.18 %). Kumari et al. (2016) found that pearl millet collections from India were more diverse (Shannon Diversity Index >0.5) among others for green fodder potential.

Studying the genetic diversity in pearl millet landraces from arid and semi-arid regions of Rajasthan, Yadav (2008) also mentioned a good variation for the agronomic value of landraces also as green fodder source.

Good plant aspect class was dominant (76.47 %), which shows that millet cultivars have performed well in the humid conditions of Mitidja although originating from dry and hyper-arid regions. Almost all plants were disease-free and had good resistance to pests, testifying the great ability of pearl millet adaptation to different environments. Pattanashetti et al. (2016) concluded that pearl millet is gaining importance as a climate-resilient beside its health-promoting nutritious crop.

I.3. Number of nodal tillers

Nodal tillers frequently do not mature before harvest and thus increase the feed quality of the stover (Weltzien et al., 1998).

The number of nodal tillers in our study presented an intermediate diversity index (0.526). Evaluation of germplasm accessions studied by Khairwal et al. (2007) revealed considerable variation among others for number of nodal tillers. In contrary, not considerable variation was observed for this trait beside anthocyanin coloration of first leaf sheath, spike girth; stem thickness; leaf mid rib color and ligule hair in a study taken by Singh et al. (2016).

All Algerian pearl millet landraces have a capacity to produce nodal tillers. Yadav (2008) reported that ability of landraces to produce nodal tillers (also called as aerial) provides developmental plasticity to landraces and is an important component of adaptation mechanism to the harsh growing environments.

In our study nodal tillers varied between 1.18 and 6.33 as average values. Evaluating 180 landraces of pearl millet in India, Khairwal et al. (2007) found a range of 6 to 14 nodes per plant.

I.4. Flag leaf attitude

Flag leaves play an important role in synthesis and translocation of photo assimilates in the pearl millet plant, affecting grain yield; similarly it was believed to be a major source of remobilizing micronutrients (Fe and Zn) for the seeds (Berwal et al., 2018).

Our study showed a high diversity index (0.736) for flag leaf attitude with a dominate class of intermediate flag leaf attitude (64.71 %) and 29.41 % for erect flag leaf class. This high variability registered is a promising result for breeding programs knowing that leaf inclination beside leaf shape could be rapidly modified by selection to increase crop photosynthesis and yield, as indicated by Sharma et al. (2013). 29.41 % of erect flag leaf attitude class among pearl millet landraces studied is also a promising result. Vanavichit (1990) reported that erect leaf habit was advantageous for enhancing photosynthetic efficiency and has been proved by many woks for rice (*Oryza sativa* L.), barley (*Hordeum vulgare* L.), forage grasses and sugar beet (*Beta vulgaris* L.).

II. Inflorescence traits

II.1. Spike shape and spikelet glume colour

According to Upadhyaya et al. (2014), panicle shape recorded based on the majority of panicles in the plot is useful for classifying the landraces.

Our study revealed that spike shape was dominated by cylindrical class (52.94 %) followed by conical class (41.18 %) and only 5.88 % for spindle class. Class of yellow-green group dominated spikelet glume colour (64.71 %) followed by tips purple class (35.29 %).

The lowest diversity among genotypes was found for spike shape (0.377) and spikelet glume colour (0.403) revealing that these traits cannot be used to distinct between these Algerian cultivars. Yadav (2008) found that the shape of spikes did not vary to a large extent and almost all collections from Rajasthan had either candle or cylindrical shaped panicles. In a study taken by Appa Rao et al. (1985) on pearl millet collection from Ghana, inflorescences were sharply conical through cylindrical. On the contrary, the study taken by Singh et al. (2016) on pearl millet hybrids and their parents showed that spike shape and spikelet glume colour distinguished among other traits all the genotypes.

II.2. Spikelet shattering/threshing

Seed shattering (or pod dehiscence, or fruit shedding) is essential for the propagation of their offspring in wild plants but is a major cause of yield loss in crops (Dong and Wang, 2015). Threshing is the removal of grains from the stalk or panicle. The threshing of millet to obtain clean grain is one of the most tedious operations in small-scale millet processing, particularly in Africa (Atsu et al., 2009).

Our study revealed that spikelet shattering/threshing had an intermediate diversity index (0.468) with non-shattering and free threshing as a dominate class (64.71 %). Ease of threshing is a preferred trait among others by farmers (Ipinge et al., 1996; Roden et al., 2006). In our case, class of non-shattering and difficult to thresh represented only 6 %. Landraces representing this class were those having panicles with long bristle length. According to Roden et al. (2006), high bristles can cause more difficult the threshing. On their side, Goron and Raizada (2015) indicated that grain threshing and milling are among the main reasons for the decline of small mils.

II.3. Anther colour

Pearl millet is allogamous and landraces are highly heterogeneous. Stigma emergence precedes anther emergence, resulting in high cross-pollination due to wind (Upadhyaya et al., 2008).

Flower colour often viewed as a trait that signals rewards to pollinators, such that the relationship between flower colour and plant fitness might result from its association with another trait (Meléndez-Ackerman and Campbell, 1998).

Intermediate diversity index among Algerian millet landraces was found for the anther colour (0.594). Gupta et al. (2011) observed within-line variability in few restorer lines of pearl millet across two replications for some traits like anther colour. The dominate class in our case was the brown colour class (52.94 %) followed by brown-yellow class and yellow class (35.29 % and 11.76 %, respectively)

In a study taken by Singh et al. (2016), the majority of pearl millet hybrids and their parents had yellow anther color.

II.4. Bristle length and bristle colour

High bristles can help to better resistance to bird damage but can cause more difficult the threshing, as indicated by farmers testimony from the study taken in Eritrea by Roden et al. (2006).

We found an intermediate diversity index for bristle length (0.497). Kumar and Andrews (1993) reported that variation exists among other characters for length of bristles. In contrary, Upadhyaya et al. (2007) found a lowest diversity index for this trait. Our study revealed a domination of medium bristle length class (76.47 %) followed by the long bristle class (23.53 %). Studying gemplasm of Indian origin and regarding to bristle length, Kumari et al. (2016) found that 97 accessions presented medium bristle length but only 16 accessions had long bristle length. In Rajasthan and with participatory approach taken by Weltzien et al. (1998), bristles and especially long of them, are always preferred, as they tend to deter birds. According to Upadhyaya et al. (2014), the long bristles of the panicle (desirable trait) will penetrate into the eye of the bird, acting as a self-defense mechanism to scare birds. In contrary, in Burkina Faso, Drabo et al. (2018) indicated that non-bristle panicle beside compact panicle and large grain size were the most preferred traits by farmers in pearl millet across agro-ecological zones.

For bristle colour, our study revealed a dominate class of tan tips (64.71) and a high diversity index for this trait (0.625). On the contrary, Rai et al. (2009) found not considerable variation for this character.

III. Seed traits

III.1. Seed colour and seed shape

Seed colour is an important trait that differentiates landraces (Upadhyaya et al. (2014). Brunken et al. (1977) identified grain shape as the most consistent trait, which follows a geographic pattern.

From the participatory approaches in pearl millet breeding, Weltzien et al. (1998) reported that grain quality traits considered in the selection process by farmers in Jodhpur district are grain colour and grain shape. According to Arya et al. (2013), marketing quality of pearl millet grain depends on the grain colour, shape, size, texture and hardness, etc.

In our case, brown group in seed colour was the dominate class (64.71 %) and yellow brown class represented only 5.88 %. Arya et al. (2013) reported that white grain and yellow grain pearl millet are known to be rich in protein and carotene. In the world collection of pearl millet landraces at the ICRISAT genebank, 50 % of the total landraces produced grey colour seeds and 32 % of the landraces produced grey-brown colour seeds (Upadhyaya et al., 2014).

Rai et al. (2009) found gray colored seeds in the majority of ICRISAT lines of pearl millet studied.

In our case, an intermediate diversity index was found (0.415) for seed colour. According to Kumar and Andrews (1993), seed colour presents considerable variability in pearl millet and its inheritance has received relatively more attention.

Concerning the seed shape, we found a high diversity index for this trait (0.632). Kumar and Andrews (1993) reported that variation exists among other characters for grain shape. In a collection of pearl millet of Ghana, Appa Rao et al. (1985) found a considerable variation among others for grain shape and grain colour. Gupta et al. (2011) also found a considerable variation among other traits for seed shape and seed colour in ICRISAT-bred restorer parents of pearl millet.

Concerning the seed shape preference, Basavaraj et al. (2015) reported that farmers in India desired among other traits, obovate shape in grains. In our case, classes of obovate and globular seed shape were represented by a same proportion (23.53 %). The dominate class for this trait was recorded by oblanceolate seed shape class (52.94 %).

III.2. Seed Covering

Yadav (2007) indicated that seed covering by glumes was more prominent in drier areas landraces.

In our study, intermediate seed covering class dominated (76.47 %) with an intermediate diversity index (0.497). 23.53 % was the proportion for exposed seeds. In most of the landraces from Rajasthan studied by Yadav (2007), seed was covered by glume wholly or partially.

Conclusion

In addition to its high nutritional quality for human diet and for animal feed, pearl millet is a resilient crop useful for global level in the face of climate change. Diversity in plants creates resilience and is benefic for breeding programs. Loss in traditional landraces known by their diversity imposes inventory and characterization of this germplasm for its protection. Our study in pearl millet landraces from Algeria revealed existence of a great diversity for the majority of the qualitative traits studied and among them those that are important for their choice by farmers, breeders and in marketing worldwide. Results are promising for genetic improvement of this threatened germplasm as well as for the promotion of pearl millet in the north of the country, among other things for animal feed.

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