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Agro-Morphological Characterization of a Collection of Fonio [*Digitaria exilis* (Kippist.) Stapf.] Accessions from Burkina Faso

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Abstract

Considered as the oldest cereal, fonio (*Digitaria exilis* Stapf.) is grown in West Africa for its therapeutic virtues, its nutritional and organoleptic qualities. It plays an important socio-cultural and economic role for the populations of western Burkina Faso. However, very few studies on the genetic diversity of fonio have been carried out. This study aims to contribute to a better knowledge of the diversity of *Digitaria exilis* in Burkina Faso using agro-morphological descriptors. Thus, 60 accessions of fonio collected from western Burkina Faso were characterized using 21 agro-morphological characters according to an Alpha Latice design with three replications. The study showed morphological variability for most of the qualitative and quantitative characters studied. Principal component analysis (PCA) explained 56.07% of the variability. Hierarchical cluster analysis splits the accessions of the collection into four clusters using seven characters. These characters can constitute basic criteria for differentiating fonio accessions in Burkina Faso. The accessions of Group II have a long cycle and high production of grain, while the accessions of Group IV have a short cycle and low production of grain. The groups identified can serve as a starting point for fonio breeding in Burkina Faso.

Keywords

Digitaria exilis, Agro-Morphological Variability, Accession, Burkina Faso

1. Introduction

Plant genetic resources are the key to food security and sustainable agricultural

development. Indeed, climate change adaptation strategies are very costly for small family farms, which makes them very vulnerable. So, the diversification of crops appears as an alternative. The use of local varieties would constitute an opportunity for the populations because they occupy an important place in the diversification of plant resources [1]. Also, these so-called traditional varieties are genetically more diversified and better adapted to local conditions [2] [3] and their preservation contributes to maintaining the genetic richness [4]. Among the important crops maintained by West African farmers, fonio (*Digitaria* spp.) is probably the oldest African cereal [5]. Well adapted to local pedoclimate conditions, fonio is tolerant to drought due to its C4 metabolism and contributes to ecological protection by guaranteeing good plant cover on fragile and undervalued soils [6]. In traditional West African agrosystems, fonio, in addition to occupying a privileged place [7]. It plays a decisive role in preventing lean season [8]. Since the beginning of the 21st century, nutritionists have paid particular attention to this food because it is very digestible for people with allergies, especially in the case of gluten intolerance. Fonio can, therefore, also contribute to nutritional balance, which is still a growing concern in many countries. As a result, it is increasingly in demand in the sub-region and developed countries.

In Burkina Faso, fonio is used in the preparation of many traditional African recipes such as couscous, porridge, tô, and fatty fonio, which are often prescribed in the diet of some patients (diabetics) [9]. However, compared to the main cereal crops (rice, maize, sorghum and millet), fonio remains a minor plant in the Burkinabè agrarian system. It is mainly produced in the western part of the country. In addition, the arduous post-harvest treatment of fonio means that it is increasingly abandoned in some production areas. This could eventually lead to significant genetic erosion of the species in Burkina Faso. It is, therefore, necessary to preserve the local genetic resources of fonio and this requires knowledge of its genetic diversity. Indeed, genetic diversity studies carried out on cereals in Burkina Faso have mainly concerned maize [10], millet [11], rice [12] and sorghum [13]. These studies revealed significant variability at the level of morphological and molecular markers. However, the level of diversity and the structuring of this diversity of fonio grown in Burkina Faso remain very little known. The main objective of this study is the assessment of the agro-morphological variability of a collection of fonio produced in Burkina Faso. Specifically, the study aims at: 1) identifying the discriminating characters, 2) determining the relationships between the studied characters, and 3) establishing the level and structure of the diversity of the accessions created.

2. Materials and Methods

2.1. Genetic Material

The plant material consists of a collection of sixty accessions of fonio from the germplasm of the Biosciences Laboratory of the University Joseph KI-ZERBO. This germplasm was collected in 2020 in five provinces located in the west of

Burkina Faso (Figure 1). 13 accessions were collected in the provinces of Houet, 11 accessions in Kénédougou, 8 accessions in Comoé, 14 accessions in Léraba and 14 accessions in Kossi.

2.2. Experimental Site

Experiments were carried out in 2020 and 2021 during the rain in Farako-Bâ (research station of INERA), 11˚03'N and 4˚20'W. Farako-Bâ is situated at 10 kilometres in the southwest. The soil texture is loamy-sandy on the surface to sandy-clay in depth. The climate is Sudano-Guinean type [14]. Climate conditions were practically identical during the two seasons. Indeed, the annual rainfall for 2020 on the site was approximately 1213.3 mm and August was the wettest month with 404.1 mm. During the year 2021, the annual rainfall was approximately 1205.4 mm and August was also the wettest month with 414 mm. The mean annual temperatures were 27.21˚C and 28.15˚C respectively in 2020 and 2021.

2.3. Experimental Design and Cultural Practices

Alpha Latice design with three replications was used for the study. Each entry

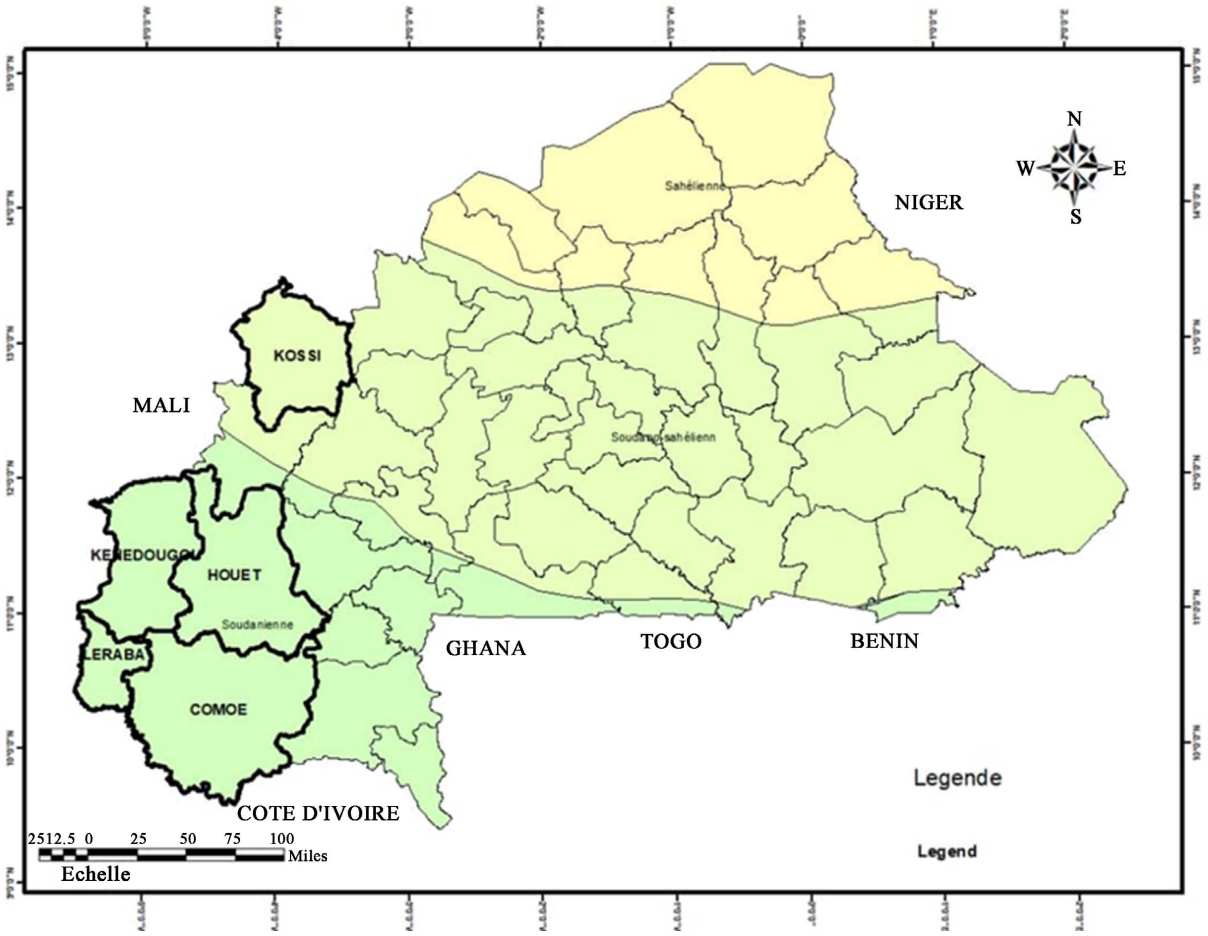

Figure 1. Investigation and collection sites of *Digitaria exilis* accessions.

was sown on 4 rows of 3m length with. The space between rows was 20 cm. the space between replications was 2 m. For sowing, on each row, 4 g of seeds were sown with 8 g of sand previously mixed in a homogeneous way. Before sowing, the soil was plowed and then leveled. Weeding was done two times and fertiliser was applied at recommended doses 100 kg of NPK 14-23-14 (35 days after emergence) [1].

2.4. Data Recording

Five plants per row were randomly selected by rejecting the border plants, to record quantitative data on characters viz, days to 50% emergence (days), days to 50% tillering (days), days to 50% flowering (days), days to 50% maturity (days), plant height at maturity (cm), total number of tillers per plant, total number of internodes, internodes length (cm), leaf length (cm), leaf width (cm), grouping of spikelets on pedicels, exertion of panicle length (cm), size of racemes (cm), total number of racemes per plant, 1000 grains weight (g), grains per accession weight (g) and dry biomass per accession weight (kg). Qualitative characters were scored through field observations and include stem color, leaf color, raceme color and grain color.

2.5. Statistical Analysis

The analysis was carried out using the Excel 2013 spreadsheet and GenStat v4.10.3 (ANOVA) and Xlstat 2016.02 software (PCA, AHC). For the qualitative variables, a descriptive analysis through the frequency calculation of the different modalities was carried out. For the quantitative variables, an analysis of variance (ANOVA) for each year was performed in order to determine the discriminating variables in order to assess the level of variability. Subsequently, the relationships between the variables were highlighted through the Pearson correlation test. Principal component analysis (PCA) was performed to assess the association of the variables measured on the different axes. The clustering of accessions was done through the agglomerative hierarchical clustering (AHC) based on the Euclidean distance between individuals at the 5% threshold.

3. Results

3.1. Phenotypic Variability Using Qualitative Characters

With the exception of leaf color (LCo) which was green for all accessions (100%), two modalities were observed for the rest of the qualitative variables studied. Thus, for the color of the stem, the majority (90%) of the accessions have green stems, and the minority (10%) have purple (**Figure 2**). Regarding raceme color (RCo), green (90%) and reddish (10%) racemes were observed (**Figure 3**). As for the color of the unshelled grain (GCo), accessions with pale yellow grains (60%) and those with brown grains (40%) were highlighted (**Figure 4**).

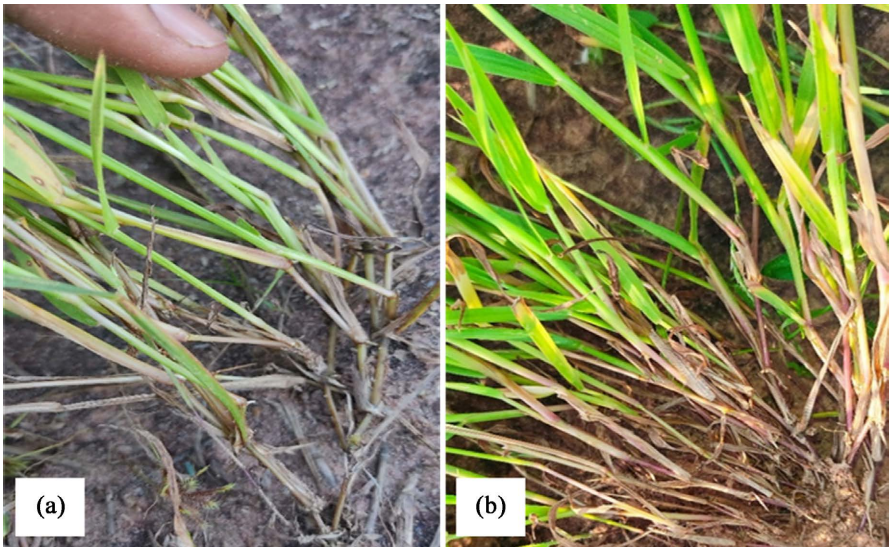

Figure 2. Stem colors of *Digitaria exilis* accessions: (a) = Green; (b) = Purple.

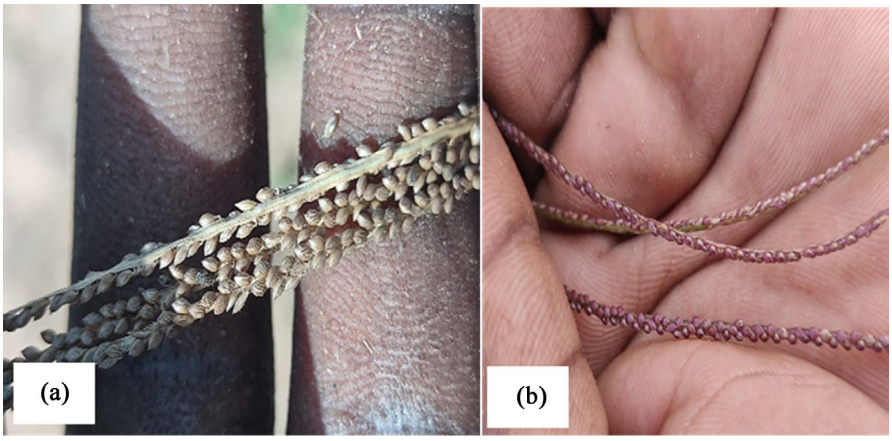

Figure 3. Raceme colors of *Digitaria exilis* accessions: (a) = Light green; (b) = Reddish.

Figure 4. Grain colors of *Digitaria exilis* accessions: (a) = Pale yellow; (b) = Brown.

3.2. Variation of the Quantitative Characters Studied

3.2.1. Mean Performance Characters Related to the Plant Cycle

The results of the analysis of variance show that of the four characters related to the plant cycle, only Days to 50% emergence did not permit to differentiate the

accessions during the two seasons. Days to 50% flowering (P = 0.019) and Days to 50% maturity (P < 0.0001) vary depending on the season (Table 1).

3.2.2. Mean Performance Characters Related to the Vegetative System

The 10 characters related to the vegetative system permit to differentiate the accessions studied during the two seasons. The factor season was significant for all characters (P < 0.0001) related to the vegetative system (Table 2).

3.2.3. Mean Performance Characters Related to the Grain

Of the three characters related to the grain, only Grain weight per accession

Table 1. Results of the analysis of the variance of the characters related to the cycle of the plant and to the mean performance of the accessions during the two seasons and of the interaction season-accession.

Characters	Season 1	Season 2	P-value between seasons	P-value interaction accession*season
DEM	6.02[a]	6.23[a]	0.943	0.364
DTA	24.09[a*]	24.04[a*]	0.834	0.998
DFL	62.52[a*]	64.68[b*]	0.019	0.938
DMA	90.11[a*]	94.63[b*]	<0.0001	0.748

Legend: The means assigned the same letter in the same column or the same rows are not significantly different at the 5% level. Days to 50% emergence (DEM); Days to 50% tillering (DTA); Days to 50% flowering (DFL); Days to 50% maturity (DMA). *Significant difference between accessions (P < 0.05).

Table 2. Results of the analysis of the variance of the characters related to the cycle of the vegetative system and to the mean performance of the accessions during the two seasons and of the interaction season-accession.

Characters	Season 1	Season 2	P-value between seasons	P-value interaction accession*season
TNT	8.59[b*]	5.52[a*]	<0.0001	0.882
TNI	5.77[b*]	5.13[a*]	<0.0001	<0.0001
INL (cm)	31.70[a*]	41.55[b*]	<0.0001	<0.0001
LLE (cm)	9.37[b*]	6.15[a*]	<0.0001	<0.0001
LWI (cm)	0.48[a*]	0.54[b*]	<0.0001	0.42
TNR	2.85[b*]	2.42[a*]	<0.0001	<0.0001
RSP (cm)	11.78[b*]	10.43[a*]	<0.0001	<0.0001
EPL (cm)	25.40[a*]	31.13[b*]	<0.0001	<0.0001
PHM (cm)	72.94[b*]	53.07[a*]	<0.0001	<0.0001
BIO (kg)	1.61[b*]	1.18[a*]	<0.0001	0.922

Legend: The means assigned the same letter in the same column or the same rows are not significantly different at the 5% level. Plant height at maturity (PHM); Total number of tillers per plant (TNT); Total number of internodes (TNI); Internodes length (INL); Leaf length (LLE); Leaf width (LWI); Exertion panicle length (EPL); Raceme size per plant (RSP); Total number of racemes per plant (TNR); Dry biomass weight (BIO). *Significant difference between accessions (P < 0.05).

permit to differentiate accessions during the two seasons. However, it has varied from season ($P < 0.0001$). The other characters do not discriminate accessions and do not vary according to the season (Table 3).

3.2.4. Structure of the Variability in the Collection

1) Principal Component Analysis

Table 4 shows the eigenvalues and the percentage of variance for each axis. The four first axes explain 56.07% of the total variability. Six characters contribute the most to the achievement of axis 1 with 25.07% of total inertia. The most important are: total number of internodes (TNI) (r = 0.447), internodes length (INL) (r = 0.639), exertion of the panicle length (EPL) (r = 0.349), total number of racemes per plant (TNR) (r = 0.388), dry biomass (BIO) (0.316) and grains per row weight (GRW) (r = 0.426) which are positively correlated with this axis. Therefore, it can be referred to as the axis of production. At the level of axis 2, the characteristics which contribute the most to its achievement are: plant height at maturity (PHM) (r = 0.459), total number of tillers per plant (TNT) (r = 0.257), leaf length (LLE) (r = 0.373), days to 50% flowering (DFL) (r = 0.262) and days to 50% maturity (DMA) (r = 0.319) with 12.64 % of total variance. This axis can be defined as that of vegetative development and the cycle of the plant. Axes 3 and 4 provide additional information to that of axis 2 relating to vegetative development and the cycle.

2) Cluster Analysis

The dendrogram resulting from the cluster analysis (Figure 5) show a structuring of the sixty accessions in four morphological groups independently of their geographical origin. The four groups (GI, GII, GIII and GIV) consist respectively of 15, 12, 18 and 15 accessions.

Group I is characterized by plants with a long cycle (93 days), large size (66.2 cm), a high and an important number of internodes, an important number of racemes (3), a high grain weight (167.78 g) and a dry biomass high (2 kg). It is made up of fifteen accessions mainly from the province of Kénédougou (5 accessions). Group II is characterized by plants with performances close to those of

Table 3. Results of the analysis of the variance of the characters related to the grain and to the mean performance of the accessions during the two seasons and of the interaction season-accession

Characters	Season 1	Season 2	P-value between season	P-value interaction accession*season
GSP	2.78[a]	2.78[a]	0.85	0.990
GrW (g)	0.53[a]	0.54[a]	0.99	0.991
GWA (g)	137.38[b]*	136.16[a]*	<0.0001	0.982

Legend: The means assigned the same letter in the same column or the same rows are not significantly different at the 5% level. Spikelet grouping on pedicels (GSP); 1000 grain weight (GrW); Grain weight per accession (GWA). *Significant difference between accessions ($P < 0.05$).

Table 4. Eigenvalues and percentage of variation expressed for the first three axes from 17 quantitative characters in PCA.

Characters	F1	F2	F3	F4
PHM	0.402	0.459*	0.000	0.000
TNI	0.447*	0.028	0.033	0.004
TNT	0.148	0.257*	0.147	0.006
INL	0.639*	0.038	0.035	0.052
EPL	0.349*	0.097	0.099	0.121
RSP	0.175	0.118	0.013	0.036
TNR	0.388*	0.105	0.009	0.034
LLE	0.209	0.373*	0.110	0.047
LWI	0.000	0.025	0.492*	0.001
GrW	0.060	0.000	0.075	0.056
GSP	0.005	0.005	0.100	0.233
DEM	0.115	0.001	0.043	0.261*
DTA	0.024	0.053	0.304	0.009
DFL	0.244	0.262*	0.024	0.250
DMA	0.315	0.319*	0.015	0.164
BIO (kg)	0.316*	0.005	0.077	0.152
GWR	0.426*	0.004	0.060	0.060
Own value	4.262	2.149	1.638	1.484
Variability (%)	25.072	12.642	9.634	8.727
% cumulative	25.072	37.714	47.348	56.075

Legend: Days to 50% emergence (DEM); Days to 50% tillering (DTA); Days to 50% flowering (DFL); Days to 50% maturity (DMA); Plant height at maturity (PHM); Total number of tillers per plant (TNT); Total number of internodes (TNI); Internodes length (INL); Leaf length (LLE); Leaf width (LWI); Spikelet grouping on pedicels (GSP); Exertion panicle length (EPL); Raceme size per plant (RSP); Total number of racemes per plant (TNR); 1000 grain weight (GrW); Grain weight per row (GWR); Dry biomass weight (BIO). *Variables contributing the most to the formation of the indicated axes

Group I. However, it differs from Group I by its longer maturity cycle (94 days), and high grain weight (208.7 g) compared to Group I. It is composed of 12 accessions mainly from the province of Léraba (5 accessions). Group III is made up of accessions with intermediate performance coming mainly from the province of Kossi (5 accessions). An addition, it differs from Group II by a low dry biomass (1.29 kg) and a low grain weight (123.8 g). Group IV is characterized by accessions with low agronomic performance and a short cycle. It contains 15 accessions mainly from the province of Kossi (7 accessions) (Table 5).

4. Discussion

The characterization of the 60 accessions of fonio revealed significant phenotypic

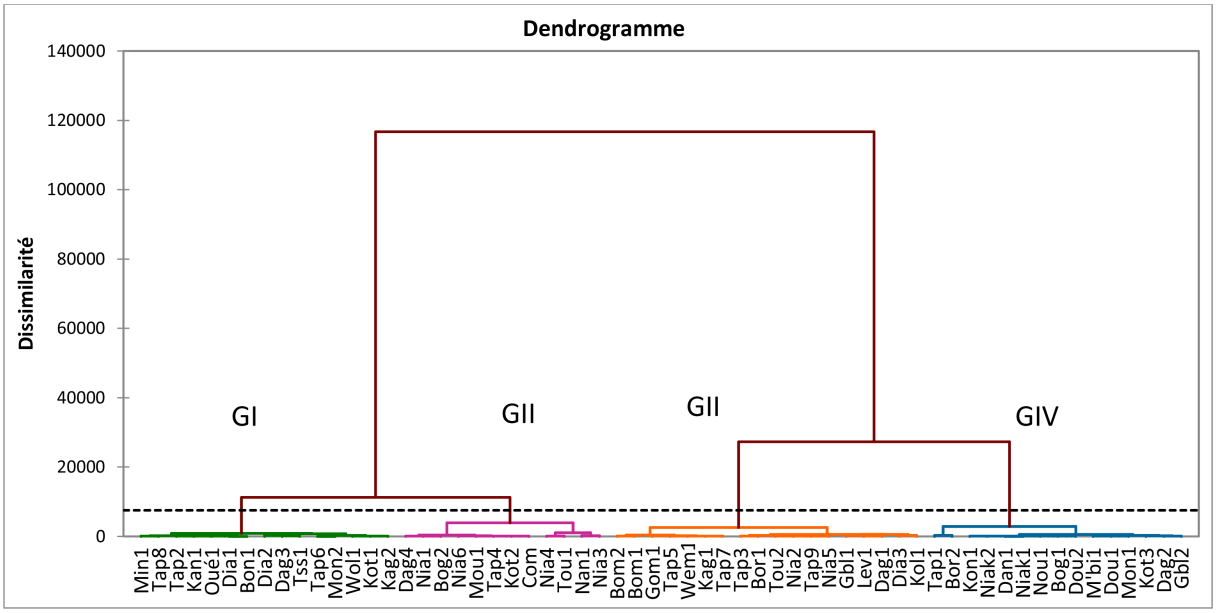

Figure 5. Dendrogram of dissimilarity among 60 accessions of *Digitaria exilis* using ward's minimum variance method of cluster.

Table 5. Mean values of characters per cluster for fonio collection in Burkina Faso.

Variables	GII	GI	GIII	GIV	Pr > F
PHM (cm)	64.89^{b}	66.27^{b}	61.95^{ab}	59.50^{a}	0.024
TNI	5.67^{b}	5.74^{b}	5.30^{ab}	5.15^{a}	0.041
TNT	6.32^{a}	6.86^{a}	6.86^{a}	7.49^{a}	0.359
INL (cm)	37.81^{bc}	39.29^{c}	35.69^{ab}	34.13^{a}	0.002
EPL (cm)	28.53^{ab}	29.21^{b}	28.19^{ab}	27.21^{a}	0.091
RSP (cm)	11.23^{a}	11.37^{a}	11.20^{a}	10.63^{a}	0.254
TNR	2.63^{ab}	2.80^{b}	2.58^{a}	2.55^{a}	0.040
LLE (cm)	7.70^{a}	8.24^{a}	7.74^{a}	7.35^{a}	0.312
LWI (cm)	0.51^{a}	0.51^{a}	0.50^{a}	0.52^{a}	0.636
GrW (g)	0.55^{b}	0.53^{ab}	0.51^{a}	0.53^{ab}	0.114
GSP	2.80^{a}	2.76^{a}	2.78^{a}	2.77^{a}	0.880
DEM	6.15^{a}	6.27^{a}	6.16^{a}	6.12^{a}	0.655
DTA	24.36^{ab}	24.52^{b}	24^{ab}	23.44^{a}	0.199
NDF	65.33^{a}	63.85^{a}	63.06^{a}	62.61^{a}	0.295
DMA	94.09^{b}	93.01^{ab}	92.15^{ab}	90.61^{a}	0.092
BIO (kg)	1.95^{b}	1.99^{b}	1.29^{a}	0.95^{a}	0.000
GWR (g)	208.79^{d}	167.78^{c}	123.81^{b}	66.167^{a}	0.000

Legend: The means assigned the same letter in the same column or the same row are not significantly different at the 5% level. Days to 50% emergence (DEM); Days to 50% tillering (DTA); Days to 50% flowering (DFL); Days to 50% maturity (DMA); Plant height at maturity (PHM); Total number of tillers per plant (TNT); Total number of internodes (TNI); Internodes length (INL); Leaf length (LLE); Leaf width (LWI); Spikelet grouping on pedicels (GSP); Exertion panicle length (EPL); Raceme size per plant (RSP); Total number of racemes per plant (TNR); 1000 grain weight (GrW); Grain weight per row (GWR); Dry biomass weight (BIO).

variability. Indeed, the significant differences between the characters of the accessions, the high coefficients of variation for most characters as well as the presence of modalities for certain qualitative characters reflect the existence of morphological variability within the accessions. The different color patterns of racemes, grains and stems observed during this study are similar to those observed by [1] within accessions of fonio in Niger based on grain color and stem color. According to these authors, this observed variability could be explained, in part, by the expression of one or more genes that govern these characters. Indeed, taking into account qualitative characters is very important in an agro-morphological characterization study insofar as these characters constitute characters of interest and selection criteria for the different actors. However, according to [15] [16], an important number of qualitative characters retained among the descriptors do not often allow fine differentiation of the varieties of cultivated plants.

The variability within the collection offers opportunities for fonio breeding in Burkina Faso. However, the highly significant effect of the rainy season-genotype interaction on the observed variability reflects the influence of pedoclimate factors on the morphological performance of the accessions of fonio studied. Indeed, fluctuations in temperature and rainfall during the two rainy seasons would have influenced this variability. Aliero and Morakinyo [17] have already reported that day length, temperature and relative humidity have variable effects on the vegetative and physiological development of fonio. Additionally, [18], on the study of the effect of the environment on the growth and yield characters of fonio accessions in Niger, revealed that the nature of the soil and the climate conditions influence the performance of the accessions of fonio.

The structuring of accessions independently of their geographical origin could be justified by the migratory flow of the population and the method of crop management, including seed exchanges between producers from one village to another neighboring or distant village which go that growers grow roughly the same accessions. Indeed, in addition to genetic factors, the level and structure of variability are generally influenced by non-genetic factors such as pedoclimate factors, population migration flows and crop management methods. Similar observations have been reported by [19], who revealed that peasant seed management methods, in particular exchanges of varieties between farmers, are the source of significant diversity between fonios grown in the commune of Boukoumbé in Benin.

The morphological and phenological dissimilarities observed between the different phenotypic groups suggest that the accessions are maintained under very different evolutionary processes in their respective agroecosystem [1]. Agroecosystems are likely to exert highly variable selective pressures on genotypes [20] as well as anthropogenic pressures [21]. Indeed, the mode of seed management by farmers, such as selective sorting, post-harvest cultivation techniques and agricultural practices, lead to a selection leading to the maintenance or even the creation of significant phenotypic diversity [22]. Group I and Group III diversity

with intermediate characteristics between early and late accessions could be the result of an adaptive process [1]. Fonio has not yet been the subject of real varietal selection and genetic improvement work in Burkina Faso, but the estimates made in this study could serve as a basis of comparison for subsequent investigations. Nevertheless, in Ivory Coast, [23] obtained similar phenotypic characters such as days to flowering, days to maturity, total number of tillers per plant, total number of nodes, total number of panicles, total number of leaves at the main stem, the height of insertion of the panicle which contributes better to the discrimination of four groups in the discriminant factor analysis.

The role played by phenotypic descriptors in the structuring of local varieties of fonio in Burkina Faso is not surprising, because it is a usual agronomic character for structuring variability in cereals. This would be linked to the difficulty for farmers to distinguish varieties other than by cycle length, a central character in management practices. Previous studies, based on the characters used by farmers, in particular the cycle, had highlighted the importance of the cycle in the characterization ok the accessions of fonio. Sekloka *et al.* [24] obtained slightly different results from ours. These authors highlighted two groups of fonio in Benin: an extra early group with a cycle of less than 90 days and a late group with more than 100 days. This observed difference could be explained by the fact that cultivars with cycle long are less appreciated by producers. According to [19], very early cultivars mature during the rainy season and pose drying problems for growers. Similarly, cultivars that are too late do not manage to complete their cycle in good conditions.

The early accessions identified in this study are qualified as extra early to early according to the criteria proposed by [25]. Late accessions with higher biomass yield can be selected for livestock feed purposes thanks to their high fodder productivity.

Moreover, the percentage of variance accumulated by the four main axes of the principal component analysis is low (56.07%). These results would reflect the absence of a strong genotypic and phenotypic organization between the accessions [26]. Similar results were obtained by [23] in Côte d'Ivoire on fonio and several authors on other species [27].

6. Conclusion

The agro-morphological characterization of accessions of *Digitaria exilis* shows the highlighted existence of diversity in Burkina Faso despite the narrowness of its area of cultivation. The results of this study have permitted to identify of important characters which permit to differentiate of the accessions, which are days to 50% flowering, days to 50% maturity, plant height at maturity, total number of tillers per plant, total number of internode, internodes length, leaf length, leaf width, exertion panicle length, total number of racemes per plant, grain weight per accession, and dry biomass weight. Since the role of local accessions in the plant resources of cultivated plants no longer needs to be demonstrated, particular attention must be paid to regions that ensure the sustainability of this source of

variability. Thus, the characters analyzed can thus constitute basic criteria for differentiating the accessions of fonio of Burkina Faso and be used in studies of the morphological diversity of fonio in West Africa. The multivariate analyses have permitted to structure of the collection into 4 morphological groups. Exceptional morphotypes have been identified and could be considered as potential parents for future breeding work. It is mainly Nia4, Tou1, Nan1, Nia3, Nia6 which presented a high grain yield, Kan1, Com, Tap2, Tss1 and Bog1 presented a high dry biomass and Min1, Nou1, Bog1, Gbl2, Bor1, Dou2 presented a short cycle. However, taking agro-morphological characters only into account is not enough to produce a definitive and credible description. Indeed, the morphological characters, especially quantitative ones, are often strongly influenced by environmental factors. It is, therefore, important to do molecular analyses to invalidate or confirm the results obtained by the agro-morphological characterization.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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