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Agro-morphological characterization of Fonio millet accessions (*Digitaria exilis* Stapf.) collected from Boukoumbé, Northwest of Benin

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Fonio is a cereal food of great socio-economic and cultural importance in south Sahara African Countries. Unfortunately, it is practically absent from National Agricultural Research Programs. To characterize the agro-morphological diversity of fonio ecotypes grown in Benin, twenty accessions collected from Boukoumbé were evaluated in a randomized complete block design (RCBD) with three replicates in Parakou. Significant variability was detected for several characters. The early accessions matured at approximately 90 days after sowing with yields below 800 kg/ha. The late accessions matured in 100 days and the most productive recorded more than 1.5 t/ha. Factor analysis of mixed data helped to classify the accessions into four morphological groups. Chi-square independence test showed that collar color, green color of foliar limb, anthocyanin coloration and its distribution in different aerial organs, type of panicle and panicle exsertion were the most discriminating qualitative parameters. The λ-wilk test revealed that date of flowering, plant height, length of panicle leaf, length of racemes and grain yield were the most discriminating quantitative traits. This study enabled a better knowledge of cultivated ecotypes and distinguishing criteria. The variability observed offered interesting perspectives for genetic progress through breeding programs of these ecotypes. However, it is important to improve our understanding on the floral biology and reproductive system for this species to create new and efficient varieties.

Key words: Genetic variability, neglected plant, morphotype, crop phenology, growth parameters.

INTRODUCTION

Fonio (*Digitaria* spp.) is one of the neglected and underutilized crops of West Africa. It is grown in an area stretching from Senegal to Lake Chad (Cruz et al., 2011). Well adapted to local pedo-climatic conditions, fonio

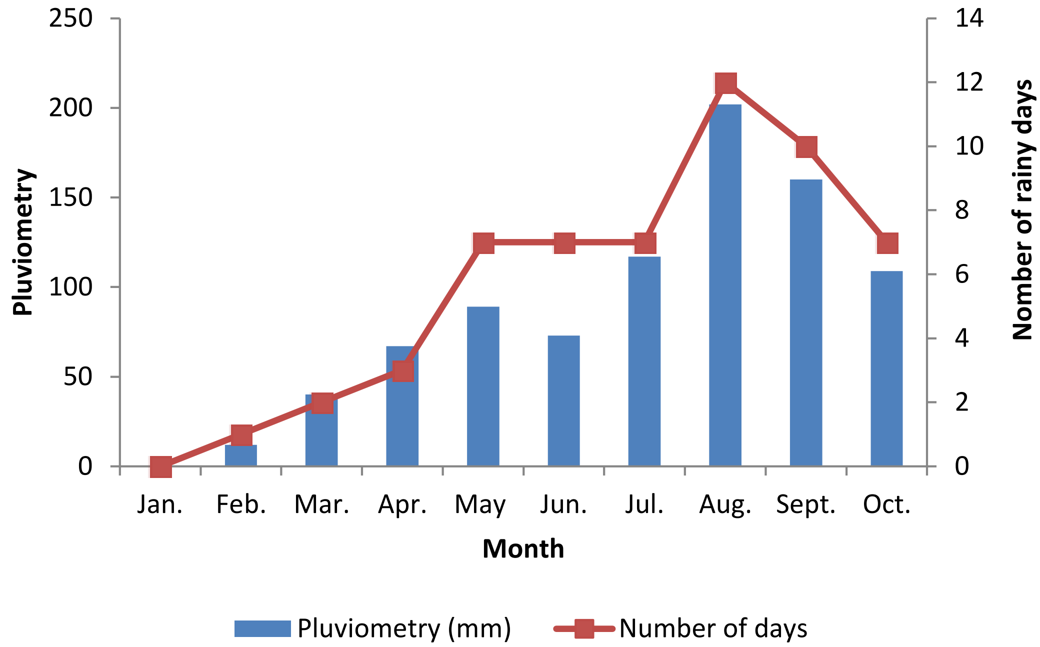

Figure 1. Distribution of rainfall during the trial period.

resists drought due to its C4 metabolism and contributes to the maintenance of the environment by ensuring vegetal cover on ecologically sensitive and undervalued soils (Vall et al., 2008; Cruz et al., 2011). Poor in gluten, fonio is indicated for diabetics and those suffering from overweight and breastfeeding women (Vodouhe and Achigan Dako, 2006). It is rich in methionine and cysteine, two essential amino acids for humans and deficient in wheat, rice, maize and sorghum (Vietmeyer et al., 1996; Ballogoun, 2013).

In Benin, unlike other cereals such as maize, sorghum, millet and rice, that are cultivated everywhere throughout the country, fonio appears as an essentially local or endemic crop to the Atacora department in the northwest of Benin (Vodouhe et al., 2003). This crop has a socio-cultural importance for the Otamari ethnic group in Boukoumbé, the main producer community providing 74% of the national production (Dramé and Cruz, 2002; Ballogoun, 2013; Paraïso et al., 2013). It also plays an important role in food security in the population especially during the lean season when early varieties are used to curb famine.

Despite its potentials, fonio remains a marginal plant and long neglected in national research programs. Most of the research has put emphasis on the management of harvest and post-harvest. Little knowledge is available on varietal breeding of this crop. The crop is thus poorly known as far as the morphological, agricultural and biological characteristics are concerned. Today, it is hard to determine with accuracy, the varieties of fonio that are grown in Benin. The objective of this study was to assess and structure the morphological and agronomic variability of fonio ecotypes cultivated in Benin in order to improve their performance.

MATERIALS AND METHODS

The trial was conducted in 2015 at the experimental farm of the Faculty of Agronomy, the University of Parakou (9° 18' 57" North latitude, 2° 42' 5" East longitude, 362 m of altitude). The soil is poor in organic matter; it is of tropical ferruginous type and consists of about 22.40% of clay and silt, 1.43% of total carbon and 0.167% total nitrogen, or a C/N ratio of 8.56 (Azontondé et al., 2009).

Rains were regular and well distributed during the period of the trial (Figure 1). The wettest months were July, August, September and October. The total annual rainfall obtained in 56 days was 869 mm. The average daily temperature varied between 20 and 25 °C with a daily average of 22°C over the period of the study.

Twenty (20) accessions of fonio collected in the commune of Boukoumbé were evaluated in a randomized complete blocks design (RCBD) with three replicates. The experimental units consisted of 3 lines of 4 m each. Sowing was done at a spacing of 0.20 x 0.20 m (20 holes/line) with a pinch of seeds. The plants were reduced to one per hole 25th day after sowing. The alley between two consecutive experimental units was 0.4 m. The plots were kept clean by regular manual weeding until harvest. The trial block was

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Table 1. Qualitative variables used for the evaluation of accessions studied.

Cycle phases	Qualitative variables	Meaning	Modalities
vegetative phase	Coul_Bas_Pl	Color of base of the plants	Green, purple green, light purple
	ColAnt_GF	Coloration of anthocyanin at foliar sheath	Absent, present
	ColAnt.LF	Coloration of anthocyanin at foliar limb	Absent, present
	DistrAnt-LF	Distribution of anthocyanin color at foliar limb	Absent, extremity only, spotted
	Pubs_LF	Pubescence of foliar limb	Glabrous, hairy
	Coul_LF	Intensity of green color of foliar limb	Medium green, light green, dark green
	Coul_Aur	Color of auricle	Absent, present
	Coul_Collet	Color of collar	Green, purple green, purple
	Att_LF	Attitude of foliar limb	Erected, horizontal, descending
Flowering phase	Form_Lig	Form of ligula	Absent, truncated, pointed, bifid
	Coul_Lig	Color of ligula	Absent, whitish, purple, light purple
	Att_FP	Attitude of panicle leaf	Erected, horizontal, descending
	Port_Tige	Port of the stem (angle)	Semi erected, open, very open
	ColAnt_Nd	Anthocyanin colouration at the nodes of the stems	Absent, light purple, purple
	ColAnt_SA_Nd	Color of underlying portion of node of the stems	Absent, light gold, green
Maturation phase	ColAnt_EnNd	Anthocyanin coloration of internodes of the stems	Absent, light purple
	ColAnt_SA_Nd	Color of the underlying portion of internodes of the stems	Absent, light gold, green
	Exs_Pan	Panicle exsertion	Good exsertion, very good exsertion
	Type_Pan	Type of panicle	Open, horizontal, falling
	Form_Ap	Apex form of grains	Pointed, curved
	Coul_raceme	Color of racemes	Brown, red

fenced with wood and protected with mosquito nets so as to exclude rodents and domestic animals. No fertilizer and pesticide treatments were applied. Harvesting was performed by mowing stems using sharp scissors for cutting the panicles. The plants were characterized using a descriptor adapted from the one utilized for the description of rice (Tia and Iliath, 2014). In total, 18 qualitative variables and 21 quantitative variables were analyzed so as to describe and partition the varieties in morphological groups. Qualitative variables were observed at the plot level. They consisted of visual observation of the coloration of different organs (stem, node, internode, leaf and panicle) during the vegetation, the flowering and the maturation phases (Table 1). Quantitative variables were measured, some at the plot level and the others at the plant level. These were collected from ten plants randomly chosen on the central lines of the elementary plots. The measures were phenology, plant growth and plant production parameters (Table 2).

R software version 3.1.3 was used for data analysis. Qualitative variables were studied by calculating, for each of them, the proportions of the accessions belonging to each category. The variability of quantitative traits was investigated through an analysis of variance. After an analysis of the correlation matrix, quantitative variables not correlated significantly ($p>0.05$) and differentiated the accessions as well as qualitative variables differentiated the accessions were submitted to a factor analysis of mixed data (FAMD) to identify morphotypes. The identified morphotypes were eventually described and the main differentiating traits for these morphotypes were determined by using Chi-squared test for categorical variables and λ-Wilk test for quantitative traits. For the later, the Tukey test was used to compare means when differences between morphotypes were significant.

RESULTS

Qualitative description of accessions

Among the 18 evaluated variables, a dozen enabled distinctions between accessions. Some of the collars were purple green while others were purple. Also, some of the foliar limbs, internodes and stem nodes showed anthocyanin coloration while others were devoid of it. The panicles, whether horizontal or open, were either brown or red at maturity. The stems had an open port, semi-erected, or very open. There were also differences in the color of the plant base, the foliar limb, the ligula and the panicle exsertion between the accessions (Table 3).

Variability of morphology measurable characters

Differences in the accessions were only observed with

Table 2. Quantitative variables used for the evaluation of accessions studied.

Phases	Quantitative variables	Meaning	Descriptions
Vegetative Phase	50% levée	Date of emergence (days)	Number of days after sowing when 50% of plants emerge
	50% tallage	Date of Start tillering (days)	Number of days from sowing to tillering of 50% of plants
	Nb talles	Number of tillers	Mean number of tillers on 10 plants of center lines
	Nb_feuilles	Number of leaves	Mean number of leaves on 10 plants of center lines
Flowering Phase	50%CSE	cycle sowing to flowering (days)	Number of days after sowing when 50% of plants let discover their flowers
	LongF	length of the leaf under panicle leaf (cm)	Measured from the level of insertion of the ligula to the top of the foliar limb
	largF	width of the leaf under panicle leaf (cm)	Measured in the middle of foliar limb
	LongFP	length of panicle leaf (cm)	Measured from the insertion level of the ligula to limb top
	LargFP	width of panicle leaf (cm)	Measured in the middle of the foliar limb
Maturation Phase	50%CSM	cycle sowing to maturation (days)	Number of days after sowing when 50% of the plants reach maturity without the grains are dry
	HP	Plant height(cm)	Measured from the soil level to the top of longest panicle
	HIP	Insertion height of panicle (cm)	Measured from the soil to insertion panicle level
	NN_plt	Number of nodes	Counting of the number of node on the main stem (longest)
	NIP	node of panicle insertion	Node of panicle Insertion on the main stem (longest)
	pan_plt	Number of panicles	Measurement taken on 10 plants of the central lines
	rac_pan	Number of raceme per panicle	Mean of number of racemes per panicle taken on 10 plants
	Lg_pan	Panicle length(cm)	Measured from the insertion panicle level to the top of longest raceme
	Lg_rac	Raceme length (cm)	Length from beginning of racemes to the top of longest raceme
Post-harvest	Rdt_grain	Grain yield (kg/ha)	Ratio of grain weight of each accession by plot after threshing, winnowing per plot area
	Rdt_biom	Yield of aerial dry biomass (kg/ha)	Ratio of Weight of aerial dry biomass (stem, leaf and panicle) per plot area
	IR	Harvest index (%)	Ratio of grain yield per biomass yield

plant height and panicle length ($P < 0.01$). Plant height, either in centimeters or number of nodes varied from simple to more than double. The shortest accession was AS1 and the longest was AS5. The same trend was observed for the height and node of panicle insertion. The shortest panicles were noted on AS12 and the longest on AS5. For the remaining variables, differences among accessions were not significant (Table 4). The analysis of the correlation matrix showed significant associations between some of these morphological variables (Table 5).

Table 3. Proportions of the categories of each qualitative variable observed.

Qualitative variables	Categories	Percentages (%)	Accessions numbers
Coul.collet	Purple green	63.16	1, 3, 5, 6, 7, 8, 9, 10, 11, 13, 17, 19
	Purple	36.84	12, 14, 18, 2, 20, 15, 16
ColAnt.LF	Absent	52.63	1, 5, 6, 7, 8, 9, 11, 12, 17, 18
	Present	47.37	2, 3,10, 14, 13, 15, 16, 19, 20
ColAntEnNd	Absent	63.16	1, 5, 6, 8, 9, 10, 11, 12, 13, 14, 17, 18
	Light purple	36.84	2, 3, 7, 15, 16, 19, 20
ColAntNd	Purple	31.58	3, 7, 15, 16, 20, 13
	Light purple	68.42	1, 2, 5, 6, 8, 9, 10, 11, 12, 14, 17, 18, 19
Coul.bas.pl	Green,	21.05	3, 5, 8, 17
	Purple green	63.16	1, 2, 6, 7, 9, 10, 11, 12, 13, 16, 19, 20
	Light purple	15.79	14, 15, 18
Coul.LF	Light green	47.37	2, 7, 11, 12, 14, 16, 18, 19, 20
	Medium green	52.63	1, 3, 5, 6, 8, 9, 10, 13, 15, 17
Coul.lig	Whitish	68.42	1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 17, 18, 20
	Light purple	31.58	3, 13, 14, 15, 16, 19
coul.raceme	Brown	73.68	1, 3, 5, 6, 7, 8, 9, 10, 11, 12, 16, 17, 18, 20
	Red	26.32	2, 19, 13, 14, 15
DistrAnt.LF	Extremity only	31.58	2, 3, 13, 16, 19, 20
	No distribution	52.63	1, 5, 6, 7, 8, 9, 11, 12, 17, 18
	Spotted	15.79	10, 14, 15
Exs.Pan	Good exsertion	68.42	1, 6, 7, 8, 12, 13, 14, 15, 16, 17, 18, 19, 20
	Verygoud exsertion	31.58	2, 3, 5, 9, 10, 11
Port.Tige	Open	57.89	5, 7, 8, 9, 10, 11, 12, 15, 16, 18, 19
	Semi erected	26.32	1, 2, 6, 14, 20
	Very open	15.79	3, 13, 17
Type.Pan	Horizontal	89.47	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 13, 15, 16, 17, 18, 19, 20
	Open	10.53	12, 14

Coul.collet: Color of collar; ColAnt.LF: coloration of anthocyanin at foliar limb; ColAnt_EnNd: anthocyanin coloration of internodes of the stems; ColAnt_Nd: anthocyanin colouration at the nodes of the stems; Coul.bas.pl: color of the base of the plant; Coul_LF: intensity of green color of foliar limb; Coul_Lig: color of ligula; Coul_raceme: color of racemes

Plant height (HP) was significantly ($p<0.05$) correlated with the width of the leaf under the panicle leaf (LargF), the height of panicle insertion (HIP), the node of panicle insertion (NIP), the number of nodes on the main stem (NN_Plt) and the number of racemes per panicle (rac_plt).

Width of panicle leaf (LargFP) was significantly ($p<0.05$) correlated with the width of the leaf under the panicle leaf (LargF), the length of the leaf under the panicle leaf (LongF) and the length of panicle leaf (LongFP). Panicle length (Lg_pan), raceme length (Lg_rac) and the number of panicles per plant (Pan_plt)

Table 4. Variability of measurable characters of plant morphology.

Variables	Minimum		Maximum		Mean	Standard deviation	CV (%)	Prob.	
LongF (cm)	8.6	(AS14)	11.6	(AS8)	10.0	0.9	8.6	0.729	
LongFP(cm)	6.1	(AS14)	9.6	(AS17)	7.5	0.9	11.4	0.139	
LargF (cm)	0.5		0.5		0.5	0.0	4.2	0.409	
LargFP (cm)	0.3		0.4		0.3	0.0	4.2	0.344	
HP (cm)	66.1	(AS1)	112.7	(AS5)	97.6	12.6	12.9	<0.001	***
NN_plt	5.0	(AS1)	12.5	(AS19)	10.2	2.3	22.5	<0.001	***
HIP (cm)	24.1	(AS1)	83.6	(AS5)	68.1	19.0	27.9	<0.001	***
NIP	5.0	(AS1)	12.5	(AS19)	10.2	2.3	22.5	<0.001	***
Pan_plt	32.0	(AS11)	54.6	(AS20)	42.3	6.0	14.2	0.385	
rac_pan	3.5	(AS1)	4.4	(AS9)	4.1	0.2	5.1	0.084	
Lg_rac (cm)	11.7	(AS1)	16.3	(AS15)	13.3	1.0	7.7	0.127	
Lg_pan (cm)	23.9	(AS12)	30.3	(AS5)	26.4	1.5	5.5	0.008	*

LongF: length of leaf under panicle leaf; LongFP: length of panicle leaf; largF: width of leaf under panicle leaf; largFP: width of panicle leaf; HP: plant height; NN_plt: number of nodes on the main stem; HIP: height of panicle insertion; NIP: node of panicle insertion; Pan_plt: number of panicle per plant; rac.pan: Number of raceme per panicle; Lg_rac: raceme length; Lg_pan: Panicle length. *** Very highly significant (<0.001), ** highly significant (<0.01), * Significant (<0.05).

Table 5. Matrix of Pearson correlations between quantitative variables.

	HIP	HP	LargF	LargFP	Lg.pan	Lg.rac	LongF	LongFP	NIP	NN.plt	Pan.plt	Rac.pan
HIP	1.0											
HP	**1.0**	1.0										
LargF	**0.5**	**0.5**	1.0									
LargFP	0.0	0.1	**0.5**	1.0								
Lg,pan	0.4	0.4	0.2	0.0	1.0							
Lg,rac	0.0	0.1	0.2	0.1	0.2	1.0						
LongF	0.2	0.4	**0.7**	**0.6**	0.1	0.1	1.0					
LongFP	-0.1	0.1	0.4	**0.7**	0.0	0.1	**0.8**	1.0				
NIP	**0.8**	**0.7**	0.3	-0.1	0.4	0.0	-0.1	-0.3	1.0			
NN.plt	**0.8**	**0.7**	0.3	-0.1	0.4	0.0	-0.1	-0.3	**1.0**	1.0		
Pan.plt	-0.1	-0.1	-0.2	0.0	-0.2	0.1	-0.1	0.0	0.0	0.0	1.0	
Rac.pan	**0.7**	**0.6**	0.3	-0.2	0.2	0.0	0.2	-0.1	**0.5**	**0.5**	0.1	1.0

LongF: Length of leaf under panicle leaf; LongFP: length of panicle leaf; largF: width of the leaf under panicle leaf; largFP: width of panicle leaf; HP: plant height; NN_plt: number of nodes; HIP: height of panicle insertion; NIP: node of panicle insertion; Pan_plt: number of panicle per plant; rac.pan: number of raceme per panicle; Lg_rac: raceme length; Lg_pan: panicle length. The correlation coefficients in bold are significantly different from zero at the 5% threshold.

were not correlated with any other variables. For descriptions of morphotypes, five variables were retained: length of panicle leaf (longFP), plant height (HP), panicles length (Lg.pan), raceme length (Lg.rac) and number of panicles per plant (Pan.plt). These variables were considered sufficient to account for the accessions of morphometric variability since each of the other variables was correlated with either of these five.

Variability of agronomic characterization parameters

Despite the large variations observed in the date of emergence (4 to 10 days after sowing), number of tillers per plant (15 to 37), number of leaves per plant (51 to 134), and the harvest index (9 to 36%), there was no significant difference among accessions (p>0.05) for these parameters (Table 6). Nevertheless, there were significant variations among accessions for other parameters such as flowering and maturation dates. The early matured varieties were AS1 and AS8, whereas AS15 and AS10 matured late.

Grain and biomass yields also showed significant variations between accessions. AS2 was the most productive accession, with more than 2 t/ha of grain yield, which was almost nine times the yield of the least

Table 6. Variability of agronomic characters.

Variables	Minimum		Maximum		Mean	Standard deviation	CV (%)	Prob.	
50% level (das)	4.3	(AS16)	10.0	(AS1)	5.8	1.8	32	0.080	
50% tallage (das)	24.0	(AS15)	25.7	(AS19)	24.4	1.0	4.3	0.646	
50% CSE (das)	64.0	(AS1)	92.0	(AS15)	83.3	10.1	12.1	<0.001	***
50% CSM (das)	79.7	(AS8)	104.7	(AS10)	99.4	7.3	7.4	<0.001	***
Nb_talles	15.3	(AS1)	36.6	(AS2)	27.1	14.3	52.6	0.979	
Nb_feuilles	50.8	(AS1)	133.9	(AS2)	104.4	52.0	49.8	0.957	
Rdt_grain (kg/ha)	286.3	(AS1)	2452.8	(AS2)	1220.2	700.0	57.4	0.012	*
Rdt_biom. (kg/ha)	1279.3	(AS1)	11905.6	(AS5)	7381.5	3437.4	46.6	0.000	***
IR (%)	8.9		36.4		19.2	6.5	33.7	0.377	

50% level: Date of emergence 50% tallage: Date of Start tillering; Nb_talle: Number of tillers; Nb_feuilles: Number of leaves; 50%CSE: cycle sowing to flowering; 50%CSM: cycle sowing to maturation; Rdt_grain: Grain yield; Rdt_biomasse: yield of aerial dry biomass; IR: Harvest index; das: days after sowing. *** Very highly significant (<0.001), ** highly significant (<0.01),* Significant (<0.05).

Table 7. Pearson correlation matrix between agronomic parameters.

	50% CSE	50% levée	50% CSM	IR	50% tallage	Rdt_biom	Rdt_grain	Nb_feuilles	Nb_talles
50% CSE	1.0								
50% level	-0.3	1.0							
50% CSM	0.9	-0.3	1.0						
IR	-0.3	-0.1	-0.4	1.0					
50% tallage	0.1	-0.2	0.0	0.4	1.0				
Rdt_biom	0.5	0.0	0.5	-0.5	-0.5	1.0			
Rdt_grain	0.2	-0.2	0.2	0.3	-0.2	0.5	1.0		
Nb_feuilles	-0.1	0.2	0.0	-0.3	-0.5	0.4	0.1	1.0	
Nb_talles	-0.1	0.2	0.0	-0.3	-0.4	0.4	0.1	0.9	1.0

50% level: date of emergence 50%tallage: date of start tillering; Nb_talle: number of tillers; Nb_feuilles: number of leaves; 50%CSE: date of flowering; 50%CSM: date of maturity; Rdt_grain: grain yield; Rdt_biom: yield in aerial dry biomass; IR: harvest index. The correlation coefficients in bold are significantly different from zero at the 5% threshold.

productive, AS1 (p <0.05). Significant differences (p <0.01) were observed among accessions for the biomass yield as well. AS1 recorded the lowest biomass yield, while AS5 recorded the highest (Table 6).

Pearson correlation matrix showed that the grain yield (Rdt_grain) was little correlated with the other variables; it was only correlated with the biomass yield (Rdt_biomasse). The biomass was correlated with most of the other variables except for the date of emergence (50% level), the number of leaves (Nb_feuilles) and the number of tillers (Nb_talle). There was also a strong correlation (p<0.01) between the date of flowering (50% CSE) and date of maturity (50% CSM), and between the number of leaves and number of tillers (Table 7).

For the identification of morphotypes, the date of emergence (50% level), date of flowering (50% CSE), harvest index (IR), grain yield (Rdt_grain) and number of tillers (Nb_talles) proved to be sufficient to describe agronomic variability of the studied accessions, given that each of the other variables was correlated with one or more of these selected parameters.

Regrouping of accessions in morphotypes

The categorical variables that distinguished accessions and quantitative parameters selected from the analysis of the correlation matrix were submitted to a factor analysis of mixed data (FAMD).

The first five axes explained 73.2% of the total information (cumulated variance) with all Eigen values greater than 1. The first two axes explained 43.37% of the total variability (Table 8). The first axis was correlated with plant height (HP), earliness (50% CSE and 50% levée) and grain yield (Rdt_grain). It is mostly an axis characterizing vigor and earliness. It also describes the coloration of different parts of the plant, in particular, anthocyanin coloration of the foliar limb (ColAnt.LF) and, to a lesser extent, coloration of the internodes of the stem (ColAntEnNd), racemes (coul.racème) and ligula

Table 8. Variance explained by the main axes from the factor analysis of mixed data (FAMD).

Variables	Axis 1	Axis2	Axis3	Axis 4	Axis 5
Eigen values	6.4	4.01	2.96	2.25	1.94
Explained variance (%)	26.66	16.71	12.34	9.39	8.07
Cumulative variances (%)	26.66	43.37	55.7	65.09	73.16

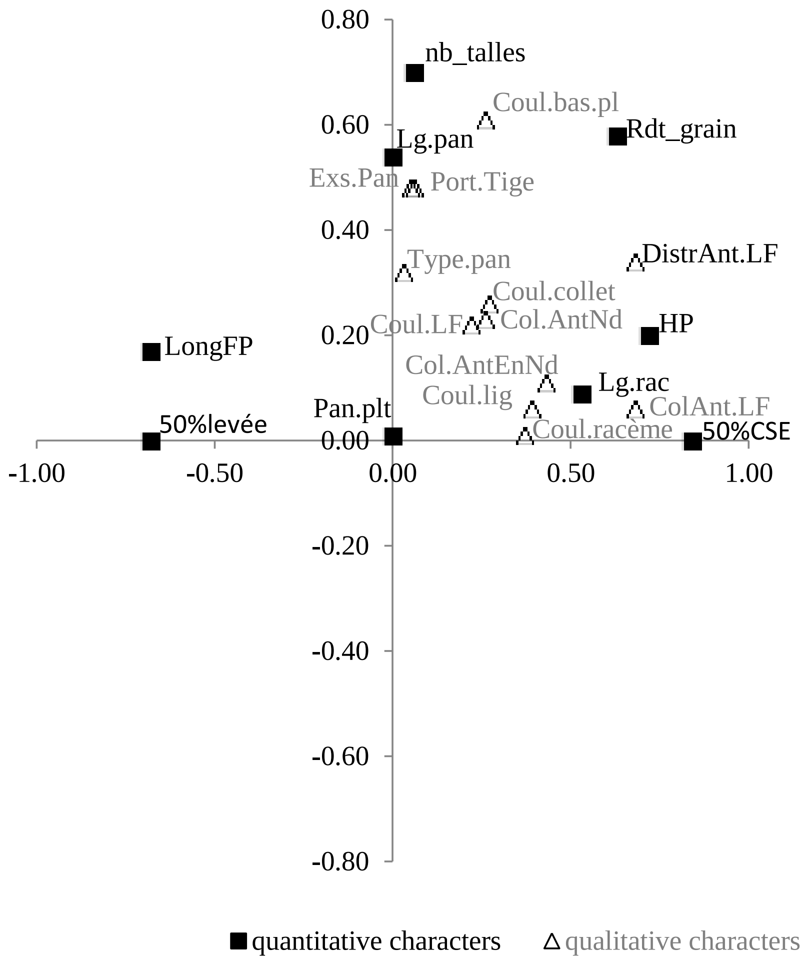

Figure 2. Projection of the variables in the factorial plane formed by the first two axes. Coul_LF: intensity of green color of foliar limb; Coul.bas.pl: color of the base of the plant; ColAnt.LF: coloration of anthocyanin at foliar limb; DistrAnt-LF: distribution of anthocyanin at the foliar limb; Coul.collet: color of collar; Coul_Lig: color of ligula; ColAnt_Nd: Anthocyanin colouration at the nodes of the stems; ColAnt_EnNd: Anthocyanin coloration of internodes of the stems; Port_Tige: port of the stem; Type_Pan: type of panicle; Exs_Pan: exsertion panicle; Coul_racème: color of racemes; HP: plant height; Lg.pan: panicle length; Lg.rac: raceme length; 50% CSE: date of flowering; Rdt_grain: grain yield; 50% levée: date of emergence; Nb_talles: number of tillers; pan.plt: number of panicles per plant; Long FP: length of panicle leaf.

(Coul.lg) (Figure 2). The second axis was correlated with the number of tillers (nb_talles), the panicles length (Lg.pan) and grain yield (Rdt_grain). Regarding qualitative characters, it describes the color of the base of the plant (Coul.bas.pl), the port of the stem (Port.Tige) and panicles form (Exs.Pan and Type.Pan) (Figure 2).

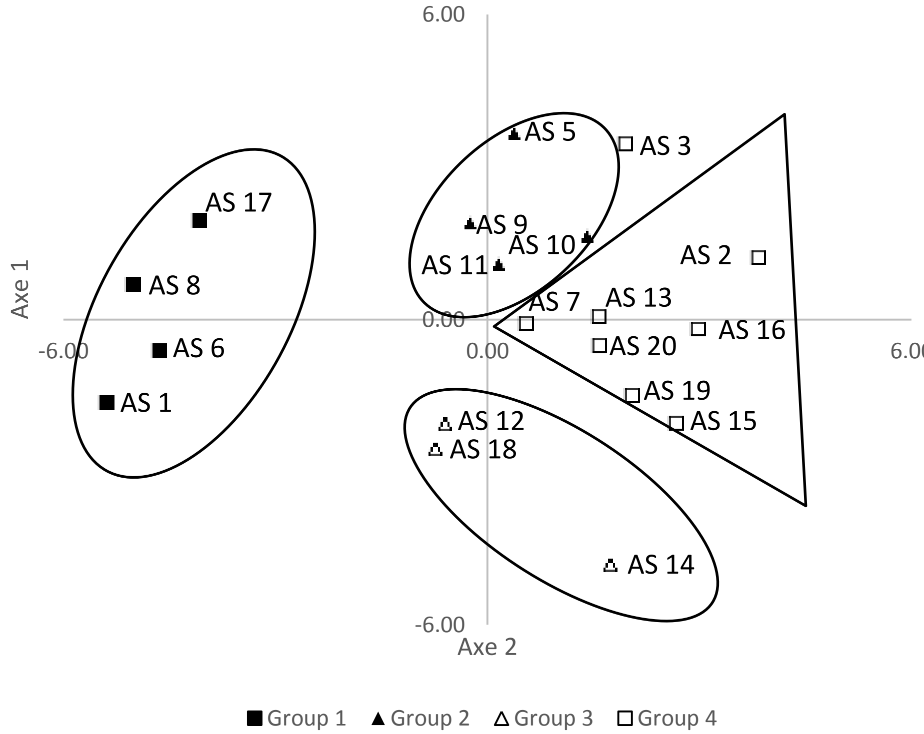

Figure 3. Projection of accessions in the factorial plane formed by the first two axes.

The projection of accessions in the factorial plane formed by the first two axes allowed separation of the accessions into four groups (Figure 3). Axis 1 opposed the accessions of group 1, earlier, of short height and longest panicle leaves to those of group 4, later and more slender. Regarding qualitative traits, this axis also opposed accessions devoid of anthocyanin coloration at foliar limb and internodes (Group 1) to others which displayed anthocyanin coloration (Group 4).

The second axis opposed the accessions of group 2 and group 3, respectively located on the upper and lower side of this axis (Figure 3). Accessions of group 2 have a higher tillering aptitude, longer panicles and higher yields than accessions of group 3. Regarding qualitative traits, this axis opposed accessions equipped with horizontal panicles and very good exsertion (Group 2) to those equipped with open panicles and good exsertion (Group 3).

Identification of discriminating traits

Chi-square tests (χ^2) showed that eight qualitative traits are significantly related to the classification of the accessions in morphological groups (Table 9). λ-Wilk test revealed that five (5) quantitative characters allowed discrimination of the identified morphotypes. These were the date of flowering (50%CSE), plant height (HP), length of panicle leaf (LongFP), raceme length (Lg.rac) and grain yield (Rdt_grain) (Table 10).

DISCUSSION

The morphological and agronomic characterization of a crop is an important step in the management of genetic diversity (Manzano et al., 2001; Yobi et al., 2002; Radhouane, 2004). It is also a prerequisite towards the selection of improved varieties (Smith et al., 1991; Fraleigh, 1987). This work had helped to characterize for the first time in station in Benin, the diversity of ecotypes of fonio grown in Boukoumbé, one of the regions described as one of the areas of origin of this crop (Adoukonou-Sagbadja et al., 2006, 2007). The results showed significant differences between several morpho-phenological and agronomic characters. This demonstrates a high variability between accessions, which could be explained by the farmers' practices of seed management coupled with the proximity to the study area with Togo, another region of origin for fonio where genetic diversity was described as very high (Adoukonou-Sagbadja et al., 2007). Indeed, several authors have shown that farmers' practices of seed management, including the exchange of varieties among farmers, are the source of an important diversity among populations of cultivated plants (Mckeye et al., 2001; Delaunay et al., 2008; Missihoun et al., 2012). The exchange of varieties among farmers, which has been described as the main mode of access to fonio seeds in this region (Sekloka et al., 2015), has been able to contribute to a significant increase in the diversity of ecotypes of fonio grown in Boukoumbé. This substantial phenotypic variability could

Table 9. Qualitative variables significantly related to the classification of the accessions in morphological groups (Chi-square test, χ²).

Qualitative variables	χ²	Probability	
ColAntEnNd	15.240	0.002	**
ColAntNd	12.058	0.007	*
Exs.Pan	12.058	0.007	
Type.Pan	11.922	0.008	*
Coul.collet	10.405	0.015	
ColAnt.LF	9.808	0.020	*
DistrAnt.LF	14.382	0.026	*
Coul.LF	8.471	0.037	*
coul.bas plant	9.566	0.144	
coul.lig	7.237	0.065	
Coul.racème	5.248	0.155	
Port.Tige	5.815	0.444	

Coul_LF: Intensity of green color of foliar limb; Coul.bas.pl: color of the base of the plant; ColAnt.LF: coloration of anthocyanin at foliar limb; DistrAnt-LF: distribution of anthocyanin at the foliar limb; Coul.collet: color of collar; Coul_Lig: color of ligula; ColAnt_Nd: anthocyanin colouration at the nodes of the stems; ColAnt_EnNd: anthocyanin coloration of internodes of the stems; Port_Tige: port of the stem; Type_Pan: type of panicle; Exs_Pan: exsertion panicle; Coul_racème: color of racemes. **Highly significant (<0.01), *Significant (<0.05).

Table 10. Quantitative variables significantly related to the classification of the accessions in morphological groups (λ-Wilk test).

Variables	λ-Wilk	Statistique F	probability	
LongFP	0.285	12.525	<0.001	***
Pan.plt	0.940	0.319	0.812	
Lg.rac	0.506	4.885	0.015	*
HP	0.118	37.303	<0.001	***
Lg,pan	0.633	2.895	0.070	
50% level	0.607	3.239	0.052	
Nb_talles	0.894	0.593	0.629	
50%CSE	0.024	200.678	<0.001	***
Rdt_grain	0.544	4.185	0.024	*

HP: Plant height; Lg.pan: panicle length; Lg.rac: raceme length; 50% CSE: date of flowering; Rdt_grain: grain yield; 50% levée: date of emergence; Nb_talles: number of tillers; pan.plt: number of panicle per plant; Long FP: length of panicle leaf. *** Very highly significant (<0.001), ** highly significant (<0.01), *Significant (<0.05).

be an expression of a strong genotypic heterogeneity. Such morphological and phenological dissimilarities between accessions are often generated and maintained by diverse evolutionary processes. Agroecosystems are likely to exert widely varying selective pressures on genotypes (Sadiki and Jarvis, 2005). This is also the case with anthropic pressures (Robert et al., 2004). Indeed, the way seed is managed by farmers such as selective sorting, post-harvest technologies and agricultural practices lead to a selection involving the maintenance, and even the creation of a remarkable phenotypic diversity (Robert et al., 2005).

Our results revealed that the studied collection encompasses extra-early accessions of less than 90 days and late accessions of more than 100 days. These results consolidate and complement those found by Vodouhe and Achigan Dako (2003) which identified in Benin short cycle varieties (90 days on average) and long cycle varieties (about 120 days). Similar results regarding earliness of Fonio were also found in Niger by Saidou et al. (2014). Identifying early accessions is of great agronomic importance for varietal breeding of fonio in the current context where climatic variations are becoming recurrent. However, the floral biology of fonio remains poorly known and the mode of reproduction, preferentially autogamic for some varieties (Cissé, 1975), allogamic for others (Vodouhe and Achigan Dako, 2006) and essentially apomictic for Adoukonou-Sagbadja et al. (2010), has not make unanimity within the scientific community yet (Cruz et al., 2011). A good understanding of its floral biology and possibilities of achieving chromosomal mixings will enable to exploit this variability better and create more efficient varieties.

In this study, four fonio morphotypes were identified, whereas Dansi et al. (2010) found five morphotypes in Boukoumbé and surrounding areas. Indeed, Dansi et al. (2010) had done their ranking based on the results of field surveys and not experimentation in station, which already made a fundamental difference in the methodological approach used for the evaluation of accessions. Also, their work had covered the entire region of Atacora where fonio is grown in Benin and not only the main production commune of Boukoumbé which was the focus of this study. These reasons could be the differences in the number of morphotypes identified. Similar to these findings, Saidou et al. (2014) identified four morphological groups of fonio in Niger for the species *Digitaria exilis* through an experimentation of fonio accessions in station.

The results of this study suggest that the accessions grown in Boukoumbé were rather of *D. exilis* and not of *Digitalia iburua*. Indeed, the descriptions obtained in this study are similar to those found by Cissé (1975) for the species *D. exilis*. Moreover, referring to the work of Portères (1955), the leaves of *D. iburua* have long lashes near the basis, leaving behind the ligula which is membranous, round, wide, long of 1 to 2 mm, with a terminal panicle consisting of 4-10 sub-racemes. These results differ from this description and suggest that our accessions were rather of *D. exilis*. The factor analyses made it possible to identify a set of quantitative and qualitative characters that discriminate the accessions. Among these traits, descriptors of earliness, vegetative development and grain productivity ranked high.

Examples of these descriptors were the date of flowering, plant height, length of foliar limb and racemes length. The importance of these types of characters in structuring the diversity of vegetal populations has been demonstrated on maize (Moreno et al., 2006; N'da et al. 2014), cotton (Sekloka et al., in review), sorghum (Koffi et al., 2011) and many other crops. Although subject to environmental variations, these parameters should not be neglected by plant genetic resources managers since they have always been important in farmers' environment and constitute important criteria for mass selection.

CONCLUSIONS AND SUGGESTIONS

This study on agro-morphological characterization showed a significant diversity of ecotypes of fonio cultivated in Benin. They are diverse in their port, the color of their raceme, the presence or absence of anthocyanin at different levels of the stems and leaves. The earliest accessions had a sowing-maturity cycle of about three months, but grain yields were mostly less than or equal to 800 kg/ha. The most productive accessions recorded more than 1.5 t/ha of grain yield, with more than 2 t/ha for AS2. These accessions can be separated into four distinct morphological groups based on discriminating traits. The most discriminating qualitative traits were the color of collar, the intensity of green coloration of foliar limb; anthocyanin coloration and its distribution across different aerial organs of the plant, and the type and exsertion of panicles. As for quantitative parameters, the most discriminating were the date of flowering, plant height, length of foliar limb and racemes length. The morphological, phenological and agronomic variability demonstrated is sufficient to implement a program of varietal breeding based on varietal homogenization followed by multiple sites evaluation of the improved ecotypes. To sum up, these results contribute to a better knowledge of fonio ecotypes and therefore, allow a better management of the species variability for the benefit of the producers. However, it is important to improve understanding onthe floral biology and reproductive system of fonio in order to be able to achieve genetic mixings leading to new genotypes.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Adoukonou-Sagbadja H, Wagner C, Ordon F, Friedt W (2010). Reproductive system and molecular phylogenetic relationships of fonio millets (*Digitaria* spp., Poaceae) with some polyploid wild relatives. Trop. Plant Biol. 3(4): 240-251.

Adoukonou-Sagbadja H, Wagner C, DansiA, Ahlemeyer J, Daïnou O, Akpagana K, Ordon F, Friedt W (2007). Genetic diversity and population differentiation of traditional fonio millet (*Digitaria spp.*) landraces from different agro-ecological zones of West Africa. Theor. Appl. Genet. 115: 917-31.

Adoukonou-Sagbadja H, Dansi A, Vodouhe R, Akpagana K (2006). Indigenous knowledge and traditional conservation of fonio millet (*Digitaria exilis, Digitaria iburua*) in Togo. Biodivers. Conserv. 1:2379-2395.

Azontondé A, Igué M, Dagbénombakin G (2009). Carte de fertilité des sols du Bénin par zone agro-écologique du Bénin, Rapport de consultation pour le compte d'Afrique Etude, Cotonou, Bénin. P 128.

Ballogoun VY (2013). Systèmes post-récolte, transformation, qualité du fonio et produits dérivés au nord du Bénin. Thèse de Doctorat unique. Faculté des Sciences Agronomique. Université d'Abomey-Calavi. Bénin. P 152.

Cissé IB (1975). La culture de fonio et quelques aspects écophysiologiques de la plante. Wageningen, Netherlands. P 72.

Cruz JF, Béavogui F, Dramé D (2011). Le fonio, une céréale africaine. Quae, CTA, Presses agronomiques de Gembloux. P 175.

Dansi A, Adoukonou-Sagbadja H, Vodouhe R (2010). Diversity, conservation and related wild species of Fonio millet (*Digitaria* spp.) in the northwest of Benin. Genet. Resourc. Crop Evol. 57(6):832-834.

Delaunay S, Tescar RP, Oualbego A, Vom Brocke K, Lançon J (2008). La culture du coton ne bouleverse pas les échanges traditionnels de semences de sorgho. Cahiers Agricultures 17:189-194.

Dramé D, Cruz J (2002). Rapport de Mission au Bénin et au Sénégal. Amélioration des technologies post-récolte du fonio (CORAF). P 21.

Fraleigh B (1987). Importance des banques de ressources phytogénétiques, In: Amélioration et protection des plantes vivrières tropicales, (Eds) Saint Pierre CA, Demarly Y, AUPELF-UREF, Québec, Canada. pp. 13-18.

Koffi CGK, Akanvou L, Akanvou R, Zoro BIA, Kouakou CK, N'da HA (2011). Diversité morphologique du Sorgho (Sorghum Bicolor L.Moench) cultivé au nord de la Côte d'Ivoire. Rev. Ivoir. Technol. 17:125-142.

Manzano AR, Nodals RAA, Gutiérrez RAIM, Mayor FZ, Alfonso CL (2001). Morphological and izoensime variability of taro (*Colocasia esculenta* L. Schott) germplasm in Cuba. Plant Genet. Newslett. 126:31-40.

Missihoun AA, Agbangla C, Adoukonou-Sagbadja H, Ahanhanzo C, Vodouhè R (2012). Gestion traditionnelle et statut des ressources génétiques du sorgho (*Sorghum bicolor* L. Moench) au Nord-Ouest du Bénin. Int. J. Biol. Chem. Sci. 6:1003-1018.

Mckeye D, Emperaie L, Elias M, Pinton F, Robert T, Desmoulière S, Rival L (2001). Gestions locale et dynamiques régionales de la diversité variétale du manioc en amazonie. Genet. Sel. Evol. 33:465-490.

Moreno LL, Tuxil JI, Moo YE, Luis RA, Alejo JC, Jarvids DI (2006). Traditional Maize Storage Methods of Mayan Farmers in Yucatan, Mexico: Implications for seed selection and crop diversity. Biodivers. Conserv. 15:1771-1795.

N'da HA, Akanvou L, Kouakou KC, Zoro AIB (2014). Diversité morphologique des variétés Locales de maïs (*zea mays* L.) collectées au centre et centre-ouest de la Cote d'ivoire. Eur. Sci. J. 12(10): 349-365.

Paraïso A, Tokoudagba S, Olodo GP, Batawila K, Yegbemey RN, Glitho E (2013). Déterminants de la Production du Fonio (*Digitaria Exilis S*.) dans le Nord-Ouest du Bénin. L'agriculture face aux défis de l'alimentation et de la nutrition en Afrique: quels apports de la recherche en zones cotonnières, Yamoussoukro. P 13.

Portères R (1955). Les Céréales mineures du genre *Digitaria* en Afrique et en Europe. J. Agric. Trop. Bot. Appl. 7-9(2):349-386.

Radhouane L (2004). Etude de la variabilité morphophénologique chez *Pennisetum glaucum* (L.) R. Br. Plant Genet. Resourc. Newslett. 138: 18-22.

Robert T, Mariac C, Allinne C, Ali K, Beidari Y, Bezançon G, Couturon E, Moussa D, Sasou MS, Seydou M, Seyni O, Tidjani M, Luxereau A (2005). Gestion des semences et dynamiques des introgressions entre variétés cultivées et entre formes domestiques et spontanées des mil (*Pennisetum glaucum ssp. glaucum*) au Sud-Niger. In: Un dialogue pour la diversité génétique. Paris: BRG, 2005, (5), pp: 555-573. (Les Actes du BRG; 5). Colloque National du BRG: Un Dialogue pour la Diversité Génétique, 5. ISBN 2-908-447-33-9.

Robert T, Luxereau A, Mariac C, Ali K, Allinne C, Bani J, Beidari Y, Bezançon G, Gayeux S, Couturon E, Dedieu V, Sadou M, Seydou M, Seyni O, Tidjani M, Sarr A (2004). Gestion de la diversité en milieu paysan: influence de facteurs anthropiques et des flux de gènes sur la variabilité génétique des formes cultivées et spontanées du mil (*Pennisetum glaucum* ssp. *glaucum*) dans deux localités du Niger. Oct 2002, Le Châtre, France. Paris: BRG; Ministère de la Jeunesse, de l'Education Nationale et de la Recherche, pp 223-245, 2003. <hal-00279168>.

Sadiki M, Jarvis D (2005). Conservation in situ de la diversité génétique des cultures par sa gestion à la ferme dans les agroécosystèmes marocains. Les Actes du BRG 5:445-464.

Saidou SI, Bakasso Y, Inoussa MM, Zaman-Allah M, Atta S, Barnaud A, Billot C, Saadou M (2014). Diversité agro-morphologique des accessions de fonio [*Digitaria Exilis* (Kippist.) Stapf.] au Niger. Int. J. Biol. Chem. Sci. 8(4):1710-1729.

Sekloka E, Kora Sabi A, Zinsou VA, Kanlindogbe C, Afouda L (2016). Phenological, morphological and agronomic characterization of sixteen genotypes of cotton plant (*Gossypium hirsutum*.L) in rainfed condition in Benin. J. Plant Breed. Genet. (In review)

Sekloka E, Adoukonou-Sagbadja H, Paraïso AA, Kouega Yoa B, Bachabi FX, Zoumarou-Wallis N (2015). Evolution de la diversité des cultivars de fonio pratiqués à Boukoumbé et environs. Int. J. Biol. Chem. Sci. 9(5):2446-2458.

Smith SE, Doss AA, Warburton M (1991). Morphological and agronomic variation in North African and Arabian alfalfas. Crop Sci. 31:1159-1163.

Tia D, Iliyath B (2014). Méthodologie de collecte des paramètres agromorphologiques sur le plant de riz. SRP-INRA-AFRICARICE. P 19.

Vall É, Dembélé K, Kanwé A (2008). Options pour le développement de la production de fonio. Projet Fonio. In: Amélioration de la qualité et de la compétitivité de la filière fonio en Afrique de l'Ouest (J.-F. Cruz, éd.) [CD-Rom], Cirad, Montpellier. P 40.

Vietmeyer ND, Borlaugh NE, Axtell J, Burton GW, Harlan JR, Rachie KO (1996). Fonio (Acha). In: BOSTID Publication. Lostcrop in Africa, In: BOSTID Publication. Lostcrop in Africa. pp. 59-75.

Vodouhè SR, Achigan Dako EG (2006). *Digitaria exilis* (Kippist) Stapf. In: PROTA 1- Cereal and pulses / Céréales et légumes secs. Brink, M., Belay, G. (Editors). [CD-ROM]. Prota, Wageningen, Pays-Bas.

Vodouhè SR, Achigan Dako EG (2003). Renforcement de la contribution du fonio à la sécurité alimentaire et aux revenus des paysans en Afrique de l'Ouest. P 71.

Yobi A, Henchi B, Neffati M, Jendoubi R (2002). System de reproduction et variabilité morpho-phénologique chez *Allium roseum.* Plant Genet. Resour. Newslett. 127:29-34.