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Yam (*Dioscorea* spp.) responses to the environmental variability in the Guinea Sudan zone of Benin

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This study analyzed the morphological characteristics and agronomic potentials of yam varieties (*Dioscorea* spp.) collected across the Guinea Sudan transition zone of Benin. *Dioscorea cayenensis - D. rotundata* varieties were characterized as wingless; some varieties were spineless, others had few or dense, robust or thin, and short or prickled spines. There was variation in leaf shape, stem and leaf colour, tuber shapes and forking tendencies. The tuber flesh presented different colours, texture, oxidation colour, oxidation time, and ability to irritate. *Dioscorea alata* varieties were all spineless and showed winged stems, pentagonal or quadrangular. Various leaf and petiole colours, and tuber shapes were observed. On average, the mean Shannon-Weaver index was 0.86 for the external morphology of the tuber, 0.55 for tuber flesh characteristics, and 1.13 for stem and leaf morphology. The pooled mean yield varied between 0.89 and 3.30 kg/heap for the early maturing varieties of the *D. cayenensis - D. rotundata*, between 0.94 and 3.03 kg/heap for the late varieties, and ranged from 1.45 to 4.17 kg/heap for the *D. alata* varieties. The year effect was highly significant for variety-type group and species, and was larger than the genotypic effect. The genotype by year interaction effects were highly significant.

Key words: *Dioscorea spp.,* genotype by environment interaction, yield, yam varieties' traits, Benin.

INTRODUCTION

Yam represents an important component of West African agriculture and contributes to the food security for large parts of the populations of West Africa, particularly in Benin. In addition to its economic and nutritional values, yam also plays a significant role in the cultural life of rural communities in Benin (Zannou et al., 2004; Zannou et al., 2007). Yam production and yield patterns are of economic importance to the livelihood of farmers in the region (Oluwasusi and Tijani, 2013). Little information exists on agronomic and morphological characteristics.

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Doing research with farmers and working on the agronomical and physiological constraints to develop adaptive technology emphasised the need to really understand the genetic diversity of crop traits (Zannou et al. 2004). Recent studies have also shown the necessity to put more emphasis on farm management of genetic resources (Zoundjihékpon et al., 1997; Pardey et al., 1999; Jarvis et al., 2000). Phenotypic performance reflects the joint influence of non-genetic and genetic factors (Brennan and Byth, 1979). The genotype by environment interaction is a phenomenon in which the relative performance of genotypes varies with environmental conditions and is attributed to the dependence of expression of underlying genes or quantitative trait loci on environments (Yin et al., 2004). As working and doing research with farmers for better technology development is a core principle of the Convergence of Sciences approach (Zannou et al., 2004), this paper aimed at characterizing the different varieties of yam in Benin using different morphological and agronomic techniques.

MATERIALS AND METHODS

Plant material

Tubers of 70 cultivars of the *Dioscorea cayenensis - D. rotundata* and 20 cultivars of *D. alata* were collected from farmers across the transitional Guinea-Sudan zone of Benin and were subsequently planted to analyze their morphological characteristics (Table 1). Over 2 years, the agronomic potential and seed tuber behaviour of 27 of the *D. cayenensis - D. rotundata* and 17 of the *D. alata* varieties were assessed.

Morphological analysis: Qualitative plant and tuber characteristics

Data were collected and analyzed on three different groups of variables. These groups comprised eight tuber flesh characteristics; ten characteristics relating to the external morphology of the tubers, and eight leaf or stem characteristics. The eight variables of tuber flesh characteristics were hardness, skin colour, flesh colour, uniformity of the colour at the central section of the tuber, oxidation time, oxidation colour, flesh texture, and skin thickness (Table 2a). The ten variables relating to the tuber's external morphology were tuber shape, forking, forking position, spine presence on tuber, spine abundance of rootlets, small excrescences on tuber, presence on tuber of wrinkles, presence on tuber of cracks, abundance of rootlets and relations between tubers from the same plant (Table 2b). The eight traits of the leaf and stem were presence of wings, wing colour, presence of spines, coloured base of the spine, leaf shape, leaf colour, stem colour, and petiole colour (Table 2c). These observations are in line with indicators used by farmers and with yam descriptors (IPGRI-IITA 1997).

Agronomic evaluation of yam varieties: Genotype by environment interaction

Yield data (kg/heap) were collected during 2003 and 2004 based on the agronomic performance of three yam species. The data set included 27 *D. cayenensis - D. rotundata* and 17 *D. alata* varieties.

Morphological and agronomic data analysis

Qualitative tuber, leaf and stem morphology characteristics

The variables of the qualitative tuber, leaf and stem characteristics were encoded into 2 to 7 classes. Frequency distributions were performed for these qualitative tuber, leaf and stem morphology variables. The frequency distributions were used to calculate the Shannon-Weaver diversity index (*H*') for each character (Grenier et al., 2004) according to the formula:

$$H' = -\sum_{i=1}^{n} p_i \ln(p_i)$$

where n is the number of phenotypic classes, p_i the frequency of the observation in the i^{th} classes. Due to its additive property, the indices of all characteristics were pooled over the characteristics and the global phenotypic diversity was estimated by the mean index value using SAS 8 program (SAS Institute Inc., 1999). In this paper, data were analysed on 70 *D. cayenensis - D. rotundata* and 20 *D. alata* farmer varieties, all of which were different according to morphological criteria.

Genotype by environment interaction

An integrated full interaction analysis of variance was carried out. Such analysis describes the phenotypic responses and allows for differential environmental sensitivity between genotypes based on the regression on the mean model of differences in environmental sensitivity (Finlay and Wilkinson, 1963; van Eeuwijk et al., 2005). The principle of this model is that in the absence of explicit physical or meteorological characterizations of an environment, a good approximation of the general biological quality of the environment is given by the average phenotypic performance across the genotypes (van Eeuwijk et al., 2005). The phenotypic responses of individual genotypes are then regressed on the average performance, and the genotype by environment interaction expresses itself by differences in the slopes between the genotypes. This regression on mean model can be written as follows:

$$\mu_{ij} = u + G_i + E_j + \beta_i E_j$$

where the genotype by environment interaction is modelled as differential genotypic sensitivity and represented by the parameters β_i to environmental characterization E_j, with the average sensitivity being zero.

In this paper, the Generalized Linear Model of Analysis of Variance (GLM ANOVA) under SAS was performed to analyze the variation of yield components in response to change in year effects. The GLM ANOVA is appropriate especially for unbalanced data, where there are unequal numbers of observations for the different combinations of class variables specified in the model structure. With this ANOVA, the yield was analyzed. The following effects were considered for each variety-type (early or late maturing) and each species: Genotype (farmer-named variety), Year (2003-2004), and Genotype × Year. The data set for the genotype by environment interaction analysis included 27 *D. cayenensis - D. rotundata* and 17 *D. alata* varieties. These data were analysed using a general linear model for the pooled analysis of variance across years using the SAS program (SAS Institute Inc., 1999). The Student-Newman-Keuls (SNK) multiple range means comparison test was used to separate genotypes with different yield performance.

Table 1. List and origins of yam cultivars collected in the transitional Guinea Sudan zone of Benin.

Code	Species' and varieties' names *D. cayenensis - D. rotundata*	Village	Region	Code	Varieties	Village	Region
DCR-1	Adigbili	Yagbo	C	DCR-54	Kaagourou	Sontou	NE
DCR-3	Aguida	Kaboua	C	DCR-55	Kokorogbarou	Ouroumonsi	NE
DCR-4	Ahimon	Yagbo	C	DCR-57	Moroko	Kpébié	NE
DCR-5	Ala N'kodjéwé	Yagbo	C	DCR-58	Morokorou	Kpébié	NE
DCR-6	Alakitcha	Ouoghi	C	DCR-59	Oroubessi	Sirarou	NE
DCR-7	Anago	Yagbo	C	DCR-60	Sika	Sakagbansi	NE
DCR-8	Assibo	Ouoghi	C	DCR-61	Singo	Sonnoumon	NE
DCR-10	Bodi	Aklampa	C	DCR-62	Wabè	Alfakpara	NE
DCR-11	Dègbo	Assanté	C	DCR-63	Wobo	Sakagbansi	NE
DCR-12	Djilaadja	Okounfo	C	DCR-64	Yakassougo	Suya/Sandiro	NE
DCR-13	Dodo	Ouèdèmè	C	DCR-65	Yontémé	Marégourou	NE
DCR-14	Effourou	Yagbo	C	DCR-39	Alassoura	Alédjo-Kpatago	NW
DCR-15	Efour	Ouoghi	C	DCR-66	Assana	Ouassa	NW
DCR-16	Enanwaï	Okounfo	C	DCR-67	Bakanon	Alfakpara	NW
DCR-17	Gangni	Ouèdèmè	C	DCR-68	Héléba	Foubéa	NW
DCR-18	Gnanlabo	Kpataba	C	DCR-69	Itolo	Foubéa	NW
DCR-19	Gnidou	Yagbo	C	DCR-70	Koutounou	Alfakpara	NW
DCR-20	Gogan	Assanté	C	DCR-71	Kpagnina	Alédjo-Kpatago	NW
DCR-21	Idoun	Pira	C	DCR-72	Kpakara	Foubéa	NW
DCR-22	Ilèkè	Kaboua	C	DCR-73	Lorie	Alédjo-Kpatago	NW
DCR-23	Kabilatonan	Yagbo	C	DCR-74	Noudoss	Ouassa	NW
DCR-24	Kanatonan	Assanté	C	DCR-75	Noukpam	Foubéa	NW
DCR-26	Kokoro	Yagbo	C	DCR-76	Papetè	Foubéa	NW
DCR-27	Kokoro Djougou	Ouoghi	C	DCR-77	Younouan	Alédjo-Kpatago	NW
DCR-28	Kokouman	Kaboua	C				
DCR-29	Kpakala	Ouoghi	C		***D. alata***		
DCR-30	Kpakra	Ouoghi	C	DA-2	APK Florido	Ouoghi	C
DCR-31	Laboko	Ouèdèmè	C	DA-4	Djekin	Aklampa	C
DCR-32	Laboko Parakou	Ouèdèmè	C	DA-6	Florido	Yagbo	C
DCR-33	Mafobo	Kpakpaza	C	DA-8	Kèègbè	Kaboua	C
DCR-35	Mondji	Ouoghi	C	DA-9	Kpakata	Kaboua	C
DCR-36	Ofègui	Kaboua	C	DA-12	Louelougan	Yagbo	C
DCR-37	Okoguin	Kaboua	C	DA-13	Ogbo	Koko	C
DCR-38	Adani	Ginagourou	NE	DA-14	Ogbo-otcho-adjana	Akpassi	C
DCR-40	Angogo	Sonoumon	NE	DA-22	Sonouko	Yagbo	C

Table 1. Contd.

DCR-42	Baniwouré Bakarou	Suya	NE	DA-24	Tchoko-la-vipère	Kaboua	C
DCR-43	Baniwouré Yantékpéron	Suya	NE	DA-25	Tifiou	Okounfo	C
DCR-44	Boniyakpa	Marégourou	NE	DA-15	Sankou arisso	Kpébié	NE
DCR-45	Danwaré	Biro	NE	DA-16	Sankou Gankou	Sonri	NE
DCR-46	Dibiri	Sontou	NE	DA-17	Sankou Garkou	Sandiro	NE
DCR-47	Dourokonou	Suya	NE	DA-18	Sankou Kergba	Sontou	NE
DCR-48	Doudouwourou	Sontou	NE	DA-19	Sankou souan	Ouroumonsi	NE
DCR-50	Youbakatanou	Sirarou	NE	DA-20	Sankou Wa	Marégourou	NE
DCR-51	Gbarao	Sakabansi	NE	DA-21	Sankourou	Ouénou	NE
DCR-52	Gonni	Ouénou	NE	DA-11	Kpatagnan Pénin	Ouassa	NW
DCR-53	Ibérégbesse	Marégourou	NE	DA-26	Toufou	Foubéa	NW

C=Centre; NE= North-East; NW= North-West.

Table 2a. Frequency distribution and Shannon-Weaver diversity index (H') for yam tuber flesh characters.

Variables	Modalities	*D. cayenensis - D. rotundata*								*D. alata*					
		C	Index	NE	Index	NW	Index	Total	Index	C	Index	N	Index	Total	Index
Tuber hardness	1=Difficult	0.31		0.19		0.25		0.26		0.09				0.06	
	2=Easy	0.66		0.71		0.75		0.69		0.91		1		0.94	
	3=Moderate	0.03	0.74	0.10	0.79		0.56	0.05	0.76		0.30				0.23
Tuber's skin colour	1 White	0.82		0.90		0.83		0.85		0.45		0.43		0.44	
	2=Yellow	0.13						0.06				0.14		0.06	
	3=Cream	0.06		0.05				0.02							
	4=White with purple			0.05				0.02		0.18		0.43		0.28	
	5=White with red spot		0.60		0.39	0.17	0.46	0.06	0.63	0.36	1.04		1.00	0.23	1.22
Flesh colour	1=Whitish	0.44		0.95		0.83		0.86		0.46		0.86		0.61	
	2=Yellow	0.13						0.06				0.14		0.06	
	3=Orange	0.38													
	4=Cream	0.06		0.05						0.09				0.06	
	5=White with purple							0.02		0.09				0.06	
	6=White with red spot		1.16		0.20	0.17	0.46	0.06	0.55	0.36	1.16		0.40	0.21	1.14
Flesh colour's uniformity	1=Uniform	0.72		0.57		1		0.72		0.27		1		0.83	

Table 2a. Contd.

	0=Non uniformity	0.28	0.59	0.43	0.68			0.28	0.59	0.73	0.58			0.17	0.46
Flesh texture	1=Smooth	0.47		0.52		0.50		0.49		0.91		1		0.94	
	2=Grainy	0.25		0.43		0.50		0.35		0.09				0.06	
	3=Very grainy	0.28	1.06	0.05	0.85		0.69	0.16	1.01		0.30				0.23
Flesh oxidation colour	0=No oxidation	0.09		0.24		0.08		0.13		0.91		0.86		0.89	
	1=Grey	0.03						0.02				0.14			
	2=Orange	0.16						0.07							
	3=Purple	0.59		0.57		0.75		0.61		0.09				0.11	
	4=Yellow	0.06		0.05		0.08		0.06							
	5=Reddish-purple	0.03		0.14				0.07							
	6=Ivory	0.03	1.31		1.18	0.08	0.82	0.04	1.39		0.30		0.40		0.35
Oxidation time	0=Absence of oxidation									0.91		0.86		0.88	
	1 min	0.44		0.33		0.42		0.40							
	1-2 min							0.14							
	2 min	0.19		0.10		0.08						0.14		0.06	
	3 min	0.38	1.04	0.57	0.92	0.50	0.91	0.46	1.00	0.09	0.30		0.40	0.06	0.45
Tuber irritation	0=Absent	0.03						0.02							
	1=Little	0.53		0.33		0.50		0.46		0.82		1		0.89	
	2=Medium	0.31		0.53		0.50		0.41		0.18					
	3=High	0.13	1.07	0.14	0.98		0.69	0.11	1.04		0.47			0.11	0.35

Genetic expression variability

The Expected Mean Squares (EMS) for the genotypic variance components (Becker, 1984; Comstock, 1996; Hebert et al., 1998; Li et al., 1998) are:

EMS (Genotypes): $\sigma_e^2 + r\sigma_{G*Y}^2 + 2r\sigma_G^2$

EMS (Genotypes*Year): $\sigma_e^2 + r\sigma_{G*Y}^2$

EMS (error): σ_e^2,

Where r is the number of replications. From the Mean Square calculated and the EMS (Genotypes), the genetic variance, the genetic coefficient of variance (GCV), the Genotype × Year variance component and the environmental variance were estimated. The Student-Newman-Keuls (SNK) multiple range means comparison test was used to separate genotypes with different yield performance.

RESULTS

Morphological diversity of yam

The tuber flesh of different varieties of *Dioscorea cayenensis - D. rotundata* presented different colours, texture, oxidation colour, oxidation time, and ability to irritate (Table 2a). Various tuber shapes and forking tendencies were observed (Table 2b). The *D. cayenensis - D. rotundata* varieties were characterized as wingless. While some varieties were spineless, others were marked with few or dense spines. On young plants 30 days after emergence, the abundance of spines varied from one variety to another. Some varieties had a few spines at the

Table 2b. Frequency distribution and Shannon-Weaver diversity index (H') for yam tuber's external morphology.

Variables	Modalities	*D. cayenensis / D. rotundata*								*D. alata*					
		C	**Index**	**NE**	**Index**	**NW**	**Index**	**Total**	**Index**	**C**	**Index**	**N**	**Index**	**Total**	**Index**
Tuber shape	1=Oval	0.19													
	2=Oval-oblong	0.28		0.31		0.40		0.15		0.08				0.04	
	3=Cylindrical	0.38		0.56		0.60		0.26		0.46		0.55		0.50	
	4=Flattened	0.03		0.07				0.45		0.23		0.18		0.21	
	5=Irregular	0.12		0.06				0.10		0.08		0.18		0.12	
	6=Snake-shaped		1.40		1.04		0.67	0.04	1.35	0.15	1.38	0.09	1.16	0.13	1.32
Digitations / forking	0=No forking	0.03		0.12		0.60		0.11		0.23		0.18		0.21	
	1=Slightly forked	0.41		0.38		0.20		0.38		0.23				0.13	
	2=Forked	0.12		0.31		0.20		0.19		0.23				0.12	
	3=Highly forked	0.44	1.09	0.19	1.30		0.95	0.32	1.29	0.31	1.38	0.82	0.47	0.54	1.18
Digitations' position	0=No forking	0.25		0.13		0.60		0.24		0.23		0.18		0.21	
	1=Third-top	0.22		0.56		0.20		0.32		0.15		0.27		0.21	
	2=Middle	0.13		0.31				0.08		0.08		0.09		0.08	
	3=Third-bottom	0.38				0.20		0.34		0.38		0.36		0.38	
	4=1+2; 2+3; 1+2+3	0.03	1.42		0.95		0.95	0.02	1.35	0.16	1.49	0.09	1.46	0.12	1.48
Relationship of tubers	1=Separate and distant	0.41		0.31		0.40		0.38		0.54		0.36		0.46	
	2=Separate but close together	0.25		0.25		0.40		0.26		0.31		0.27		0.29	
	3=Fused at neck	0.28		0.44		0.20		0.32		0.15		0.36		0.25	
	4=1, 2, 3	0.06	1.24		1.07		1.05	0.04	1.21		0.98		1.09		1.06
Rootlet abundance	0=Absent	0.03		0.06				0.04							
	1=Few	0.69		0.63		0.80		0.68		0.31		0.45		0.37	
	2=Abundant	0.19		0.13		0.20		0.17		0.31		0.09		0.21	
	3=Very abundant	0.09	0.89	0.19	1.04		0.50	0.11	0.94	0.38	1.09	0.46	0.93	0.42	1.06
Rootlet position on tuber	0=Absent	0.06		0.06				0.06							
	1=Basal	0.09		0.13				0.09		0.08		0.09		0.04	
	2=Middle									0.08				0.04	
	3=Proximal	0.66		0.56		1		0.66		0.08				0.04	
	4=Combination of 1, 2, and 3	0.18	0.97	0.25	1.11			0.19	0.98	0.76	0.81	0.91	0.30	0.88	0.50

Table 2b. Contd.

Wrinkles on tuber	0=Absent	0.28		0.38		0.20		0.30		0.92		0.73		0.83	
	1=Few	0.47		0.50		0.60		0.49				0.27		0.13	
	2=Abundant	0.16		0.13		0.20		0.13							
	3=Very abundant	0.09	1.22	0	0.98		0.95	0.08	1.18	0.08	0.28		0.58	0.04	0.55
Cracks on tuber	0=Absent	0.44		0.38		0.60		0.43		0.85		0.82		0.83	
	1=Present	0.56	0.69	0.62	0.66	0.40	0.67	0.57	0.68	0.15	0.42	0.18	0.47	0.17	0.46
Spine on tuber	0=Absent	0.65		0.63		0.60		0.63		0.85		0.91		0.87	
	1=Present	0.35	0.65	0.37	0.66	0.40	0.67	0.37	0.66	0.15	0.42	0.09	0.3	0.13	0.39
Bulb on tuber	0=Absent	0.47		0.50		0.60		0.49		0.69		0.64		0.67	
	1=Present	0.53	0.69	0.50	0.69	0.40	0.67	0.51	0.69	0.31	0.62	0.36	0.65	0.33	0.63

Table 2c. Frequency distribution and Shannon-Weaver diversity index (H') for yam stem and leaf morphology.

Variable	Modalities	*D. cayenensis / D. rotundata*								*D. alata*					
		C	**Index**	**NE**	**Index**	**NW**	**Index**	**Total**	**Index**	**C**	**Index**	**N**	**Index**	**Total**	**Index**
Stem colour	1=Light green	0.65		0.64		0.58		0.63		0.54		0.46		0.50	
	2=Green	0.05		0.04		0.08		0.06		0.33		0.27		0.31	
	3=Dark green	0.11		0.14		0.08		0.11		0.07		0.27		0.15	
	4=Purple	0.06		0.09		0.09		0.06							
	5=Reddish-purple	0.13	1.11	0.09	1.12	0.17	1.24	0.14	1.15	0.07	1.07		1.06	0.04	1.12
Wing colour	1=Light green									0.13				0.08	
	2=Green									0.13		0.10		0.12	
	3=Dark green														
	4=Purple									0.14		0.10		0.12	
	5=Reddish-purple									0.60	1.11	0.80	0.64	0.68	0.97
Presence of coloured spot at spine base	0=Absent	0.73		0.91		0.92		0.82		1		1		1	
	1=Purple	0.08						0.04							
	2=Reddish-purple	0.19	0.75	0.09	0.30	0.08	0.28	0.14	0.57						
Presence of spines	0=Absent	0.08		0.05		0.33		0.06		1		1		1	
	1=Very sparse	0.38		0.45		0.42		0.39							

Table 2c. Contd.

	2=Abundant	0.41		0.36		0.17		0.39							
	3=Very abundant	0.14	1.21	0.14	1.15	0.08	1.23	0.16	1.20						
	1=Light green	0.51		0.45		0.67		0.52		0.33		0.09		0.23	
	2=Green	0.30		0.18		0.08		0.23		0.27		0.09		0.19	
Leaf colour	3=Dark green	0.19		0.37		0.25		0.25		0.27		0.73		0.46	
	4=Purple														
	5=Reddish-purple		1.02		1.04		0.82		1.02	0.13	1.34	0.09	0.88	0.12	1.27
	1=Light green	0.95		0.86		0.92		0.91		0.33		0.73		0.50	
Vein colour	2=Green	0.05		0.14				0.07		0.47		0.18		0.35	
	3=Dark green					0.08		0.02							
	4=Reddish-purple		0.20		0.40		0.28		0.35	0.20	1.04	0.09	0.76	0.15	1.01
	1=Light green	0.67		0.69		0.50		0.65		0.26		0.64		0.43	
	2=Green	0.14		0.18		0.25		0.17		0.40		0.18		0.31	
Petiole colour	3=Dark green	0.05		0.09		0.08		0.07		0.07		0.18		0.12	
	4=Purple	0.14		0.04		0.17		0.11		0.13				0.08	
	5=Reddish-purple		0.97		0.91		1.20		1.01	0.14	1.44		0.90	0.04	1.31
	1=Small	0.22		0.04				0.13							
	2=Medium	0.16		0.27		0.25		0.21				0.18		0.08	
	3=Large	0.22		0.41		0.33		0.29		0.67		0.64		0.65	
Leaf shape	4=Cordate long	0.19				0.25		0.14		0.07				0.04	
	5=Funnel-shape	0.13		0.14		0.08		0.13		0.07		0.09		0.08	
	6=Ovate	0.08	1.74	0.14	1.4	0.08	1.46	0.1	1.72	0.20	0.96	0.09	1.03	0.15	1.1

first internodes, but the rest of the stems (main and secondary ones) were spineless (DCR-11). Some varieties were characterized by robust stem and dense spines (DCR-6, DCR-4, DCR-1, DCR-19, and DCR-32); the stems of others were thin but had dense spines (DCR-7, DCR-3, DCR-15, and DCR-8). The size of spines also varied: short (DCR-57) or prickled (DCR-36) spines. Very small leaves and numerous stems (14 - 24 stems as for DCR-54). On adult plants, there was variation in leaf shape, stem and leaf colour (Table 2c).

Dioscorea alata varieties were characterized by differences in the colours of the skin or flesh of the tubers (Table 2a). There is a high variation in tuber shape as reflected by presence and position of forking. There were also differences in abundance of presence of rootlets on tubers (Table 2b). *Dioscorea alata* varieties were all characterized by spineless and winged stems, pentagonal or quadrangular at the basis of the stem, but changing to triangular towards the top (Table 2c). On young plants (30 days after emergence), the leaf shape was variable: oval, long and lanceolate, or funnel-shaped. Various leaf colours, ranging from slight green, green, to red-purple, were observed (Table 2c). Some varieties also showed red-purple petioles. The petiole was red-purple mainly at the insertion point of the leaf on the stem. The number of stems emerging from the planted materials varied from 1 to 10, depending on the variety. On adult plants there was a high variation in stem shape and leaf shape). On average for the characteristics considered, the mean Shannon-Weaver index was 0.86 for the external morphology of the tuber, 0.55 for tuber flesh characteristics, and 1.13 for stem and leaf morphology.

Agronomic evaluation of yam varieties

Genotypic variability

Table 3 presents the mean yield (kg/heap) per variety and shows the variation of the yield from one year to another. The mean yield varied from 0.83 to 3.12 kg/heap in 2003 and from 0.95 to 4.73 kg/heap in 2004 for the early maturing varieties of the *D. cayenensis* - *D. rotundata*. The pooled mean over 2003 and 2004 varied between 0.89 and 3.30 kg/heap. On average, the mean yield of the late maturing varieties of the *D. cayenensis* – *D. rotundata* varied between 0.86 to 2.46 kg/heap in 2003 and between 1.15 and 3.81 kg/heap in 2004. The pooled mean for these late varieties ranged from 0.94 to 3.03 kg/heap.

The *D. alata* varieties were essentially all late maturing. The mean yield of *D. alata* varied from 1.01 to 3.22 kg/heap in 2003 and between 1.07 and 5.26 kg/heap in 2004, with a pooled mean ranging from 1.45 to 4.17 kg/heap over the two years.

Table 4 provides the variance components using the GLM-ANOVA as described in the methodology section. Varieties showed highly significant differences (significance level $p<0.01$). The year effect was highly significant for variety-type group and species ($p<0.01$). This year effect was larger than the genotypic effect. The genotype by year interaction effects were also highly significant ($p<0.01$).

Genetic variability

After removing the year and genotype by year interaction from the total genotypic variation, the genetic variance component remained significant for the two species with large numbers of varieties included in the analysis (Table 5). For the early-maturing varieties of *D. cayenensis* – *D. rotundata* genotypes, the genetic variance was greater in 2004 (2.34) than in 2003 (1.29). For the late-maturing varieties, the environmental variance was greater than the genetic variance both in 2003 (0.69 and 0.29, respectively) and 2004 (3.36 and 2.02, respectively). For the *D. alata* genotypes, the genetic variance was greater in 2003 (1.05) but lower than the environmental variance in 2004 (3.36). Over the two years, the environmental variance was greater than the genetic variance for both species groups. There was a large non-genetic component in the phenotypic behaviour of these two species groups of yams. Moreover, the *D. cayenensis* – *D. rotundata* genotypes responded differently to the year effect compared to *D. alata* genotypes.

Grouping varieties based on the mean yield

The Student-Newman-Keuls (SNK) test was used to separate the different varieties based on the mean yield over the two years (Table 3). Means followed by the same letters are not significantly different at the level of 0.05. That test separates the early-maturing varieties of the *D. cayenensis* - *D. rotundata* into 11 groups, while the late ones were grouped into two groups. The highest yields were obtained by Anago (3.30 kg/heap), Adigbili (3.04 kg/heap) and Alakitcha (3.03 kg/heap) and the lowest by Affo (0.89 kg/heap), Baniwouré (0.94 kg/heap), Kokorogbarou (1.03 kg/heap) and Dibiri (1.05 kg/heap).

Eight groups were distinguished for *D. alata* varieties. Three of the groups composed of individual variety (Djekin, Sankou-garkou, Sankou-souan) showed the highest yields (4.17; 3.44 and 3.37 kg/heap, respectively) (Table 3). The lowest yield was obtained for the group with the varieties Hounvè, Dangbéko and Sankou-wa.

DISCUSSION

This paper has analysed in-depth various relevant morphological and agronomic traits characterizing cultivated yam varieties in the Guinea Sudan zone of Benin. Among the qualitative morphological characteristics, internal and external morphology of the tuber and the stem and leaf characteristics form groups of distinctive traits that allow farmers and consumers to differentiate between varieties and guide farmers and consumers in their choice of planting materials and food choices. Classification systems help to identify the primary responses that exist in a species, which aids plant breeders and agronomists in their choice of the most appropriate germplasm and testing environments (Ehlers and Hall 1996). The joint experimental approach described is likely to form classifications embodying both breeders and farmers interests. Oluwasusi and Tijani (2013) analysed farmers' adaptation strategies to the effect of climate variation on yam production in Nigeria and found that there is significant difference in the level of production of farmers across the years. Their study suggested the need for increased research and development of innovation for sustainable yam cropping in the face of climate variation.

The earliness, post-harvest dormancy, number of days

Table 3. Mean yield (kg/heap) of 27 *D. cayenensis - D. rotundata* and 17 *D. alata* yam varieties over 2003–2004.

Species	Variety-type	Variety	2003		2004		Pooled mean	
			Mean	SE	Mean	SE	2003 - 2004	SE
	Early	Anago	1.77	0.27	4.73	0.47	3.30[a]	0.38
	Early	Adigbili	3.12	0.33	2.81	0.59	3.04[ab]	0.28
	Early	Effourou	1.88	0.23	3.23	0.51	2.71[abc]	0.35
	Early	Ahimon	1.78	0.15	3.57	0.72	2.58[abcd]	0.36
	Early	Gnidou	1.60	0.11	4.19	0.62	2.44[abcd]	0.27
	Early	Kpakra	2.28	0.19	2.18	0.29	2.25[abcde]	0.15
	Early	Ala N'kodjewe	1.35	0.23	2.82	0.25	2.13[abcdef]	0.22
	Early	Djilaadja	1.01	0.25	2.55	0.35	2.13[abcdef]	0.30
	Early	Dodo	3.05	0.51	1.66	0.23	2.12[abcdef]	0.27
	Early	Gangni	1.64	0.18	2.94	0.29	2.09[abcdef]	0.18
	Early	Laboko	1.92	0.45	1.89	0.40	1.90[bcdef]	0.32
	Early	Okoguin	1.55	0.17	2.21	0.45	1.75[bcdef]	0.19
	Early	Ofegui	0.96	0.13	2.27	0.21	1.66[cdef]	0.17
D. cayenensis-D. rotundata	Early	Danware	0.85	0.21	1.90	0.22	1.38[def]	0.20
	Early	Dibiri	1.10	0.46	1.02	0.08	1.05[ef]	0.16
	Early	Affo	0.83	0.23	0.95	0.05	0.89[f]	0.11
	Late	Alakitcha	1.60	0.50	3.48	0.43	3.03[a]	0.39
	Late	Kokoro	1.02	0.11	3.81	0.79	1.93[b]	0.32
	Late	Degbo	2.46	0.30	1.33	0.48	1.89[b]	0.34
	Late	Klatchi	1.57	0.13	2.18	0.32	1.80[b]	0.15
	Late	Bodi	1.26	0.21	2.03	0.14	1.77[b]	0.16
	Late	Dourokonou	1.18	0.25	1.85	0.79	1.42[b]	0.32
	Late	Aguida	0.60	0.25	1.53	0.14	1.41[b]	0.14
	Late	Gnanlabo	0.58	0.14	1.63	0.23	1.34[b]	0.20
	Late	Enanwai	0.98	0.31	1.67	0.24	1.24[b]	0.24
	Late	Kokorogbarou	0.92	0.10	1.10	0.16	1.03[b]	0.11
	Late	Baniwoure	0.86	0.13	1.15	0.18	0.94[b]	0.11
	Late	Djekin	2.65	0.46	4.65	0.63	4.17[a]	0.52
	Late	Sankou Garkou	2.22	0.24	5.26	1.48	3.44[ab]	0.68
	Late	Sankou Souan	2.03	0.20	3.73	0.65	3.37[abc]	0.54
	Late	Kpakata	3.22	0.44	3.11	0.63	3.15[abcd]	0.42
	Late	Keegbe	2.62	0.29	3.67	0.48	3.08[abcd]	0.28
	Late	Sankou Kergba	2.22	0.27	3.10	0.54	2.79[bcde]	0.37
	Late	Tchoko-la-Vipere	2.74	0.25	2.51	0.52	2.67[bcde]	0.23
	Late	Sankounou	1.96	0.39	2.58	0.33	2.39[bcde]	0.26
	Late	Afe	1.01	0.27	3.12	0.32	2.30[bcde]	0.33
	Late	Louelougan	1.32	0.09	3.07	0.36	2.15[cde]	0.23
	Late	Gobiledo	1.42	0.20	2.24	0.28	2.04[de]	0.23
	Late	Egni-Eri	1.14	0.21	2.37	0.32	1.93[de]	0.25
	Late	APK Florido	1.55	0.10	2.94	0.74	1.92[de]	0.24
	Late	Florido	1.58	0.05	2.88	0.42	1.83[de]	0.10
	Late	Hounve	2.20	0.37	1.36	0.16	1.65[e]	0.18
	Late	Dangbeko	1.16	0.20	1.78	0.25	1.63[e]	0.20
D. alata	Late	Sankou Wa	2.04	0.24	1.07	0.14	1.45[e]	0.17

Means followed by the same letter or letters are not significantly different at the level of 0.05 using the test of Student Newman Keuls.

Table 4. Estimated parameters for genotypic and genetic variability of 17 *D. alata* and 27 *D. cayenensis - D. rotundata* yam varieties from pooled ANOVA.

Species	Variety-type	Source of variation	DF	Mean square	F-statistics
		Variety	15	8.57	4.99**
		Year	1	60.09	35.04**
		Variety × Year	15	7.78	4.54**
	Early maturing	Model	31	12.13	7.07**
		Error	403	1.71	
		Mean (kg/heap)=2.26			
		R-square=0.35			
D. cayenensis – D. rotundata					
		Variety	10	5.94	4.27**
		Year	1	21.98	15.79**
		Variety × Year	10	5.21	3.74**
	Late maturing	Model	21	8.53	6.13**
		Error	207	1.39	
		Mean (kg/heap)=1.70			
		R-square=0.38			
		Variety	16	9.49	4.68**
		Year	1	79.59	39.23**
		Variety × Year	16	5.84	2.88**
D. alata	Late maturing	Model	33	12.56	6.19**
		Error	448	2.03	
		Mean (kg/heap)=2.39			
		R-square=0.31			

Level of significance: **: 0.01.

after planting to emergence, and the yield are important agronomic and physiological characteristics of yam diversity in Benin. In experimenting under real farmer conditions, this study has revealed that the duration of dormancy depends not only on the species but also on the variety, the physical storage conditions and the duration of the storage. Passam (1982) found that the duration of dormancy does not only depend on the plant but is also influenced by physical factors. Work also confirmed that as the environmental conditions change from year to year there is variation in the yield of the same variety. This study has shown that the genotype by environment interaction was highly determinant of yam performance. For important agronomic characteristics, the differential response of a genotype or cultivar for a given trait is an important and essential component of plant breeding programs dedicated to cultivar development (Campbell and Jones, 2005), and is

Table 5. Genetic variability from individual and pooled year analyses.

	D. cayenensis - D. rotundata					*D. cayenensis - D. rotundata*					*D. alata*				
	Early		**Early**		**Early**	**Late**		**Late**		**Late**					
Genotypic variability	**2003**	**F**	**2004**	**F**	**Pooled**	**2003**	**F**	**2004**	**F**	**Pooled**	**2003**	**F**	**2004**	**F**	**Pooled**
Mean Square (genotype × year)	0		0		7.78	0		0		5.21	0		0		5.84
Mean Square (genotype)	5.83	6.88**	12.07	4.43**	8.57	1.72	4.73**	10.41	4.43**	5.94	4.87	7.10**	14.43	4.30**	9.49
Error	0.85		2.73		1.71	0.36		2.35		1.39	0.69		3.36		2.03
Mean	1.79		2.79		2.26	1.19		2.19		1.7	1.92		2.85		2.38
CV (%)	51.3		59.17		58.2	50.77		70		69.17	43.21		64.26		59.69
Genetic expression variability															
Genotype-by-Year variance	/		/		1.92	/		/		1.06	/		/		1.27
Genetic variance	1.29		2.34		0.10	0.26		2.02		0.09	1.05		2.77		0.46
Environmental (error) variance	0.69		3.36		2.03	0.69		3.36		2.03	0.69		3.36		2.03
Phenotypic variance	1.98		5.70		4.05	0.95		5.38		3.18	1.74		6.13		3.76
Genetic Coef. Variation (GCV) (%)	71.79		83.69		4.37	21.64		92.01		5.37	54.43		97.11		19.17

Level of significance: **: 0.01.

thus also of great importance for farmers. In selecting for better plant types in white and yellow yams information on the quantitative inheritance of important plant characters is needed. Tewodros and Getachew (2013) have analysed the qualitative and quantitative traits among the accessions of the aerial yam, *Dioscorea bulbifera* and revealed that the phenotypic variance was contributed from the genotypic and environmental variances. They suggested that profound descriptions of accessions based on genetic variance are to have significant impact on the genetic improvement of the crop, and that selection based on these characters are efficient to maximize the yield of the yam.

Most of the *D. alata* varieties (65%) yielded more than 2 kg/heap. The most widely cultivated *D. alata* variety Florido (Zannou et al., 2004) did not perform as well as the other *D. alata* varieties. This result suggests that the choice of this variety Florido by many farmers is not related to its high yield performance, but to the quality of the tuber, storability and perhaps other agronomic characteristics.

Conclusion

The current study suggests that the Guinea Sudan zone of Benin represents a very large gene-pool of yam varieties. Yam farmers in Benin, with their continuous commitment to domestication of material from the wild, clearly play a significant role in the enrichment and the maintenance of the genetic diversity of yam cultivars. Their participation in the research, and perception of the benefits of such participation, suggest new ways of designing research projects to enhance impact.

Conflict of Interest

The author(s) have not declared any conflict of interests.

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