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.
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 (Yín 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 $\beta$, 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 | Village | Region | Code | Varieties | Village | Region |
|------|-------------------------------|---------|--------|------|-----------|---------|--------|
| DCR-1 | D. cayenensis - D. rotundata | 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    | Kpéié    | NE    |
| DCR-5 | Ala N’kodjéwé                | Yagbo   | C      | DCR-58 | Morokorou | Kpéié    | NE    |
| DCR-6 | Alakitcha                    | Ouoghi  | C      | DCR-59 | Oroubessi | Sirarou  | NE    |
| DCR-7 | Anago                        | Yagbo   | C      | DCR-60 | Sika      | Sakagbans | NE    |
| DCR-8 | Assibo                       | Ouoghi  | C      | DCR-61 | Singo     | Sonnoumon | NE    |
| DCR-10 | Bodi                         | Aklampa | C      | DCR-62 | Wabé      | Alfakpara | NE    |
| DCR-11 | Dègbo                        | Assanté | C      | DCR-63 | Wobo      | Sakagbans | NE    |
| DCR-12 | Djilaadjia                   | Okounfo | C      | DCR-64 | Yakassougo | Suya/Sandiro | NE |
| DCR-13 | Dodo                         | Ouédémé | C      | DCR-65 | Yontémé   | Marégourou | NE    |
| DCR-14 | Effourou                     | Yagbo   | C      | DCR-39 | Allassoura | 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                       | Ouédémé | 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 | Noupam    | 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 | Kpakoua                      | Ouoghi  | C      |       |           |         |        |
| DCR-30 | Kpakra                       | Ouoghi  | C      | DA-2  | APK Florido | Ouoghi   | C      |
| DCR-31 | Laboko                       | Ouédémé | C      | DA-4  | Djekin    | Aklampa  | C      |
| DCR-32 | Laboko Parakou               | Ouédémé | C      | DA-6  | Florido   | Yagbo    | C      |
| DCR-33 | Mafobo                       | Kpakpaza| C      | DA-8  | Kèègbè   | Kaboua   | C      |
| DCR-35 | Mondjì                       | Ouoghi  | C      | DA-9  | Kpakata   | Kaboua   | C      |
| DCR-36 | Ofégui                       | 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   | Location          | Settlement      | NE | DA-24 | Tchoko-la-vipère | Kaboua | C |
|-------|-------------------|-----------------|----|-------|------------------|--------|---|
| 42    | Baniwouré Bakarou | Suya            | NE |       |                  |        | C |
| 43    | Baniwouré Yantékpéron | Marégourou | NE |       |                  |        | C |
| 44    | Boniyakpa         | Biro            | NE |       |                  |        | NE|
| 45    | Danwaré           | Sontou          | NE |       |                  |        | NE|
| 46    | Dibiri            | Suya            | NE |       |                  |        | NE|
| 47    | Dourokonou        | Suya            | NE |       |                  |        | NE|
| 48    | Doudouwourou      | Sontou          | NE |       |                  |        | NE|
| 50    | Youbakatanou      | Sirarou         | NE |       |                  |        | NE|
| 51    | Gbarao            | Sakabansi       | NE |       |                  |        | NE|
| 52    | Gonni             | Ouénou          | NE |       |                  |        | NW|
| 53    | Ibérégbesse       | Marégourou      | NE |       |                  |        | 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| 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| 0.76| 0.30 |     |     |
| Tuber's skin colour        | 1 White                           | 0.82|     | 0.90|     | 0.83|     | 0.85 |     | 0.45|     | 0.44 |     |
|                            | 2=Yellow                          | 0.13|     | 0.05|     | 0.02|     | 0.06 |     | 0.14|     | 0.06 |     |
|                            | 3=Cream                           | 0.06|     | 0.05|     | 0.02|     | 0.18 |     |     |     | 0.43 |     |
|                            | 4=White with purple               | 0.05|     | 0.05|     | 0.02|     | 0.18 |     |     |     | 0.43 |     |
|                            | 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               | 0.06| 0.05|     |     | 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 |     |     |


**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    |      |      |      |      |
| 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 | 1.01 | 0.30 |      |      |      |
| **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 |      | 1    |      |
| 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 | 0.41 | 0.39 | 0.30 | 0.40 | 0.35 |
| **Oxidation time** |                |      |      |      |      |      |      |      |      |      |      |
| 0=Absence of oxidation |         | 0.44 | 0.33 | 0.42 | 0.40 |      | 0.91 | 0.86 | 0.88 |      |      |
| 1 min           |                  |      |      |      |      |      |      |      |      |      |      |
| 1-2 min         |                  | 0.19 | 0.10 | 0.08 |      | 0.14 | 0.06 |      |      |      |      |
| 2 min           |                  | 0.38 | 1.04 | 0.57 | 0.92 | 0.50 | 0.91 | 1.00 | 0.09 | 0.30 | 0.40 |
| 3 min           |                  | 0.38 | 1.04 | 0.57 | 0.92 | 0.50 | 0.91 | 1.00 | 0.09 | 0.30 | 0.40 |
| **Tuber irritation** |              |      |      |      |      |      |      |      |      |      |      |
| 0=Absent        |                  | 0.03 |      |      |      |      | 0.02 |      |      |      |      |
| 1=Little        |                  | 0.53 | 0.33 | 0.50 | 0.46 | 0.82 | 1    |      |      |      |      |
| 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):** $\sigma^2_G + r\sigma^2_{G\cdot r} + 2r\sigma^2_r$
- **EMS (Genotypes*Year):** $\sigma^2_{G\cdot Y} + r\sigma^2_{G\cdot Y\cdot r}$
- **EMS (error):** $\sigma^2_e$

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    | 0.09        |
|                            |            |          |          |             |         |         |             |
| 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        |
|                            |            |          |          |             |         |         |             |
| 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        |
|                            |            |          |          |             |         |         |             |
| 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        |
|                            |            |          |          |             |         |         |             |
| 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        |
|                            |            |          |          |             |         |         |             |
| Rootlet on tuber           |            |          |          |             |         |         |             |
| 2=Middle                   | 0.66       | 0.56     | 1        | 0.66        | 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        |
Table 2b. Contd.

| Variable         | Modalities   | D. cayenensis / D. rotundata | D. alata |
|------------------|--------------|-----------------------------|----------|
|                  |              | C   | Index | NE | Index | NW | Index | Total | Index | C   | Index | NE | Index | NW | Index | Total | Index |
| 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 | 0.09 | 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 | 0.67 | 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 | 0.67 | 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 | NE | Index | NW | Index | Total | Index |
| Stem colour                     | 1=Light green       | 0.65 | 0.64 | 0.08 | 0.63 | 0.63 | 0.54 | 0.46 | 0.50 |
|                                 | 2=Green             | 0.05 | 0.04 | 0.08 | 0.66 | 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 | 0.12 | 1.07 | 1.06 | 0.04 | 1.12 |
| Wing colour                     | 1=Light green       | 0.13 | 0.10 | 0.12 |
|                                 | 2=Green             | 0.13 | 0.10 | 0.12 |
|                                 | 3=Dark green        | 0.14 | 0.10 | 0.12 |
|                                 | 4=Purple            | 0.14 | 0.10 | 0.12 |
|                                 | 5=Reddish-purple    | 0.60 | 1.11 | 0.80 | 0.68 | 0.97 |
| Presence of coloured spot at spine base | 0=Absent         | 0.73 | 0.91 | 0.92 | 0.82 | 1.0 | 1.0 |
|                                 | 1=Purple            | 0.08 | 0.04 |
|                                 | 2=Reddish-purple    | 0.19 | 0.75 | 0.09 | 0.30 | 0.28 | 0.14 | 0.57 |
| Presence of spines              | 0=Absent            | 0.08 | 0.05 | 0.33 | 0.06 | 1.0 | 1.0 |
|                                 | 1=Very sparse       | 0.38 | 0.45 | 0.42 | 0.39 |
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

### 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 |

#### Leaf colour

|                | 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 |
|                | 3=Dark green | 0.19 | 0.37 | 0.25 | 0.25 | 0.27 | 0.73 | 0.46 |
|                | 4=Purple     | 1.02 | 1.04 | 0.82 | 1.02 | 0.13 | 1.34 | 0.09 | 0.88 | 0.12 | 1.27 |
|                | 5=Reddish-purple | 0.20 | 0.40 | 0.28 | 0.35 | 0.20 | 1.04 | 0.09 | 0.76 | 0.15 | 1.01 |

#### Vein colour

|                | 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 |
|                | 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 | 0.07 | 0.08 |
|                | 5=Reddish-purple | 0.97 | 0.91 | 1.20 | 1.01 | 0.14 | 1.44 | 0.90 | 0.04 | 1.31 |

#### Petiole colour

|                | 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 |
|                | 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 |
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 Mean | 2003 SE | 2004 Mean | 2004 SE | Pooled mean | 2003-2004 Mean | 2003-2004 SE |
|------------------|--------------|---------|-----------|---------|-----------|---------|-------------|----------------|---------------|
| **Early**        | Anago        | 1.77    | 0.27      | 4.73    | 0.47      | 3.30^a  | 0.38        |                 |               |
|                  | Adigibili    | 3.12    | 0.33      | 2.81    | 0.59      | 3.04^ab | 0.28        |                 |               |
|                  | Effourou     | 1.88    | 0.23      | 3.23    | 0.51      | 2.71^abc| 0.35        |                 |               |
|                  | Ahimon       | 1.78    | 0.15      | 3.57    | 0.72      | 2.58^bddef| 0.36      |                 |               |
|                  | Gnidou       | 1.60    | 0.11      | 4.19    | 0.62      | 2.44^bddef| 0.27      |                 |               |
|                  | Kpakra       | 2.28    | 0.19      | 2.18    | 0.29      | 2.25^bddef| 0.15      |                 |               |
|                  | Ala N’kodjewe | 1.35   | 0.23      | 2.82    | 0.25      | 2.13^bddef| 0.22      |                 |               |
|                  | Djilaadja    | 1.01    | 0.25      | 2.55    | 0.35      | 2.13^bddef| 0.30      |                 |               |
|                  | Dodo         | 3.05    | 0.51      | 1.66    | 0.23      | 2.12^bddef| 0.27      |                 |               |
|                  | Gangni       | 1.64    | 0.18      | 2.94    | 0.29      | 2.09^bddef| 0.18      |                 |               |
|                  | Laboko       | 1.92    | 0.45      | 1.89    | 0.40      | 1.90^bddef| 0.32      |                 |               |
|                  | Okoguin      | 1.55    | 0.17      | 2.21    | 0.45      | 1.75^bddef| 0.19      |                 |               |
|                  | Ofegui       | 0.96    | 0.13      | 2.27    | 0.21      | 1.66^bddef| 0.17      |                 |               |
| **D. cayenensis-D. rotundata** | Danware     | 0.85    | 0.21      | 1.90    | 0.22      | 1.38^def | 0.20      |                 |               |
|                  | Dibiri       | 1.10    | 0.46      | 1.02    | 0.08      | 1.05^ef | 0.16      |                 |               |
|                  | 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        |                 |               |
|                  | Kokoro       | 1.02    | 0.11      | 3.81    | 0.79      | 1.93^b  | 0.32        |                 |               |
|                  | Degbo        | 2.46    | 0.30      | 1.33    | 0.48      | 1.89^b  | 0.34        |                 |               |
|                  | Klatchi      | 1.57    | 0.13      | 2.18    | 0.32      | 1.80^b  | 0.15        |                 |               |
|                  | Bodi         | 1.26    | 0.21      | 2.03    | 0.14      | 1.77^b  | 0.16        |                 |               |
|                  | Dourokonou   | 1.18    | 0.25      | 1.85    | 0.79      | 1.42^b  | 0.32        |                 |               |
|                  | Aguida       | 0.60    | 0.25      | 1.53    | 0.14      | 1.41^b  | 0.14        |                 |               |
|                  | Gnanlabo     | 0.58    | 0.14      | 1.63    | 0.23      | 1.34^b  | 0.20        |                 |               |
|                  | Enanwai      | 0.98    | 0.31      | 1.67    | 0.24      | 1.24^b  | 0.24        |                 |               |
|                  | Kokorogbarou | 0.92    | 0.10      | 1.10    | 0.16      | 1.03^b  | 0.11        |                 |               |
|                  | 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        |                 |               |
|                  | Sankou Garkou| 2.22    | 0.24      | 5.26    | 1.48      | 3.44^ab | 0.68        |                 |               |
|                  | Sankou Souan| 2.03    | 0.20      | 3.73    | 0.65      | 3.37^abc | 0.54        |                 |               |
|                  | Kpakata      | 3.22    | 0.44      | 3.11    | 0.63      | 3.15^bddef| 0.42      |                 |               |
|                  | Keegbe       | 2.62    | 0.29      | 3.67    | 0.48      | 3.08^bddef| 0.28      |                 |               |
|                  | Sankou Kergba| 2.22   | 0.27      | 3.10    | 0.54      | 2.79^bddef| 0.37      |                 |               |
|                  | Tchoko-la-Vipere | 2.74  | 0.25      | 2.51    | 0.52      | 2.67^bddef| 0.23      |                 |               |
|                  | Sankounou    | 1.96    | 0.39      | 2.58    | 0.33      | 2.39^bddef| 0.26      |                 |               |
|                  | Afe          | 1.01    | 0.27      | 3.12    | 0.32      | 2.30^bddef| 0.33      |                 |               |
|                  | Louelougan   | 1.32    | 0.09      | 3.07    | 0.36      | 2.15^cde | 0.23        |                 |               |
|                  | Gobledo      | 1.42    | 0.20      | 2.24    | 0.28      | 2.04^de | 0.23        |                 |               |
|                  | Egni-Eri     | 1.14    | 0.21      | 2.37    | 0.32      | 1.93^de | 0.25        |                 |               |
|                  | APK Florido  | 1.55    | 0.10      | 2.94    | 0.74      | 1.92^de | 0.24        |                 |               |
|                  | Florido      | 1.58    | 0.05      | 2.88    | 0.42      | 1.83^de | 0.10        |                 |               |
|                  | Hounve       | 2.20    | 0.37      | 1.36    | 0.16      | 1.65^e  | 0.18        |                 |               |
|                  | Dangbeeko    | 1.16    | 0.20      | 1.78    | 0.25      | 1.63^e  | 0.20        |                 |               |
| **D. alata**     | 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**      |
| Early maturing |       | Variety × Year      | 15  | 7.78        | 4.54**       |
|         |              | Model               | 31  | 12.13       | 7.07**       |
|         |              | Error               | 403 | 1.71        |              |
| D. cayenensis – D. rotundata | Mean (kg/heap)=2.26 |                    |     |             |              |
|         |              |                     |     |             | R-square=0.35|
|         |              | Variety             | 10  | 5.94        | 4.27**       |
|         |              | Year                | 1   | 21.98       | 15.79**      |
| Late maturing |       | Variety × Year      | 10  | 5.21        | 3.74**       |
|         |              | 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**      |
| D. alata | Late maturing | Variety × Year      | 16  | 5.84        | 2.88**       |
|         |              | 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.

| Genotypic variability | Early | Early | Early | Late | Late | Late | Early | Early | Early | Late | Late | Late |
|-----------------------|-------|-------|-------|------|------|------|-------|-------|-------|------|------|------|
|                       | 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     | 5.15 | 1.06 | 2.03 | 2.77 |
| 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

| Genetic variance | Genotype-by-Year variance | 1.92 | 2.02 | 1.06 | 2.77 | 0.46 |
|------------------|---------------------------|------|------|------|------|------|
| Genetic variance | 1.29                      | 2.34 | 0.10 | 0.26 | 0.09 | 2.77 |
| Environmental (error) variance | 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 |
| Genetic Coef. Variation (GCV) (%) | 71.79 | 83.69 | 4.37 | 21.64 | 92.01 | 5.37 |

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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