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Table of Content

Characterisation of three morphotypes of Solenostemon rotundifolius [(Poir.) J. K. Morton] cultivated in Burkina Faso using quantitative traits
Romaric Kiswendsida NANEMA, Zakaria KIEBRE, Renan Ernest TRAORE, Aminata Hamidou BA and Francis KUSI

Primary morphological characterization of West African dwarf (Djallonké) ewes from Côte d’Ivoire based on qualitative and quantitative traits
N’Goran K. Edouard, Kouadja G. Severin, Kouassi N. Cyrille, Loukou N. Etienne, Eka Jean Yves, Dayo G. K. Charles, Sangare Mamadou and Yapi-Gnaore C. Valentine
Full Length Research Paper

Characterisation of three morphotypes of *Solenostemon rotundifolius* [(Poir.) J. K. Morton] cultivated in Burkina Faso using quantitative traits

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Evaluation of intra specific variability is a key step toward conservation and sustainable use of species. This study was carried out to describe the morphotypes of *Solenostemon rotundifolius* (Lamiaceae) based on quantitative traits. Three accessions (E02, E35 and E20), representing the morphotypes “A”, “B” and “C” were characterised in Randomised Complete Block Design with three replications. Twenty-four (24) traits related to the cycle, the canopy size, the production and the tuber size were measured. Analysis of variance (ANOVA) revealed significant difference of the morphotypes (at level P = 0.05 or 0.01) in the traits related to the canopy and leaf size, the crop cycle, the production and the tuber size. The morphotype “A” was identified to be the most promising one. It was early maturing (107 to 113 days) and the most productive (134.98 g per plant). The cycle of the morphotypes “B” and “C” varied from 154 to 164 days and 118 to 149 days and tuber weight per plant was 46.03 and 45.17 g, respectively. This work is a step toward a full description of the morphotypes of *S. rotundifolius*. It provided a useful list of quantitative traits that can be used as descriptors for future description of genetic resources of *S. rotundifolius* and for breeding purposes.

**Key words:** Breeding, genetic resources, Lamiaceae, tuber, variability.

INTRODUCTION

*Solenostemon rotundifolius* [(Poir.) J. K. Morton] or frafra potato is one of the most widespread Lamiaceae. It is cultivated as a tuber crop in many African countries including Burkina Faso, Ghana, Mali, Nigeria, Togo (in West Africa), Cameroon and Chad (in Central Africa) and some parts of South and East Africa (Schippers, 2000; Gouado et al., 2003; Sugri et al., 2013). The tubers contain significant amount of reducing sugars (25 mg), proteins (14.6 mg), phosphorus (36 mg), calcium (29 mg) and vitamins A and C (13.6 and 10.3 mg) (Anbuselvi and Balamurugan, 2013). They are consumed as a curry, baked or fried. Besides its nutritional attributes, *S. rotundifolius* holds strong economic potentials to the farmers (Enyiukwu et
al., 2014). A survey carried out in Ouagadougou (Burkina Faso) revealed that 16 to 32 g of tubers are sold per day/trader and the prices varied from 1.2 to 3 USD/kg (Nanéma et al., 2017). *S. rotundifolius* is also known to be one of the most adapted tuber crop of West Africa. It is suited for cultivation on marginal areas in the dry savannah regions with poor fertility soils (Aculey et al., 2011). The potential yield reported in West Africa ranged from 7 to 15 t/ha (Enyiukwu et al., 2014).

Because of its nutritional, economical and agronomical potentials, *S. rotundifolius* is one of the current minor crops that could play an important role in the improvement of food security in the context of climate change. However, conservation, breeding and sustainable use of genetic resources depend on knowledge of the extent and patterns of intra specific variation. Agromorphological characterisation is a key step of the description of plant genetic resources. Previous research activities focused on agromorphological variability within *S. rotundifolius* genetic resources and contributed to identify a set of traits that could be used as descriptors for this crop (Opoku-Agyeman et al., 2007; Nanéma et al., 2009). Based on tuber skin colour (black, reddish and white-yellow), three morphotypes called “A”, “B” and “C”, respectively, were identified in Burkina Faso (Nanéma, 2010). Therefore a comparative descriptive analysis of the morphotypes based on traits related to the cycle, the canopy size, the production and the tuber size were not yet reported. These characteristics of the morphotypes are key tools for further description and breeding purposes.

This study was carried out to describe the morphotypes of *S. rotundifolius* using quantitative traits related to the cycle, the canopy size, the production and the tuber size.

**MATERIALS AND METHODS**

**Study area and experimental design**

The study was carried out on the research farm of the Faculty of Earth and Life Sciences of the University Ouaga I Pr Joseph Ki-Zerbo in Ouagadougou (12°21′56″ N; 1°32′01″ W). A total rainfall of 665.1 mm was registered during the experiment (July 2016 to January 2017).

The experimental design was a Randomised Complete Block with three replications. The replication consisted in three rows of eight plastic buckets (diameter = 29.5 cm and depth = 19 cm) perforated at the bottom to improve drainage. Each bucket contained a mix of sand (1/3) and potting soil (2/3). One sprouted tuber was planted in each plastic bucket on 25 July 2016. The distance between the plants within the row of buckets was 40 cm and the rows of buckets were spaced at 50 cm. Plots were hand-weeded during the early growth stage. A supplementary irrigation (3 L/bucket every three days) was given after the rainy season (from October 2016 to January 2017). Mineral or organic fertilization was not applied.

**Plant material**

Plant materials used for the study consisted of three accessions selected in the gene bank of the University Ouaga I Pr Joseph Ki-Zerbo (Burkina Faso). These accessions were identified based on the tuber skin colour. The information at the gene bank indicate that the accession E02 (black tuber skin) was collected in the province of Passoré in the North of Burkina Faso whereas the accessions E35 (red tuber skin) and E20 (white-yellow tuber skin) were both collected in the province of Nahouri in the South of Burkina Faso (Table 1). The accessions E02, E35 and E20 represented the morphotypes “A”, “B” and “C”, respectively. For each accession, thirty (30) tubers were selected for the experiment.

**Quantitative traits**

Twenty-four (24) traits were measured to describe the morphotypes (Table 2). Nine of them were measured on leaves and stems at the end of the development stage (60 days after planting). These were: (1) plant height (PHe), (2) and (3) diameter and circumference of canopy (CDi and CCl), (4) central stem length (CSL), (5) number of internodes (NIn), (6) internodal length (ILe = CSL/NIn), (7) leaf width (LWi), (8) leaf length (LLe) and (9) leaf ratio (Lra = LWi/LLe). The circumference of the canopy was measured using a tape measure but for the other traits, a meter rule graduated in centimetres was used.

During the reproductive stage (60 to 100 days after planting), six traits related to crop cycle were measured. These were: (1) days to first spike initiation (DFS), (2) days to 50% spike initiation (DSI), (3) days to last spike initiation (LSI), (4) days to first maturity (DFM), (5) days to 50% maturity, and (6) days to last maturity (DLM). All the traits related to the cycle were evaluated from the planting date as the reference (day 0 after planting).

At maturity (100 to 170 days after planting), tubers from each plant were graded into three categories using two sieves of 16 and 26 mm diameter, respectively. These categories were: small (diameter d ≤ 16 mm); medium (16 < d ≤ 26 mm) and large tubers (d > 26 mm). Nine traits were measured: (1) total number of tubers (TNT), (2) number of small tubers (diameter d ≤ 16 mm) (NST), (3) number of medium tubers (16 < d ≤ 26 mm) (NMT), (4) number of large tubers (d > 26 mm) (NTL), (5) tubers weight per plant (TWP), (6) weight per tuber (Wt=TWP/TNT), (7) tuber length (TLe), (8) tuber diameter (TDi), and (9) percentage of small tubers (PST = 100 x weight of small tubers/TWP). The number of tubers was counted. The length and the diameter were measured on ten randomly selected tubers per category using a calliper ruler, then the mean value was estimated per plant. The tubers weight was evaluated using an electronic balance of 610 g maximum with a precision of 0.1 g.

**Statistical analysis**

Mean values of quantitative traits were calculated for each morphotype. Analysis of variance (ANOVA) was carried out using GENSTAT 10.1 and difference between means verified using the Student-Newman-Keuls test at the significant level P = 0.05. The Pearson correlation coefficients between morphometric parameters were calculated using XLSTAT 7.5.2 at the significant levels P = 0.05 and P = 0.01. A discriminant analysis was performed using a set of relevant and non-highly correlated traits to compare the morphotypes based on Mahalanobis distances. This analysis was carried out using GENSTAT 10.1.

**RESULTS**

**Description of the morphotypes based on traits related to canopy and leaf size**

The morphotypes significantly differed (at levels P = 0.05
Table 1. Accessions used for the characterisation of the morphotypes of *S. rotundifolius*.

| Accession number | Province of origin | GPS Coordinates       | Morphotypes | Tuber skin colour |
|------------------|-------------------|-----------------------|-------------|------------------|
| E02              | Passoré           | 12° 58' 00'' N        | A           | Black            |
|                  |                   | 2° 16' 00'' W         |             |                  |
| E35              | Nahouri           | 11° 15' N             | B           | Red              |
|                  |                   | 1° 15' W              |             |                  |
| E20              | Nahouri           | 11° 15' N             | C           | White-Yellow     |
|                  |                   | 1° 15' W              |             |                  |

A, B and C are morphotypes classification of *S. rotundifolius*. E02, E35 and E20 are accessions’ numbers.

Table 2. Traits used for describing the morphotypes of *S. rotundifolius*.

| Trait     | Meaning                              | Units          |
|-----------|--------------------------------------|----------------|
| PHe       | Plant height                         | cm             |
| CDi       | Canopy diameter                      | cm             |
| CCI       | Canopy circumference                 | cm             |
| CSL       | Central stem length                  | cm             |
| NIn       | Number of internodes                 | number/stem    |
| ILe       | Internodal length                    | cm             |
| LWi       | Leaf width                           | cm             |
| LLe       | Leaf length                          | cm             |
| LRa       | Leaf ratio                           |                |
| DFS       | Days to first spike initiation       | days after planting |
| DSI       | Days to 50% spike initiation         | days after planting |
| DLS       | Days to last spike initiation        | days after planting |
| DFM       | Days to first maturity               | days after planting |
| DMA       | Days to 50% maturity                 | days after planting |
| DLM       | Days to last maturity                | days after planting |
| TNT       | Total number of tubers               | number/plant   |
| NST       | Number of small tubers (d≤16 mm)     | number/plant   |
| NMT       | Number of medium tubers (16 < d ≤ 26 mm) | number/plant |
| NLT       | Number of large tubers (d > 26 mm)   | number/plant   |
| WeT       | Weight per tuber                     | g              |
| TLe       | Tuber length                         | mm             |
| TDi       | Tuber diameter                       | mm             |
| TWP       | Tubers weight per plant              | g              |
| PST       | Percentage of small tubers           | %              |

or 0.01) in the traits related to canopy and leaf size. These traits are canopy diameter (CDi), canopy circumference (CCI), leaf width (LWi) and leaf length (LLe) (Table 3). No significant difference was identified between the morphotypes for plant height (PHe), central stem length (CSL), number of internodes (NIn), internodal length (ILe) and leaf ratio (LRa).

Plant height (PHe) varied from 25.50 to 30.38 cm for morphotypes the “C” and “A”, while central stem length (CSL) ranged from 39.00 to 46.71 cm for the morphotypes “A” and “C”, respectively. The morphotypes developed 9 (morphotypes “A” and “B”) to 11 internodes (NIn) (morphotype “C”) measuring less than 5 cm (ILe). Leaf ratio ranged between 0.51 and 0.57 for the morphotypes “A” and “B”, respectively.

The morphotypes “A” and “B” developed large canopy. The diameter (CDi) and the circumference (CCI) of the canopy were 56.50 and 95.00 cm for the morphotype “A”
Table 3. Morphometric characteristics of the morphotypes of *S. rotundifolius* at development stage.

| Trait          | Accessions' number | F   | F pr | Significance of F |
|----------------|---------------------|-----|------|-------------------|
|                | E02 (A)             | E35 (B) | E20 (C) |       |
| PHe (cm)       | 30.38<sup>a</sup>   | 30.07<sup>a</sup> | 25.50<sup>a</sup> | 1.24 | 0.309 | NS       |
| CDi (cm)       | 56.50<sup>a</sup>   | 59.00<sup>a</sup> | 46.79<sup>b</sup> | 10.41 | <.001 | **       |
| CFi (cm)       | 95.00<sup>ab</sup>  | 100.43<sup>a</sup> | 78.86<sup>b</sup> | 4.69 | 0.021 | *        |
| CSL (cm)       | 39.00<sup>a</sup>   | 40.57<sup>a</sup> | 46.71<sup>b</sup> | 0.93 | 0.408 | NS       |
| NIn            | 9<sup>a</sup>       | 9<sup>a</sup>     | 11<sup>a</sup>     | 1.25 | 0.307 | NS       |
| ILe (cm)       | 4.27<sup>a</sup>    | 4.73<sup>a</sup>  | 4.14<sup>a</sup>  | 0.55 | 0.583 | NS       |
| LLe (cm)       | 9.58<sup>a</sup>    | 6.57<sup>b</sup>  | 5.14<sup>c</sup>  | 24.56 | <.001 | **       |
| LWi (cm)       | 4.74<sup>a</sup>    | 3.74<sup>b</sup>  | 2.74<sup>c</sup>  | 36.52 | <.001 | **       |
| LRa            | 0.51<sup>b</sup>    | 0.57<sup>b</sup>  | 0.54<sup>b</sup>  | 1.63 | 0.220 | NS       |

PHe: Plant height; CDi: canopy diameter; CFi: canopy circumference; CSL: central stem length; NIn: number of internodes; ILe: internodal length; LLe: leaf length; LRa: leaf ratio. The values followed by the same superscript in each row are not significantly different (*P* < 0.05) by Student-Newman-Keuls test. A, B and C: Morphotype names of *S. rotundifolius*. NS: No Significant at *P* < 0.05; *Difference significant at *P* < 0.05; **Difference significant at *P* < 0.01.

Table 4. Characteristics of the morphotypes for traits related to cycle.

| Trait          | Accessions' number | F   | F pr | Significance of F |
|----------------|---------------------|-----|------|-------------------|
|                | E02 (A)             | E35 (B) | E20 (C) |       |
| DFS (days)     | 61<sup>a</sup>      | 71<sup>b</sup> | 74<sup>a</sup> | 52.75 | <.001 | **       |
| DSI (days)     | 61<sup>c</sup>      | 75<sup>b</sup> | 84<sup>a</sup> | 86.96 | <.001 | **       |
| DLS (days)     | 66<sup>b</sup>      | 89<sup>a</sup> | 90<sup>a</sup> | 29.22 | <.001 | **       |
| DFM (days)     | 107<sup>c</sup>     | 154<sup>a</sup> | 118<sup>b</sup> | 175.83 | <.001 | **       |
| DMA (days)     | 108<sup>c</sup>     | 156<sup>a</sup> | 125<sup>b</sup> | 157.89 | <.001 | **       |
| DLM (days)     | 113<sup>c</sup>     | 164<sup>a</sup> | 149<sup>b</sup> | 90.10 | <.001 | **       |

DFS: Days to first spike initiation; DSI: days to 50% spike initiation; DLS: days to last spike initiation; DFM: days to first maturity; DMA: days to 50% maturity; DLM: days to last maturity. A, B and C: morphotype names of *S. rotundifolius*. The values followed by the same superscript in each row are not significantly different (*P* < 0.05) by Student-Newman-Keuls test. **Difference significant at *P* < 0.01.

and 59.00 and 100.43 cm for the morphotype “B”. The morphotype “C” showed the least developed canopy of 46.79 and 78.86 cm for the diameter and the circumference, respectively. Leaf length (LLe) was 9.58 cm for morphotype “A”, 6.57 cm for morphotype “B” and 5.14 cm for morphotype “C”. Leaf width (LWi) was 4.74 cm for morphotype “A”, 3.74 cm for morphotype “B” and 2.74 cm for morphotype “C”.

Description of the morphotypes based on traits related to cycle

After the development stage, mature plants of *S. rotundifolius* developed a terminal spike. Significant difference (at level *P* = 0.01) were observed between the morphotypes in traits related to the spike development (Table 4). The early spike initiation occurred 61 days after planting for the morphotype “A”. This morphotype is followed by the morphotypes “B” and C with 71 and 74 days to spike initiation after planting, respectively. The spike initiation was synchronised for morphotype “A”. It occurred within 7 days after the first spike initiation. Therefore, the last spike initiation occurred 18 days after the first spike initiation for morphotype “B” and 16 days for morphotype “C”.

The morphotypes also differed significantly in number of days to maturity. The early maturity occurred 107 days after planting (morphotype “A”). This morphotype was followed by morphotypes “C” and “B” with 118 and 154 days after planting, respectively.

Description of the morphotypes based on traits related to production and tuber size

The total number of tubers (TNT) varied from 36 to 50 per plant for the morphotypes “C” and “A”, respectively (Table 5). The number of small tubers (NST; diameter d≤16 mm) per plant varied from 35 (morphotype “C”) to 43 (morphotype “A”), representing the most important part of tubers. No significant difference between the was
observed for these traits.

Therefore, some medium (NMT) and large tubers (NLT) were obtained within tubers of the morphotype “A”. This morphotype is also the most productive (difference at level P = 0.01). The tubers weight per plant (TWP) was 134.98 g. The average diameter (TDi) of the tubers of this morphotype was 15.62 mm and the length was 33.48 mm (TLe). The average weight per tuber (WeT) was 2.69 g. The morphotypes “B” and “C” did not significantly differed in weight per tuber (1.08 to 1.25 g), tuber length (23.3 to 24.02 mm), and tubers weight per plant (46.03 to 45.17 g). The percentage of small tubers (PST) was very high for these morphotypes (more than 80%).

**Correlations between the evaluated traits of *S. rotundifolius***

There were significant correlations (at levels P = 0.05 or 0.01) among many of the evaluated traits. Positive correlation coefficients between the traits related to canopy and leaf size varied from 0.45 (between canopy size: CDi and CCi) to 0.89 (between leaf size: LLe and LWi). Negative correlation coefficients ranged between -0.59 (leaf length and leaf ratio: LLLe and LRa) and -0.52 (between internodal length and number of internodes: ILe and Nin). The correlation coefficient between the dates to spike initiation and the dates to maturity varied from 0.43 to 0.69 (Table 6). All the traits that showed positive correlations were related to plant cycle (spike initiation and maturity). These correlations were observed between the days to spike initiation (DSI) and the days to maturity (DLM) and between the days to first spike initiation (DFS) and the days to last maturity (DLM).

The highest positive correlation coefficient (r = 0.99) among the traits evaluated was observed between the number of small tubers (NST) and the total number of tubers per plant (TNT). On the other hand, the lowest positive correlation coefficient among the traits related to tubers size and productivity was observed between the number of medium tubers (NMT) and the number of large tubers (NLT) (r = 0.46). The negative correlation coefficients varied from -0.88 (between the number of medium tubers and the percentage of small tubers: NMT and PST) to -0.55 (between the number of large tubers and the percentage of small tubers: NLT and PST).

Some significant correlation coefficients (at levels P = 0.05 or 0.01) were also observed across different categories of traits. The highest positive correlation coefficient between the traits related to the canopy and those related to the plant cycle was observed between the date of spike initiation (DSI) and the central stem length (CSL) (r = 0.43). The most important negative correlation coefficient was observed between the leaf width (LWi) and the days to spike initiation (DSI) (r = -0.83). The correlation coefficient between the leaves to last maturity (DLM) and the percentage of small tubers (PST) was the highest positive correlation (r = 0.85) and these traits related to plant cycle and production, respectively. The most important negative correlation coefficient was observed between the days to last maturity (DLM) and the tuber length (TLe) (r = -0.79). The correlation coefficient between the leaf length (LLe) and the tubers weight per plant (TWP) (r = 0.65) was the highest positive correlation between the traits related to the vegetative development and production. The highest negative correlation coefficient was observed between the number of internodes (Nin) and the number of small tubers (NST) (r = -0.52).

**Discriminant analysis of the morphotypes**

The discriminant analysis of the morphotypes was
realised based on nine traits. Three of these traits were related to the canopy development: leaf length (LLe), plant height (PHe) and canopy diameter (CDi). Four traits were related to the tuber size: length (TLe) and width (TWi) and production: number of tubers (TNT) and tubers weight per plant (TWP). Two traits were related to plant cycle: days to spike initiation (DSI) and days to maturity (DMa).

The score 1 of the discriminant analysis was positively correlated to plant cycle (DMa and DSI) and negatively to tuber length (TLe) and tubers weight per plant (TWP) (Table 7). It determined the axis of production (late maturing and low yield). The score 2 was positively correlated to days to maturity (DMa), and negatively to days to spike initiation (DSI). It was positively correlated to canopy diameter (CDi) and leaf length (LLe). This score determined the axis of large canopy development and early maturing.

The discriminant analysis revealed significant

| Trait | DFS | DSI | DLE | CDi | CCI | PHe | CSL | NIn | LLe | LWi | LRa | DFM | DMa | DLM | NST | NMT | NLT | TNT | TWP | WeT | PST | TLe |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| DSI   | 0.89* |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| DLS   | 0.93* | 0.85* |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| CDi   |       | -0.28 | -0.34 | -0.08 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| CCI   |       | -0.22 | -0.27 | -0.13 | 0.45 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| PHe   |       |       | -0.18 | -0.26 | -0.05 | -0.21 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| CSL   |       | 0.34  | 0.43  | 0.4  | -0.03 | -0.1 | -0.2 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| NIn   |       | 0.25  | 0.26  | 0.22 | 0.05 | -0.21 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| LLe   |       | 0.12  | 0.15  | 0.25 | 0.12 | -0.05 | 0.02 | -0.52* |     |     |     |     |     |     |     |     |     |     |     |     |     |
| LWi   |       | 0.72* | -0.65* | 0.62* | 0.4  | 0.19 | 0.48 | 0.17 | -0.14 | -0.14 | 0.9* |     |     |     |     |     |     |     |     |     |     |
| LRa   |       | 0.25  | 0.2  | 0.24 | 0.21 | 0.05 | 0.15 | 0.04 | -0.01 | 0.11 | -0.59* | -0.19 |     |     |     |     |     |     |     |     |     |
| DFM   |       | 0.4  | 0.39  | 0.56* | 0.37 | 0.4  | -0.1 | 0.04 | -0.12 | 0.26 | -0.39 | -0.31 | 0.28 |     |     |     |     |     |     |     |     |
| DMa   |       | 0.5  | 0.43  | 0.62* | 0.32 | 0.37 | -0.18 | 0.05 | -0.09 | 0.22 | -0.45 | -0.37 | 0.31 | 0.97* |     |     |     |     |     |     |     |     |
| DLM   |       | 0.69* | 0.65* | 0.68* | 0.02 | 0.21 | -0.21 | -0.02 | -0.09 | 0.16 | -0.68* | -0.65* | 0.31 | 0.85* | 0.90* |     |     |     |     |     |     |     |
| NST   |       | -0.11 | -0.15 | -0.03 | 0.17 | -0.14 | 0.23 | -0.28 | -0.52* | 0.55* | 0.19 | 0.15 | -0.16 | -0.06 | 0.1 | -0.11 |     |     |     |     |     |     |
| NMT   |       | -0.65* | -0.67* | -0.67* | 0.2 | -0.15 | 0.13 | -0.24 | -0.11 | 0.21 | 0.54* | 0.58* | -0.15 | -0.68* | -0.69* | 0.77* | 0.17 |     |     |     |     |     |
| NLT   |       | -0.29 | -0.26 | -0.23 | 0.25 | -0.04 | 0.02 | -0.09 | 0.16 | -0.36 | 0.3 | 0.15 | 0.26 | -0.21 | -0.22 | -0.31 | -0.1 | 0.46 |     |     |     |     |
| TNT   |       | -0.21 | -0.25 | -0.14 | 0.2 | -0.16 | 0.25 | -0.31 | -0.51 | 0.49 | 0.27 | 0.24 | -0.17 | -0.17 | -0.21 | -0.23 | 0.99* | 0.33 | -0.01 |     |     |
| TWP   |       | -0.68* | -0.69* | -0.63* | 0.24 | -0.12 | 0.26 | -0.35 | -0.34 | 0.07 | 0.65* | 0.63* | -0.27 | -0.60* | -0.65* | -0.76* | 0.54* | 0.87* | 0.32 | 0.66* |     |
| WeT   |       | -0.69* | -0.66* | -0.67* | 0.24 | -0.07 | 0.2 | -0.2 | -0.04 | -0.23 | 0.62* | 0.63* | -0.21 | -0.65* | -0.7* | -0.83* | 0 | 0.86* | 0.50 | 0.15 | 0.81* |     |
| PST   |       | 0.50 | 0.49 | 0.54* | 0 | 0.28 | -0.09 | -0.04 | -0.18 | 0.28 | -0.50 | -0.49 | 0.22 | 0.78* | 0.80* | 0.85* | -0.04 | -0.88* | -0.50 | -0.19 | -0.73* | -0.84* |
| TLe   |       | -0.76* | -0.69* | -0.74* | 0.07 | -0.05 | 0.15 | -0.29 | -0.18 | -0.13 | 0.64* | 0.57* | -0.32 | -0.62* | -0.7* | -0.79* | 0.13 | 0.74* | 0.26 | 0.25 | 0.80* | 0.85* | -0.71* |     |
| TDi   |       | -0.34 | -0.27 | -0.4 | 0 | -0.24 | 0.04 | -0.13 | 0.05 | 0.24 | 0.28 | 0.24 | -0.2 | -0.68* | -0.7* | -0.68* | -0.05 | 0.70* | 0.50 | 0.07 | 0.59* | 0.81* | -0.83* | 0.66* |
The morphotypes were less different with intergroup distance of 76.18. The overall characteristics of the morphotype “A” was the early maturing and high production compared to the morphotypes “B” and “C” (Figure 1). The morphotypes “B” and “C” were relatively late maturing and low production. However, the morphotype “B” differed from the morphotype “C” for its large canopy development.

**DISCUSSION**

Morphometric variability of three morphotypes of *S. rotundifolius* was described based on twenty-four (24) traits related to canopy development, crop cycle, tuber size and production. In previous research, some traits such as plant height, length of branches, size of leaves, internodal distance, number of tubers, tubers weight, tuber length and tuber diameter were used in a comparative analysis of varieties of *Plectranthus esculentus* and *S. rotundifolius* and revealed significant interspecific variability (Agyeno et al., 2014). The tuber size and weight were also used for germplasm evaluation of *S. rotundifolius* (Opoku-Agyeman et al., 2007).

During the vegetative stage, significant variation (at levels P = 0.05 and 0.01) between the morphotypes was observed for traits related to canopy and leaf size. The largest canopy development was observed for morphotype “B” followed by the morphotypes “A” and “C”, respectively. Agyeno et al. (2014) also observed difference in canopy size between two varieties of *S. rotundifolius*. The canopy of variety with white tuber skin colour (“alba”) was less developed than landrace with dark brown tuber skin colour (“nigra”). The canopy size is also used by farmers as a landrace characteristic in Burkina Faso (Ouedraogo et al., 2007). According to farmers classification, the landraces with large canopy are female and called “pess yanga” in a local language (mooré) and those with small canopy size are male and called “pess raaga” or “pess raogo”.

The traits measured on the stems did not reveal significant variability. Agyeno et al. (2014) observed most important variation of plant height (19.52 to 66.48 cm). However, the reported values for length of branches (28.87 to 30.91 cm) and the internode distance (2.90 to 3.04 cm) were less than the present results. The number of internodes and the leaf ratio were quite similar for all the morphotypes. These categories of traits can be considered as characteristic of the species.

The plant cycle is one of the key parameters for genetic resources management in farming conditions. The morphotypes significantly varied for cycle. The morphotype “A” is early maturing (107 to 113 days), the morphotype “C” is medium (118 to 149 days) and the

| Trait       | Scores[1] | Scores[2] |
|-------------|-----------|-----------|
| LLe         | -0.2235   | 0.2506    |
| PHe         | -0.0343   | 0.0798    |
| CDi         | 0.0061    | 0.2766    |
| TLe         | -0.2764   | 0.0735    |
| TWi         | -0.1565   | -0.0917   |
| TNT         | -0.0512   | 0.0276    |
| TWP         | -0.253    | 0.0903    |
| DSI         | 0.4091    | -0.4949   |
| DMa         | 0.6468    | 0.4177    |

LLe: Leaf length, PHe: plant height, CDi: canopy diameter, TLe: tuber length, TWi: tuber width, TNT: total number of tubers, TWP: tubers weight plant, DSI: days to spike initiation, DMa: days to maturity.

Table 7. Correlations between the quantitative traits of *S. rotundifolius* and discriminant functions.

Table 8. Intergroup distances-Mahalanobis (D-squared).

| Morphotype | Accession | A     | B     | C     |
|------------|-----------|-------|-------|-------|
| A          | E02       | 0     |       |       |
| B          | E35       | 148.28| 0     |       |
| C          | E20       | 115.04| 76.18 | 0     |
| Accessions |           | E02   | E35   | E20   |

Table 8. Intergroup distances-Mahalanobis (D-squared).
Nanema et al.

Figure 1. Discriminant analysis of the morphotypes of *S. rotundifolius*. A, B and C are morphotypes of *S. rotundifolius*. E02, E35 and E20 are accessions' numbers.

The morphotype “B” is late maturing (154 to 164 days). These results gave additional clarification on the cycle of *S. rotundifolius*. The cycle variation reported by other authors, 150 to 180 days by NRI (1987) and 120 to 150 days by Ouédraogo et al. (2007), is lower than the results of this study.

According to Guillaumet and Cornet (1976) and Abraham and Radhakrishnan (2005), *S. rotundifolius* is a photosensitive species. However, the impact of this characteristic on the cycle and the production of the morphotypes was not yet reported. The strategy developed by farmers to face this problem is the early planting of *S. rotundifolius* (Nanéma, 2010). Such strategy was also applied by farmers in Ghana (Sugri et al., 2013). Nevertheless, the long cycle of *S. rotundifolius* is critical for on-farm conservation of its genetic resources in a context of climate change.

Comparatively to the common tuber crop such as yam, sweet potato or potato, *S. rotundifolius* produced numerous of small tubers. The morphotype “A” was identified to be the most productive. The number of tubers could go up to 50 and the total tubers weight was 134.98 g per plant. The potential number of tubers per plant could go higher than this if they were planted on ridges because in buckets, the plants were limited in proportion of the stems or plant parts that can get into the contact with the soil. Agyeno et al. (2014) reported most important potential of production in Nigeria. The number of tubers of local varieties was up to 88 per plant and the tubers weight for variety “nigra” and “variety “alba” was 866.67 and 533.33 g, respectively. The tuber size of these varieties was also most important than the evaluated accessions. The tuber length varied from 6.83 to 8.23 cm. In Ghana, the tubers weight per plant can reach 480 g (Opoku-Agyeman et al., 2007).

The good agronomic potentialities of the landraces of *S. rotundifolius* from Nigeria and Ghana could be explained by the genetic potentialities of the local accessions and good growing conditions. These factors were reported by many authors to have significant effects on tubers size and yield of potato (Kawakami et al., 2005; Bombik et al., 2013; Sanli et al., 2015; Mangani et al., 2016; Bijeta et al., 2017; Dash et al., 2018), sweet potato (Esan and Omilani, 2018) and cassava (Agbaje and Akinlosotu, 2004). However, the potential of the morphotypes was close to the general potential of *S. rotundifolius* in Africa. According to Kwarteng et al. (2017), most tubers found in Africa are 2.5 - 4 cm × 1 -
The small tuber size was identified to be one of the main marketing constraints for *S. rotundifolius*. In Burkina Faso, the minimum expected length of tubers that could be easily accepted by consumers varied from 5 to 9 cm while the diameter ranged from 3 to 5 cm (Nanéma et al., 2017). The morphotype “A” was preferred by consumers because of the bigger size of its tubers and the good taste. Future breeding activities and development of innovative agronomic techniques on *S. rotundifolius* could be focused on this morphotype. Sharing the genetic resources of *S. rotundifolius* should be a significant contribution to increase genetic diversity of frafra potato for sustainable breeding programs of this crop.

The correlations between the traits gave useful information for breeding activities on *S. rotundifolius*. The highest correlation observed between the number of tubers and the number of small tubers per plant clearly revealed that increasing the number of tubers will significantly contribute to increase the percentage of small tubers (non-marketable tubers). A balance should be found between the number of tubers and the optimal tuber size through improved agronomic practices and breeding effort.

**Conclusion**

This study successfully described morphometric variability between three morphotypes (“A”, “B” and “C”) of *S. rotundifolius* identified on the basis of tuber skin colour. The most significant differences were related to canopy and leaf size, crop cycle, production and tuber size. All the evaluated quantitative traits can be used as descriptors for future description of genetic resources of *S. rotundifolius*.

The three morphotypes were identified to be different groups of landraces. The morphotype “A” was found to be early maturing and the most productive landrace. Accessions of this morphotype could be very interesting material for the development of early varieties with high yielding and large tubers.

**CONFLICT OF INTERESTS**

The authors have not declared any conflict of interests.

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Full Length Research Paper

Primary morphological characterization of West African dwarf (Djallonké) ewes from Côte d’Ivoire based on qualitative and quantitative traits

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Phenotypic characterization is used to identify and document diversity within and between distinct breeds, based on their observable attributes. Study to assess the body characteristics and variability of 204 Djallonké (West African dwarf) ewes was conducted in three agro-ecological zones (central, western and northern) of Côte d’Ivoire, from November 2016 to April 2017. Animals were described using visual appreciation of the body hair coat (colour type and pattern), hair length, ear orientation, tail type and the facial (head) profile. The linear body measurements, such as ear and tail length, muzzle length and width, height at wither, chest depth, and chest girth were also described. The data collected were subjected to principal component (PCA) and discriminant analysis. Results showed that the most common Djallonké ewes had erected ear (87.25%), thin tail and straight face. The dominant colour pattern of the body hair coat was patchy (64.22%) followed by plain (32.84%) and spotted (2.94%). The agro-ecological zone had a significant (p˂0.01) effect on some linear body measurements (muzzle length, ear length and height wither). Based on PCA performed with all the above morphological variabilities, we were able to segregate the Djallonké ewes’ into three clusters (I, II and III). Discriminant analysis revealed that 76.27% sheep of cluster I, 92.80% sheep of cluster II and 90% sheep of cluster III were correctly classified in their original cluster. This result indicated that Ivorian Djallonké sheep population comprises of three well characterized morphological types of animals. This information could constitute a basis for further characterization and development of conservation strategies for Djallonké sheep breeding in Côte d’Ivoire.

Key words: Local, sheep, breed, morphological, variability, West Africa.

INTRODUCTION

West African sub region has a large variety of Animal Genetic Resources (AnGR) that provides food, fibre, transport, fuel, manure and draught power to people. They are important in terms of economic, food, social, religious and cultural values (Boutrais et al., 2014; FAO, 2015; Hounet et al., 2016). However, most West African countries like Côte d’Ivoire are yet to attain self-sufficiency in animal protein production. Therefore, there
is a need to increase animal production as the demand for animal protein is increased in Sub-Saharan Africa (SSA), especially in West Africa. (Pangui and Kabore, 2013).

Djallonké sheep are one of the local breeds of West Africa that play a major role in the maintenance of rural populations living and of major cultural importance due to their traditional use in rites and celebrations (OCDE/CEDEAO, 2008). The Djallonké sheep genetic resources in West Africa possess important adaptive traits which make them to cope with harsh agro-pastoral production systems such as lack of quality fodder and disease mainly Trypanosomiasis and ticks (Ammar, 2013; Touré et al., 2014; Acapovi-Yao et al., 2016; Biguezoton, 2017; Diaha-Kouamé et al., 2018). However, the genetic diversity exists between and within breeds which can provide the raw materials for breed improvements and for the adaptation of the populations to changing environments and changing demands (FAO, 2015).

In Côte d’Ivoire, Djallonké sheep have been the subject of genetic improvement studies and zootechnical parameters analysis (SODEPRA, CNO and PNSO) (MIRAH-DPE, 2013). Due to their small body size, they are used in crossbreeding particularly with the Sahelian sheep in different breeding systems (Yapi-Gnaoré, 1992). However, the introgression of different genes into Djallonké could lead to a serious threat to this AnGR and lead to the loss of some of their adaptive traits. Thus, finding Côte d’Ivoire Djallonké sheep’s genetic characteristics would be a huge challenge that we will have to face to set up the genetic improvement of this Ivoirian sheep breed.

According to FAO (2013), the development of conservation and production programs requires the implementation of the management strategies and more information about animal genetic resources. The present study aimed to describe the physical and morphological characteristics of the Djallonké sheep breed from three agroecological zones of Côte d’Ivoire.

MATERIALS AND METHODS

Area selected for the study

The study was conducted in seven administrative localities including three in the northern region (Korhogo, Boundiali and Odienne), two in the central region (Bouaké and Toumodi) and two in the western region (Touba and Sipilou) of Côte d’Ivoire (Figure 1).

The northern region is characterized by grassy and wooded savannah vegetation. It is located at 9°30’ North latitude and 5°30’ West longitude). This region has a Sudanese climate, with an annual average warm temperature from 20 to 35°C and a high rainfall of 1500 to 1600 mm. The climate of Sudanese region is divided into two seasons, the rainy from June to October and dry season from November to May (Touré, 1997; MIRAH-DPE, 2013). The Central region is located at 7°41’37” North and 5°16’36” West longitude. The annual mean temperature and rain fall range from 14 to 39°C and 1200 to 1600 mm, respectively. This central region has a tropical climate with four seasons; a long dry season from December to May and a short dry season from July to October as well as a long rainy season from May to July and a short rainy season from October to November (Eroarome, 2009). The central region is covered by a pre-forest savannah with trees grouped into small forest Island and with galleries of forest in the lowlands.

The Northwest Region is located at 7°55’0” North latitude and 8°4’60” West longitude. It has a Sudan Guinean climate characterized by an annual average temperature and rain fall that range from 20 to 26°C and 1127 to 2400 mm, respectively. This climate has two vegetation including a dense forest and transitional vegetation between forest and savannah, with two seasons; a long wet season from April to October and a dry season from November to March (Viennot, 1983; Eroarome, 2009).

Farm sampling and data collection

Farm sampling

The selected farms were chosen based on an investigative survey on the five (5) important livestock regions (North, Central, West, East and South) of Côte d’Ivoire and discussions with local livestock extension officers and researchers. The discussions aimed to identify the regions where pure Djallonké breed can be found. Based on the outcome, three important regions were selected: the northwest region which is one of the major sheep breeding regions in Côte d’Ivoire, the Central region, where Djallonké sheep breeding has been developed through different national livestock project such as SODEPRA, CNO and PNSO, and the North region which accounts for more than 75% Ivoirian livestock farming (MIRAH-DPE, 2013; Eroarome, 2009). Since the objective of the study was to describe the pure Djallonké sheep breed, 19 farms dealing with pure Djallonké sheep breed and using no others sheep breed in their reproduction system were purposely selected. In these farms, the flock size ranged from 25 to 70 animals which were either raised on fenced natural pastures where they grazed day and night or herded by day and kept in pens at night. The animals had access to mineral salt licks and were dipped or sprayed 2 to 4 times a month.

Data collection

From November 2016 to April 2017 data on qualitative and quantitative morphological traits of 204 Djallonké ewes were collected on 19 traditional farms. For the purpose of even comparison, only animals within the age range of 2 to 6 years were considered. In each farm, the morphological measurements taken on each animal were those advocated by FAO for breed characterization according to the DAD-IS programs (FAO, 2013).

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The qualitative characters such as colour type and colour pattern of the body hair coat, hair length, ear orientation, tail type and facial (head) profile were recorded based on subjective visual observation. The quantitative morphometrical characters were obtained by measuring the animals with a tape calibrated in centimetres (cm) after restraining and holding them in an unforced position. All measurements were taken by the same team on all farms. The linear body measurements taken were muzzle length (CC), muzzle width (AC), tail length (LQ), ear length (LO), height at wither (HG), chest depth (PT), chest girth (Pt), and body length (LC). The age of the animals was estimated by dentition method suggested by Charray et al. (1992).

**Statistical analysis**

Descriptive statistics were used to analyse the phenotypic characterization data. Discrete measurement on the form and appearance of the investigated animals was analysed using the frequency procedure of $\chi^2$ test (chi-square test) at 95 % confidence level. Quantitative linear body measurements were analysed using the generalized linear model procedures. Agro-ecological zones were fitted as fixed independent variables, whereas linear body measurements were fitted as dependent variables. Thus, agro-ecological effects on body measurements were assessed using ANOVA. Means were separated using Duncan's multiple range test procedure and values were considered significant at p<0.05. To determine the major quantitative variables in the morphological variability and the Pearson’s coefficients of correlation ($r$) between them, principal component factor analysis (PCA) was used. The obtained result was then used to perform the Hierarchical cluster analysis which would allow the construction of the dendrogram and the determination of the Euclidean distances between populations derived from linear body measurement. The different identified cluster sheep were subjected to the discriminant analysis in order to evaluate their differentiation. All analyses were done using XLSTAT 2015.4.01 (Addinsoft, 2015), SPSS (2011) and STATISTICA 7.1. (StatSoft, 2005)

**RESULTS**

**Phenotypic characterization**

**Qualitative characters**

The results of the qualitative characters of all female
The colour pattern of the sheep’s body hair coat observed in the three agroecological zones was plain (37%), patchy (60%) and spotted (3.94%) (Figure 2). The tail type and facial (head) profile of Djallonké sheep in the three agro-ecological zones were thin and straight, respectively. The colour type of the body hair coat of Djallonké ewes breed was black and white for 55%, white for 24%, white and fawn for 18%, fawn and black for 8%. Most of Djallonké sheep had erected ear (87%) versus semi-pendulous (13%). Medium hair length was observed for 53% of the sheep. Long and short hairs were noticed, respectively for 30 and 17% of the sheep population.

### Morphometrical characterization

Means for body measurements are presented in Table 2. The overall average of CC, AC, LQ, LO, HG, PT, Pt and LC of sampled Djallonké ewes was 14.03, 8.05, 24.66, 10.38, 59.56, 33.3, 70.80 and 57.77 cm, respectively.

**Table 1.** Percentage values for some morphological qualitative traits observed in Djallonké ewes breed of three agro-ecological zones.

| Discrete variable                  | Trait                     | Zone 1 (n = 70) | Zone 2 (n = 75) | Zone 3 (n = 59) | TOTAL (n = 204) |
|-----------------------------------|---------------------------|-----------------|-----------------|-----------------|----------------|
|                                   |                           | N   | %                  | N   | %                  | N   | %                  | N   | %                  | x²   | p     | N   | %                  | x²   | p     |
| Colour pattern of the body hair coat | Plain                   | 9   | 13     | 66.46 | <0.001        | 42  | 56     | 1.08  | 0.29            | 24  | 41     | 1.37 | 0.24            | 75  | 37     | 100.4 | <0.001  |
|                                   | Patchy                   | 55  | 78     | 13.46 | <0.001        | 33  | 44     | 1.08  | 0.29            | 35  | 59     | 1.37 | 0.24            | 123 | 60     | -     | -      |
|                                   | Spotted                  | 6   | 9      | 0.57  | <0.001        | 0   | 0      | 0.03  | 0.03            | 0   | 0      | 0.03 | 0.03            | 6   | 3      | -     | -      |
| Colour type of the body hair coat | White                    | 15  | 21     | 35.43 | <0.001        | 26  | 35     | 42.6  | <0.001        | 7   | 12     | 72.73 | <0.001        | 48  | 24     | 186   | <0.001  |
|                                   | Black                    | 8   | 12     | 21.59 | 0.083         | 2   | 3      | 72.73 | <0.001        | 6   | 10     | 100.4  | <0.001        | 16  | 8      | -     | -      |
|                                   | Fawn                     | 8   | 11     | 7.32  | 0.083         | 0   | 0      | 0.03  | 0.03            | 3   | 5      | 14.03 | 0.001         | 11  | 8      | -     | -      |
|                                   | Black + white            | 32  | 46     | 57.77 | <0.001        | 38  | 63     | 57.77 | <0.001        | 43  | 73     | 15.44 | <0.001        | 113 | 55     | -     | -      |
|                                   | White + fawn             | 7   | 10     | 3.94  | 0.083         | 9   | 12     | 3.94  | 0.083          | 0   | 0      | 0.03  | 0.03            | 16  | 18     | -     | -      |
| Hair length                       | Short                    | 22  | 31     | 3.94  | 0.083         | 6   | 8      | 34.16 | <0.001        | 6   | 10     | 21.59 | <0.001        | 32  | 17     | 41.06 | <0.001  |
|                                   | Medium                   | 27  | 39     | 60.85 | 0.083         | 47  | 63     | 57.77 | <0.001        | 35  | 60     | 15.44 | <0.001        | 109 | 53     | -     | -      |
|                                   | Long                     | 21  | 30     | 3.94  | 0.083         | 22  | 30     | 3.94  | 0.083          | 18  | 30     | 18.6  | 0.083         | 61  | 30     | -     | -      |
| Ear orientation                   | Semi-pendulous           | 0   | 0      | 0.03  | 0.03          | 26  | 35     | 7.32  | 0.083          | 0   | 0      | 0.03  | 0.03            | 26  | 13     | 113.3 | <0.001  |
|                                   | Erected                  | 70  | 100    | 0.03  | 0.03          | 49  | 65     | 3.94  | 0.083          | 59  | 100    | 15.44 | <0.001        | 179 | 87     | -     | -      |
| Tail type                         | Thin                     | 70  | 100    | 0.03  | 0.03          | 75  | 100    | 0.03  | 0.03            | 59  | 100    | 15.44 | <0.001        | 204 | 100    | -     | -      |
| Facial (head) profile             | Straight                 | 70  | 100    | 0.03  | 0.03          | 75  | 100    | 0.03  | 0.03            | 59  | 100    | 15.44 | <0.001        | 204 | 100    | -     | -      |

Zone 1 = northwest region of Côte d’Ivoire, Zone 2 = central region of Côte d’Ivoire, Zone 3 = north region of Côte d’Ivoire.

Djallonké sheep raised in the three agro-ecological zones (west, central and north regions of Côte d’Ivoire) are presented in Table 1. The colour pattern of the sheep’s body hair coat observed in the three agroecological zones was plain (37%), patchy (60%) and spotted (3.94%) (Figure 2). In the last one (zone 3), this coefficient of variation was found between 6.57% (HG) and 15.79% (AC). In the agro-ecological zone 1, the coefficient of variation of the different measurements was observed bet 7.69% (Pt); in the agro-ecological zone 2 this coefficient of variation varied from 7.32% (HG) to 15.44% (LQ). The data showed that the agro-ecological zone significantly affected (p<0.01) the CC, LO and HG of the sheep but had no effect on AC, LQ, PT, Pt and LC characters. These underlined certain heterogeneity among the Djallonké sheep raised in the three agro-ecological zones.
Multivariate analysis

Correlation between body measurements

Pearson’s correlation coefficients between all pairs of the various body traits of Djallonké sheep according to PCA are shown in Table 3.

One can see that the significant correlations between the linear body measurements are positive. In addition some values are found to be higher than 0.3. Indeed, a positive correlation was observed between HG, PT, Pt and LC. The LC character correlated with four other linear body measurements such as CC, AC, LQ and LO. The PT and Pt correlated with CC and AC, while HG correlated with CC and LQ. A significant correlation was also noticed between CC and AC.

Morphological variability

Results of the factor and communality of the body measurements of Djallonké sheep breed are reported in
Table 2. Average values (cm) of quantitative morphometrical traits of Djallonké ewes (means ± SD; N = 204).

| Trait          | Zone 1 (n = 70) | Zone 2 (n = 75) | Zone 3 (n = 59) | Overall means 204 | Fisher test | SIG |
|----------------|-----------------|-----------------|-----------------|-------------------|-------------|-----|
|                | M ±SD           | CV (%)          | M ±SD           | CV (%)            |             |     |
| CC             | 13.7 ± 1.1      | 12.2            | 14.6 ± 1.7      | 11.7              | 13.8 ± 1.5  | 10.9 | 14 ± 1.7 | 7.057 | ** |
| AC             | 8 ± 1           | 11.9            | 8.1 ± 1         | 12.5              | 8.1 ± 1.3   | 15.8 | 8.1 ± 1  | 0.31 | NS |
| LQ             | 24.3 ± 3.4      | 14              | 24.5 ± 3.8      | 15.5              | 25.3 ± 2.9  | 11.4 | 24.7 ± 3.4 | 1.305 | NS |
| LO             | 10.8 ± 1.8      | 16.7            | 10.1 ± 1.1      | 10.9              | 10.2 ± 1.1  | 10.9 | 10.4 ± 1.4 | 4.57 | ** |
| HG             | 56.1 ± 5.6      | 9.9             | 60.9 ± 4.5      | 7.3               | 62.0 ± 4.1  | 6.6  | 59.6 ± 5.4 | 28.54 | *** |
| PT             | 33.3 ± 2.7      | 8.2             | 33.8 ± 3.5      | 10.2              | 32.6 ± 2.6  | 7.9  | 33.3 ± 3.3 | 2.397 | NS |
| Pt             | 70.8 ± 5.5      | 7.7             | 70.4 ± 8.3      | 11.8              | 71.3 ± 5.1  | 7.1  | 70.8 ± 6.5 | 0.314 | NS |
| LC             | 57.8 ± 6.2      | 10.7            | 57.5 ± 5.6      | 9.7               | 58.1 ± 4.1  | 7.1  | 57.8 ± 5.4 | 0.166 | NS |

**Highly significant (p<0.01); *significant (p<0.05); **p<0.01; ***p<0.001.**

Table 3. Pearson’s correlations among measurements of ewes Djallonké breed populations.

|          | CC     | AC     | LQ     | LO     | HG     | PT     | Pt     | LC     |
|----------|--------|--------|--------|--------|--------|--------|--------|--------|
| CC       | 1      | -      | -      | -      | -      | -      | -      | -      |
| AC       | 0.2*   | 1      | -      | -      | -      | -      | -      | -      |
| LQ       | 0.13   | 0.18   | 1      | -      | -      | -      | -      | -      |
| LO       | 0.02   | 0.03   | 0.35** | 1      | -      | -      | -      | -      |
| HG       | 0.44** | 0.18   | 0.37** | 0.06   | 1      | -      | -      | -      |
| PT       | 0.39** | 0.41** | 0.12   | 0.03   | 0.25** | 1      | -      | -      |
| Pt       | 0.39** | 0.41** | 0.14   | 0      | 0.22*  | 0.76** | 1      | -      |
| LC       | 0.39** | 0.23** | 0.29** | 0.29** | 0.24** | 0.52** | 0.46** | 1      |

**Highly significant (p<0.01); *significant (p<0.05), **p<0.01; ***p<0.001.**

Table 4. Eigenvalues and percent of total variance along with factor loadings and communalities of the body measurements of three Djallonké ewes breed populations.

| Variable | F1     | F2     | F3     | Communality |
|----------|--------|--------|--------|-------------|
| CC       | -0.643 | -0.069 | -0.466 | 0.550       |
| AC       | -0.555 | -0.188 | 0.200  | 0.603       |
| LQ       | -0.433 | 0.679  | -0.050 | 0.633       |
| LO       | -0.221 | 0.731  | 0.437  | 0.505       |
| HG       | -0.542 | 0.268  | -0.664 | 0.620       |
| PT       | 0.804  | -0.341 | 0.200  | 0.617       |
| Pt       | -0.785 | -0.367 | 0.186  | 0.647       |
| LC       | -0.727 | 0.151  | 0.230  | 0.735       |
| Eigenvalue | 3.04   | 1.38   | 1.02   | -           |
| Explained variance (%) | 38.03 | 17.26 | 12.02 | -           |
| Cumulative variance (%) | 38.03 | 55.3  | 68.04  | -           |

**Highly significant (p<0.01); *significant (p<0.05), CC : Muzzle length, AC: Muzzle width, LQ : Tail Length, LO : Ear Length, HG : Height at wither, PT : Chest depth, PT : Chest girth, LC : Body Length. Bold values are more associated with the factor.**

Table 4. The Kaiser-Meyer-Olkin, which measures the suitability of the sample collection, was equal to 0.69.
This value confirmed that the proportion of the variance in difference measurements was caused by the underlying factors. Three factors with eigenvalues superior to 1 were observed (Table 4). They explained 68.04% of total variance. The first factor explained 38.04% of variability, and loadings were negatively high for CC, AC, HG, Pt and LC but positively high for PT. The second factor described 17.26% of the total variability, and loadings were positively high for LQ and LO. The third factor defined 12.02% of variability. It was represented by a significant negative high loading for HG. Likewise, variables communalities, which represent the proportion of variance of each of the eight (8) variables shared by all remaining body measurements, were medium to high. They varied from 0.505 to 0.735 (Table 4).

Animals' plot in bi-dimensional presentation (F1-F2), according to PCA, accounting for 50.96% of the total variability, explains better the Djallonké sheep’s morphometrical variability (Figure 3). The bi-dimensional presentation of individuals showed that the animals were not separated based on the three agro-ecological zones which were previously found to have a significant effect on the Djallonké sheep’s body measurements.

Identification of the Djallonké sheep groups using hierarchical cluster analysis (HCA)

On the basis of the eight (8) major quantitative morphological variables, the cluster analysis revealed the formation of three distinct clusters (Figure 4).

The comparison of the quantitative morphological traits of the three Djallonké ewes clusters is shown in Table 5.

Animals from cluster I are characterized by a smaller size (Figure 2F). The second cluster shows a medium size (Figure 2A and E), with an average HG significantly higher than the data from the others. Except their HG, the cluster III body size is significantly bigger (Figure 2D) than the two previous clusters (Table 5).

The canonical discriminant analysis of the three Djallonké sheep clusters generated two statistically significant (p<0.05) canonical variables (axe1 and axe2) that accounted for 75.1 and 24.9% of the total variability, respectively. Lambda-Wilk test (Table 6) obtained by
Figure 4. Unweighted pair-group method with arithmetic averaging dendrogram based on 204 ewes population Euclidean differences derived from morphological variables.

discriminant analysis indicated that seven (7) of the eight (8) variables had a most discriminant power. Therefore, these seven (7) variables (CC, AC, LQ, LO, HG, Pt and LC) could be used to differentiate the three Djallonké sheep clusters. 

Djallonké sheep plot in bi-dimensional presentation ($F_1$-$F_2$) according to discriminant analysis is shown in Figure 5.

The discriminant analysis used to determine the percentage of sheep correctly grouped into their own cluster is presented in Table 7. The analysis revealed that 76.27, 92.80 and 90% of the sheep
DISCUSSION

Here we reported the main qualitative characteristics of the North, Central and West Africa agro-ecological Djallonké dwarf sheep, they are straight facial profile (head), thin tail and erect ear. However, one can notice that Djallonké sheep from Côte d’Ivoire are different from those of Africa according to their colour pattern and body hair. These results show that most of the qualitative traits studied for the Djallonké ewes breed found in Côte d’Ivoire are consistent with those found in Togo (Dayo et al., 2015). However, the most qualitative traits of Djallonké sheep investigated in this study were different from the indigenous sheep breed in different areas of Ethiopian (Edea et al., 2010; Tibbo et al., 2004 and Melesse et al., 2013). Those Ethiopian indigenous sheep populations of different areas are characterized by three tail types (fat, thin and docked) and a countless variability of the body hair coat colour type (white, black, red, fawn, brown, roan, grey and any combinations of these colours).

The little issue during this study is that all the ewes examined have different age (from 2 to 6 years old) which could have an influence on the linear body measurements. However the effect of the age could be neglected because, of the fact that in adulthood of the ewes linear body measurements are not significant and in any farm the population of ewes is composed of different age. In this study the variation of the coefficients of the eight quantitative characters range from 6.6 to 16.7% indicating no important variation in the ewes.
Table 7. Percentage of animal correctly or incorrectly classified in respect with the three clusters.

| Group       | % de classification | Cluster I | Cluster II | Cluster III |
|-------------|---------------------|-----------|------------|-------------|
| Cluster I   | 76.27               | 45        | 13         | 1           |
| Cluster II  | 92.8                | 8         | 116        | 1           |
| Cluster III | 90                  | 0         | 2          | 18          |
| Total       | 87.75               | 53        | 131        | 20          |

The height at withers of Djallonké sheep of present study was similar to those reported by Traoré et al. (2006) for Mossi sheep (59.3 ± 5.5 cm) from Burkina Faso, by Kunene et al. (2007) for ewes Zulu (Nguni) sheep (61 cm) from South Africa, as well as by Abegaz et al. (2011) for Gumuz, Horro and Menz (55 to 70 cm) ewes from Ethiopia.

Higher values for these height at withers, body length and chest girth have been reported by Yakubu and Ibrahim (2011) for Yankasa sheep (75.8 ± 0.48, 70.9 ± 0.37 and 84 ± 0.51 cm), for Uda sheep (83.9 ± 0.21, 76.6
reported the same observations for Rambi MIRAH, but with a positive correlation coefficient on traits. Nevertheless, classification of the sheep in each lower genetic variability observed were due to the influence of the cattle environment. The significant morphologic correlations observed are similar with those reported by Cam et al., 2013 and in Morocco (Hilal et al., 2016) for the Hamra goat (73.5%) in Morocco where four factors were extracted to explain the total variance.

The communalities found in the current study showed that all the linear body measurement had high loadings on factor 1, which is a good descriptor of general body size. Factors 2 seemed to reflect the ear and tail length while factor 3 seemed to describe the height at withers of the Djallonké sheep. In respect with the Principal Component Analysis (PCA), all used variables in this study can be useful to describe the variability of the Djallonké populations from three agro ecological zones.

The similarity of the results with the other sheep breed differentiation could suggest that the three Djallonké sheep clusters might be the sheep genotype types. Furthermore the discriminant analysis that showed a high degree of correct classification of the sheep in each cluster could mean that the three Ewe clusters could establish well individualized morphological types. Thus if the three clusters were unspecific with the three agro-ecological zones of the study, this could suggest that the differentiation between these clusters would not be due to an adaptation to the breeding environment, but to the subpopulation formation hence the sheep genotype.
types. There might be two possible main reasons to explain this hypothesis; the Djallonké sheep’ cross-breeding with the sahelian sheep in the breeding through country have generated the hybrids. Secondly, the use of improved Djallonké rams obtained from the breeding program (PNSO) in livestock farms in order to promote genetic gain has equally generated various phenotype types.

Conclusion

The present study focused on description of the qualitative characters and quantitative morphometrical traits of Djallonké sheep breed in Côte d’Ivoire. The results revealed the presence of variability in the qualitative and quantitative morphometrical characteristics among the Djallonké sheep breed population that reflect the heterogeneity of the Djallonké sheep population. Djallonké ewes can be classified into three well-characterized sub-populations. This information is quite useful in the designing of sustainable sheep improvement programs in Côte d’Ivoire. To assess the population structure of the Djallonké sheep, further molecular tools should be used to specify the genetic status of this sheep breed in Côte d’Ivoire.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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