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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

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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 description 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 CCi), (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 (DLS), (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 $d \leq 16$ mm); medium ($16 < d \leq 26$ mm) and large tubers ($d > 26$ mm). Nine traits were measured: (1) total number of tubers (TNT), (2) number of small tubers (diameter $d \leq 16$ mm) (NST), (3) number of medium tubers ($16 < d \leq 26$ mm) (NMT), (4) number of large tubers ($d > 26$ mm) (NLT), (5) tubers weight per plant (TWP), (6) weight per tuber (WeT=TWP/TNT), (7) tuber length (TLe), (8) tuber diameter (TDi), and (9) percentage of small tubers (PST = 100 × 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 2° 16' 00'' W	A	Black
E35	Nahouri	11° 15' N 1° 15' W	B	Red
E20	Nahouri	11° 15' N 1° 15'W	C	White-Yellow

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
Traits related to the canopy (measured 60 days after planting)	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	
Traits related to the cycle (evaluated 60-100 days after planting)	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
Traits related to tubers size and weight (measured 100-170 days after planting)	TNT	Total number of tubers	number/plant
	NST	Number of small tubers (diameter 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[a]	30.07[a]	25.50[a]	1.24	0.309	NS
CDi (cm)	56.50[a]	59.00[a]	46.79[b]	10.41	<.001	**
CFi (cm)	95.00[a/b]	100.43[a]	78.86[b]	4.69	0.021	*
CSL (cm)	39.00 [a]	40.57 [a]	46.71 [a]	0.93	0.408	NS
NIn	9[a]	9[a]	11[a]	1.25	0.307	NS
ILe (cm)	4.27[a]	4.73[a]	4.14[a]	0.55	0.583	NS
LLe (cm)	9.58[a]	6.57[b]	5.14[c]	24.56	<.001	**
LWi (cm)	4.74[a]	3.74[b]	2.74[c]	36.52	<.001	**
LRa	0.51[a]	0.57[a]	0.54[a]	1.63	0.220	NS

PHe: Plant height; CDi: canopy diameter; CCi: canopy circumference; CSL: central stem length; NIn: number of internodes; ILe: internodal length; LWi: leaf width; 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[c]	71[b]	74[a]	52.75	<.001	**
DSI (days)	61[c]	75[b]	84[a]	86.96	<.001	**
DLS (days)	66[b]	89[a]	90[a]	29.22	<.001	**
DFM (days)	107[c]	154[a]	118[b]	175.83	<.001	**
DMa (days)	108[c]	156[a]	125[b]	157.89	<.001	**
DLM (days)	113[c]	164[a]	149[b]	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

Table 5. Characteristics of the morphotypes for traits related to tubers size and production.

Trait	Accessions' number			F	F pr	Significance of F
	E02 (A)	E35 (B)	E20 (C)			
TNT	50[a]	42[a]	36 [a]	0.94 [a]	0.405	NS
NST	43[a]	42[a]	35[a]	0.29	0.748	NS
NMT	6[a]	0[b]	1[b]	19.84	<.001	**
NLT	1[a]	0[a]	0[a]	1.00	0.385	NS
WeT (g)	2.69[a]	1.08[b]	1.25[b]	25.16	<.001	**
TLe (mm)	33.48[a]	23.3[b]	24.02[b]	25.23	<.001	**
TDi (mm)	15.62[a]	10.55[b]	13.73[a]	9.00	0.002	**
TWP (g)	134.98[a]	46.03[b]	45.17[b]	25.16	<.001	**
PST (%)	58.32[c]	99.07[a]	82.16[b]	16.43	<.001	**

TNT: Total number of tubers; NST: number of small tubers (diameter d≤16 mm); NMT: number of medium tubers (16 < d ≤ 26 mm); NLT: number of large tubers (d > 26 mm); WeT: weight per tuber; TLe: tuber length; TDi: tuber diameter; TWP: tubers weight per plant; PST: percentage of small tubers. 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. NS: Not significant at P < 0.05; **Difference significant at P.

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: LLE 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 (DMa) 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 days 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

Table 6. Pearson correlation coefficients between morphometric traits of *S. rotundifolius.*

Trait	DFS	DSI	DLE	CDi	CCi	PHe	CSL	NIn	ILe	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	-0.22	0.05	-0.21																		
CSL	0.34	**0.43**	0.4	-0.03	-0.1	-0.2																	
NIn	0.25	0.34	0.23	-0.17	-0.19	-0.16	0.84*																
ILe	0.12	0.15	0.25	0.22	0.12	-0.05	0.02	-0.52*															
LLe	-0.71*	-0.80*	-0.63*	0.23	0.12	0.29	-0.18	-0.14	-0.14														
LWi	-0.72*	-0.85*	-0.62*	0.4	0.19	**0.48**	-0.17	-0.14	-0.14	0.89*													
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	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*

PHe: Plant height; CDi: canopy diameter; CCi: canopy circumference; CSL: central stem length; ILe: internodal length; NIn: number of internodes; LWi: leaf width; LLe: leaf length; LRa: leaf ratio; 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; TNT: total number of tubers; NST: number of small tubers (diameter d≤16 mm); NMT: number of medium tubers (16 < d ≤ 26 mm); NLT : number of large tubers (d > 26 mm); WeT: weight per tuber; TLe: tuber length; TDi: tuber diameter; TWP: tubers weight per plant; PST: percentage of small tubers.
*Correlation significant at P < 0.01. Bold values are significant at P < 0.05.

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

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

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 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

differences between the morphotypes. The most important intergroup distances were observed between morphotype “A” and the other two morphotypes, “B” and “C” (148.28 and 115.04, respectively) (Table 8). The morphotypes “B” and “C” 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 inter specific 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 landraces characteristic in Burkina Faso (Ouédraogo 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

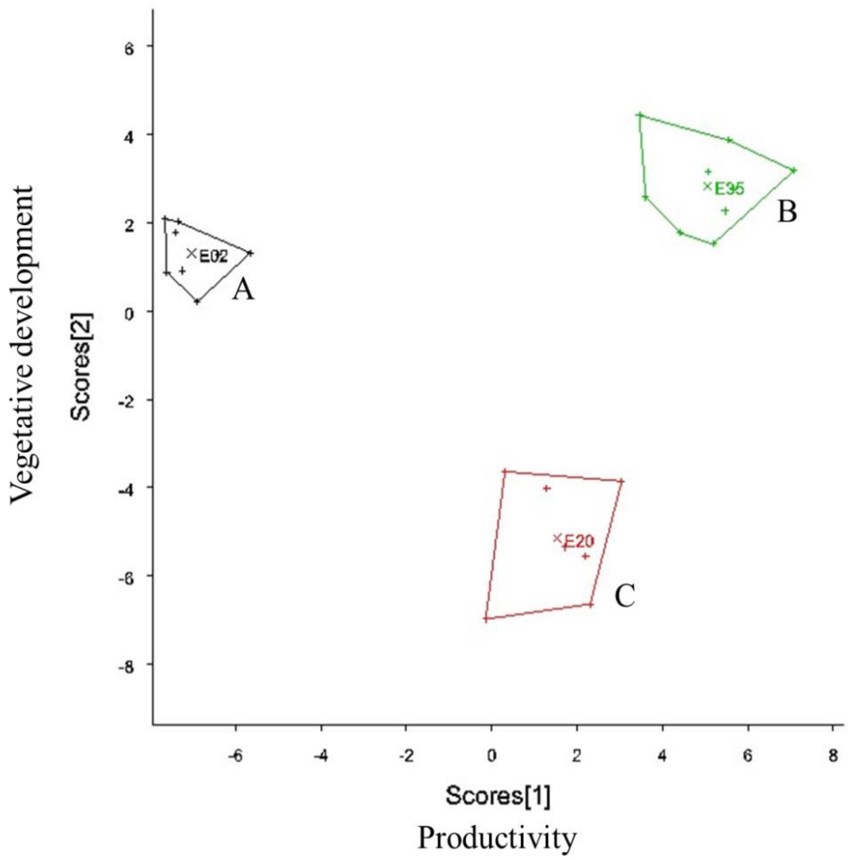

Figure 1. Discriminant analysis of the morphotypes of *S. rotundifolius*. A, B and C are morphotypes of *S. rotundifolius*. E02, E35 and E20 are accessions' numbers.

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 -

1.5 cm.

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 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 par 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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