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Morphoagronomical characterization of *Solenostemon rotundifolius* (Poir. J. K. Morton) (Lamiaceae) germplasm from Burkina Faso

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ABSTRACT

Solenostemon rotundifolius or country potato is a tropical multipurpose tuber crop species. It has been one of the staple crops in West Africa but currently, its genetic resources are in a process of disappearing. Characterization of *S. rotundifolius* genetic variability is recognized as a prior intervention to support a sustainable conservation and use of its genetic resources. For identifying suitable descriptors for *S. rotundifolius*, a morphoagronomical characterization was carried out on 155 cultivars from Burkina Faso. A total of 50 morphological traits (16 qualitative and 34 quantitative) related to the foliage, the cycle and the tubers were scored. The results showed variability within cultivars for the foliage, the cycle and the potential yield (number and weight of tubers). However, no significant variability was found for tubers size. Cultivars from different geographical origin discriminated for the cycle and the potential yield. Significant correlations were found between the cycle, the foliage and the potential yield. Most of the qualitative morphological traits were shown to be varietal criteria. The studied morphological traits could be used as descriptors for *S. rotundifolius* germplasm characterization and for breeding purpose.

Keywords : Country potato, tuber, germplasm, conservation, morphological traits.

INTRODUCTION

Solenostemon rotundifolius (2n=64) is an annual herbaceous belonging to the family of Lamiaceae . The family of Lamiaceae includes more than 200 species comprising ornamental, medicinal plants, and edible tubers crops (Risa et al., 2004 ; Abraham and Radhakrishnan, 2005 ; Moshi et al., 2005). *Solenostemon* is a tropical genus of Lamiaceae (Chevalier and Perrot, 1905 ; Ryding, 1994). *S. rotundifolius* is believed to have originated in Central or East Africa (NRI, 1987; Schoeninger et al., 2000; Abraham and Radhakrishnan, 2005 ; Edison et al., 2006). It was early spread throughout tropical Africa and into South-East Asia (India, Sri Lanka, Malaysia, and Indonesia) (NRI, 1987). It is cultivated on small scale in many West African countries (Burkina Faso, Ghana, Mali, Niger, Nigeria, and Togo) (Chevalier and Perrot, 1905 ; Bognounou, 1970 ; Tetteh and Guo, 1997 ; Nkansah, 2004).

S. rotundifolius is known as Chinese potato, Sudan potato, country potato, Fra Fra potato, Hausa potato, Zulu round potato, innala, fabirama, or pessa (Chevalier and Perrot 1905 ; Bognounou, 1970 ; Niino et al., 2000; NRC, 2006). It grows well in regions receiving annual rainfall between 700 and 1000 mm (NRC, 2006 ; Ouédraogo et al., 2007). Yield usually range from 7 to 15 t/ha (IRAT, 1977), however under favorable conditions, it may reach 18 to 20 t/ha (NRI, 1987), 30 t/ha (Tarpaga, 2001), or 45t/ha (Nkansah, 2004). *S. rotundifolius* is one of the world best tasting and most nutritious tuber crops. Its tubers have a high carbohydrates content (83.5% of the dry weight) (Gouado et al., 2003). Comparatively to other tuber crops such as cassava, yams, and sweet potato, *S. rotundifolius* has a high content of protein, calcium, magnesium, fibres, and iron (Chevalier and Perrot, 1905 ; NRI, 1987 ; Gouado et al., 2003 ; Prematilake, 2005). It is an important foodstuff both for rural and urban communities (NRI, 1987) and helps to supplement tuber requirement in families menus (Jada et al., 2007). It is food source for the people during the period of food scarcity (Bennett-Lartey and Oteng-Yeboah, 2008). *S. rotundifolius* tubers can be boiled, baked, or fried similarly to potato chips (NRI, 1987). In Ghana, an alcoholic drink has also been brewed from *S. rotundifolius* tubers (Opoku-Agyeman et al., 2007).

S. rotundifolius tubers possess elite flavor and taste and have medicinal properties due to the presence of flavonoids that help to lower the cholesterol level of the blood (Horvath et al., 2004 ; Abraham and Radakrishnan, 2005; Sandhya and Vijahalakshmi, 2005). They also contain enzymes inhibitors (Prathiba et al., 1995). In Africa and Asia, *S. rotundifolius* is commonly used in the treatment of dysentery, eyes disorders, sore throat, and hematuria (NRI, 1987 ; Niino et al., 2000 ; Tarpaga, 2001 ; Ouédraogo et al., 2007). In addition, *S. rotundifolius* has a lot of sociocultural importance. Actually, it serves as gift to in-laws, or snack at child naming ceremonies (Opoku-Agyeman et al., 2007).

S. rotundifolius has been a staple crop in West Africa but it has been progressively replaced by other tuber crops such as yams and potatoes (Chevalier and Perrot, 1905 ; Prost, 1971 ; IRAT, 1977, 1980). The most unfavorable feature of *S. rotundifolius* is the small tubers size (2.5 cm in diameter) (Prematilake, 2005). In West Africa and particularly in Burkina Faso, there is a growing interest to evaluate, to conserve and to use local food crops such as *S. rotundifolius* (Tarpaga, 2001; Ojewola et al., 2006; Aboagye et al., 2007 ; Opoku-Agyeman et al., 2007; Bernnett-Lartey and Oteng-Yeboah, 2008) Conservation and sustainable use of genetic resources depend on knowledge of the extent and patterns of intra specific variation as well as geographical provenances.

In plant populations, patterns of genetic variation are extremely varied and involve complex interactions between plants attributes, such as life form, reproduction modes, mating system and ecological and environmental factors that may influence pollination events, population size and isolation (Coates and Byrne, 2005). *S. rotundifolius* is normally propagated vegetatively by suckers or soft-woody stems cutting because its produces few seeds despite the many flowers (NRI, 1987 ; Nkansah, 2004), thus affecting the gene flow and the enhancing genetic differentiation between populations from different geographical locations. In addition, the large heterogeneity in environmental conditions within the natural range of the species would favor monomorphic, specialized, and genetically different populations. The genetic component of this variation among populations from different regions can therefore be identified by provenance testing and exploited through selection of superior populations for reproduction material collection.

This study was carried out to identify the main morphological traits and to evaluate their variation with the aim of using them as descriptors for *S. rotundifolius* future characterization and for breeding program.

MATERIALS AND METHODS

Plant material

A total of 155 accessions of *S. rotundifolius* were collected in 20 provinces of Burkina Faso (Table 1) that represent the major geographical sites of *S. rotundifolius* cultivation. Each sample (about 30 tubers) was registered with an accession number in a database. The samples were stored at room temperature until the rainy season.

Study area and experimental design

A morphoagronomical characterization was carried out from July to December 2007 at Boulbi (coordinates (UTM: Universal Transverse Mercator) : longitude= 660841.50;

Table 1: Geographical coordinates of the sites of *S. rotundifolius* germplasm collection.

Provinces	Departments	Number of accessions	Coordinates (UTM)	
			Longitude	Latitude
Balé	Boromo	04	507798.00	1298875.00
Bazèga	Saponé	01	655862.06	1337880.00
	Ipelcé	02	659894.00	1322271.00
	Doulougou	01	667752.00	1325547.00
	Kombissiri	02	680779.00	1334151.00
Bougouriba	Bondigui	09	445908.00	1205696.00
	Diébougou	05	472736.00	1211997.00
Boulgou	Bagré	02	774998.00	1276401.00
Boulkiemdé	Niandala	02	590260.00	1363403.00
Ganzourgou	Meguet	01	748323.25	1374023.13
Gourma	Diabo	03	823424.00	1329743.75
Houet	Bama	01	345042.00	1258545.00
	Toussiana	02	323549.84	1198157.13
Ioba	Guégueré	02	480617.56	1229914.63
	Dissin	03	508146.00	1209393.00
Kadiogo	Pabré	05	655583.00	1383763.00
	Tanghin-Dassouri	01	640058.00	1357194.00
	Komki-Ipala	07	629936.00	1346902.00
	Komsilga	03	648237.00	1346872.00
Kourwéogo	Boussé	01	620135.00	1399786.00
Nahouri	Zecco	09	732546.85	1218321.96
	Tiebélé	11	722328.00	1227199.00
	Ziou	15	742563.00	1220775.00
	Pô	05	702541.00	1234922.00
Noumbiel	Batié	11	508458.00	1091728.00
	Midebdo	01	483765.00	1104022.00
Passoré	Arbolé	02	603334.00	1420663.00
Poni	Gaoua	01	479827.00	1141623.00
	Nako	03	493729.00	1175340.00
Sanguié	Pouni	01	549105.00	1321917.00
Sanmatenga	Boussouma	09	707756.00	1427732.00
	Kaya	05	707428.00	1447926.00
	Pibaoré	03	737196.88	1426176.13
Sissili	Léo	04	598018.00	1226977.00
Ziro	Cassou	02	603715.00	1279740.00
Zoundwéogo	Gogo	05	722274.00	1278635.00
	Bindé	04	707317.00	1299215.00
	Noberé	07	696008.00	1278155.00
Total : 20	38	155		

UTM: Universal Transverse Mercator

Latitude = 1354452.59). From July to November, a total rainfall of 498.5 mm was registered for a total of 39 rainy days; August being the most humid month (295.5 mm). October and November respectively registered 0.3 mm and 0.1 mm of rain. The minimum and maximum temperatures were respectively 26 °C in December and 31.1 °C in October. Two additional irrigations (of about 15 mm of water each) were provided on 9th and 30th October 2007.

The experiment was laid out in Fischer randomized blocks design with three replications. An experimental field of 3 072.8 m^2 (66.8m x 46m) was subdivided into three blocks two meters apart.

Before the plowing, 100 kg/ha of NPK (14-23-14) were supplied to the experimental field. For each block, 160 ridges 20 cm high and 6 m long were established. The ridges were spaced at 0.8 m. The sprouted tubers were planted on July 10, 2007. The plants in the ridge were spaced at 50 cm. There were thirteen plants in each ridge.

Morphological traits measurement

A total of 50 morphological traits (16 qualitative and 34 quantitative) were assessed at different stages of the plant growth. For each qualitative trait, the different variants were identified and scored (Table 2). The quantitative morphological traits related to the cycle (days to earring, days to flowering and days to maturity) were noted for all the plants in the ridge (Table 3). The other quantitative traits were taken from three randomly selected plants in the ridge. The parameters related to the foliage were measured using a graduated ruler.

The tubers from each plant were subdivided into three categories using two sieves of respectively 16 mm and 26 mm of diameter. The length and the diameter were measured for four randomly chosen tubers per category using a caliper rule. The tubers weight was measured using a balance of 1 Kg maximum with a precision of 0.1 kg. The rate of disliked tubers (RDT) was calculated on the basis RDT = [weight of small tubers (WST) / weight of tubers per plant (WTP)] x 100.

Statistical analysis

The collected data were summarized and accessions with missing data were eliminated from the analysis. In all, 146 cultivars were included in the analysis of the qualitative morphological traits and 115 for the quantitative morphological traits. Percent distribution of the different variants for the qualitative traits were calculated. For each of the three blocks, the mean value for each quantitative morphological trait was first calculated for each cultivar. Then, these values were subjected to an analysis of variance (ANOVA) to determine significant variable traits. The mean values and the standard deviation of each quantitative morphological trait were calculated and a Paerson’s correlation test was also performed to assess the relation between the main traits. A second analysis of variance was performed to assess the differentiation between cultivars from different provinces.

The software XLTAT-pro 7.1 was used to perform the data analysis.

RESULTS

Quantitative morphological traits

Mean, standard deviation and the variation of the different quantitative morphological traits are summarized in the table 4. Except for the diameter of the foliage (DFO), and the leaf ratio (LRA), the cultivars revealed significant difference ($p<0.05$) for the quantitative morphological traits related to the foliage, particularly for the principal stem and the third leaf. The height and the diameter of the foliage were respectively FHE =14.70 ± 2 cm and DFO = 33.89 ± 6.42 cm. The principal stem was 14.53 ± 2.49 cm long (LPS) with at mean 9 internodes (NIN) long of 1.57 ± 0.21 cm (INL). The third leaf was 4.25 ± 0.55 cm long (LTL) and 2.79 ± 0.36 cm wide (WTL) with a ratio (LRA) of 0.66 ± 0.03.

A part the days to last flowering (DLF), the quantitative morphological traits related to the plant cycle were the most variable. The earring ranged from 64 ± 5 to 88 ± 10 days after planting (DFE and DLE). The flowering occurred between 84 ± 10 (DFF) and 90 ± 9 days (DLF). About one month was necessary

Table 2: Qualitative morphological traits of *S. rotundifolius*.

Stage	Traits	Abbreviations
Young plant (6-8 weeks after planting)	Basal color of the stem	BCS
	Color of first node	CFN
During the vegetative development (8-14 weeks after planting)	Presence of red color on the leaves	PRC
	Presence of yellow color on the leaves	PYC
	Color of injured leaves	CIL
	Foliage color	FCO
	Leaves waffleness	LWA
	Leaves density	LDE
After flowering (14-18 weeks after planting)	Stem section	SSE
	Type of flower	TFL
	Color of leaves at senescence	CLS
After harvest (After 23 weeks)	Tuber texture	TTE
	Tuber shape	TSH
	Tuber's skin color	TSC
	Presence of lateral tubers	PLT
	Raw tuber taste	RTT

between flowering and the first maturity (DFM= 119 ± 8 days). The days to maturity was 125 ±8.

For most of the tubers parameters, no significant difference was observed between cultivars. However, the number and the weight of tubers (NTP and WTP), the number and the weight of small tubers (NST and WST) and the rate of disliked tubers (RDT), revealed significant differences between cultivars.

The mean number of tubers per plant (NTP) was 26 ± 10 corresponding to a weight of 62.07 ± 28.78 g (WTP). The diameter and the length of the tubers were respectively 1.53 ± 0.18 cm and 3.78 ± 0.48 cm. The most important part of the tubers was small size (NST = 24 ± 8.91, WST = 46.06 ± 18.98 g and RDT = 77.77 ± 17.30%). The small tubers were 3.55 ± 0.44 cm long (LST) with a diameter (DST) of 1.30 ± 0.09 cm. The number and the weight of the average and the big tubers were very low (NAT = 2 ± 2, WAT = 15.67 ± 15.43 g, NBT= 1 ± 1 and WBT= 0.34 ± 1.98 g). The average tubers (DAT = 1.88 ± 0.19 cm and LAT = 4.01 ± 0.55 cm) and the big tubers (DBT = 2.85 ± 0.19 cm and the LBT = 6.15 ± 2.88 cm) represented less than 25% of the plant potential yield (WTP).

Differentiation between cultivars from different provinces

In all, cultivars from 18 provinces were compared. The comparison was based on seven main quantitative morphological traits: the foliage height (FHE), the width of the third leaf (WTL), the days to maturity (DMA), the number and the weight of tubers per plant (NTP and WTP), the diameter and the length of tubers (DTU and LTU). Significant differences between cultivars were found for the days to maturity (DMA), the weight of tubers per plant (WTP) and the diameter of the average tubers (DTU) (table 5). The mean values of the main traits per province revealed that the cultivars from Houet had the higher foliage (FHE = 16.99 cm). The cultivars from the provinces of Passoré and Gourma had the larger leaves (WTL = 3.38 cm). The later plants were found within the cultivars from the province of Ioba (DMA = 135.28 days). The cultivars from the province of Ziro had the most important potential yield (NTP = 42 and WTP = 171.55 g). Longer tubers cultivars were found in the province of Balé (LTU = 4.27 cm) while the cultivars with bigger diameter were from the province of Gourma (DTU = 1.93 cm).

Table 3: Quantitative morphological traits of *S. rotundifolius*.

Stage	Traits	Abbreviations
Earring and flowering (8-15 weeks after planting)	Days to the first earring	DFE
	Days to earring	DEA
	Days to last earring	DLE
	Days to first flowering	DFF
	Days to flowering	DFL
	Days to last flowering	DLF
	Diameter of the foliage	DFO
	Foliage height	FHE
	Length of the principal stem	LPS
	Number of internodes	NIN
	Internodes length	INL
	Length of the third leaf	LTL
	Width of the third leaf	WTL
	Leaf ratio (WTL/ LTL)	LRA
Maturity (15-23 weeks after planting)	Days to first maturity	DFM
	Days to maturity	DMA
	Days to last maturity	DLM
After harvest (After 23 weeks)	Number of small tubers (diameter D≤16 mm)	NST
	Diameter of small tubers	DST
	Length of small tubers	LST
	Weight of small tubers	WST
	Number of average tubers (16 < D ≤ 26 mm)	NAT
	Diameter of average tubers	DAT
	Length of average tubers	LAT
	Weight of average tubers	WAT
	Number of big tubers (D > 26 mm)	NBT
	Diameter of big tubers	DBT
	Length of big tubers	LBT
	Weight of big tubers	WBT
	Number of tubers per plant	NTP
	Weight of tubers per plant	WTP
	Rate of disliked tubers (WST/WTP) x 100	RDT
	Diameter of tubers	DTU
	Length of tubers	LTU

Table 4: Mean, standard deviation and variation of *S. rotundifolius* quantitative traits.

Traits	Mean	SD	ddl	F	p-value
FHE: Foliage height (cm)	14.70	2.00	114	1.334	0.034
DFO: Diameter of the foliage (cm)	33.89	6.42	114	1.262	0.071
LPS : Length of principal stem (cm)	14.53	2.49	114	1.330	0.036
NIN : Number of internodes	9	1	114	1.745	0.000
INL : Internodes length (cm)	1.57	0.21	114	1.352	0.028
LTL : Length of the third leaf (cm)	4.25	0.55	114	2.012	< 0.0001
WTL : Width of the third leaf (cm)	2.79	0.36	114	2.290	< 0.0001
LRA : Leaf ratio	0.66	0.03	114	0.938	0.645
DFE : Days to first earring	64	5	114	2.293	< 0.0001
DEA : Days to earring	74	7	114	1.918	< 0.0001
DLE : Days to last earring	88	10	114	1.807	< 0.0001
DFF : Days to first flowering	84	10	100	2.616	< 0.0001
DFL : Days to flowering	90	9	61	1.728	0.005
DLF : Days to last flowering	90	9	27	1.298	0.203
DFM : Days to first maturity	119	9	114	3.010	< 0.0001
DMA : Days to maturity	125	8	114	3.293	< 0.0001
DLM: Days to last maturity	133	9	114	2.017	< 0.0001
NTP : Number of tubers per plant	26	10	114	1.361	0.026
WTP : Weight of tubers per plant (g)	62.07	28.78	114	1.406	0.016
DTU : Diameter of tubers (cm)	1.53	0.19	114	1.281	0.059
LTU : Length of tubers (cm)	3.78	0.48	114	0.811	0.896
NST : Number of small tubers	24	9	114	1.493	0.006
WST : Weight of small tubers (g)	46.06	18.98	114	1.351	0.029
LST : Length of small tubers (cm)	3.55	0.44	114	1.193	0.132
DST : Diameter of small tubers (cm)	1.30	0.09	114	0.840	0.851
NAT : Number of average tubers	2	2	82	1.110	0.284
WAT : Weight of average tubers (g)	15.67	15.43	82	1.106	0.290
DAT : Diameter of average tubers (cm)	1.88	0.12	82	1.118	0.272
LAT : Length of average tubers (cm)	4.01	0.55	82	0.787	0.888
NBT : Number of big tubers	1	1	3	1.333	0.330
WBT : Weight of big tubers (g)	0.34	1.98	3	1.333	0.330
DBT : Diameter of big tubers (cm)	2.85	0.19	3	1.333	0.330
LBT : Length of big tubers (cm)	6.15	2.88	3	1.333	0.330
RDT : Rate of disliked tubers (%)	77.77	17.30	114	1.388	0.019

F : Fisher's coefficient

Table 5: Geographical differentiation of the cultivars of *S. rotundifolius.*

	Traits						
Provinces	**FHE (cm)**	**WTL (cm)**	**DMA (days)**	**NTP**	**WTP (g)**	**DTU (cm)**	**LTU (cm)**
Balé	15.17	2.71	125(b/c)	30	73.53(bcd)	1.63(ab)	4.27
Bazèga	15.28	2.81	126(b/c)	25	68.91(bcd)	1.64(ab)	3.83
Bouguiriba	15.07	2.64	133(b)	30	63.42(cd)	1.58(ab)	3.66
Boulkiemdé	12.67	2.38	130(b/c)	24	22.40(d)	0.85(b)	3.75
Ganzourgou	16.06	3.04	124 (b/c)	32	59.50 (cd)	1.59(ab)	3.73
Gourma	15.67	3.38	120(c)	26	93.20 (bcd)	1.93(a)	3.99
Houet	16.99	2.99	125(b/c)	34	104.39(bc)	1.67(ab)	3.99
Ioba	15.99	2.72	135(a)	28	64.31(bcd)	1.53(ab)	4.25
Kadiogo	13.32	3.10	119(c)	23	47.39(cd)	1.41(b)	3.85
Nahouri	14.32	2.78	124(c)	24	55.33(cd)	1.47(ab)	3.88
Noumbiel	13.94	2.73	119(c)	20	55.46(cd)	1.61(ab)	3.68
Passoré	15.58	3.38	111(c)	12	30.45(cd)	1.51(ab)	4.04
Poni	13.83	2.47	132(b/c)	38	82.79(bcd)	1.63(ab)	3.80
Sanguié	13.50	2.77	122(c)	39	126.12(ab)	1.65(ab)	4.16
Sanmatenga	14.68	2.88	124(c)	25	61.18(cd)	1.59(ab)	3.64
Sissili	12.33	3.01	119 (c)	19	43.08(cd)	1.31(b)	3.52
Ziro	14.50	3.16	116(c)	42	171.55(a)	1.66(ab)	4.14
Zoundwéogo	15.46	2.68	129(b/c)	28	61.81(cd)	1.52 (ab)	3.61
ddl	17	17	17	17	17	17	17
F	1.46	1.50	5.41	1.43	2.74	2.02	1.51
p-value	0.107	0.081	< 0.0001	0.121	0.000	0.010	0.089

FHE : Foliage height ; WTL : Width of the third leaf ; DMA : Date of maturity ;NTP : Number of tubers per plant ;WTP : Weight of tubers per plant DTU : Diameter of tubers ; LTU : Length of tubers ; F : Fisher's coefficient
a, b, c, d : groups issued from Newman and Keuls classification (d<c<b<a)

Correlations between quantitative morphological traits

Many significant correlations ($p< 0.01$) were observed between the foliage (FHE and WTL), the cycle (DMA), the potential yield (NTP and WTP) and the tubers size (LTU and DTU) (table 6). The foliage height (FHE) was positively correlated to the days to maturity (DMA), the number and the weight of tubers per plant (NTP and WTP) and to tuber length (LTU). The width of the third leaf (WTL) was negatively correlated to the days to maturity (DMA) and to the number of tubers per plant (NTP). However, WTL is positively correlated to the tuber length (LTU). The days to maturity (DMA) is positively correlated to the number of tubers per plant (NTP) and to the weight of tubers per plant (WTP).

Qualitative morphological traits

There were variations in all the sixteen qualitative morphological traits (Table 7). The basal color of the stem (BCS) was green or red. For all the evaluated cultivars, 31% were green, 2% were red and 67% had both colors (green and red). The first node (CFN) was green (22%) or red (21%). During the vegetative development, 48% of the cultivars presented red color on the leaves (PRC). This coloring was central or apical respectively for 10 and 19% of the cultivars; 9% of the cultivars presented both of the two variants. At the same stage, only 1% of the cultivars presented yellow color on the leaves (PYC).

According to the degree of thickness, two types of leaves were found for the morphological trait leaf waffleness (LWA). The first type was lightly thick and distinctly veined. The second type of leaves was very thick with quite invisible veins. The two types respectively correspond to the low and strong waffled leaves. Among the evaluated cultivars 40% had law waffled leaves and 20% had strong waffled leaves. During the vegetative stage, a red color was observed on 23% of the

Table 6: Correlations between quantitative morphological traits of *S. rotundifolius.*

Traits	FHE	WTL	DMA	NTP	LTU	DTU
WTL	0.25**					
DMA	0.39**	-0.42**				
NTP	0.26**	-0.27**	0.43**			
LTU	0.39**	0.26**	0.06	0.11		
DTU	0.17	-0.1	0.17	0.33**	0.16	
WTP	0.35**	-0.16	0.33**	0.78**	0.31**	0.60**

FHE : Foliage height ; WTL : Width of the third leaf ; DMA : Date of maturity ;NTP : Number of tubers per plant ;WTP : Weight of tubers per plant DTU : Diameter of tubers ; LTU : Length of tubers
** : significant correlation (p<0.01)

cultivars when the leaves are injured by caterpillars (CIL).

The foliage had generally strong density of leaves (LDE) (95%). There were three variants (light green, green and dark green) for the foliage color (FCO). The cultivars with green or dark green leaves represented respectively 44% and 3% of the evaluated cultivars. The other cultivars (53%) presented the three variants of leaves color.
Adult plants presented four variants for stem section (SSE). Plant stem section was generally quadrangular but the principal stem section was hexagonal, diamond, or triangular respectively for 16%, 4% and 2% of the cultivars. During the same stage, 8% of cultivars presented a red color on senescent leaves (CLS).

After flowering, two types of flowers (TFL) were identified. The first type of flower was blue-pale (19% of the cultivars) and the second type was intensively colored purple (12% of the cultivars). Besides these types, there were 9% of the cultivars without flowering after earring.

The harvested tubers presented variable texture, shape, taste and skin color. The tubers texture (TTE) was smooth (44%) or rough (10%) but 46% of the cultivars presented both smooth and rough tubers. Two variants were found for tuber shape (TSH). Tubers were oblong (7%) or ovoid (27%) but the majority of the cultivars (66%) presented both types of tubers. Three main tuber skin colors (blackish, reddish or whitish) were identified (TSC). The majority of the cultivars (56%) produced red tubers. The cultivars with black or red tubers respectively represented 10% and 3% of analyzed cultivars. An important rate of the cultivars (87%) produced lateral tubers (PLT). The lateral tubers were basal or on the upper part of the principal tuber. The raw tuber taste (RTT) after peeling was succulent or very succulent respectively for 10% and 58% of the cultivars.

DISCUSSION

The quantitative morphological traits revealed variability within the germplasm collection. The days to earring, the days to maturity and the potential yield (number and weight of tubers per plant) were reported to be variable traits (Tarpaga, 2001). However, the foliage parameters were not included in this previous work. On the contrary, not significant variability was found for the tubers size (length and diameter) and for the number and the weight of average and big tubers. Abraham and Radhakrishnan (2005) mentioned the low variability of *S. rotundifolius* tubers size in India. The principal stem length and the foliage height were both less than 20 cm. The reported height, including inflorescence stalk length, ranged from 20 to 30 cm (Chevalier and Perrot, 1905; NRI, 1987). According to Chevalier and Perrot (1905), leaf length ranged from 2 to 4.5 cm and the width from 1.5 to 3 cm. The presented results corroborate this finding. Guillaumet and Cornet (1976) reported that the foliage length varied according to the season.

The days to earring and the days to maturity reported by Tarpaga (2001) were respectively 63 and 106.46 with important variations as observed in the present study. However, the days to maturity reported by NRI (1987) and Ouédraogo et al. (2007) are

Table 7: Variability of the qualitative traits of *S. rotundifolius* (1).

Traits	Variants	Rate
BCS :Basal color of the stem	green	31
	Red	2
	green and red	67
CFN : Color of first node	green	22
	Red	21
	green and red	57
PRC : Presence of red color on the leaves	absent	62
	apical	19
	centred	10
	variable	9
PYC : Presence of yellow color on the leaves	present	1
	absent	99
LWA : Leaves waffleness	Low	46
	strong	20
	Low and strong	34
CIL : Color of injured leaves	green	73
	Red	27
LDE : Leaves density	Low	6
	strong	57
	Low and strong	38
FCO : Foliage color	green	44
	dark green	3
	variable	53
SSE : Stem section	quadrangular	77
	diamond	4
	hexagonal	16
	triangular	2
	diamond and hexagonal	1
CLS : Color of leaves at senescence	green	92
	Red	8
TFL : Type of flower	blue pale	19
	purple	12
	no flowering	9
	variable	60
TET : Tuber texture	smooth	44
	rough	10
	smooth and rough	46
TSH : Tuber shape	Oblong	7
	ovoid	27
	Oblong and ovoid	66
TSC : Tuber's skin color	Red	56
	black	10
	white	3
	Red and noir	31
PLT : Presence of lateral tubers	absent	13
	basal	69
	variable	18
RTT : Raw tuber taste	succulent	10
	very succulent	58
	succulent and very succulent	32

longer (120 to 180) than those found. According to Guillaumet and Cornet (1976), He et al (1998), and Abraham and Radhakrishnan (2005), *S. rotundifolius* is a photosensitive tubers crop. The cycle can then vary according to the planting period.

The number and the weight of tubers per plant were low comparatively to previous findings. Tarpaga (2001) found that cultivars produced at mean 90 tubers corresponding to a weight of 369.31 g per plant. According to Ouédraogo et al. (2007), the number of tubers per plant ranged from 100 to 150. However, the results are similar to those reported by Abraham and Radhakrishnan (2005) and Tanzubil et al. (2005). According to the cited authors, the number of tubers per plant ranged from 32 to 65 and the weight of tubers per plant from 9 to 20 g or 54 to 126 g according to the cultivar.

In spite of the variation in cultivars potential yield, the produced tubers had similar size comparatively to previous works (Tarpaga 2001 ; Opoku-Agyeman and al., 2004; Prematilake, 2005). According to these authors, the diameter of the tubers was around 1.5 cm. The small tubers size is the most unfavorable feature in *S. rotundifolius* (IRAT, 1980 ; Nkansah, 2004; Prematilake, 2005).

Within the main quantitative morphological traits, days to maturity, weight of tubers and diameter of tubers revealed significant difference between the cultivars geographical origin. Tarpaga (2001) reported similar results between cultivars from the province of Kadiogo and Ganzourgou, in Burkina Faso. These traits could be the main morphological traits for germplasm conservation or breeding purpose.

Many significant correlations were identified between the main qualitative morphological traits. The correlations between the foliage height and the other traits revealed that high cultivars had long cycle and produced many long tubers and had better yield. The negative correlations between the third leaf width and the days to maturity and to the number of tubers per plant showed that cultivars with large leaves were earlier and produced no much tubers. The width of the leaf was positively correlated to the tubers length indicating that the cultivars with large leaves produced longer tubers. The correlation between the days to maturity and the number and weight of tubers revealed that later cultivars had higher potential yield. Some previous works mentioned the correlations between the cycle, the tubers size, and the potential yield (Tarpaga, 2001). IRAT (1980) found that foliage development favored the production of multiple small size tubers.

All the qualitative traits revealed variability within the cultivars. Previous works recorded variability for the qualitative morphological traits. According to Price and Sturgess (1938), the coloration on Lamiaceae is due to anthocyanins (mainly the cyanidin saccharrides). This coloration is disappearing with the maturity. The different positions of the red coloration on the leaves were mentioned by Opoku-Agyeman et al. (2007) as anthocyanin pigmentation. The red coloration on the injured leaves could be due to the presence of anthocyanin as generally observed in plant species.

S. rotundifolius is known to have thikish leaves (NRI, 1987 ; Tarpaga, 2001). Kirhorekumar et al. (2006) showed that chloroplast and stomata number both increase with the leaves thickness. Leaves structure is recognized to be important for the control of water use in crop (Edison et al., 2006). This trait could be considered as a criterion of *S. rotundifolius* adaptation to tropical zone as mentioned by Chevalier and Perrot (1905), Ryding (1994) and Nkansah (2004). For foliage color, Opoku-Agyeman et al. (2007), also found the three identified variants. In this previous work, the plants with green foliage represented 55% of evaluated cultivars.

S. rotundifolius stems section was generally quadrangular. Particularly, hexagonal and triangular sections were reported as varietal criteria in *S. rotundifolius* (Chevalier and Perrot, 1905). The stems hexagonal section was also found in other *Solenostemon* such as *Solenostemon veyretae* and *Solenostemon rutenbergians* (Guillaumet and Cornet, 1976). The diamond section of the stem seems to have not been yet reported.

According to Chevalier and Perrot (1905), the red coloration on the leaves at the senescence is common in *S. rotundifolius*. This coloration was also reported by Opoku-

Agyeman et al. (2007). Traits related to the flowers are known to be particularly useful in recent classification of Lamiaceae (Ryding, 1994). Opoku-Agyeman et al. (2007) reported two colors of flowers bud (brown and greenish-purple). Tarpaga (2001) identified two types of cultivars based on flowers color. The two types had respectively blue-pale and purple flowers. However, only the blue-pale flowers were described by Chevalier and Perrot (1905) as *S. rotundifolius* flower. Chevalier and Perrot (1905), Tarpaga (2001) and Opoku-Agyeman et al. (2007) mentioned the presence of cultivars without flower. The different types of cultivars could be considered as different morphotypes within *S. rotundifolius* germplasm.

Tubers color and shape were largely used as varietal criteria in *S. rotundifolius.* In West Africa, three main varieties were identified based on tubers color (Chevalier and Perrot, 1905; NRI, 1987). These varieties are *Nigra*, *Rubra* and *Alba* respectively with blackish, reddish and whitish tubers. Tanzubil et al. (2005) mentioned *S. rotundifolius* morphotypes based on the cited colors. Jayakody et al. (2005) and Prematilake (2005) mentioned two varieties in Asia. These varieties are named *Dik* and *Bola* respectively with elongated brown and round black tubers. However, Opoku-Agyeman et al. (2007) recognized nine colors of tubers. Previous works only reported the presence of the varieties *Nigra* and *Rubra* in Burkina Faso (Bognounou, 1970 ; IRAT, 1980 ; Tarpaga, 2001). The variety *Alba* is not well cultivated and seems to have been ignored as *S. rotundifolius* variety in Burkina Faso.

Conclusion

The morphoagronomical characterization showed variability mainly based on the cycle, the leaves and the potential yield of *S. rotundifolius*. Differentiation between cultivars from different provinces was mainly based on the cycle and the potential yield. The results revealed a low variability for tubers size. Most of the qualitative morphological traits were reported to be varietal criteria. Significant correlations were found between the foliage, the cycle and the potential yield. The evaluated traits successfully described the variability within the collected cultivars and could be used as descriptors for *S. rotundifolius* germplasm characterization and for breeding purpose.

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