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Extent and Structure of Phenotypic Variability in *Solenostemon rotundifolius* Germplasm from Ghana and Burkina Faso

Ignace Tonde[1*], Romaric Kiswendsida Nanema[2], Alphonse Tegawende Sawadogo[2]

[1]Department of Plant Biology and Plant Physiology, Faculty of Earth and Life Sciences, Joseph Ki-Zerbo University, Ouagadougou, Burkina Faso
[2]Équipe Génétique et Amélioration des Plantes, Laboratoire Biosciences, Joseph Ki-Zerbo University, Ouagadougou, Burkina Faso
Email: *ignace.tonde15@gmail.com, nanemaromaric@gmail.com, alphonsesawadogo1@gmail.com

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Abstract

Solenostemon rotundifolius is a species belonging to the Lamiaceae family. It is currently one of the minor plants of high socio-economic interest. One of the limitations to promoting this species in Burkina Faso is the lack of varieties that meet consumers' demands. Implementing a breeding program is an important step toward achieving this goal. Such a program is based on the variability of agronomical traits of interest within evaluated germplasm. This study aimed to assess the level of two germplasms variability of *S. rotundifolius* from Ghana and Burkina Faso for traits related to vegetative development, cycle, and yield. Agromorphological characterization of 174 accessions, including 116 from Ghana and 58 from Burkina Faso was carried out in Randomised Complete Block Design with three replications. The characterization was made on the basis of fifteen (15) quantitative traits related to the canopy and leaf size, the cycle, and the yield. Analysis of variance revealed significant differences between accessions within each germplasm for all the evaluated traits. The analysis of the structuration of this agromorphological variability allowed organizing the accessions into different groups. These results could lead to the identification of accessions within each germplasm for breeding purposes or future research on genotype-environment interactions.

Keywords

Lamiaceae, Tuber, Germplasm, Agromorphological Variability

1. Introduction

Solenostemon rotundifolius belongs to the Lamiaceae family. It is a tuber crop of

tropical countries. It is native to central or eastern Africa, but has spread to all tropical regions of the world [1]. In Africa, *S. rotundifolius* is cultivated in Burkina Faso, Mali, Ghana, Nigeria, Togo, Cameroon, Chad and South Africa [2] [3]. It is also widespread in South-East Asia, particularly India, Sri Lanka, Malaysia and Indonesia, where it is grown on small scales [4]. This crop is a vital food source during lean seasons in Africa. The potential yield reported in West Africa varied from 5 to 15 t/ha [5] [6].

Tubers of *S. rotundifolius* are consumed as curries, baked or fried [7]. They contain high calories and essential micronutrients [2]. Raw tubers contain 95.45% of carbohydrates, 2.22% of protein and have an energy value of 395.18 kcal/100g [2]. The pulp of the tubers contains high levels of Magnesium (811.52 mg/100g), Calcium (716.59 mg/100g), and Potassium (73.33 mg/100g) [8].

Solenostemon rotundifolius has the potential to generate significant income for farmers through the sale of its tubers. This helps to decrease poverty, famine, and hunger in numerous rural households [5] [9]. In Ouagadougou, a survey revealed that traders sold between 16 to 32 kg of *S. rotundifolius* tubers per day, with prices ranging from 1.2 to 3 USD/kg [10].

In the current context of climate changes, promoting species that can thrive in harsh soil and weather conditions, is crucial. Research initiatives on the genetic resources of *S. rotundifolius* have made it possible to suggest descriptors that can be used to study agromorphological variability within the species. One of the perspectives of these studies is the characterization of the extent of variability of *S. rotundifolius* germplasm for agronomic traits of interest in order to guide the selection of genotypes that meet the needs of consumers.

This study aims at analyzing the extent of germplasm variability of *S. rotundifolius* from Ghana and Burkina Faso for traits related to canopy and leaf sizes, cycle and yield.

2. Material and Methods

2.1. Plant Material

The plant material consisted of tubers from 174 accessions of *S. rotundifolius*, with 116 from Ghana and 58 from Burkina Faso. Burkina Faso's accessions come from the gene bank of the Biosciences Laboratory of Joseph KI-ZERBO University. They were collected in 32 villages spread over nine (9) provinces in all the three (3) agroecological zones of the country (**Table 1**). Ghana's accessions come from Savanna Research Institute (SARI) gene bank. They were collected in 13 districts spread over two (2) agroecological zones.

2.2. Study Area

An agromorphological evaluation plot was established on the experimental station of the Institute of Rural Development of Nazi Boni University during the rainy season of 2020. The station is located at Gampela (12˚15'N and 1˚12'W) (**Figure 1**). The climate of Gampela is of the Sudano-Sahelian type characterized

Table 1. Origin of accessions of *S. rotundifolius* from Burkina Faso and Ghana.

GHANA			BURKINA FASO		
Districts	Number of accessions	Agroecological zones	Provinces of origin	Number of accessions	Agroecological zones
Bolgatanga	6	Sudan-savannah	Bazega	4	Soudano-sahelian
Talensi	19	Sudan-savannah	Gourma	4	Soudano-sahelian
Navrongo municipal	7	Sudan-savannah	Kadiogo	6	Soudano-sahelian
Kassena	14	Sudan-savannah	Kourweogo	3	Soudano-sahelian
Nabdam	10	Sudan-savannah	Nahouri	7	Soudanian
Garu	3	Sudan-savannah	Noumbiel	13	Soudanian
Bulisa north	18	Sudan-savannah	Passore	8	Soudano-sahelian
Bongo	3	Sudan-savannah	Sanmatenga	9	Sahelian
Wa east	9	Guinea-savanah	Sissili	4	Soudano-sahelian
Sissala west	12	Guinea-savanah	-		
Wa municipal	4	Guinea-savanah	-		
Jirapa municipal	6	Sudan-savannah	-		
Sissala east	5	Guinea-savanah	-		

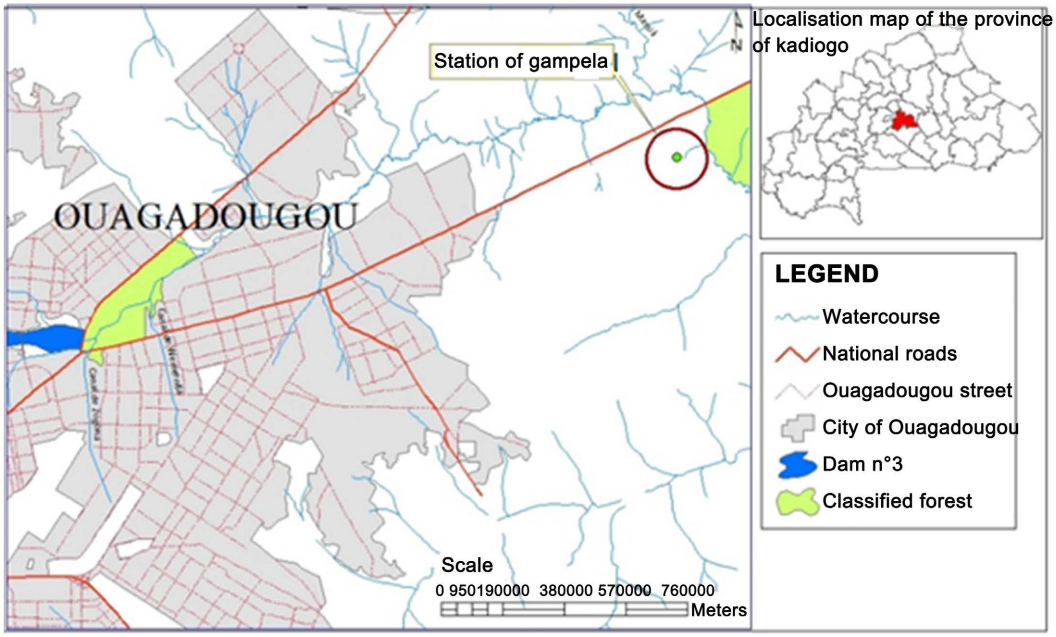

Figure 1. Geographic location of the study area.

by the alternation of a short rainy season of four to five months, from June or July to October and a long dry season of seven to eight months, from November to May or June. During the rainy season of 2020, at total of 865.6 mm of rain was recorded at Gampela research station. The highest rainfall was recorded in August (329 mm) when the lowest rainfall was observed during the month of Oc-

tober (48.2 mm). The average temperature for this month was 28.01˚C, making it the warmest month. The lowest monthly temperature was recorded during the month of December (25.38˚C).

2.3. Experimental Design and Cultural Operations

The experimental plot was ploughed after applying 15 t/ha of organic manure. The experimental design was a Randomised Complete Block with three replications. Each block consisted in two (2) sub blocks of 87 lines. The length of the line was 4.5 m. The spacing between two consecutive lines and two plants within the line was 0.5 m while the distance between the sub-blocks was 1 m. The blocks were spaced at 1.5 m. The size of the experimental plot was 2100 m^2 (60 m × 35 m).

The seeds (pre-germinated tubers) were planted on 18 July 2020 on ridges 25 cm wide and 25 cm high. After planting, the plot was covered with mulching to protect the buds from the sun and predators. The whole plot was weeded when required. A mounding was carried out at the beginning of flowering in order to facilitate tuber development. Supplementary irrigation was brought every three days from October to November. The harvesting was done gradually according to the rate of maturity of the cultivars.

2.4. Quantitative Traits

Fifteen quantitative traits related to canopy and leaf size, cycle and yield were evaluated. The traits related to the cycle were days to the last spike initiation (DLS) which corresponded to the number of days between planting and the spike initiation of the last plant on the line, and days to last maturity (DLM) which corresponded to the number of days between planting and maturity of the last plant on the line.

The traits related to canopy and leaf size and those related to yield were measured on three (3) plants randomly selected per line. A total of eight (8) traits were assessed. Foliage height (FHE) and circumference of canopy (CIC) were recorded on the whole foliage. The traits measured on the leaves were the length and width of the limb of the leaf in position 3 (LLe and LWi). These two traits were used to calculate the leaf ratio (LRa) according to the formula: LRa = LWi/LLe. The main stem length (MSL) and flower stalk length (FSL) were also measured. The total length of the main stem (TLS) was obtained using the formula TLS = MSL + FSL.

Five traits related to yield were measured. These are the number and weight of all tubers per plant (NTP and WTP), mean tuber weight and mean tuber length and diameter (MTL and MTD). The weight was estimated using an electronic scale of a maximum weight 1 Kg. The mean tuber weight (MWT) was calculated using the formula MWT = WTP/NTP. For each category of tubers, the diameter and the length were measured on three randomly selected tubers (9 tubers per plant) using a calliper.

2.5. Statistical Analysis

Data analysis consisted in the evaluation of variability within each germplasm for each category of traits. Analysis of variance (ANOVA) was carried out and difference between means verified using the Student-Newman-Keuls test at the significant level p = 0.05. The Pearson correlation coefficients between traits were calculated at the significant levels p = 0.05 and p = 0.01. A hierarchical ascending classification with the average link as an aggregation criterion was carried out to set up the structuration of variability within each germplasm. The different groups were compared on the basis of the main traits using analysis of variance. All the data analysis were carried out using XLSTAT 18.02.01.

3. Results

3.1. Variability within *S. rotundiflolius*' Germplasm from Burkina Faso

Variability in traits related to canopy and leaf size

The accessions from Burkina Faso significantly differed (at levels p = 0.05 or 0.01) in the traits related to canopy and leaf size (Table 2). Large amplitude of variation was observed in foliage height (FHE) (9.50 - 32.00 cm) and circumference of canopy (CIC) (35.00 - 220.00 cm). The main stem length (MSL) ranged from 4.00 cm to 30 cm and the stalk length (FSL) from 4.00 and 24.00 cm. Then the total length of the main stem (TLS) varied between 9.40 cm to 48.00 cm. The leaf length (LLe) and width (LWi) varied from 2.40 to 6.50 cm and from 1.20 to 4.40 cm respectively. The leaf ratio (LRa) ranged between 0.39 and 0.83. The lowest value of the coefficient of variation was observed for leaf ratio (LRa) (11.08%) and the highest (45.04%) for the flower stalk length (FSL).

Table 2. Variability of *S. rotundifolius* from Burkina Faso in traits related to canopy and leaf size.

Traits	Min.	Max.	Mean	S.D	C.V (%)	Pr > F	Significance of F
FHE (cm)	9.50	32.00	17.51	3.60	20.57	0.001	**
CIC (cm)	35.00	220.00	99.83	32.47	32.52	0.003	**
MSL (cm)	9.00	30.00	17.19	4.26	24.75	<0.0001	**
FSL (cm)	4.00	24.00	9.69	4.36	45.04	0.024	*
TLS (cm)	9.40	48.00	21.01	8.01	38.14	<0.0001	**
LLe (cm)	2.40	6.50	4.34	0.65	14.99	<0.0001	**
LWi (cm)	1.20	4.40	2.78	0.50	18.00	0.001	**
LRA	0.39	0.83	0.64	0.07	11.08	0.021	*

Legend: **Min**.: minimum; **Max**.: maximum; **S.D**: standard deviation; **CV**: coefficient of variation. *Significant difference at p < 0.05; **Significant difference at p < 0.01; **FHE**: foliage height; **MSL**: main stem length; **FSL**: flower stalk length; **TLS**: total length of the main stem; **CIC**: circumference of canopy; **LWi**: leaf width; **LLe**: leaf length; **LRA**: leaf ratio.

Variability in traits related to the cycle

The traits related to the cycle (spike initiation and maturity) were found to discriminate the accessions at the 1% threshold (Table 3). The spike occurred between the 52nd and the 86th day after planting. Three weeks (21 days) were observed between the first maturity (120) and the last maturity (141 days). The coefficients of variation were relatively low (3.64 for DLS to 10.43 for DLM).

Variability in traits related to yield

All the traits related to the yield were found to discriminate the accessions (Table 4). The number of tubers per plant (NTP) and the mean tuber length (MTL) discriminated accessions at the 1% threshold. The less productive accession produced only 5 tubers (NTP) when the number of tubers can up to 123 for the most productive one. The weight of tubers per plant (WTP) varied from 3.60 g to 402.40 g. The mean weight of the tuber (MWT) ranged from 0.38 to 5.32 g. The tuber length (MTL) ranged from 14.90 to 47.64 mm and the diameter (MTD) from 8.00 to 19.39 mm. The values of the coefficient of variation ranged from 18.74% to 105.09% respectively for the mean tuber length (MLT) and tuber weight per plant (WTP).

Correlations between quantitative traits of accessions from Burkina Faso

The evaluation of the relationship between the quantitative traits revealed several significant correlations (Table 5). For traits related to the canopy and leaf size, significant positive correlations at the 1% threshold were observed between foliage height (FHE) and main stem length (MSL) (r = 0.60), total stem

Table 3. Variability of *S. rotundifolius* from Burkina Faso in traits related to the cycle.

Traits	Min.	Max.	Mean	S. D.	C.V (%)	Pr > F	Significance of F
DLS (day)	52.00	86.00	68.17	7.11	10.43	0.004	**
DLM (day)	120.00	141.00	131.15	4.78	3.64	<0.0001	**

Legend: **Min**.: minimum; **Max**.: maximum; **S.D**: standard deviation; **CV**: coefficient of variation; **difference significant at $p < 0.01$; **DLS**: days to last spike initiation; **DLM**: days to the last maturity.

Table 4. Variability of *S. rotundifolius* from Burkina Faso in traits related to yield.

Traits	Min.	Max.	Mean.	S. D	CV (%)	Pr > F	Significance of F
NTP	5.00	123.00	28.30	20.49	72.40	0.000	**
WTP (g)	3.60	402.40	50.10	52.65	105.09	0.013	*
MWT (g)	0.38	5.32	1.72	1.00	58.25	0.021	*
MTL (mm)	14.90	47.64	31.63	5.93	18.74	0.008	**
MTD (mm)	8.00	19.39	13.56	2.38	17.58	0.013	*

Legend: **Min**.: minimum; **Max**.: maximum; **S.D**: standard deviation; **CV**: coefficient of variation; *Significant difference at $P < 0.05$; **Significant difference at $P < 0.01$; **NTP:** number of tubers per plant; **WTP**: weight of tubers per plant; **MWT**: mean weight of the tuber; **MTL**: mean tuber length; **MTD**: mean tuber diameter.

Table 5. Correlations between quantitative traits of *S. rotundifolius* accessions from Burkina Faso.

Traits	DLS	DLM	FHE	MSL	FSL	TLS	CIC	LLe	LWi	LRa	NTP	WTP	MWT	MTL	MTD
DLS	**1**														
DLM	**0.32***	**1**													
FHE	−0.11	0.23	**1**												
MSL	−0.12	0.18	**0.70****	**1**											
FSL	−0.02	−0.20	0.18	0.19	**1**										
TLS	−0.17	0.17	**0.53****	**0.70****	**0.44****	**1**									
CIC	−0.16	0.17	**0.60****	**0.66****	0.12	**0.61****	**1**								
LLe	−0.12	0.16	**0.42****	**0.39****	**0.26***	**0.37****	**0.36****	**1**							
LWi	−0.05	0.05	**0.43****	**0.36****	**0.27***	**0.35****	**0.38****	**0.82****	**1**						
LRa	0.08	−0.12	0.11	0.03	0.03	0.07	0.13	−0.07	**0.50****	**1**					
NTP	−0.09	−0.11	0.22	0.20	0.15	0.24	**0.37****	0.08	0.20	0.23	**1**				
WTP	−0.14	0.02	**0.33***	**0.34****	0.23	0.30	**0.56****	0.25	**0.31***	0.16	**0.83****	**1**			
MWT	−0.17	0.13	0.18	0.17	0.17	0.14	**0.35****	**0.27***	**0.28***	0.07	0.02	**0.47****	**1**		
MTL	**−0.30***	0.04	0.21	0.21	0.10	0.17	**0.30***	**0.40****	**0.45****	0.19	**0.34****	**0.57****	**0.51****	**1**	
MTD	**−0.28***	−0.11	0.16	0.08	0.22	0.18	**0.42****	**0.28***	0.28	0.07	**0.31***	**0.55****	**0.64****	**0.35****	**1**

Legend: *Significant at $p < 0.05$; **Significant at $p < 0.01$; **FHE**: foliage height; **MSL**: main stem length; **FSL**: flower stalk length; **TLS**: total length of the main stem; **CIC**: circumference of canopy; **LWi**: leaf width; **LLe**: leaf length; **LRa**: leaf ratio; **DLS:** days to the last spike initiation; **DLM**: days to last maturity; **NTP**: number of tubers per plant; **WTP**: weight of tubers per plant; **MWT**: mean weight of the tuber; **MTL**: mean tuber length; **MTD**: mean tuber diameter.

length (TSL) and circumference of canopy (CIC) (r = 0.61) and leaf length (LLe) and width (LWI) (r = 0.82). Significant positive correlations at the 5% threshold were also found between flower stalk length (FSL) and the dimensions of the leaf namely the length (LLe) (r = 0.26) and the width (LWi) (r = 0.27).

The correlation between the traits related to the development cycle of the plant (spike initiation and maturity) is significant and positive at the 5% threshold (r = 0.32). The correlations between the traits related to production potential are all significant and positive. Significant correlations at the 1% threshold were obtained between weight (WTP) and number (NTP) of tubers per plant (r = 0.83), and between mean tuber length (MTL) and tuber diameter (MTD) (r = 0.35). There is also a correlation at the 5% level between the diameter of the tuber (MTD) and the number of tubers per plant (NTP) (r = 0.31).

Structuration of the variability of *S. rotundifolius* accessions from Burkina Faso

Structuration of the variability of *S. rotundifolius* based on traits related to canopy and leaf size

Hierarchical ascendant classification was based on foliage height (FHE), circumference of canopy (CIC), leaf ratio (LRa), main stem length (MSL), flower stalk length (FSL), total stem length (TSL), third leaf limb length and width (LLe

and LWi). Four groups of accessions were established (Figure 2).

Analysis of variance between accessions based on HAC groups showed significant differences at the 1% threshold for foliage height (FHE), circumference of canopy (CIC), main stem length (MSL), limb length (LLe) and total stem length (TSL) (Table 6). No significant differences were observed between the groups for flower stalk length (FSL), limb width (LWi) and leaf ratio (LRa). The groups were significantly different for circumference of canopy (CIC). Accession from the group I developed large canopy (CIC = 136.22 cm) followed by groups II and III with respectively CIC = 107.73 cm and 89.97 cm. The group IV gathered the accessions with small canopy size (CIC = 69.42 cm). Groups I and II have higher foliage height (FHE), main stem length (MSL) and limb length (LLe) compared to groups III and IV. In average, group I included individuals with higher vegetative development. Group IV showed the least vegetative growth while groups II and III had intermediate levels.

Structuration of the variability of *S. rotundifolius* based on traits related to the cycle

The hierarchical ascendant classification (HAC) was made based on the number of days to the last spike initiation (DLS) and the number of days to the last maturity (DLM). Three different groups were identified (Figure 3).

Analysis of variance between accessions based on HAC groups showed significant differences (Table 7). Different groups showed discrimination based on traits related to the cycle, with a significance level of $p < 0.01$. The accessions of the group III were earliest with effective spike initiation (DLS) and maturity (DLM) by 63.12 days and 125.65 days after planting. The accessions of the group I had an intermediate cycle (DLS = 68.10 days and DLM = 131.48 days). The group II gathered the late maturing accessions. The number of days to spike initiation was 77.03 when the days to maturity was 135.46 days.

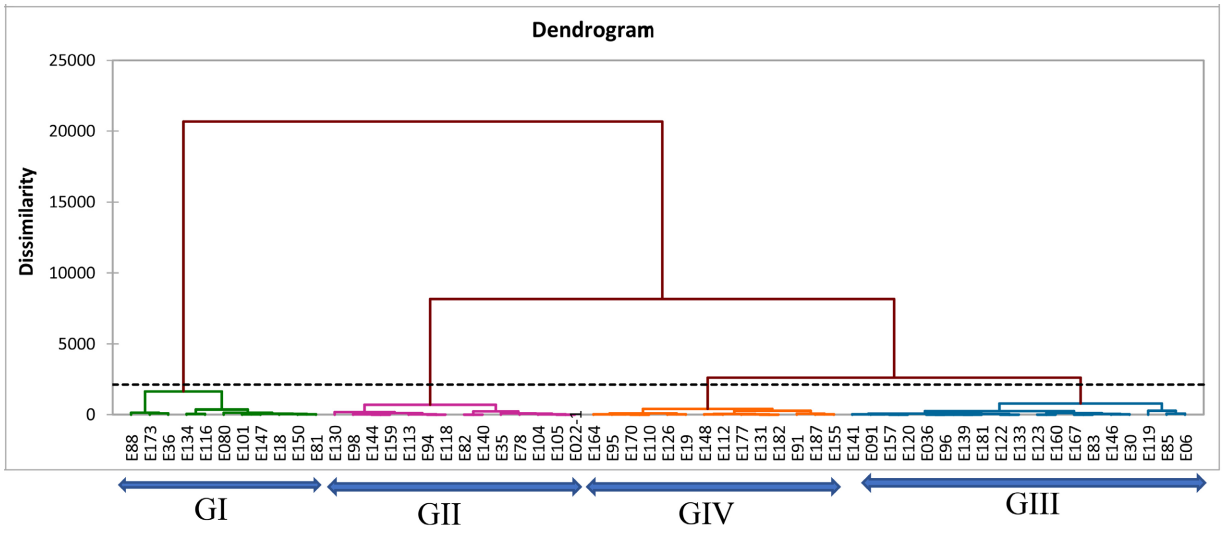

Figure 2. Dendrogram from the hierarchical ascendant classification (HAC) of *S. rotundifolius* accessions from Burkina Faso based on traits related to canopy and leaf size.

Table 6. Characteristics of the groups of accessions from Burkina for traits related to canopy and leaf size.

Groups	Number of accessions	**FHE** (cm)	**MSL** (cm)	**FSL** (cm)	**TLS** (cm)	**CIC** (cm)	**LLe** (cm)	**LWe** (cm)	**LRa**
GI	11	20.36 a	20.67 a	10.29	27.28 a	136.22 a	4.67 a	3.01	0.65
GII	14	18.14 ab	18.13 ab	9.27	21.40 ab	107.73 b	4.41 ab	2.88	0.65
GIII	19	16.41 bc	16.45 bc	9.64	19.88 bc	89.97 c	4.30 ab	2.72	0.63
GIV	14	15.33 c	13.10 c	8.81	15.43 c	69.42 d	4.06 b	2.60	0.64
Pr > F		0.000	0.000	0.799	0.000	0.000	0.037	0.054	0.754
Significance of F		**	**	NS	**	**	**	NS	NS

Legend: **NS**: No Significant at P < 0.05; *Significant difference at P < 0.05; **Significant difference at P < 0.01; **G**: group; **a**, **b**, c and **d**: classes of values from the comparison by the Newman and Keuls test such as a > b > c > d; **FHE**: foliage height; **MSL**: main stem length; **FSL**: flower stalk length; **TLS**: total length of the main stem; **CIC**: circumference of canopy; **LWi**: leaf width; **LLe**: leaf length; **LRa**: leaf ratio.

Table 7. Characteristics of the groups of accessions from Burkina for traits related to cycle.

Groups	Number of accessions	DLS (days)	DLM (days)
GI	40	68.10 b	131.48 b
GII	7	77.03 a	135.46 a
GIII	11	63.12 c	125.65 c
Pr > F		0.000	0.000
Significance of F		**	**

Legend: **Difference significant at P < 0.01; **G**: group; **a**, **b**, and **c**: classes of values from the comparison by the Newman and Keuls test such as a > b > c; **DLS**: days to last spike initiation; **DLM**: days to last maturity.

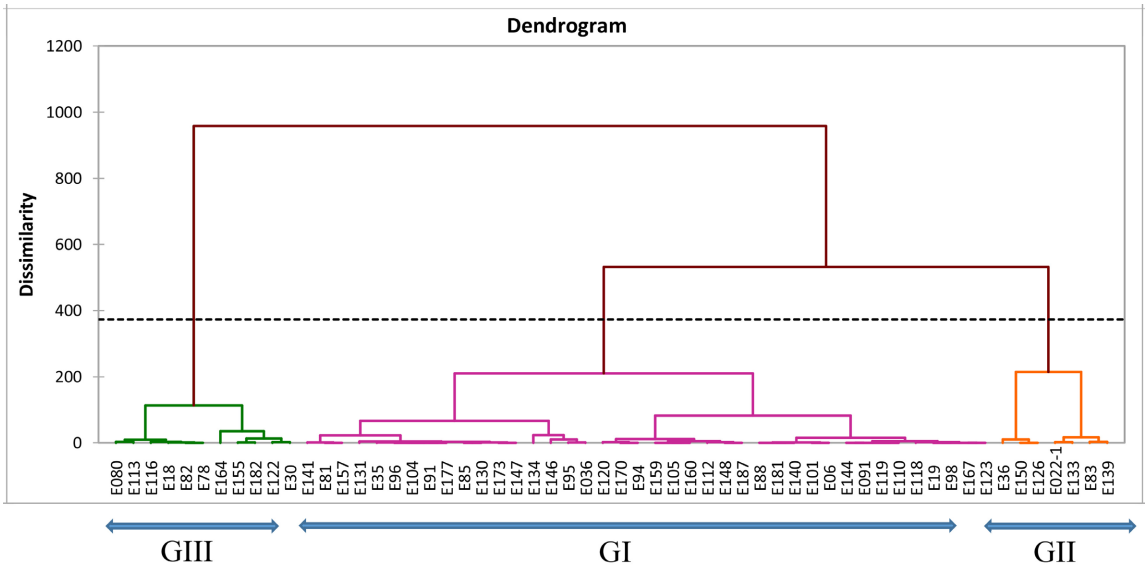

Figure 3. Dendrogram from the hierarchical ascendant classification (HAC) of *S. rotundifolius* accessions from Burkina Faso based on traits related to the cycle.

Structuration of the variability of *S. rotundifolius* based on traits related to yield

Hierarchical ascendant classification (HAC) was performed using the number of tubers per plant (NTP), the tuber weight per plant (WTP), the mean tuber weight (MTW), the mean tuber length (MTL) and the mean tuber diameter (MTD). Four groups were established (Figure 4).

The results of the analysis of variance indicated that the traits related to yield significantly discriminated ($p < 0.01$) the four groups (Table 8). Group III recorded the best performance in number (NTP) (56.26) and weight (WTP) (125.12 g) of tubers per plant. This group is followed by groups I and IV which produced respectively 31.64 and 31.81 tubers (NTP) for a total weight (WTP) of 68.54 g and 43.47 g. Group II has the lowest performance. The number and the weight of tubers per plant were 16.99 and 21.90 g respectively. The accessions of groups I and II did not discriminate for mean tuber weight (MWT). The accessions of the group II and IV had the lowest mean tuber weight (MWT) of 1.48 g and 1.31 g. Tuber length (MTL) was 29.40 cm to 36.57 cm for groups II and III, respectively. The mean diameter of the tuber was 12.91 cm and 15.39 cm for groups II and III respectively. Overall, the group III was the most productive and Group II the least productive. Groups I and IV had an intermediate level of production between the two groups.

3.2. Variability within *S. rotundiflolius*' Germplasm from Ghana

Variability in traits related to canopy and leaf size

The traits related to the canopy and leaf size were all found to be discriminant traits (Table 9). Foliage height (FHE) varied from 9.00 to 47.00 cm, while the

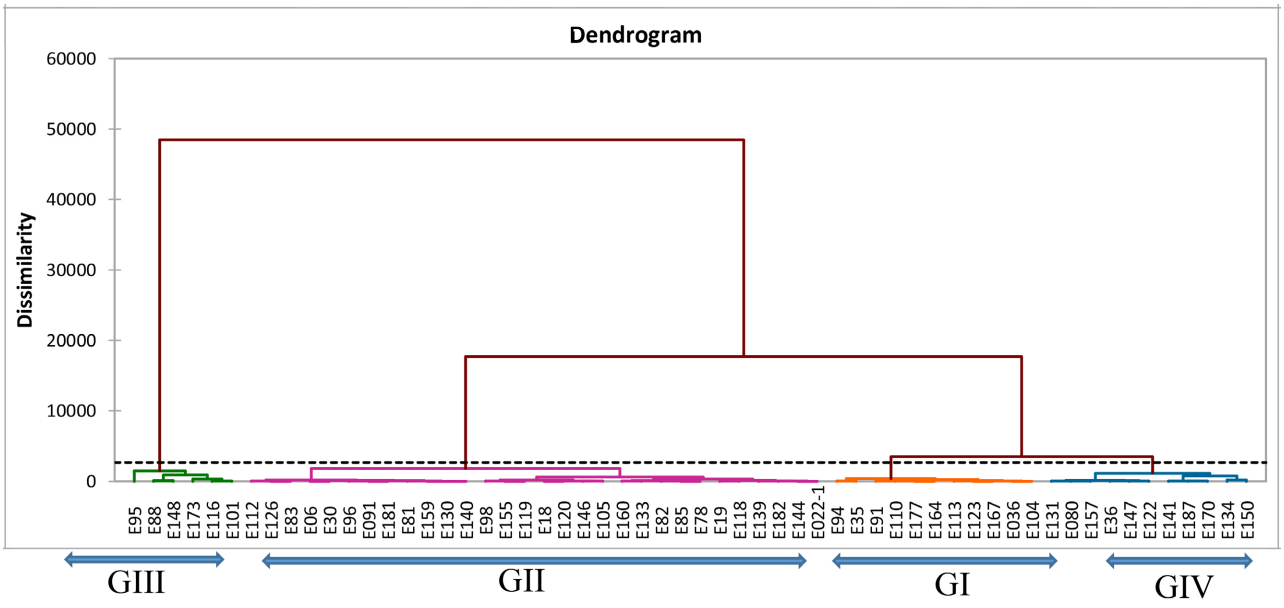

Figure 4. Dendrogram from the hierarchical ascendant classification (HAC) of *S. rotundifolius* accessions from Burkina Faso based on traits related to yield.

Table 8. Characteristics of the groups of accessions from Burkina for traits related to yield.

Groups	Number of accessions	NTP	WTP (g)	MWT (g)	MTL	MTD
GI	11	31.64 b	68.54 b	2.28 a	33.68 a	14.59 ab
GII	30	16.99 c	21.90 d	1.48 b	29.40 b	12.91 c
GIII	6	56.26 a	125.12 a	2.22 a	36.57 a	15.39 a
GIV	11	31.81 b	43.47 c	1.31 b	31.95 ab	13.12 bc
Pr > F		0.000	0.000	0.001	0.000	0.001
Significance of F		**	**	**	**	**

Legend: **Difference significant at $p < 0.01$. **a, b, c and d**: classes of values from the comparison by the Newman and Keuls test such as a > b > c > d. **NTP**: number of tubers per plant; **WTP**: weight of tubers per plant; **MWT**: mean weight of the tuber; **MTL**: mean tuber length; **MTD**: mean tuber diameter.

Table 9. Variability of *S. rotundifolius* from Ghana in traits related to canopy and leaf size.

Traits	Min.	Max.	Mean	S.D	CV	Pr > F	Significance of F
FHE (cm)	9.00	47.00	17.85	4.00	22.41	0.000	**
CIC (cm)	40.00	200.00	106.97	29.60	27.67	<0.0001	**
MSL (cm)	8.50	45.00	17.55	4.28	24.37	<0.0001	**
FSL (cm)	1.50	20.70	8.23	3.97	48.16	0.000	**
TLS (cm)	8.50	55.00	20.42	7.09	34.73	<0.0001	**
LLe (cm)	2.50	6.20	4.35	0.63	14.52	0.001	**
LWi (cm)	1.50	4.60	2.77	0.46	16.70	<0.0001	**
LRa	0.44	1.32	0.64	0.08	12.37	0.029	*

Legend: **Min.**: minimum; **Max.**: maximum; **S.D**: standard deviation; **CV**: coefficient of variation. *Significant difference at $p < 0.05$; **Significant difference at $p < 0.01$; **FHE**: foliage height; **MSL**: main stem length; **FSL**: flower stalk length; **TLS**: total length of the main stem; **CIC**: circumference of canopy; LWi: leaf width; **LLe**: leaf length.

canopy circumference (CIC) ranged from 40.00 to 200.00 cm. Stems and leaf measurements also showed large amplitudes of variation for main stem length (MSL) (8.50 - 45.00 cm), flower stalk length (FSL) (1.50 - 20.70 cm) and total stem length (TSL) (8.50 - 55.00 cm). The leaf length (LLe) and width (LWi) varied from 2.50 to 6.20 cm and 1.50 - 4.60 cm, respectively while the leaf ratio ranged between 0.39 and 0.83. The coefficient of variation was lowest (12.37%) for leaf ratio (LRa) and highest (48.16%) for flower stalk length (FSL).

Variability in traits related to cycle

The traits related to the cycle (spike initiation and maturity) were found to be discriminating at the 1% threshold (Table 10). The spike occurred between the 44th day and the 90th day after planting. Thirty-one (31) days separated the early

Table 10. Variability of *S. rotundifolius* from Ghana in traits related to the cycle.

Traits	Mini.	Max.	Mean	S. D	CV%	Pr > F	Significance of F
DLS (day)	44.00	90.00	67.39	7.17	10.64	<0.0001	**
DLM (day)	110.00	141.00	132.27	5.74	4.34	<0.0001	**

Legend: **Min**.: minimum; **Max**.: Maximum; **S.D**: standard deviation; **CV**: coefficient of variation; **Difference significant at $p < 0.01$; **DLS**: days to last spike initiation; **DLM**: days to last maturity.

maturing (110 days) from the late maturing accession (141 days). The coefficients of variation were relatively low (4.34 for DLM and 10.64 for DLS).

Variability in traits related to yield

All the traits related to yield were found to discriminate the accessions at the 1% threshold (Table 11). The less productive accession produced only 4 tubers (NTP) when the number of tubers can up to 172 for the most productive one. The weight of tubers per plant (WTP) varied from 4.60 g and 409.90 g. The mean weight of the tuber (MWT) ranged from 0.35 g to 4.32 g. The length of the tuber (MTL) varied from 16.92 mm to 73.69 mm and the diameter (MTD) from 7.00 to 31.75 mm. The values of the coefficient of variation ranged from 22.02 and 81.93% respectively for the mean diameter of the tuber (MTD) and the weight of tubers per plant (WTP).

Correlations between quantitative traits of accessions from Ghana

The evaluation of the relationship between the quantitative traits revealed several significant correlations (Table 12). For traits related to canopy and leaf size, significant and positive correlations at the 1% threshold were observed between foliage height (FHE) and main stem length (MSL) ($r = 0.65$), total stem length (TSL) and circumference of canopy (CIC) ($r = 0.58$); the length (LLe) and width (LWI) of the third leaf under the spike ($r = 0.73$). The significant correlations at the 5% threshold were found between flower stalk length (FSL) and main stem length (MSL) ($r = 0.19$), the height of the foliage (FHE) and the leaf length (LLe) ($r = 0.18$).

The correlation between the traits related to the cycle of the plant (spike initiation and maturity) is significant and positive at the 1% threshold ($r = 0.34$). The correlations between the traits related to production potential are all significant and positive at the 1% threshold. A high correlation was found between the number (NTP) and weight (WTP) of tubers per plant ($r = 0.856$).

Structuration of the variability of *S. rotundifolius* accessions from Ghana

Structuration of the variability of *S. rotundifolius* based on traits related to canopy and leaf size

Hierarchical ascendant classification (HAC) was based on foliage height (FHE), circumference of canopy (CIC), leaf ratio (LRa), main stem length (MSL), the length of the flower stalk (FSL), total stem length (TSL), the length and width of the limb of the third leaf (LLe and LWi). Three groups of accessions were established (Figure 5).

Table 11. Variability of *S. rotundifolius* from Ghana in traits related to yield.

Traits	Mini.	Max.	Mean	S. D	CV%	Pr > F	Significance of F
NTP	4.00	172.00	34.07	22.48	66.00	<0.0001	**
WTP (g)	4.60	409.90	60.92	49.92	81.93	<0.0001	**
MWT (g)	0.35	4.32	1.74	0.71	41.05	<0.0001	**
MTL (mm)	16.92	73.69	33.31	6.68	24.77	<0.0001	**
MTD (mm)	7.00	31.75	13.56	2.62	22.02	<0.0001	**

Legend: **Min.**: minimum; **Max.**: maximum; **S.D**: standard deviation; **CV**: coefficient of variation; **Significant difference at $p < 0.01$; **NTP:** number of tubers per plant; **WTP**: weight of tubers per plant; **MWT:** mean weight of the tuber; **MTL**: mean tuber length; **MTD**: mean tuber diameter.

Table 12. Correlations between quantitative traits of *S. rotundifolius* accessions from Ghana.

Variables	DLS	DLM	FHE	MSL	FSL	TLS	CIC	LLe	LWi	LRa	NTP	WTP	MWT	MTL	MTD
DLS	**1**														
DLM	**0.34****	**1**													
FHE	−0.05	0.06	**1**												
MSL	−0.02	0.15	**0.66****	**1**											
FSL	0.04	−0.14	**0.24****	**0.19***	**1**										
TLS	−0.13	−0.02	**0.53****	**0.77****	**0.45****	**1**									
CIC	−0.18	−0.04	**0.56****	**0.69****	0.12	**0.58****	**1**								
LLe	−0.03	−0.05	**0.19***	0.01	−0.03	0.04	**0.21***	**1**							
LWi	−0.10	**−0.27****	0.04	−0.07	−0.03	−0.04	0.17	**0.73****	**1**						
LRa	−0.14	**−0.33****	−0.16	−0.12	−0.02	−0.11	0.01	−0.11	**0.59****	**1**					
NTP	−0.18	−0.23	**0.26****	**0.38****	0.09	**0.32****	**0.58****	0.02	0.11	0.14	**1**				
WTP	**−0.25****	**−0.27****	**0.39****	**0.35****	0.17	**0.32****	**0.63****	0.12	**0.18***	0.14	**0.85****	**1**			
MWT	**−0.28****	−0.18	**0.35****	0.14	0.17	0.16	**0.37****	0.10	0.11	0.06	**0.26****	**0.65****	**1**		
MTL	−0.08	−0.12	**0.37****	**0.23***	0.07	0.14	**0.35****	0.12	0.11	0.03	**0.28****	**0.44****	**0.44****	**1**	
MTD	**−0.29****	−0.13	**0.30****	**0.21***	**0.19***	0.17	**0.29****	−0.02	0.02	0.06	0.22	**0.40****	**0.53****	**0.57****	**1**

Legend: *Significant at $p < 0.05$; **Significant at $p < 0.01$; **FHE**: foliage height; **MSL**: main stem length; **FSL**: flower stalk length; **TLS**: total length of the main stem; **CIC**: circumference of canopy; **LWi**: leaf width; **LLe**: leaf length; **LRa**: Leaf ratio; **DLS**: days to the last spike initiation; **DLM**: days to last maturity; **NTP**: number of tubers per plant; **WTP**: weight of tubers per plant; **MWT**: mean weight of the tuber; **MTL**: mean tuber length; **MTD**: mean tuber diameter.

The agromorphological groups discriminated for foliage height (FHE), mean stem length (MSL), total length of the main stem (TLS) and the circumference of the canopy (CIC) at the 1% threshold (Table 13). The first group (group I) consisted in accessions with a high vegetative development (FHE = 20.64 cm; CIC = 145.42 cm; MSL = 21.54 cm; TLS = 27.34 cm) followed by group II which included accessions with medium vegetative development (FHE = 17.99 cm; CIC = 109.40 cm; MSL = 17.60 cm; TLS = 20.11 cm). The third group (group III) gathered

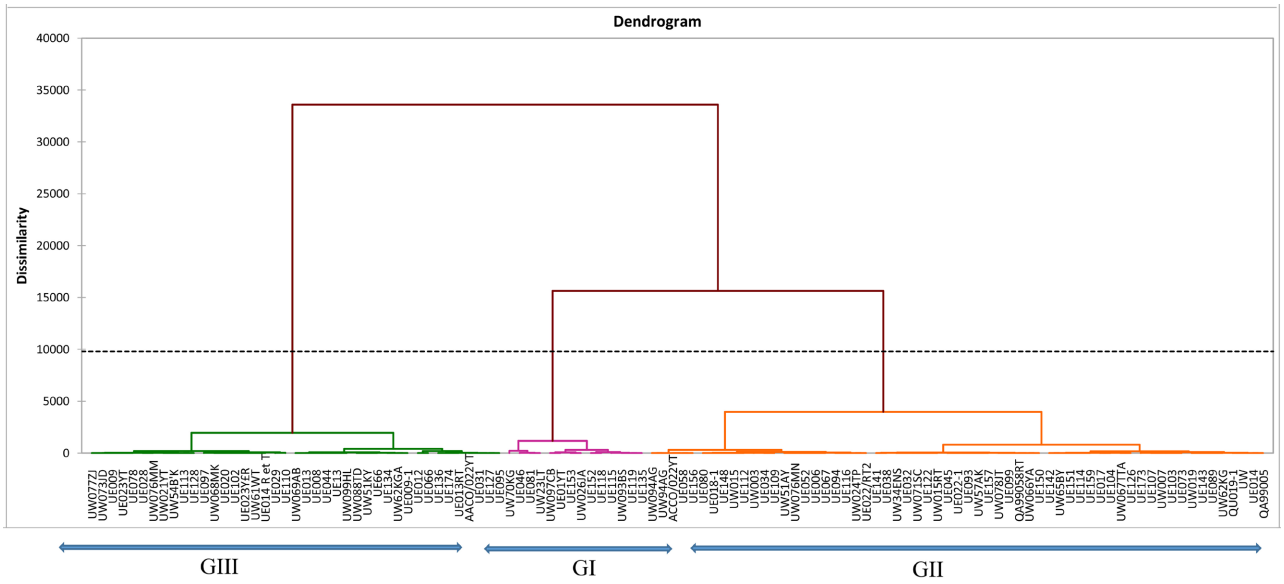

Figure 5. Dendrogram from the hierarchical ascendant classification (HAC) of *S. rotundifolius* accessions from Ghana based on traits related to canopy and leaf size.

Table 13. Characteristics of the groups of accessions from Ghana for traits related to canopy and leaf size.

Groups	number of accessions	FHE (cm)	MSL (cm)	FSL (cm)	TLS (cm)	CIC (cm)	LLe (cm)	LWi (cm)	LRa (cm)
GI	15	20.64 a	21.54 a	8.89	27.34 a	145.42 a	4.55	2.94	0.65
GII	60	17.99 b	17.60 b	8.52	20.11 b	109.40 b	4.37	2.75	0.63
GIII	41	16.07 c	15.14 c	7.97	17.09 c	81.12 c	4.30	2.74	0.64
Pr > F		0.000	0.000	0.633	0.000	0.000	0.158	0.137	0.494
Significance of F		**	**	NS	**	**	NS	NS	NS

Legend: **NS**: No Significant at $p < 0.05$; *Significant difference at $p < 0.05$; **Significant difference at $p < 0.01$; **FHE**: foliage height; **MSL**: main stem length; **FSL**: flower stalk length; **TLS**: total length of the main stem; **CIC**: circumference of canopy; **LWi**: leaf width; **LLe:** leaf length; **LRa**: Leaf ratio.

the accessions with low vegetative development (FHE = 16.07 cm; CIC = 81.12 cm; MSL = 15.14 cm; TLS = 17.09 cm).

Structuration of the variability of *S. rotundifolius* based on traits related to the cycle

The hierarchical ascendant classification (HAC) was made based on the number of days to the last spike initiation (DLS) and the number of days to the last maturity (DLM). Six different groups were identified (Figure 6).

The groups discriminated for traits related to the cycle ($p < 0.01$) (Table 14). Groups III and VI gathered the late maturing accessions (DLM = 138.48 and 136.54 days to maturity respectively). However, the spike initiation started early for the accessions of group III (DLS = 64.83 days). The groups I and IV were characterized by medium-cycle accessions. The maturity occurred 131.25 and 132.39 days after planting. The spike initiation for groups I and III occurred

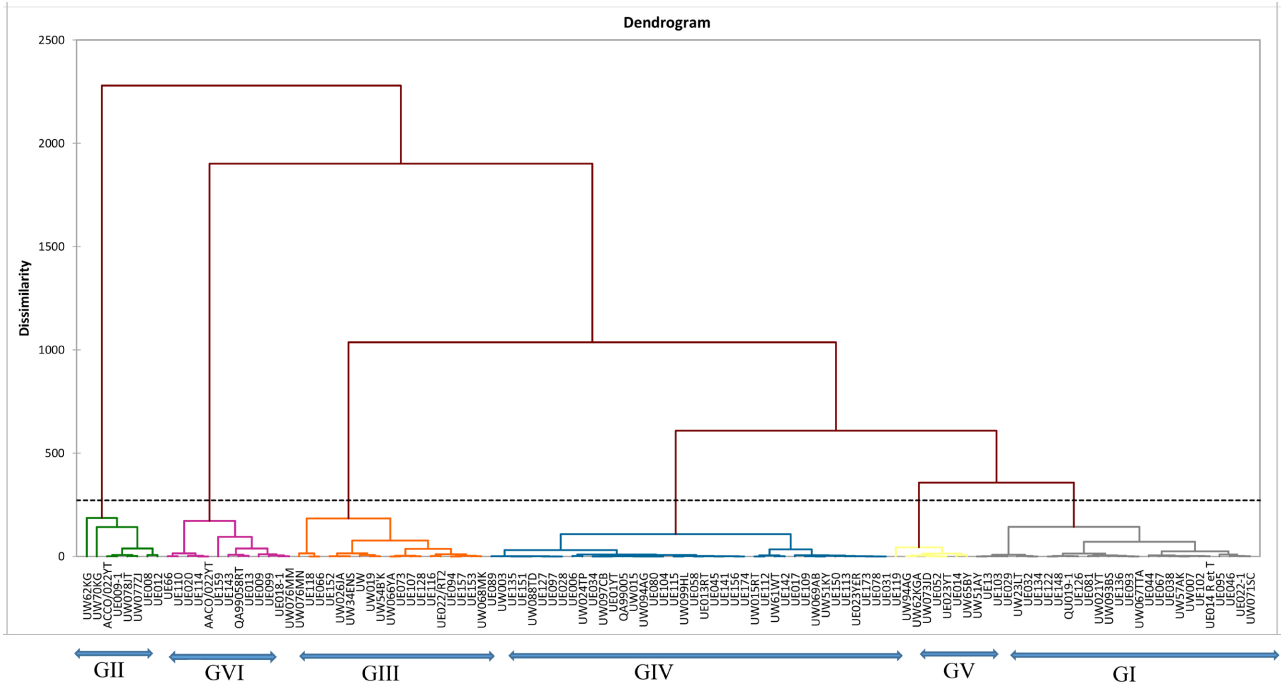

Figure 6. Dendrogram from the hierarchical ascendant classification (HAC) of *S. rotundifolius* accessions from Ghana based on traits related to the cycle.

Table 14. Characteristics of the groups of accessions from Ghana for traits related to cycle.

Groups	Number of accessions	DLS (days)	DLM (days)
GI	28	64.00 c	131.25 b
GII	8	68.25 b	125.71 c
GIII	19	64.83 c	138.48 a
GIV	40	69.73 b	132.39 b
GV	8	55.27 d	121.62 d
GVI	13	79.28 a	136.54 a
Pr > F		0.000	0.000
Significance of F		**	**

Legend: **Difference significant at $p < 0.01$; **G**: group; **a**, **b**, **c** and **d**: classes of values from the comparison by the Newman and Keuls test such as a > b > c > d; **DLS**: days to last spike initiation; **DLM**: days to last maturity.

64.00 and 64.83 days after planting, respectively. Group V gathered the early maturing accessions (DLS = 55.27 days and DLM = 121.62 days).

Structuration of the variability of *S. rotundifolius* based on traits related to yield

Hierarchical ascending classification (HAC) was performed using the number of tubers per plant (NTP), the tubers weight per plant (WTP), the mean tuber weight (MTW), the mean tuber length (MTL) and the mean tuber diameter (MTD). Three groups were established (Figure 7).

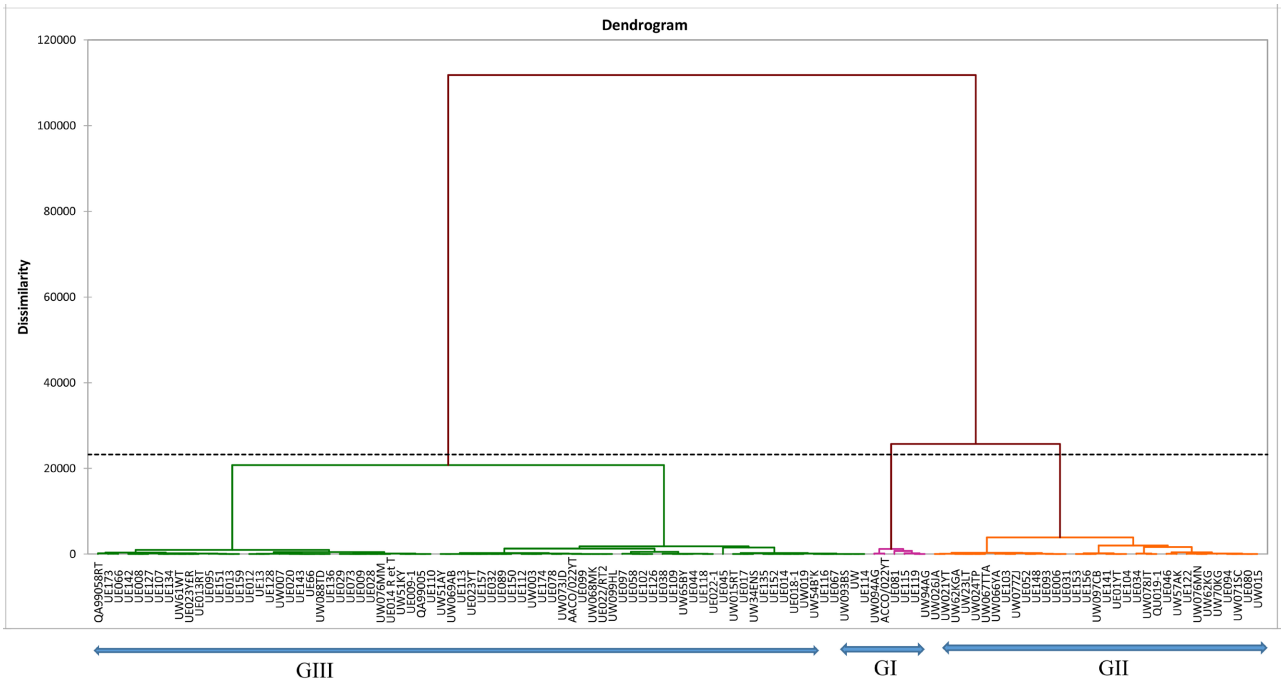

Figure 7. Dendrogram from the hierarchical ascendant classification (HAC) of *S. rotundifolius* accessions from Ghana based on traits related to yield.

Table 15. Characteristics of the groups of accessions from Ghana for traits related to yield.

Groups	Number of accessions	NTP	WTP (g)	MWT (g)	MTL (mm)	MTD (mm)
GI	6	63.23 a	153.06 a	2.52 a	39.42 a	15.19 a
GII	33	45.09 b	84.42 b	1.92 b	34.58 a	13.10 ab
GIII	77	22.82 c	34.36 c	1.51 c	31.65b	13.12 b
Pr > F		0.000	0.000	0.000	0.001	0.013
Significance of F		**	**	**	**	**

Legend: **Difference significant at $p < 0.01$. **a, b, c and d**: classes of values from the comparison by the Newman and Keuls test such as a > b > c > d. **NTP**: number of tubers per plant; **WTP**: weight of tubers per plant; **MWT**: mean weight of the tuber; **MTL**: mean tuber length; **MTD**: mean tuber diameter.

The results of the analysis of variance indicated that the traits related to yield significantly discriminated ($p < 0.01$) the three groups (Table 15). The accessions of the group I were the most productive (NTP = 62.23; WTP = 153.06 g) and produced large tubers (MWT = 2.25 g, MTL = 39.42 mm and MTD = 15.19 cm). This group is followed by the group II which included accessions with intermediate performance (NTP = 45.09; WTP = 84.42 g and MWT = 1.92 g). Group III was the less productive one (NTP = 22.82; WTP = 34.36 g and MWT = 1.51 g).

4. Discussion

Varietal selection is based on the genetic variability of species. Morphological

markers are the basis for the identification and classification of plant species. These markers are still used successfully in many agronomic characterization and evaluation studies, allowing easier and faster differentiation of phenotypes. These descriptors are related to foliage size, the cycle, and the potential of tuber production. Indeed, the performance of the accessions of the two germplasms, including canopy and stem size, the cycle and the tuber production potential (number, weight and size) are substantially similar to those observed by [3] and [11]. This level of variability was also reported for vegetatively propagated plants such as *Colocasia esculenta* (L.) Schott [12] and *Dioscorea sp* [13].

The variability observed for each category of traits revealed distinct groups for each germplasm. These results are similar to those of [14] and [7], which mentioned foliage size, productivity and cycle as key parameters in structuring phenotypic variability in *S. rotundifolius* germplasm.

The grouping of accessions on the basis of canopy development characteristics revealed three and four distinct groups respectively for the germplasm of Ghana and Burkina Faso, reflecting a great variability within the accessions. The different groups of accessions have been characterized, allowing the identification of those with large or low canopy. Accessions with high vegetative development offer huge benefits. Since *S. rotundifolius* is a vegetatively propagated plant, large canopy could help producing more cuttings that can be used as planting materiel. The use of the entire length of the stem could be an alternative to increase the number of cuttings. Such technique is applied to sweet potato and yam [15]. In traditional medicine, plants with high vegetative growth could be useful because the leaves of *S. rotundifolius* have healing and antiseptic properties [6].

Grouping accessions on the basis of cycle traits also identified six and three distinct groups of germplasm from Ghana and Burkina Faso, respectively. The characteristics related to the cycle discriminated the different groups within each germplasm. The days to spike initiation and maturity have thus allowed a characterization of the different accessions of *S. rotundifolius* of the two countries. There was no synchronization of spike initiation, or maturity. This highlights the variability within each germplsm, allowing the identification of short and long-cycle accessions. Thirty-one days and twenty-one days separated the first maturity from the last, respectively for the germplasm of Ghana and Burkina Faso. The absence of flowering in some accessions did not allow flowering dates to be included in the evaluation. The variation in cycle reported by other authors, 150 to 180 days by [16] and 112 to 161 days by [7], is greater than our results. This difference could be due to the photosensitivity of the plant [17].

The description of the different groups resulting from the grouping of the accessions of the two germplasms on the basis of traits related to production potential showed significant differences ($p < 0.01$). The tuber size and weight were also used for germplasm evaluation of *S. rotundifolius* [11]. Group I and Group III germplasm accessions from Ghana and Burkina Faso were identified as the

most productive. The good agronomic potentialities of these accessions of *S. rotundifolius* could be explained by their genetic potential. This factor was reported by [3] who studied morphometric variability between three morphotypes of *Solenostemon rotundifolius*. Future breeding works may focus on the accessions of these groups.

The variability observed in these two germplasms explains the genetic diversity in S. *rotundifolius* as described by [3] and [11].

5. Conclusion

Our study of the phenotypic variability of *S. rotundifolius* accessions cultivated in Burkina Faso and Ghana showed significant variation in vegetative development, cycle, and yield traits. Thus, this work allowed identification of groups of accessions with agronomic interest.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Murugesan, P., Koundinya A.V.V. and Asha, K.I. (2020) Evaluation of Genetic Resource of Chinese Potato (*Plectranthus rotundifolius*) for Abiotic Stress Management—A Review. *Current Horticulture*, **8**, 7-11. https://doi.org/10.5958/2455-7560.2020.00002.3

[2] Hua, L., Hadziabdic, D., Amissah, N., Nowicki, M., Boggess, S. L., Staton, M., *et al.* (2018) Characterization of Fifteen Microsatellite Loci and Genetic Diversity Analysis for the Ghanaian Food Security Crop *Solenostemon rotundifolius* (Frafra Potato). *African Journal of Biotechnology*, **17**, 1352-1357. https://doi.org/10.5897/AJB2018.16666

[3] Nanema, R.K., Kiebre, Z., Traore, R.E., Aminata Hamidou B.A. and Kusi, F. (2019) Characterisation of Three Morphotypes of *Solenostemon rotundifolius* [(Poir.) JK Morton] Cultivated in Burkina Faso Using Quantitative Traits. *International Journal of Genetics and Molecular Biology*, **11**, 6-15. https://doi.org/10.5897/IJGMB2019.0171

[4] Tindall H.D. (1983) Vegetables in the Tropics. The Macmillan Press Limited, London, 242-245. https://doi.org/10.1007/978-1-349-17223-8

[5] Enyiukwu, D.N., Awurum, A.N. and Nwaneri, J.A. (2014) Potentials of Hausa Potato (*Solenostemon rotundifolius* (Poir.) J.K Morton and Management of Its Tuber Rot in Nigeria. *Greener Journal of Agronomy, Forestry and Horticulture*, **2**, 27-37. https://doi.org/10.15580/GJAFH.2014.2.010314008

[6] Kwarteng, A.O., Ghunney, T., Adu Amoah, R., Nyadanu, D., Abogoom, J., Nyam, K.C., Ziyaaba, J.Z., *et al.* (2018) Current Knowledge and Breeding Avenues to Improve upon Frafra Potato (*Solenostemon rotundifolius* (Poir.) J. K. Morton. *Genetic Resources and Crop Evolution*, **65**, 659-669. https://doi.org/10.1007/s10722-017-0581-6

[7] Nanema, K.R. (2010) Ressources génétiques de *Solenostemon rotundifolius (*Poir.*) J. K.* Morton du Burkina Faso: système de culture, variabilité agromorphologique et

relations phylogénétiques entre ses différents morphotypes cultives au Burkina *Faso*. Thèse de doctorat, Université Ouaga I Professeur Joseph KI-ZERBO, Ouagadougou, 48 p.

[8] Kwazo, H.A., Sulaiman, A.U., Abdulmumin, U., Muhammad, M.U., and Mohammed, S. (2021) Comparative Assessment of Chemical Composition and Anti-Nutrient Components of *Solenostemon rotundifolius* Tuber Pulp and Peel. *African Journal of Food Science and Technology*, **12**, 1-6.

[9] Ouédraogo, A., Sedego, A. and Et Zongo, J.D. (2007) Perceptions paysannes de la culture et des utilisations du «fabirama» (*Solenostemon rotundifolius* (Poir.) J.K. Morton) dans le plateau central du Burkina Faso. *Annale de Botanique en Afrique de l'Ouest*, **4**, 13-21.

[10] Nanéma, K.R., Sawadogo, N., Traoré, E.R. and Ba, A.H. (2017) Marketing Potentialities and Constraints for Frafra Potato: Case of the Main Markets of Ouagadougou (Burkina Faso). *Journal of Plant Science*, **5**, 191-195.

[11] Opoku-Agyeman, M.O., Bennett-Lartey, S.O., Vodouhe, R.S., Osei, C., Quarcoo, E., Boateng, S.K. and Osekere, E.A. (2007) Morphological Characterization of Frafra Potato (*Solenostemon rotundifolius*) Germplasm from the Savannah Regions of Ghana. Plant Genetic Resources and Food Security in West and Central Africa. *Regional Conference*, Ibadan, 26-30 April 2004, 116-123.

[12] Traoré, E.R., Nanéma, K.R., Bationo/Kando, P., Sawadogo, M., Nebie, B. and Zongo, J.D. (2015) Variation agromorphologique dans une collection de taro (*Colocasia esculenta* (L.) Schott) adapté aux conditions de culture pluviale au Burkina Faso. *Internationnal Journal of Biological and Chemical Sciences*, **6**, 1490-1502.

[13] Tiama, D., Zoundjihekpon, J., Sawadogo, N., Nebie, B., Bationo-Kando, P., Sawadogo, M. and Zongo, J.-D. (2016) Agro-Morphological Characterization *of* Yams (*Dioscorea sp*) of Passoré in Burkina Faso. *Journal of Applied Environmental and Biological Sciences*, **6**, 1.

[14] Tarpaga, W.V. (2001) Etude de la variabilité agromorphologique d'une collection de Solenostemon rotundifolius du Burkina Faso. Bachelor's Thesis, Université Bobo Dioulasso, Bobo Dioulasso, 56 p.

[15] Chauhan, A., Sharma, D., Kumar, R., Shiwani, K. and Sharma, N. (2021) Methods of Propagation in Vegetable Crops.
https://www.researchgate.net/publication/355393673

[16] NRI (1987) Root Crops. 2nd Edition, Tropical Development and Research Institute, London, 308 p.

[17] Abraham, M. and Radhakrishnan, V.V. (2005) Assessment and Induction of Variability in Coleus (*Solenostemon rotundifolius*). *Indian Journal of Agricultural Sciences*, **75**, 834-836.