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Morphological characteristics of morphotypes of *Solenostemon rotundifolius* [(Poir.) J. K. Morton] cultivated in Burkina Faso and Ghana.

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Abstract

Solenostemon rotundifolius, also known as *fabirama*, *frafra* potato or *pessa*, is an annual herb belonging to the *Lamiaceae* family. It is widely cultivated in tropical regions of Africa and Asia for its edible tubers. *S. rotundifolius* has significant nutritional, medicinal and socio-economic potential. Despite its proven potential, *S. rotundifolius* is one of the minor plants in its cultivation area. As a vegetatively propagated species, the morphotypes characteristics of *S. rotundifolius* are stable and could be a reference for a clear description and use of landraces. Several studies on the species were based mainly on tuber skin color to identify the morphotypes. However, using this criterion alone can lead to errors in identifying the morphotypes of *S. rotundifolius*. The present study was carried out to contribute to a better description of the morphotypes of *S. rotundifolius* cultivated in Burkina Faso and Ghana based on qualitative traits. Twelve accessions of *S. rotundifolius*, including five from Burkina Faso and seven from Ghana, identified based on leaves and inflorescence aspect, were characterized in Fisher block design with three replications. Thirty qualitative traits related to foliage, flowers, and tubers were recorded. Based on the morphological variability, eight morphotypes were identified. The most discriminating morphological traits were the young plant stem and leaves color, the leaves thickness, the apical leaves

color, the flower organs color, the tuber shape, the tuber skin and flesh color. The characteristics of the morphotypes could be a reference for future descriptions of *S. rotundifolius* morphological variability and for breeding purposes.

Keywords: *Solenostemon rotundifolius*, *Lamiaceae*, morphotypes, genetic resources, tuber.

INTRODUCTION

Solenostemon rotundifolius [(Poir.) J. K. Morton] is an edible tuber plant from tropical Africa and Asia. It belongs to the *Lamiaceae* family and is also known as Hausa potato, Chinese potato, Zulu round potato, Sudan potato, Saluga, *fabirama* or *Frafra* potato. *S. rotundifolius* is thought to have originated in Central or East Africa, and its cultivation has spread to tropical countries in Africa and South-East Asia (Tindall, 1983). In West Africa, *S. rotundifolius* is cultivated in Burkina Faso, Ghana, Nigeria, Mali and Togo (Nanéma et al., 2009; Sugri et al., 2013) in Central Africa in Cameroon, Central African Republic and Chad, and in East Africa in Tanzania (Schoeninger et al., 2001; Gouado et al., 2003) and western Sudan (Burkill, 1995). It is also cultivated in South Africa (Reinten and Coetzee, 2002). In Asia, *S. rotundifolius* is cultivated in India, Indochina, Indonesia, Malaysia, Thailand, Philippines and Sri Lanka (Kwarteng et al., 2018; Sethuraman et al., 2020).

S. rotundifolius is an annual herb that can grow up to 30 cm in height. It has ascending or prostrate stems and green leaves that vary in thickness depending on the morphotype (Sugri et al., 2013; Nanéma et al., 2019). It produces blue, pinkish-white or pale purple hermaphrodite flowers (Acheampong, 2010; Enyiukwu et al., 2014), most of which do not persist long enough (Nanéma et al., 2018). *S. rotundifolius* produces many tubers with various colour, shape and size (Prota, 2013; Nanéma et al., 2018). The number of tubers per plant can reach 100 to 150 (Ouédraogo et al., 2007). In West Africa, average yields generally vary between 5 to 15 t/ha (Enyiukwu et al., 2014).

S. rotundifolius tubers are commonly consumed raw, curry, baked, fried, or cooked (Schippers, 2000; Wulueng et al., 2000 ; Gouado et al., 2003 ; Enyiukwu et al., 2014). They contain high levels of calories, carbohydrates, proteins, fibre, fat, calcium, vitamins and antioxidants (Anbuselvi et Priya, 2013). Besides its nutritional attributes, *S. rotundifolius* is commonly used in Africa and Asia to treat dysentery, eye diseases, sore throat and haematuria (Niino et al., 2000 ; Ouédraogo et al., 2007), and has strong economic potential (Enyiukwu et al., 2014; Nanéma et al., 2017). A survey carried out in Ouagadougou (Burkina Faso) revealed that the price per kilogram of tubers of *S. rotundifolius* varied from 1.2 to 3 USD/Kg depending on the period of availability. *S. rotundifolius* tubers are increasingly used as a raw material in the manufacture of food products such as bread (Rahman, 2010), cakes (Cicilia et al., 2018), vermicelli (Herawati et al., 2018) and instant porridge (Natasya et al., 2022).

Despite its proven socio-economic importance, *S. rotundifolius* is one of the minor crops in its area of cultivation and its full potential is not sufficiently exploited. According to Houdegbe et al. (2016), neglected and underutilized species could contribute to food and nutrition security if their potential is

sufficiently exploited. Knowledge of the agromorphological variability of a species is an essential step toward a sustainable use and management of its genetic resources. Previous research has highlighted some variability within the germplasm of *S. rotundifolius* and helped to identify traits that could be used as descriptors (Opoku-Agyeman et al., 2007; Nanéma et al., 2018). However, this variability has not been sufficiently exploited to identify the main morphotypes of *S. rotundifolius*. Tuber skin color was previously used as main criterion to identify the morphotypes within *S. rotundifolius* genetic resources (Nanéma et al., 2009 ; Sugri et al., 2013; Nanéma et al., 2018). Some research, particularly in biochemistry and nutrition, was carried out using the tuber skin color as the main criterion for the identification of the morphotypes (Jayakody et al., 2005 ; Priya et al., 2013). However, the use of this criterion alone can lead to errors in the identification of *S. rotundifolius* morphotypes. A reliable description of the morphotypes should include large number of relevant traits related to foliage, flower and tubers as well. The aim of this study was to contribute to a better description of the main morphotypes of *S. rotundifolius* cultivated in Burkina Faso and Ghana, based on qualitative traits related to foliage, flower, and tuber characteristics.

MATERIALS AND METHOD

Plant material

The plant material used consisted of twelve (12) accessions of *S. rotundifolius*, of which five were from Burkina Faso and seven from Ghana. The accessions from Burkina Faso were namely E120, E125, E165, E183 and E186. Ghanaian accessions were represented by QA99056YT, UE023-1, UE072ID, UE088, UW070AIA, UW086M and WHITE. These accessions were selected from *S. rotundifolius* gene bank in

Burkina Faso and Ghana to cover the variability observed previously in traits related to foliage, flower and tuber. For each accession, eighteen (18) tubers were selected for the experiment.

Study area and experimental design

The experiment was carried out in the experimental garden of Life and Earth Sciences Training and Research Unit of Joseph KI-ZERBO University (12°21'56" N; 1°32'01" W) during the 2020 rainy season. During the trial period, 852.5 mm of rain was recorded in 61 rainy days. A total of 216 plastic pots (diameter: 45 cm; depth: 15 cm) were used for the experiment. The pots had holes drilled in the bottom to allow water to drain. They were then filled to 4/5 capacity with a mixture of potting soil, sand and organic fertiliser in proportions of 2/5, 2/5 and 1/5 respectively. The mixture was watered several times before planting. The trial was carried out in a completely randomized Fisher block design with three replications. Each block consisted of 12 lines of six pots. A path of 1m was observed between the blocks and 0.5 m between the lines. The distance between pots was 15 cm. The tubers were planted on 24 June 2020. One pre-germinated tuber was transplanted per pot.

Morphological traits

A total of thirty (30) qualitative morphological traits were observed from the emergence to maturity (table 1). These traits were identified during previous agromorphological characterization of *S. rotundifolius*

genetic resources. The traits were recorded on 18 plants per accession.

Morphological traits observed at the vegetative phase

Ten (10) morphological traits were observed during the vegetative phase. At the juvenile stage, young plant stem (YSC) and leaves (YLC) color and the young plant leaves hairiness (YLH) were observed. During the vegetative growth of the plants, leaf shape (LSH) and margin type (LMT), limb thickness (LTH), stem (SCO) and apical leaves color (ACO), main stem (MSS) and lateral stems stature (LSS), were observed.

Morphological traits observed at flowering stage and after harvesting

Fifteen (16) traits related to the inflorescence, the stem and the leaves were observed during the heading and the flowering stage. These were: flower buds color (FBC), number of flower buds per cluster (NFB), shape of inflorescence (SIN), type of inflorescence (TIN), level of inflorescence branching (LIB), flowers arrangement on the rachis (FAR), flowers' persistence (FPE), sepal color (SEC), petal color (PCO) and flowering stem color (FSC), adult plant leaf color (ALC), adult plant stem color (ASC), adult plant leaf hairiness (ALH), adult plant stem hairiness (ASH), main stem section (MSE) and presence of particular stem section (PPS). After harvesting, four (04) traits related to the tubers were observed. These were tuber shape (TSH), tuber skin color (TSC), tuber flesh color (TFC) and presence of lateral tubers (PLT).

Table 1. Morphological traits observed on the morphotypes of *S. rotundifolius*

Stage	Morphological traits	Abbreviations
Young plant	Young plant stem color	YSC
	Young plant leaf color	YLC
	Young plant leaf hairiness	YLH
	Leaf shape	LSH
	Leaf margin type	LMT
	Limb thickness	LTH

Vegetative growth stage		Stem color	SCO
		Apical leaves color	ACO
		Main stem stature	MSS
		Lateral stems stature	LSS
Flowering stage	Reproductive organs	Flower buds color	FBC
		Number of flower buds per cluster	NFB
		Shape of inflorescence	SIN
		Type of inflorescence	TIN
		Level of inflorescence branching	LIB
		Flowers arrangement on the rachis	FAR
		Flowers' persistence	FPE
		Sepal color	SEC
		Petal color	PCO
		Flowering stem color	FSC
	Vegetative organs	Adult plant leaf color	ALC
		Adult plant stem color	ASC
		Main stem section	MSE
		Presence of particular stem section	PPS
		Adult plant leaf hairiness	ALH
		Adult plant stem hairiness	ASH
After harvesting		Tuber shape	TSH
		Tuber skin color	TSC
		Tuber flesh color	TFC
		Presence of lateral tubers	PLT

Data analysis

An Excel spreadsheet was used to enter and process the data. Data from the three blocks were summarized by trait for each accession. The plant with missing data were excluded from the analyses. A descriptive and comparative analysis of the accessions was carried out, based on the main qualitative traits observed, in order to describe the morphotypes.

RESULTS

Variability of the *Solenostemon rotundifolius* accessions at juvenile stage

After the emergence, the accessions differed in the color of the stem (YSC) and leaves of the young plant (YLC) (Table 2). Stems and leaves of young plants of accessions E120, E125 and QA99056YT were green, while stems of accessions E165, UE023-1, UE088, UW072ID and WHITE were reddish and their leaves were green. Accessions E183 and E186 produced young plants with reddish stems and green leaves with white-purple spots, while accessions UW070AIA and UW086M produced young plants with reddish stems and green-purple leaves (Figure 1). The leaves of the young plants (YLH) of all accessions were pubescent.



Green stems (E120)



Green stems (E125)



Reddish Stems (E165)



Green leaves (E120)



Green leaves (E125)



Green leaves (E165)



Green stems (QA99056YT)



Reddish Stems (UE023-1)



Reddish Stems (UE088)



Green leaves QA99056YT



Green leaves (UE023-1)



Green leaves (UE088)



Reddish Stems (UW072ID)



Reddish Stems (WHITE)



Reddish Stems (E183)



Green leaves (UW072ID)



Green leaves (WHITE)



Green leaves with purple to whitish spots. (E183)



Reddish Stems (E186)



Purple stem (UW070AIA)



Purple stem (UW086M)



Green leaves with purple to whitish spots (E186)



Green leaves with purplish veins (UW070AIA)



Green leaves with purplish veins (UW086M)

Figure 1: Young plants of *S. rotundifolius* presenting different stems and leaves color.

Table 2. Variability between accessions at juvenile stage

Accessions	Morphological traits		
	YSC	YLC	YLH
E120	Green	Green	Pubescent
E125	Green	Green	Pubescent
E165	Red	Green	Pubescent
E183	Red	Green with purple to whitish spots.	Pubescent
E186	Red	Green with purple to whitish spots.	Pubescent
QA99056YT	Green	Green	Pubescent
UE023-1	Red	Green	Pubescent
UE088	Red	Green	Pubescent
UW070AIA	purple	Green with purplish veins	Pubescent
UW072ID	Red	Green	Pubescent

UW086M	purple	Green with purplish veins	Pubescent
WHITE	Red	Green	Pubescent

YSC: Young plant stem color; YLC: Young plant leaf color; YLH: Young plant leaf hairiness.

Variability of the accessions at vegetative growth stage

Except for leaf shape (LSH), several variants were identified for all morphological traits observed during vegetative growth, highlighting differences between *S. rotundifolius* accessions (table 3). All accessions leaves were oval. Two leaf types were identified based

on leaf thickness (LTH) and leaf margin (LMT) (Figure 2). The leaves of accessions E120, E125, UE088, UW070AIA and UW086M were very thick and very crenellated, while those of accessions E165, E183, E186, QA99056YT, UW072ID and WHITE were less thick and less crenellated. The leaves of accession UE023-1 were very thick and less crenellated.



Very thick and very crenellated leaf



Very thick and very crenellated leaf



Very thick and very crenellated leaf



Very thick and very crenellated leaf



Very thick and very crenellated leaf



Less thick and less crenellated leaf



Less thick and less crenellated leaf



Less thick and less crenellated leaf

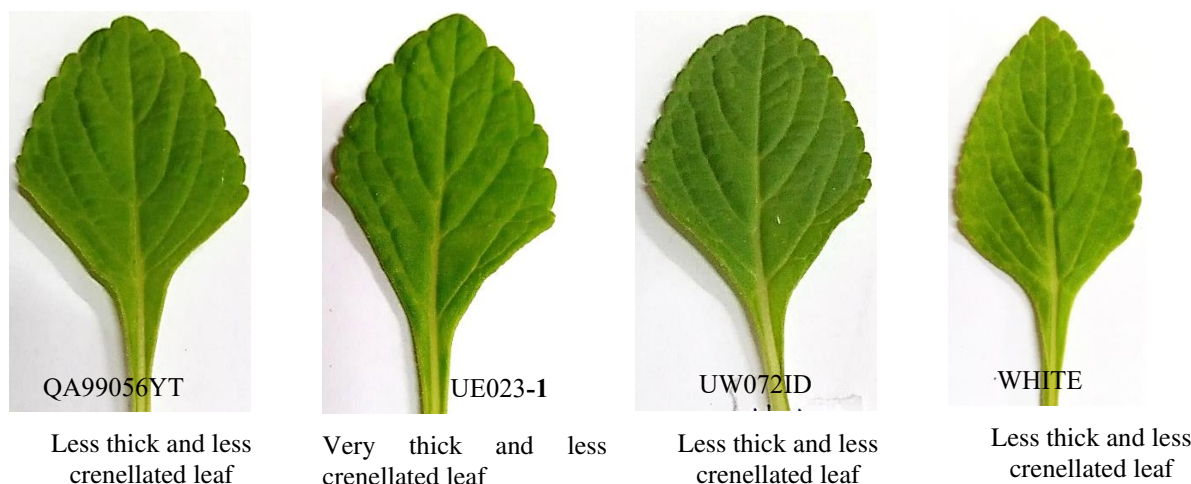


Figure 2: Thickness and margin type of *S. rotundifolius* leaves

The leaves of accessions UW070AIA and UW086M were purple-green, while those of the other accessions were green, with variations in the apical leaves (ACO) of accessions E183, E186, UE088, UW072ID and WHITE (Figure 3). The apical leaves of accessions UE088 and WHITE were green with reddish margins.

Accession UW072ID showed green apical leaves with reddish tips, while those of accessions E183 and E186 were yellowish-green. However, for accessions E120, E125, E165, QA99056YT and UE023-1, there was no variation between the leaves of the whole canopy.



Green-purple



Green-purple



Green



Green with reddish margins



Green with reddish margins



Green with reddish tips



Figure 3: Variation in the color of apical leaves of *S. rotundifolius*

The accessions varied in the main stem stature (MSS) but all developed prostrate lateral stems (LSS). The main stem was ascending or prostrate for most of the accessions but accession E165 developed only ascending main stems when accession QA99056YT developed only prostrate main stems. Variation between accessions was also observed for stem color (SCO). The stems of the accessions E120, E125, UE088 and WHITE were green. The stems of the accessions E165, E183, E186, QA99056YT, UE023-1 and UW072ID were Green-reddish and those of the accessions UW070AIA and UW086M were purple.

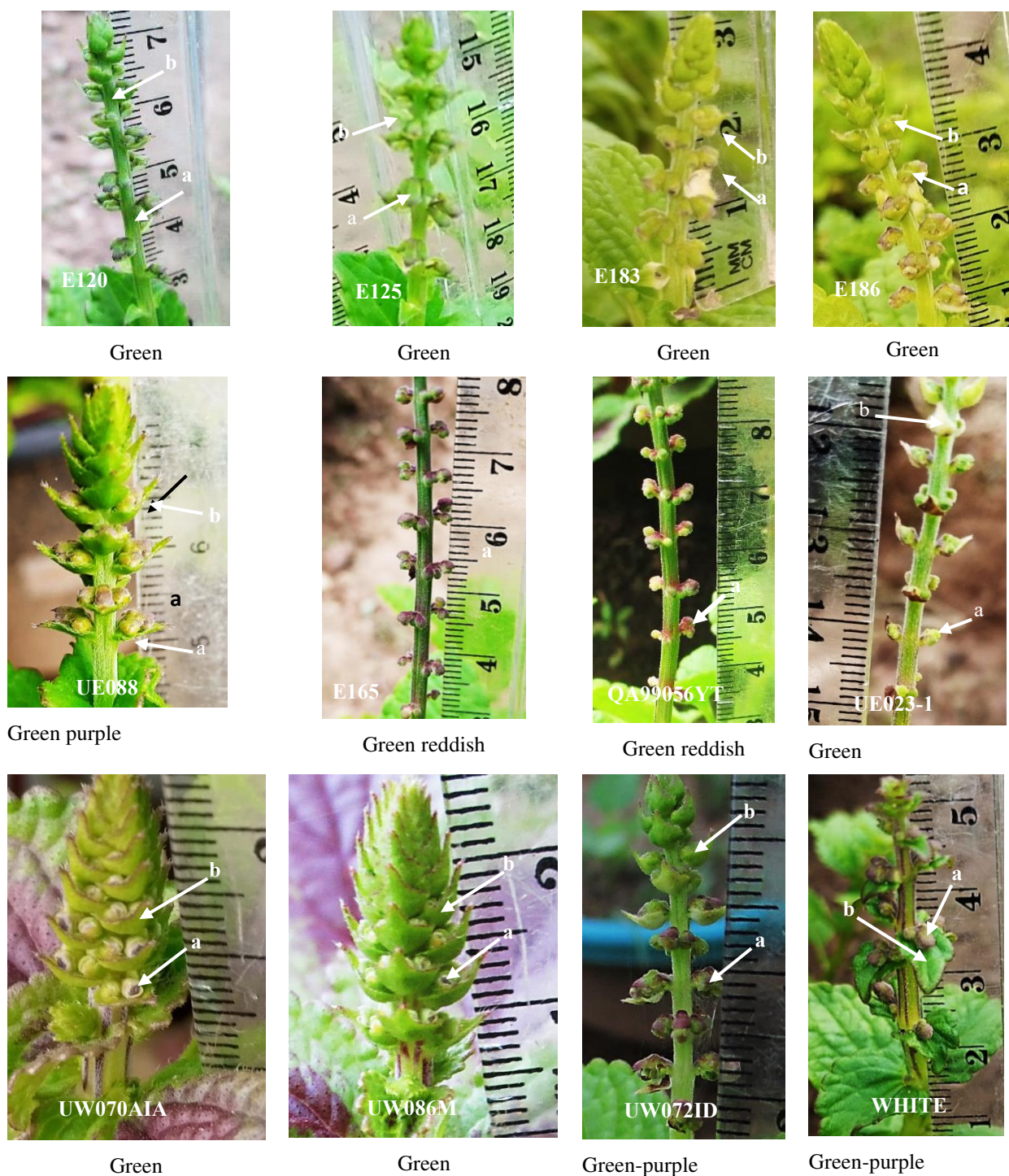
Table 3. Variability between accessions at vegetative growth stage

Accessions	Morphological traits						
	LSH	LMT	LTH	SCO	ACO	MSS	LSS
E120	Oval	Very crenellated	Strong	Green	Green	Ascending or prostrate	Prostrate
E125	Oval	Very crenellated	Strong	Green	Green	Ascending or prostrate	Prostrate
E165	Oval	Slightly crenellated	Low	Green	Green	Ascending	Prostrate
E183	Oval	Slightly crenellated	Low	Green-reddish	Green-yellow	Ascending or prostrate	Prostrate
E186	Oval	Slightly crenellated	Low	Green-reddish	Green-yellow	Ascending or prostrate	Prostrate
QA99056YT	Oval	Slightly crenellated	Low	Green-reddish	Green	Prostrate	Prostrate
UE023-1	Oval	Slightly crenellated	Strong	Green-reddish	Green	Ascending or prostrate	Prostrate
UE088	Oval	Very crenellated	Strong	Green	Green with reddish margins	Ascending or prostrate	Prostrate
UW070AIA	Oval	Very crenellated	Strong	Purple	Green-purple	Ascending or prostrate	Prostrate
UW072ID	Oval	Slightly crenellated	Low	Green-reddish	Green with reddish tips	Ascending or prostrate	Prostrate
UW086M	Oval	Very crenellated	Strong	Purple	Green-purple	Ascending or prostrate	Prostrate
WHITE	Oval	Slightly crenellated	Low	Green	Green with reddish margins	Ascending or prostrate	Prostrate

LSH: Leaf shape; LMT: Leaf margin type; LTH: Limb thickness; SCO: Stem color; ACO: Apical leaves color; MSE: Main stem section; PSS: Presence of particular stem section; MSS: Stature of main stem; LSS: Stature of secondary stems

Variability of the accessions at flowering stage

A variability was observed within the accessions at the flowering stage. After abundant vegetative development, the accessions produced cluster inflorescences (SIN) at the top of the stems (Figure 4). These inflorescences were compact (TIN) for accessions UW070AIA and UW086M, loose for accessions E120, E125, E183, E186, UE088 and UW072ID and very loose for accessions E165, QA99056YT, UE023-1 and WHITE (Table 4). Some primary inflorescence branching (LIB) was observed for accessions E183, QA99056YT, UE088, UW070AIA and UW086M, while no inflorescence branching was observed for accessions E120, E125, E165, E186, UW072ID and WHITE. The flower buds (FBC) of accessions E120, E125, E183, E186, UE023-1, UW070AIA and UW086M were green. Accessions E165 and QA99056YT showed green reddish flower buds, while those of accessions UE088, UW072ID and WHITE were green-purple. In all accessions, the flower buds were inserted in groups on the flowering stem (FAR). These groups were arranged in opposite pairs and alternated with the next group. The number of flower buds (NFB) per group were three for the accessions E165, QA99056YT, UE023-1 and WHITE, four for the accessions E120, E125, E183, E186, UE088 and UW072ID and six for the accessions UW070AIA and UW086M. In all accessions the flower buds were covered by bracts. The bracts of E165, QA99056YT and UE023-1 accessions fell rapidly before the end of flower bud development. For accessions E120, E125, E183, E186, UW072ID, UW070AIA and UW086M the bracts persisted until the beginning of flowering. Only the bracts of accessions UE088 and WHITE remained until the end of the flowering.



Legend: a: flower bud; b: bract

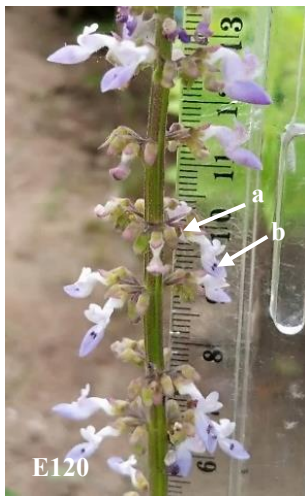
Figure 4: Variation in the colour of the flower buds of *S. rotundifolius* accessions.

After flowering (figure 5), the color of the flowering stem (FSC) of accessions E120, E125, E165, UE023-

1, UE088 and WHITE was reddish green, while that of accessions E183, E186, UW072ID and QA99056YT

was green. For accessions UW070AIA and UW086M, the flowering stem was purple. Accessions E120 and E125 developed flowers with green reddish sepals (SEC) and white petals (PCO) with slightly purple margins. The sepals and petals of accessions E183, E186 and UW072ID were green reddish and white, respectively, with very purplish margins. The flowers of accessions UE088, UW070AIA and UW086M showed reddish sepals and white petals with very purple margins. Accessions E165, QA99056YT and

UE023-1 developed flowers with reddish sepals and very purple petals. The sepals and petals of the WHITE accession were reddish (table 4). The flowers of E165, QA99056YT, UE023-1, UE088 and WHITE dropped rapidly (FPE) just after their development (one to seven days). Flowers of accessions E120, E125, E183, E186 and UW072ID persisted for a few days (five to twelve days) before dropping. The most persistent flowers were recorded in accessions UW070AIA and UW086M (one to two weeks).



Green-reddish sepals, white, slightly purplish



Green-reddish sepals, white, slightly purplish



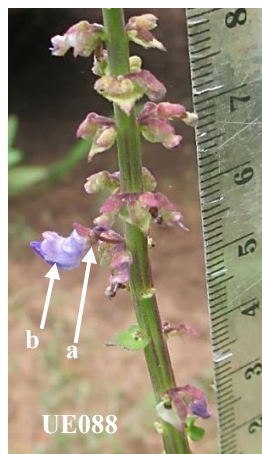
Green-reddish sepals, white very purplish petals



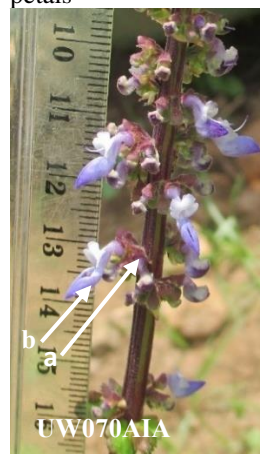
Green-reddish sepals, white very purplish petals



Green-reddish sepals, white very purplish petals



Reddish sepals, white very purplish petals



Reddish sepals, white very purplish petals



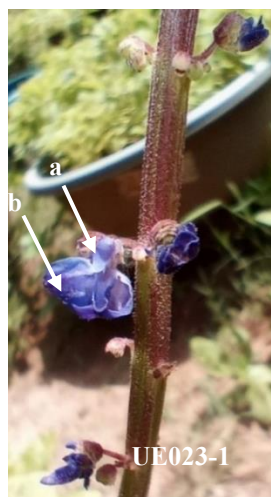
Reddish sepals, white very purplish petals



Reddish sepals and very purple petals



Reddish sepals and very purple petals



Reddish sepals and very purple petals



Reddish sepals and petals

Legend: a: sepals; b: petals

Figure 5: Clusters of the *S. rotundifolius* accessions sowing flowers

Table 4. Variability between accessions at flowering stage (flowers organs).

Accessions	Morphological traits								
	FBC	NFB	TIN	LIB	FAR	FPE	SEC	PCO	RCO
E120	Green	Four	Cluster	No branching	Opposite	Persistent	Green-reddish	White, slightly purplish	Green-reddish
E125	Green	Four	Cluster	No branching	Opposite	Persistent	Green-reddish	White, slightly purplish	Green-reddish
E165	Green reddish	Three	Cluster	No branching	Opposite	No persistent	Reddish	Purple	Green-reddish
E183	Green	Four	Cluster	Primary branching	Opposite	moderately persistent	Green	White, very purplish	Green
E186	Green	Four	Cluster	No branching	Opposite	moderately persistent	Green-reddish	White, very purplish	Green
QA99056YT	Green reddish	Three	Cluster	Primary branching	Opposite	No persistent	Reddish	Purple	Green
UE023-1	Green	Three	Cluster	Primary branching	Opposite	No persistent	Reddish	Purple	Reddish
UE088	Green purple	Four	Cluster	Primary branching	Opposite	No persistent	Reddish	White, very purplish	Green-reddish
UW070AIA	Green	Six	Cluster	Primary branching	Opposite	Persistent	Reddish	White, very purplish	Purple
UW072ID	Green purple	Four	Cluster	No branching	Opposite	moderately persistent	Reddish	White, very purplish	Green
UWO86M	Green	Six	Cluster	Primary branching	Opposite	Persistent	Reddish	White, very purplish	Purple
WHITE	Green purple	Three	Cluster	No branching	Opposite	No persistent	Reddish	Reddish	Green-reddish

FBC: Flower buds' color; NFB Number of flower buds per cluster; TIN: Type of inflorescence; LIB: Level of inflorescence branching; FAR: Flowers arrangement on the rachis; FPE: Flowers' persistence; SEC: Sepal color; PCO: Petal color; RCO: Rachis color.

Observation of morphological traits on leaves and stems after flowering revealed variation within the accessions (Figure 6) (Table 5). Accession E120 developed green apical leaves with reddish margins and reddish marks in the centre of the leaf (ALC). Green apical leaves with reddish margins were observed in accessions UE088 and WHITE, while those of the other accessions were green. As with

apical leaf color (ALC), stem color (ASC) also varied within accessions. Accessions E120, E125, UE088, UW072ID and WHITE developed green stems when accessions E183 and E186 developed red-green stems. Purple stems were observed for accessions UW070AIA and UW086M and reddish stems for accessions E165, QA99056YT and UE023-1.



Green with reddish spots



Green



Green



Green



Green



Green



Green



Green with reddish margins



Green-purple

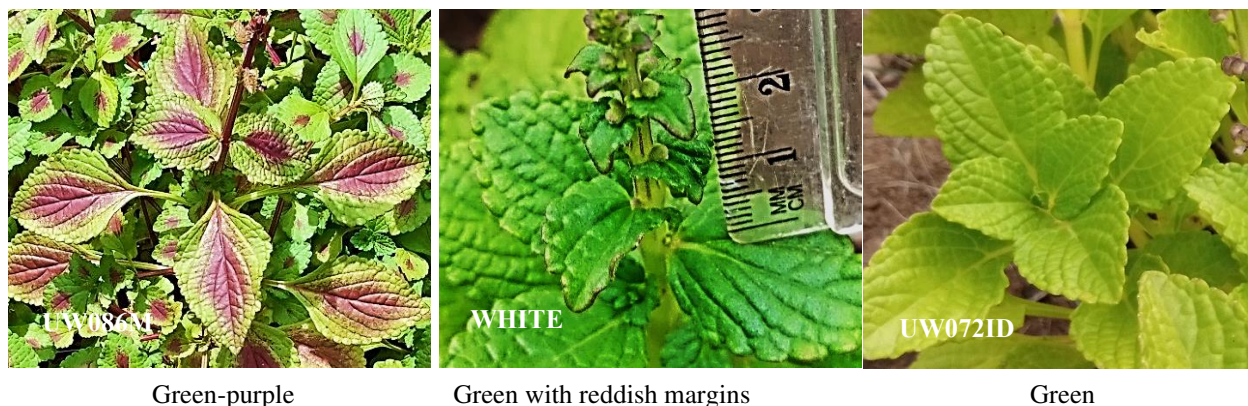


Figure 6: Different colors of the apical leaves of *S. rotundifolius*;

The main stem section was generally quadrangular (MSE) for all accessions. However, stems with a particular section (PPS) were observed in some accessions (Figure 7). Stems with hexagonal section were observed for accessions E165, E186 and UE088. The presence of stems with hexagonal and pentagonal

sections was noted for accession UW072ID. Stems with pentagonal and triangular sections were observed for accession UW086M. Stems with hexagonal section developed whorled leaves, while stems with triangular, quadrangular and pentagonal sections developed opposite leaves.

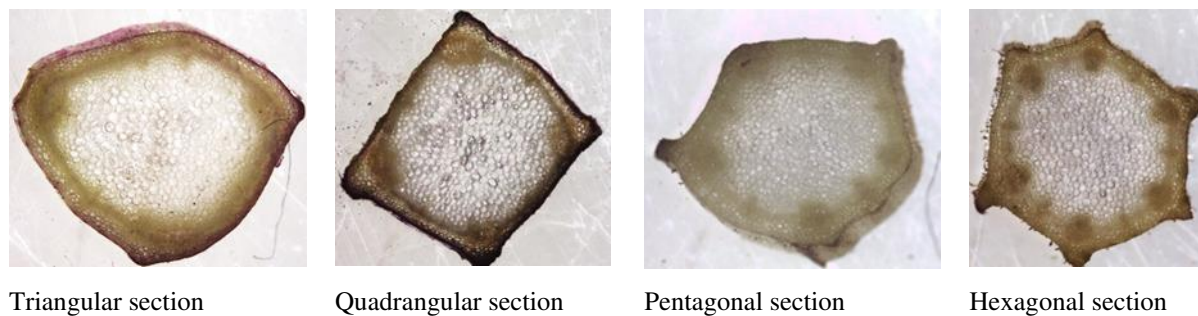


Figure 7: Different sections of the stem of *S. rotundifolius*

Table 5: Variability between accessions at flowering stage (vegetative organs)

Accessions	Morphological traits					
	ALC	ASC	MSE	PSS	ALH	ASH
E120	Green with reddish spots	Green	Quadrangular	No	Pubescent	Pubescent
E125	Green	Green	Quadrangular	No	Pubescent	Pubescent
E165	Green	Reddish	Quadrangular	Hexagonal	Pubescent	Pubescent
E183	Green-yellow	Green-reddish	Quadrangular	No	Pubescent	Pubescent
E186	Green	Green-reddish	Quadrangular	Hexagonal	Pubescent	Pubescent
QA99056YT	Green	Reddish	Quadrangular	No	Pubescent	Pubescent
UE023-1	Green	Reddish	Quadrangular	No	Pubescent	Pubescent
UE088	Green with reddish margins	Green	Quadrangular	Hexagonal	Pubescent	Pubescent
UW070AIA	Green-purple	Purple	Quadrangular	No	Pubescent	Pubescent
UW072ID	Green	Green	Quadrangular	Hexagonal & pentagonal	Pubescent	Pubescent
UWO86M	Green-purple	Purple	Quadrangular	Pentagonal & triangular	Pubescent	Pubescent
WHITE	Green with reddish margins	Green	Quadrangular	No	Pubescent	Pubescent

ALC: Adult plant leaf color; ASC: Adult plant stem color; MSE: Main stem section; PSS: Presence of particular stem section; ALH: Adult plant leaf hairiness; ASH: Adult plant stem hairiness.

Morphological variation of *S. rotundifolius* accessions for traits related to the tuber

After harvesting, the most discriminating morphological traits were tuber skin (TSC) and flesh color (TFC) (figure 8, table 6). Accessions E120, E125 and UE088 produced blackish tubers with yellowish-white flesh. The tuber skin color of E165 and E183 was reddish and that of accession UW070ID was blackish, but their flesh color was whitish. Accessions E186, QA99056YT and UE023-1 produced reddish tubers

with yellowish-white flesh. Reddish tubers with pinkish-white flesh were observed in accessions UW070AIA and UW086M. The skin and flesh color of accession “WHITE” tubers were yellowish white and yellowish respectively. Tubers of the accessions E120, E125, E165, E183, E186, UW070AIA, UW086M and WHITE were ovoid (TSH) and those of the accessions UW072ID and QA99056YT were oblong. Lateral tuber branching (PLT) was observed in some accessions.



Black skin (E120)



Black skin (E125)



Black skin (UE088)



White-yellow flesh (E120)



White-yellow flesh (E125)



White-yellow flesh (UE088)



Blackish-brown (UW072ID)



Red skin (E165)



Red skin (E183)



White flesh (UW072ID)



White flesh (E165)



White flesh (E183)



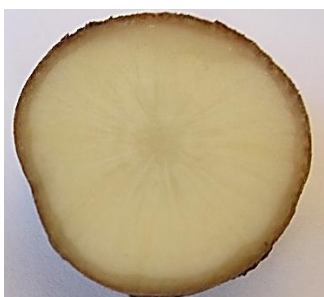
Red skin (E186)



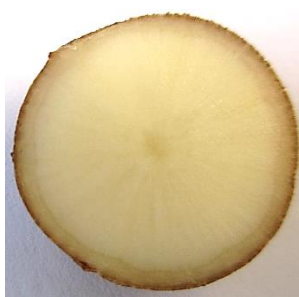
Red skin (QA99056YT)



Red skin (UE023-1)



White-yellow flesh (E186)



White-yellow flesh QA99056YT



White-yellow flesh (UE023-1)



Red skin (UW070AIA)



Red skin (UW086M)



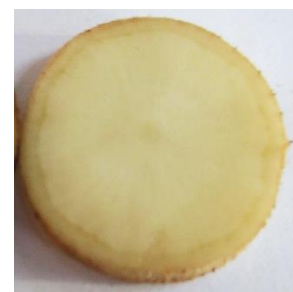
White-yellow skin (WHITE)



Pinkish-white flesh (UW070AIA)



Pinkish-white flesh (UW086M)



Yellow (WHITE)

Figure 8: Variations of the color of *S. rotundifolius* tubers skin and flesh

Table 6. Variability of the accessions in tuber morphology

Accessions	Morphological traits			
	TSH	TSC	TFC	PLT
E120	Ovoid	Black	White-yellow	Present
E125	Oblong	Black	White-yellow	No
E165	Ovoid	Red	White	Present
E183	Ovoid	Red	White	No
E186	Ovoid	Red	White-yellow	Present
QA99056YT	Oblong	Red	White-yellow	Present
UE023-1	Round	Red	White-yellow	Present
UE088	Ovoid	Black	White-yellow	Present
UW070AIA	Ovoid	Red	Pinkish-white	Present
UW072ID	Oblong	Blackish-brown	White	Present
UW086M	Ovoid	Red	Pinkish-white	No
WHITE	Ovoid	White-yellow	Yellow	No

TSH: *Tuber shape*; TSC: *Tuber skin color*; TFC: *Tuber flesh color*; PLT: *Presence of lateral tubers*.





Figure 9: Illustrations of twelve (12) accessions of *S. rotundifolius* at the adult stage.

Identification of the main morphotypes of *S. rotundifolius*

Based on the most discriminating traits and the previous works on *S. rotundifolius* (Nanema et al., 2018), the 12 accessions were classified in 8 morphotypes (table 7). Three morphotypes (A, B and

C) were previously named by Nanéma and *al.* (2018) and five were newly named. The accessions with similar characteristics were assigned to the same morphotype. Accessions E120 and E125 were assigned to morphotype A. The accessions E165 and QA99056YT were assigned to morphotype B and the

accession WHITE to morphotype C. Accessions E183 and E186 were classified in the morphotype F. Accessions UE023-1, UE088, UW070AIA, UW086M and UW072ID were assigned to morphotypes D, E, G and H respectively. The accessions E120, E165, WHITE, UE023-1, UE088, E186, UW086M and UW072ID were retained as reference individuals.

Table 7: Main characteristics of the morphotypes of *S. rotundifolius*

Accessions	Morphotypes	Country	Morphological traits											Reference individual
			YSC	YLC	LTH	ACO	TIN	NFB	PCO	ALC	ASC	TSH	TSC	
E120	A	BF	Green	Green	Strong	Green	Loose	Four	WSP	GRS	Green	Ovoid	Black	E120
E125	A	BF	Green	Green	Strong	Green	Loose	Four	WSP	Green	Green	Oblong	Black	
E165	B	BF	Red	Green	Low	Green	V-loose	Three	Purple	Green	Reddish	Ovoid	Red	E165
QA99059YT	B	GH	Red	Green	Low	Green	V-loose	Three	Purple	Green	Reddish	Oblong	Red	
WHITE	C	GH	Red	Green	Low	GRM	V-loose	Three	Reddish	GRM	Green	Ovoid	W-yellow	WHITE
UE023-1	D	GH	Red	Green	Strong	Green	V-loose	Three	Purple	Green	Reddish	Round	Red	UE023-1
UE088	E	GH	Red	Green	Strong	GRM	L-compact	Four	WVP	GRM	Green	Ovoid	Black	UE088
E183	F	BF	Red	GPWS	Low	G-yellow	Loose	Four	WVP	Green	G-reddish	Ovoid	Red	E186
E186	F	BF	Red	GPWS	Low	G-yellow	Loose	Four	WVP	Green	G-reddish	Ovoid	Red	
UW070AIA	G	GH	Purple	GPV	Strong	G-purple	V-compact	Six	WVP	G-purple	Purple	Ovoid	Red	UW086M
UW086M	G	GH	Purple	GPV	Strong	G-purple	V-compact	Six	WVP	G-purple	Purple	Ovoid	Red	
UW072ID	H	GH	Red	Green	Low	GRT	Loose	Four	WVP	Green	Green	Oblong	B-brown	UW072ID

BF: Burkina Faso; GH: Ghana; YSC : Young plant stem color ; YLC : Young plant leaf color; LTH : Limb thickness ; SCO : Stem color ; ACO : Apical leaves color ; TIN: Type of inflorescence; NFB Number of flower buds per cluster; PCO: Petal color ; ALC : Adult plant leaf color ; ASC : Adult plant stem color; GRM : Green with reddish margins ; GPWS : Green with purple to whitish spots; GPV : Green with purplish veins ; GRT : Green with reddish tips ; GRS : Green with reddish spots ; WSP : White, slightly purplish ; WVP : White, very purplish ; G :Green ; W : White ; B : Blackish ; V :Very ; L :Less .

Discussion

The results of the morphological characterization showed the existence of large variability within the accessions of *S. rotundifolius* collected in Burkina Faso and Ghana. Twelve (12) accessions of *S. rotundifolius* were successfully described based on morphological traits related to vegetative organs, floral organs and tubers in the agromorphological evaluation. These accessions were classified into eight (08) morphotypes based on the most discriminating traits. Previous research reported the existence of morphological variability within the genetic resources of *S. rotundifolius* (Opoku-Agyeman et al., 2007; Nanéma et al., 2009). These studies also mentioned the presence of three morphotypes of *S. rotundifolius*: the black tuber skin or brown tuber skin morphotype, the red tuber skin morphotype and the white tuber skin morphotype (Tanzubil et al., 2005; Nanéma et al., 2010). These morphotypes corresponded respectively to the varieties nigra, rubra and alba described by (Chevalier et Perrot, 1905). These authors suggested the existence of a fourth variety, called javanicaminum, with a black skin tuber. The high number of morphotypes identified in this study could be explained by the size of the collection used, which consisted of a collection from two countries, compared to previous studies that focused on local collections. This number could also be explained by the use of several variants in the identification of morphotypes, whereas in previous studies the colour of the tuber skin was the main criterion for the identification of morphotypes.

At the juvenile stage, the main traits that discriminated the accessions were the color of the stem and leaves of young plants. Variation of young plants stem, color was mentioned by (Nanéma et al., 2018) as a criterion for differentiation of *S. rotundifolius* morphotypes. However, they did not mention the purple coloration

observed on the stems of some accessions. During the vegetative development of the plants, the accessions differed for leaf thickness, leaf margin type and the color of apical leaves. All accessions produced thick leaves with crenellated margins. According to (Nanéma et al., 2018) and (Nkansah, 2004), the thickness of *S. rotundifolius* leaves could be considered as one of the plant adaptation to water scarcity. The reddish and yellowish coloration observed on the apical leaves of plants of some accessions was observed by (Agyeno et al., 2014) on two cultivars of *S. rotundifolius* in Nigeria. However, they did not mention any variation in stem color. According to Rein (2005), Tanaka et al. (2008), and Boldt (2013) the reddish color of plant organs is due to the presence of anthocyanins in plant tissues, which help the plant to resist water stress.

After flowering, the type of inflorescence, the color and the shape of floral components were the most discriminating traits. According to Nanéma et al. (2018), these parameters alone would be sufficient to identify morphotypes. Indeed, floral structure is an important criterion for the classification of *Lamiaceae* (Ryding, 1994). This parameter was cited by (Ouédraogo et al., 2002) as being of taxonomic importance. This difference between the inflorescences of the morphotypes could suggest different species within *Solenostemon* (Ouédraogo et al., 2007).

Variability was also observed in stem and apical coloration. In all accessions, main stem section was generally quadrangular, but the presence of stems with hexagonal, pentagonal and triangular section was observed. Similar results were obtained by Nanéma et al. (2009).

After harvesting, tuber skin color was the most discriminant trait for morphotype identification. This trait was used by several authors (Tanzubil et al., 2005;

Nanéma et al., 2010; Sugri et al., 2013) as the main criterion for identifying morphotypes. However, the use of this trait alone as the only criterion for identification of morphotypes remains insufficient. In this study, several morphotypes with different floral structures produced tubers with the same skin colour. This parameter could also be influenced by the color of the soil (Ouédraogo et al., 2007). According to Nanéma et al. (2018), any error in tubers skin color appreciation could lead to ambiguous results. Variability was also observed in tuber flesh color and tuber shape. The classification of the twelve accessions into eight morphotypes could be explained by the occasional variation in some individuals, causing instability of certain traits observed in the same morphotype. However, future research on *S. rotundifolius* could focus on the description of flower morphology, the stability of morphological traits according to the planting period, and the genetic profile of the morphotypes. Karyotype analysis of the different morphotypes will also be a major asset for their description.

Conclusion

Twelve accessions of *S. rotundifolius* from Burkina Faso and Ghana based were successfully characterized based on morphological traits related to foliage, floral organs and tubers. The different morphological traits observed enabled the grouping of these accessions into eight (08) morphotypes based on the most discriminating traits. These traits could be used as descriptors for *S. rotundifolius*. A description of the floral structure will be an essential step towards a complete description of the morphotypes of *S. rotundifolius*.

Declarations

Not applicable

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