Identification of elite local accessions of Roselle (*Hibiscus sabdariffa*) through the evaluation of morpho-phenological characters.

Summary

In Côte d'Ivoire, the available data on the diversity and genetic structuring of Guinea sorrel remain limited and not very popularized, thus making research work and varietal improvement efforts particularly difficult. To overcome this problem, a survey carried out in 12 localities has made it possible to have an in-situ collection of 80 accessions. Twenty-nine (29) accessions from this collection were evaluated in this study. The objective was to identify elite accessions, potentially candidates for an improvement program. Nineteen (19) quantitative traits were analyzed on a Fisher block device. Descriptive analysis revealed a high morphological variability between accessions. The coefficient of variation showed a strong heterogeneity between accessions for certain traits. The Principal Component Analysis revealed 70.07% of the total variability. The classification made it possible to distinguish three groups of accessions according to their similarity. The classification by the k-means method made it possible to classify accessions into three groups and to identify the most efficient ones according to the stages of development. Thus, the accessions HSKO 037, HSFE 031, HSBK 004 and Bangolo stood out respectively at the 2-leaf, vegetative, flowering, and fruiting stages by presenting the highest values for the traits evaluated.

Keywords : Identification, local elite accessions, *Hibiscus sabdariffa*, Roselle, morpho-phenological evaluation.

Introduction

Hibiscus sabdariffa L., commonly known as roselle, is a species belonging to the Malvaceae family (**Bakasso*et al*., 2013**). It is an annual or biennial plant of tropical and subtropical areas that adapts to all climatic conditions (**Kone *et al*., 2018**). According to **Grubben and Denton (2004),** it was initially domesticated in Africa, probably in Sudan, about 6000 years ago, before spreading to Asia and America. Other authors such as **Duke (1993)** and (**Abu-Tarboush*et al*., 1997**) suggest an origin in eastern India or Saudi Arabia. Sudan is the main producer of sorrel in Africa (**Ternoy*et al*., 2006**). The annual area under cultivation varies between 11,000 ha and 57,000 ha, depending on rainfall and prices. In 1995, Sudan exported about 32,000 tonnes of Guinea sorrel calyx (**Mc Clintock*et al*., 2011**). According to the Central Bank of Sudan (2012), the quantity of dry calyxes exported was 18,531 tonnes in

2011 and 15,656 tonnes in 2012 for a net gain of US$17.59 million and US$14.09 million, respectively (**Ibrahim *et al.*, 2013**). Senegal and Mali are the main producers of sorrel in West Africa. However, much of their production is for family consumption or sold in local markets (**McClintock *et al.*, 2011**). In Senegal, the average annual income from the sale of sorrel leaves ranges from US$41 to US$500 (**Diouf *et al.*, 2007**). In addition, in Burkina Faso, Benin, Côte d'Ivoire, Mali, Mauritania and Senegal, a 30 to 50 cl ice pack is sold for between 25 and 50 CFA francs, while a 1-litre bottle for between 1,000 and 1,500 CFA francs (**McClintock, 2004**).

In Côte d'Ivoire, most research on *H. sabdariffa* is mainly carried out at the biochemical level; little information is available on the morphological, agronomic, and molecular characteristics of *H. sabdariffa* cultivars. Research activities on regeneration from cuttings (**Sié *et al.*, 2008**) and agromorphological characterizations (**Sié *et al.*, 2009)** made it possible to evaluate the diversity of 159 seeds from seeds collected on the markets of Korhogo (Côte d'Ivoire). The research of **Anzara*et al.* (2023)** made it possible to have 80 accessions collected in 12 localities in Côte d'Ivoire.

The evaluation of accessions collected in 2023 identified 29 elite accessions. Our study proposed to evaluate the morpho-phenological characteristics of these accessions toidentify the best ones. The aim was to identify the elite accessions at each stage of development and to identify the elites in a global way by cross-referencing the best at each stage.

Material and Method

Study site

The study was conducted at the experimental site of the botanical garden of the Peleforo GON COULIBALY UNIVERSITY (UPGC). The experimental plot is located at longitude 5°38 West and Latitude 9°26.

Plant material

The plant material consists of 29 *Hibiscus sabdariffa* accessions from different localities in Côte d'Ivoire (**Table I**). These accessions are in the form of seeds and are the result of a survey conducted in 2023 (**Anzara*et al.*, 2023**).

Method

Experimental design and data collection

The trial was conducted using the randomized Fisher block device with three (3) replicates.

The parameters measured concerned 450 plants due to 15 plants per accession.

Quantitative variables (**Table II)** were measured during (4) life stages: the 2-leaf stage, the vegetative stage, the flowering stage, and the fruiting stage (**Figure 1**).

Table I. List of accessions studied, their origin and number

Area	Collection location	Accession Code
Centre (05)	Bouaké (05)	HSBK 003
		HSBK 004
		HSBK 005
		HSBK 002
		HSBK 006
Centre-West (01)	Daloa (01)	HSDA 001
North (17)	Boundiali (03)	HSBO 023
		HSBO 024
		HSBO 026
	Ferkessédougou (03)	HSFE 028
		HSFE 031
		HSFE 032
	Korhogo (09)	HSKO 037
		HSKO 040
		HSKO 042
		HSKO 043
		HSKO 044
		HSKO 046
		HSKO 047
		HSKO 052
		HSKO 053
	Niakara (02)	HSNI 054
		HSNI 058
Northeast (01)	Agnibilékrou (01)	HSAG 080
West (04)	Bangolo (01)	Bangolo
	Bangolo campement (01)	Bangolo campement
	Duékoué (01)	HSDU 022
	Ziagolo (01)	Ziagolo
South (01)	Abobo-baoulé (01)	Abobo-Baoulé
	Koumassi (01)	HSAB 015

Source : Prospecting data (**Anzara et al., 2023**)

Table II. Quantitative parameters studied during the study

Stage of development	Descriptors (unit)	Code
Seedling (2-leaf stage)	Germination time	TeGe
	Sheetlength (cm)	LoFe
	SheetWidth (cm)	LaFe
	Diameter from Stem to Collar (cm)	DiTc
Vegetative stage	ShaftDiameter (cm)	DiTi
	Number of Separated Lobes	NoLs
	LeafPetioleLength (cm)	LoPf
	LeafPetioleWidth (cm)	LaPf
	Blade length	LoLe
	Blade width (cm)	LaLe
	Plant Height (cm)	HaPl
Flowering stage	First flower appearance time (days)	TaF
	Flower diameter (cm)	DiF
	Flower PeduncleLength (cm)	LpF
Fruiting stage	Number of Fruits per Plant	NoFr
	Opening date of the first capsules (day)	DoCa
	Number of fruiting branches	NoBf
	Weight of 100 seeds	Seln
	Number of Seeds per Fruit	NgFr

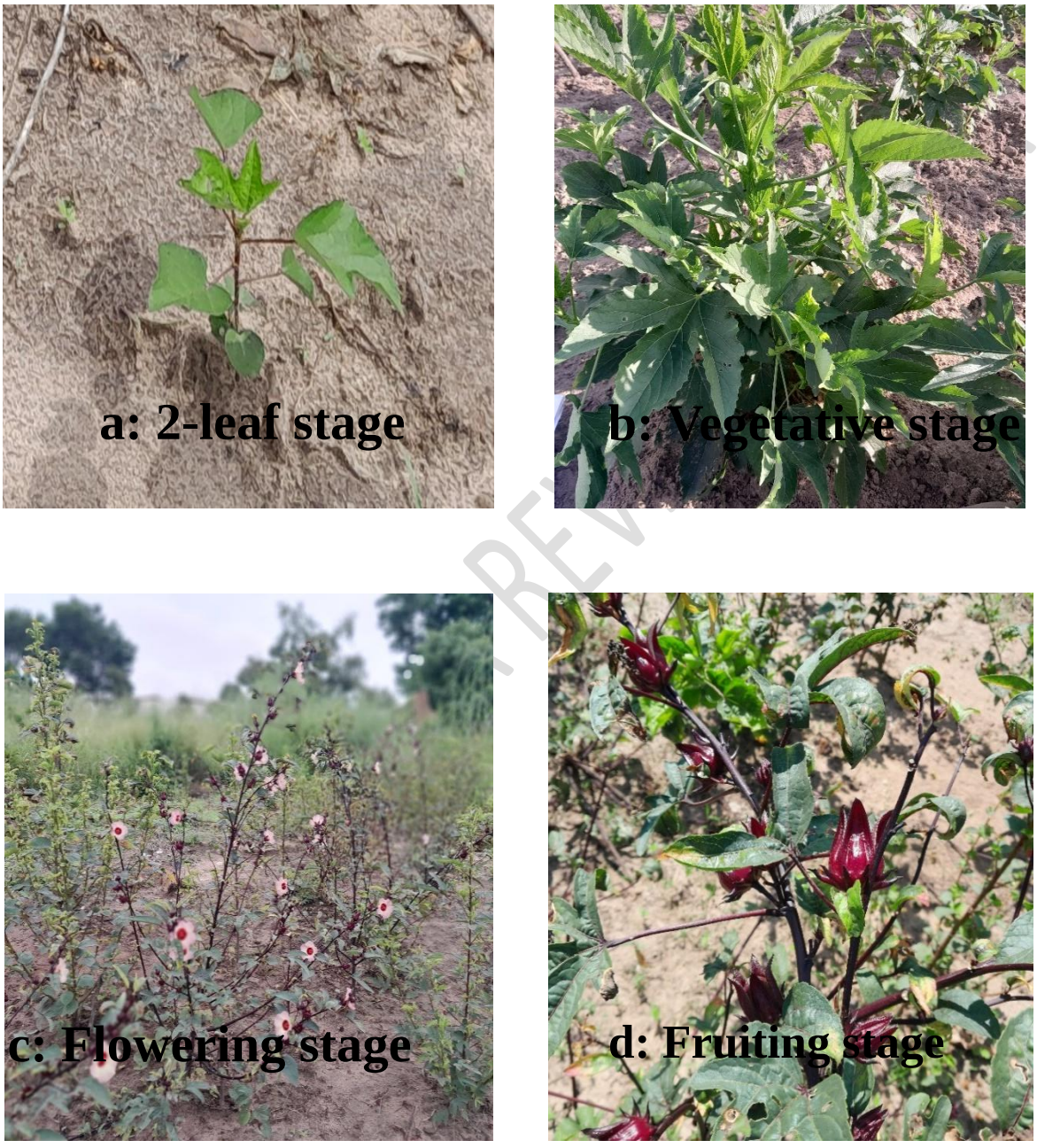


Figure 1. Different stages of development

Statisticalprocessing of data

Descriptive analysis at a 95% confidence interval showed the variability of the measured traits. After checking for normality, the Kruskal-wallis test was performed to check if there

was a difference between the accessions according to the parameters studied. When there was a difference, Dunn's post-hoc test made it possible to group them together and classify the groups obtained. A Pearson correlation test was performed, to see the link between the parameters taken two by two.

With K=3, the Classification by the dynamic cloud method (k-means) made it possible to divide the accessions into three different groups, namely the performers, the average performers, and the worst performers. The F-value of the ANOVA coupled with the k-means method made it possible to test the significance of the established groups at a 95% confidence level.

Results and Discussion

Results

Variability of quantitative traits at each stage

Descriptive analysis coupled with the Kruskal-wallis test at each stage of development revealed significant differences ($P<0.05$) between accessions for all variables studied at the 5% threshold except for five variables including leaf length at the 2-leaf stage, stem diameter, leaf petiole width and leaf blade length at the vegetative stage and weight of 100 seeds at the stage of fruiting.

At the 2-leaf stage (**Table III**), the germination time varies between 3 and 6 days with an average of 3.87 ± 0.95 days, for a coefficient of variation (CV) of 25%. The average leaf length is 2.61 ± 0.85 cm (CV = 33%), while the average width is 2.41 ± 0.64 cm with CV = 26%. As for the diameter of the stem at the collar, it shows an average of 0.40 ± 0.13 cm and a coefficient of variation CV of 33%, reflecting a moderate diversity within the accessions. In the vegetative stage (**Table IV**), the stem diameter increases to an average of 0.807 ± 0.201 cm with a coefficient of variation of 25%, which remains relatively stable. On the other hand, the number of separated lobes varies greatly between accessions (0 to 5), with a mean of 3.393 ± 1.329 and a high coefficient of variation of 39.1%. The average leaf petiole length is 7.473 ± 1.741 (CV = 23.3%), while the leaf petiole width is highly variable and has a high coefficient of variation of 32.7%. The length and width of the blade show averages of 10.947 ± 1.939 cm (CV = 17.7%) and 9.728 ± 2.072 cm (CV = 21.3), respectively. The height of the plants varies greatly, with an average of 31,560 ± 10,607 cm and a coefficient of variation of 33.5% showing high variability in growth between individuals. At the flowering stage (**Table V**), the appearance of the first flower varies from 74 to 192 days with an average of 146.705 ±

24.809 days, for a coefficient of variation of 16.9%. While the mean flower diameter is 5.242 ± 1.089 cm (CV = 20.7%), indicating a significant average variability between accessions.

The length of the flower peduncle has an average of 1.097 ± 0.509 cm with a coefficient of variation CV = 46.3%, this translates into a high variation.

Finally, at the fruiting stage (**Table VI),** the number of fruits per plant shows a high variability with an average of 28,898 ± 12,080 fruits and a high coefficient of variation of 89.4%. Similarly, the number of fruiting branches shows a significant variation (CV = 71.5%). However, parameters such as the date of opening of the first capsules and the weight of 100 seeds show little variation, with coefficients of variation CV = 12.7% and 18.4% respectively. The number of seeds per fruit shows moderate variability (CV = 21.2%) with a mean of 28.384 ± 6.039

Table III. Mean value ± standard deviation, minimum, maximum and coefficient of variation (CV) of the quantitative traits analyzed at the 2-sheet stage

Statistics	Min	Max	Mean ± Standard Deviation	CV (%)	F	Pr > F
TeGe	3	6	3,87 ± 0,95	25	2,681	< 0.0001
LoFe	1	5,1	2,61 ± 0,85	33	1,309	0,147
LaFe	1	5	2,41 ± 0,64	26	1,927	0,005
DiTc	0,11	0,94	0,40 ± 0,13	33	3,189	< 0.0001

TeGe : Germination time, LoFe : Leaf length, LaFe : Leaf width, DiTc : Diameter from stem to collar

Table IV. Mean value ± standard, minimum, maximum deviation and coefficient of variation (CV) of quantitative traits analysed at the vegetative stage

Statistics	Min	Max	Mean ± Standard Deviation	CV (%)	F	Pr > F
DiTi	0,35	1,69	0,807± 0,201	25,00	1,218	= 0,217
NoLs	0,00	5,00	3,393 ± 1,329	39,1	6,134	< 0.0001
LoPf	2,40	13,40	7,473 ± 1,741	23,3	1,938	= 0,005
LaPf	0,20	9,34	0,443 ± 0,146	32,7	0,862	= 0,667
LoLe	6,10	16,20	10,947 ± 1,939	17,7	1,059	= 0,390
LaLe	4,50	19,50	9,728 ± 2,072	21,3	1,674	= 0,023
HaPl	8,20	71,50	31,560 ± 10,607	33,5	5,011	< 0.0001

DiTi : Diameter of the stem, NoLs : Number of separate lobes, LoPf : Length of the leaf petiole, LaPf : Width of the leaf petiole, LoLe : Length of the blade, LaLe : Width of the blade, HaPl : Height of the plant

Table V. Mean value ± standard deviation, minimum, maximum and coefficient of variation (CV) of quantitative traits analyzed at the flowering stage

Statistics	Min	Max	Mean ± Standard Deviation	CV (%)	F	Pr > F
TaF	74,00	192,00	146,705 ± 24,809	16,9	31,720	< 0.0001
DiF	3,168	7,736	5,242 ± 1,089	20,7	11,986	< 0.0001
LpF	0,450	2,700	1,097 ± 0,509	46,3	13,152	< 0.0001

TaF: First Flower Onset Time, DiF: Flower Diameter, LpF: Flower Peduncle Length

Table IV. Mean value ± standard, minimum, maximum deviation and coefficient of variation (CV) of quantitative traits analysed at the fruiting stage

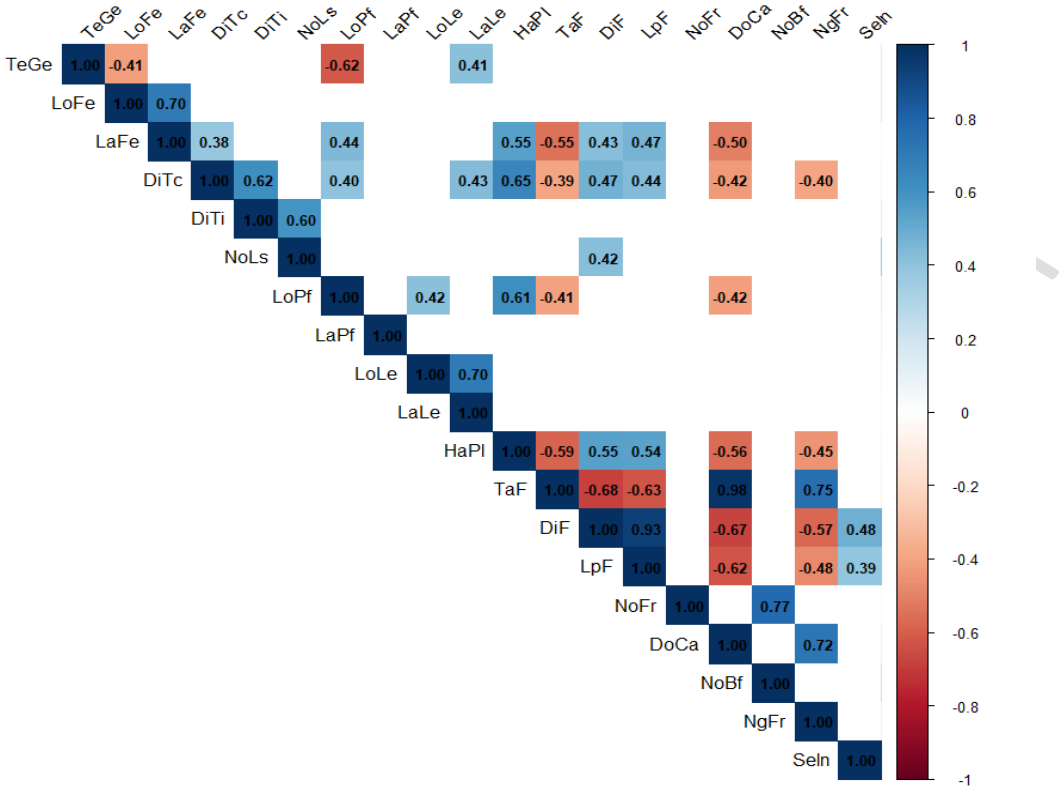
Statistics	Min	Max	Mean ± Standard Deviation	CV (%)	F	Pr > F
NoFr	5	155	28,898 ± 12,080	89,4	2,623	< 0.0001
DoCa	109	217	187,347 ± 23,780	12,7	29,289	< 0.0001
NoBf	1	18	4,625 ± 3,311	71,5	1,820	= 0,010
NgFr	12,6	41,4	28,384 ± 6,039	21,2	7,444	< 0.0001
Selen	2	4	2,161 ± 0,396	18,4	1,375	= 0,108

NoFr: Number of Fruit per plant, DoCa: Date of opening of the first capsules, NoBf: Number of fruiting branches, Seln: Weight of 100 seeds, NgFr: Number of Seeds per fruit

Relationship between the parameter traits studied

The Pearson correlation matrix between quantitative traits is shown in **Figure 2**. It revealed significant relationships between the traits studied, with a strong structuring of vegetative, floral and productive traits. Leaf traits are positively correlated with each other, including leaf length and width (**r = 0.70**), and leaf blade length and width (**r = 0.70**), reflecting proportional vegetative growth. Plant height is positively associated with flower diameter (**r = 0.55**) and flower peduncle length (**r = 0.54**), indicating that vigorous plants develop larger floral organs. On the other hand, the time of appearance of the first flower is negatively correlated with flower diameter (**r = –0.68**), flower peduncle length (**r = –0.63**) and number of fruits per plant (**r = –0.56**), suggesting that late flowering penalizes the expression of yield traits. The production parameters are strongly related to each other, with a very high positive correlation

between flower diameter and the number of fruits per plant (**r = 0.93**), as well as between the number of fruits per plant and the number of fruiting branches (**r = 0.77**) and the number of seeds per fruit (**r = 0.72**).



TeGe : Germination time, LoFe : Leaf length, LaFe : Leaf width, DiTc : Diameter of stem at collar, DiTi : Diameter of stem, NoLs : Number of Separate Lobes, LoPf : Length of leaf petiole, LaPf : Width of leaf petiole, LoLe : Blade length, LaLe : Width of leaf blade, HaPl : Height of plant, TaF: First Flower Appearance Time, DiF: Flower Diameter, LpF: Flower Peduncle Length, NoFr: Number of Fruit per Plant, DoCa: Date of Opening of First Capsules, NoBf: Number of Fruiting Branches, Seln: Weight of 100 Seeds, NgFr: Number of Seeds per Fruit

Figure 2. Pearson correlation matrix between quantitative traits

Structure of the morpho-phenological diversity of accessions

Table **VII** presents the results of the Principal Component Analysis performed on quantitative traits. This analysis made it possible to identify five main axes that explain 70.07% of the total variability observed. Axis 1 accounted for 30.39% of the total variability. The variables that contributed most to the formation of this component were the time of appearance of the first flower (TaF), the date of opening of the first capsules (DoCa) and the number of seeds per fruit. All these variables were positively correlated with axis 1. The variables leaf width (LaFe), stem diameter at crown (DiTc), leaf petiole length (LoPf), plant height (HaPl), flower diameter (DiF), and flower peduncle length (LpF) were negatively correlated with this axis, this axis can be referred to as the vegetative vigour axis. Axis 2, which represents 14.75% of

the total variance, combining germination time (TeGe), stem diameter (DiTi), blade length (LaLe) and number of fruits per plant. These variables were positively correlated with axis 2. This axis can be considered as an axis of potential yield and robustness. Axis 3, representing 12.20% of the total inertia, positively associates the variable limb length (LoLe). The variable number of separate lobes is negatively correlated with this axis. Axis 4, showing 10.53% of the total variability, positively associates the variable number of fruiting branches (NoBf). Axis 5 (7.21%) was formed, primarily, from leaf length.

Table VII. Eigenvalues, percent variance and correlation between morphophenological traits and the five main PCA factors

	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 5**
Eigenvalue	5,772	2,802	2,319	2,001	1,370
Variability (%)	30,378	14,745	12,204	10,532	7,210
Cumulative %	30,378	45,123	57,327	67,859	75,070
Variable	Correlation between variables and factors				
TeGe	0,377	**0,538**	-0,313	-0,439	-0,008
LoFe	-0,279	-0,486	0,216	0,216	**0,561**
LaFe	**-0,688**	-0,321	0,278	-0,078	0,333
DiTc	**-0,655**	0,481	0,173	-0,172	0,060
DiTi	-0,440	**0,479**	-0,096	-0,129	**0,472**
NoLs	-0,160	0,599	**-0,649**	0,155	0,292
LoPf	**-0,612**	-0,085	**0,562**	0,142	-0,071
LaPf	0,086	-0,018	**0,401**	-0,166	0,313
LoLe	-0,109	**0,506**	**0,725**	-0,103	0,054
LaLe	-0,131	**0,684**	0,317	-0,476	0,062
HaPl	**-0,770**	0,064	0,344	-0,025	-0,274
TaF	**0,860**	0,149	0,166	0,085	0,269
DiF	**-0,843**	0,136	-0,319	0,164	0,014
LpF	**-0,809**	-0,030	-0,281	0,221	0,028
NoFr	0,156	**0,650**	0,153	**0,553**	-0,260
DoCa	**0,848**	0,114	0,181	0,097	0,255
NoBf	-0,076	0,345	0,210	**0,804**	-0,190
NgFr	**0,706**	0,047	0,245	0,410	0,196
Selen	-0,270	0,139	-0,217	0,433	0,409

TeGe : Germination time, LoFe : Leaf length, LaFe : Leaf width, DiTc : Diameter of stem at collar, DiTi : Diameter of stem, NoLs : Number of Separate Lobes, LoPf : Length of leaf petiole, LaPf : Width of leaf petiole, LoLe : Blade length, LaLe : Width of leaf blade, HaPl : Height of plant, TaF: First Flower Appearance Time, DiF: Flower Diameter, LpF: Flower Peduncle Length, NoFr: Number of Fruit per Plant, DoCa: Date of Opening of First Capsules, NoBf: Number of Fruiting Branches, Seln: Weight of 100 Seeds, NgFr: Number of Seeds per Fruit

Morphophenological groups of Guinea sorrel accessions

At the 2-leaf stage

Class 1 includes accessions with longer germination times (TeGe=3.961 days), longer leaves (LoFe=2.871 cm) and widest leaves (LaFe=2.587 cm), reflecting good morphological development from this early stage.

Class 2 is distinguished by intermediate values for most of the measured traits The germination time is the shortest (TeGe=3.441 days), but the leaves are significantly smaller than those of class 1. This class is then composed of the moderately growing accessions, but with faster germination.

Class 3 is characterized by a high value of germination time, showing a longer time for seedling emergence, however it has the lowest values for other traits such as leaf length, leaf width and stem diameter at the collar, suggesting a slower initial development despite late germination. Only the length of the leaves (LoFe) made it possible to clearly differentiate the three groups formed (**Table VIII**).

Table VIII. Average characteristics of K-Means classes at the 2-leaf stage

Characters	**Class 1**	**Class 2**	**Class 3**	**Pr > F(Model)**
TeGe	3,961[ab]	3,441[b]	4,286[a]	**0,007**
LoFe	2,871[a]	2,548[b]	2,163[c]	**<0.0001**
LaFe	2,587[a]	2,371[a]	2,100[b]	**<0.0001**
DiTc	0,42	0,412	0,362	**0,132**
2-leaf stage	HSKO 044_A	Ziagolo_S	HSDA 001_A	
	HSFE 031_S	HSAB 015_S	HSBK 006_A	
	HSKO 047_S	HSFE 032_A	HSNI 058_S	
	HSAG 080_A	HSBO 024_A	HSBK 003_A	
	Bangolocampement_S	HSBK 002_S	HSKO 040_A	
	HSFE 028_A	HSKO 052_S	HSKO 042_S	
	Bangolo_S	HSBO 026_S	HSNI 054_S	
	HSKO 043_A		Abobo-Baoulé_A	
	HSKO 037_A		HSBO 023_A	

	HSBK 004_S		HSKO 046_A
	HSKO 053_A		

TeGe : Germination time, LoFe : Leaf length, LaFe : Leaf width, DiTc : Diameter from stem to collar

In the vegetative stage

Class 1 is characterized by a high plant height (HaPl=37.74 cm), a large blade length (Lole=11.19 cm) and a noticeable blade width (LaLe=9.97 cm). These accessions therefore show good vegetative development and have a high growth potential.

Class 2 is composed of accessions with a higher number of separated lobe (NoLs=4), a length and width of the blade comparable to that of Class 1, but a slightly lower plant height.

Class 3, on the other hand, has the lowest values for many of the traits studied. (**Table IX).** Only leaf petiole length (LoPf) and plant height (HaPl) significantly differentiated the three classes. However, only the height of the plant made it possible to differentiate them distinctly.

Table IX. Average characteristics of K-Means classes at the vegetative stage

Characters	**Class 1**	**Class 2**	**Class 3**	**Pr > F(Model)**
DiTi	0,797	0,402	0,772	**0,643**
NoLs	2,682	3,838	3,449	**0,071**
LoPf	7,970[a]	7,540[a]	6,681[b]	**0**
LaPf	0,429	0,41	0,47	**0,701**
LoLe	11,194	11,203	10,573	**0,162**
LaLe	9,977	9,94	9,588	**0,743**
HaPl	37,742[a]	30,624[b]	23,853[c]	**< 0.0001**
	HSBK 006_A	HSAG 080_A	HSDA 001_A	
	Bangolocampement_S	HSBO 024_A	HSKO 047_S	
	HSAB 015_S	HSKO 042_S	HSBO 023_A	
	HSBK 004_S	HSKO 040_A	HSBK 002_S	
	HSFE 032_A	HSBO 026_S	HSKO 053_A	
Vegetative stage	HSKO 043_A	HSKO 044_A	HSKO 046_A	
	Ziagolo_S	HSNI 054_S	HSFE 028_A	
	HSKO 037_A		HSKO 052_S	
	Bangolo_S		HSNI 058_S	
	HSBK 003_A		Abobo-Baoulé_A	
	HSFE 031_S			

DiTi : Diameter of the stem, NoLs : Number of separate lobes, LoPf : Length of the leaf petiole, LaPf : Width of the leaf petiole, LoLe : Length of the blade, LaLe : Width of the blade, HaPl : Height of the plant

In the flowering stage

Class 1 occupies an intermediate position, with late flowering and medium-sized flowers (DiF=5.8 cm).

Class 2 has an early flowering (TaF=108.26 days), large diameter flowers (DiF=6.14 cm) and relatively longer peduncles. The accessions of this class are the earliest to flower with large fruits with long stalks.

Class 3 is characterized by the highest time of appearance of the first flowers (TaF=161.38 days), associated with the smallest flower diameter (DiF=4.69 cm) and the length of the flower peduncle (LpF=0.837). This shows that the accessions of this class are characterized by a late flowering accompanied by smaller flowers. (**Table X**)

Table V. Average characteristics of K-Means classes at the flowering stage

Characters	**Class 1**	**Class 2**	**Class 3**	**Pr > F(Model)**
TaF	143,609[b]	108,268[c]	161,703[a]	< **0.0001**
DiF	5,800[a]	6,138[a]	4,660[b]	< **0.0001**
LpF	1,381[a]	1,469[a]	0,811[b]	< **0.0001**
Flowering stage	HSKO 046_A HSAB 015_A HSBO 026_S HSKO 040_A	Ziagolo_S Bangolocampement_S HSBK 004_S HSFE 031_S Bangolo_S HSKO 037_A HSKO 043_A	HSKO 044_A HSDA 001_A HSKO 047_S HSKO 042_S HSFE 028_A HSFE 032_A HSBO 023_A HSBO 024_A HSKO 053_A HSBK 006_A HSAG 080_A HSBK 002_S HSKO 052_S HSNI 054_S	

	HSNI 058_S
	HSBK 003_A
	Abobo-Baoulé_A

TaF: First Flower Onset Time, DiF: Flower Diameter, LpF: Flower Peduncle Length

At the fruiting stage

Class 1 shows an intermediate position, with an average number of fruits (25.51) and seeds (30.11), but with a longer capsule opening time (DoCa) (201.97 days), which could slow down the availability of seeds at maturity.

Class 2 brings together the best performing accessions in terms of productivity with the highest number of fruits per plant (46,046) and a high number of seeds per plant (31,27). It also has the highest number of fruiting branches (6.31).

Class 3 is characterized by the lowest values in number of fruits per plant (20.86) and number of seeds per fruit. (**Table XI)**

Table XI. Average characteristics of K-Means classes at the fruiting stage

Characters	**Class 1**	**Class 2**	**Class 3**	**Pr > F(Model)**
NoFr	25,514[b]	46,046[a]	20,864[b]	**< 0.0001**
DoCa	201,971[a]	191,117[a]	158,476[b]	**< 0.0001**
NoBf	4,198[a]	6,308[a]	4,230[b]	**0,008**
NgFr	30,269[a]	31,269[a]	22,958[b]	**< 0.0001**
Selen	2,115	2,156	2,190	**0,54**
Fruiting stage	HSBO 023_A HSKO 042_S HSAG 080_A HSBK 002_S HSBO 024_A HSKO 040_A Abobo-Baoulé_A HSKO 047_S HSKO 053_A HSNI 058_S HSNI 054_S HSFE 028_A HSFE 032_S HSKO 043_A HSBK 003_A HSDA 001_A HSKO 052_S	HSKO 037_A HSFE 031_S HSBK 004_S HSKO 046_A Bangolo_S	Ziagolo_S HSBK 006_A HSBO 026_S Bangolocampement_S HSAB 015_S HSKO 044_A	

NoFr: Number of Fruit per plant, DoCa: Date of opening of the first capsules, NoBf: Number of fruiting branches, Seln: Weight of 100 seeds, NgFr: Number of Seeds per fruit

Selection of elite accessions by stage of development

The k-means classification made it possible to select the best ones at each stage of development. At the 2-leaf stage, Class 1, shows the highest values for leaf length, leaf width and stem diameter at the collar, reflecting good morphological development from this early stage. The elite accessions at this stage are **HSKO 044, HSFE 031, HSKO 047, HSAG 080, Bangolo camp, HSFE 028, Bangolo, HSKO 043, HSKO 037, HSBK 004, HSKO 053.** At the vegetative stage, the accessions (**HSBK 006, Bangolocampement, HSAB 015, HSBK 004, HSFE 032, HSKO 043, Ziagolo, HSKO 037, Bangolo, HSBK 003, HSFE 031**) belonging to class 1 appear to be the most promising in terms of vegetative vigour. Class 2 from the flowering stage has the most favourable characteristics early flowering, large flowers, long peduncle, which is often sought after in varietal improvement. The elite accessions belonging to this class are **Ziagolo, Bangolo camp, HSBK 004, HSFE 031 Bangolo, HSKO 037, HSKO 043**. Class 2 at the fruiting stage, whose elite accessions are **HSKO 037, HSFE 031, HSKO 004, HSKO 046, Bangolo,** was distinguished by its high yield potential, characterized by a high number of fruits per plant, many seeds per fruit. Some accessions are consistently found in the best performing classes. These accessions (**HSKO 037, HSFE 031, HSBK 004, Bangolo**), which can be described as elite accessions, have good vigour at the 2-leaf stage, balanced vegetative growth, abundant flowering and a high yield of fruit and calyx at maturity.

Discussion

The morpho-phenological evaluation of the different accessions at each stage of development carried out based on quantitative parameters, revealed a heterogeneity between accessions, as indicated by the Kruskal-wallis test. High values of coefficients of variation of traits such as leaf length, stem diameter at collar, number of separated lobes, leaf petiole width, plant height, peduncle length, number of fruits per plant, number of fruiting branches. According to **Aljane and Ferchichi (2007),** a high value of the coefficient of variation (30%) reflects the heterogeneity of the material studied. The mixing of several morphotypes within the same

accession and the spontaneous shattering at maturity of certain accessions, which leads to seed losses, can also explain these results. Regarding morpho-phenological performance, the leaves varied from 4.5 cm to 19.5 cm (width) and from 6.1 cm to 16.20 cm (length) with petioles with an average length of 7.47 cm. According to **McClintock *et al*. (2011),** the leaf blade can reach 9 to 15 cm long and 9 to 20 cm wide in Senegalese varieties, and 10 to 16 cm long and 10 to 20 cm wide for Thai varieties (**Bakasso, 2010; Hien, 2012**). The blade is connected to the stem by a petiole 4 to 12 cm long. The average number of fruits per plant (28.38 capsules) remains low compared to the results of **Bakasso (2010),** which could be attributed to temperature variation and an early cessation of rains, resulting in flower bud drop. The accessions collected have a flowering date between 74 and 192 days. Our results differ from those of **Bakasso (2010)** and **Satyanarayana *et al*. (2017)** which found respectively a cycle of 65 to 97 days for 50% flowering for genotypes grown in Niger and 153 to 163 days for 50% flowering for genotypes grown in India. According to **Islam *et al*. (2008)**, the flowering date of *Hibiscus sabdariffa* depends not only on environmental conditions and genotypes but also on the sowing date. **Hacket and Carolene (1982)** reported that *Hibiscus sabdariffa* was sensitive to day length (i.e., it was a short-day plant that flowered when day length shortened).

The correlations observed between the variables, whether positive or negative, could be exploited in a breeding program. For example, positive correlations are observed between leaf blade width and blade length (r = 0.70), petiole length and blade width (r = 0.58), plant height and flower diameter (r = 0.39), and petiole length and leaf blade width (r = 0.58) show that more vigorous plants produce more leaves and fruit. These results are like those obtained by **Islam *et al*. (2008)** and **Bakasso (2010).**Similarly, the positive and significant correlation between the date of opening of the first capsules and the time of appearance of the first flowers (r = 0.88), the length of the peduncle and the diameter of the flower (r = 0.82) and between the number of fruiting branches and the number of fruits per plant (r = 0.81), shows that certain morphological characteristics are directly related to reproductive performance and yield. In addition, negative correlations between certain variables, such as plant height and first flower appearance time (r = -0.47), first flower appearance time and flower diameter (r = -0.60), show that floral earliness is often associated with better vegetative performance.

Analysis by the classification of dynamic swarms applied to the different stages of development has made it possible to highlight three homogeneous groups ranked according to the stage of development. At the 2-leaf stage, Class 1, shows the highest values for leaf length, leaf width and stem diameter at the collar, reflecting good morphological development

from this early stage. Also at the vegetative stage, accessions belonging to class 1 appear to be the most promising in terms of vegetative vigour. Class 2 from the flowering stage has the most favourable characteristics early flowering, large flowers, long peduncle, which is often sought after in varietal improvement. Class 2 at the fruiting stage was distinguished by a high yield potential, characterized by a high number of fruits per plant, many seeds per fruit. The analysis shows that the most successful accessions are not always consistent from one stage to another. Some early accessions at the 2-leaf stage showed average vegetative vigour thereafter, while others that were slower at the start expressed better agronomic performance at maturity. However, a few accessions stood out for their regularity in the most successful classes at all stages observed. This phenotypic stability suggests good adaptability and high genetic potential. These accessions, considered elite, represent priority candidates for varietal improvement programs.

Conclusion

The goal of plant breeding is to create cultivars. It requires both elite accessions for their characteristics and a good understanding of them.

The objective of our study was to identify elite accessions of Guinea sorrel through their morpho-phenological evaluation during four (4) stages of development.

The results obtained based on the quantitative traits revealed a high variability for several traits related to growth and yield, such as plant height, leaf length, stem diameter and the number of fruits per plant. The structuring of the morpho-phenological diversity of accessions revealed three groups, regardless of the geographical origin of accessions. This study also highlighted important correlations between several variables related to yield and plant cycle. The comparison of accessions over the four stages of development made it possible to identify, at each stage, elite accessions. Some of them, such as **HSKO 037, HSFE 031, HSBK 004** and**Bangolo**, have shown high stability and performance over the entire cycle, and could thus be used as starting material for a Guinea sorrel breeding programme.

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