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Agro-Morphological Characterization of Cassava (*Manihot esculenta* Crantz) Cultivars from Chad

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Abstract

Cassava is a considerable source of food and income for the rural community of the south of Chad. Despite the importance of the diversity of cultivars *in situ*, their morphological traits and agronomic performance are under investigated. The aim of this study is to characterize and analyze the variability structure of the cassava's germplasm. Fifty nine cultivars collected from five main cassava growing regions, were evaluated by forty five agro-morphological descriptors in a Fisher design replicated three times. Data were collected at three, six, nine and twelve months after planting. High phenotypic variability was shown within the collection for the color of apical leaf, vein leaf, petiole, roots and pulp. The same case was observed for the root peduncle, the shape of the central leaflet and the root, the cortex root thickness and the texture of root epidermis. Significant to highly significant differences were observed for all the quantitative traits. High variability were shown for the size of the leaf lobe, petiole length, plant height, root number and length, harvest index, above-ground biomass and fresh root weight. Positive correlations were found between the leaflet and leaf lobe number. Fresh root weight was also positively correlated to the root number, length and diameter. Principal component analysis (PCA) on quantitative variable revealed four groups with two

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of them containing performant cultivars: Group II with small root, high potential yield but less leaflet and leaf lobe and group III characterized by some cultivars with high productivity, more leaflet and leaf lobe, more and bigger roots. At regional level, significant differences were shown within cultivars which were discriminated in relation to their origin region by the number of the leaf lobes. The better cultivars and the interesting traits could be used to improve cassava production in Chad.

Keywords

Variability, Traits, Cassava Cultivars, Local, Improved, Chad

1. Introduction

Cassava (*Manihot esculenta* Crantz), native to Latin America, is increasingly grown in tropical and subtropical areas. It is the main source of calories in the tropics [1] and income for small-scale farmers. In Chad, it is widely cultivated with little or no chemical fertilizers, since its introduction in 1930 [2]. Over the past 10 years, the average annual production was estimated at 226,000 t over 44,000 ha. At regional level, for the last six years, the production is ranged from 32,000 to 85,000 t [3]. In the study area, the farmers often use local and improved cultivars in the same field. However, most of them use local cultivars not only for the stability of their production, but because they are often well adapted to marginal areas as reported by Willemen *et al*., [4] and also for socio-cultural reasons. To distinguish them, they use a local nomenclature based on the origins of the cultivar, cultural and socio-economic considerations and mainly phenotypic traits as reported by many authors [5]-[7]. These naming method based on agro-morphological traits are also common in other plants [8]-[10]. According to Lozano [11], Nweke *et al*. [12], Dixon *et al*. [1], cassava has many genotypes which respond differently to soil, climatic and biotic factors. Some of these characters can be relevant for varietal improvement and breeding programs. Indeed, Fukuda and Guevara [13] indicated that the evaluation of the existing genetic variability is necessary and must be based on appropriate and recognized descriptors. In Guyana, Elias *et al*. [14] showed that morphological traits and their plasticity have a heritable genetic variation. Several studies carried out in the world, using morphological and agronomic traits, revealed an important heterogeneity within cassava cultivars held by farmers [15] [16]. Others were evaluated by morphological traits and classified in separate groups [17]-[20]. Similar studies were also conducted on local onion ecotypes [21], maize [22], cowpea [23] and even plants threatened of extinction as *Solenostemon rotundifolius* [24]. The agro-morphological traits are frequently used in the preliminary evaluation because they are fast and easy approach for assessing the extent of diversity [17]. These traits reveal the true diversity as perceived by farmers [25] [26]. Phenotypic characterization has been also used in the taxonomic and genotypic classification by Nassar [27]. In Chad, despite the importance of cassava cultivars and their perfect knowledge by farmers that keep them *in situ*, their agronomic performance and morphological traits were not identified or documented, except for the improved cultivars. However, a preliminary agro-morphological assessment of these cultivars can then be used for molecular studies. The objective of this study was to evaluate, based on phenotypic and agronomic traits, the cassava germplasm, to determine the relation among traits and analyze the structure of the agro-morphological variability.

2. Material and Methods

2.1. Plant Material

A total of 59 cultivars were collected from 5 major cassava growing regions: Mandoul, Moyen Chari, Tandjilé, Logone Occidental and Oriental. These cultivars correspond to the total number of cultivars recorded during the survey. Nine were identified as improved by their phenotypic traits observed in the fields and information collected from farmers.

2.2. Study Area and Experimental Design

The study was carried out from August 2014 to July 2015 at the agronomical research station of Bebedjia (latitude: 8˚40'N; longitude: 16˚33'E; altitude: 384 m). The climate is hot and humid. From June to November, a total rainfall of 1031.3 mm was collected for 70 rainy days. August with 307.6 mm for 13 rainy days was the wettest month, while in November, was recorded only 4.7 mm in 2 days. The annual average temperature was 27.3˚C. Tropical ferruginous soils are dominant, the vegetation is characterized by woodlands and wooded savannahs [28]. The trial was carried out in Fisher design with 3 replications. Per block, 59 cultivars were used. After plowing, each block was delimited. Twelve cuttings (25 - 30 cm) of each cultivar were horizontally planted with spacing 1 m (rows) × 1 m (plants). Blocks were separated by paths of 2 m. The experimental unit was represented by a line of 12 m with 12 plants of a cultivar. Ten central plants of each cultivar per block were marked to facilitate observation. Weeding was done when it was necessary.

2.3. Data Collection

The agro-morphological traits were observed at 4 periods of months after planting (MAP). The qualitative data collection at 3, 6, 9 MAP (**Table 1**) and at harvest stage corresponding at 12 MAP (**Table 2**) was made by using 32 descriptors with modalities that varied between 2 and 7. The most frequently observed variant is noted. The presence or absence of flowers (Flw), seeds (Sed) and dates, were recorded throughout the vegetative stage until harvest. For quantitative data (**Table 3**), measures and counting were taken on 3 plants for each cultivar per repetition. Number of leaflets, leaves, lobes and tubers per plant were counted. The widths of the lobes, lengths of lobes, petioles, tubers, plant height, stems and tubers diameters were measured. The aboveground biomass (leaves, branches, stems) and the roots were separately weighed. Harvest index (HI) were calculated using the formula: HI = WFR/[(WFR + WFAB)] where WFR = Weight of fresh roots; WFAB = Weight of fresh aboveground biomass. The equipment used are a double-decimeter, graduated ruler, calipers, digital balance and the descriptor of the cassava [29].

Table 1. Qualitative traits and corresponding variants observed at 3, 6 and 9 MAP.

Period	Traits observed	Code	Variants
3 MAP*	Color of apical leaves	CAL	3. Light green 5. Dark green 7. Purplish green 9. Purple
	Pubescence on apical leaves	PAF	0. Absent 1.Présent
	Velum on mature leaf	Vel	0. Absent 1. Present
6 MAP	Shape of central leaflet	SCL	1. Ovoïd 2. Elliptic-lanceolate 3. Obovate-lanceolate 4. Oblang-lanceolate 5. Lanceolate 6. Linear 7.Others
	Petiole color	PeC	1. Yellowish-green 2. Green 3. Reddish-green 5. Greenish-red 7. Red 9. Purple
	Leaf color	LeC	3. Light green 5. Dark green 7. Purple green 9. Purple
	Lobe margins	LoM	3. Smooth 7. Winding
	Color of leaf vein	CLV	3. Green 5.Reddish-green in less than half of the lobe 7. Reddish-green in more than half of the lobe 9. All red
	Orientation of petiole	OrP	1. Inclined upwards 3. Horizontal 5. Inclined downwards 7. Irregular
9 MAP	Prominence of foliar scars	PFS	3. Semi-prominent 5. Prominent
	Color of cortex stem	CCS	1. Orange 2. Light green 3. Dark green
	Color of stem epidermis	CSEp	1. Cream 2. Light brown 3. Dark brown 4. Orange
	Color of stem exterior	CSEx	3. Orange 4. Greeny-yellowish 5. Golden 6. Light brown 7. Silver 8.Gray 9. Dark brown
	Growth habit of stem	GHS	1. Straight 2. Zig-zag
	Distance between leaf scars	DLS	3. Short (≤8 cm) 5. Medium (8 - 15 cm) 7. Long (≥15)
	Color of end branches of adult plant	CEB	3. Green 5. Green-purple 7. Purple
	Stipule margin	StM	1. Entire 2. Split or forked
	Length of stipules	LSt	3. Short 5. Long

MAP*: Month after planting.

Table 2. Qualitative morphological traits and corresponding variants observed at harvest (12 MAP).

Traits observed	Code	Variants
Branching habit	BH	1. Erect 2. Dichotomus 3. Trichotomous 4. Tetrachotomus
Shape of plant	ShP	1. Compact 2. Open 3. Umbrella 4. Cylindrical
Extent of root peduncle	ERP	0. Sessile 3.Pedunculate 5.Mixed
Root constrictions	RoC	1. Few to none (3 or less) 2. Some (4 - 6) 3. Many (>6)
Root shape	RoS	1. Conical 2. Conical-cylindrical 3.Cylindrical 4. Irregular
External color of storage root	ECR	1. White or cream 2. Yellow 3. Light brown 4. Dark brown
Color of root pulp	CRP	1. White 2. Cream 3. Yellow 4. Orange 5. Pink
Color of root cortex	CRC	1. White or cream 2. Yellow 3. Pink 4. Purple
Cortex: ease of peeling	CEP	1. Easy 2. Difficult
Texture of root epidermis	TRE	3. Smooth 5. Intermediate 7. Rough
Cortex thickness	CoT	1. Thin 2. Intermediate 3. Thick
Root taste	RoT	1. Sweet 2. Intermediate 3. Bitter
Flowering	Flw	0. Absent 1. Present
Seed	Sed	0. Absent 1. Present

Table 3. Quantitative traits measured at 3, 6 and 12 MAP and their code.

Period	Traits observed	Code
	Number of leaflet	NLt
3 MAP	Number of leaves	NLe
	Number of leaf lobes	NLB
6 MAP	Ratio: length lobe/width lobe (cm)	Rt
	Petiole length	PL (cm)
	Height of plant	HP (cm)
	Diameter of stem at 50 cm from ground	DSt (cm)
12 MAP	Number of storage roots per plant	NRo
	Weight of fresh roots per plant	WFR (g)
	Weight of fresh aboveground biomass per plant	WFAB (g)
	Root lenght	RoL (cm)
	Median diameter of root	MDR (cm)
	Harvest index	HI

2.4. Statistical Analysis

The cultivars were described using morphological and agronomic list of descriptors of cassava developed by Fukuda *et al.* [29]. The collected data and observations were processed using XLSTAT-Pro software version 2013.5.01. The distribution percentage of the different variants of qualitative traits was determined. The organization and structure of the morphological variability were visualized using a dendrogram. Quantitative variables were analyzed using descriptive statistics methods, correlations and then subjected to analysis of variance (ANOVA) to identify significant traits. Principal Component Analysis (PCA) was used to determine the relationships between the traits. Groups formed by the Ascending Hierarchical Clustering (AHC) were characterized by the analysis of variance. Analysis of variance was also used to assess the differences between cultivars from regions.

3. Results

3.1. Morphological Qualitative Traits

Some variants were observed in more than 80% to 95% of the cultivars (**Table 4**). These variants are: erect branching habit, greeny-yellowish stems, light brown epidermis of the stems, entire stipules, no pubescence on apical leaves and roots easy to peel. On the other hand, no variability was observed for 5 traits. So all the studied cultivars have prominent foliar of scars, closely spaced between leaf scars and light green cortex of stems, no velum on mature leaf and straight habit growth. Furthermore, the number of cultivars with light green leaf was approximately equal to those with dark green leaf. It is the same case for smooth and winding lobe. The study also revealed that 69% of cultivars are sweet. About 75% or more have roots which the cortex is not thick and easy to peel. Yellow root pulps are less present (15%) in the study area. Less cultivars have flowers and seeds. Only 5% are early maturing and present flowers at 6 MAP. The flowering stage was reached at 9 and 12 MAP for 17% of them. At harvest, seeds were observed on only 7% of the cultivars.

Ascending Hierarchical Clustering analysis, based on qualitative morphological traits, revealed three major groups (**Figure 1**). Group I contained 29 cultivars characterized by purplish green apical leaves, green vein, sessile and conical-cylindricalroot. Within this group, two couples of cultivars, GAN0606 and BOR0808, DVA3 and TE1355, present many similarities. In Group II, there are cultivars with mixed peduncle root and elliptic-lanceolate central leaflets. In this group, DVA5 and TL0101 present many similarities. Cultivars of group III have light green leaves, red vein, smooth lobes and irregularly shaped roots.

3.2. Descriptive Analysis of Quantitative Traits

Results (**Table 5**) revealed high gap for some variables such as the number of leaves per plant (NLe), the size of the lobes (Rt), the petiole length (PL), the number of roots per plant (NRo) and length (RoL), the weight of fresh aboveground biomass (WFAB), the weight of fresh roots per plant (WFR) and the harvest index (HI). Significant to highly significant differences were observed for all the traits with coefficients of variation ranging from 11.80% in the number of leaflets (NLt) and lobes (NLB) to 48.60% for the fresh roots weight per plant (WFR). The studied cultivars have long petioles (PL = 24.07 cm) except one with shorter petiole (PL = 1.25 cm). The height of the plant (HP) varied from 167.50 to 294.00 cm. The average number of roots per plant (NRo) is 7 with only 3 roots for less productive cultivars and 13 for more productive. However, the sizes (RoL) of these roots are significant with an average of 32.56 cm. The fresh aboveground biomass (WFAB) is very high with an average of 4825.15 g per plant. Root (WFR) production values range from 583.3 to 7833.33 g per plant and from 9.3% to 63.5% for harvest index (HI).

3.3. Correlation between Quantitative Traits

The matrix (**Table 6**) shows highly significant correlations among some couples of traits. Positive correlations were observed between the number of leaflets (NLt) and the number of leaf lobes (NLB). The weight of fresh roots (WFR) is positively correlated to the number of roots (NRo), root length (RoL) and median diameter of the roots (MDR). Harvest index (HI) is positively correlated with weight of fresh roots (WFR) but negatively to fresh aboveground biomass (WFAB). The Kaiser-Meyer-Olkin index (KMO = 0.687) and the highly significant Bartlett's test of sphericity ($p < 0.0001$) obtained, means that it's possible to envisage a principal component analysis to estimate the contribution of each trait to total variability.

3.4. Structuring Agro-Morphological Diversity

The first six axes of the principal component analysis (PCA) explain 83.27% of the total variation (**Table 7**). Eleven of the quantitative traits contribute for more than 18% to a given axe.

Table 4. Variability of qualitative traits and their variants observed on 59 cassava cultivars.

Traits observed	Variants	Rate (%)	Traits observed	Variants	Rate (%)
Color of apical leaves	Light green Purplish	37	Growth habit of stem	Straight	100
	green	48			
	Purple	15			
Pubescence on apical leaves	Absent	93	Color of end branches of adult plant	Green	42
	Présent	7		Green-purple	58
Velum on mature leaf	Absent	100	Length of stipules	Short	22
				Long	78
Leaf color	Light green	44	Stipule margin	Entire	95
	Dark green	56		Split or forked	5
Lobe margins	Smooth	53	Extent of root peduncle	Sessile	61
				Pedonculate	12
				Mixed	27
	Winding	47			
Petiole color	Reddish-green	2	Roots constriction	Few to	5
	Greenish-red	49			
	Red	20		none Some	70
	Purple	29		Many	25
Shape of central leaflet	Elliptic-lanceolate	74	External color of storage root	White or cream	27
	Oblang-lanceolate	2		Yellow	29
				Light brown	22
	Linear	24		Dark brown	22
Color of leaf vein	Green	63	Texture of root epidermis	Smooth	53
	Reddish-green	10		Intermediate	20
	All Red	27		Rough	27
Orientation of petiole	Inclined upwards	22	Root shape	Conical-cylindrical	59
	Horizontal	70		Cylindrical	2
	Irregular	8		Irregular	39
Prominence of foliar scars	Prominent	100	Color of root pulp	White	20
				Cream	65
				Yellow	15
Color of stem exterior	Orange	9	Cortex thickness	Thin	29
	Greeny-yellowish	83		Intermediate	46
	Gray	8		Thick	25
Color of cortex stem	Light green	100	Color of root cortex	White or cream	69
				Yellow	24
				Pink	5
				Purple	2
Distance between leaf scars	Short	100	Cortex: ease of peeling	Easy	85
				Difficult	15

Continued

Color of stem epidermis	Cream	2	Root taste	Sweet	69
	Light brown	95		Intermediate	17
	Orange	3		Bitter	14
Branching habit	Erect	85	Flowering	Present	22
	Dichotomus	13			
	Trichotomus	2		Absent	78
Shape of plant	Compact	5	Seed	Present	7
	Open	5			
	Umbrella	9		Absent	93
	Cylindrical	81			

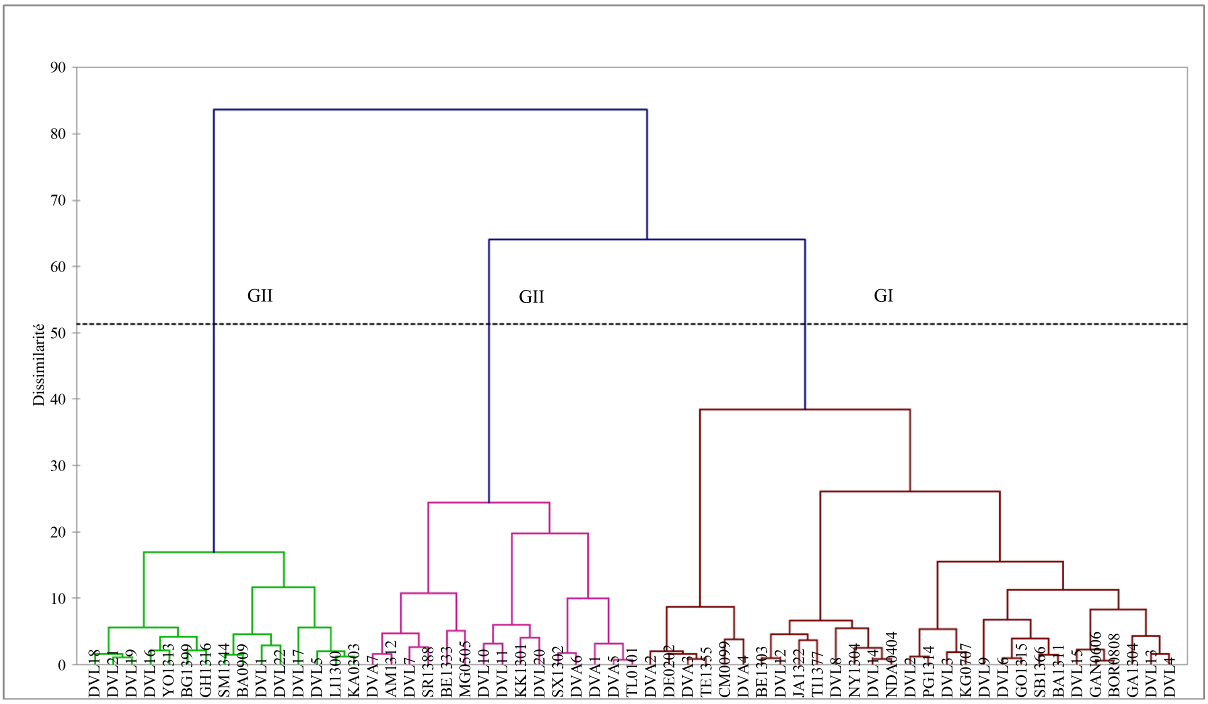

Figure 1. Classification of cultivars based on qualitative data and Ward Method.

The first three factorial axes contribute to 60.34% of the total variation (**Table 8**). The results show also correlations between some variables and the 3 axes.The length (RoL) and median diameter of the roots (MDR), diameter of the stem (DSt), weight of fresh roots (WFR) and harvest index (HI) are correlated to axe 1 and contribute to 29.56% of the total variation. This axe is characterized by cultivars with large roots and important root median diameter. The diameter of the main stem is also big, as the weight of roots and harvest index. The number of leaflets (NLt), the number of lobes (NLB) and their size (Rt) were associated to axes 2 which contribute to 17.98% of the total variation. Cultivars had many leaflets and many wide lobes. With 12.80% of the level of variability, axe 3 is correlated to the number of leaves (NLe) and the height of the plant (HP) and characterized by tall and leafy plants.

An ascending hierarchical clustering (AHC) carried out on 11 quantitative traits revealed 4 cultivars groups. Groups I and II have a high number of cultivars with 27 and 16, respectively. Nine individuals were in group III and 7 in group IV. Significant to highly significant differences were observed for all the characters (**Table 9**). Six traits allow differentiating at least three groups. Stem diameter and root median diameter distinguish only two groups (I, II, III/IV). The performance analysis of these classifications show that Group I is composed of tall

Table 5. Descriptive statistics and results of the analysis of variance (ANOVA) of 59 cassava cultivars for the quantitative traits.

Traits	Minimum	Maximum	Average	SD	CV	F
NLt	7.000	10.000	8.006	0.944	11.80	**
NLe	24.000	53.333	34.705	4.585	13.20	**
NLB	7.000	9.000	7.718	0.910	11.80	**
Rt	2.927	12.100	5.245	2.346	44.60	**
PL (cm)	1.250	34.000	24.070	4.866	20.20	**
HP (cm)	167.500	294.000	237.420	24.979	10.50	**
NRo	2.667	12.333	6.588	2.116	32.00	**
Rol (cm)	22.111	52.444	32.563	6.334	19.40	**
MDR (cm)	3.149	7.472	5.039	0.940	18.60	*
DSt (cm)	1.943	4.459	2.787	0.474	17.00	*
WFAB (g)	1466.667	9722.222	4825.152	1635.559	33.80	**
WFR (g)	583.333	7833.333	3048.349	1486.418	48.60	**
HI	0.093	0.635	0.378	0.117	30.80	**

SD: Standard Deviation; CV: Coefficient of Variation; F: Fisher's coefficient; *: Significant; **: Highly significant.

Table 6. Correlation matrix between quantitative traits.

Variables	NLt	NLe	NLB	Rt	PL	HP	NRo	RoL	MDR	DSt	WFAB	WFR	HI
NLt	1												
NLe	0.000	1											
NLB	**0.577**	0.011	1										
Rt	**0.342**	−0.135	**0.384**	1									
PL	**0.275**	0.120	**0.362**	0.036	1								
HP	0.088	**0.374**	0.020	−0.074	**0.243**	1							
NRo	**−0.150**	0.026	**−0.236**	0.060	0.054	**0.197**	1						
RoL	**0.182**	**0.220**	**0.161**	**0.264**	**0.243**	0.095	**0.220**	1					
MDR	**0.156**	0.121	0.146	−0.055	**0.419**	**0.222**	**0.212**	**0.216**	1				
DSt	**0.232**	**0.231**	**0.173**	−0.042	**0.392**	**0.250**	0.147	**0.383**	**0.501**	1			
WFAB	**0.167**	**0.150**	0.107	**0.179**	**0.235**	**0.178**	**0.298**	**0.356**	**0.167**	**0.298**	1		
WFR	0.066	**0.156**	0.070	0.140	**0.292**	**0.185**	**0.529**	**0.566**	**0.533**	**0.431**	**0.316**	1	
HI	−0.028	0.071	0.051	0.006	**0.193**	0.093	**0.344**	**0.336**	**0.456**	**0.249**	**−0.317**	**0.757**	1

Values in bold are significant at alpha = 0.05.

cultivars (HP) with the highest average number of leaves per plant (NLe). Their roots have significant median diameters (MDR), intermediate root weight and harvest index. Group II contains cultivars characterized by less leaflets (NLt), less (NLB) and small lobes (Rt), many roots (NRo) and productive as the individuals from group III. This last group (III) is composed of individuals with wide, many lobes and numerous lengthy roots. In the Group IV, there are small-sized plants (HP), less productive (WFR) with less and small root diameter (MDR).

Table 7. Contributions of variables to the formation of the 6 factorial axes.

Factorial Axes	Axe 1 (29.56%)	Axe 2 (17.98%)	Axe 3 (12.80%)	Axe 4 (9.24%)	Axe 5 (7.48%)	Axe 6 (6.21%)
Variable	C (%)	C (%)	C (%)	C (%)	C (%)	C (%)
NLt	1.96	**31.01**	1.32	0.43	4.09	0.70
NLe	2.98	0.85	**31.06**	14.10	12.58	9.90
NLB	1.67	**33.28**	0.34	1.27	0.25	9.29
Rt	0.84	18.74	12.89	**19.47**	2.15	0.02
HP	4.25	0.79	25.44	9.34	**30.26**	0.97
NRo	7.33	9.76	7.46	9.64	**18.59**	6.17
RoL	13.26	1.18	1.21	11.39	**26.51**	6.10
MDR	14.69	0.12	0.97	**24.14**	3.12	0.00
DSt	13.37	0.33	7.39	6.37	1.82	**36.20**
WFR	**24.11**	1.33	5.14	0.02	0.21	1.66
HI	15.54	2.63	6.79	3.84	0.41	**28.98**

C: Contributions in %; In bold, significant contributions values.

Table 8. Proper values, correlations between variables and the first three factorial axes.

	Axe 1	Axe 2	Axe 3
Proper values	3.250	1.980	1.410
% Variability	29.560	17.980	12.800
% Cumulative	29.560	47.540	60.340
NLt	0.253	**0.783**	0.136
NLe	0.311	−0.129	**0.661**
NLB	0.233	**0.811**	0.069
Rt	0.165	**0.609**	−0.426
HP	0.372	−0.125	**0.598**
NRo	0.488	−0.439	−0.324
RoL	**0.657**	0.152	−0.131
MDR	**0.691**	−0.048	0.117
DSt	**0.659**	0.080	0.323
WFR	**0.885**	−0.162	−0.269
HI	**0.711**	−0.228	−0.309

In bold, significant and highly significant values.

Table 9. Characteristics of 4 cassava cultivars groups from ascending hierarchical clustering.

Variable	GI	GII	GIII	GIV	P
Num	27	16	9	7	
NLt	8.35 ± 0.09 a	7.29 ± 0.11 b	8.70 ± 0.15 a	7.43 ± 0.17 b	**
NLe	35.54 ± 0.50 a	34.83 ± 0.65 ab	33.65 ± 0.87 ab	32.57 ± 0.98 b	*
NLB	8.06 ± 0.08 b	7.00 ± 0.10 c	8.44 ± 0.14 a	7.10 ± 1.16 c	**
Rt	4.53 ± 0.12 b	3.95 ± 0.16 c	10.09 ± 0.21 a	4.75 ± 0.24 b	**
HP	245.03 ± 2.66 a	234.02 ± 3.46 ab	231.99 ± 4.61 ab	222.83 ± 5.23 b	*
NRo	6.01 ± 0.20 b	8.04 ± 0.26 a	7.23 ± 0.35 a	4.70 ± 0.40 c	**
RoL	31.11 ± 0.60 c	33.73 ± 0.78 b	39.04 ± 1.04 a	27.16 ± 1.18 d	**
MDR	5.23 ± 0.09 a	5.21 ± 0.12 a	5.08 ± 0.16 a	3.89 ± 0.18 b	**
DSt	2.88 ± 0.05 a	2.74 ± 0.07 a	2.87 ± 0,09 a	2.44 ± 0.10 b	*
WFR	2711.31 ± 128.39 b	4001.43 ± 166.78 a	3924.14 ± 222.37 a	1043.87 ± 252.14 c	**
HI	0.36 ± 0.01 b	0.45 ± 0.01 a	0.41 ± 0.02 ab	0.25 ± 0.02 c	**

Num: Number of cultivars. Values with same letters and in the same line are not significantly different according to the test of Student Newman-Keuls at 0.05.

3.5. Differentiation between Cultivars at Regional Level

At regional level, 7 quantitative traits showed significant differences (**Table 10**). Number of leaf lobe is the relevant variable. Cultivars with more leaflets (NLt = 9), leaf lobe (NLB = 9), productive with the highest harvest index (HI = 0.42) was found in Mandoul. In Moyen Chari and Logone Occidental, cultivars are also productive with high number of roots (NRo = 7). The cultivars from Logone Oriental were characterized by the importance of their leaves (NLe = 36) and an intermediate weight of fresh roots (WFR = 2792.06 g). Tandjilé contains the less productive cultivars (WFR = 2204 g), less roots (NRo = 5) and lobes (NLB = 7).

Table 10. Performances of 59 cassava cultivars at regional level.

Region	NLt	NLe	NLB	Rt	NRo	WFR	HI
Mandoul	9 a	34 ab	9 a	6.13 a	5 b	3524.38 a	0.42 a
Moyen Chari	8 ab	33 b	8 b	6.09 a	7 a	3265.32 a	0.38 ab
L$^{(1)}$. Oriental	7 b	36 a	8 b	4.65 b	6 ab	2792.06 ab	0.37 ab
L$^{(1)}$. Occidental	7 b	34 ab	8 b	4.79 b	7 a	3508.31 a	0.39 ab
Tandjilé	7 b	34 ab	7 c	4.99 ab	5 b	2204.63 b	0.33 b
p-value	0.018	0.023	<0.0001	0.008	0.004	0.001	0.018

L$^{(1)}$: Logone. Values with same letters and in the same column are not significantly different according to the test of Student Newman-Keuls at 0.05.

4. Discussion

The increasing importance of cassava in the food security in Chad requires extensive study. Valorization and use of this diversity maintained *in situ* by farmers are opportunities for improving national production. The agro-morphological characterization of this potential is the preliminary phase for molecular studies. This study permitted to evaluate the level of cassava variability in Chad by using morphological and agronomic traits. The analysis of qualitative characteristics in various organs showed a significant variation within the studied cultivars. The colour appears as the most representative and the most distinctive trait. Similar results were obtained by Asare *et al*. [17]. In addition, Agre *et al*. [30] have reported that farmers use the colors of the leaves and stems to identify the cassava cultivars. The analysis also reveals that most cultivars have no pubescence and the cortex of their stems is light green. These results are similar to those of Kosh-Komba *et al*. [16] who studied the typology of the diversity of cassava in Central Africa Republic and highlighted groups of cultivated varieties some of which are characterized by the colour light green of the stems and the absence of pubescence. Furthermore, 22% of cultivars flowered, which seems important, compared to what was reported by N'Zue *et al*. [19], which with a higher number of accessions only 20% were flowered. In this study, this percentage can be explained partly by the fact that most of the cultivars have an erected branching habit and cylindrical shape. In general, farmers select slightly branched cultivars for easy harvest and crops associations. According to Médard [31], cassava cultivars without ramifications, do not bloom. Others authors also pointed out that this character is linked to flowering [32], therefore, domestication of this type of cultivars, reduces the number of flowers. In addition, due to the ignorance of the importance of sexual reproduction in cassava cultivation by farmers, especially in several African countries [15] [33] [34], flowering is not a relevant criteria in the choice of cultivars. Although most farmers in Central and South Benin [30] and those from Congo [15] admit that cassava plants produce flowers. However, on a total of 198 producers, less than third of them (30%) recognize that cassava seedlings could emerge from seeds [30]. In the present study, root flesh color diversity was observed among cultivars at harvest stage. These colors are generally associated with pigments, carotenoids and flavonoids present in varying concentrations. Approximately, 15% of cultivars have yellow pulp. This variant was also observed in some cultivars, but to low percentages in the forest areas of Benin and Nigeria [35], Gabon [34] and in Cote d'Ivoire [19]. In Gabon, nine yellow cultivars corresponding to four different genotypes were identified by Delêtre [34]. The yellow coloring of the pulp is a high content indicator of carotenoids and amino acids. Emperaire *et al*. [36] indicate that they so rare in Africa unlike Amazonia. In Chad, their introduction seems to be made either through the improved varieties from IITA, or from Central Africa Republic. Moreover, the absence or low presence of root constriction observed, make easier post-harvest operations and limit losses while peeling [37]. Similarly, smooth or intermediate epidermis texture and the thinness of the roots cortex of most cultivars, reduce the volume of peeling activity done primarily by women. Very few cultivars have red petioles and pink cortex of roots compared to more than 60% to 70% observed in Cote d'Ivoire by N'Zue *et al*. [19]. On the other hand, stems of all evaluated cultivars have a straight mode of growth with light green cortex, prominent foliar scars, short distance between leaf scars and without velum. Based on qualitative variables, the 59 cultivars were clustered into 3 classes. They were differentiated by the color of their leaves and their leaf vein, the extent of their root peduncle, the shape of leaflets and roots.

Three couples of cultivars with a significant number of similarities between them seem to attest the presence of duplicates. Duplicates were often highlighted by several authors in numerous collections throughout the world, for example in cassava [17] [19] and cowpea [38]. On farm, different cultivars can have the same name or several names can be assigned to one cultivar [14]. The detection and identification of these duplicates will be made using molecular biological techniques (RFLP, RAPD). These techniques have been successfully used not only in assessing genetic diversity but also in duplicate detection within cassava collections [39] [40].

The analysis of quantitative traits revealed significant gaps and high coefficients of variation for some characters, showing heterogeneity between the cultivars studied. Similar results on cassava were obtained in Benin by Agre *et al*. [20] where some averages are identical. On the other hand, the plants are taller with shorter roots in Chad. Highly significant differences and correlations between certain pairs of characters confirm the importance of this variability. Based on quantitative traits, the first six axes with 83.27% account for a higher overall variability as demonstrated in Central Africa Republic, with 55%, but whose characters contributions ($C \geq 18$) are nearness. The analysis of the first axe shows that the relevant quantitative traits to assess this variability are similar to those used by Agre *et al*. [20], except the height of the first ramification that has not been the subject of this study. However, there are no clear differentiation and real structuring between local and improved cultivars as also reported Kosh-Komba *et al*. [16]. Groups II and III obtained from quantitative variables present interesting traits and can be integrated into a breeding program. These cultivars are characterized by high productivity, medium and large roots.

Indeed, parental lines can be formed with some cultivars, such as Kebiang (KG0707), Tinodji (DV18), Madjiganem (GA1304), Pangassou (PG1314) Mandarakako (DVL12), Tolmade (TL0101), Biyo (YO1313) and Tolmbadjé (BA1311), identified on the entire collection. In Uganda, Turyagyenda *et al*. [41] reported that the genetic diversity and heterozygosity in local cassava cultivars were slightly higher than in elite cultivars. On a total of 154 alleles revealed, 24% were unique and only present in the local cultivars.

The regional differentiation of cultivars generally corresponds to people's needs. Many factors can influence the choice of cultivars. However, there is a fairly average regional differentiation. In each region, cultivars have specific characteristics but some are identical to other regions. Their diversity is linked to the communities' experiences in cassava production.Tandjilé is a traditional area of rice production. Cassava production is recent and therefore farmers have less experience in the cultural practices,contrary to Moyen Chari and Mandoul regions, which are cassava entry points in Chad and Logone Occidental where is located a national research station. In these regions, there are the highest productive cultivars. In the Moyen Chari and Logone Occidental cultivars are selected with many roots per plant. This is an interesting trait for selection as the rate of heritability is 29.03% for cassava [42]. Wide lobes were observed in Moyen Chari and Mandoul. The cultivars were clearly discriminated by the numbers of lobes leaf when they are compared to their region of origin. According to Graner [43] and Nweke *et al*. [12], the size or shape of these lobes depends on genotype and agro ecological areas.

5. Conclusion

The study reveals the existence of significant variability within the collection. Agro-morphological relevant traits and three classes of performing cultivars were identified: Cultivars with better vegetative traits, cultivars with short, productive roots but with fewer leaflets and lobes and finally those with long roots and very productive. At regional level, cultivars have specific traits but some are identical. The number of the lobes per plant is the most relevant variable in the differentiation of cultivars of different regional origin. The varietal diversity observed, prove the key role of farmers who maintain and preserve them on farm. To safeguard and enhance these genotypes, those with relevant traits will be integrated into breeding programs after complementary molecular analyzes.

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