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Characterization of Potato (*Solanum tuberosum* L.) Genotypes from the Western Highlands Region of Cameroon Using Morphological and Agronomic Traits

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Abstract: Seventy-seven (77) potato accessions were collected from production areas in Western highlands of Cameroon (5°10'-6°30'N and 9°30'- 10° 80'E). Out of the 77 accessions, 69 were traditional and 8 were modern varieties. The genotypes were grown under Menoua (5°27'N, 10°04'E) ecological conditions. 23 morphological and agronomical traits from the internationally accepted descriptor list for potato were used. When considering 7 agronomic traits used in this study, there were no significant difference among collection zone and among altitudes; however, highly significant differences among the accessions were found. Dried matter content (21.25%), total tubers number (15.55), mean eyes number (10.46) and mean stem number (3.21) were significantly higher in traditional varieties than in modern varieties which however had the highest percentage of marketable tubers (84.89%). Significant correlations were found between marketable tuber number and plant height ($r = 0.44$; $p \leq 0.0001$) and between dried matter content, mean stems number ($r = 0.38$; $p \leq 0.001$), mean eyes number ($r = 0.30$; $p \leq 0.01$) and total tubers number ($r = 0.44$; $p \leq 0.0001$). Cluster analysis identified 2 distinct groups with high level of variation. Significant differences were observed on all agronomic traits between the 2 groups; the first group was made up of Forty-seven (47) individuals, all of them were traditional varieties out of the sixty-nine (69) collected; The second group comprised et mixture of local and exotic varieties. Implications of these results in connection with the potato breeding programs in Cameroon are discussed.

Keywords: *Solanum tuberosum* L., Characterization, Morpho-Agronomic Traits, Accession, Cameroon

1. Introduction

Millions of farmers in the world depend on potato (*Solanum tuberosum* L.) to enhance their livelihoods. Recent uncertainties in world food supply and demand have placed potato high in the list of recommended food security crops [1]. In Cameroon, potato is cultivated mainly in highland zones (Altitude: 1000 to 3000 m above the see level) and in six of the ten regions of the country. The West and Northwest regions are the top potato producers with more than 80% of the 435354 tons of the national production [2]. Potato represents one of the main sources of incomes to farmers of these regions. It is eaten locally and sold in local markets, while significant quantities are also exported to neighboring countries such as Gabon, Equatorial Guinea, Chad and Central Africa Republic [2].

Despite increases in potato production in the tropics, yields are generally low in Cameroon: less than half millions metric tons/year as compared to the average production in many other countries in tropical Africa [3]. The yields are far low to satisfy the consumption needs. These low yields could be associated to the high severity of diseases [4] and probably the genetic make-up. Another potato production constraint is the lack of adaptable planting material that is free from major diseases [5]. Consequently, most potato farmers continue to grow imported varieties that are not always adapted to the Cameroonian agro-ecologies and are often susceptible to diseases [6]. The existing local cultivars used by farmers consist of old European varieties introduced into the country in the early 20th century by missionaries and colonial explorers [7]; these conditions lead to low yields (3.3 - 6.7 $t.ha^{-1}$) [8].

High yielding varieties of potato (cipira and tubira) proposed earlier by CIP (International potato center) and IRAD (Research Institute for Agriculture and development) have lost their performances and have become susceptible to diseases [6]. Njualem [8] proposed that Cipira and Tubira should be replaced by four populations B3 clones from CIP which are resistant to diseases and adaptable to Cameroon highland ecological conditions. However, these clones were not tested in farmers' conditions. The best approach would have been to identify the best varieties and to test them in farmer's conditions.

For sustainable potato production, local (traditional) varieties are the best potential candidates for selection and breeding program. However, Studies carried out by Njualem [8] concerned only two varieties (Cipira and Tubira) among many other varieties that are actually cultivated. The genetic background of local varieties of potatoes grown in Cameroon is yet to be known. They are disappearing in the profit of exotic varieties. Prior for conservation purposes and in order to be useful for plant breeders, local potato genotypes need to be characterized using morphological and agronomical traits [9, 10].

Genetic diversity studies are used to assess the taxonomic relationship among genotypes and to choose varieties with good qualities for breeding programs [10, 11]. Morphological characterization is the first step in description and classification of genetic resources [12]. Local varieties of potatoes in Cameroon have not been characterized and are threatened of genetic erosion by introduced varieties. Their Genetic characterization is therefore essential and appears as a prerequisite in respect of setting up a potatoes breeding program in Cameroon.

The objective of this study was to determine the similarity and differences in respect to morphological and agronomical variations of local potato (*S. tuberosum*) genotypes grown in the Western Highlands Region of Cameroon.

2. Material and Methods

2.1. Plant Material Sampling and Preparation

Seventy-seven (77) potato accessions were collected from farmers in the Western Highlands region of Cameroon during the harvesting period (October 2013 to January 2014) using random sampling strategy. In order to avoid mixture of varieties for each accession, tubers of a single plant were harvested in the farm. Accessions were collected in 13 divisions along 3 altitudes classes in the West and North-West Regions of Cameroon. The altitude of the collection areas ranged from 1100 to 2400 m. Geographical data of the collection sites were recorded as well (Table 1).

Out of the seventy-seven (77) accessions, eight (08) were modern varieties; out of them, six (06) exotic varieties named Atlas, Caieser, Dosa, Mondial, Pamela, Spenta and two (02) (Cipira and Tubira) were CIP-IRAD varieties.

In order to produce enough seeds for the experiment, tubers of each potato accessions, were planted in March 2014, the harvest was completed in early June 2014 and the tubers were stored until experiment time.

Table 1. *Potato accessions collected from different location in the Western highlands region of Cameroon.*

Accession code/name	Variety	Source location		Latitude	Longitude	Altitude (m)
		Division	Village			
Cipira	modern	Bamboutos	Bangang	N 5°38'84"	E 10°6'32"	2376.75c
WBT01	traditional	Bamboutos	Bangang	N 5°38'84"	E 10°6'32"	2376.75c
WBT02	traditional	Bamboutos	Bangang	N 5°38'84"	E 10°6'32"	2376.75c
Mondial	modern	Bamboutos	bangang	N 5°38'84"	E 10°6'32"	2376.75c
WBM01	traditional	Bamboutos	Balatchi	N 5°38'65"	E 10°10'32"	1745.46c
Dosa	modern	Bamboutos	Bangang	N 5°38'84"	E 10°6'32"	2376.75c
WBT03	traditional	Bamboutos	Bangang	N 5°38'84"	E 10°6'32"	2376.75c
WBB01	traditional	Bamboutos	Babadjou	N 5°45'346"	E 10°8'36"	1743.43b

Accession code/name	Variety	Source location		Latitude	Longitude	Altitude (m)
		Division	Village			
WBB02	traditional	Bamboutos	Babadjou	N 5°45'346"	E 10°8'36"	1743.43b
WBT04	traditional	Bamboutos	Bangang	N 5°38'84"	E 10°6'32"	2376.75c
NBoB01	traditional	Boyo	Kom	N 6°12'4"	E 10°22'42"	1494.37b
NBoB02	traditional	Boyo	kom	N 6°12'4"	E 10°22'42"	1494.37b
NBoF01	traditional	Boyo	Fundong	N 6°16'18"	E 10°18'1"	1629.44b
NBuKu04	traditional	Bui	Tatum	N 6°20'245"	E 10°45'58"	2028.09c
NBuKo13	traditional	Bui	Nso	N 6°11'18"	E 10°42'23"	1923.40c
NBuJ01	traditional	Bui	Jakiri	N 6°3'549"	E 10°36'24"	1679.84b
NBuKu05	traditional	Bui	Dom	N 6°21'403"	E 10°35'19"	1542.03b
NBuKu01	traditional	Bui	Dzeng	N 6°12'576"	E 10°48'47"	2135.41c
NBuKo09	traditional	Bui	Nso	N 6°11'18"	E 10°42'23"	1923.40c
Tubira	modern	Bui	Tadu	N 6°14'117"	E 10°35'55"	2049.67c
Spenta	modern	Bui	Tadu	N 6°11'18"	E 10°42'23"	1923.40c
Caeser	modern	Bui	Tadu	N 6°11'18"	E 10°42'23"	1923.40c
NBuJ02	traditional	Bui	Jakiri	N 6°3'549"	E 10°36'24"	1679.84b
NBuKo17	traditional	Bui	Nso	N 6°11'18"	E 10°42'23"	1923.40c
NDN01	traditional	Donga-Mantung	Ndu	N 6°22'268"	E 10°47'14"	2014.48c
NDN02	traditional	Donga-Mantung	Ndu	N 6°22'268"	E 10°47'14"	2014.48c
NDN03	traditional	Donga-Mantung	Ndu 4	N 6°22'268"	E 10°47'14"	2014.48c
WHkB01	traditional	Haut-Kam	Bandja	N 5°16'395"	E 10°13'31"	1280.67a
WHkB04	traditional	Haut-Kam	Bandja	N 5°16'395"	E 10°13'31"	1280.67a
WHkB02	traditional	Haut-Kam	Bandja	N 5°16'395"	E 10°13'31"	1280.67a
WHkB03	traditional	Haut-Kam	Bandja 4	N 5°16'395"	E 10°13'31"	1280.67a
WHkB05	traditional	Haut-Kam	Fotouni	N 5°21'529"	E 10°14'39"	1575.72b
WHkB06	traditional	Haut-Kam	Fotouni	N 5°21'529"	E 10°14'39"	1575.72b
WHpM07	traditional	Hauts-Plateaux	BalatsitIII	N 5°21'158"	E 10°17'48"	1590.32b
WHpM05	traditional	Hauts-Plateaux	Badang	N 5°23'139"	E 10°19'44"	1610.63b
Atlas	modern	Hauts-Plateaux	Atlas	N 5°21'158"	E 10°17'48"	1590.32b
WHpG06	traditional	Hauts-Plateaux	Bangou	N 5°15'33"	E 10°24'1"	1828.63c
Pamela	modern	Hauts-Plateaux	BalatsitIII	N 5°21'158"	E 10°17'48"	1590.32b
WHpG07	traditional	Hauts-Plateaux	Bapa	N 5°18'13"	E 10°19'37"	1684.96b
WHpG08	traditional	Hauts-Plateaux	Bapa	N 5°18'13"	E 10°19'37"	1684.96b
WHpG04	traditional	Hauts-Plateaux	Bangou	N 5°15'33"	E 10°24'1"	1828.63c
WHpG05	traditional	Hauts-Plateaux	Bangou	N 5°15'33"	E 10°24'1"	1828.63c
WHpM08	traditional	Hauts-Plateaux	BalatsitIII	N 5°21'158"	E 10°17'48"	1590.32b
WHpM09	traditional	Hauts-Plateaux	BalatsitIII	N 5°21'158"	E 10°17'48"	1590.32b
WHpM11	traditional	Hauts-Plateaux	BalatsitIII	N 5°21'158"	E 10°17'48"	1590.32b
WHpM10	traditional	Hauts-Plateaux	BalatsitIII	N 5°21'158"	E 10°17'48"	1590.32b
WHpM02	traditional	Hauts-Plateaux	Bameya	N 5°23'414"	E 10°15'10"	1527.84b
WHpM04	traditional	Hauts-Plateaux	Bameya	N 5°23'414"	E 10°15'10"	1527.84b
WKB01	traditional	Koung-Ki	Batoufam	N 5°15'6"	E 10°27'46"	1555.11b
WKP02	traditional	Koung-Ki	Bandjoun	N 5°21'110"	E 10°24'36"	1521.65b
WKB03	traditional	Koung-Ki	Bayangam	N 5°17'471"	E 10°25'47"	1648.03b
WKB02	traditional	Koung-Ki	Bayangam	N 5°17'471"	E 10°25'47"	1648.03b
WKB04	traditional	Koung-Ki	Bayangam	N 5°17'471"	E 10°25'47"	1648.03b
WMeD01	traditional	Menoua	Foto	N 5°28'38"	E 10°2'27"	1395.26a
WMeF01	traditional	Menoua	Fongo-tongo	N 5°31'185"	E 10°1'43"	1556.48b
WMeP03	traditional	Menoua	BamendouII	N 5°24'526"	E 10°9'54"	1630.95b
WMeP04	traditional	Menoua	BamendouII	N 5°24'526"	E 10°9'54"	1630.95b
WMeK06	traditional	Menoua	Baleveng	N 5°30'481"	E 10°10'46"	1421.22b
WMeK07	traditional	Menoua	Baleveng	N 5°30'481"	E 10°10'46"	1421.22b
WMeP01	traditional	Menoua	BamendouII	N 5°24'526"	E 10°9'54"	1630.95b
WMeP02	traditional	Menoua	BamendouII	N 5°24'526"	E 10°9'54"	1630.95b
NMeBf01	traditional	Mezam	Bafut	N 6°1'462"	E 10°12'32"	1240.02a
NMeBl01	traditional	Mezam	Bali	N 5°54'314"	E 10°2'3"	1338.64a
WMiM01	traditional	Mifi	Bamoungoum	N 5°27'360"	E 10°22'60"	1345.15a
WMiL04	traditional	Mifi	Baleng	N 5°30'542"	E 10°26'5"	1339.87a
WMiL01	traditional	Mifi	Baleng	N 5°30'542"	E 10°26'5"	1339.87a
WMiL02	traditional	Mifi	Baleng	N 5°30'542"	E 10°26'5"	1339.87a
NMoM01	traditional	Momo	Mbengwi	N 5°58'240"	E 10°1'34"	1278.05a
NMoNj01	traditional	Momo	Njikwa	N 6°6'523"	E 9°52'8"	1434.47b

Accession code/name	Variety	Source location		Latitude	Longitude	Altitude (m)
		Division	Village			
NMoNg01	traditional	Momo	Andek	N 5°59'164"	E 9°51'23"	1439.92b
NMoNj02	traditional	Momo	Njikwa	N 6°6'523"	E 9°52'8"	1434.47b
WNBg02	traditional	Nde	Batchingou	N 5°9'519"	E 10°23'9"	1382.17a
WNBg01	traditional	Nde	Bangoulap	N 5°5'289"	E 10°30'58"	1472.49b
WNBz01	traditional	Nde	Balengou	N 5°7'316"	E 10°26'33"	1479.72b
NNN01	traditional	Ngo-ketunjia	Ndop	N 6°0'358"	E 10°26'43"	1198.35a
NNN02	traditional	Ngo-ketunjia	Ndop	N 6°0'358"	E 10°26'43"	1198.35a
NNB01	traditional	Ngo-ketunjia	Babessi	N 6°2'170"	E 10°35'29"	1206.47a

a = low altitudes (≤ 1400 m); b = medium altitudes (1401 to 1800 m); (c = high altitudes ≥ 1800m).

2.2. Cropping, Data Collection and Statistical Analysis

The experiment was carried out in Dschang (5°27'N; 10°04'E) in the western region of Cameroon, at 1400 m altitude; this zone is characterized by 20.5 ± 6°C average annual temperature, 2000 mm mean annual rainfall, a relative humidity of 76.8% and a sandy loam soil with a pH of 5.2. Tubers of all genotypes were planted on October 1st 2014. The potato tubers were planted on 2.8 m^2 plots in randomized block design with three replications. Planting was made at 0.70 x 0.35 m distances, with 5 tubers planted per row, each measuring 4 m. Each plot had two rows. Prior to planting, 18 g of a simple mix-fertilizer NPK 11:11:22 was applied per plant at planting, followed by addition of 3 g of Urea during the first moulding (40 days after planting) to give a total of 120 kg of N, 180 kg of P and 100 kg of K per hectare, because the soils are relatively deficient in nitrogen and phosphorus [13, 14]. The experimental plots were watered when needed. Weeds were controlled by harrowing and hilling. A total of two sprays of Cypermetrine (200 $g.l^{-1}$) were applied for pest control. A total of three sprays of 6.25 $g.l^{-1}$ fungicide (640$g.kg^{-1}$ Mancozeb + 80$g.kg^{-1}$ Metalaxyl) were applied on one-week interval to control late blight. Harvesting began in December and ended in January. Data on 23 different morpho-agronomic characters were recorded on 4 randomly selected plants in each row of each replication. The characters used (Table 2) were described according to Huaman et al. [15], IBPGR [16], Huaman and Spooner [17]. Analysis of variance was performed using GraphPad Prism package v. 7.01, whereas hierarchical cluster analysis was performed with Ward's method [18] using XlStat package V. 2014. Cluster analysis was conducted on dissimilarity estimates using the Euclidian distance, from which a dendrogram representing the relationship among the accessions was obtained.

Table 2. *Description of the characters used in the morphological analyses the potato cultivars.*

N°	Character	Description
1	Plant height (cm)	Measurements of the distance between the top point of the plant and the ground surface at maturity using meter
2	Main stem number	Main stem number per plant
3	Growth habit	(1) extremely-erect, (3) erect, (5) semi-erect, (7) decumbent
4	Foliage cover	(1) poor, (3) moderate and (5) abundant
5	Predominant sprout colour	(1) white-green; (3) pink; (5) red; (7) Violet; (9) purple; (11) brown
6	Secondary sprout colour	(0) absent; (1) cream; (3) green; (5) purple
7	Distribution of the secondary sprout colour	(0) absent; (1) at the apex; (3) scartted; (5) at the base
8	Degree of flowering	(0) no buds; (1) buds abortion; (3) scarce; (5) moderate; (7) abondant.
9	Maturity time	(1) very early (shorter than 80 days); (3) early (between 80 and 100 days); (5) moderate (between101 and 110 days); (7) late (between 111 and 120 days) and (9) Very late (later than 120 days)
10	Tuber shape	(1) oblate (compressed); (3) round; (5) ovate; (7) obovate; (9) elliptic; (11) oblong; (13) long-oblong
11	Tuber Skin colour	(1) white-cream; (3) yellow; (5) brown; (7) pink; (9) red
12	Tuber flesh colour	(1) white; (3) cream; (5) yellow; (7) deep yellow
13	Eye depth	(1) protruding; (3) shallow; (5) medium; (7) deep, (9) very deep,
14	Eye distribution	(1) predominantly apical; (3) evenly distributed
15	Eye colour	(1) white-cream; (3) yellow; (5) brown; (7) pink; (9) red
16	Total number of tubers	Total number of tubers per plant
17	Percentage of markatable tubers	Number of healty tuber with size higher than 28 mm, expressed as percentage of the total number of tubers per plant
18	Mean eyes number	Number of eyes per tuber
19	Total yield	Weight of tubers in tonnes per hectare (t/ha).
20	Dry matter content	Dry matter content in potato tubers
21	Dormancy period	(1) Very short (shorter than 30 days); (3) short (between 31 and 110 days); (5) medium (between 111 and 90 days); (7) long (between 91 and 120 days) and (9) very long (longer than 120 days)
22	Colour of corolla	(1) white; (3) light pink; (5) pink; (7) light violet; (9) deep violet; (11) light blue; (13) purple
23	Stamen formation	(0) No flower; (1) normal; (3) shrivelled

3. Results

3.1. Variability of 7 Quantitative Characters Studied Among Altitudes, Locations, Accessions and Varieties

Analysis of variance indicated no significant difference in respect to the 7 agronomic traits among altitudes and among locations. Highly significant differences were however observed among the accessions for all traits (Table 3).

The percentage of marketable tubers (84.89%) was significantly higher in modern varieties than in traditional varieties (76.23%). The highest total tuber number (15.58), mean eyes number (10.46), mean stem number (3.21) and dried matter content (21.25%) were found in traditional varieties. There was no significant difference between traditional and modern varieties for total yield and plant height (Table 4).

Table 3. *Mean squares of analysis of variance (ANOVA) of 7 quantitative characters between (I) altitudes, (II) locations and accessions (III).*

	Mean squares		Total tuber yield	Total tubers number	percentage of marketable tubers	Mean eyes number	Plant height	Mean stem number	Dried matter content
	Source of variation	**df**							
I	altitude	2	72.43^{ns}	4.60^{ns}	216.60^{ns}	11.53^{ns}	433.50^{ns}	2.44^{ns}	0.37^{ns}
	error	66	55.7	42.3	120.1	4.24	437.3	1.08	3.8
II	location	12	78.88^{ns}	46.15^{ns}	172.30^{ns}	5.35^{ns}	723.30^{ns}	0.58^{ns}	4.22^{ns}
	error	56	51.33	40.13	112.4	4.27	375.8	1.24	3.59
III	accession	76	168^{****}	131.6^{****}	377.2^{****}	13.36^{****}	1274^{****}	3.75^{****}	14.69^{****}
	error	154	22.98	3.59	31.66	0.03165	12.14	0.2803	0.05845

^{ns}: not significant.
****Significantly different at p<0.0001.

Table 4. *Mean differences of 7 agronomic characters between traditional and modern cultivars.*

	Total tuber yield (t/ha)	Total tubers number	Percentage of marketable tubers (%)	Mean eyes number	Plant height (cm)	Mean stem number	Dried matter content (%)
Modern	21.02 ± 2.78a	9.42 ± 2.16b	84.89 ± 3.42a	8.88 ± 0.58b	82.38 ± 6.57a	2.37 ± 0.49b	18.53 ± 1.09b
Traditional	20.35 ± 0.90a	15.58 ± 0.77a	76.23 ± 1.34b	10.46 ± 0.25a	78.18 ± 2.52a	3.21 ± 0.13a	21.25 ± 0.23a
t-value	0.2406	2.583	2.114	2.053	0.5427	2.08	3.541
p-value	0.81	0.01	0.04	0.04	0.59	0.041	0.0007

Mean values followed by different letters are significantly different at p < 0.05.

3.2. Analysis of Correlation Coefficients Among 7 Agronomic Characters

Correlation coefficients between 7 agronomic traits are given in Table 5. Total tuber yield was significantly and positively correlated with total tubers number at p≤0.01, percentage of marketable tubers at p≤0.0001 and plant height at p≤0.001, probability level with coefficient (r) 0.33, 0.46 and 0.38 respectively. Dried matter content was significantly and positively correlated with mean stems number (r=0.38), mean eyes number (r=0.30) and total tubers number (r=0.44) at the 0.001, 0.01 and 0.0001 probability level respectively. Positive and significant correlation was observed between percentage of marketable tubers and plant height (r=0.44) at p≤0.0001. Total tubers number was significantly and positively correlated with mean stems number (r=0.42) at p≤0.0001 Dried matter content showed negative and significant correlation with percentage of marketable tubers, plant height and total tuber yield. Negative and significant correlation was found between Marketable tubers number, total tubers number and mean eyes number. This was also observed between plant height, mean stems number and mean eyes number.

Table 5. *Correlation coefficients among 7 agronomic traits of Solanum tuberosum.*

	Total tuber yield	Total tubers number	% of marketable tubers number	Mean eyes number	Plant height	Mean stem number
Total tubers number	0.33^{**}					
% of marketable tubers	0.46^{****}	-0.44^{****}				
Mean eyes number	0.11^{ns}	0.16^{ns}	-0.10^{ns}			
Plant height	0.38^{***}	-0.18^{ns}	0.44^{****}	-0.23^{*}		
Mean stem number	0.12^{ns}	0.42^{****}	-0.11^{ns}	0.19^{ns}	-0.30^{**}	
Dried matter content	-0.16	0.44^{****}	-0.41^{***}	0.30^{**}	-0.50^{****}	0.38^{***}

^{ns}: not significant.
*correlation is significant at the 0.05 level.
**correlation is significant at the 0.01 level.
***correlation is significant at the 0.001 level.
****correlation is significant at the 0.0001 level.

3.3. Cluster Analysis

The cluster analysis grouped the seventy-seven accessions into 2 main clusters using 23 morphological and agronomic characters (Figure. 1). The distribution of accessions in different clusters is shown in Table 6. Table 7 shows the distribution of accessions of each cluster in locations and altitudes. Cluster wise mean values of 23 traits are also shown in Table 9. The clusters obtained from the classification were subdivided in several sub-clusters and means values of the different sub-groups for the 23 characters are shown in Table 9.

The student's t-test distinguished the 2 clusters according to 7 (seven) agronomic characters (Table 8). All the potato accessions used in this study had very early maturity time (shorter than 80 days) (Table 9).

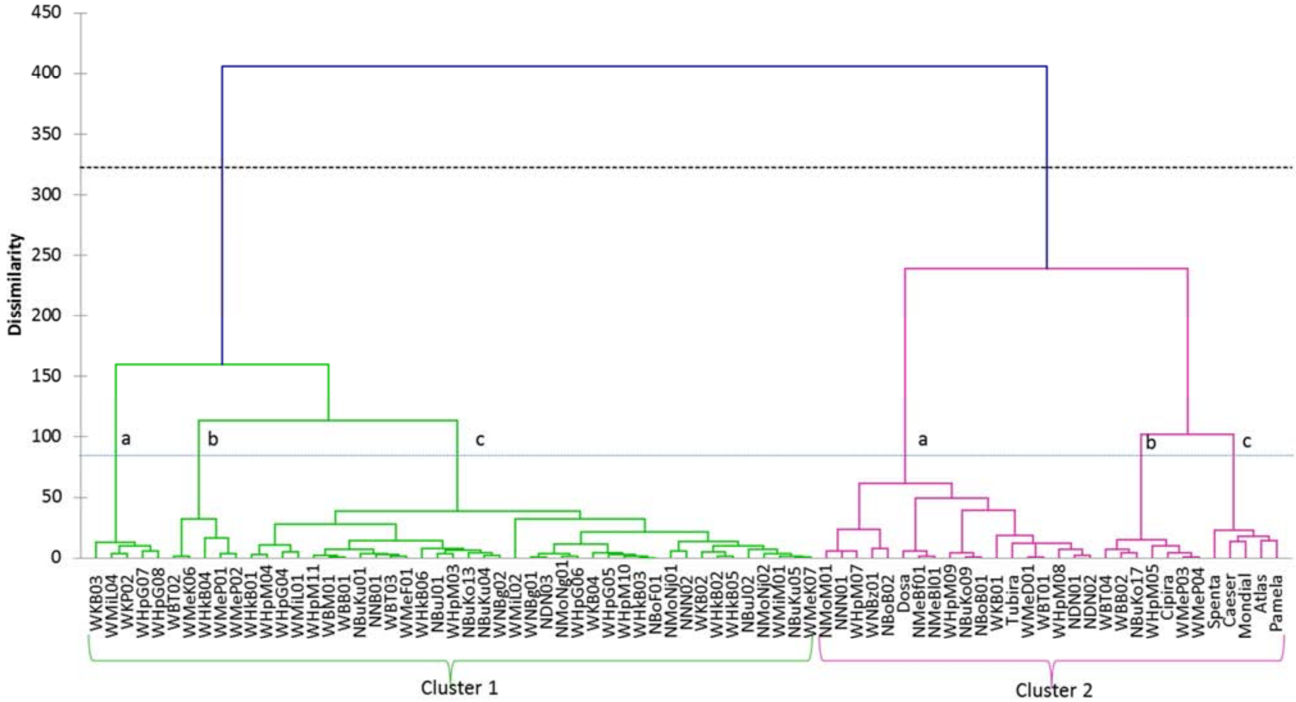

Figure 1. *Dendrogram representing the clustering of the 77 potato accessions.*

Table 6. *Potato accessions' clusters obtained from the classification.*

Cluster	Sub cluster	accessions	Number of accessions
1	a	WKB03, WKP02, WMiL04, WHpG07, WHpG08	5
	b	WBT02, WMeK06 WHkB04, WMeP01, WMeP02	5
	c	WHkB01, WHpG04, WHpM04, WMiL01, NBuKu01, NNB01, WBB01, WBM01, WBT03, WHpM03, WHpM11, WMeF01, NBuKo13, NBuJ01, WHkB06, NBuKu04, WNBg02, WMiL02, NBuKu05, NBuJ02, NDN03, NMoNj01, NMoNj02, NMoNg01, NNN02, WHpG06, WMeK07, WKB02, WMiM01, WNBg01, WKB04, WHpG05, WHpM10, NBoF01, WHkB03, WHkB02, WHkB05	47
2	a	NMoM01, NNN01, NBoB02, WHpM07, WNBz01 Dosa, NMeBf01, NMeBl01, WHpM09, NBuKo09, NBoB01, NDN01, NDN02, Tubira, WBT01, WKB01, WHpM08, WMeD01	18
	b	Cipira, WBB02, WBT04, WHpM05, WMeP03, WMeP04, NBuKo17	7
	c	Atlas, Caieser, Mondial, Pamela, Spenta	5

Table 7. *Clustering of the 77 accessions according to locations and altitudes.*

Cluster	Number of accessions	Distribution	
		Location	Altitude*
1	47	Bamboutos, Boyo, Bui, haut-Plateaux, Haut-Nkam, Koung-Khi, Menoua, Mifi, Momo, Ndé, Donga-Mantung, Ngo-ketunjia	LA, MA, HA
2	30	Bamboutos, Boyo, Bui, hauts-Plateaux, Koung-khi, Menoua, Mezam, Momo, Ndé, Donga-Mantung, Ngo-ketunjia,	LA, MA, HA

*LA= Low altitude; MA= Medium altitude; HA=High altitude.

Table 8. *Variation of 7 quantitative characters between clusters.*

	Total tuber yield (t/ha)	Total tubers number	percentage of marketable tubers (%)	Mean eyes number	Plant height (cm)	Mean stem number	Dried matter content (%)
Cluster 1	18.06 ± 0.99b	16.65 ± 0.95a	72.81 ± 1.58b	10.91 ± 0.30a	67.18 ± 1.48b	3.49 ± 0.15a	22.3 ± 0.18a
Cluster 2	24.11 ± 1.29a	12.26 ± 1.09b	83.91 ± 1.48a	9.33 ± 0.35b	96.54 ± 3.68a	2.54 ± 0.17b	18.88 ± 0.32b
t-value	3.74	2.98	4.82	3.42	8.47	4.01	10.08
P-value	0.0004	0.004	0.0001	0.001	0.0001	0.0001	0.0001

Mean values followed by different letters are significantly different at $p<0.05$.

Table 9. *Cluster means for 23 characters in the 77 potato accessions.*

	Cluster 1				Cluster 2			
Character*	**1a**	**1b**	**1c**	**Mean**	**2a**	**2b**	**2c**	**Mean**
Total tuber yield (t/ha)	10.91	20.08	18.76	18.06	26.66	20.59	19.83	24.11
Total number of tubers	10.76	15.53	17.60	16.65	14.90	10.80	4.83	12.26
Percentage of marketable tubers (%)	73.74	76.73	72.15	72.81	82.72	82.72	89.87	83.91
Mean eyes number	9.40	9.40	11.32	10.91	10.33	7.29	8.60	9.333
Plant height (cm)	70.38	73.40	65.91	67.18	92.25	119.31	80.10	96.54
Mean stem number	3.09	3.59	3.54	3.499	2.83	2.36	1.78	2.542
Dried matter content (%)	21.41	20.93	22.60	22.3	19.49	18.30	17.11	18.88
Maturity time	1	1	1	1	1	1	1	1
Dormancy period	3	5	1,3,5	1,3,5	1,3,5	5,7	7,9	1,3,5,7,9
Eye deep	3,5	1,3,5	1,3,5,7,9	1,3,5,7,9	3,5,7,9	3	1,3	1,3,5,7,9
Eye distribution	3	3	3	3	1,3	1	1,3	1,3
Degree of flowering	0	0,3,5	0	0,3,5	3,5,7	5,7	0,5	0,5,7
Growth habit	1	3	5	1,3,5	3,5	7	3,5	3,5,7
Foliage coverage	1	1,3	1,3	1,3	3,5	3,5	1,3	1,3,5
Tuber skin color	1	5,9	3	1,3,5,9	1,3	1	1,7	1,7
Eye color	1	5,9	3	1,3,5,9	1,3,7	1	1	1
Tuber shape	11	3,9,11	3,5,11,13	3,5,9,11,13	1,3,7,11	1	7,13	1,3,7,11,13
Tuber flesh color	1	3,5,7	3,5	1, 3,5,7	1,3,5	3	3	3
Predominant sprout color	1	3,5	7	1, 3,5,7	3,7,9	1	1,3,7	1,3,7
Secondary sprout color	0	1,3	3	0,1,3	1,3	5	0,3,5	0,3,5
Distribution of secondary sprout color	0	1	1	0,1	1,3	3	0,1,3	0,1,3
Corolla color	0	0,5,13	0	0,5,13	1,3,7,9,11,13	1	0,1	0,1
Stamen formation	0	0,1	0	0,1	1,3	1	0,1	0,1

*Description of the characters is given in Table 2.

3.3.1. Cluster 1

Cluster 1 included forty-seven (47) accessions of traditional varieties collected in 12 of the 13 locations (apart from Mezam location) at all altitudes (Tables 6 and 7). This group had the lowest total tuber yield (18.06 t/ha), percentage of marketable tubers (72.81%) and plant height (67.18 cm) as compared to cluster 2. Meanwhile, the highest total number of tubers (16.65), mean number of eyes (10.91), main stems number (3.49) and dried matter content (22.3%) were recorded in this group (table 8). accessions of this group had very short to medium dormancy period (shorter than 91 days). The foliage coverage was scarce or moderate. Eyes were evenly distributed on the tubers (Table 9).

In addition, this cluster was subdivided into 3 sub-clusters, all of them made up of traditional varieties (Figure 1).

Sub-cluster 1a included five (05) accessions and had the lowest total tuber yield (10.91 t/ha) and total number of tubers (10.76) as compared to sub-clusters 1b and 1c. The growth habit was extremely-erect. Tubers had oblong shape, white-cream skin color and white flesh color. Predominant sprout color was white-green with secondary sprout color absent. Accessions of this sub-group did not produce flowers (Table 9).

Accessions within sub-cluster 1b were five (05) and had the highest total tuber yield (20.08 t/ha), percentage of marketable tubers (76.73%) and plant height (73.40 cm). The growth habit was erect. Tubers had round, elliptic or oblong shape. Tuber skin color was red or brown and the tuber flesh color was cream, yellow or deep yellow. Predominant sprout color was red or pink with cream or green secondary color distributed at the apex of the sprout. Some accessions in this sub-cluster did not produced flowers while others produced flowers with deep pink or purple color; the degree of flowering was moderate and stamen formation was normal (Table 9).

Sub-cluster 1c included thirty-seven (37) accessions; it had the highest total number of tubers (17.60), mean eyes number (11.32) and dried matter content (22.60%). The lowest plant height (65.91 cm) was also recorded in this sub-cluster. The growth habit was sub-erect. The tuber shape was round, ovate, oblong or long-oblong with yellow skin, eyes and flesh color. The predominant sprout color was violet with a green secondary color distributed at the apex. Accessions of this sub-group did not produce flowers (Table 9).

3.3.2. Cluster 2

This cluster included thirty (30) accessions distributed in 12 of the 13 locations (apart from Mifi location) at all altitudes (tables 6 and 7). The highest total tuber yield (24.11 t/ha), percentage of marketable tubers (93.91%) and plant height (96.54 cm) were recorded in this cluster. However, this group had the lowest total number of tubers (12.26), mean number of eyes (9.33), main stems number (2.54) and dried matter content (18.88%) (Table 8). Accessions of this group had very short to very long dormancy period (shorter than 30 days to longer than 120 days). The growth habit was erect or sub-erect or decumbent, and the foliage coverage was scarce, moderate or abundant. Eyes were evenly distributed on the tubers or predominant at the apex (Table 9).

Cluster 2 was divided into 3 sub-clusters (Figure 1).

Sub-cluster 2a included eighteen (18) accessions. Two (02) modern varieties (Dosa and Tubira) were found in this sub-cluster. Sub-cluster 2a had the highest total tuber yield (26.66 t/ha), total tuber number (14.90) mean number of eyes (10.33), main stems number (2.83) and dried matter content (19.49%). Accessions of this sub-group had very short to medium dormancy period (shorter than 91 days). Tubers had oblate, round, oblate or oblong shape. Tuber skin color was white-cream or yellow. Tuber eyes were shallow, medium, deep or very deep with white-cream, yellow or pink color. Tuber flesh color was white, cream or yellow. Accessions within this sub-cluster produced flowers with a wide diversity of colors (white, light pink, pink, light violet, deep violet, light blue or purple). Stamen had normal or shriveled formation. The degree of flowering was scarce, moderate or abundant (Table 9).

Sub-cluster 2b comprised seven (07) accessions, six (06) of them so called traditional varieties clustering with the modern variety Cipira (Figure 1). The highest plant height (119.31 cm) was recorded in this sub-group. The growth habit was decumbent, and their foliage coverage was moderate or abundant. Individuals of this sub-group had oblate tuber shape, with white-cream skin and eyes color; the tuber flesh color was cream. The predominant sprout color was white-green with purple secondary sprout color scattered on the sprout. The degree of flowering was moderate or abundant with white flower color and normal stamen formation (Table 9).

Sub-cluster 2c comprised five (05) accessions; all of them were modern varieties (Atlas, Caeser, Mondial, Pamela, and spenta) (figure 1). The lowest total tuber yield (19.83 t/ha), total tuber number (4.83) mean number of eyes (8.60), plant height (80.10 cm), main stems number (1.78) and dried matter content (17.11%) were recorded in sub-cluster 2c. this sub-cluster also showed the highest percentage of marketable tubers (89.87%). Their growth habit was erect or sub-erect, and their foliage coverage was poor or moderate. Individuals of this sub-group had obovate or long-oblong shape, with white-cream skin and eye color except Pamela which have pink skin color with white-cream eyes color; the tuber flesh color was cream. In this sub-group the predominant sprout color was white-green, pink or violet and the secondary sprout color is absent, green or purple. This secondary sprout color when present is predominantly apical or scattered on the sprout. Individuals of this sub-group did not produce flowers apart from Caieser which produced white flowers with a moderate degree of flowering and normal stamen formation (Table 9).

4. Discussion

The present study has identified the relationship between traditional potato genotypes from the western highlands region of Cameroon. Analysis of variance revealed high value of the percentage of marketable tubers in modern varieties; this may explain why farmers prefer them to traditional varieties. However, high dry matter content observed in traditional varieties should be an important reason to conserve them. No significant difference was observed among potato collected from different altitudes or locations. In general, genotypes did not cluster according to the collection zone. This may be a result of seeds transport from farmer to farmer, from a location to another as reported by Arslanoglu et al. [19] when analyzing 146 traditional potato genotypes from the Eastern Black Sea region of Turkey. In fact, potato yield in Cameroon is generally low due to diseases [6, 8, 20, 21]; so farmers keep exchanging their seeds looking for disease resistant varieties with better yield. Many authors working on traditional potato genotypes from Turkey found that the lack of clustering within location may be due to the fact that potato genotypes are suited to the ecological conditions of the region, and are widely accepted by the farmers because of cooking quality and taste of tubers [22, 23]. Moreover, there was no grouping of accessions within altitudes, probably a result of seed transport from high altitudes to low altitudes; Potato production being better in high altitudes, where the optimum conditions such as low temperature are found [24, 25].

Correlation coefficients of 7 quantitative traits were analyzed; knowledge about correlations among characters is useful in designing an effective breeding program for any crops. Complex plant characters such as yield are quantitatively inherited and influenced by genetic factors, as well as by genotype and environment interaction. Due to these details, selections may be difficult and time consuming to improve yield directly. Therefore, identification and use of highly correlated characters are appropriate and useful [26]. In this study, plant height was significantly and positively correlated with percentage of marketable tubers; meanwhile mean eyes number, mean stems number and total tubers number was significantly and positively correlated with dried matter content. This indicates that plant height and tuber eyes number can be considered as important characters for early selection. Similar selection processes were reported by Ahmadizadeh and Felenji [27]. These traits are easy to measure and selection for any of them will help to improve potato collection from the western highlands of Cameroon.

Phenotypic variations have been reported previously by several authors among potato accessions [19, 23, 27, 28] and other crop species [29, 30, 31] for different characters in different populations. In this study, the dendrogram showed that the 77 potato accessions collected from western highlands of Cameroon were separated into two major clusters. This is the result of differences for morphological and agronomical traits within traditional varieties; between traditional and modern varieties. Out of the sixty-nine (69) traditional varieties collected in the western highlands of Cameroon, forty-seven (47) were found in cluster 1. The eight (08) modern varieties used in this study appeared in cluster 2 which was divided into three sub-clusters; Two (02) of them (Dosa and Tubira) clustered with sixteen (16) traditional varieties. Five (05) traditional varieties namely Spenta, Pamela, Caeser, Atlas and Mondial constituted sub-cluster 2c. Six (06) traditional varieties were much closed to Cipira; these varieties may be modern not traditional varieties, since potato tubers of many varieties may look alike especially when the size is small and may be confused by during seed collection. Bassil et al. [32] reported that vegetatively propagated crops can be easily misidentified based of the phenotype.

5. Conclusion

The present study revealed high levels of genetic variations for 23 morphological and agronomic characters among the 77 potato accessions grown in the western highlands of Cameroon. In addition, most of the potato characters had positive correlations between each other. This will assist for the combined improvement of these characters by selecting only easily measurable characters. This is also an opportunity for plant breeders to select important traits with less environmentally induced errors. From this study, genotypes with desirable characteristics could be selected and identified for inclusions in potato breeding program.

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