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Research Article

Phenotypic Characterization, Evaluation, and Classification of Cassava (*Manihot esculenta* Crantz) Accessions in Ethiopia

Berhanu Bilate Daemo,[1,2] **Derbew Belew Yohannes**,[2] **Tewodros Mulualem Beyene**,[3] **and Wosene Gebreselassie Abtew**[2]

[1]*Department of Plant Science, Wolaita Sodo University, Dawuro Tarcha Campus, P.O. Box 138, Tarcha, Ethiopia*
[2]*Department of Horticulture and Plant Sciences, Jimma University College of Agriculture and Veterinary Medicine, P.O. Box 307, Jimma, Ethiopia*
[3]*Jimma Agricultural Research Centre, P.O. Box 192, Jimma, Ethiopia*

Correspondence should be addressed to Berhanu Bilate Daemo; berhanubil@gmail.com and Wosene Gebreselassie Abtew; wosish@yahoo.com

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Cassava has a crucial role in benefiting smallholder farmers as the main food and income source in southern Ethiopia. Characterization accessions are crucial for assessing variation, classifying, and identifying desirable accessions for crop improvement and conservation. In this regard, there needs to be more information on the morphological characterization and classification cassava accessions. Thus, the aim of this research was to systematically characterize, evaluate, and classify cassava accessions using qualitative characters to provide useful information for breeding program and conservation. A total of 64 accessions were planted using a simple lattice design during the 2020-2021 cropping season. Thirty qualitative data were collected at 3, 6, 9, and 18 months after planting and analyzed using the SAS and R-software packages. The high variable characteristics were the shape of the central leaflet, petiole color, leaf retention, branching habit, the color of the stem epidermis, the color of the stem exterior, the external color of the storage root, and the color of the root pulp towards frequency distribution analysis. The Shannon–Weaver diversity index ranged from 0.24 to 1.47, with an overall mean of 0.84. The first three dimensions in the multiple correspondent method explained approximately 39.39% of the total variation, with Dim 1 accounting for 20.77% and Dim 2 accounting for 9.98%, while petiole color and texture of the root epidermis were the leading contributors to the total variation, respectively. In clustering analysis, 64 accessions were classified into 4 clusters of varying sizes. The distribution of accessions in each cluster revealed that 52 accessions were in cluster I, 6 in cluster II, 5 in cluster III, and 1 in cluster IV. Each cluster was varied by a major group characteristic that it represented. Furthermore, the study identified the desirable accessions for desired storage root characteristics such as root constrictions, the external color of the storage root, the color of root pulp, the color of the root cortex, and cortex peeling tendency. In conclusion, the various analyses performed indicated the existence of sufficient genetic variability for the characteristics evaluated, which could be attributed to the dissimilar genetic backgrounds of the evaluated accessions. Thus, these could be utilized for breeding work and conservation.

1. Introduction

Cassava (*Manihot esculenta* Crantz) grows more frequently in subtropical and tropical regions despite being native to Latin America, and it is the fourth major food crop in the world, next to maize, rice, and wheat [1]. It is regarded as an important nutrient source for ensuring food security in developing countries and a key source of food calories for two out of every five people in Africa [2]. A number of industrial products are made with cassava starch, including paper, cardboard, textiles, plywood, glue, alcohol, animal feed, nongrain starch, ethanol, and biofuel [3]. Cassava has been shown to adapt and grow well in different agroecologies in Ethiopia, with various levels of yield [4]. It is an essential food crop that provides a large portion of people's daily consumption as well as the principal supply of carbohydrates in southern Ethiopia [5].

Cassava is a major storage root crop with a lot of potentially useful genetic variation [6]. Jahufer and Gawler [7] stated that genetic variation is central to plant breeding, as good management of variation can produce permanent gains in the yield of the plant and can buffer seasonal fluctuations. Farmers continue to keep a diverse set of accessions (landraces) on their farms, despite the fact that they may be low yielding and susceptible to some biotic and abiotic stresses [8]. These landraces may have greater genetic variability, which may enhance gene flow via hybridization [8, 9]. Thus, landraces are valuable genetic resources for breeding and other crop enhancement efforts [9, 10]. Furthermore, maintaining genetic resources is crucial for achieving genetic progress in breeding programs throughout the recombination and selection cycles [11]. To make the best use of available genetic variability, the genetic material must be properly organized and analyzed, increasing the likelihood of selecting genotypes with superior performance on the traits of interest [12]. Both morphological and agronomic variables, as well as molecular analysis, can be used to evaluate genetic variability [12]. The primary goal of characterization is to get rid of duplicate accessions, generate a genetically unique core sample for use in breeding programs, and produce progeny who have a higher level of heterotic [13].

The morphological characteristics of cassava are prominently variable, signifying a high degree of interspecific hybridization [14, 15]. Information on the genetic relationship between accessions is an important component of plant breeding programs because it provides knowledge of the genetic diversity available for producing new allelic combinations in a segregated population [11]. In cassava, it is supposed that a broad range of genetic variability was produced through centuries of farmer management [10]. Morphological characterization and evaluation of locally available accessions are indispensable for making information available for cassava root yield improvement. According to Fukuda and Guevara [16], assessing existing genetic variability is necessary and should be based on appropriate and recognised descriptors. So far, studies using qualitative characteristics conducted in various countries around the world have revealed significant variability within farmer-owned cassava cultivars [17]. According to Asare et al. [18], morphological characters are commonly used in primary evaluation because they are a quick and easy way to determine the degree of variability. These morphological characters reveal the true variability as perceived by farmers, and morphological characterization has been used to identify genetic diversity among cassava varieties [19].

Cassava is an essential food crop in Ethiopia that provides food security and income as well as a significant percentage of the daily diet [5, 20]. However, there are various research gaps in this genetic research on important morphological characteristics in cassava, which lagged far behind other root and tuber crops [5]. Such research gaps are attributed to major problems such as a lack of desired features for the cassava storage root and high-root-yielding cultivars. This highlighted the significance of extending research efforts to look at the morphological characterization and relationships among cassava accessions through the collection of available genetic resources. Therefore, the aim of this research was to characterize, evaluate, and classify cassava accessions obtained from different sources using qualitative characteristics to provide valuable knowledge for cassava improvement programs and conservation efforts.

2. Materials and Methods

2.1. The Study Area's Description. The experiment was carried out during the 2020-2021 cropping season at the Tarcha research site in the Dawuro zone, Southwest Ethiopia People' Regional State, and Bonbe research site in the Wolaita zone, Southern Nations Nationalities and Peoples' Region State. Tarcha research site is situated at an altitude of 1250 meters above sea level at latitude 07°09′32″N and longitude 037° 10′16″E [21]. The average annual rainfall in the area is 1392 mm, with a mean maximum and minimum temperature of 30°C and 17°C, respectively [21]. The soil in the study area is nitosol, which is weathered brown and has a pH of 5.6. Bonbe research site is located at an altitude of 1701 meters above sea level at latitude 07°08′15.5″N and longitude 037°34′54.1″E [21]. The average annual rainfall in the area is 1450 mm, with a mean maximum and minimum temperature of 26°C and 15°C, respectively [21]. The soil in the study area is nitosol, which is weathered red and has a pH of 4.25.

2.2. Plant Materials and Design. Sixty-four cassava accessions were used for the study, fifteen were from the Nigeria and forty-nine accessions were from the Jimma and Hawassa Agricultural Research Centers (Table 1). The experiment was designed as an 8×8 simple lattice. Mature cassava cuttings measuring 25–30 cm long were planted in an experimental plot (7 m^2) at an inter-row spacing of 1 m and an intrarow spacing of 1 m on the top of the ridge at a slanting (an angle of 45°) position. The evaluation was conducted on three plants for each accession per plot. All cultural practices were performed as recommended by Markos et al. [22] and farmers' practices in the area.

2.3. Data Collection. The morphological characters were observed at four periods, 3, 6, 9, and 18 months after planting (MAP), based on 30 descriptors of cassava as developed by Fukuda et al. [23]. The most frequently observed variant was noted in three plants (Table 2). The presence or absence of seeds and fruit was recorded throughout the vegetative stage until harvest.

2.4. Data Analysis. Morphological frequency distributions were estimated based on the characters observed in the accessions. To assess the phenotypic diversity of all accessions, the Shannon–Weaver diversity index (H') was computed using the phenotypic frequencies. The Shannon–Weaver was estimated using the following formula [24]:

Table 1: The list and source of cassava accessions used in the study.

Accession code	Source
G1	Jimma
G2	Hawassa
G3	Hawassa
G4	Hawassa
G5	Hawassa
G6	Hawassa
G7	Nigeria
G8	Hawassa
G9	Hawassa
G10	Hawassa
G11	Hawassa
G12	Nigeria
G13	Hawassa
G14	Hawassa
G15	Nigeria
G16	Hawassa
G17	Nigeria
G18	Nigeria
G19	Hawassa
G20	Hawassa
G21	Hawassa
G22	Nigeria
G23	Nigeria
G24	Nigeria
G25	Hawassa
G26	Hawassa
G27	Nigeria
G28	Hawassa
G29	Nigeria
G30	Hawassa
G31	Nigeria
G32	Nigeria
G33	Hawassa
G34	Hawassa
G35	Hawassa
G36	Nigeria
G37	Nigeria
G38	Hawassa
G39	Hawassa
G40	Hawassa
G41	Hawassa
G42	Nigeria
G43	Hawassa
G44	Hawassa
G45	Hawassa
G46	Hawassa
G47	Hawassa
G48	Hawassa
G49	Hawassa
G50	Hawassa
G51	Hawassa
G52	Hawassa
G53	Hawassa
G54	Hawassa
G55	Hawassa
G56	Hawassa
G57	Hawassa
G58	Hawassa
G59	Jimma
G60	Jimma
G61	Jimma
G62	Jimma
G63	Hawassa
G64	Hawassa

$$H' = -\sum_{i=1}^{n} \mathrm{Pi} \ln \mathrm{pi}, \quad (1)$$

where pi is the proportion of accessions in the i^{th} class of the trait to the total number of accessions grouped in the trait, where "n" is the number of phenotypic classes in the trait. Multiple correspondent analyses (MCA) were performed using the method developed by Abdi and Valentin [25] to analyze a set of observations for a set of categorical variables using statistics [26]. The MCA is a method helpful for understanding the similarities between the categories of variables and the associations between the variables [27]. It displays and allows the identification of factorial axes that reveal the most discriminant variables [28]. Clustering analysis was performed based on unweighted pair group methods with an arithmetic average (UPGMA). The numbers of clusters were determined using the cubic clustering criteria (CCC) as described by Mohammadi and Prasanna [29]. The appropriate numbers of clusters were determined from the values of pseudo-F and pseudo-T^2 using the SAS software [26] and *R*–software package [30].

3. Results and Discussion

3.1. Distribution in Characters. Accessions showed high to low variations in the qualitative characters' frequency distribution among 64 accessions (Table 3). Apical leaf color 49% of accessions were observed as purple-green, 45% showed purple, and 6% showed dark green (Table 3). Similarly, the distribution of pubescence on apical leaves was observed to be present (53.12%) and absent (46.88%) among accessions. The central leaflet shape of the accessions varied more, with 39% having a lanceolate central leaflet shape, 26% having an elliptic-lanceolate shape, 22% having an oblong-lanceolate shape, 5% having an ovoid shape, 5% being straight or linear, and 3% having an obovate-lanceolate shape (Table 3).

Similarly, the characters showed higher variability among accessions for petiole color (36% red, 25% reddish green, 22% yellowish green, 9% purple, and 8% greenish red) and leaf retention (45.31% better than average retention, 17.19% outstanding leaf retention, 17.19% both less than average and average leaf retention, and 9.38% very poor retention) (Table 3). Some characters showed medium variability, such as leaf lobe number (55% seven lobes, 39% nine lobes, and 6% five lobes), leaf vein color (75% green, 12.5% reddish green in less than half of the lobe, and 12.5% reddish green in more than half of the lobe), and petiole orientation (62.5% horizontal, 31.25% inclined upwards, and

Table 2: Qualitative characters used for evaluation in 64 accessions based on the descriptors of Fukuda et al. [23].

Characters observed	Scoring	Observed period (MAP)
(1) Color of apical leaves	3: light green; 5: dark green; 7: purplish green; and 9: purple	3
(2) Pubescence on apical leaves	0: absent and 1: present	6
(3) Shape of central leaflet	1: ovoid; 2: elliptic-lanceolate; 3: obovate-lanceolate; 4: oblang-lanceolate; 5: lanceolate; 6: linear; 7: pandurates; 8: linear-piramidal; 9: linear pandurate; and 10: linear-hostatilobalate	6
(4) Leaf retention	1: very poor retention; 2: less than average retention; 3: average leaf retention; 4: better than average retention; and 5: outstanding leaf retention	6
(5) Petiole color	1: yellowish green; 2: green; 3: reddish green; 5: greenish red; 7: red; and 9: purple	6
(6) Leaf color	3: light green 5: dark green; 7: purple green; and 9: purple	6
(7) Number of leaf lobe	3: three lobes; 5: five lobes; 7: seven lobes; 9: nine lobes; and 11: eleven lobe	6
(8) Lobe margins	3: smooth and 7: winding	6
(9) Color of leaf vein	3: green; 5: reddish green in less than half of the lobe; 7: reddish green in more than half of the lobe; and 9: all red	6
(10) Orientation of petiole	1: inclined upwards; 3: horizontal; 5: inclined downwards; and 7: irregular	6
(11) Prominence of foliar scars	3: semiprominent and 5: prominent	9
(12) Color of stem cortex	1: orange; 2: light green; and 3: dark green	9
(13) Color of stem epidermis	1: cream; 2: light brown; 3: dark brown; and 4: orange	9
(14) Color of stem exterior	3: orange; 4: greeny-yellowish; 5: golden; 6: light brown; 7: silver; 8: gray; and 9: dark brown	9
(15) Growth habit of stem	1: straight and 2: zigzag	9
(16) Distance between leaf scars	3: short (≤8 cm); 5: medium (8–15 cm); and 7: long (≥15)	9
(17) Color of end branches of adult plant	3: green; 5: green-purple; and 7: purple	9
(18) Stipule margin	1: entire and 2: split or forked	9
(19) Length of stipules	3: short and 5: long	9
(20) Branching habit	1: erect; 2: dichotomus; 3: trichotomous; and 4: tetrachotomus	18
(21) Shape of plant	1: compact; 2: open; 3: umbrella; and 4: cylindrical	18
(22) Fruit	0: absent and 1: present	6–18
(23) Seed	0: absent and 1: present	6–18
(24) Root constrictions	1: few to none (3 or less); 2: some (4–6); and 3: many (>6)	18
(25) Root shape	1: conical; 2: conical-cylindrical; 3: cylindrical; and 4: irregular	18
(26) External color of storage root	1: white or cream; 2: yellow; 3: light brown; and 4: dark brown	18
(27) Color of root pulp	1: white; 2: cream; 3: yellow; 4: orange; and 5: pink	18
(28) Color of root cortex	1: white or cream; 2: yellow; 3: pink; and 4: purple	18
(29) Cortex: ease of peeling	1: easy and 2: difficult	18
(30) Texture of root epidermis	3: smooth; 5: intermediate; and 7: rough	18

Table 3: The frequency distribution of 30 qualitative characters and Shannon–Weaver diversity index (H') on 64 cassava accessions.

No.	Qualitative character	Variants	Scoring	n	Frequency (%)	H'
1	Color of apical leaves	Dark green	5	3	6.25	0.88
		Purplish green	7		48.44	
		Purple	9		45.31	
2	Pubescence on apical leaves	Absent	0	2	46.88	0.69
		Present	1		53.12	
3	Shape of central leaflet	Ovoid	1	6	4.69	1.45
		Elliptic-lanceolate	2		26.56	
		Obovate-lanceolate	3		3.13	
		Oblong-lanceolate	4		21.88	
		Lanceolate	5		39.06	
		Straight or linear	6		4.68	
4	Leaf retention	Very poor retention	1	5	9.38	1.43
		Less than average retention	2		14.06	
		Average leaf retention	3		14.06	
		Better than average retention	4		45.31	
		Outstanding leaf retention	5		17.19	
5	Petiole color	Yellowish green	1	5	21.88	1.47
		Reddish green	3		25	
		Greenish red	5		7.81	
		Red	7		35.94	
		Purple	9		9.37	
6	Leaf color	Light green	3	2	45.31	0.69
		Dark green	5		54.69	
7	Number of leaf lobe	Five lobes	5	3	6.25	0.87
		Seven lobes	7		54.69	
		Nine lobes	9		39.06	
8	Lobe margins	Smooth	3	2	48.44	0.69
		Winding	7		51.56	
9	Color of leaf vein	Green	3	3	75.00	0.74
		Reddish green in less than half of the lobe	5		12.5	
		Reddish green in more than half of the lobe	7		12.5	
10	Orientation of petiole	Inclined upwards	1	3	31.25	0.83
		Horizontal	3		62.5	
		Inclined downwards	5		6.25	
11	Prominence of foliar scars	Semiprominent	3	2	34.38	0.64
		Prominent	5		65.62	
12	Color of stem cortex	Orange	1	2	4.69	0.26
		Light green	2		95.31	
13	Color of stem epidermis	Cream	1	3	25	0.93
		Light brown	2		14.06	
		Orange	4		60.94	
14	Color of stem exterior	Orange	3	4	3.13	0.89
		Greeny-yellowish	4		28.13	
		Golden	5		4.69	
		Silver	7		64.05	
15	Growth habit of stem	Straight	1	2	76.56	0.55
		Zigzag	2		23.44	
16	Distance between leaf scars	Short ≤ (8 cm)	3	3	45.31	1.01
		Medium (8–15 cm)	5		40.63	
		Long ≥ (15 cm)	7		14.06	
17	Color of end branches of adult plant	Green	3	2	54.69	0.69
		Green-purple	5		45.31	
18	Stipule margin	Entire	1	2	20.31	0.51
		Split or forked	2		79.69	

Table 3: Continued.

No.	Qualitative character	Variants	Scoring	n	Frequency (%)	H'
19	Length of stipules	Short Long	3 5	2	62.5 37.5	0.66
20	Branching habit	Erect Dichotomous Trichotomous Tetrachotomous	1 2 3 4	4	12.5 29.69 32.81 25	1.33
21	Shape of plant	Compact Open Umbrella Cylindrical	1 2 3 4	4	31.25 31.25 18.75 18.75	1.36
22	Fruit	Absent Present	0 1	2	9.38 90.62	0.31
23	Seed	Absent Present	0 1	2	9.38 90.62	0.31
24	Root constrictions	Few to none Some	1 2	2	93.75 6.25	0.24
25	Root shape	Conical Conical-cylindrical Cylindrical Irregular	1 2 3 4	4	20.31 42.19 23.44 14.06	1.31
26	External color of storage root	White or cream Yellow Light brown Dark brown	1 2 3 4	4	34.38 32.81 28.13 4.68	1.23
27	Color of root pulp	White Cream Yellow Pink	1 2 3 5	4	53.13 40.63 3.13 3.11	0.92
28	Color of root cortex	White or cream Yellow Pink	1 2 3	3	31.25 25 43.75	1.10
29	Cortex: ease of peeling	Easy Difficult	1 2	2	43.75 56.25	0.69
30	Texture of root epidermis	Smooth Rough	3 7	2	65.62 34.38	0.64
	Overall mean					0.84

6.25% inclined downward), while others showed low variability, such as leaf color (54.69% dark green and 45.31% light green) and lobe margins (51.56% winding and 48.44% smooth) (Table 3). Furthermore, accessions displayed wide variation in the following stem characteristics: the stem exterior color (64% silver, 28% greeny-yellowish, 5% golden, and 3% orange), the stem epidermis color (61% orange, 25% cream, and 14% light brown), the branching habit (12.5% erect, 29.69% dichotomous, 32.81% trichotomous, and 25% tetrachotomous), and the measurement between leaf scars (45.31% short, 40.63% medium, and 14.06% long) (Table 3). The stem cortex color was 95.31% light green and 4.69% orange, while the growth habits of the stem were straight (76.56%) and zigzag (23.44%).

The root shape of the accessions varied from conical-cylindrical (42%) to irregular (14%), while the root constriction showed few to none (94%) and some (6%) accessions (Table 3). White or cream (34% of the total) was the most common external color of storage roots, followed by yellow (33%), light brown (28%), and dark brown (5%), with dominant white and cream root pulp colors (Table 3). Similarly, the root cortex color was observed to be pink (44%), white or cream (31%), and yellow (25%), whereas the cortex peeling extent and texture of the root epidermis were dominantly difficult and smooth, respectively (Table 3). Cassava has few to no root constriction, white or cream external roots, yellow root pulp color, white or cream root cortex, and ease of removing the root cortex, as reported by Gomes [31], Vieira et al. [32], and Tiago et al. [33], which are desirable features for the cassava storage root from both a genetic improvement and an agronomic point of view. According to Table 3, our study found that 94% (except G59, G61, G62, and G64) of the evaluated accessions had little to no root constriction, 34.4% (G1, G3, G4, G5, G6, G10, G11, G15, G22, G23, G30, G33, G38, G41, G43, G44, G45, G46, G47, G57, G60, and G64) had white or cream external root color, 5% (G23, G36, and G40) had yellow root pulp color, 31.3% (G2, G9, G12, G13, G15, G24, G28, G29, G33, G34, G35, G36, G48, G49, G50, G52, G53, G55, G59, and G63) had white or cream root cortex, and 46.9% (G7, G9, G11, G13, G16, G20, G25, G26, G29, G32, G35, G37, G39, G40, G41, G42, G43, G45, G46, G48, G49, G50, G51, G53, G54, G55, G56, G57, G58, and G61) had ease of removing the root cortex.

Phenotypic characterization and evaluation could make the management and the use of several gene banks more efficient [34, 35]. Hence, the characterization and evaluation of plant genetic resources indicate the procedures used to assess, classify, distinguish, identify, avoid duplication, and efficiently utilize accessions. As a result, Francisco et al. [36] estimated the genetic variability in 16 sweet cassava accessions using 33 qualitative characters and found high divergence among the accessions. In Vietnam, cassava characterization and evaluation have been carried out for genetic variability and to classify seven cassava accessions using 20 morphological descriptors [37]. They found variability among accessions and classified them according to their morphological characteristics. Similarly, Zago et al. [12] evaluated 158 cassava accessions in Brazil to assess genetic variability using 38 qualitative characters, and the 37 characters showed variation among the tested accessions.

In the present study, several morphological characteristics revealed sufficient variation within the tested accessions. Among the characters, the shape of the central leaflet, leaf retention, petiole color, branching habit, the color of the stem epidermis, the color of the stem exterior, the external color of the storage root, and the color of root pulp were found to be the most variable factors in the evaluated cassava accessions towards frequency distribution. The variability of characters as indicated by frequency distribution in cassava agrees with the findings of Brice et al. [28], who found petiole color, branching habit, the color of root pulp, the color of the stem exterior, and plant shape to be the major discriminating characteristics. The other study was conducted by João Afonso et al. [38], who observed high variation in the foliar scar prominence, the cortex stem color, the petiole color, and the shape of the lobe. Carine et al. [39] reported that petiole color, branching habit, the shape of the plant, flowering, shape of the central leaflet, the orientation of the petiole, the color of end branches, and the color of the root cortex were observed to have high variability and offered possibilities for selection. Furthermore, the study reported by Nadjiam et al. [40] stated three variants of the stem exterior color, the stem epidermis color, and branching habit. However, these authors also found that the cortex stem color, the measurement between leaf scars, and the foliar scar prominence did not show variability among the evaluated 59 cassava accessions. This may be due to genetic similarities among accessions.

3.2. The Shannon–Weaver Diversity Index (H'). The Shannon–Weaver diversity index (H') was used to calculate the diversity of cassava accessions based on the frequency distribution of 30 qualitative characters and phenotypic classes [41]. In this aspect, the H' value for most observed phenotypic characters exhibited a normal level of diversity among tested cassava accessions, which ranged from 0.24 for root constriction to 1.47 for petiole color, with a mean value of 0.84 (Table 3). As adopted by Islam et al. [42], H' is classified as low ($H' < 0.50$), medium ($H' = 0.50–0.75$), and high ($H' \geq 0.75$). Based on this classification, four characters were categorized as low diversity, such as the color of the stem cortex, the presence or absence of fruit and seed, and root constrictions (Table 3). Additionally, eleven characters had medium genetic diversity, while the remaining fifteen characters had high genetic diversity.

A low level of diversity may indicate the narrow genetic base of the plant and be more frequent than others [43], while a high H' value shows a relatively high level of diversity and an even distribution of the landraces [41, 44]. Moreover, the overall mean H' value of 0.84 defined the presence of high phenotypic diversity among the tested cassava accessions. Thus, hybridization among accessions could produce the best hybrids and desirable segregants. This result is in agreement with the work of João Afonso et al. [38], who found a high H' value for petiole color, stem exterior color, and color of the root bark.

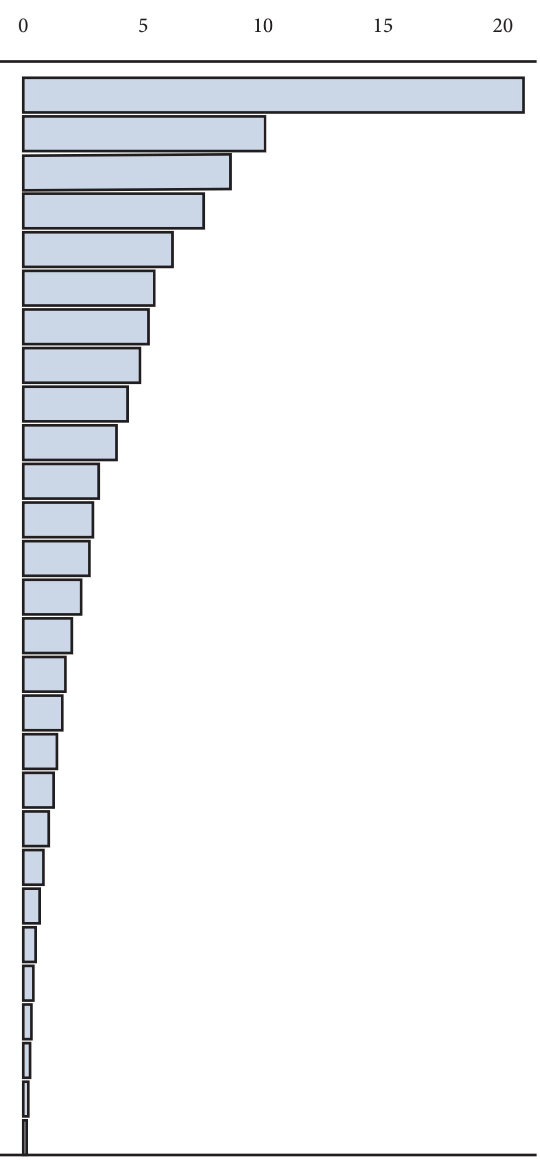
3.3. Multiple Correspondent Analysis. The multiple correspondent analyses (MCA) of the qualitative characters are presented in Table 4. The first three dimensions of MCA were found to be responsible for up to 39.39% of the overall variation among the accessions (Table 4). The petiole color, leaf retention, the shape of the plant, pubescence on apical leaves, the external color of the storage root, and the color of root pulp were major contributors to the first dimension in multiple correspondent analysis (Dim1), which explained 20.77% of the total variation (Tables 4 and 5). The second dimension in multiple correspondent analysis (Dim 2) explained 9.98% of the total variation and was primarily related to the contrasting effects of root epidermis texture, lobe margins, root cortex color, leaf vein color, and petiole orientation (Tables 4 and 5). This finding was supported by those of Brice et al. [28], who characterized 89 accessions using 19 morphological characters, where the color of the apical leaves, the petiole color, flowering, and the yellow pulp color were the major contributing variables. In another study, Agre et al. [45] assessed the degree of genetic diversity of 116 elite cassava collections in Benin using 41 qualitative traits, while the apical leaf color, the shape of the plant, leaf retention, and constriction of the root are the leading contributors to the total variability.

3.4. Cluster Analysis. The clustering analysis results are presented in Figure 1, and the four divergent clusters' formation was performed using the criteria with a pseudo-F and a pseudo-t-squared, which had values of 7.9 and 2.4, respectively; the maximum increase occurred at this point (Figure S1). The distribution of the 64 accessions (Table 6 and Figure 1) showed that 52 accessions were in cluster I, 6 in cluster II, 5 in cluster III, and 1 in cluster IV. The accessions grouped under cluster I have mainly been identified

Table 4: Multiple correspondent analyses for eigenvalues, proportion, cumulative, and factorial dimensions.

Inertia and Chi-Square Decomposition

Singular Value	Principal Inertia	Chi-Square	Percent	Cumulative Percent
0.15484	0.02397	146.340	20.77	20.77
0.10733	0.01152	70.318	9.98	30.75
0.09985	0.00997	60.857	8.64	39.39
0.09264	0.00858	52.382	7.43	46.82
0.08417	0.00709	43.249	6.14	52.96
0.07986	0.00838	38.926	5.52	58.49
0.07716	0.00595	36.340	5.16	63.64
0.07445	0.00554	33.836	4.80	68.45
0.07028	0.00494	30.154	4.28	72.73
0.06693	0.00448	27.344	3.88	76.61
0.05960	0.00355	21.679	3.08	79.68
0.05793	0.00336	20.487	2.91	82.59
0.05626	0.00316	19.319	2.74	85.33
0.05194	0.00270	16.469	2.34	87.67
0.04733	0.00224	13.673	1.94	89.61
0.04495	0.00202	12.333	1.75	91.36
0.04237	0.00180	10.959	1.56	92.92
0.03983	0.00159	9.686	1.37	94.29
0.03826	0.00146	8.937	1.27	95.56
0.03483	0.00121	7.406	1.05	96.61
0.03093	0.00096	5.839	0.83	97.44
0.02856	0.00082	4.979	0.71	98.15
0.02324	0.00054	3.296	0.47	98.62
0.02193	0.00048	2.937	0.42	99.03
0.02045	0.00042	2.552	0.36	99.39
0.01642	0.00027	1.645	0.23	99.63
0.01532	0.00023	1.432	0.20	99.83
0.01394	0.00019	1.185	0.17	100.00
	0.11543	704.560	100.00	



Degrees of Freedom = 1827

by the purplish green color of apical leaves, the absence of pubescence on apical leaves, outstanding leaf retention, greenish red petiole color, leaf lobe number of seven, smooth lobe margins, the horizontal orientation of the petiole, the light green stem cortex color, the white color of root pulp, and the pink color of root cortex (Tables S1, Table 6, and Figure 1). Additionally, the study found that three accessions, G23, G36, and G40, had roots with a yellow pulp color under this cluster (Table S1). It is interesting to note that one of the elements determining the root pulp's value is its color. In cassava commercialization, it is preferable to use the pulp's yellow color since it denotes a high content of carotenoids, which are precursors to vitamin A and are crucial for both human and animal diets [33, 46].

Under cluster II, six accessions were grouped together by having the difficult cortex removed or peeled, the cream color of root pulp, and the yellow color of root cortex, while cluster III was represented by the light brown external color of storage root, the white color of root pulp, the white or cream color of root cortex, and the easy cortex removed or peeled (Tables S1, Table 6, and Figure 1). Finally, one accession was classified as cluster IV due to the following characteristics: reddish green in less than half of the lobe, leaf vein color, red petiole color, inclined upwards orientation of the petiole, zigzag growth habit of the stem, the dark brown external color of the storage roots, the pink color of root pulp and cortex, difficulty in cortex peeling, and rough texture of the root epidermis (Tables S1, Table 6, and Figure 1).

Table 5: Multiple correspondent analyses of 30 qualitative characteristics and their contributions to total variability along respective dimensions.

Characters	Dim1	Dim2
Color of apical leaves	0.0193	−0.0009
Pubescence on apical leaves	0.3898	−0.0262
Shape of central leaflet	0.0459	−0.1176
Leaf retention	0.4008	0.0769
Petiole color	−0.5124	0.0949
Leaf color	0.0849	−0.0539
Number of leaf lobe	0.0324	0.0061
Lobe margins	0.0853	−0.3233
Color of leaf veins	−0.0249	0.3349
Orientation of petiole	0.0826	0.3358
Prominence of foliar scars	0.0692	−0.0113
Color of stem cortex	0.0386	0.0024
Color of stem epidermis	0.0805	0.1048
Color of stem exterior	0.0942	0.0728
Grow habit of stem	0.0464	−0.0621
Distance between leaf scars	0.0936	−0.0475
Color of end branches of adult plant	−0.1902	0.0423
Stipule margin	0.0491	0.0542
Length of stipules	−0.0193	0.0029
Branching habit	−0.1131	−0.0704
Shape of plant	0.3980	0.0955
Fruit	0.0732	−0.0043
Seed	0.0732	−0.0043
Root constrictions	0.0267	0.0247
Root shape	−0.0570	0.1009
External color of storage root	−0.3372	−0.1791
Color of root pulp	−0.3580	0.1418
Color of root cortex	0.0092	0.3830
Cortex: ease of peeling	0.0990	0.0650
Texture of root epidermis	−0.1341	−0.4527

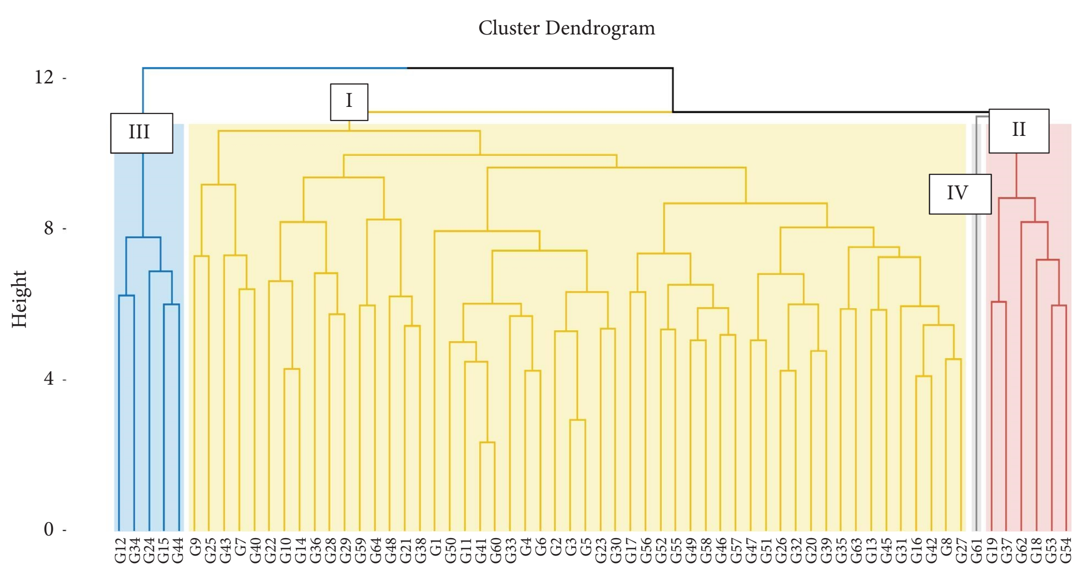


Figure 1: A dendrogram displaying the dissimilarity of 64 cassava accessions by an average distance method of hierarchical clustering patterns using thirty qualitative characters.

Table 6: Clusters of cassava accessions based on 30 qualitative characters.

Cluster	Number of accessions	List of 64 accessions within cluster	% of contribution
I	52	G27, G8, G42, G16, G31, G45, G13, G63, G35, G39, G20, G32, G26, G51, G47, G57, G46, G58, G49, G55, G52, G56, G17, G30, G23, G5, G3, G2, G6, G4, G33, G60, G41, G11, G50, G1, G38, G21, G48, G64, G59, G29, G28, G36, G14, G10, G22, G40, G7, G43, G25, and G9	81.25
II	6	G19, G37, G62, G18, G53, and G54	9.38
III	5	G12, G34, G24, G15, and G44	7.81
IV	1	G61	1.56

Variations in morphological characters have been considered simple indicators of genetic variability in crop species and varieties. Cluster analysis is used to categorize accessions that are alike into one group and others into a different one [20]. Based on unweighted pair group methods, the 64 accessions were classified into four clusters, and the accessions represented in each cluster varied from 1 in cluster IV to 52 in cluster I, indicating that the studied cassava accession has a good chance of improving a character's interest through effective selection. The distribution of accessions (Tables S1, Table 6, and Figure 1) showed that there were 52 (81.25%) accessions in cluster I (39 from the Hawassa, 3 from the Jimma, and 10 from the Nigeria); 6 (9.38%) accessions in cluster II (3 from the Hawassa, 1 from the Jimma, and 2 from Nigeria); 5 (7.81%) accessions in cluster III (2 from the Hawassa and 3 from the Nigeria); and 1 (1.56%) accessions in cluster IV from the Jimma. Accessions from the same or different sources are grouped into different clusters, implying that the genetic make-up of the accessions differs.

The clustering analysis result is consistent with a similar study in Côte d'Ivoire, where a total of 89 accessions of cassava were characterized using 19 qualitative characters and were classified into three groups [31]. In Benin, a total of 116 accessions were classified, by Agre et al. [45], into six clusters using 41 qualitative descriptions, and in Brazil, 45 cassava cultivars were classified, by Nadjiam et al. [40], into 5 clusters based on 36 qualitative characteristics. All those studies reported the presence of wide variability among tested accessions.

4. Conclusion

The aim of this study was to characterize and evaluate cassava accessions in order to provide useful information for breeding programs and conservation. In this regard, the evaluated accessions showed high variability for the shape of the central leaflet, branching habit, leaf retention, petiole color, color of the stem epidermis, the color of the stem exterior, external color of the storage root, and color of root pulp towards frequency distribution analysis. Thus, the various organ colors had a great role in identifying accessions. The Shannon–Weaver diversity index (H') value for most observed phenotypic characters has exhibited an optimum level of diversity among accessions. The multivariate statistical analysis allows for identifying and grouping the accessions into different categories for various characters individually. As a result, the first two dimensions in the multiple correspondent analyses revealed 30.75% total variability, which was mainly related to 11 major characters. Thus, those characters are considered the most relevant for use in describing cassava accessions. In the cluster analysis, the 64 accessions are classified into four groups, with the number of accessions shared by each cluster being not uniform and varying from 1 in cluster VI to 52 in cluster I. This study could also facilitate breeders' identification and classification of desired features for the cassava storage root from both a genetic improvement and an agronomic point of view. For instance, accessions G23, G36, and G40 are identified for optimal nutritional content. Finally, this study confirmed the existence of sufficient genetic variability for the characteristics evaluated, which could be attributed to the dissimilar genetic backgrounds of the evaluated accessions. Thus, the observed variation could be useful for a breeding program to develop cassava cultivars with desired root characteristics and conservation.

Data Availability

The datasets that support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Berhanu Bilate carried out the field work, performed the statistical analysis, and drafted the manuscript. The rest of the authors coordinated the study, supervised fieldwork, and contributed to the writing of the manuscript. All authors have read and given their approval for the final manuscript to be submitted.

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Supplementary Materials

Table S1: The 64 cassava accessions and their score of qualitative characteristics. Figure S1: Criteria for the number of clusters based on a pseudo-F and pseudo-t-squared values. (*Supplementary Materials*)

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