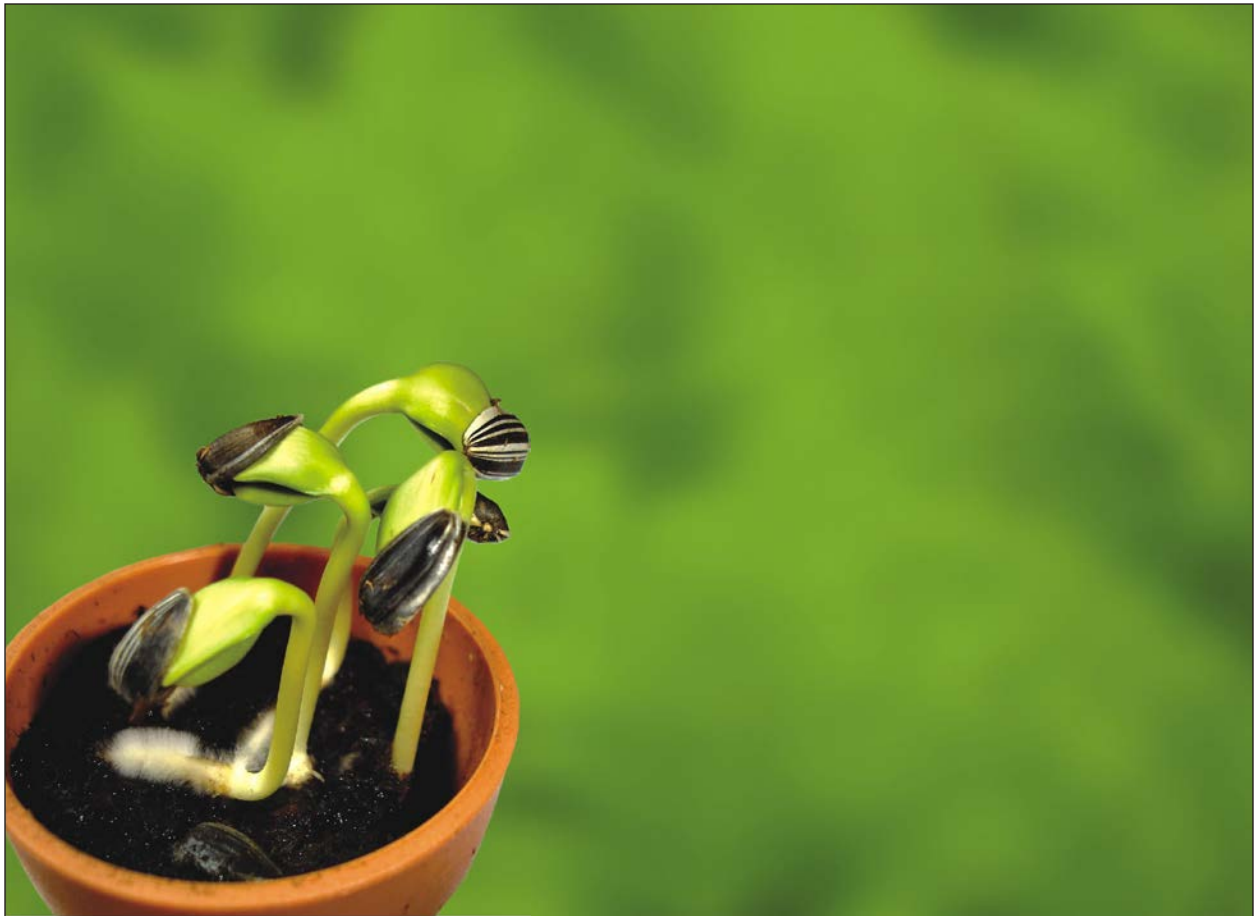




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Research Article

Qualitative Trait-Based Characterization and Identification of Elite Cowpea (*Vigna unguiculata* (L.) Walp.) Accessions from the Seed Bank of Peleforo GON COULIBALY University

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Abstract

Background and Objective: Cowpea (*Vigna unguiculata* (L.) Walp.) is an important grain legume in Sub-Saharan Africa due to its significant contribution to food security, nutrition and soil fertility. The effective characterization and utilization of genetic resources conserved in seed banks are essential for crop improvement and sustainable breeding programs. This study aimed to evaluate the morphological diversity of cowpea accessions based on qualitative traits and identify elite genotypes with superior agronomic performance from the seed bank of Peleforo GON COULIBALY University, Côte d'Ivoire. **Materials and Methods:** Forty cowpea accessions conserved in the university seed bank were evaluated under field conditions. Qualitative morphological traits were recorded from the vegetative to the reproductive stage, including characteristics of leaves, stems, flowers, pods and seeds. Multiple correspondence analysis (MCA) and hierarchical cluster analysis (HCA) were used to classify the accessions into distinct phenotypic groups. Key agronomic traits, including seed yield, leaflet size, seed length and days to maturity, were assessed to identify elite accessions. **Results:** The qualitative traits revealed considerable phenotypic variation among the 40 accessions and enabled their classification into distinct morphological groups. The multivariate analyses effectively discriminated among the accessions according to their phenotypic characteristics. Several accessions exhibited superior agronomic performance, combining high seed yield, desirable seed size, large leaflets and appropriate maturity periods, making them promising candidates for breeding and varietal improvement. **Conclusion:** The study demonstrated substantial morphological diversity among the evaluated cowpea accessions and identified elite genotypes with favorable agronomic traits. These findings provide valuable information for germplasm conservation, genetic improvement and the development of improved cowpea varieties adapted to local production systems.

Key words: *Vigna unguiculata*, morphological diversity, elite accessions, seed yield, varietal improvement

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is one of the most important dietary legumes in tropical and subtropical regions, particularly in Sub-Saharan Africa. This crop plays a major role in the food and nutrition security of rural populations due to its high content of proteins, vitamins and minerals¹. In addition, cowpea contributes to improved soil fertility through its ability to bind atmospheric nitrogen symbiotically, making it an essential crop in sustainable agricultural systems in semi-arid areas².

West Africa is the main production and consumption area of cowpea in the world. In this region, cultivation is widely practiced by smallholder farmers due to its ability to adapt to varied agro-ecological conditions, including environments characterized by poor soil and erratic rainfall. However, cowpea productivity remains relatively low in many production areas due to various biotic and abiotic constraints, such as pests, diseases, water deficits and climate variability³.

In this context, the conservation and enhancement of cowpea genetic resources are essential elements to support varietal improvement programs. Gene banks maintain a wide diversity of accessions representing an important reservoir of genes of interest for improving yield, environmental adaptation and resistance to biotic and abiotic stresses. The characterization of this diversity is thus a fundamental step for effective germplasm management and for the identification of promising genotypes that can be used in breeding programs^{4,5}.

The morphological and agronomic characterization of accessions remains one of the most widely used approaches to assess genetic diversity in cowpea collections. Agromorphological traits not only make it possible to describe the phenotypic variability that exists within the collections, but also to identify genotypes with interesting agronomic characteristics such as earliness, yield or seed size. Several studies conducted in West Africa have highlighted significant morphological diversity within local cowpea collections, highlighting the potential of these genetic resources for varietal improvement programs^{6,7}.

In Côte d'Ivoire, initiatives aimed at conserving and enhancing cowpea genetic resources have led to the establishment of a gene bank made from accessions collected in the north of the country. This region is recognized as the main cowpea production area in Côte d'Ivoire (Bio, 2002). The collection was initially established following the collection and preliminary characterization work carried out⁸, which made it possible to gather and document several local

accessions conserved with a view to their valorization in varietal improvement programs. A first study conducted on this genetic material highlighted a morphological structuring of accessions mainly based on seed-related traits⁹. However, further characterisation incorporating a wider set of agromorphological and agronomic traits is still needed to better understand the extent of the existing variability and to effectively exploit the potential of these genetic resources.

In this perspective, the present study aims to evaluate the morphological diversity and agronomic variability of a set of cowpea accessions from this genebank. More specifically, the objectives of this study are: (i) To analyze the morphological structuring of accessions using multivariate analyses, in particular multiple correspondence analysis (MCA) and hierarchical ascending classification (HAC) and (ii) To identify elite accessions with superior agronomic performance likely to be valued in cowpea varietal improvement programs.

MATERIALS AND METHODS

Plant material: The plant material used in this study consists of 40 accessions of cowpea (*Vigna unguiculata* (L.) Walp.) stored in the seed bank of the Peleforo GON COULIBALY University (UPGC) in Korhogo, Northern Côte d'Ivoire. These accessions are mainly the result of collections carried out in various localities in the northern zone of the country, which represents the main cowpea production Region in Côte d'Ivoire.

This collection constitutes a reservoir of local genetic resources with morphological and agronomic diversity that can potentially be exploited in varietal improvement programs. The accessions were codified according to their locality or collection site and kept in the UPGC seed bank for characterization and valorization work.

Experimental site: The study was conducted from July to November 2023, at the Botanical Garden of the Peleforo GON COULIBALY University (UPGC) located in Korhogo, in the Poro Region, in Northern Côte d'Ivoire. This area belongs to the Sudano-Sahelian domain characterized by two main seasons: A rainy season and a dry season. The average annual rainfall varies between 1000 and 1200 mm, with average temperatures between 25 and 30°C. The soils of the region are mainly tropical ferruginous, generally poor in organic matter but favorable to cowpea cultivation.

Experimental set-up and management of culture: The experiment was conducted in the field using a completely randomized block design, with three replicates. Each

Table 1: Qualitative traits used for agromorphological characterization of accessions

Characters	Code	Description
Saved for the final leaflet of a young adult leaf at the 6th week after sowing		
Shape of the leaflets	FFo	1-Globular, 2-Sub-Globular, 3-Lanceolate
Evaluated in the 6th week after semi		
Stem habit	Loan	1-Straight sharp (the branches form sharp angles with the main stem) 2-Erect (branching angle less acute than above) 3-Semi-erect (branches perpendicular to the main stem, but not touching the ground) 4-Intermediate (the lowest branches touch the ground) 5-Semi-prostrate (the main stem reaches 20 centimeters or more) 6-Prostrate (flat plants on the ground, branches spread out several meters)
Recorded for stems, branches, petioles and peduncles within 6 weeks after sowing		
Plant pigmentation	PgPI	1-None, 2-Very light, 3-Moderate at base and tips of petioles, 4-Intermediate, 5-extensive, 6-solid
Observed from the beginning of flowering		
Flower color	CFI	1-Purple, 2-Purple, 3-White
Observed after harvest and drying		
Pod shape	FGo	1-Straight, 2-Slightly curved, 3-Curved
Observed after harvest and drying		
Pod color	CGo	1-Cream, 2-Yellow, 3-Brown, 4-Purple, 5-Purple
Observed after harvest and drying		
Seed color	CGr	1-White, 2-Ochre, 3-Light-Red, 4-Dark-Red, 5-Brown, 6-Ash-Grey, 7-Black
Observed on seed coat		
Appearance of the seed	AGr	1-Smooth, 2-Wrinkled
Observed the shape of the seed		
Seed shape	FGr	1-Ovoid, 2-Globular, 3-Rhomboid, 4-Kidney-shaped
Observed on seed coat, presence or absence of spot		
Task on the seed	TGr	1-Absence, 2-Presence
Seed eye shape	FOGr	1-Small, 2-Big

Table 2: Agronomic traits used for characterization and selection of elite accessions

Characters	Code	Observation stage and measurement method
Leaflet length	LoFo	Average measurement carried out on three terminal leaflets of the plant at the 6th week after sowing
Width of the leaflet	LaFo	Average measurement carried out on three terminal leaflets of the plant at the 6th week after sowing
Time to maturity	TMa	Number of days from sowing to early maturity
Seed length	LGr	Average measurement with a digital caliper on 5 seeds per plant after harvest
Seed yield per hectare	YieldKg/ha	Estimate in Kg/ha from the average production of a plant with a seeding density of 26667.67 plants/ha

accession was shown on an elementary plot made up of cultivation lines, with a spacing of 50 cm between the rows and 20 cm between the pockets. Two seeds were sown per pocket and a separation was carried out after emergence to keep only one plant per pocket.

Cultural practices such as manual weeding have been carried out regularly to limit weed competition and ensure good plant development. No specific phytosanitary treatment was applied during the experiment.

Morphological characterization of accessions: The morphological characterization of the accessions was carried out based on qualitative and quantitative agromorphological characteristics, observed throughout the development cycle of the plant, from the vegetative stage to production.

Qualitative characteristics: The qualitative characteristics concerned the morphological description of the plant from the vegetative stage to the reproductive stage.

The quantitative traits measured concerned several agronomic parameters related to vegetative growth and production.

These observations were made according to morphological descriptors commonly used for cowpea and highlighted the phenotypic variability between accessions (Table 1 and 2)¹⁰.

Analysis of morphological structuring: The morphological structuring of accessions from qualitative variables was studied using Multiple Correspondence Analysis (MCA). This analysis allows us to explore the relationships between the modalities of qualitative variables and to visualize the proximities between accessions in a factor space.

The accessions were then grouped using a Hierarchical Ascending Classification (HAC) based on factor coordinates from the MCA to identify morphologically homogeneous groups.

Discriminant group analysis: A discriminant function analysis (DFA) was performed on quantitative agronomic variables to assess the ability of these traits to discriminate morphological groups identified by MCA and HAC.

This analysis made it possible to determine the variables most contributing to group discrimination and to evaluate the performance of the model through the rate of good classification, the Kappa coefficient and cross-validation.

Analysis of agronomic variability: Variability in agronomic traits between groups was analyzed using the nonparametric Kruskal-Wallis test, which compares the medians of quantitative variables between different morphological groups.

Descriptive statistics (mean, minimum, maximum, standard deviation and coefficient of variation) were also calculated for each group to characterize the variability of the parameters studied.

Identification of elite accessions: Identification of elite accessions was made from several key agronomic traits, including seed yield, time to maturity, leaflet size and seed length. These traits are commonly used in cowpea varietal breeding programs because of their direct influence on genotype productivity and adaptation. Seed yield is the main selection criterion in cowpea breeding programs^{3,11}. Maturity time is also a determining trait, with early varieties being particularly sought after in areas subject to high climatic variability¹². In addition, seed size is an important agronomic and commercial trait that influences market value and consumer preference. Finally, traits related to vegetative development, such as leaflet size, are indicators of plant vigor and can indirectly contribute to improved yield.

Statistical analysis: All statistical analyses were performed using R software (version 4.5.2)¹³ with packages specifically designed for descriptive statistics, statistical modeling and multiple comparisons.

RESULTS

Structuring cowpea accessions based on qualitative variables

Multiple correspondence analysis of accessions: Multiple correspondence analysis (MCA) was carried out to explore all

the agromorphological qualitative variables and to highlight the similarities between the modalities of the variables as well as between the accessions studied. By considering the variables whose contributions of the modalities is the most important in the formation of the axes, two main axes have been retained.

These two axes explain, respectively, 19.4% and 11.3% of the total inertia, i.e. 30.70% of the overall variability observed.

The analysis of the symmetrical graph of the modalities (Fig. 1) shows that axis 1 opposes two sets of morphological characters. On the one hand, plants are characterized by white flowers, wrinkled white seeds with large eyes, sub-globular leaves, a prostrate habit and curved or slightly curved pods. On the other hand, plants with purple or mauve flowers, colorful, smooth seeds with small eyes and stems that range from straight acute to semi-prostrate.

As for axis 2, it mainly differentiates accessions with erect or sharp straight stems associated with purple flowers from accessions with semi-erect or semi-prostrate stems and purple flowers.

The projection of the 40 accessions in the factorial plane defined by axes 1 and 2 highlights three distinct morphological groups (Fig. 2).

- Group 1 includes accessions characterized by smooth seeds of globular or ovoid shape, associated with stems with intermediate or moderate pigmentation and a semi-prostrate or intermediate habit
- Group 2 consists of accessions with smooth, rhomboid seeds and straight acute or erect stems
- Group 3 is characterized by plants with wrinkled, large-eyed, kidney-shaped white seeds associated with strongly or intensely pigmented prostrate stems

Hierarchical classification of accessions: The results obtained by Multiple Correspondence Analysis (MCA) were confirmed by Hierarchical Ascending Classification (HAC) analysis shown in Fig. 3. The dendrogram obtained from all the qualitative variables also makes it possible to group the 40 accessions into three distinct groups. These groups generally present the same morphological characteristics as those identified by the MCA, which confirms the robustness of the structuring observed.

The detailed examination of the dendrogram also reveals an internal structuring of the groups into several morphotypes. Indeed, beyond the three main groups identified, each group has subdivisions reflecting the morphological diversity of accessions. In total, the 40 accessions of the gene bank are subdivided into 24 morphotypes coded from M1 to M24.

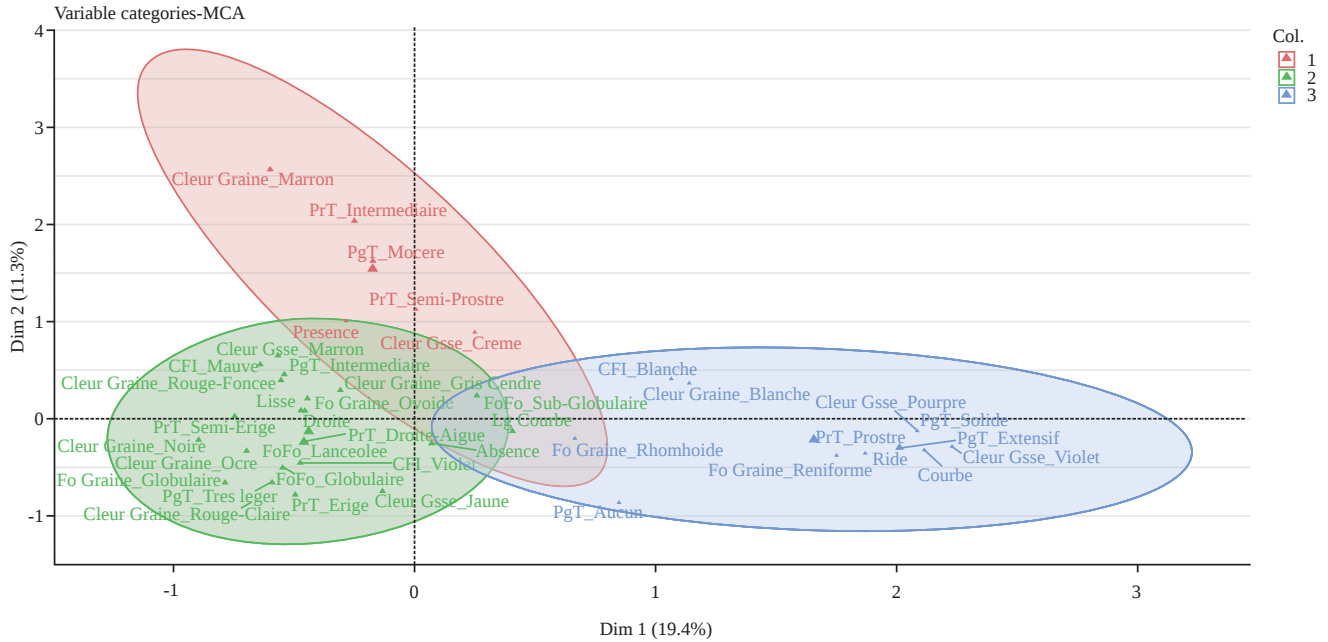


Fig. 1: Biplot of genebank cowpea accession variables

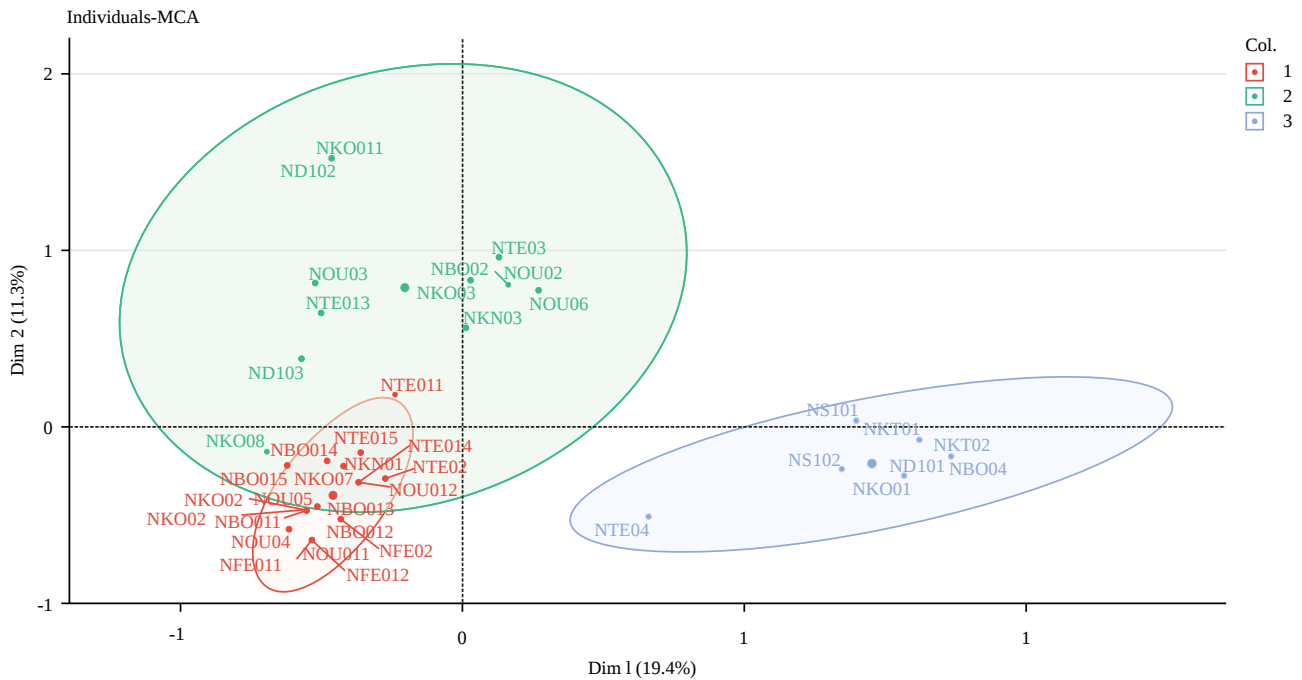


Fig. 2: Biplot of cowpea accessions from the gene bank

Group 1, which is the largest group in terms of number of accessions, is subdivided into 10 distinct morphotypes, reflecting a high intra-group morphological variability. These morphotypes, denoted from M1 to M10, include the following accessions:

- M1 (NOU04 and NOU05)
- M2 (NFE011, NFE012 and NOU011)
- M3 (NBO012, NBO013 and NFE02)
- M4 (NBO011, NKN02 and NKO02)
- M5 (NBO015)
- M6 (NKO08)
- M7 (NTE015)
- M8 (NBO014 and NKN01)
- M9 (NTE02)
- M10 (NTE014, NKO07 and NOU012)

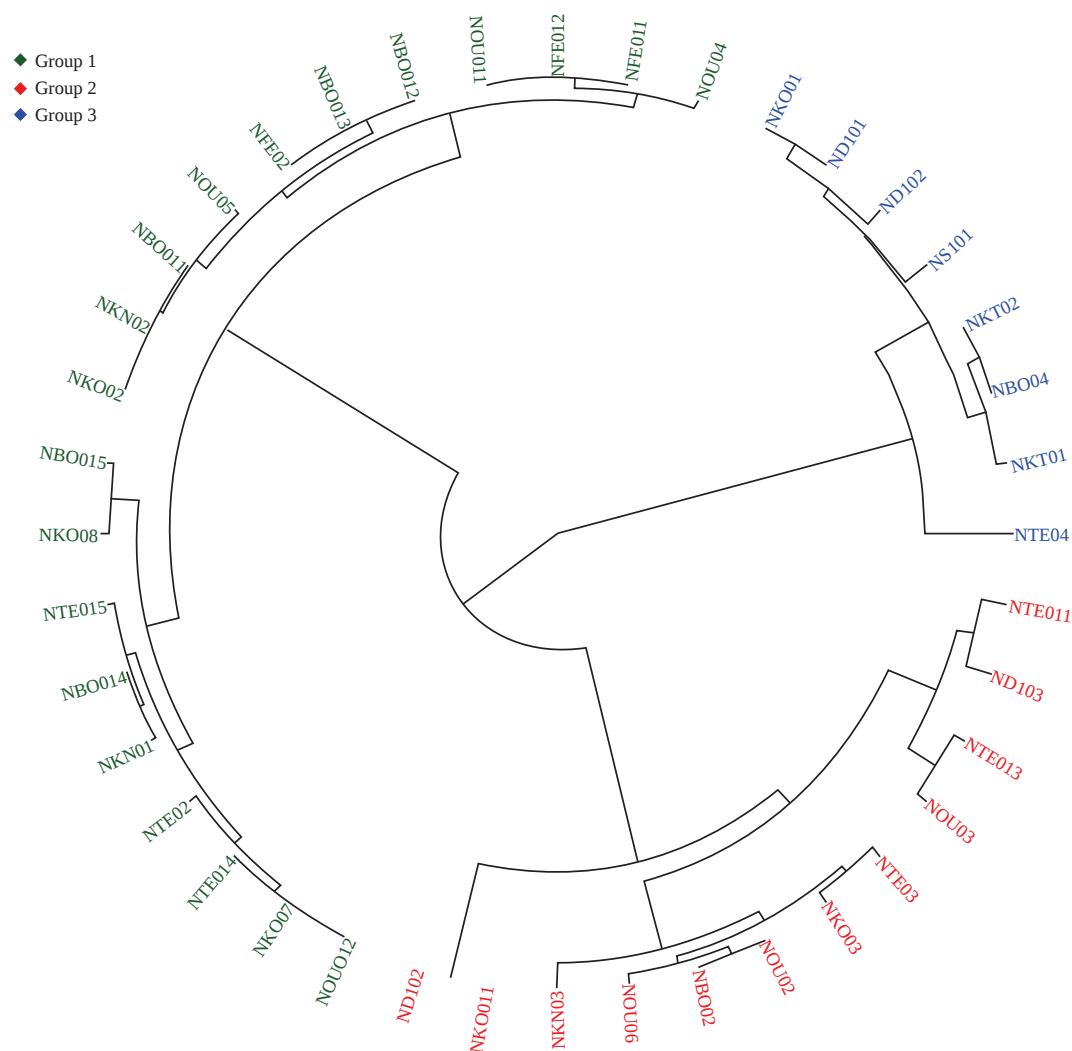


Fig. 3: Hierarchical ascending classification of cowpea accessions based on qualitative traits

Group 2 also shows internal diversification with 8 morphotypes, indicating a relatively important morphological heterogeneity among the accessions that compose it. The morphotypes of this group, noted from M11 to M18, are made up of the following accessions:

- M11 (NDI02 and NKO011)
- M12 (NKN03)
- M13 (NOU06 and NTE03)
- M14 (NBO02 and NOU02)
- M15 (NKO03)
- M16 (NOU03 and NTE013)
- M17 (NDI03)
- M18 (NTE011)

Finally, group 3, although comprising a smaller number of accessions, is subdivided into 6 morphotypes, which also

testifies to a significant morphological diversity within this group. The morphotypes of this group, noted from M19 to M24, include the following accessions:

- M19 (NTE04)
- M20 (NKT01)
- M21 (NBO04 and NKT02)
- M22 (JSS01)
- M23 (JSS02)
- M24 (NDI01 and NKO01)

Agronomic characteristics of the different types generated from the agromorphological traits

Discriminant factor analysis: The discriminant analysis was carried out since agronomic variables such as leaflet length (LoFo), leaflet width (LaFo), maturation time (T_{Ma}), seed length (LGr) and yield (rend) made it possible to partially

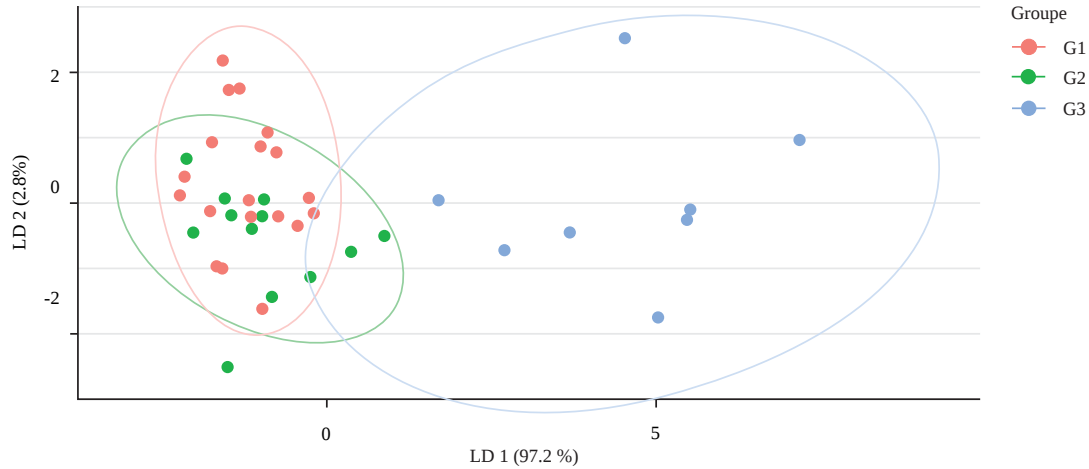


Fig. 4: Representation of the different groups in the discriminating canonical plane formed by the canonical components of the AFD (Discriminant Analysis Factor Projection of Individuals)

Table 3: Description of AFD's values

	LD1	LD2
Explained variance (%)	97.17	2.83
Cumulative variance (%)	97.17	100.00
Variable		
LoFo	-0.034	-0.175
LaFo	-0.721	-0.836
TMa	0.045	0.098
LGr	1.523	-0.953
Renders	-0.00013	0.00142

LoFo: Leaflet length, LaFo: leaflet width, Tma: Time of maturity, LGr: Seed length, LD1: First linear discriminant axis, LD2: Second linear discriminant axis; AFD: Discriminant factor analysis

Table 4: Model classification performance

Indicator	Value
Rate of good classification	72.5 %
Cohen's kappa	0.54
Accuracy (validation croisée)	62.5 %
Kappa (cross-validate)	0.38
p (Accuracy>NIR)	0.003

Table 5: Sensitivity and accuracy per group

Group	Sensitivity (%)	Specificity (%)	Balanced accuracy (%)
G1	85.0	65.0	75.0
G2	41.7	85.7	63.7
G3	87.5	100.0	93.8

discriminate the three groups from the ACM classification. The two discriminating functions explain the entire variance, with a large majority of the contribution of the first axis (97.17%). The model has an overall good classification rate of 72.5% and a Kappa coefficient of 0.54, indicating moderate to good agreement. Cross-validation confirms a real but more moderate structuring (accuracy = 62.5%), suggesting a partial overlap between certain groups. The main discriminating axis is strongly structured by seed length and leaf area, opposing

the G3 group, clearly individualized, to the G1 and G2 groups, whose morphological profiles appear to be closer (Table 3-5, Fig. 4).

Agronomic parameters of the different groups: Table 6 presents the effect of the different dispersion parameters of the quantitative variables on the groups obtained from the qualitative variables. The Kruskal-Wallis tests performed were significant for the variables Leaflet Length (LoFo), Leaflet

Table 6: Descriptive statistics of groups formed from qualitative data

	Statistic	LoFo	LaFo	TMa	LGr	Yield
Group 1	avg	9.95 ^b	6.34 ^b	63.71 ^b	6.68 ^c	2223.16 ^a
	min	7.10	4.80	56.00	5.35	521.33
	max	16.30	9.00	69.00	7.99	6283.68
	AND	1.81	0.94	2.45	0.46	1095.19
	CV (%)	18.18	14.78	3.84	6.85	49.26
Group 2	avg	10.54 ^a	6.75 ^a	63.69 ^b	7.05 ^b	2159.35 ^a
	min	8.40	5.30	57.00	6.15	510.72
	max	13.70	8.80	70.00	8.19	4132.80
	AND	1.45	0.88	2.76	0.66	868.43
	CV (%)	13.78	12.96	4.34	9.43	40.22
Group 3	avg	8.91 ^c	5.09 ^c	78.88 ^a	9.36 ^a	1901.13 ^a
	min	5.00	2.30	66.00	7.50	244.05
	max	13.70	8.00	92.00	11.30	4211.20
	AND	2.05	1.36	8.37	1.15	1125.60
	CV (%)	23.05	26.77	10.62	12.27	59.21
f- value		17.76	33.53	74.82	74.82	0.83
p-value		0.00	0.00	0.00	0.00	0.66

LoFo : Length of the leaflets, LaFo : Width of the leaflets, Tma: Maturity time (plant growth cycle), LGr: Seed length, Yield: Seed yield, avg: Average, min: Minimum, max: Maximum, SD: Standard deviation, CV: Coefficient of variation, F: F-statistic, P: Probability value, Different lowercase superscript letters within a column indicate significant differences among groups (p<0.05)

Table 7: Agronomic parameters of accessions within group 1

Accessions	LoFo (cm)	LaFo (cm)	TMa (days)	LGr (mm)	Yield (kg/ha)
NBO011	10.45 ± 1.29 ^{bc}	7.00 ± 0.56 ^{bc}	63.75 ± 0.96 ^{ab}	6.64 ± 0.33 ^{bc}	2319.08 ± 978.25 ^{bc}
NBO012	8.75 ± 0.24 ^{bc}	5.63 ± 0.41 ^c	64.50 ± 1.29 ^{ab}	6.47 ± 0.46 ^{bc}	2006.47 ± 1086.10 ^{cd}
NBO013	8.90 ± 0.73 ^{bc}	5.38 ± 0.17 ^c	65.25 ± 0.50 ^{ab}	6.34 ± 0.29 ^{bc}	1696.49 ± 506.49 ^{cd}
NBO014	9.90 ± 1.02 ^{bc}	5.63 ± 0.80 ^c	64.50 ± 1.00 ^{ab}	6.42 ± 0.20 ^c	1962.35 ± 1127.01
NBO015	9.98 ± 1.92 ^{bc}	6.25 ± 1.01 ^c	64.75 ± 2.36 ^{ab}	6.89 ± 0.15 ^{bc}	1862.51 ± 634.63 ^{cd}
NFE011	10.20 ± 0.45 ^{bc}	6.33 ± 0.69 ^c	57.50 ± 0.58 ^c	6.93 ± 0.06 ^{bc}	3855.07 ± 287.29 ^a
NFE012	9.08 ± 0.80 ^{bc}	6.60 ± 0.75 ^{bc}	63.25 ± 0.50 ^{ab}	6.82 ± 0.29 ^{bc}	2014.05 ± 212.13 ^{cd}
NFE02	8.35 ± 0.68 ^c	5.80 ± 0.45 ^c	65.25 ± 1.50 ^{ab}	6.92 ± 0.25 ^{ab}	1593.10 ± 573.10 ^{cd}
NKN01	9.93 ± 0.87 ^{bc}	6.60 ± 0.18 ^{bc}	65.00 ± 0.82 ^{ab}	6.45 ± 0.53 ^{bc}	2554.26 ± 524.87 ^{cd}
NKN02	8.75 ± 1.26 ^{bc}	5.38 ± 0.48 ^c	66.75 ± 2.06 ^a	6.66 ± 0.11 ^{bc}	931.29 ± 603.27 ^d
NKO02	8.35 ± 0.90 ^c	5.95 ± 0.72 ^c	64.00 ± 0.00 ^{ab}	6.73 ± 0.18 ^{bc}	2133.99 ± 466.87 ^{cd}
NKO07	10.40 ± 0.36 ^{bc}	6.28 ± 0.38 ^c	63.50 ± 0.58 ^{ab}	6.01 ± 0.46 ^c	1867.48 ± 215.21 ^{cd}
NKO08	11.13 ± 0.71 ^b	7.85 ± 0.95 ^{ab}	63.75 ± 2.50 ^{ab}	7.17 ± 0.32 ^{ab}	1576.23 ± 317.65 ^{cd}
NOU011	8.18 ± 0.64 ^c	5.80 ± 0.63 ^c	64.75 ± 0.96 ^{ab}	6.77 ± 0.32 ^{bc}	1200.60 ± 521.98 ^d
NOU012	9.50 ± 0.83 ^{bc}	6.10 ± 0.79 ^c	65.00 ± 1.63 ^{ab}	6.35 ± 0.25 ^{bc}	3021.71 ± 1847.00 ^{bc}
NOU04	10.15 ± 1.37 ^{bc}	6.73 ± 0.57 ^{bc}	64.25 ± 0.96 ^{ab}	6.48 ± 0.21 ^{bc}	1396.48 ± 392.89 ^{cd}
NOU05	10.00 ± 0.65 ^{bc}	6.85 ± 0.19 ^{bc}	63.00 ± 0.00 ^b	6.64 ± 0.64 ^{bc}	1631.96 ± 205.80 ^{cd}
NTE014	9.45 ± 0.85 ^{bc}	5.80 ± 0.28 ^c	65.00 ± 1.15 ^{ab}	6.21 ± 0.08 ^{bc}	2427.47 ± 867.83 ^{cd}
NTE015	15.25 ± 0.90 ^a	6.78 ± 0.92 ^{bc}	58.25 ± 3.20 ^c	7.32 ± 0.24 ^a	3737.30 ± 664.85 ^a
NTE02	11.00 ± 1.19 ^b	8.28 ± 1.19 ^a	63.00 ± 0.00 ^b	7.10 ± 0.20 ^{bc}	3668.89 ± 1888.25 ^{ab}
f-value		5.245	9.764	4.486	3.880
p-value		<0.001	<0.001	<0.001	<0.001

LoFo: Length of the leaflets, LaFo: Width of the leaflets, TMa: Maturity time (the cycle of the plant), LGr: Seed length and Yield: Seed yield

Width (LaFo), Time to Maturity (Tma) and Seed Length (LGr). Thus, group 1 is characterized by an average LoFo leaflet length (9.95 cm), an estimated leaflet width (LaFo) of 6.34 cm and a relatively short cycle with a maturity time (Tma) of 63.71 days. The seeds in this group have an average length of 6.68 mm smaller than the other two groups. Group 2 is characterized by long leaflets (LoFo = 10.54 cm) and a width (LaFo) of 6.75 cm relatively longer than those of group 1 and group 3. The seeds in this group are also small (LGr = 6.68 mm) but larger than those in group 1. Group 3 is characterized

by small leaflets (LoFo = 8.91 cm and LoFo = 5.09 cm). This group contains individuals with particularly large seeds (LGr = 9.36 mm) and the longest cycle (Tma = 78.88 days)

Agronomic parameters and identifications of elite accessions within the different groups

Group 1: The analysis of the agronomic parameters of the accessions belonging to group 1 reveals highly significant differences between the accessions for all the traits

Table 8: Agronomic parameters of accessions within group 2

Accessions	LoFo (cm)	LaFo (cm)	TMa (days)	LGr (mm)	Yield (kg/ha)
NBO02	8.83±0.34 ^d	5.75±0.30 ^c	64.75±1.50 ^a	6.40±0.23 ^b	1102.83±490.54 ^d
NDI02	9.00±0.55 ^d	6.15±0.40 ^{bc}	63.50±1.00 ^a	6.30±0.14 ^b	1558.87±656.07 ^{bcd}
NDI03	11.80±0.68 ^{ab}	7.23±0.39 ^{ab}	64.25±4.11 ^a	6.60±0.32 ^b	2328.59±929.41 ^{bc}
NKN03	11.18±0.70 ^{bc}	6.68±0.74 ^{bc}	65.75±3.10 ^a	6.83±0.16 ^b	2021.78±368.43 ^{bc}
NKO011	9.05±0.54 ^d	6.13±0.40 ^{bc}	63.50±1.00 ^a	6.35±0.14 ^b	1414.55±833.64 ^{cd}
NKO03	11.63±0.42 ^{ab}	7.15±0.44 ^{ab}	57.50±0.58 ^b	6.79±0.35 ^b	3653.74±516.36 ^a
NOU02	9.63±0.69 ^d	6.10±0.56 ^{bc}	63.50±0.58 ^a	6.71±0.27 ^b	1863.60±313.55 ^{bc}
NOU03	9.43±0.22 ^d	6.28±0.56 ^{bc}	63.25±0.50 ^a	8.05±0.20 ^a	2492.75±702.94 ^{bc}
NOU06	13.08±0.87 ^a	7.85±0.61 ^a	64.00±2.00 ^a	7.77±0.34 ^a	2967.69±651.28 ^{ab}
NTE011	12.48±1.47 ^{ab}	7.68±0.90 ^a	63.00±0.00 ^a	7.56±0.37 ^a	2582.64±653.74 ^b
NTE013	10.13±1.06 ^{cd}	6.55±0.80 ^{bc}	63.50±1.00 ^a	7.86±0.08 ^a	2424.08±611.77 ^{bc}
NTE03	11.58±0.74 ^{ab}	7.35±0.82 ^{ab}	67.00±1.63 ^a	7.76±0.29 ^a	2507.52±311.72 ^{bc}
f-value	15.098	5.165	6.192	26.675	5.230
p-value	<0.001	<0.001	<0.001	<0.001	<0.001

LoFo: Length of the leaflets, LaFo: Width of the leaflets, TMa: Maturity time (the cycle of the plant), LGr: Seed length and Yield: Seed yield

Table 9: Agronomic parameters of accessions within group 3

Accessions	LoFo (cm)	LaFo (cm)	TMa (hours)	LGr (mm)	Yield (kg/ha)
NBO04	12.90±0.74 ^a	7.13±0.80 ^a	82.25±1.71 ^b	10.78±0.46 ^a	3068.15±342.69 ^a
NDI01	8.85±1.19 ^{ab}	5.00±0.53 ^{ab}	79.25±4.99 ^b	10.01±0.14 ^a	2151.75±329.65 ^b
NKO01	8.68±1.38 ^{ab}	5.10±0.61 ^{ab}	79.25±4.99 ^b	10.01±0.14 ^a	2076.27±653.44 ^b
NKT01	6.28±1.17 ^c	2.90±0.59 ^c	89.25±1.71 ^a	7.86±0.40 ^b	317.88±78.42 ^c
NKT02	8.58±2.19 ^{ab}	4.83±0.96 ^{ab}	89.75±1.71 ^a	10.75±0.46 ^a	2563.52±1101.4 ^b
NSI01	8.78±0.93 ^{ab}	5.03±0.74 ^{ab}	70.00±3.56 ^{ab}	8.35±0.07 ^{ab}	1251.29±676.76 ^{ab}
NSI02	8.15±0.81 ^{ab}	4.38±1.00 ^{ab}	74.00±4.24 ^{ab}	8.53±0.58 ^{ab}	834.74±967.64 ^{ab}
NTE04	9.08±0.71 ^b	6.35±0.50 ^a	67.25±1.26 ^c	8.55±0.30 ^{ab}	2945.44±651.23 ^a
f-value	8.978	11.694	23.918	41.230	8.733
p-value	<0.001	<0.001	<0.001	<0.001	<0.001

LoFo: Length of the leaflets, LaFo: Width of the leaflets, TMa: Maturity time (the cycle of the plant), LGr: Seed length and Yield: Seed yield

studied ($p < 0.001$). These traits relate to leaflet length (LoFo), leaflet width (LaFo), time to maturity (TMa), seed length (LGr) and seed yield (Rend) (Table 7).

The length of the leaflets varies significantly between accessions. The highest values are observed in NTE015 (15.25 cm), followed by NK008 (11.13 cm) and NTE02 (11.00 cm). Conversely, the lowest values are recorded for NOU011 (8.18 cm) and NFE02 (8.35 cm).

Regarding the width of the leaflets, the accession NTE02 (8.28 cm) has the highest value, followed by NK008 (7.85 cm), while the lowest values are observed in NKN02 and NBO013.

The maturation time varies from 57.50 days to 66.75 days. The NFE011 accession has the shortest cycle (57.50 days), followed by NTE015 (58.25 days). In contrast, NKN02 (66.75 days) has the longest cycle.

Seed length also shows significant variation between accessions. The highest values are observed in NTE015 (7.32 mm), followed by NK008 (7.17 mm) and NTE02 (7.10 mm).

As far as seed yield is concerned, the highest values are recorded in NFE011 (3855.07 kg/ha), NTE015 (3737.30 kg/ha) and NTE02 (3668.89 kg/ha), while the lowest yields are observed in NKN02 (931.29 kg/ha) and NOU011 (1200.60 kg/ha).

Regarding all the agronomic parameters evaluated, the NFE011, NTE015 and NTE02 accessions stand out for their superior agronomic performance. These accessions have high value for most of the traits studied, including seed yield, leaflet size and seed length, while exhibiting a relatively short maturity cycle.

Thus, these three accessions can be considered elite within Group 1 due to their high agronomic potential.

Group 2: Analysis of agronomic parameters of Group 2 accessions reveals the existence of highly significant differences between accessions for all traits studied ($p < 0.001$). These traits relate to leaflet length (LoFo), leaflet width (LaFo), time to maturity (TMa), seed length (LGr) and seed yield (Rend).

The length of the leaflets varies significantly between accessions. The highest values are observed in NOU06 (13.08 cm), followed by NTE011 (12.48 cm), NDI03 (11.80 cm) and NK003 (11.63 cm). Conversely, the lowest values are recorded for NBO02 (8.83 cm) and NDI02 (9.00 cm).

Regarding the width of the leaflets, the highest values are observed in NOU06 (7.85 cm) and NTE011 (7.68 cm), while the lowest values are recorded in NBO02 (5.75 cm).

The maturation time varies from 57.50 to 67 days. The NKO03 accession has the shortest cycle (57.50 days), which is a particularly interesting agronomic characteristic. In contrast, NTE03 (67 days) has the longest cycle.

Seed length also varies between accessions. The highest values are observed in NOU03 (8.05 mm), NTE013 (7.86 mm), NOU06 (7.77 mm) and NTE03 (7.76 mm).

In terms of seed yield, accession NKO03 has the highest value (3653.74 kg/ha), followed by NOU06 (2967.69 kg/ha) and NTE011 (2582.64 kg/ha).

With regard to all the agronomic parameters studied, the NKO03, NOU06 and NTE011 accessions stand out for their superior agronomic performance. These accessions combine high values for several morpho-agronomic traits, including leaflet size, seed length and yield, while presenting a relatively favorable maturity cycle.

Thus, these accessions can be considered as the elite accessions of group 2, due to their high agronomic potential (Table 8).

Group 3: The analysis of the agronomic parameters of the accessions belonging to group 3 also shows highly significant differences between the accessions for all the traits studied ($p < 0.001$) (Table 9).

The length of the leaflets varies between 6.28 cm and 12.90 cm. The highest values are observed in NBO04 (12.90 cm), followed by NTE04 (9.08 cm). In contrast, NKT01 (6.28 cm) has the lowest value.

The width of the leaflets also shows significant variation between accessions. The highest values are observed in NBO04 (7.13 cm) and NTE04 (6.35 cm), while NKT01 (2.90 cm) has the lowest value.

The time to maturity varies greatly between accessions, with values between 67.25 and 89.75 days. NTE04 accession has the shortest cycle time (67.25 days), which is a significant agronomic advantage. Conversely, NKT02 (89.75 days) and NKT01 (89.25 days) have the longest cycles.

Seed length is particularly high in this group, with values reaching 10.78 mm in NBO04 and 10.75 mm in NKT02, while NKT01 (7.86 mm) has the lowest value.

In terms of seed yield, the highest values are observed in NBO04 (3068.15 kg/ha) and NTE04 (2945.44 kg/ha), while NKT01 (317.88 kg/ha) has a significantly lower yield.

With regard to all the agronomic parameters evaluated, the NBO04 and NTE04 accessions stand out for their superior agronomic performance, combining high values for several morpho-agronomic traits as well as a high yield. In addition, NTE04 has a relatively short maturity cycle, which is an advantage for varietal improvement programs.

Thus, these accessions can be considered as the elite accessions of group 3.

DISCUSSION

The analysis of the morphological diversity of cowpea accessions based on qualitative traits revealed a clear structuring of the collection into three distinct groups based on multiple correspondence analysis (MCA) and hierarchical ascending classification (CAH). This structuring reflects the existence of a significant phenotypic variability within the accessions conserved in the gene bank studied. The subdivision of these groups into several morphotypes (24 morphotypes) also highlights a notable within-group diversity, resulting from different combinations of morphological characters observed in the accessions.

The results obtained in this study are broadly in agreement with those reported⁹, who also studied the morphological diversity of accessions from the same genebank. These authors have highlighted a structuring of accessions into three distinct groups based on the MCA and CAH analyses, thus confirming the coherence and stability of the morphological organization of this cowpea collection. However, they identified 16 morphotypes, whereas the present study highlights a higher number of morphotypes. This difference could be explained by the nature of the traits used in the analysis. Indeed, their study was mainly based on seed-related traits, whereas the present study incorporates a broader set of agromorphological traits, including traits related to leaves, flowers, pods and plant habits. The use of more descriptors thus allows finer discrimination among accessions and a better demonstration of morphological variability.

These results confirm the importance of qualitative morphological characteristics in the characterization of cowpea diversity. According to^{14,15}, morphological traits are relevant indicators of genetic variability and represent an essential first step in the management and use of cowpea genetic resources in varietal improvement programs. Indeed, the identification of morphologically distinct groups makes it possible to better structure germplasm collections and to facilitate the selection of genotypes with agronomic characteristics of interest.

Several studies conducted in West Africa have also highlighted a high morphological and genetic diversity within local cowpea collections. For example⁶, in Ghana showed, based on multivariate analyses of agromorphological traits, the existence of a marked structuring of accessions into several distinct groups. Similar results have been reported in

Nigeria and Burkina Faso where various studies have revealed significant variability within cowpea germplasm, both based on morphological traits and molecular markers^{5,7,16}. This significant diversity reflects the evolutionary history and broad agro-ecological adaptation of cowpea in West Africa, the main center of diversity of this species^{4,17}. This morphological diversity observed is a major asset for varietal improvement programs. Indeed, according to³, the availability of a broad genetic base is essential for the development of improved varieties combining high yield, environmental adaptation and resistance to biotic and abiotic constraints. Thus, the morphological structuring highlighted in this study reflects the existence of a genetic reservoir potentially exploitable for the selection and improvement of cowpeas.

Evaluation of the agronomic parameters of accessions within the different morphological groups revealed significant variability for all traits studied, including leaflet length, seed length, seed yield and maturation time. This variability reflects the existence of important genetic differences between accessions and confirms the interest of these traits in the identification of high-performance genotypes.

The presence of significant agronomic variability within cowpea collections has been widely documented in the literature. For example, studies^{3,6} showed that local cowpea collections in West Africa show considerable diversity for key agronomic traits such as earliness, yield and seed size. This variability is an essential resource for breeding programs aimed at improving the productivity and adaptation of varieties.

In the present study, the comparative analysis of agronomic performance identified several accessions with superior performance for several traits simultaneously. Within Group 1, NFE011, NTE015 and NTE02 are distinguished by their high agronomic performance, particularly in terms of vegetative development, seed characteristics and yield. In groups 2 and 3, other accessions, including NKO03, NOU06, NTE011, NBO04 and NTE04, also showed remarkable agronomic performance.

The identification of these elite accessions is particularly important for cowpea varietal improvement programs. Indeed, the selection of genotypes combining several favorable agronomic traits is an essential strategy for the sustainable increase in the productivity of this crop. According to a study¹², traits such as earliness, seed yield and vegetative vigor are among the main criteria used in the selection of improved cowpea varieties.

In addition, the presence of accessions with a relatively short maturation cycle is an important agronomic advantage in West African production systems, which are characterized

by high climatic variability and sometimes short growing seasons. Early varieties reduce the risks associated with water deficits at the end of the cycle and improve yield stability.

Thus, the elite accessions identified in this study represent promising genetic resources for breeding programs and could be used either as potential varieties or as parents in hybridization programs aimed at developing new improved varieties adapted to the agro-ecological conditions of the region.

CONCLUSION

The morphological characterization of cowpea accessions (*Vigna unguiculata* (L.) Walp.) preserved in the seed bank of the Peleforo GON COULIBALY University has highlighted a significant phenotypic variability within the plant material studied. The evaluation of the qualitative traits observed from the vegetative stage to the reproductive stage made it possible to describe the different accessions and to identify several groups with distinct morphological characteristics. This diversity is a valuable resource for cowpea breeding programs.

In addition, the identification of elite accessions on the basis of agronomic criteria such as seed yield, leaflet size, seed length and time to maturity has made it possible to highlight genotypes with interesting agronomic potential. These accessions could be used in breeding programs aimed at improving the productivity, adaptation and quality of cowpea varieties.

Thus, the results obtained contribute to a better knowledge and development of local cowpea genetic resources. They also provide an important basis for further studies, including multi-environment evaluation and molecular characterization, with a view to a more efficient use of these resources in varietal breeding programs.

SIGNIFICANCE STATEMENT

This study provides important insights into the morphological diversity of cowpea germplasm conserved in Côte d'Ivoire. The identification of accessions combining high seed yield, desirable seed size, large leaflets and suitable maturity periods provides useful genetic resources for breeding programs. The findings can support more effective germplasm utilization and contribute to the development of improved cowpea varieties adapted to local production conditions, thereby supporting food security and sustainable crop production in Sub-Saharan Africa.

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