International Journal of Agriculture and Biosciences 2026 15(2): 727-736.
https://doi.org/10.47278/journal.ijab/2025.218

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

Evaluation of the Agro-Morphological Variability of Okra Ecotypes from a Humid and a Semi-Arid Zone in West Africa

Akpadji A. Rébecca Amaba [1,2,*], Windpouiré V. Tarpaga [2], Rasmata Nana [1], Abdoul Hadi Diaby Kassamba [1] and Rafiatou Sèmata Fofana [2,3]

[1]Plant Ecophysiology Team, Biosciences Laboratory, Doctoral School of Science and Technology, Joseph KI-ZERBO University, 03 BP 7021 Ouagadougou 03, Burkina Faso
[2]Regional Center of Excellence in Fruits and Vegetables (CRE-FL), INERA Farako-bâ, 01 BP 910 Bobo-Dioulasso 01, Burkina Faso
[3]Plant Genetics and Breeding Team, Biosciences Laboratory, Doctoral School of Science and Technology, Joseph KI-ZERBO University, 03 BP 7021 Ouagadougou 03, Burkina Faso
*Corresponding author: rebeccaamaba94@gmail.com

ABSTRACT

Okra (*Abelmoschus esculentus* (L.) Moench), a fruiting legume of the Malvaceae family, is widely cultivated in Africa and Asia for its nutritional and economic value. In Burkina Faso, despite its importance and several studies, the varietal offer registered in the national catalog remains limited to a single improved variety, hindering crop diversification. The aim of this study was to assess the agro-morphological variability of okra ecotypes from two different agro-ecological zones (humid and semi-arid), in order to diversify the range of varieties available in Burkina Faso. An experiment was conducted from June to September 2023 at the Farako Bâ station, Burkina Faso. Forty okra ecotypes (29 from Togo and 11 from Burkina Faso) were evaluated in a randomized complete block design with four replications. The study covered 11 qualitative and 12 quantitative traits. The results revealed considerable variability in the qualitative traits, notably the color and shape of stems, leaves and fruit, as well as great diversity in the quantitative traits measured. Marked phenotypic differences were observed between ecotypes from humid and semi-arid zones. Multivariate analyses, in particular hierarchical ascending classification, enabled the collection to be grouped into four distinct classes, revealing clear patterns of variability. Fifteen ecotypes (BF-13G1-2, BF-11G1-1, BF-1G1-6, TGO-037, TGO-026, TGO-009, TGO-022, TGO-033, TGO-013, TGO-002, TGO-006, TGO-015, TGO-030, TGO-014, TGO-025) stood out for their good agronomic performance, particularly in terms of earliness (average cycle of 59days after sowing) and yield (with an average fruit diameter of 21.56mm, a final stem diameter of 66.63mm, an average number of 7 Fruits harvested per plant and 100 seeds per capsule). These elite ecotypes, combining earliness and productivity traits, represent a promising genetic base for future breeding programs aimed at developing and disseminating new okra varieties adapted to farmers' needs and local conditions.

Keywords: Okra, Agro-morphological, Variability, Yield, BURKINA Faso, Togo.

Article History
Article # 25-231
Received: 02-May-25
Revised: 16-Aug-25
Accepted: 07-Oct-25
Online First: 18-Dec-25

INTRODUCTION

Okra (*Abelmoschus esculentus* (L.) Moench), known as Maana in Mooré (Burkina Faso) or Fétri in Mina (Togo), is a tropical vegetable species belonging to the Malvaceae family. This plant species, which probably originated in Central Africa or South Asia, spread via trade routes to West Africa, India, Middle East and Mediterranean (Vidhi, 2023). Today, the plant is cultivated on all tropical and subtropical continents and considered one of the main vegetable crops in Africa, India and parts of South America. Botanically speaking, okra (*Citrullus lanatus*) is defined as an annual herbaceous plant with an upright habit, reaching heights of between 1 and 2.5 meters (Ogunbor, 2020). This species is characterized by large palmate leaves, solitary pale yellow flowers with purple centers, and elongated capsule- shaped

Cite this Article as: Amaba AAR, Tarpaga WV, Nana R, Kassamba AHD and Fofana RS, 2026. Evaluation of the Agro-morphological variability of okra ecotypes from a humid and a semi-arid zone in West Africa. International Journal of Agriculture and Biosciences 15(2): 727-736. https://doi.org/10.47278/journal.ijab/2025.218

A Publication of Unique Scientific Publishers

fruits with numerous seeds (Swamy, 2023). The seeds can be used to extract edible oil (Anwar et al., 2010) or as a coffee substitute when roasted. The leaves are eaten as leafy vegetables, while the fruits are used fresh, dried or processed as mucilaginous powder, a highly prized ingredient in African cuisine (Petropoulos et al., 2017).

Among okra's notable characteristics are its versatility and adaptability. Its adaptability enables it to grow in a wide range of soil and climate conditions, from humid to semi-arid regions. This adaptability explains its wide geographical distribution. At 2021, global okra production was estimated at over 10 million tonnes, of which around 70% came from Asia, while Nigeria, Mali and Ghana were among the main African producers (FAOSTAT, 2022). This species is of significant agronomic importance, with notable nutritional qualities and easy cultivation, which justifies the growth of scientific research devoted to it, particularly in the context of sustainable agriculture and food sovereignty in sub-Saharan Africa.

From a nutritional point of view, okra is a first-rate food for rural and urban populations in many tropical countries. It is a natural source of soluble dietary fiber, fat-soluble vitamins (A and K) and water-soluble vitamins (B2, B3, B6, B9, C), as well as essential minerals such as calcium, magnesium and potassium (Sami et al., 2013). In addition to its nutritional composition, okra has proven medicinal properties. Analysis of the sample's composition reveals the presence of bioactive compounds, including flavonoids, polyphenols and polysaccharides. These compounds are recognized for their antioxidant, anti-diabetic, anti-inflammatory and cholesterol-lowering properties. As demonstrated by (Woumbo et al., 2022; Kenaw et al., 2023; Ullah et al., 2024) in their respective studies, several in vitro and in vivo investigations have highlighted the ability of the element studied to modulate glycemia, inhibit cellular oxidative stress and regulate blood lipid levels. These physiological effects make it a promising functional food in the fight against chronic non-communicable diseases, notably type 2 diabetes, cardiovascular disease and certain metabolic disorders. In developing countries, where access to health care may be limited, regular consumption of okra could make a significant contribution to improving public health and reducing nutritional inequalities. Therefore, in addition to its gastronomic appeal, okra has considerable health significance for food and nutrition policies in sub-Saharan Africa. Okra plays a fundamental socio-economic role, particularly for small-scale farmers and rural women. In several West African countries, this cultural practice is proving to be a reliable source of income throughout the year, thanks in particular to sales in local or regional markets (Alabi et al., 2023). Indeed, this species is an essential link in food security, acting as a safety net for populations.

Although okra is of strategic importance, the varied diversity officially available remains extremely limited. In Burkina Faso, only one improved variety is listed in the national catalog. This is the result of research carried out by ICRISAT and is currently maintained by INERA (SNS, 2014). This situation is out of step with the needs of growers and consumers, particularly during the cool dry season (November-February), when demand for okra is high but supply insufficient.

The introduction of new varieties adapted to this specific growing season is becoming imperative. These varieties are subject to selective criteria designed to guarantee their earliness, productivity, tolerance to moderate temperatures, and conformity to market requirements in terms of shape, color and shelf life. The wealth of local okra ecotypes represents a major opportunity to meet these challenges. These species are characterized by specific adaptations and remarkable phenotypic diversity (Jemal et al., 2022). In this context, the agro-morphological approach presents itself as a relevant method for exploring this diversity. This approach is characterized by its simplicity of implementation, low cost and alignment with practical field realities. In addition, the use of multivariate statistical tools such as principal component analysis (PCA) and the antagonistic correspondence method (ACM) makes it possible to structure diversity and identify promising genotypes (Gerrano et al., 2018; Jemal et al., 2022). The relevance of this methodological approach is closely linked to the choice of study areas, which include a humid and a semi-arid zone. This duality makes it possible to analyze the adaptation of ecotypes to contrasting climatic contexts, typical of Togo and Burkina Faso, and to identify tolerance traits of interest for varietal selection in the context of climate change. This is the background to the present study, which aims to contribute to the diversification and genetic improvement of okra in West Africa. This approach is based on exploiting the agro-morphological variability of local ecotypes.

(i) Significant variability in morphological, phonological and agronomic traits,

(ii) Adaptation traits specific to local environmental conditions, and

(iii) Selecting potential for short cycles, high vegetative vigour and good yields in the cool dry season.

Within the framework of this research, the specific objectives to be achieved are as follows: Characterize the morpho-agronomic diversity of 40 okra ecotypes collected in humid and semi-arid zones of Burkina Faso and Togo; Identify discriminating characters between these ecotypes using quantitative and qualitative measurements; Structure the observed diversity using multivariate statistical tools; Select the most promising ecotypes for breeding programs adapted to wet-season cultivation. The expected results should help strengthen varietal selection efforts in the region, improve the resilience of market gardening systems in the face of climatic constraints, and enhance the value of local plant genetic resources for more sustainable and inclusive agriculture.

MATERIALS & METHODS

Study Site

The study was carried out at the Farako-Bâ research station, part of the Institut de l'Environnement et de Recherches Agricoles (INERA), located in Bobo-Dioulasso in the south-western region of Burkina Faso (11°11' N, 4°17' W, altitude: 400 m) (Fig. 1). The site studied is located in the northern region of Sudan, characterized by a tropical climate with three distinct seasons: a rainy season from June to October, with an average temperature of 28°C; a cool dry season from November to February, with an average temperature of 25°C; and a hot dry season from March to May, with average temperatures between 40°C and 45°C. The average annual rainfall recorded at the meteorological station shows inter-annual variability in rainfall, with values generally between 900 and 1,100 millimeters. The experimental period of this study took place in 2023. During the specific period concerned, recorded rainfall totalled 194.56 millimetres. It is worth mentioning that the station's average annual rainfall, as observed over the last five years and documented by (Bandaogo et al., 2022) for the 2019-2020 season, varies between 1248 mm and 1282 mm over 63 to 73 rainy days. The soil at the experimental site is predominantly ferralsol, characterized by a silty-clay texture, good drainage and significant water retention capacity. The pH of the sample is slightly acidic, usually between 5.5 and 6.5. It also has a moderate organic matter content.

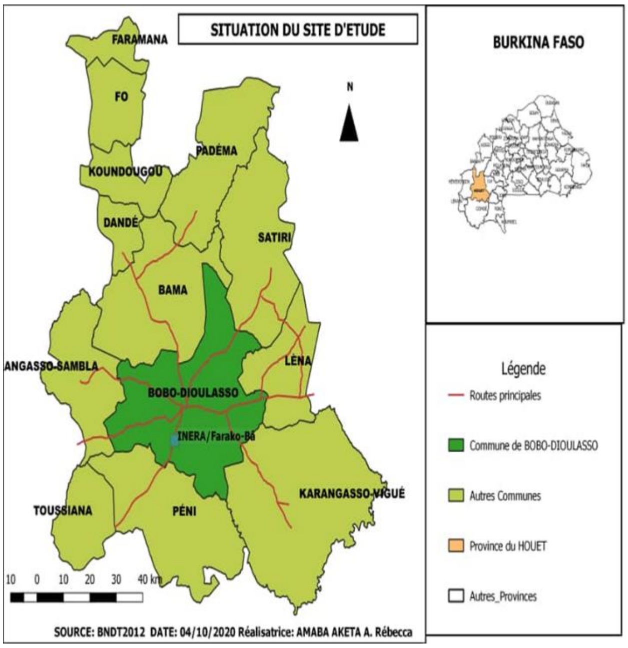


Fig. 1: Geographical location of the study area.

Plant Material

The study involved a sample of forty okra (*Abelmoschus esculentus* (L.) Moench) ecotypes. This collection comprised 39 local ecotypes and one improved variety. As part of a comparative study of agricultural practices in West Africa, a research team conducted a collection of ten local ecotypes in different agroecological zones of Burkina Faso between 2017 and 2018. These ecotypes were collected by the INERA Farako-Bâ breeding team (Table 1). In addition, an in-depth survey conducted with the technical support of the Institut Togolais de Recherche Agronomique (ITRA) in Togo between 2021 and 2023 yielded a further twenty-nine local ecotypes (Table 2). The aim of this study was to analyze the phenotypic diversity of okra grown by local producers in humid and semi-arid climatic zones. In addition, the UAE22 variety, an improved cultivar developed in 2005 through participatory varietal selection by the UFR/SVT of the Joseph KI ZERBO University, was included because of its high yield and adaptability, which is recognized in the region.

Table 1: Okra ecotypes collected in Burkina Faso

Order number	Ecotypes	Villages	Climate zones
1	BF-11G1-1	Bilanga	Sudan-Sahel
2	BF-11G1-2	Bilanga	Sudan-Sahel
3	BF-11G1-6	Bogande	Sudan-Sahel
4	BF-12G1-2	Dendé	Sudanese
5	BF-13G1-2	Lophing	Sudanese
6	BF-1G1	Oulo	Sudan-Sahel
7	BF-1G1-2	Oulo	Sudan-Sahel
8	BF-1G1-3	Oulo	Sudan-Sahel
9	BF-1G1-6	Oulo	Sudan-Sahel
10	BF-24G1-1	Souri	Sudan-Sahel

Table 2: Ecotypes collected with ITRA technical support

Order Number	Ecotypes	Villages	Climate zones
1	TGO- 002	Yalombe	Sudanese-Guinean
2	TGO -006	Kpotome	Guinéen
3	TGO -007	Opime Tomegbe	Guinéen
4	TGO -009	Boade	Sahélien
5	TGO -011	Boade	Sahélien
6	TGO-013	Bagre	Sahélien
7	TGO-014	Bagre	Sahélien
8	TGO-015	Bagre	Sahélien
9	TGO-016	Bagre	Sahélien
10	TGO-020	Kolo	Sahélien
11	TGO-021	Kolo	Sahélien
12	TGO-022	Natchamba	Sahélien
13	TGO-024	Kpankpandja	Sahélien
14	TGO-025	Kpankpandja	Sahélien
15	TGO-026	Tambiegou	Sahélien
16	TGO-027	Tambiegou	Sahélien
17	TGO-029	Tambiegou	Sahélien
18	TGO-030	Mono Nassiegou	Sahélien
19	TGO-031	Mono Nassiegou	Sahélien
20	TGO-032	Mono Nassiegou	Sahélien
21	TGO-033	Bagre	Sahélien
22	TGO-034	Bagre	Sahélien
23	TGO-037	Sagbiebou	Sahélien
24	TGO-038	Sagbiebou	Sahélien
25	TGO-040	Sagbiebou	Sahélien
26	TGO-041	Namon	Sahélien
27	TGO-042	Namon	Sahélien
28	TGO-046	Doufoulli	Sudanese-Guinean
29	TGO-047	Gbadjahé	Guinéen

Experimental Design and Conduct of the Trial

The experiment was conducted using a completely randomized block design (RCBD) with four replicates. Each elementary plot consisted of a single two-meter-long line, corresponding to a specific ecotype. In the experiment, the planting lines were spaced 0.8 meters apart, with five bunches per line, spaced 0.5 meters apart. This configuration made it possible to achieve a planting density of around 25,000 plants per hectare. Prior to sowing, the soil was deeply ploughed with a daba, followed by levelling. In the experiment conducted by Ezeh et al. (2020), 10 tonnes per hectare (10t/ha) of compost at an advanced stage of decomposition was uniformly incorporated into the soil during site preparation. The sowing date was set for June 15, 2023, with direct planting on moist soil. The experiment consisted in sowing three to four seeds per poquet, followed by de-sowing at 15 days after sowing (DAS). This operation was carried out with the aim of retaining only two vigorous seedlings per poquet, thus enabling optimum plant establishment.

Mineral fertilization consisted of a total of 300 kilograms of NPK fertilizer (15-15-15), split into three applications. A first application of 100 kilograms per hectare was made 15 days after emergence, followed by two other identical applications at 30 and 45 days after emergence. This contribution is in line with traditional local practices in Burkina Faso. Weeding was carried out manually with a daba, as required, to maintain a weed-free environment. It should be noted that, during the entire experimental period, a specific treatment against pests and fungal diseases was administered. The fungicide COGA 80WP (Mancozeb 800g/kg) at a dose of 2kg/ha and an insecticide PACHA (Lambda-cyhalothrin 15g/L+Acetamipride 10g/L). The experiment was conducted under rain-fed conditions, with supplementary irrigation applied only in the event of insufficient rainfall during the first two weeks after sowing, to ensure good emergence. Harvesting of tender okra fruits began between the fiftieth and sixtieth days after flowering (DAF), and was carried out manually at regular two-day intervals. This operation involved careful selection of fruits that were soft to the touch, thus ensuring optimum quality for consumption.

Data Collection

Data collection was carried out on the three central plants of each line. Qualitative data were collected from the 60th day after sowing (DAS), using a standardized visual assessment, in accordance with the standards set by the International Plant Genetic Resources Institute (IPGRI) descriptor (Fig. 2) (Biodiversity International, 2007). These data covered the following traits: plant habit (GAS), stem branching (BRA), stem pubescence (STP), fruit pubescence (FPU), stem coloration (STC), leaf coloration (LC), petal coloration (PTC), fruit coloration (FCL), fruit shape (FCL) and leaf shape (LSH).

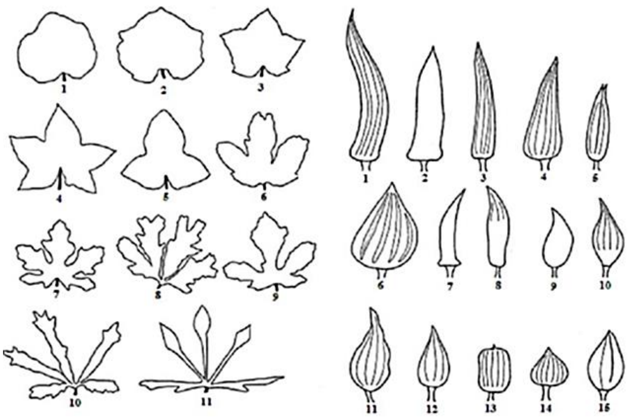


Fig. 2: Shape of okra leaves and fruits.

Quantitative data focused on the agronomic characteristics and yield of the ecotypes. These data were collected using the method established by (Jemal et al., 2022) from the start of flowering. The aim of this study was to measure:

- Plant height at flowering (PHP) and fruiting (HTP) is measured using a height gauge and expressed in meters.
- The time to flower bud formation corresponds to the number of days after sowing (DAS) required for half the plants on each line to appear as a flower bud (NDB).
- The time to flowering corresponds to the number of days after sowing (DAS) required for 50% of the plants on each line to have a flower (NDF).
- Time to fruit corresponds to the period between sowing and the appearance of 50% of edible fruit (NDFr).
- Length of fruit at maturity (FL) is measured with a tape measure. It is expressed in meters.
- Stem diameter at flowering (DTI) and at the end of the cycle (DTF). To do this, we used a caliper, a metric tool that enables us to take precise measurements in millimeters.
- The fruit diameter (FD) is measured with a caliper. This measurement is expressed in millimeters.
- The number of fruits harvested per plant (NFP) was evaluated. This analysis focused on fruit harvested during the first three harvests.
- The number of seeds per dry fruit (NS/F) was determined by systematically counting the seeds after harvesting the dry bolls.
- The thousand-seed weight (WTS) was determined. This measurement was obtained by counting a thousand seeds of each ecotype studied. It was also expressed in grams, using an electronic balance.

Data Processing and Analysis

Data collection was methodically organized and rigorously processed. Microsoft Excel software was used for this purpose, enabling structured and efficient management of the information gathered. Statistical analyses were carried out using R software (version 2024.12.1+563) and its associated packages. As part of this study, an analysis of variance (ANOVA) was conducted to assess significant differences between the forty okra accessions for each quantitative trait. This methodological approach, known as "one-factor analysis of variance", is a rigorous statistical technique for identifying significant variations between groups of individuals or data. When a significant difference was observed ($P<0.05$), a comparison of means was made using Tukey's Honestly Significant Difference (HSD) test. As part of the correlation analysis, Pearson correlation coefficients were determined. This statistical approach made it possible to assess the linear relationships between the various quantitative agro-morphological traits. Analysis of the correlation matrix revealed significant associations ($P<0.05$) between the variables. Within the framework of our study, a Principal Component Analysis (PCA) was carried out on quantitative traits. This methodological approach aims to reduce the dimensionality of the data and identify the main axes of variation between okra accessions. The aim of this analysis was to visualize variable structuring and ecotype distribution patterns in multivariate space. As part of this study, a hierarchical cluster analysis (HCA) was carried out following the principal component analysis (PCA). This analysis was carried out using Ward's method and Euclidean distance, in order to group ecotypes according to their agro-morphological performance. This methodical approach enabled the identification of distinct groups of accessions, based on the analysis of their phenotypic characteristics.

In the present study, a significance level of $P<0.05$ was used for all statistical tests.

RESULTS

Variability among Qualitative Characteristics

This analysis revealed variability among the ecotypes for nearly all of the studied traits (Table 3), especially with regard to plant posture, stem branching, stem color, stem pubescence, leaf color, leaf shape, fruit color, and fruit shape. In contrast, petal color was homogeneous.

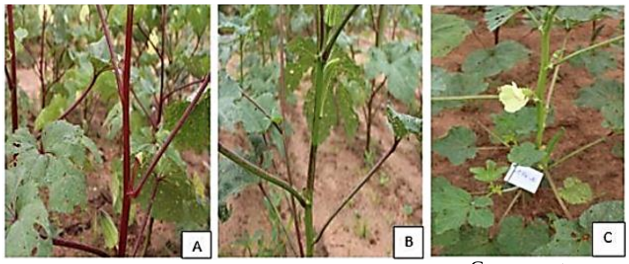
Table 3: Frequency of occurrence of the studied trait modalities

Characters	Modalities	Frequency of occurrence (%)
Plant habit	-erect	95
	-intermediate	5
Stem branching	-moderately branched	80
	-very branched	20
Stem pubescence	- Glabrous	20
	-slightly pubescent	80
Stem staining	-green	50
	-Green with red veining	27.5
	-purple;	22.25
Leaf colouring	-green	27.5
	-green with red rib	72.5
Leaf shape	-simple	40
	-Lobe	27.5
	-Digitaline	32.5
Petal colouring	-cream	100
Fruit colouring	-reddish green	50
	-green	32.5
	-red	17.5
Fruit pubescent	-Duvet	10
	-slightly rough	70
	-Pungent	20
Fruit shape	-flûte	10
	-Filiforme	60
	-conical	17.5
	-trapue	7.5
Position of the fruit on the main stem	- erect	75
	-horizontal	25

In terms of stem colour, green stems were predominant (50%) (Fig. 3C), followed by stems with green and red veins (27.5%) (Fig. 3B) and finally fully purple stems (22.2%) (Fig. 3A). As for leaf colour, most leaves were green with red veins (72.5%) (Fig. 4B), followed by fully green leaves (27.5%) (Fig. 4A). Analysis of qualitative traits revealed three fruit colors: green with red patches, green and red. Reddish green was the most common colour, accounting for 50% of the ecotypes, followed by green (32.5%). Red was less frequent, but still observed in 17.5% of the ecotypes. In terms of fruit shape, significant variability was noted. The most predominant were filiform fruit, representing 60% of the ecotypes (Fig. 5B), followed by short, conical fruits 17.5%, (Fig. 5D), long, fluted fruits 10%, (Fig. 5A), and short, trapue fruits 7.5%, (Fig. 5C). Variability was also observed among the ecotypes regarding stem and fruit pubescence. Stems were either slightly pubescent (80%) or glabrous (20%). Regarding the fruits, most were pungent (20%), while others were slightly pubescent (70%). Most of the observed stems were erect (95%).

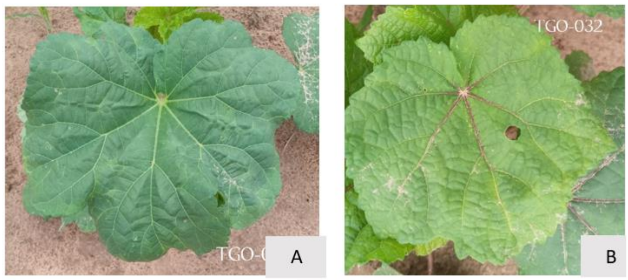
Variability of Quantitative Characteristics Studied

The results of the analysis of cycle traits revealed that, on average, the ecotypes reached 50% bud formation at 52±9.7 days after sowing (DAS), 50% flowering at 62±12.4DAS, and 50% fruiting at 55±12.8DAS. The ecotype cycles ranged from 48 to 106 DAS. The ecotypes BF-1G1-6 (47DAS) and TGO-009 (48DAS) exhibited the shortest cycles. Regarding yield traits, the descriptive analysis revealed average fruit diameter and length values of 19.53±20.2mm and 12.39±5cm, respectively. The largest fruit diameter was observed in ecotype TGO-013 (31.86mm), the longest fruit length in ecotype BF-24G1-1 (20.99cm), the highest number of fruits in ecotype TGO-038 (14), the highest number of seeds per capsule in ecotype BF-11G16-1 (150) and the highest thousand-seed weight in ecotype TGO-029 (67.18g). Regarding growth traits, the average plant height was 92.93±34.6cm and the stem diameter averaged 51.89±20.2 mm. Ecotype TGO-014 stood out due to its height (145cm), while écotype BF-13G1-2 had the largest stem diameter (25.27mm).



A : purple stem B: green stem with red veins C : green stem

Fig. 3: Stem color variability of the ecotypes studied.



A : green leaf B: green leaf with red veins

Fig. 4: Variability of leaf color in the ecotypes studied.

A : slender greenish red-fruit B : slender green fruit C : grooved greenish-red fruit D : conial greenish red fruit

Fig. 5: Variability in the color and shape of the fruits of the okra ecotypes studied.

Analysis of variance (Table 4) revealed that there were no significant differences between ecotypes at the 5% threshold for initial stem diameter (DTI) (P=0.663), number of fruits per plant (NFP) (P=0.089) and number of seeds per fruit (NS/F) (P=0.147). However, differences between ecotypes for traits such as number of days to bud formation (NDB), number of days to flowering (NDF), number of days to fruiting (NDFr), plant height at flowering (PHP), total plant height (HTP), final stem diameter (DTF), fruit diameter (FD) and length (FL), and thousand-seed weight (WTS) were significant or highly significant (P=0.001). This reflects the variability of these traits within the studied ecotypes.

Except for the thousand-seed weight trait, which had an R^2 value of 99.9% or higher, the determination coefficient (R^2) was 22.9% or higher for other traits. The high coefficients of variation (CVs) for certain traits, such as initial stem diameter (CV=51.6%) and number of fruits per plant (CV=53.9%), indicate strong variation among ecotypes for these traits. Among the fruit-related variables, the number of seeds per capsule (CV=22.7%) and thousand-seed weight (CV=21.3%) had CVs below 50%, suggesting lower heterogeneity among ecotypes for these traits.

Table 4: Analysis of variance of quantitative characteristics measured

Variables	Min	Max	Avg	CV	R^2 %	P-value
NDB(days)	45	102	52.96±9.7	18.3	73.2	0.001
NDF(days)	48	106	62.94±12.4	19.7	99.8	0.001
NDFr(days)	51	109	65.82±12.8	19.5	99.8	0.001
PHF(cm)	12	103	47.95±19.1	40.7	45.1	0.001
HT(cm)	28	175	92.93±34.6	37.2	64.3	0.001
DTI(mm)	4.14	66	12.89±6.6	51.6	22.9	0.663
DTF(mm)	17.53	177	51.89±20.2	38.9	54.6	0.001
NFP	0	14	6.79±3.6	53,9	31.9	0.089
FD(mm)	0	39.86	19.53±7	35.8	66	0.001
FL(cm)	0	36.43	12.39±5	40.5	67.4	0.001
NS/F	39	150	97.62±22.2	22.7	30.3	0.147
WTS(g)	19	67.18	41.50±8.85	21. 3	99.9	0.001

***Legend**: Minimum (Min); Maximum (Max); Mean (Avg); Standard deviation (SD); Coefficient of variation (CV); Number of days to budding (NDB); Number of days to flowering (NDF); Number of days to fruiting (NDFr); Plant height at flowering (PHF); Total plant height (HTP); Initial stem diameter (DTI); Final stem diameter (DTF); Total number of fruits per plant (NFP); number of seeds per fruit (NS/F); Fruit diameter (FD); Fruit length (FL); Thousand seed weight (WTS).*

Structuring the Agro-morphological Variability of the Okra Ecotypes Studied

Relationships between Characters

Analysis of Pearson's correlation coefficients revealed several significant relationships among the quantitative traits evaluated in okra (Fig. 6).

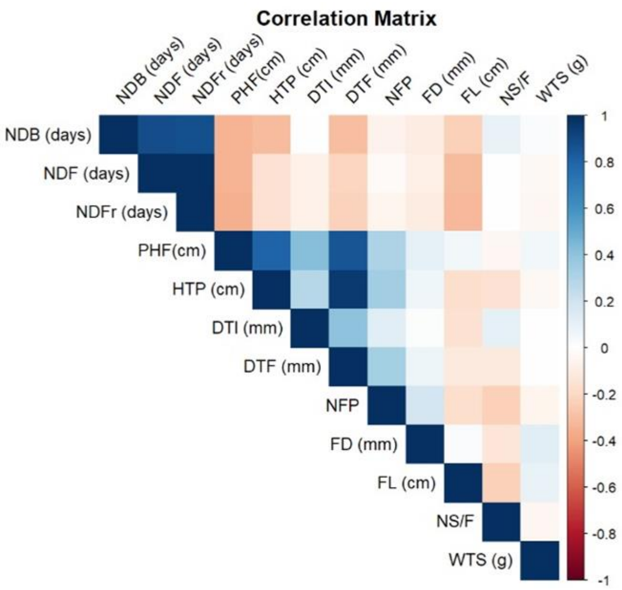


Fig. 6: Correlation matrix for the various quantitative characteristics studied

***Legend 1**: Blue indicates a positive correlation, while red indicates a negative correlation. The intensity of the color is proportional to the strength of the correlation (the darker the color, the stronger the correlation). The statistical significance of the correlations is discussed in the results section.*

***Legend 2:** Number of days to budding (NDB); Number of days to flowering (NDF); Number of days to fruiting (NDFr); Plant height at flowering (PHF); Total plant height (HTP); Initial stem diameter (DTI); Final stem diameter (DTF); Total number of fruits per plant (NFP); number of seeds per fruit (NS/F); Fruit diameter (FD); Fruit length (FL); Thousand seed weight (WTS).*

Phenological traits exhibited very strong, highly significant positive correlations (P<0.001), particularly between the number of days to budding (NDB), flowering (NDF), and fruiting (NDFr) (r ≥ 0.88). These associations reflect the sequential nature of these developmental stages. Growth-related traits also exhibited strong positive correlations. Plant height at flowering (PHF) was positively associated with total plant height (HTP) (r=0.80) and final stem diameter (DTF) (r=0.86); the latter was highly correlated with total plant height (r=0.95). These results suggest that more vigorous plants tend to develop thicker stems. Moderate correlations were observed between initial and final stem diameters (r=0.41; P<0.01), indicating consistent stem growth. In contrast, moderate negative correlations were observed between plant height at flowering and phenological traits (r=-0.35), suggesting that more vigorous ecotypes tend to flower earlier. Similarly, early flowering and fruiting were moderately associated with longer fruits (r=-0.32; P<0.05). There were weak but significant correlations between plant vigor (HTP, DTF) and fruit production (NFP) (r=0.34; P<0.05), indicating a modest influence of vegetative growth on fruit yield. Finally, several traits, particularly thousand seed weight (WTS), showed weak, non-significant correlations with most other variables, suggesting that seed weight is relatively independent of growth and yield traits.

Phenotypic Variability between the Studied Ecotypes.

Principal component analysis (PCA) shows that the total inertia of three axes explains 80.97% of the variability (Fig. 7). In plane 1-2, the first axis (with 47.3% inertia) revealed a strong association between total plant height (HTP) and final stem diameter (DTF). The second axis, with an inertia of 27.5%, is associated with days to budding (NDB), flowering (NDF), and fruiting (NDFr). The third axis, with an inertia of 11.82%, is related to the number of fruits per plant (NS/F) and initial stem diameter (DTI). Therefore, axes 1 and 3 relate to the size of the plants' vegetative organs, and axis 2 relates to the plant life cycle.

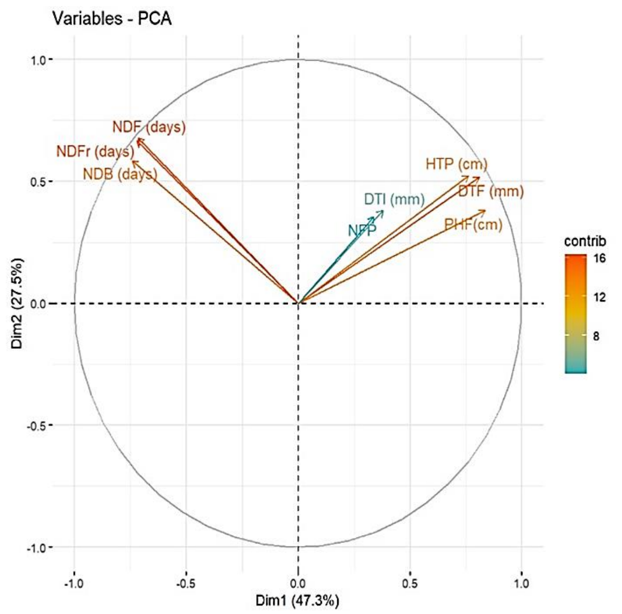


Fig. 7: Projection of measured variables in the plane formed by the first two axes.

***Legend:** Number of days to budding (NDB); Number of days to flowering (NDF); Number of days to fruiting (NDFr); Plant height at flowering (PHF); Total plant height (HTP); Initial stem diameter (DTI); Final stem diameter (DTF); Total number of fruits per plant (NFP); number of seeds per fruit (NS/F); Fruit diameter (FD); Fruit length (FL); Thousand seed weight (WTS).*

Table 5: Average values of variables by class

Cluster	N° Écotypes	NDB (days)	NDF (days)	NDFr (days)	PHF (cm)	HTP(cm)	DTI(mm)	DTF(mm)	NFP	FD(mm)	FL(cm)	NS/F	WTS(g)
1	15	50	59	61	61.12	119.07	14.68	66.63	7	21.56	11.56	100	41.26
2	14	53	67	70	37.74	80.22	12.17	43.38	6	19.31	10.72	96	39.81
3	2	84	99	102	31.68	48.64	12.56	30.96	4	18.07	9.18	108	39.82
4	9	49	54	57	45.50	78.98	11.12	45.20	6	16.80	17.07	94	44.88

***Légende:** Number of days to budding (NDB); Number of days to flowering (NDF); Number of days to fruiting (NDFr); Plant height at flowering (PHF); Total plant height (HTP); Initial stem diameter (DTI); Final stem diameter (DTF); Total number of fruits per plant (NFP); number of seeds per fruit (NS/F); Fruit diameter (FD); Fruit length (FL); Thousand seed weight (WTS)*

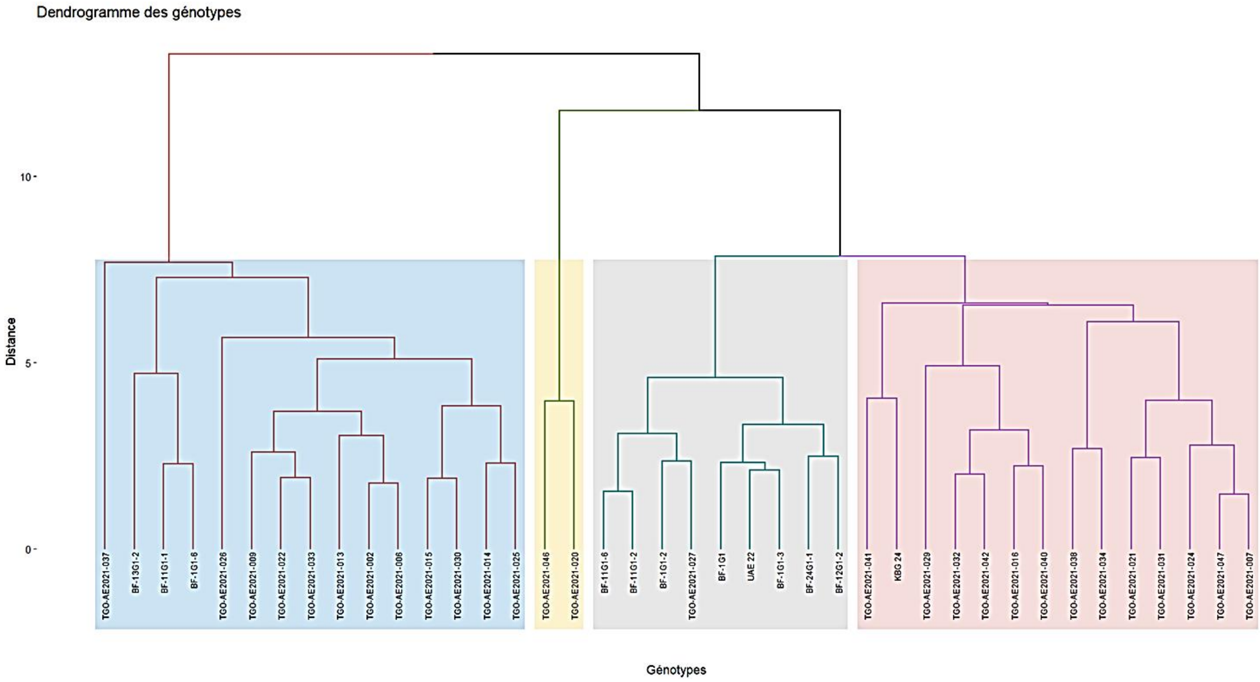


Fig. 8: Dendrogramme resulting from the hierarchical ascending classification of the 40 ecotypes on the basis of dissimilarity.

Structuring Ecotype Variability

The Hierarchical Ascending Classification (HAC) analysis, performed based on the studied quantitative traits, revealed four distinct classes (Fig. 8). Class 1 comprises 15 ecotypes characterized by an intermediate cycle (59 days after sowing [DAS]), plant height (119.07cm), final stem diameter (66.63mm), and fruit diameter (21.56mm). This class also has an average of seven harvested fruits and 100 seeds per capsule. These averages are higher than those of the other three classes. Class 2 comprises 14 ecotypes characterized by intermediate values across all studied traits, positioning this group as phenotypically intermediate compared to the other classes. Class 3 consists of two ecotypes characterized by late cycles (99DAS). These ecotypes have lower plant height (48.64cm), total stem diameter (30.96mm), and number of harvested fruits (7) than the other classes. Finally, class 4 comprises nine ecotypes characterized by a short cycle (54DAS), long fruits (17.07cm), and seeds with high weight (44.88g) (Table 5).

DISCUSSION

This study revealed significant agronomic and morphological variability among the forty okra (Abelmoschus esculentus (L.) Moench) ecotypes analyzed. This diversity was observed in qualitative traits, such as color and shape, and quantitative traits, such as growth and yield, reflecting a wide genetic heterogeneity within the studied plant material. Carefully collected from various agroecological zones in West Africa, particularly in Burkina Faso and Togo, these ecotypes exhibit diverse shapes, colors, and leaf and fruit structures. This diversity is not coincidental but rather the result of centuries of adaptation to different environments and the development of specific agricultural practices by farming communities. This diversity is a valuable asset for breeding programs because it provides a variety of traits that can be used to create new varieties. This enables the development of future crops that can withstand climate challenges and meet increasing food demands (Temam et al., 2020; Syfullah et al., 2025). Exploring this genetic wealth is particularly relevant, as the analysis of the okra's genome architecture (Nieuwenhuis et al., 2024) has deepened our understanding of its genetic diversity. This highlights the importance of this variance for adaptation and targeted cultivar selection. This genomic insight validates and enriches the phenotypic approach adopted in our study.

The variability observed in pubescent traits and stem branching highlights the remarkable genetic potential of these ecotypes. These traits are often under polygenic control, meaning multiple genes interact to determine their expression. Therefore, they are relevant indicators of environmental adaptation and the selection exerted by farmers over generations. For instance, the presence or absence of pubescence on plant organs is not merely a morphological curiosity; it can play a pivotal role in a plant's resistance to pests and diseases or tolerance of water stress by reducing transpiration. A recent study showed that pubescence-related traits directly affect insect resistance and ease of harvesting. Therefore, identifying and selecting ecotypes with low pubescence or an erect, less branched growth habit could offer significant agronomic benefits, particularly in confined spaces where crop protection and labor efficiency are critical. The work of (Osekita & Atimokhale, 2024), which confirms the vast genetic variability of okra, as well as the work of Khalid et al. (2018) on morphological changes during maturation, reinforces our understanding of the species' complexity and phenotypic plasticity. This knowledge is essential for the responsible use of okra genetic resources.

The agronomic performance observed in this study is promising overall, demonstrating the productive potential of the evaluated ecotypes. Plant heights of up to 175cm, stem diameters of over 17mm, and fruit lengths of more than 35cm are significant indicators of remarkable vegetative vigor and promising production capacity. These characteristics are crucial for ensuring food security for populations. Bereded et al. (2023) confirmed that these morphological parameters are strongly correlated with yield performance, particularly under optimized cultivation conditions. This underscores the importance of robust growth for abundant fruit production. In their evaluation of okra genotypes in Ethiopia, Bereded et al. (2023) demonstrated that vigorous plants exhibit robust architecture and superior photosynthetic efficiency, resulting in a higher number of fruits and seeds. These results align with those of other recent studies (Yadav et al., 2024) that explore ways to optimize okra growth performance and examine genetic variability in yield traits. These results confirm that our observations align with the general trend that vegetative vigor is a key predictor of productivity. The averages obtained in our study are encouraging indicators of the potential of these ecotypes for producing fresh fruit and seeds, which are vital elements for the local economy and nutrition. For instance, the average number of fruits per plant was 14, and the average number of seeds per fruit was 150. The analysis of variance (ANOVA) revealed highly significant differences ($P<0.001$) between ecotypes for all measured quantitative traits. This finding is not merely statistical; it aligns perfectly with (Al-Juboori et al., 2021) results, who also identified significant phenotypic differences in okra populations evaluated under similar semi-arid conditions. This inter-ecotype variability is not an obstacle; rather, it is an essential foundation for genetic selection programs. It allows breeders to identify, characterize, and conserve high-performing genotypes, providing them with the necessary raw materials to develop more productive and better-adapted varieties. Genetic diversity is indeed the cornerstone of the sustainability of seed systems and the resilience of agricultural systems in the face of increasingly frequent and intense climatic hazards (Osekita & Atimokhale, 2024). These significant differences confirm okra's capacity to adapt and evolve, presenting a tremendous opportunity for agricultural development in the region. (Temam et al., 2020) also support this idea, emphasizing the importance of genetic variability in improving okra yield continuously.

Correlation analyses of the measured traits revealed valuable, interesting relationships that proved to be useful for indirect selection in varietal improvement (Zafar et al., 2024; Singh et al., 2025; Shaban et al., 2025; Zafar et al., 2025). For example, a significant positive correlation was observed between plant height, stem diameter, and the number of fruits per plant. Total plant height (HTP) exhibited a strong positive correlation with final stem diameter (DTF) ($r=0.95$, $P<0.001$) and was also significantly correlated with number of fruits per plant (NFP) ($r=0.35$, $P=0.0280$). These results align closely with those of (Yadav et al., 2024), who also emphasized the importance of these correlations in predicting overall yield. A plant with a thick, tall stem is larger and offers greater mechanical stability in windy conditions. It also has increased leaf area for photosynthesis and a greater capacity to support a larger number of fruits, thereby enhancing yield potential. Therefore, selecting for better vegetative vigor can directly translate into better fruit productivity, a key criterion for farmers. Similarly, (Al-Juboori et al., 2021) work, which used correlation analysis to evaluate okra yield, reinforces the validity of our observations on these key relationships.

Another notable point of great agronomic relevance is the negative correlation observed between fruit length and precocity, as expressed by the number of days to flowering and fruiting. Specifically, a moderate and significant negative correlation was noted between fruit length (FL) and the number of days to flowering (NDF) and fruiting (NDF) ($r=-0.32$, $P=0.0445$ and 0.0423, respectively). This suggests that more precocious ecotypes tend to produce longer fruits. This relationship is advantageous for off-season agriculture and in regions with limited water availability or a short growing season. Earliness enables farmers to avoid end-of-cycle droughts, achieve multiple harvests per year, and engage in more complex crop rotations. (Temam et al., 2020) also confirmed this phenomenon in trials conducted in Ethiopia, observing an inverse relationship between earliness and fruit size. These results reinforce the idea that it is possible to identify and select early and productive genotypes adapted to local agroclimatic constraints, thus offering increased flexibility to production systems (Arshad et al., 2024; Hamza et al., 2024).

Hierarchical ascending classification (HAC) analysis is a powerful tool for simplifying complex data and grouping ecotypes into four distinct phenotypic classes. This facilitates targeted selection and germplasm management (Firdous et al., 2025). The first group, characterized by large ecotypes that produce high yields of fruit and seeds, has particular potential for intensive production systems and food security. These ecotypes could be ideal for developing new, high-yielding commercial varieties capable of feeding more people. In contrast, the fourth group comprises ecotypes that demonstrate remarkable precocity with notably long pods and high thousand-seed weight. These ecotypes are of particular interest for short-cycle production systems. These are crucial in areas with short rainy seasons or for intercropping. Identifying these groups based on specific combinations of agronomic, morphological, and phenological traits gives breeders an invaluable roadmap for guiding crosses within participatory breeding programs (Syfullah et al., 2025).

Furthermore, the differences and complementarities among these phenotypic groups offer practical and strategic insights into hybridization strategies. For example, judicious crossbreeding between contrasting ecotypes such as an early ecotype from Group 4 and a high-yield ecotype from Group 1 could combine earliness with high yield potential. This could promote the development of hybrid or synthetic varieties adapted to different agroecological niches that meet the diverse needs of farmers and markets. This innovative approach is already being used successfully with other crops and could effectively be adapted to okra in the Sudanian-Sahelian zones, where resilience and productivity are major challenges. Recent advances in our understanding of okra genome architecture (Nieuwenhuis et al., 2024) open up pathways for more precise selection, potentially assisted by molecular markers, which could accelerate the improvement process. Finally, the results of this study confirm the central and irreplaceable role local genetic resources play in ensuring food security and agricultural resilience in West Africa. By revealing the underutilized potential of okra ecotypes collected in Burkina Faso and Togo, the study underscores the importance of in situ conservation and promoting peasant diversity. This diversity represents genetic capital accumulated over generations that is adapted to local conditions and often resistant to specific stresses. This research combines rigorous agromorphological analysis with robust statistical tools to offer concrete and promising avenues for developing okra varieties that are more resilient to climate change and better suited to off-season cultivation requirements. These improvements will directly contribute to enhancing farmers' livelihoods and regional food security.

Conclusion

The present study involved the rigorous evaluation and in-depth characterization of 40 okra (Abelmoschus esculentus (L.) Moench) ecotypes from humid and semi-arid regions. The study was conducted during the rainy season in Burkina Faso. Using a robust approach that integrated qualitative and quantitative traits, our analyses revealed remarkable agromorphological variability within this germplasm. Multivariate analyses, particularly analysis of variance, revealed significant heterogeneity in quantitative traits, emphasizing the ecotypes genetic potential. Furthermore, hierarchical cluster analysis organized this variability into four distinct groups, providing a clearer picture of phenotypic profiles and ecological adaptations. These analyses also revealed meaningful correlations among the studied traits, providing valuable insights for indirect selection and optimizing breeding strategies. Fifteen ecotypes (BF-13G1-2, BF-11G1-1, BF-1G1-6, TGO-037, TGO-026, TGO-009, TGO-022, TGO-033, TGO-013, TGO-002, TGO-006, TGO-015, TGO-030, TGO-014, and TGO-025) exhibited promising yield performance. Identified as elite, these ecotypes represent a valuable genetic resource for future breeding programs. In summary, this research's findings demonstrate the intrinsic value and practical potential of diversity, which extends beyond mere documentation. The findings emphasize the critical importance of in situ conservation and the utilization of farmer-managed genetic resources as a foundational pillar for food security and the resilience of West African farming systems in the face of current and future climate challenges. The elite ecotypes identified in this study could provide a solid genetic foundation for breeding programs focused on developing high-performing okra varieties for off-season cultivation. This would enhance farmers' livelihoods in a sustainable manner.

DECLARATIONS

Funding: The Food System Resilience Program (FSRP), through the World Bank, funded the work presented in this report as part of the West and Central African Council for Agricultural Research and Development's (CORAF) 2023 strategic plan implementation. CORAF was responsible for fund administration and project implementation.

Acknowledgement: The Togolese ecotypes of plant material were obtained through a collection and prospecting mission carried out with the technical support of the Togolese Institute of Agricultural Research (ITRA). The experiment was conducted at the Farako-Bâ research station under the authority of the Regional Directorate of Environmental and Agricultural Research for the West (INERA). The Breeding Team at the Regional Center of Excellence in Fruits and Vegetables (CRE-FL), which is based at the INERA Farako-Bâ station, also contributed to the success of the trials. We would also like to thank the members of the BioSciences Laboratory's Plant Ecophysiology Team at Joseph KI-ZERBO University for their scientific support.

Conflict of Interest: The authors declare no conflict of interest.

Data Availability: Data will be made available upon request.

Ethics Statement: As no live animals were involved in the study, no ethical approval statement is required.

Author’s Contribution: Rébecca Akpadji Akéta AMABA: Conceptualization, methodology, software, formal analysis, data storage, original writing, and project preparation. Vianney Windpouiré TARPAGA: conceptualization, writing, editing, and supervision. Rasmata Nana: supervision, copyediting, and editing. Abdoul Hadi Diaby Kassamba: methodology, software, formal analysis, and proofreading. Rafiatou Sèmata FOFANA: Methodology.

Generative AI Statement: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

Publisher’s Note: All claims stated in this article are exclusively those of the authors and do not necessarily represent those of their affiliated organizations or those of the publisher, the editors, and the reviewers. Any product that may be evaluated/assessed in this article or claimed by its manufacturer is not guaranteed or endorsed by the publisher/editors.

REFERENCES

Alabi, O.O., Ihegwuagu, N.E., Isah, H., Abiloro, A.C., Simpa, O.J., Haruna, O.E., & Aluwong, J.S. (2023). Economic efficiency of smallholder okra (*Abelmoschus* species) production in Kaduna State, Nigeria: Implication for poverty alleviation. *International Journal of Agriculture, Environment and Food Sciences*, 7(4), 853-863. https://doi.org/10.31015/jaefs.2023.4.16

Al-Juboori, A.W.A. (2021). Evaluation yield of okra with associated traits using analysis corrélation and path. *IOP Conference Series: Earth and Environmental Science*, 761(1), 012036. https://doi.org/10.1088/1755-1315/761/1/012036

Anwar, R., Rashid, U., Ashraf, M., & Nadeem, M. (2010). Okra (Hibiscus esculentus) seed oil for biodiesel production. *Applied Energy*, 87(3), 779-785. https://doi.org/10.1016/j.apenergy.2009.09.020

Arshad Khan, M.A., Hazrat, A., & Shakir, M. (2024). Effect of Salt Stress on the Morphological Attributes of Common Bean. *Trends in Animal and Plant Sciences,* 4, 14-20. https://doi.org/10.62324/TAPS/2024.042

Bandaogo, A.A., Traoré, A., Savadogo, O.M., Saba, F., Ouédraogo, A.L., Sako, Y., Sermé, I., & Ouédraogo, S. (2022). Optimizing Tomato (*Solanum lycopersicum* L.) Growth with Different Combinations of Organo-Mineral Fertilizers. *Frontiers in Sustainable Food Systems*, 5, 694628. https://doi.org/10.3389/fsufs.2021.694628

Bereded, M., Mohammed, W., Woldetsadik, K., & Atinku, E. (2023). Fruit yield and yield-related traits of okra [Abelmoschus esculentus (L.) Moench] génotypes as influenced by different seed priming techniques in Dire Dawa, Ethiopia. *Heliyon*, 9(7), e17830. https://doi.org/10.1016/j.heliyon.2023.e17830

Ezeh, O., & Adejumo, S.A., (2020). Ameliorative roles of compost on okra (*Abelmoschus esculentus* L.) exposed to drought stress at vegetative and reproductive growth stages. *Notulae Scientia Biologicae,* 12, 884-900. https://doi.org/10.15835/nsb12410651

FAOSTAT (2022). FAO database. Food and Agriculture Organization of the United Nations, Genève. https://www.fao.org/faostat/fr/#data/QCL (Vew Mai 24 th, 2025).

Firdous, H., Habib, A., Abbas, H., & Jamil, M.A. (2025). *Genetic assessment of elite cotton genotypes for Cotton Leaf Curl Virus Disease (CLCuD) through multivariate analysis. Agrobiological Records, 21, 67-77.* https://doi.org/10.47278/journal.abr/2025.034

Gerrano, A.S. (2018). Agronomic performance, nutritional phenotyping and trait associations of okra [*Abelmoschus esculentus* (L.) Moench] génotypes in South Africa. In: *Rediscovery of Landraces as a Resource for the Future*. IntechOpen. https://doi.org/10.5772/intechopen.70813

Hamza, M., Hamza, U., Shaheen, N., & Hayat, H.M. (2024). Multivariate Analysis for Evaluation of Morphological Diversity in Pisum sativum L. *Trends in Animal and Plant Sciences*, 3, 1-9. https://doi.org/10.62324/TAPS/2024.021

Jemal, M., Wassu, M., & Shiferaw, E. (2022). Performance and Genetic Variability of Okra (*Abelmoschus esculentus* (L.) Moench) Genotypes in Ethiopia for Agromorphology and Biochemical Traits. *Advances in Agriculture*, 20, 5521151. https://doi.org/10.1155/2022/5521151

Kenaw, W., Mohammed, W., & Woldetsadik, K. (2023). Morpho-agronomic variability of okra [Abelmoschus esculentus (L.) Moench] genotypes in Dire Dawa, eastern Ethiopia. *Plos one*, *18*(7), e0288534.

Khalid S.M., Nasir H.S., Saifullah O.N., Sohely PM., Mahasab H.R., Mohammad Saiful Islam, & Sarowar H., (2018). Genetic Variability, Heritability, Character Association and Morphological Diversity in Okra (*Abelmoschus Esculentus* L. Moench). *International Journal of Plant & Soil Science* 25 (6), 1–11. https://doi.org/10.9734/IJPSS/2018/45828

Nieuwenhuis, R., Hesselink, T., Van den Broeck, H. C., Cordewener, J., Schijlen, E., Bakker, L., Diaz Trivino, S., Struss, D., de Hoop, S.-J., de Jong, H., & Peters, S.A. (2024). Genome architecture and genetic diversity of allopolyploid okra (*Abelmoschus esculentus*). *The Plant Journal*, 117(3), 456–472. https://doi.org/10.1111/tpj.16602

Ogunbor, G. (2020). Okra: origine, classification, uses, Pest, Disease. Itsmyschoollibrary. https://itsmyschoollibrary.com/2020/02/02/okra-origin-classification-uses-pest-diease/ (Vew Mai 24 th, 2025).

Osekita, O.S., & Atimokhale, D. (2024). Genetic Diversity Studies for the Assessment of Variability on Okra (*Abelmoschus esculentus*). *International Journal of Science Letters*, 6(2), 1-14. https://doi.org/10.57969/ijsl.v6i2.753

Petropoulos, S., Fernandes, A., Barros, L., Ciric, A., Sokovic, M., & Ferreira, I.C.F.R. (2017). The Chemical Composition, Nutritional Value and Antimicrobial Properties of *Abelmoschus esculentus* Seeds. *Food and Function*, 8, 4733-4743. https://doi.org/10.1039/C7FO01446E

Sami, R., Lianzhou, J., Yang, L., & Jing, J. (2013). Evaluation of fatty acid and amino acid compositions in okra (*Abelmoschus esculentus*) grown in different geographical locations. *BioMed Research International*, 2013, 574283. https://doi.org/10.1155/2013/574283

Shaban, M.U.R., Rubbani, M.S., Saleem, M., Khawar, Z., & Ul, Z. (2025). Comparative Morphological Responses of Maize Genotypes at the 3-leaf Stage to Drought and Salinity Stress. *Trends in Animal and Plant Sciences*, 5, 85-97. https://doi.org/10.62324/TAPS/2025.068

Singh, R. K., Dwivedi, S. V., Kumar, M., Priyadarsini, S., & Singh, S. (2025). Genetic variability studies based on agro-morphological and quality traits in Indian garlic clones under the Bundelkhand region. *New Zealand Journal of Crop and Horticultural Science*, 53(5), 2285-2302. https://doi.org/10.1080/01140671.2025.2461525

Swamy, K.R.M. (2023). Origin, distribution, taxonomy, botanical description, cytogenetics, genetic diversity and breeding of okra (*Abelmoschus esculentus* (L.) Moench.). *International Journal of Development Research,* 13(03), 62026-62046. https://doi.org/10.37118/ijdr.26440.03.2023

Syfullah, K., Islam, M.S., J'ahan, N., Haque, M.I., & Manik, M.M.H. (2025). Exploring genetic diversity and variation in okra (*Abelmoschus esculentus* L. Moench: A comprehensive study on cultivars. *Asian Journal of Research in Crop Science*, 10(1), 37–43. https://doi.org/10.9734/ajrcs/2025/v10i1330

Temam, N., Mohamed, W., & Aklilu, S. (2020). Agro-morphological characterization and evaluation of okra [*Abelmoschus esculentus* (L.) Moench] génotypes for yield and other variability components at Melkassa, Central Ethiopia. *MOJ Ecology & Environmental Sciences*, 5(2), 80–87. https://doi.org/10.15406/mojes.2020.05.00179

Ullah, H., Hayat, J., Tour, A., Ahmad, B., Nawaz, T., Khan, I., Ahmad, K., Rehman, A.U., Murshed, A., Abduh, L., Jun, A., Ali, A., Azizullah, A., Rehman, S.U., Abdel-Maksoud, M.A., Ebaid, H., & Zaky, M.Y. (2024). Phytochemical Profiling and Therapeutic Potential of Abelmoschus esculentus Fruit Extracts: Insights Into Antidiabetic Potential in In Vitro and In Vivo Experiments. *Journal of Food Quality*, 24, 7096736,. https://doi.org/10.1155/2024/7096736

Vidhi, J. (2023). Okra: Origin, Inheritance and Varieties India. BiologyDiscussion. https://www.biologydiscussion.com/vegetable-breeding/okra (View May 24th 2025).

Woumbo, C.Y., Kuate, D., Metue Tamo, D.G., & Womeni, H.M. (2022). Antioxidant and antidiabetic activities of a polyphenol rich extract obtained from *Abelmoschus esculentus* (okra) seeds using optimized conditions in microwave-assisted extraction (MAE). *Frontiers in Nutrition*, 9, 1030385. https://doi.org/10.3389/fnut.2022.1030385

Yadav, Y.S., Kaur, H., & Korake, S.R. (2024). Analysis of genetic variability and correlation studies on fruit yield and its component characters in okra (*Abelmoschus esculentus* L.). *Journal of Scientific Research and Reports*, 30(8), 977–986. https://doi.org/10.9734/jsrr/2024/v30i82319

Zafar, M.M., Ijaz, A., Anwar, Z., Iqbal, M.S., Zafar, S., Subhan, M., & Jiang, X. (2024). Harnessing genetic diversity in cotton for enhanced resilience against salt stress by using agro-physiological characters. *Plant Production Science*, *28*(1), 51–68. https://doi.org/10.1080/1343943X.2024.2439874

Zafar, M.M., Razzaq, A., Anwar, Z., Ijaz, A., Zahid, M., Iqbal, M.M., Farid, G., Seleiman, M.F., Zaman, R., Rauf, A., & Xuefei, J. (2025). Enhancing salt tolerance and yield potential in cotton: insights from physiological responses, genetic variability, and heterosis. *Turkish Journal of Agriculture and Forestry*, *49*(1), 110–124. https://doi.org/10.55730/1300-011x.3252