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Phenotypic diversity and performance of agro-nutritional characters in okra germplasm collection from Nigeria

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Abstract
Phenotypic characterization of 29 okra accessions kept in the National Horticultural Research Institute gene bank was done along with a local check variety. The study assessed the magnitude of variability in the agronomic traits, nutritional and physicochemical properties of okra accessions. The experiment was carried out at the Teaching and Research Farm of Ladoke Akintola University of Technology, Ogbomoso, in the derived savanna agro-ecology of Nigeriain a 6×5 alpha lattice designs replicated three times. The analysis of variance showed highly significant (P< 0.001) differences for 22 characters, and the results confirms the okra accessions as potential source of nutrients. Fruit weight per plot ranged from 27.2 g to 1893.1 g and showed a positive significant correlation with leaf length (r = 0.47), leaf width (r = 0.48), fruit width (r = 0.26), and number of fruits per plant (r = 0.62). Principal component analysis showed that the first nine components had eigenvalues >1 and explained 81.73 % of the total variation among the okra accessions. Cluster analysis grouped the accessions into three major clusters. The phenotypic diversity observed in this study may be exploited in the selection of parental lines for hybridization when breeding okra for yield and nutritional quality.

Keywords: Accessions, Characterization, Improvement, Plant breeding, Variation.

Introduction

The widely cultivated okra, *Abelmoschus esculentus* (L.) Moench belongs to Malvaceae (mallow) family, and it is an important autogamous species grown in the tropical, sub-tropical and warmer portions of the temperate region of the world (Patil et al., 2015). Petropoulos et al. (2018) described okra fruits as sources of primary and secondary metabolites which are rich in dietary fibre, carbohydrates, vitamins (A, B and C), and minerals (sodium, potassium, magnesium, calcium, zinc, iron, manganese and nickel). The seed contains oil (13-22%) and protein (20-24%) with balanced amounts lysine and tryptophan (Hughes, 2009). Thus, okra is a multipurpose fruit vegetable, highly nutritive and medicinal, playing a substantial role in averting malnutrition and alleviating food insecurity.

Genetic materials used in pre-breeding programs rely on germplasm collection as an essential resource to facilitate crop improvement. According to the International Plant Genetic Resources Institute (IPGRI) germplasm database, more than 46 research institutions in different countries worldwide possess about 11,000 accessions of okra and related wild species. The WCA (with 1,769) is far more heavily represented than other continents and countries (Hamon and Van Sloten, 1989). Even though the region of WCA has diverse genetic resources of

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indigenous okra species, these have not received sufficient effort for genetic improvement (Kumar et al., 2013). The highest number of okra accessions without useful information on their agro-morphological traits and nutritional properties has been reported to be found in West Africa (Oppong-Sekyere et al., 2012) making it the region of greatest diversity (Ahiakpa et al., 2013), but with limited okra improvement research (Amoatey et al., 2015). There are numerous okra germplasm collections in Nigeria, with limited information on their potential and variability. Previous studies on agro-morphological variation are limited to a few accessions (Alake, 2020) without considering their diverse nutritional and physicochemical properties. This has resulted in the absence of utilization information relative to a combination of agronomic traits, nutritional and physicochemical properties of each unique accession. According to Petropoulos et al. (2018) okra pod yield and seed nutritional content are paramount in attaining adequate nutrition. Moreover, variability among genotypes is crucial in selecting parents with a diverse genetic background for recombination in crop improvement programs.

One of the steps towards identification of sources of genes for novel traits entails phenotypic diversity assessment and agronomic performance (Chheda and Fatokun, 1982). Depending on the genetic variability available, identifying accessions that exhibit variation for traits of interest will reduce the threat or actual loss of genetic diversity. Thereafter, substantial breeding efforts will be required to select accessions and recombine superior lines with desirable or combination traits (Jan et al., 2017).

This study aimed to assess the magnitude of variability in okra accessions maintained at National Horticultural Research Institute (NIHORT), Genetic Resources Unit, with respect to agronomic traits, nutritional and physicochemical properties and to identify divergent okra accessions with complementary traits which may be useful as parental lines for hybridization and efficient utilization.

Materials and Methods

Experimental Materials and Design

Twenty nine okra accessions collected from seven states in Nigeria and conserved by Genetic Resources Unit of NIHORT Ibadan, Nigeria, and one popular farmers' variety (LC), which is well adapted to the Savanna agro-ecologies were used in this study. The largest collection of nine okra accessions was from Kano State, Nigeria, and the information about geographical coordinates of the various collection points is presented in Table 1. The accessions were evaluated during the main growing season of 2020 at the Teaching and Research (T&R) Farm of Ladoke Akintola University of Technology (LAUTECH), Ogbomoso (8°10′ N, 4°10′ E, and altitude 341 m above sea level) in the derived Savanna agro-ecology of Nigeria. The annual mean rainfall of the experimental site ranges between 1,000 and 1,200 mm while the daily temperature is between 28 - 30° C, and the soils are characterized as alfisol, which are generally low in nitrogen.

The accessions and the commercial variety were evaluated on the field in a 6×5 alpha lattice design with three replicates. Each plot was 4.32 m^2 (2.4 m × 1.8 m) consisting of one row, spaced at 1.2 m between rows and 0.9 m between the plants within a row. Three seeds were sown directly to the field in beds and thinned to one plant per hill when plants reached the 4-5 leaves stage. Manual weeding was carried out as and when due; to protect the leaves from defoliating pests, plants were sprayed with Promethrin® (containing profenofos 40% and cypermethrin 4% EC) at planting and at two weeks intervals at the rate of 30 ml active ingredients per 15 liters of water per hectare using knapsack sprayer. Two okra accessions (NHOK 0149 and NHOK-0608) had stunted growth and severe flower abortion, resulting in missing data for almost all measured traits. Henceforth, data from 28 genetic

Table 1. Okra accessions collected in Nigeria used in this study

S/N	Accessions Code	Collection Source	Global Positioning System coordinates
1	NHOK-0149	Bebeji, Kano	11° 32' 0" North, 8° 15' 0" East
2	NHOK-0158	Kura, Kano	11° 41' 0" North, 8° 22' 0" East
3	NHOK-0165	Bebeji, Kano	11° 32' 0" North, 8° 15' 0" East
4	NHOK-0171	Bebeji, Kano	11° 32' 0" North, 8° 15' 0" East
5	NHOK-0172	Babura, Jigawa	12° 26' 0" North, 8° 51' 0" East
6	NHOK-0188	Nnewi, Anambra	6°1' 6.02"North, 6°55' 6.92" East
7	NHOK-0195	Babura, Jigawa	12° 26' 0" North, 8° 51' 0" East
8	NHOK-0418	Babura, Jigawa	12° 26' 0" North, 8° 51' 0" East
9	NHOK-0422	Bakori, Katsina	11° 12' 0" North, 7° 38' 0" East
10	NHOK-0462	Okigwe, Imo	5° 48' 0" North, 5° 29' 0" East
11	NHOK-0464	Bebeji, Kano	11° 42' 0" North, 8° 8' 0" East
12	NHOK-0465	Bebeji, Kano	11° 42' 0" North, 8° 8' 0" East
13	NHOK-0544	Kudan, Kaduna	11°16' 22.80" North, 7°47'56.40" East
14	NHOK-0548	Kudan, Kaduna	11°16' 22.80" North, 7°47'56.40" East
15	NHOK-0549	Kudan, Kaduna	11°16' 22.80" North, 7°47'56.40" East
16	NHOK-0563	Port Harcourt, Rivers	4°492 273 North, 7° 22 13 East
17	NHOK-0601	Bebeji, Kano	11° 42' 0" North, 8° 8' 0" East
18	NHOK-0602	Awka, Anambra	6°12' 25" North, 7°04' 04" East
19	NHOK-0603	Awka, Anambra	6°12' 25" North, 7°04' 04" East
20	NHOK-0607	Bakori, Katsina	11° 12' 0" North, 7° 38' 0" East
21	NHOK-0608	Bakori, Katsina	11° 12' 0" North, 7° 38' 0" East
22	NHOK-0611	Bakori, Katsina	11° 12' 0" North, 7° 38' 0" East
23	NHOK-0614	Bakori, Katsina	11° 12' 0" North, 7° 38' 0" East
24	NHOK-0619	Bebeji, Kano	11° 42' 0" North, 8° 8' 0" East
25	NHOK-0621	Bebeji, Kano	11° 42' 0" North, 8° 8' 0" East
26	NHOK-0622	Bebeji, Kano	11° 42' 0" North, 8° 8' 0" East
27	NHOK-0623	Bakori, Katsina	11° 12' 0" North, 7° 38' 0" East
28	NHOK-0629	Port Harcourt, Rivers	4°492 273 North, 7° 22 13 East
29	NHOK-0635	Bakori, Katsina	11° 12' 0" North, 7° 38' 0" East
30	LOCAL CHECK (LC)	Ogbomoso, Oyo	8° 8' 0" North, 4° 16' 0" East

materials (27 accessions from NIHORT and 1 commercial variety used as check) were reported in this study.

Agronomic data Collection

All data collected were as described by the International Plant Genetic Resources Institute (IPGRI, 1991) descriptor list for okra species.

Sample collection and preparation for nutritional and physicochemical analyses

A total of 10-15 representative matured okra fruits were harvested and bulked from each of the 28 genetic materials evaluated, packed in polyethylene bags, kept in an ice box (to prevent moisture loss), and transported to the Product Development Laboratory of NIHORT, Nigeria. All chemicals used were of analytical grades, and analyses were done in triplicate for each sample.

Determination of nutritional and physico-chemical properties

The mineral (mg 100 g^{-1}) content [sodium (Na), potassium (K), manganese (Mn), calcium (Ca), iron (Fe) and zinc (Zn)], proximate composition (%) [total ash, crude fat and moisture] as well as fruit pH, ascorbic acid (vitamin C), chlorophyll-α/β (mg/g) and viscosity (cP) of the okra accessions were determined according to standard laboratory procedures (AOAC, 2000; Ibitoye, 2005; Shah et al., 2009).

Data Analyses

Analysis of variance (ANOVA) was computed on the quantitative and qualitative data according to Gomez and Gomez(1984), considering accessions as fixed effects and replications as random effects to determine the significant probability levels of the observed variation for the various characters measured using PROC GLM (General Linear Model) in SAS (SAS Institute, 2010). The traits that exhibited significant mean squares in ANOVA were subjected to further analyses. The means were separated by Fisher's Least Significant Difference (LSD) test at 0.05 probability level (Steel and Torrie, 1985). Correlation coefficients were computed following Pearson's method using PROC CORR in SAS version 9.4 (SAS Institute, 2010). Correlation coefficients were categorized as weak (0.0-0.4), moderate (0.4-0.6), and strong (0.6-1.0) (Belsley et al., 2005). The mean data were standardized and subjected to multivariate analysis. Contribution of each trait to the total variability was determined through principal component analysis (PCA) based on a correlation matrix of all variables, and principal components with Eigen values > 1.0 were selected. To assess extent of relatedness among the okra accessions, a cluster analysis using Ward's minimum variance method by accession was conducted to generate a dendrogram using PROC CLUSTER and PROC TREE (SAS Institute, 2010).

Results and Discussion

Variation in qualitative and quantitative characters among okra accessions

About 71 % of the accessions had green with red patches stem colour and more than half (54 %) of

Table 2. Variation observed in qualitative descriptors among the okra accessions evaluated

Accession	Leaf colour	Stem colour	Fruit colour	Pubescence on stem	Pubescence on fruit
NHOK-0158	green with slight red veins	green with red patches	green	present	abundant
NHOK-0165	green with slight red veins	green	green	absent	slight
NHOK-0171	green with slight red veins	green	green	absent	slight
NHOK-0172	green with slight red veins	green with red patches	green	absent	slight
NHOK-0188	green with slight red veins	green with red patches	green	absent	abundant
NHOK-0195	green	green	green	present	abundant
NHOK-0418	green with slight red veins	green	green	absent	slight
NHOK-0422	green with slight red veins	green with red patches	green with red patches	absent	slight
NHOK-0462	green with slight red veins	green with red patches	green	absent	slight
NHOK-0464	green with slight red veins	green	green with red patches	present	slight
NHOK-0465	green with slight red veins	green	green	present	abundant
NHOK-0544	green with slight red veins	green	green	present	slight
NHOK-0548	green with slight red veins	green	green	present	slight
NHOK-0549	green with slight red veins	green	green	absent	slight
NHOK-0563	green	green	green	present	slight
NHOK-0601	green with slight red veins	green with red patches	green	present	slight
NHOK-0602	green	green	green	present	abundant
NHOK-0603	green with slight red veins	green with red patches	green	present	abundant
NHOK-0607	green with slight red veins	green	green	absent	slight
NHOK-0611	green with slight red veins	green	green	absent	slight
NHOK-0614	green with slight red veins	green	green	present	abundant
NHOK-0619	green with slight red veins	green	green	present	slight
NHOK-0621	green with slight red veins	green	green with red patches	present	slight
NHOK-0622	green with slight red veins	green	green	absent	slight
NHOK-0623	green with slight red veins	green	green	absent	abundant
NHOK-0629	green with slight red veins	green with red patches	green with red patches	absent	slight
NHOK-0635	green with slight red veins	green	green	present	slight
LC	green	green	green	present	abundant

LC = Local check variety

the accessions evaluated had pubescence on the stem. Majority (86 %) of the accessions had green with slight red vein leaf, whereas; the fruit colour was mostly green. Fruits exhibited either slight or abundant pubescence, and only 32 % of the okra fruits had visible pubescence (Table 2). The okra accessions differed significantly ($P< 0.001$) for most of the agronomic, nutritional and physicochemical properties characters except for the number of leaves per plant, number of branches per plant, number of days to first flowering, number of fruits per plant and fruit weight (Table 3). More than half of the measured characters had coefficient of variation (CV) < 20, indicating that their estimation were reasonably precise. This result implies that the significantly diverse characters could be employed in distinguishing the accessions, and these variants can be exploited to meet diverse demands for yield and nutrients. Thus, the availability of unique parental lines useful for hybridization and improvement through selection in breeding programs is feasible (Vandana et al., 2014).

In okra improvement program, which entails the development of superior genotypes, the selection of potential parent lines is based on their possession of desirable traits. Considering the variations in the mean performance of the okra accessions for all measured characters (Table 4), only two accessions were significantly ($P< 0.05$) taller than the commercial check. Accession NHOK-0601 was the tallest, followed closely by NHOK-0544, and they

Table 3. Mean squares from ANOVA for agronomic traits, nutritional composition and physicochemical properties of okra accessions

Character	Source of variation					Minimum	Maximum	Mean	Standard Deviation
	Replication (df = 2)	Block (Replication) (df = 15)	Accession (df = 27)	Error (df = 39)	CV (%)				
Number of leaves per plant	842.23***	173.45***	51.55	32.86	37.92	2.00	51.60	15.24	9.35
Stem colour	0.06	0.07	0.30***	0.08	22.65	1	2	1	0.41
Plant height (cm)	622.43	604.86	673.00*	380.03	38.55	25.28	92.65	50.89	24.39
Number of branch per plant	35.76***	13.39***	6.92	4.18	37.94	2.47	14.00	5.39	2.84
Pubescence on stem	0.34*	0.19**	0.39***	0.08	55.07	0	1	1	0.50
Leaf length (cm)	72.03**	34.10**	26.75*	14.10	18.41	13.51	27.87	20.38	5.04
Number of days to first flowering	334.75*	123.01	112.52	107.07	16.62	45.00	102.00	62.59	11.85
Number of days to first harvest	135.61	97.92*	151.14***	50.50	9.77	57.19	95.94	73.23	10.44
Number of fruit ridges	0.03	1.06	2.64***	0.79	11.79	4.13	9.08	7.56	1.23
Pubescence on fruit	0.09	0.04	0.60***	0.03	7.25	2	3	2	0.50
Number of fruits per plant	90.81	98.32***	27.79	33.14	67.59	0.20	29.38	8.30	6.62
Number of fruits per accession	15780.85***	5214.43***	2624.34*	1428.42	72.01	1.11	157.99	49.56	38.34
Fruit colour	0.03	0.04	0.27***	0.06	20.16	1	2	1	0.38
Fruit weight (g)	2872776.13**	829302.4	486716.94	543825.21	109.3	27.22	1893.11	655.08	475.82
Vitamin C (mg 100 g^{-1})	3.65	5.18	63.69***	6.15	5.92	28.55	53.63	41.81	403.95
Chlorophyll-α /β (mg 100 g^{-1})	0.23	0.15	11.75***	0.10	8.18	0.98	9.15	3.912	2.19
Potassium (mg 100 g^{-1})	49.97	14.24	5471.57***	16.20	1.84	83.25	291.73	218.08	46.26
Zinc (mg 100 g^{-1})	0.001	0.000	0.12***	0.000	1.87	0.73	1.73	1.16	0.24
Manganese (mg 100 g^{-1})	0.004	0.001	2.54***	0.001	2.54	0.44	4.66	1.51	1.00
Calcium (mg 100 g^{-1})	0.152	0.179	62.63***	0.147	4.81	3.31	25.90	8.00	5.08
Sodium (mg 100 g^{-1})	0.116	0.019	13.76***	0.031	2.55	2.71	12.01	6.90	2.42
Iron (mg 100 g^{-1})	0.001	0.005	35.63***	0.007	0.89	8.14	28.32	9.60	3.70
Ash (%)	0.001	0.028	0.24***	0.077	33.98	0.30	2.11	0.81	0.42
Fat (%)	0.003	0.010	0.08***	0.011	14.64	0.38	1.24	0.73	0.22
Moisture (%)	0.076	0.774	7.22***	0.807	12.62	3.71	10.92	7.06	2.00
Fruit pH	0.048*	0.011	0.02*	0.008	1.74	4.89	5.45	5.20	0.12
Viscosity (cP)	687545.08***	12414.89	270485.89***	21213.27	19.76	115.85	1619.35	731.74	445.76

*,**,*** Significant at 0.05, 0.01 and 0.001 probability levels, respectively may be prone to lodging, but their high biomass can serve as livestock feed. Other accessions with minimum heights may be desirable in a breeding program, because plant height at flowering and fruiting can potentially affect yield (Myanmar 1995). Okra leaf size contributes to biomass and leaf yield (Ngomuo et al., 2017), which are freshly consumed by some cultures in Nigeria. Okra accessions NHOK-0188, NHOK-0418, and NHOK-0465 with leaves significantly (P< 0.05) longer than the commercial variety can be considered important candidates when selecting for leaf production.

The number of days to first harvest was significantly (P< 0.05) earlier in NHOK-0418, NHOK-0422, and NHOK-0462 compared to the commercial variety. These accessions can be exploited when selecting for early maturity. Only six okra accessions had a significantly higher number of fruits than the commercial check whereas three had significantly higher fruit weight than the commercial check. Variations in fruit parameters had been reported earlier (Duggi et al., 2013). The number of fruit per accession and fruit weight in this study was higher than the report of Shivaramegowda et al. (2016). The results showed that most of the okra accessions had more vigorous growth characteristics than the commercial check, which corroborates the findings of Temam et al. (2020). Therefore, parental lines with desirable traits can be selected from these okra accessions for hybridization and other breeding activities.

Furthermore, in selecting parental lines for breeding

Table 4. Mean performance of agronomic traits with significant variation among the okra accession

Accession	Plant height (cm)	Leaf length (cm)	Number of days to first harvest	Number of fruit ridges	Number of fruits per accession	Fruit weight (g)
NHOK-0158	56.52±12.91	24.15±2.49	78.69±4.73	8.30±0.59	60.07±25.14	771.40±490.54
NHOK-0165	40.90±12.96	17.98±2.50	76.46±4.72	8.77±0.59	80.69±25.12	1893.11±490.21
NHOK-0171	72.81±12.85	21.00±2.48	73.53±4.69	7.73±0.59	1.11±24.96	39.63±487.10
NHOK-0172	62.03±13.27	17.81±2.56	77.76±4.91	8.19±0.61	40.11±26.12	568.92±509.58
NHOK-0188	78.23±13.12	27.87±2.53	72.76±4.79	6.79±0.60	10.66±25.46	107.78±496.69
NHOK-0195	33.44±12.77	16.30±2.46	78.58±4.66	7.21±0.58	1.21±24.76	244.15±483.09
NHOK-0418	51.20±13.07	25.97±2.52	57.19±4.77	7.91±0.59	41.18±25.35	345.27±494.57
NHOK-0422	36.51±12.83	14.88±2.47	59.21±4.68	6.98±0.58	39.81±24.87	513.01±485.29
NHOK-0462	48.74±13.49	21.38±2.60	58.10±4.92	7.17±0.61	157.99±26.16	1687.51±510.37
NHOK-0464	40.16±13.28	21.63±2.56	77.45±4.87	8.84±0.61	20.32±25.88	480.94±504.95
NHOK-0465	46.68±13.36	26.66±2.57	78.26±4.87	8.42±0.61	45.28±25.90	589.54±505.27
NHOK-0544	88.78±12.82	16.55±2.47	95.94±4.67	7.52±0.58	21.58±24.86	291.15±485.05
NHOK-0548	39.37±14.36	19.72±2.77	70.04±5.24	5.82±0.65	130.81±27.84	1261.07±543.23
NHOK-0549	34.02±13.11	18.52±2.52	78.36±4.78	7.79±0.60	19.12±25.41	27.22±495.80
NHOK-0563	57.59±13.09	21.46±2.52	76.51±4.77	7.67±0.60	80.21±25.38	906.69±495.29
NHOK-0601	92.65±12.86	21.87±2.48	70.32±4.69	7.72±0.59	36.30±24.94	389.87±486.68
NHOK-0602	54.74±13.03	24.38±2.51	65.53±4.75	8.69±0.59	53.22±25.26	825.21±492.80
NHOK-0603	38.28±13.37	20.67±2.57	67.32±4.90	7.87±0.61	53.96±26.06	720.37±508.50
NHOK-0607	43.49±13.10	22.82±2.52	79.48±4.88	7.69±0.61	35.73±25.95	555.51±506.38
NHOK-0611	40.60±13.04	18.32±2.51	80.94±4.78	8.61±0.60	8.51±25.41	212.69±495.71
NHOK-0614	25.28±13.22	17.83±2.55	66.13±4.93	4.13±0.62	40.88±26.24	410.54±511.96
NHOK-0619	53.01±13.35	19.81±2.57	67.70±4.89	8.18±0.61	88.51±26.02	1434.40±507.69
NHOK-0621	30.23±12.92	17.56±2.49	72.41±4.71	6.63±0.59	23.76±25.04	349.49±488.60
NHOK-0622	42.34±14.36	13.51±2.77	71.04±5.24	4.95±0.65	111.48±27.84	917.57±543.23
NHOK-0623	51.45±13.33	20.88±2.57	76.47±4.86	7.47±0.61	41.16±25.84	989.62±504.22
NHOK-0629	58.36±13.55	19.78±2.61	76.83±6.04	8.08±0.75	48.69±32.15	711.73±627.27
NHOK-0635	53.57±13.12	22.72±2.53	72.32±4.78	9.08±0.60	79.49±25.43	910.87±496.18
LC	53.83±13.28	18.66±2.56	75.15±4.84	7.51±0.60	15.88±25.75	187.11±502.38
LSD (0.05)	32.20	6.20	11.74	1.47	62.46	1218.69

LC = Local check variety

nutritionally enhanced okra, the proximate and mineral compositions of okra accessions evaluated are crucial in assessing their quality. The percentage composition of ash from this study (Table 5) is higher than the value reported by Petropoulos et al. (2018) but lower than the range reported by Sami et al. (2013). The low percentage composition of crude fat observed in this study is comparable to the range reported by Gemede et al. (2016), which infers that the okra fruits can absorb and retain flavors, hence increasing their palatability and prevent the consumption of excess fats (Antia et al., 2006). The observed moisture content in the okra fruits falls within the acceptable range, according to James (1995). Low moisture content in dried okra fruit implies good keeping quality, nutrient preservation, and high yield (Edem et al., 2009), whereas the high moisture content may result in increased microbial action (Onyeike et al., 1995). The pH values of okra fruit in this study are lower than the range reported by Combo et al. (2020), which makes it ideal for individuals with ulcers-related problems. Appreciable amount of vitamin C, an antioxidant property that could boost the immune body system and prevent diseases, were also detected in the okra accessions. Additionally, accession NHOK-0602 had the highest amount of chlorophyll-α/β, which is higher than the quantity reported by Yora et al. (2018). Thus, this okra accession has higher photosynthetic efficiency and a source of green pigment, which plays an essential role in stimulating the immune system, preventing cancer, cardiovascular disease, and anemia (Znidarcic et al., 2011). Viscosity of more than 1000cP recorded for five okra accessions were significantly ($P< 0.05$) different from the commercial check variety. The range of okra mucilage viscosity in this study was higher than the report of Adetuyi et al. (2011) and Oforiet al. (2020). Accession NHOK-0418 recorded the highest

Table 5. Mean performance of nutritionalcomposition and physicochemical properties of the evaluated okra accession

Accession	Vitamin C	Chlorophyllα/β	Potassium	Zinc	Manganese	Calcium	Sodium	Iron	Ash(%)	Fat(%)	Moisture(%)	pH	Viscosity(cP)
NHOK-0158	36.46±1.64	2.74±0.21	210.68±2.67	1.00±0.01	1.16±0.03	5.25±0.25	7.01±0.12	8.68±0.06	0.40±0.24	0.38±0.09	4.69±0.79	5.34±0.08	209.44±126.08
NHOK-0165	41.07±1.65	4.95±0.21	219.29±2.68	1.15±0.01	0.76±0.03	12.51±0.26	8.88±0.12	8.67±0.06	0.59±0.25	1.02±0.10	10.48±0.86	5.32±0.08	1272.75±129.74
NHOK-0171	40.59±1.63	6.00±0.21	227.24±2.65	1.08±0.01	1.56±0.03	25.90±0.25	4.70±0.12	28.32±0.06	0.42±0.25	0.94±0.10	8.23±0.80	5.20±0.08	806.36±129.42
NHOK-0172	50.30±1.69	2.35±0.22	249.13±2.74	1.42±0.01	4.66±0.03	6.73±0.26	4.46±0.12	11.69±0.06	0.41±0.26	0.49±0.10	5.42±0.92	5.20±0.08	1602.31±135.07
NHOK-0188	38.03±1.67	3.97±0.22	190.49±2.71	0.96±0.01	0.85±0.03	9.37±0.26	5.62±0.12	8.14±0.06	0.58±0.24	0.73±0.09	6.19±0.78	5.45±0.08	401.60±124.96
NHOK-0195	40.54±1.62	1.65±0.21	83.25±2.64	1.23±0.01	1.29±0.03	7.85±0.25	10.99±0.12	8.66±0.06	0.98±0.23	0.93±0.09	7.97±0.79	5.07±0.08	757.77±121.92
NHOK-0418	28.55±1.66	0.98±0.21	239.51±2.70	1.37±0.01	2.76±0.03	6.69±0.26	6.79±0.12	8.63±0.06	0.82±0.24	0.60±0.09	5.85±0.79	5.18±0.08	1619.35±128.03
NHOK-0422	50.47±1.63	2.72±0.21	169.98±2.65	0.99±0.01	2.11±0.03	4.57±0.25	9.70±0.12	9.15±0.06	0.68±0.23	0.99±0.09	10.92±0.76	5.35±0.08	358.19±122.01
NHOK-0462	38.72±1.72	6.11±0.22	174.80±2.79	1.15±0.01	0.95±0.03	12.99±0.27	6.27±0.12	8.99±0.06	0.69±0.27	0.62±0.10	5.13±0.88	4.89±0.09	643.69±139.21
NHOK-0464	44.29±1.69	2.24±0.22	268.98±2.74	1.68±0.01	2.09±0.03	18.36±0.26	9.57±0.12	9.13±0.06	1.04±0.24	0.61±0.09	6.24±1.23	4.98±0.08	968.59±125.00
NHOK-0465	38.36±1.70	3.46±0.22	211.57±2.76	1.14±0.01	0.80±0.03	4.67±0.26	5.41±0.12	8.67±0.06	0.87±0.25	0.67±0.10	6.66±0.83	5.36±0.08	585.72±132.88
NHOK-0544	40.68±1.63	2.40±0.21	189.76±2.65	0.89±0.01	0.66±0.03	3.42±0.25	4.49±0.12	8.35±0.06	2.11±0.23	0.92±0.09	8.76±0.75	5.22±0.08	863.24±121.77
NHOK-0548	42.57±1.83	6.45±0.24	248.39±2.96	1.09±0.02	1.18±0.03	7.74±0.28	5.35±0.13	8.95±0.06	0.68±0.29	1.24±0.11	9.57±0.96	5.05±0.09	472.63±152.23
NHOK-0549	43.34±1.67	5.69±0.21	143.31±2.71	0.80±0.01	0.44±0.03	3.31±0.26	4.21±0.12	8.45±0.06	0.82±0.24	0.68±0.09	7.35±0.79	5.28±0.08	647.35±128.03
NHOK-0563	49.77±1.66	4.64±0.21	234.30±2.70	1.25±0.01	2.90±0.03	9.05±0.26	2.93±0.12	10.80±0.06	0.53±0.24	0.69±0.09	6.21±0.78	5.26±0.08	276.17±125.99
NHOK-0601	43.35±1.64	1.90±0.21	233.51±2.66	1.73±0.01	1.08±0.03	9.36±0.25	12.01±0.12	9.15±0.06	1.13±0.25	0.60±0.10	5.73±0.86	5.04±0.08	948.75±129.74
NHOK-0602	37.56±1.66	9.15±0.21	171.68±2.69	0.99±0.01	1.12±0.03	4.05±0.26	6.56±0.12	8.38±0.06	0.83±0.25	0.59±0.10	6.67±0.85	5.23±0.08	920.70±130.31
NHOK-0603	42.36±1.70	7.98±0.22	171.25±2.76	0.73±0.01	0.51±0.03	3.43±0.26	9.21±0.12	8.72±0.06	0.30±0.26	1.10±0.10	10.22±0.85	5.29±0.08	115.85±133.88
NHOK-0607	38.43±1.67	1.30±0.21	261.35±2.70	1.40±0.01	3.48±0.03	8.83±0.26	7.95±0.12	8.49±0.06	0.73±0.24	0.85±0.09	8.64±0.78	5.33±0.08	812.31±126.17
NHOK-0611	44.20±1.66	3.70±0.21	185.26±2.69	1.01±0.01	0.55±0.03	3.44±0.26	8.68±0.12	8.68±0.06	0.44±0.24	0.51±0.09	5.65±0.83	5.12±0.08	1270.06±125.79
NHOK-0614	44.69±1.68	2.33±0.22	212.52±2.73	1.25±0.01	2.56±0.03	5.28±0.26	2.74±0.12	9.14±0.06	0.42±0.25	0.75±0.10	7.73±0.80	5.22±0.08	241.36±129.42
NHOK-0619	37.38±1.70	3.14±0.22	233.16±2.76	1.12±0.01	0.54±0.03	3.52±0.26	7.62±0.12	8.62±0.06	0.82±0.26	0.53±0.10	4.47±0.85	5.14±0.08	770.85±133.88
NHOK-0621	39.28±1.64	1.48±0.21	281.61±2.67	1.18±0.01	1.16±0.03	7.41±0.25	3.98±0.12	8.21±0.06	1.51±0.24	0.53±0.09	4.70±0.77	5.20±0.08	116.40±124.25
NHOK-0622	43.28±1.83	2.42±0.24	291.73±2.96	1.17±0.02	1.81±0.03	10.65±0.28	9.38±0.13	8.98±0.06	0.68±0.29	0.85±0.11	9.57±0.96	5.11±0.09	749.63±152.23
NHOK-0623	53.63±1.69	3.40±0.22	213.82±2.75	1.04±0.01	2.20±0.03	12.99±0.26	6.44±0.12	8.71±0.06	0.87±0.25	0.49±0.10	4.66±0.83	5.36±0.08	554.72±132.88
NHOK-0629	44.97±1.72	6.76±0.22	268.98±2.80	1.42±0.01	1.06±0.03	4.93±0.27	5.05±0.12	9.05±0.06	1.16±0.26	0.96±0.10	9.17±0.92	5.16±0.08	351.31±135.07
NHOK-0635	43.33±1.67	2.51±0.22	240.64±2.71	0.77±0.01	0.78±0.03	3.44±0.26	8.65±0.12	8.74±0.06	0.92±0.25	0.38±0.10	3.71±0.82	5.16±0.08	1298.38±130.14
LC	34.54±1.69	7.32±0.22	280.00±2.74	1.34±0.01	1.27±0.03	8.24±0.26	8.49±0.12	8.68±0.06	1.17±0.25	0.69±0.10	6.96±0.82	5.05±0.08	853.38±130.14
LSD (5 %)	4.09	0.53	6.65	0.04	0.06	0.63	0.29	0.14	0.59	0.23	1.48	0.19	307.29

LC = Local check variety; Unit of measurement for all concentration of mineral elements were in mg 100 g^{-1}

viscosity, which suggests its ability to form gel during cooking (Shimelis et al., 2006) and suitability for consumption (Fatokun et al., 1979). Even though okra with low viscosity is desirable as composite for baby foods (Ofori et al., 2020). Viscosity in okra fruit has been described by Adams et al. (2019) as an indication of the extent of granule swelling and the strength of the associative forces between the molecules.

Bearing in mind the connection between agriculture and health, it is important to mention that humans need an adequate amount of essential macro and micro nutrients (minerals and vitamins) to fight malnutrition. Minerals are essential for physical and mental development, immune system functioning, and various metabolic processes. The concentration of the mineral elements was in the order of potassium > iron > calcium > sodium > manganese > zinc in this study. According to Graham et al. (2007) 5 mg 100 g^{-1} of iron consumption daily is required for improved nutrition. All the okra accessions surpassed this concentration, and NHOK-0171 specifically contained a highly significant concentration of iron (Table 5). This accession may be improved for yield and yield related traits as it has the potential to meet the recommended daily intake of iron for Nigerians who consume okra regularly. The concentrations of potassium, calcium, manganese, zinc were consistent with prior reports while iron and sodium concentrations were higher in comparison to previous studies (Adetuyi et al., 2011; Gemede et al., 2016; Combo et al., 2020). Moreover, the evaluated accessions had higher mineral content of 21 % zinc, 39 % manganese, 36 % calcium, 32 % sodium, 54 % iron, 46 % fat, 32 % viscosity, 89 % vitamin C, and 7 % each of chlorophyll-α/β, potassium, ash with lower content of moisture (54 %) and pH (11 %) than the commercial variety used as a check. These results confirm these okra accessions can be exploited to meet the demand for yield and nutritional quality.

Pearson correlations among characters

Correlations among characters play an important role during crop improvement and increase the effectiveness of selection (Falconer and Mackay, 1996). Significant coefficients (r) of correlation in this study ranged from -0.31 to 0.87 (Table 6). This

Table 6. Pearson's correlation coefficients (r) between pairs of agronomic traits and nutritional characters of the evaluated okra accession

	PH	PS	LLNT	LWDT	DTF	DHF	FWDT	PF	NFPP	FWT	CHPLα/β	K	Zn	Mn	Ca	Na
PS	-0.09															
LLNT	0.17	-0.19														
LWDT	0.19	-0.08	0.87***													
DTF	0.13	0.13	-0.48***	-0.42***												
DHF	0.18	0.09	-0.38***	-0.31***	0.75***											
FWDT	-0.02	-0.15	0.42***	0.41***	-0.26	-0.26										
PF	-0.10	0.28**	0.20	0.15	-0.06	0.00	0.04									
NFPP	-0.10	-0.19	0.55***	0.42***	-0.54	-0.52***	0.36***	0.10								
FWT	-0.07	-0.14	0.47***	0.48***	-0.48	-0.50***	0.26**	-0.02	0.62***							
CHPLα/β	-0.11	0.02	0.00	0.03	-0.06	-0.07	0.05	0.37***	0.11	0.05						
K	0.13	-0.07	-0.02	-0.03	0.11	0.06	0.00	-0.40***	0.01	-0.04	-0.14					
Zn	0.19	-0.03	-0.03	-0.04	-0.01	0.02	-0.10	-0.37***	-0.11	-0.13	-0.32***	0.48***				
Mn	0.05	-0.14	-0.03	0.03	-0.03	0.02	0.01	-0.19	-0.09	-0.13	-0.38***	0.33***	0.49***			
Ca	0.16	-0.34***	0.10	0.06	-0.09	0.02	0.03	-0.24*	-0.02	0.00	0.04	0.24*	0.34***	0.20		
Na	-0.06	-0.10	-0.09	-0.06	-0.11	-0.13	0.08	-0.26**	-0.09	0.10	-0.16	-0.12	0.19	-0.20	0.03	
Fe	0.22*	-0.19	0.05	0.08	-0.04	0.01	0.08	-0.20	0.00	-0.11	0.17	0.08	0.01	0.14	0.69***	-0.22*

*,**,*** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

PH = Plant height, PS = Pubescence on stem, LLNT = Leaf length, LWDT = Leaf width, DTF = Number of days to first flowering, DHF = Number of days to first harvest, FWDT = Fruit width, PF = Pubescence on fruit, NFPP = Number of fruits per plant, FWT = Fruit weight, CHPL a/b = chlorophyll-α/β, K = Potassium, Zn = Zinc, Mn = Manganese, Ca = Calcium, Na = Sodium indicated that some characters can be indirectly targeted in a selection criterion, especially characters that are costly to measure or easily influenced by the environment (Nyadanu et al., 2017). The strongest positive association was observed between leaf length and leaf width ($r = 0.87$, $P < 0.001$). Improvement of okra leaf length could be accomplished indirectly through selection for secondary traits such as: leaf width, fruit width, number of fruits per plant, and fruit weight, as they shared a strong positive association with leaf length. The number of days to the first harvest had the strongest, negative, significant ($P < 0.001$) correlations with the number of fruits per plant ($r = -0.52$). The strongest positive relationship exhibited by the flowering trait was found between the number of days to first flowering and the number of days to first harvest ($r = 0.75$, $P < 0.001$), whereas number of days to first flowering had a negative association with the number of fruits per plant ($r = -0.54$) and fruit weight ($r = -0.48$). The strongest positive relationship exhibited by fruit related trait was found between the number of fruits per plant and fruit weight ($r = 0.62$, $P < 0.001$) which may be as a result of their similar physiology (Adiger et al., 2011). Pubescence on stem had a positive significant ($P < 0.01$) correlation with pubescence on fruit ($r = 0.28$) and a negative significant ($P < 0.001$) correlation with calcium content ($r = -0.34$). Pubescence on fruit had a significant positive correlation with chlorophyll-α/β ($r = 0.37$) but with a moderate negative significant correlation with potassium ($r = -0.40$), zinc ($r = -0.37$), calcium ($r = -0.24$) and sodium ($r = -0.26$). Pubescence on fruit will be sufficient as a selection criterion for chlorophyll-α/β but with a lower constituent of potassium, zinc, calcium, and sodium, thus revealing the impact of pubescence on the mineral composition of okra fruits. Chlorophyll-α/β had a negative association with zinc ($r = -0.32$) and manganese ($r = -0.38$) whereas potassium had a positive association with zinc ($r = 0.48$) and manganese ($r = 0.33$). Additionally, zinc had significant positive correlations with manganese ($r = 0.49$) and calcium ($r = 0.34$). There was a strong positive correlation between calcium and iron ($r = 0.69$) and a negative association between sodium and iron ($r = -0.22$). Thus, any of those mineral elements may be considered a secondary character when selecting for improved nutrient in the okra improvement program.

Clustering pattern of okra accessions

The multivariate analysis revealed the pattern of variation among the accessions. Regardless of the similar collection site for some accessions, phenotypic variability was evident among the okra accessions. Cluster analysis grouped the 28 okra accessions initially into two major clusters and further placed them into three distinct clusters (Figure 1). The clustering was, to a larger extent, independent of the collection site of the accessions, as cluster I and III had accessions from all collection sites. This pattern of clustering has been reported by Sunil et al. (2009) and Sunil et al. (2014). The common distinguishing qualitative descriptor of the three clusters was the stem and fruit colour. All the accessions in cluster III had green colour stems and fruits except for only NHOK-0462 with green with red patches of stem colour but green fruits. The cluster analysis revealed that cluster I (accounting for 57 % of the total accessions) represents accessions from diverse locations in Nigeria. The distinguishing characteristics of okra fruits in this group were short duration of days to fruit harvest, few fruit ridges, low fruit weight, low composition of iron, vitamin C, calcium, and manganese, high zinc concentration, high pH, high viscosity, high fat, and moisture content. The grouping of the majority of the accessions into cluster I could probably be due to the active exchange of cultivars within the same locality, because accessions grouped together into the same cluster are less divergent than those which are placed in a different cluster. Another plausible explanation may be that farmers have mixed these seeds during cultivation to meet different demands and these accessions are often genetically identical.

Cluster II had just two accessions categorized as

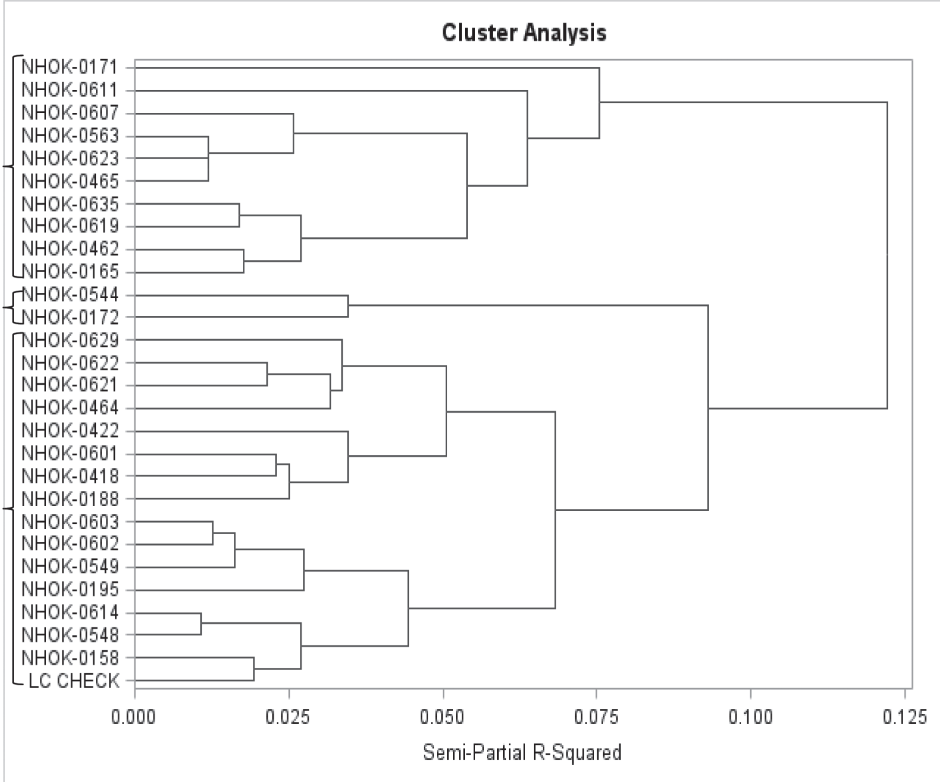

Figure 1. Multivariate cluster analysis using Ward's minimum variance method showing relatedness of okra accession

having high manganese and ash content. The peculiarity of accessions in Cluster III were many fruit ridges, high fruit weight, high composition of iron, vitamin c, and calcium, low zinc concentration, low pH, low viscosity, low fat, ash and moisture content. This cluster (accounting for 36 %) comprises accessions with characters of greater significance in breeding programs that may be useful in developing new hybrid or variety. Since clusters I and II comprised of accessions with other desirable characters, hybridization of accessions in cluster I with cluster III or cluster II with cluster III would be more responsive to improvement. Genetically divergent accessions may be selected from these clusters for different desirable characters when selecting parents for hybridization. The selection of the superior divergent accessions would give greater chances of obtaining, desirable recombination, heterotic effects, and genetic variability for quantitative and qualitative characters in the segregating generations (Mallikarjun et al., 2010).

Principal component analysis (PCA)

Principal component analysis identified characters that contribute most to the variability and characterization of the okra accessions. The first nine principal axes had eigen values >1 and accounted for 81.73 % of the total cumulative variation among the agronomic and nutritional characters of the okra accessions (Table 7). All agronomic and nutritional characters measured had high coefficients in more than one PC axes. The first two PCs, with values of 18.13 % and 13.50 %, had the highest contribution to the total variation. Considering that highest coefficient for a certain character indicates the relatedness of such character to the respective PC axes; leaf length, plant height, number of leaves per plant, number of fruits per plant, number of fruit ridges, number of branches

Table 7. Association of agronomic and nutritional characters with nine principal components accounting for total variability among okra accessions evaluated

	PC axis								
	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9
Eigenvalues	4.71	3.51	2.80	2.33	1.94	1.83	1.52	1.33	1.27
Explained Proportion of Variation (%)	18.13	13.50	10.77	8.96	7.45	7.04	5.86	5.13	4.89
Cumulative Proportion of Variation (%)	18.13	31.63	42.39	51.36	58.81	65.85	71.71	76.84	81.73
Character	Eigenvectors								
Number of leave per plant	0.26	0.27	0.13	-0.13	0.18	-0.07	-0.07	0.08	0.01
Stem colour	-0.12	-0.10	-0.16	-0.17	-0.02	0.17	-0.25	-0.35	0.50
Plant height (cm)	-0.20	0.31	0.03	0.14	-0.05	0.16	-0.24	-0.15	-0.04
Number of branch per plant	0.09	0.30	0.22	-0.14	-0.09	-0.28	0.08	0.05	0.25
Pubescence on stem	-0.09	-0.16	0.28	0.01	-0.34	0.10	0.19	0.39	-0.04
Leaf length (cm)	0.27	0.20	-0.05	0.24	-0.22	0.16	0.15	-0.18	0.04
Number of days to first flowering	-0.23	0.20	0.38	-0.01	0.14	-0.15	-0.12	0.06	0.02
Number of days to first harvest	-0.24	0.24	0.35	0.05	0.14	-0.09	-0.10	0.06	0.01
Fruit colour	-0.19	-0.14	-0.15	-0.22	0.13	0.14	0.12	0.18	0.48
Number of fruit ridges	0.00	0.29	0.14	-0.17	0.09	0.47	0.08	0.14	0.15
Pubescence on fruit	0.12	-0.21	0.28	0.30	-0.29	0.06	-0.02	-0.01	0.08
Number of fruits per accession	0.31	-0.07	-0.11	0.13	0.05	-0.27	-0.20	-0.17	0.17
Fruit weight (g)	0.36	0.05	-0.02	-0.28	-0.02	-0.11	-0.22	0.12	-0.06
Vitamin C (mg 100 g^{-1})	0.01	0.07	0.16	-0.01	0.45	0.02	0.37	-0.38	-0.07
Chlorophyll-α/β (mg 100 g^{-1})	0.13	-0.14	0.12	0.19	0.22	0.14	-0.25	0.24	0.33
Potassium (mg 100 g^{-1})	-0.10	0.19	-0.19	0.00	0.03	-0.38	0.16	0.35	0.20
Zinc (mg 100 g^{-1})	-0.19	0.18	-0.29	-0.06	-0.12	-0.15	0.20	0.08	-0.05
Manganese (mg 100 g^{-1})	-0.15	0.17	-0.27	0.05	-0.26	-0.17	0.14	-0.10	0.16
Calcium (mg 100 g^{-1})	-0.01	0.18	-0.36	0.22	0.16	0.09	-0.17	0.26	-0.22
Sodium (mg 100 g^{-1})	0.01	-0.03	-0.10	-0.40	0.13	0.18	0.13	-0.09	-0.32
Iron (mg 100 g^{-1})	-0.03	0.15	-0.23	0.35	0.23	0.23	-0.17	0.21	-0.06

per plant, and fruit weight with high coefficients and positive association (PC1 and PC2) contributed most (31.63 %) to the total variability among the evaluated okra accessions. This implies that genes controlling the inheritance of these characters accounted for most of the observed variability (Sharma and Prasad, 2010), as they were the ones that most differentiated the accessions. Therefore, these characters can be selected when considering the phenotypic variability of okra accessions which may be useful in okra improvement programs.

The okra accessions evaluated showed variability for a majority of the characters measured, which is essential for selection towards improvement. Each accession had distinct colour (stem, leaf, and fruit), and pubescence (stem and fruit). Also, the clustering pattern indicates diversity among the accessions and the opportunity to select superior lines for further breeding activities. The mean performance of the accessions showed wide variations for agronomic traits, mineral content and proximate composition. Accessions NHOK-0165, NHOK-0171, NHOK-0188 NHOK-0418, NHOK-0462,NHOK-0544, NHOK-0601,NHOK-0602, NHOK-0622, NHOK-0623, and NHOK-0635 had desirable agronomic traits, mineral and proximate composition and should be utilized in further breeding programs for developing superior varieties. This pioneer report on some of NIHORT's okra germplasm implies that the accessions in the institutes' gene bank had desirable agronomic traits and are potential sources of essential nutrients that are beneficial to human health. These results will be useful for the appropriate conservation and utilization of the okra accessions. However, it is important to mention that the observed morphological variation may not reflect actual genetic variation that exists at the DNA level. Thus, further studies may consider the genetic diversity of the okra accessions with the aid of molecular markers and evaluation across environments to confirm the reliability of the results.

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