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Nutritional and phenotypic variations among newly selected African eggplant (*Solanum aethiopicum* L.)

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Abstract: African eggplant (*Solanum aethiopicum* L.) is an important but underutilized leafy and fruit vegetable. Systematic characterization of available eggplant accessions for morphological and nutritional traits is paramount to their genetic improvement. This study characterized the diversity among selected *S. aethiopicum* accessions from Nigeria to identify promising genotypes for future eggplant breeding activities in the region. Twenty new purified African eggplant accessions collected from farmers' fields were characterized using morphological and nutritional descriptors. The accessions varied significantly in qualitative, quantitative and nutritional parameters. Top performers for selected yield-contributing traits and nutritional parameters were NHEPA54, NHEPA39-1, NHEAP10, NHEPA10, NHEPA1, NHEPA56, NHEPA23 for vitamin C, iron, calcium, days to flowering, number of branches, plant height at maturity and number of fruits per plant respectively. The first four principal components accounted for 72.42% of total variability. The first principal component with the largest variation (28.77%) was loaded with number of branches, plant height at maturity, number of fruits per cluster, number of fruits per plant, and fruit width. A significant positive association was exhibited between iron and yield-increasing traits such as number of fruits per plant (r = 0.532) and number of fruits per cluster (r = 0.551). Plant height at maturity positively correlated with vitamin C (r = 0.492) indicating predictable success in selecting top-performing eggplant genotypes combining high-yield potential and nutritional content. Top-performing eggplant genotypes identified in this study could be deployed as donors for a hybridization programme to develop new eggplant varieties with higher yield potential and improved nutritional quality.

Keywords: Diversity, accessions, breeding, principal component, variability, correlation

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Introduction

The African eggplant (*Solanum aethiopicum* L.) is one of the important indigenous fruit vegetables widely grown and consumed across most regions of tropical Africa. It is the third most consumed fruit vegetable after tomato, pepper and onion both in quantity and value in the region (Osei *et al*, 2010). Mature fruits of African eggplant are eaten fresh, with fried groundnuts or used to prepare special delicacies called 'African salad' in southern Nigeria (Igwe *et al*, 2003). A significant increase has been observed in its production across sub-Saharan Africa from 606,672 tonnes in 1994 to 2,079,920 tonnes in 2018 (FAO, IFAD, UNICEF, WFP and WHO, 2018).

Eggplant is considered amongst the healthiest fruit vegetables for its low calories and high concentration of various macro and micro minerals essential for maintaining good health (Docimo *et al*, 2016). They are rich sources of fibres, vitamins (A, B1, B2, B6, B12, C, D), magnesium, calcium and iron even though potassium is the most abundant mineral ranging from 200 to 600mg/100g of fresh matter (Kowalski *et al*, 2003; Nyadanu and Lowor, 2015; Nimenibo and Omotayo, 2019). The crop has been reported to play an essential role in meeting the nutritional needs of the Igbo-speaking tribe in southern Nigeria

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where consumption of fresh fruits might be of great benefit to glaucoma patients and to prevent heart disease (Igwe *et al*, 2003; Denkyirah, 2013). *S. aethiopicum* is used in the management and treatment of diarrhoea and hypertension (Adeniji and Aloyce, 2012). The high yield and nutritive value of the leaves and fruits complemented with resistance to pests and diseases endear the crop to consumers, farmers and researchers (Bonsu *et al*, 1998; Toppino *et al*, 2008; Taher *et al*, 2019).

Eggplants belong to the Solanaceae family, which encompasses three closely related cultivated species endemic to Afro-Eurasia. Two sections exist at the subgenus level, namely *Melongena* and *Oliganthes* sections. The section *Melongena* comprises two species (*S. melongena* and *S. macrocarpon*) while the *Oliganthes* group has only one species (*S. aethiopicum*). *S. aethiopicum* has been grouped into four different ecotypes or cultivars including Aculetum, Gilo, Kumba and Shum groups as revealed by similarities in genotypic characterization through varied phenotypes (Sharmin *et al*, 2011). Aculetum is mostly used as ornamental, Gilo is used for its fruits, Kumba is for both fruits and leaves while Shum is used for its leaves (Lester and Daunay, 2003).

Consumer preferences for an African eggplant cultivar are based on a number of traits including fruit size, form, fruit colour and taste (sweet or bitter). Morphological characterization using conventional descriptors has proved useful for describing and establishing relationships among cultivar groups and accessions in scarlet eggplants (Adeniji *et al*, 2013). The enormous morphological variability present in the eggplant family, despite being characterized by a narrow genetic base, might be attributed to new segregants emanating from natural hybridization and backcrossing (Meyer *et al*, 2012).

Despite their socioeconomic significance and their role in meeting the nutritional needs of the ever-increasing population across sub-Saharan Africa, these heirloom and indigenous adapted cultivars are becoming less popular, and the efforts to improve them for traits of interest to farmers and end-users are scarce (Bationo-Kando *et al*, 2015).

Continuous planting and selection of many diverse cultivars of *S. aethiopicum* by small-scale farmers as well as the existence of germplasm collections have helped to conserve the majority of desired traits within families over the years. The long period of selection by these poorly resourced farmers has resulted in a number of landraces exhibiting different variants with unique traits such as earliness, colour, size and taste. In essence, the African eggplant has long been neglected by formal crop improvement programmes except in breeding programmes where it is used as a source of specific traits. Furthermore, they are considered neglected and underutilized crops since their nutritional and economic potentials are mostly underexploited (Padulosi *et al*, 2019).

Systematic characterization of African eggplant accessions using morphological and nutritional traits is an important prerequisite toward their conservation and use in further studies and genetic improvement in the region (AVRDC, 2003). Unfortunately, minimal efforts have been directed to identify and select promising genotypes with a good combination of desired agronomic and nutritional qualities that could be used as parental materials for hybridization or released as new open-pollinated varieties. The process of germplasm characterization and trait screening to identify and select desired gene combinations can be challenging.

This study characterized newly selected and purified eggplant accessions collected in Nigeria to ascertain their mineral composition and to identify promising elite lines with the best combination of desired agronomic traits that could further be deployed for eggplant genetic improvement programmes.

Materials and methods

Experimental materials

Twenty new eggplant accessions (Table 1) were selected from the 2019 characterization of germplasm collections from farmers' fields across the south-west and north-central regions of Nigeria based on observable traits under field conditions. These materials have gone through two cycles of selection and selfing.

Experimental design and conditions

The experiment was conducted at the experimental field of the National Horticultural Research Institute (NIHORT), Ibadan, Oyo State, Nigeria. NIHORT is located in the humid forest-savannah transition zone (210m above sea level, 7° 30′ N, 3° 54′ E) with a bimodal annual rainfall pattern of about 120–128 rainy days amounting to 1,200–1,400mm. Pan evaporation is between 1,550–1,600mm. The wet season is from March through October and the dry season from November through February with an annual maximum temperature ranging between 27°C and 34°C and an annual minimum temperature of 20–23°C (Ogungbenro and Morakinyo, 2014).

The eggplant accessions were first raised in a nursery and transplanted to the field after 35 days using a randomized complete block design with three replications. The plot size was 2 x 1m with a spacing of 0.5 x 0.6m between and within rows having 10 plants per plot. Manual weeding was carried out to reduce the competitiveness of soil nutrients. Fertilizer was not applied while insecticides (Cypermethrin) were used at the rate of 200ml/20l of water when needed to reduce damage caused by insects.

Phenotypic characterization

Phenotypic data collection was carried out on 5 uniform tagged plants out of 10 plants from each plot for the 20 accessions using 12 quantitative (number of branches, number of days to flowering, number of days to 50%

flowering, plant height at maturity, number of fruits per cluster, number of harvested fruits, weight of harvested fruits, petiole length, fruit length, fruit width, stem girth, pedicel length) and 10 qualitative traits (fruit colour, stem colour, petiole colour, leaf hairs, sepal colour, fruit colour, fruit shape, fruit position, fruit-end shape, presence/ absence of stripes). Physiochemical variables were iron, vitamin C and calcium, using the descriptor list for eggplant by the International Board for Plant Genetic Resources (IBPGR, 1990).

Table 1. Status, collection source and states of *Solanum aethiopicum* L. accessions collected in Nigeria

	Accessions	Status	Source	States
1	NHEPA01	Farmers cultivar	Local Market	Ogun
2	NHEPA03	Farmers cultivar	Local Market	Ogun
3	NHEPA10	Farmers cultivar	Local Market	Ogun
4	NHEPA12	Farmers cultivar	Farmers	Kogi
5	NHEPA17	Farmers cultivar	Farmers	Kogi
6	NHEPA19	Farmers cultivar	Farmers	Kogi
7	NHEPA23	Farmers cultivar	Farmers	Kogi
8	NHEPA35	Farmers cultivar	Farmers	Kogi
9	NHEPA36	Farmers cultivar	Farmers	Kogi
10	NHEPA38	Farmers cultivar	Farmers	Kogi
11	NHEPA39-1	Farmers cultivar	Farmers	Kogi
12	NHEPA39-2	Farmers cultivar	Farmers	Kogi
13	NHEPA39-3	Farmers cultivar	Farmers	Kogi
14	NHEPA51	Farmers cultivar	Farmers	Kaduna
15	NHEPA52	Farmers cultivar	Farmers	Kaduna
16	NHEPA53	Farmers cultivar	Farmers	Kaduna
17	NHEPA54	Farmers cultivar	Farmers	Kaduna
18	NHEPA55	Farmers cultivar	Farmers	Kaduna
19	NHEPA56	Farmers cultivar	Farmers	Kaduna
20	YALO	Farmers cultivar	Green seed company	Oyo

Calcium, iron and vitamin C determination

Fruit samples were dried in an oven at 600°C for 4 hours. Ashes and crucibles were previously decontaminated with a solution of 10% nitric acid at rest for a night and rinsed. Then, 10ml of 5% nitric acid was added to the sample, and this mixture was heated until complete dissolution of the ash which was then filtered. After the sample had reached room temperature, the solution was put into a 25ml volumetric flask and the volume supplemented with deionized water.

The determination of calcium and iron contents was performed according to AOAC METHOD 2005 using an atomic absorption spectrophotometer flame (BULKS SCIENTIFIC® model AA 240). Calibration curves for each element were plotted using standard mineral diluted with deionized water. All analyses were performed in triplicate; the results were expressed in milligrams per 100g (mg/100g) of sample on a dry basis.

The amount of vitamin C in analyzed samples was determined by titration using the method described by Mondal et al., (1995). About 0.5g of sample were soaked for 10 minutes in 40ml metaphosphoric acid-acetic acid (2%, w/v). The mixture was centrifuged at 3,000rpm for 20 minutes and the supernatant obtained was diluted and adjusted with 50ml of bi-distilled water. Ten (10)ml of this mixture was titrated to the endpoint with dichlorophenol-indophenol (DCPIP) 0.5g/l (AOAC. 1990).

Statistical analysis

Analysis of variances (ANOVA) was calculated using Plant Breeding Tools (ver.1.1.0, http://bbi.irri.org/product) to determine significant variations in quantitative characters among the eggplant genotypes. The estimate of co-efficient of variation (CV) was calculated using the standard formulae (Burton, 1952) and expressed in percentage. Inter-species diversity pattern was analyzed through Ward's minimum variance while correlation, dendrogram clustering and principal components analysis (PCA) were carried out using STAR software.

Results

The frequency distribution of qualitative traits observed in all 20 accessions is presented in Table 2. All the genotypes (100%) exhibited green stems, petioles and sepals. At the reproductive stage, 48.48% of the fruits had a white colour, 45.45% expressed lemon green while 3.03% were light green and 3.03% exhibited deep green fruit colour. Three prominent fruit shapes were observed: oval (51.51%), long (30.30%) and round (18.18%). All accessions exhibited perpendicular fruit position with 69.69% and 30.30% of the populations having pointed and flat ends respectively. The fruits of selected eggplant accessions are presented in Figure 1.

Table 3 lists the descriptive statistics measures of spread: mean, range, standard deviation and coefficient of variation (CV). The partitioning of the means revealed high significant variations for all traits at $P \leq 0.01$. For most traits, higher variations in terms of range and CV were observed in the nutritional data compared to the phenotypic data. The highest CV was recorded for calcium (43.91%) followed by average

Table 2. Qualitative traits of 20 *Solanum aethiopicum* accessions

	Traits	Modality	Frequency (%)
1	Stem colour	Green	100
2	Petiole colour	Green	100
3	Leaf hairs	Very few	100
4	Sepal colour	Green	100
5	Fruit colour	White	48.48
		Lemon green	45.45
		Light green	3.03
		Deep green	3.03
6	Fruit shape	Oval	51.51
		Long	30.3
		Round	18.18
7	Fruit position	Direct	100
8	Fruit end	Pointed	69.69
		Flat	30.3
9	Stripe presence	Present	100

Figure 1. Sample of fruits for selected eggplant accessions, where V04, V10, V12, V17, V19, V24, V29 and V35 represent NHEPA4, NHEPA10, NHEPA12, NHEPA17, NHEPA19, NHEPA24, NHEPA29 and NHEPA35 respectively.

number of fruits per plant (37.13%) and average yield per plant (32.21%). The top performers for selected yield-contributing traits and nutritional parameters are NHEPA54, NHEPA39-1, NHEPA10, NHEPA10, NHEPA1, NHEPA56, NHEPA23, for vitamin C, iron, calcium, days to flowering, number of branches, plant height at maturity and number of fruits per plant, respectively, while NHEPA54 was outstanding for high yield potential and vitamin C content. Accession NHEPA10 was the top performer for calcium and days to flowering while average number of fruits per cluster had NHEPA17, NHEPA19, NHEPA23 as the top performers.

Principal component analysis (PCA), which is a statistical technique used to emphasize variation and bring out strong patterns in data sets, was performed to show the traits that best contributed to the observed genetic variation. The eigenvalues and proportion of accounted variance for each variable are shown in Table

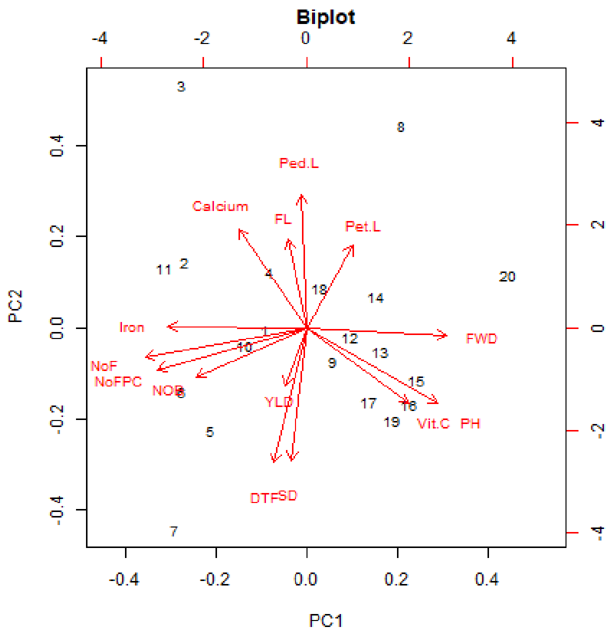

Figure 2. Distribution of 20 eggplant accessions for the first two principal components based on 14 quantitative traits. DTF, days to flowering; NoB, number of branches; PH, plant height at maturity; NoFPC, average number of fruits per cluster; NoF, average number of fruits per plant; YLD, average yield per plant; FL, fruit length; FWD, fruit width; SD, stem diameter; Pet.L, petiole length; Ped.L, pedicel length. Numbers 1-20 represent genotypes: 1, NHEPA01; 2, NHEPA03; 3, NHEPA10; 4, NHEPA12; 5, NHEPA17; 6, NHEPA19; 7, NHEPA23; 8, NHEPA35; 9, NHEPA36; 10, NHEPA38; 11, NHEPA39-1; 12, NHEPA39-2; 13, NHEPA39-3; 14, NHEPA51; 15, NHEPA52; 16, NHEPA53; 17, NHEPA54; 18, NHEPA55; 19, NHEPA56; 20, Yalo.

4. PC1 had an eigenvalue of 4.027 while PC2, PC3 and PC4 had eigenvalues of 2.889, 1.861 and 1.363, respectively. The first four principal component axes (PCA) accounted for 28.77%, 20.64%, 13.29%, 9.73% of the total variation individually and, cumulatively, 72.42% of the total variability while the first two PCs contributed 49.41% (Figure 2). The first PC axis, which accounted for the highest proportion (28.77%) of the variability, was dominated by traits with relatively high factor scores (> 2.60) corresponding to number of branches, plant height at maturity, number of fruits per cluster, number of fruits per plant, and fruit width. The second PC axis was dominated by days to flowering, fruit length, stem diameter, petiole length and pedicel length. Also, the third PC axis was dominated by average yield per plant, fruit length, stem diameter, petiole length and pedicel length while the fourth PC axis was dominated by days to flowering, number of branches, fruit length, fruit width and petiole length.

Correlations between pairs of quantitative variables are recorded in Table 5. There was no significant association between the nutritional parameters except for a negative moderate significant association between vitamin C and iron ($r = -0.50$, $P < 0.05$). Iron content correlated positively with number of branches ($r =$

Table 3. Nutritional and phenotypic data for relevant yield-contributing traits on 20 African eggplant accessions, including descriptive statistics measures of spread. Means vary significantly for all traits at P = 0.05. DTF, days to flowering; NoB, number of branches; PH, plant height at maturity; NoFPC, average number of fruits per cluster; NoF, average number of fruits per plant; YLD, average yield per plant; FL, fruit length; FWD, fruit width; StemD, stem diameter; Pet.L, petiole length; Ped.L, pedicel length; CV, coefficient of variation; SD, standard deviation.

Nutritional data (mg/100g)				Phenotypic data										
Accessions	Vit.C	Iron	Calcium	DTF	NoB	PH (cm)	NoFPC	NoF	YLD (g)	FL (mm)	FWD (mm)	StemD (mm)	Pet.L (mm)	Ped.L (mm)
NHEPA01	3.11	0.43	7.73	109.12	7.13	57.66	2.70	58.55	1370.10	65.90	37.37	19.50	23.08	20.01
NHEPA03	2.02	0.47	4.47	104.00	5.79	48.58	4.98	74.61	1699.17	67.31	32.45	11.84	18.57	15.17
NHEPA10	2.90	0.50	14.24	97.91	4.39	46.31	4.49	81.03	1320.72	58.54	22.73	10.44	19.96	19.06
NHEPA12	2.90	0.25	8.88	103.04	5.01	54.58	4.49	81.68	1673.41	50.49	36.32	12.57	20.24	15.06
NHEPA17	3.15	0.43	4.86	109.44	4.70	50.69	5.79	65.29	1726.48	45.37	32.66	17.58	14.72	14.86
NHEPA19	3.99	0.50	10.69	106.56	5.48	52.47	5.79	76.38	1522.60	44.91	33.05	13.76	12.93	11.78
NHEPA23	4.81	0.46	4.42	107.52	6.42	58.80	5.79	111.71	1731.05	45.62	26.84	19.12	13.96	12.58
NHEPA35	3.78	0.25	7.53	100.79	3.92	60.09	3.34	36.87	1666.91	78.18	41.88	13.07	26.63	22.54
NHEPA36	4.24	0.18	5.62	104.96	5.48	60.42	3.51	71.56	1747.09	57.16	31.49	15.55	18.09	15.84
NHEPA38	3.15	0.42	4.10	104.00	6.26	57.34	4.16	78.14	1682.95	54.81	32.11	14.56	19.42	15.18
NHEPA39-1	3.53	0.51	12.77	102.08	6.16	52.80	4.65	77.66	2019.68	76.44	30.42	16.02	11.51	17.77
NHEPA39-2	3.92	0.43	6.85	102.72	5.84	62.52	4.11	45.54	1309.34	51.03	64.21	12.77	15.50	14.43
NHEPA39-3	5.80	0.33	11.27	103.36	5.32	61.12	4.21	34.94	989.17	53.52	60.30	14.91	13.60	14.12
NHEPA51	4.28	0.36	7.53	99.19	5.01	60.69	2.48	36.22	2035.71	47.56	38.84	12.26	15.06	14.04
NHEPA52	4.84	0.21	5.95	105.28	4.80	60.80	3.13	35.26	1666.91	56.52	45.62	16.11	21.60	12.10
NHEPA53	4.95	0.37	5.45	103.68	3.66	62.52	2.59	47.15	2420.55	54.42	51.03	18.11	16.01	14.26
NHEPA54	6.01	0.25	3.31	104.00	4.70	58.53	3.56	53.89	2805.39	75.11	36.08	15.37	15.68	13.21
NHEPA55	2.58	0.45	7.04	102.08	5.43	59.06	3.24	64.81	1522.60	56.94	59.61	14.07	21.02	13.78
NHEPA56	3.50	0.36	4.29	104.96	4.70	66.96	3.56	44.26	2335.03	37.03	51.94	16.58	20.99	14.34
YALO	5.05	0.21	4.11	104.00	3.61	57.01	1.88	21.45	219.29	47.08	70.86	11.87	16.18	16.30
Mean	3.93	0.37	7.06	103.93	5.19	57.45	3.92	59.85	1673.21	56.2	41.79	14.8	17.74	15.32
Min	2.02	0.18	3.31	97.91	3.61	46.31	1.88	21.45	219.29	37.03	22.73	10.44	11.51	11.78
Max	6.01	0.51	14.24	109.44	7.13	66.96	5.79	111.71	2805.39	78.18	70.86	19.50	26.63	22.54
CV	27.23	29.73	43.91	2.78	17.92	8.95	28.83	37.13	32.21	20.12	32.30	17.23	21.76	17.62
SD	1.07	0.11	3.10	2.89	0.93	5.14	1.13	22.22	538.91	11.31	13.5	2.55	3.86	2.70

Table 4. Eigenvalues and the proportion of accounted variance for each trait across 20 accessions of eggplant for the first four principal components (PC). DTF, days to flowering; NoB, number of branches; PH, plant height at maturity; NoFPC, average number of fruits per cluster; NoF, average number of fruits per plant; YLD, average yield per plant; FL, fruit length; FWD, fruit width; StemD, stem diameter; Pet.L, petiole length; Ped.L, pedicel length.

Variables	PC1	PC2	PC3	PC4
Vitamin C	0.2777	-0.2423	0.1295	-0.3933
Iron	-0.3759	0.0049	0.1498	0.0992
Calcium	-0.1837	0.3163	0.2492	-0.1366
DTF	-0.0896	-0.4322	-0.1783	0.3571
NoB	-0.2992	-0.1570	-0.1479	0.2603
PH	0.3553	-0.2406	-0.1429	0.0086
NoFPC	-0.4063	-0.1331	0.1653	-0.0500
NoF	-0.4371	-0.0926	-0.0639	-0.0384
YLD	-0.0591	-0.1850	-0.3516	-0.5664
FL	-0.0488	0.2823	-0.4034	-0.3045
FWD	0.3804	-0.0242	0.2446	0.2843
StemD	-0.0412	-0.4246	-0.3557	0.0549
Pet.L	0.1243	0.2639	-0.4563	0.3129
Ped.L	-0.0135	0.4255	-0.3351	0.1488
Proportion of Variance	0.2877	0.2064	0.1329	0.0973
Cumulative Proportion	0.2877	0.494	0.6269	0.7242
EigenValues	4.0274	2.8891	1.8605	1.3625

0.487, $P < 0.05$), average number of fruits per plant ($r = 0.532$, $P < 0.05$) and number of fruits per cluster ($r = 0.551$, $P < 0.05$). Plant height had a negative but moderate significant association with iron ($r = -0.461$, $P < 0.05$) and calcium ($r = -0.407$, $P < 0.05$) but was positively correlated with vitamin C ($r = 0.492$, $P < 0.05$). The strongest and most persistent correlation was recorded for association between fruit width and plant height ($r = 0.574$, $P < 0.01$) and number of fruits per plant ($r = -0.737$, $P < 0.01$); stem diameter with days to flowering ($r = 0.734$, $P < 0.01$). A positive significant correlation was observed between pedicel length and fruit length ($r = 0.561$, $P < 0.05$), and between pedicel length and petiole length ($r = 0.528$, $P < 0.05$).

Based on variation in the phenotypic parameters the 20 eggplant accessions were clustered into four unique groups (Figure 3). Clusters I and II contained seven and three accessions, respectively, while clusters III and IV both had five accessions. Means of variables, ranges and standard deviation for each cluster are presented in Table 6. Cluster III was unique in having accessions with high vitamin C content and high yield potential while clusters II was characterized by accessions with high iron content, an increased number of fruits per plant and a higher number of fruits per cluster. Clusters I and IV were characterized by early maturing accessions dominated by top-performing accessions in fruit-related traits (fruit length and fruit width respectively).

Discussion

The success of genetic improvement programmes in enhancing desired traits of interest to farmers and breeders depends on the magnitude of genetic variability available in the germplasm and the extent to which the desirable traits are heritable. The high significant variation observed for most qualitative and quantitative traits considered in this study establishes the feasibility of imposing selections towards the improvement of desired traits of interest in African eggplant. Frequency distribution among the qualitative traits with a preponderance of fruits characterized by white to cream colours and lemon green suggests that the majority of the accessions belong to the *S. aetihiopicum* group. This supports earlier reports by Osei *et al* (2010) that eggplant accessions belonging to *S. aethiopicum* had mixtures involving cream white to light yellow fruits; thus, fruit colour combined with fruit shape might be considered a strong phenotypic marker in characterizing eggplant taxa in Africa.

The high CVs and range for some of the quantitative characters could be attributed to genetic variations from natural crossings and ecogeographical factors. The maximum and minimum mean values could present a rough estimate of the variation in magnitude of variability present among genotypes. Traits such as average number of fruits per plant and fruit width that exhibited a high range of variation had more scope for improvement in the eggplant population.

The principal component analysis identified traits that contributed the most to observed variations within a group of entries (Sneath and Sokal, 1973; Grittins, 1975). The first four principal component axes in the current study accounted for 72.42% of the total variability measured. The first principal component analysis had the highest discriminating ability (contributing 28.77% out of 79.47% of variability from the first four axes) and was dominated by traits with relatively high factor scores (> 2.60) corresponding to number of branches, plant height at maturity, number of fruits per cluster, number of fruits per plant, and fruit width. This is in agreement with Clifford and Stephen (1975) who reported that the first principal component axis was the most important in reflecting the variation patterns among accessions and that the characters highly associated with these should be used in differentiating the accessions. Furthermore, this is in line with the findings of Iezzoni and Pritts (1991) and Chikaleke (2018) who reported that the implication of principal components can be accessed from the contribution of the different variables to each principal component (PC).

Correlation analysis is used to identify the relationship between variables (Anshori *et al*, 2018) and to facilitate the identification of elite traits to rely on in selection exercises of a breeding programme. The positive significant association between iron content, number of branches, number of fruits per cluster and number of fruit per plant; number of fruit per plant with number

Table 5. Correlation coefficients for nutritional and phenotypic parameters of the20 eggplant accessions evaluated. *, significant at $P \leq 0.05$, **, significant at $P \leq 0.01$, DTF, days to flowering; NoB, number of branches; PH, plant height at maturity; NoFPC, average number of fruits per cluster; NoF, average number of fruits per plant; YLD, average yield per plant; FL, fruit length; FWD, fruit width; StemD, stem diameter; Pet.L, petiole length; Ped.L, pedicel length.

Traits	Vit.C	Iron	Calcium	DTF	NoB	PH	NoFPC	NoF	YLD	FL	FWD	StemD	Pet.L
Iron	-0.500*												
Calcium	-0.162	0.377											
DTF	0.064	0.028	-0.446										
NoB	-0.308	0.487*	0.091	0.370									
PH	0.492*	-0.461*	-0.407*	0.051	-0.100								
NoFPC	-0.279	0.551*	0.225	0.293	0.370	-0.537*							
NoF	-0.418	0.532*	0.151	0.200	0.545*	-0.510*	0.730**						
YLD	0.063	0.040	-0.233	-0.001	-0.007	0.213	0.086	0.193					
FL	-0.045	-0.050	0.181	-0.260	0.097	-0.229	-0.127	0.005	0.217				
FWD	0.319	-0.316	-0.200	-0.085	-0.339	0.574**	-0.554*	-0.737**	-0.410	-0.255			
StemD	0.239	0.065	-0.303	0.734**	0.336	0.350	0.068	0.174	0.363	-0.058	-0.125		
Pet.L	-0.394	-0.315	-0.142	-0.123	-0.133	0.154	-0.387	-0.186	-0.032	0.256	0.029	-0.099	
Ped.L	-0.340	-0.013	0.313	-0.275	-0.061	-0.212	-0.236	-0.095	-0.212	0.561*	-0.147	-0.147	0.528*

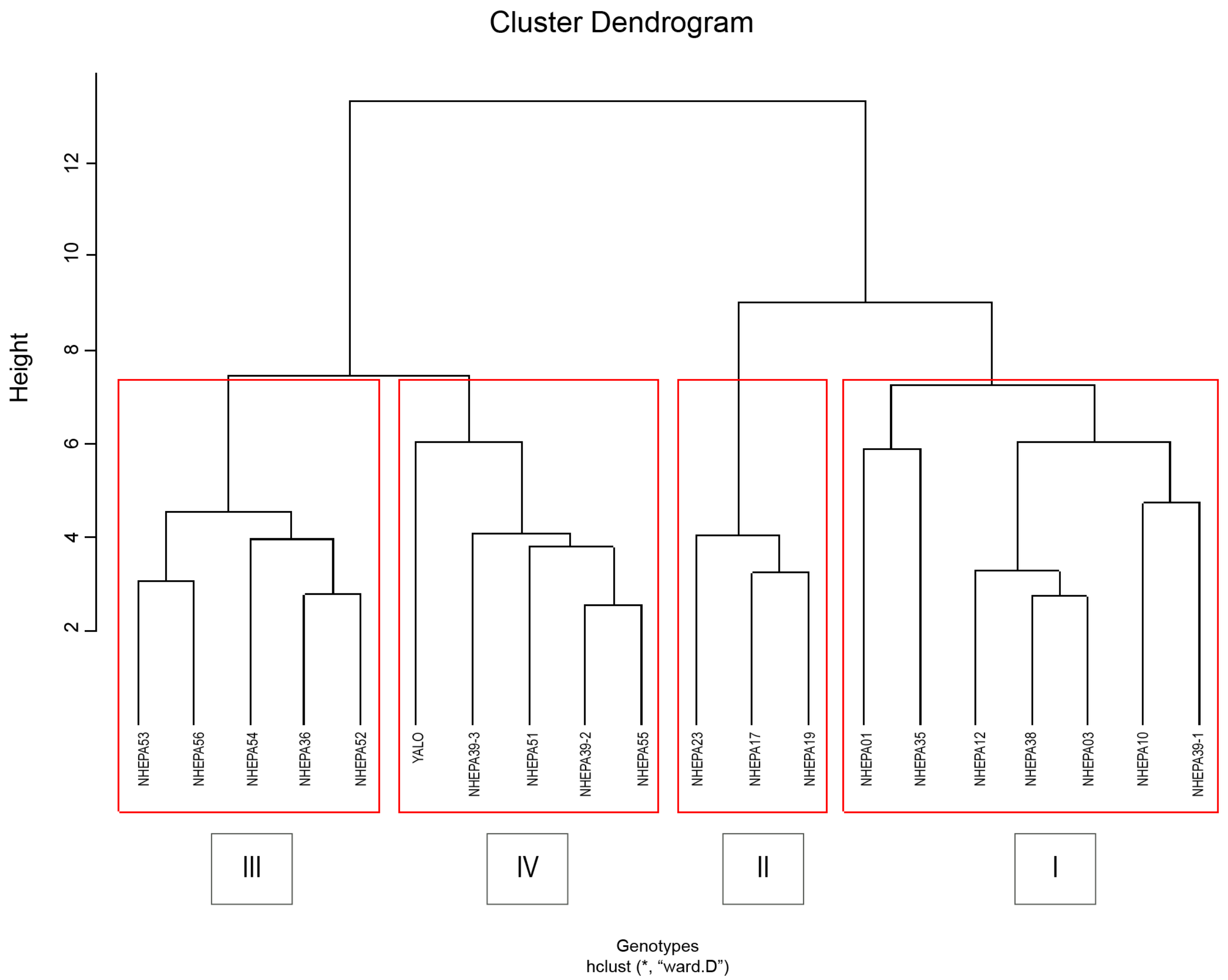

Figure 3. Cluster dendrogram showing the relationships among the 20 eggplant accessions with cluster tree cut value at 7.3.

of branches and number of fruits per cluster; fruit width and plant height at maturity; stem diameter and days to flowering; pedicel length with fruit length and with petiole length will facilitate selection of eggplant accessions with a good combination of these traits. The significant positive correlation displayed by these traits is in agreement with Dhaka and Soni (2013) who reported a positive significant association between yield and yield-related traits. However, where the traits had significant negative correlation coefficients (vitamin C and iron content, plant height at maturity and iron content, plant height at maturity and calcium content, number of fruits per cluster and plant height at maturity, number of fruits per plant and plant height at maturity, fruit width with number of fruits per cluster and with number of fruits per plant) indicates that an increase in one trait might lead to a decrease in the other trait or vice versa. This is in agreement with Mazer *et al* (1999) and Nyadanu and Lowor (2015) who reported that traits with significant inverse relationships could be improved independently among eggplant accessions in Ghana. However, selecting tall plants in this eggplant population might result in an indirect selection for low calcium content, while favouring increased iron content will lead to selecting genotypes with low vitamin C. Selection pressure can be deployed for an increased number of fruits per plant to simultaneously increase iron content and number of branches. Similar observations were reported by Arivalagan *et al* (2013) and Nyadanu and Lowor (2015) in their earlier works on mineral composition and morphological characterization of eggplant.

The cluster analysis emphasized further the relative contribution of various quantitative parameters to the total variability. The grouping of accessions in each cluster based on quantitative descriptors could be attributed to the fact that these accessions share some similarities. The high-yielding accessions in cluster III (NHEPA54) expressing high vitamin C and iron content could be deployed as progenitors to combine with eggplant genotypes from cluster I and create a new gene combination with improved calcium content and yield potential. Creating new eggplant varieties with high-yield potential and increased vitamins and minerals (iron, calcium and vitamin C) will not only increase farmers' income but will also help to reduce health challenges associated with hidden hunger among the

Table 6. Means and standard deviations for various traits in different clusters. The clusters with the highest values for each trait are highlighted in bold font. DTF, days to flowering; NoB, number of branches; PH, plant height at maturity; NoFPC, average number of fruits per cluster; NoF, average number of fruits per plant; YLD, average yield per plant; FL, fruit length; FWD, fruit width; StemD, stem diameter; Pet.L, petiole length; Ped.L, pedicel length.

Trait	Cluster	Min	Max	Mean	StdDev	Trait	Cluster	Min	Max	Mean	StdDev
Vit.C	I	2.02	3.78	3.06	0.56	NoF	I	36.87	81.68	69.79	16.50
Vit.C	II	3.15	4.81	3.98	0.83	**NoF**	**II**	**65.29**	**111.71**	**84.46**	**24.24**
Vit.C	**III**	**3.50**	**6.01**	**4.71**	**0.93**	NoF	III	35.26	71.56	50.42	13.58
Vit.C	IV	2.58	5.80	4.33	1.22	NoF	IV	21.45	64.81	40.59	16.03
Iron	I	0.25	0.51	0.40	0.11	YLD	I	1,320.72	2,019.68	1,633.28	233.03
Iron	**II**	**0.43**	**0.50**	0.46	0.04	YLD	II	1,522.60	1,731.05	1,660.04	119.05
Iron	III	0.18	0.37	0.27	0.09	**YLD**	**III**	**1,666.91**	**2,805.39**	**2,194.99**	**480.25**
Iron	IV	0.21	0.45	0.36	0.10	YLD	IV	219.29	2,035.71	1,215.22	674.45
Calcium	**I**	**4.10**	**14.24**	**8.53**	**3.84**	**FL**	**I**	**50.49**	**78.18**	**64.52**	**10.53**
Calcium	II	4.42	10.69	6.66	3.50	FL	II	44.91	45.62	45.30	0.36
Calcium	III	3.31	5.95	4.92	1.10	FL	III	37.03	75.11	56.05	13.50
Calcium	IV	4.11	11.27	7.36	2.56	FL	IV	47.08	56.94	51.23	4.14
DTF	I	97.91	109.12	102.99	3.44	FWD	I	22.73	41.88	33.33	6.08
DTF	II	106.56	109.44	107.84	1.47	FWD	II	26.84	33.05	30.85	3.48
DTF	III	103.68	105.28	104.58	0.69	FWD	III	31.49	51.94	43.23	9.10
DTF	**IV**	**99.19**	**104.00**	**102.27**	**1.86**	**FWD**	**IV**	**38.84**	**70.86**	**58.76**	**12.00**
NoB	I	3.92	7.13	5.52	1.13	StemD	I	10.44	19.50	14.00	3.02
NoB	II	4.70	6.42	5.53	0.86	StemD	II	13.76	19.12	16.82	2.76
NoB	III	3.66	5.48	4.67	0.65	StemD	III	15.37	18.11	16.34	1.10
NoB	IV	3.61	5.84	5.04	0.85	StemD	IV	11.87	14.91	13.18	1.28
PH	I	46.31	60.09	53.91	5.03	**Pet.L**	**I**	**11.51**	**26.63**	**19.92**	**4.62**
PH	II	50.69	58.80	53.99	4.26	Pet.L	II	12.93	14.72	13.87	0.90
PH	III	58.53	66.96	61.85	3.19	Pet.L	III	15.68	21.60	18.47	2.74
PH	IV	57.01	62.52	60.08	2.11	Pet.L	IV	13.60	21.02	16.27	2.82
NoFPC	I	2.70	4.98	4.12	0.81	**Ped.L**	**I**	**15.06**	**22.54**	**17.83**	**2.89**
NoFPC	**II**	**5.79**	**5.79**	**5.79**	**0**	Ped.L	II	11.78	14.86	13.07	1.60
NoFPC	III	2.59	3.56	3.27	0.42	Ped.L	III	12.10	15.84	13.95	1.40
NoFPC	IV	1.88	4.21	3.18	1.01	Ped.L	IV	13.78	16.30	14.53	1.01

rural and urban populace in the region. Selection and hybridization of genotypes from clusters I and IV such as NHEPA35 and Yalo will produce new segregants characterized by bigger fruits with increased iron concentration.

Conclusion

This study successfully characterized 20 eggplant accessions for phenotypic and nutritional traits of interest and identified top-performing new eggplant accessions with unique traits that could be deployed in crosses to facilitate the step-wise creation of new eggplant varieties with the best combination of desired traits. Furthermore, selection in favour of yield-increasing traits such as number of fruits per plant and number of fruits per cluster that showed a significant positive correlation with iron, will lead to selecting genotypes with increased iron content and higher yield potential simultaneously. Top-performing accessions for iron (NHEPA39-1), calcium (NHEPA39-1) and vitamin C content (NHEPA54) identified in this study should be deployed for hybridization to create new eggplant varieties with improved nutritional content.

Author contributions

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Olofintoye Temidayo Joseph A, study design and execution.

Conflict of interest statement

The authors declare no conflict of interest. All authors approved the final manuscript.

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