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Assessment of genetic diversity in horticultural and morphological traits among papaya (*Carica papaya*) accessions in Nigeria

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Assessment of genetic diversity in horticultural and morphological traits among papaya (Carica papaya) accessions in Nigeria.

Abstract — Introduction. Although Nigeria has the largest area planted to papaya (*Carica papaya*) in the world, this country has one of the lowest yields reported. A good knowledge of the available genetic variability is a first step in the exploitation of this crop for the development of improved cultivars. Until now, there has been no report on genetic diversity in the papaya accessions available in Nigeria. **Materials and methods**. Sixty accessions of papaya obtained from ten districts in Southeastern Nigeria were evaluated using 21 variables following the IBPGR descriptors for papaya. The data was subjected to descriptive statistics, analysis of variance (ANOVA), and multivariate analysis including principal component (PCA) and cluster analysis. **Results**. ANOVA showed significant variation among accessions in fruit length, fruit diameter, fruit edible volume, leaf petiole length, fruit shape, flesh color and central cavity shape. The first seven principal component axes accounted for 73.47% of total variation and five cluster groups were generated from cluster analysis. Accessions were classified into two broad groups corresponding to female (15%) and hermaphrodite (85%) plants. A strong and highly significant correlation was found between leaf blade and petiole length and fruit characteristics such as length, diameter and fruit edible volume, a variable derived for the first time in this study. There was a preponderance of yellow flesh color in fruits from female plants and reddish-orange flesh color among hermaphrodite plants. **Discussion and conclusions**. Each of the five cluster groups consists of accessions that could be used as parents in further breeding or clones for vegetative propagation. This study revealed significant variation that could be exploited for genetic improvement of papaya in Nigeria. It is recommended that a focused papaya genetic improvement program should be pursued to exploit the genetic variation available.

Nigeria / *Carica papaya* / genetic variation / statistical methods

Évaluation de la diversité génétique des caractéristiques horticoles et morphologiques au sein d'accessions de papaye (Carica papaya) au Nigéria.

Résumé — Introduction. Bien que le Nigéria ait la plus grande superficie plantée en papayers (*Carica papaya*) dans le monde, ce pays aurait l'un des rendements les plus faibles. Une bonne connaissance de la variabilité génétique disponible serait une première étape pour l'exploitation de cette culture afin de développer des cultivars améliorés. Jusqu'à présent, il n'existait aucun rapport sur la diversité génétique des accessions des papayers disponibles au Nigéria. **Matériel et méthodes**. Soixante accessions de papayers obtenus à partir de dix districts du sud-Nigeria ont été évalués en utilisant 21 variables définies à partir des descripteurs pour le papayer publiés par l'IBPGR. Les données ont été soumises à des statistiques descriptives, à une analyse de variance, à une analyse multivariée, dont une analyse en composantes principales (ACP) et une analyse typologique. **Résultats**. L'analyse de variance a montré une variation significative entre les accessions pour la longueur, le diamètre et le volume comestible du fruit, ainsi que pour la longueur du pétiole des feuilles, et pour la forme, la couleur de la chair et la forme de la cavité centrale du fruit. Les sept premiers axes de l'ACP ont représenté 73,47 % de la variation totale et cinq groupes ont été générés à partir de l'analyse typologique. Les accessions ont été classées en deux grands groupes correspondant aux plantes femelles (15 %) et aux plantes hermaphrodites (85 %). Une forte et hautement significative corrélation a été trouvée entre la longueur du limbe et la longueur du pétiole et entre des caractéristiques du fruit telles que la longueur, le diamètre et le volume comestible des fruits, une variable définie pour la première fois dans cette étude. Il y a eu une prépondérance de fruits à chair jaune dans les plantes femelles et à chaire rouge-orange parmi les plantes hermaphrodites. **Discussion et conclusions**. Chacun des cinq groupes mis en évidence contient des accessions qui pourraient être utilisées en tant que parents pour une sélection à venir ou en clone pour une multiplication végétative. Notre étude a révélé une variation significative qui pourrait être exploitée pour l'amélioration génétique du papayer au Nigeria. Il est recommandé qu'une amélioration génétique ciblée du papayer soit envisagée afin d'exploiter la variabilité génétique disponible.

Nigéria / *Carica papaya* / variation génétique / méthode statistique

1. Introduction

Pawpaw, *Carica papaya,* the only species in the genus *Carica*, is a dicotyledenous, polygamous (with male, female or hermaphrodite flowers on the same plant) plant species belonging to the small family Caricaceae. It is a diploid species with a small genome of 372 megabases (Mb) [1] and nine pairs of chromosomes ($2n$ = 18)[1]. It has a short generation time, 9–15 months, flowers continuously throughout the year and carries a primitive sex chromosome system [2]. Papaya ranked first among 38 common fruits on a nutritional score basis in percentage of the United States recommended daily allowance (RDA) for vitamin A and vitamin C [3]. Consumption of papaya fruit is recommended for preventing vitamin A deficiency, a cause of childhood blindness in tropical and subtropical developing countries.

Papaya, which originated from the lowlands of Eastern Central America, from Mexico to Panama [3], was first cultivated in Mexico several centuries before the emergence of the Mexo-American classic cultures. It is one of the most cultivated and exploited fruit species in the tropical and warmer subtropical regions around the world [4, 5]. *Carica papaya* is a large tree-like plant, with a single stem growing from 5–10 m (16–33 ft) tall, with spirally arranged leaves confined to the top of the trunk. The petioles are long, hollow and pale green or purple-tinged in color [6, 7]. Green *papaya* fruit and the tree's latex are both rich in an enzyme called papain, a protease which is useful in tenderizing meat and other proteins. Its ability to break down tough meat fibers was used for thousands of years by indigenous Americans. The *papaya* fruits, seeds, latex and leaves also contain carpain, an anthelmintic alkaloid (a drug that removes parasitic worms from the body) which can be dangerous in high doses[2].

The fruit of papaya is a fleshy berry, variable in weight from 200 g to 9 kg [8]. The fruit shape is a sex-linked character. While fruits from female flowers are spherical to ovoid, those from hermaphrodite flowers are long, cylindrical or pyriform. The flesh of ripe fruit is yellow, orange or red in color. The color is related to carotenoids present in papaya. In red ripe papaya fruit, three provitamin A carotenoids (beta-carotene, beta-carotene-5-6-epoxide and beta-cryptoxanthin) and two nonprovitamin A carotenoids (zeta-carotene and lycopene) are found. In yellow ripe papaya fruit, only beta-carotene, beta-cryptoxanthin and zeta-carotene are found. Papaya seeds are in the ovarian cavity, which is larger in female fruits than in hermaphrodites [8, 9].

The world production of papaya was estimated to be around 9.1 Mt in 2008[3]. Nigeria accounts for the world's third largest production with 765,000 t after India and Brazil with (2.7 and 1.9) Mt, respectively. Although Nigeria has the largest area planted to papaya, with some 92,500 ha, it records the lowest productivity of 8.3 $t{\cdot}ha^{-1}$ compared with Indonesia's 72.7 $t{\cdot}ha^{-1}$, Brazil's 51.7 $t{\cdot}ha^{-1}$ and Guatemala's 52.7 $t{\cdot}ha^{-1}$. Although most of Nigeria's production is consumed locally, unlike Mexico and Brazil, with significant export of around (101,000 and 32,000) t, there is a huge potential for export[3]. The United States followed by the Netherlands, the United Kingdom, Canada and Germany are the largest importers of papaya, with a total import value in excess of US $145 M in 2007 alone.

Papaya is usually grown by small farmers and commercial farmers for local and foreign markets. The medium- and large-fruited varieties with yellow and red flesh are often preferred for local markets. On the other hand, the small- and medium-sized fruits with yellow and red flesh are preferred for export [10–12]. Uniformity in size and ripeness is a major market value for export fruits [10].

A low level of polymorphism is reported in the existing germplasm [13, 14]. Genetic breeding programs must therefore be

[1] Bennett M.D., Leitch I.J., Plant DNA C-values Database, http://data.kew.org/Cvalues/homepage.html (Release 4.0, October 2005).

[2] http://www.nal.usda.gov/fnic/foodcomp/

[3] FAOSTAT, FAO - Statistics online website, 2004, 2007, 2008), http://faostat.fao.org (accessed 24 March 2011).

reinforced to provide a broader genetic base and to develop varieties with tolerance or resistance to the main diseases, such as ringspot and the sticky disease virus, besides desirable agronomic characteristics [15]. Prominent among desired traits in new cultivars are fruit phenotypes such as fruit shape, taste, size, flesh color, firmness and uniformity as well as agronomic characteristics such as fruit column compaction, yield and disease resistance [16]. Recently, high papain levels have become an important trait for industrial usage [17].

Although molecular marker studies tend to show limited diversity in the papaya germplasm [14, 18], recent studies showed significant diversity in morphological and horticultural traits among Kenyan, Caribbean and Venezuelan papaya germplasm accessions [19, 20]. In Nigeria, with the largest area planted to papaya in the world, there has been no report to date on the extent of the genetic diversity of the papaya germplasm grown or maintained in farmers' fields. As a first step, therefore, this study was conducted to determine agro-morphological trait variation among different types of *Carica papaya* grown in Southeastern Nigeria. This is an important effort towards genetic improvement of papaya in Nigeria, especially in terms of yield, which is reported to be the lowest in the world.

2. Materials and methods

2.1. Papaya germplasm collection in study sites

The sixty papaya accessions used in this study were obtained from germplasm collections locally maintained by farmers [Akpanim, Bataba, Daniel Hogan, Ebrutu, Eastern-Highway Lane, Eteta Ita, Goldie, Inyang-Edem, Orok Orok, Umoh Edem, University of Calabar campus (= Unical)] in ten districts of Cross River State located in the humid forest vegetation zone of Nigeria (*figure 1*; *table I*). The latitude, longitude and altitude of collection sites were obtained using a global positioning system (GPS, Etrex Legend, Garmin).

2.2. Data collection on morphological and horticultural traits

The International Board for Plant Genetic Resources (IBPGR, 1988) descriptor list for papaya was used in characterizing the sixty (60) pawpaw accessions. Twenty-one descriptors were used for characterization of the tree, fruit, leaf and flower parts following procedures outlined for sampling in the IBPGR descriptor list. Five replicates were taken to represent each accession for quantitative traits such as fruit length, fruit diameter, central cavity diameter, leaf length and petiole length. Qualitative traits including fruit shape, stalk-end fruit shape, shape of central cavity, stem color, color of mature leaf petiole, fruit skin color, fruit flesh color, flower color, tree habit, flower size and skin color of immature fruit were determined by careful observation and comparison with the IBPGR descriptor. Tree habit was also recorded as either single- or multiple-stemmed for each accession. Mature pawpaw fruits were carefully harvested and measurement was taken of the fruit length and other traits at maturity such as the flesh color, among others. A kitchen knife was used to cut the fruit at the broadest part into two so as to obtain the diameter of the fruits and the fruit central cavity diameter. A digital camera was used to take photographs of the fruit shapes and fruit central cavity.

Some horticultural traits of importance were also deduced for analysis. These were the fruit length to breadth ratio, petiole to leaf length ratio and fruit edible volume (FEV), given as the difference between total fruit volume and central cavity volume as defined by a constant, K, the 'Edibility constant'. The equation used in deriving the FEV was: FEV = $[\pi \times l \times (R^2 - r^2)] \times K$, where R = fruit radius (half the fruit diameter), r = radius of fruit central cavity, l = fruit length, π = 3.142 and K = 1 – (fruit central cavity diameter ÷ fruit length).

Figure 1.
Location of Calabar metropolis in Cross River State, Nigeria, where the studied papaya accessions were collected.

Table I.
Accession code, location, altitude, longitude and latitude of 60 papaya accessions studied in Nigeria.

Code	Location	Attitude (m)	Longitude (E)	Latitude (N)
AKPA-1	Akpanim	46	8° 20.52’	4° 56.73’
AKPA-2	Akpanim	45	8° 20.51’	4° 56.70’
BAT-1	Bataba	61	8° 20.18’	4° 57. 05’
BAT-2	Bataba	42	8° 20.14’	4° 57.10’
BAT-3	Bataba	46	8° 20.13’	4° 57.08’
DAH-1	Daniel Hogan	34	8° 20.50’	4° 56.55’
DAH-2	Daniel Hogan	32	8° 20.51’	4° 56.53’
DAH-3	Daniel Hogan	30	8° 20.50’	4° 56.53’
DAH-4	Daniel Hogan	31	8° 20.50’	4° 56.52’
DAH-5	Daniel Hogan	32	8° 20.49’	4° 57.52’
EBRU-1	Ebrutu	43	8° 20.16’	4° 56.73’
EBRU-2	Ebrutu	21	8° 20.19’	4° 57.03’
EHW-1	Eastern Highway	39	8° 20.61’	4° 56.92’
EHW-2	Eastern Highway	49	8° 20.25’	4° 56.87’
EHW-3	Eastern Highway	57	8° 20.24’	4° 56.87’
EHW-4	Eastern Highway	41	8° 20.16’	4° 56.73’
ETEI-1	Eteta Ita	20	8° 19.94’	4° 57.74’
GOLD-1	Goldie	36	8° 19.95’	4° 57.75’
GOLD-2	Goldie	38	8º 19.74’	4° 57.25’
GOLD-3	Goldie	44	8° 19.75’	4° 57.24’
INYE-1	Inyang Edem	18	8° 19.69’	4° 55.75’
INYE-2	Inyang Edem	21	8º 19.69’	4° 55.76’
INYE-3	Inyang Edem	16	8° 19.69’	4° 55.74’
INYE-4	Inyang Edem	26	8° 19.26’	4° 55.65’
INYE-5	Inyang Edem	53	8° 20.27’	4° 56.70’
INYE-6	Inyang Edem	26	8° 20.46’	4° 56.50’
INYE-7	Inyang Edem	16	8° 19.63’	4° 55.63’
OROK-1	Orok Orok	40	8° 21.06’	4° 56.91’
OROK-2	Orok Orok	45	8° 20.61’	4° 56.85’
UME-1	Umoh Edem	35	8° 20.89’	4° 56.65’
UME-2	Umoh Edem	20	8° 19.69’	4° 55.77’
UME-3	Umoh Edem	10	8° 19.56’	4° 55.63’
UME-4	Umoh Edem	18	8° 19.57’	4° 55.64’
UME-5	Umoh Edem	21	8° 19.49’	4° 55.54’
UNI-1	Unical	21	8° 20.72’	4° 56.81’
UNI-10	Unical	20	8° 20.75’	4° 56.56’
UNI-11	Unical	37	8° 20.68’	4° 56.55’
UNI-12	Unical	19	8º 20.91’	4° 56.39’
UNI-13	Unical	18	8° 20.93’	4° 56.37’
UNI-14	Unical	18	8° 21.08’	4° 56.41’
UNI-15	Unical	15	8° 21.06’	4° 56.41’
UNI-16	Unical	19	8° 21.20’	4° 56.69’
UNI-17	Unical	13	8° 21.19’	4° 56.74’
UNI-18	Dr. Ekong	24	8° 19.89’	4° 57.47’
UNI-19	Dr. Ekong	26	8° 19.89’	4° 57.46’
UNI-2	Unical	43	8° 21.04’	4° 57.05’
UNI-20	Dr. Ekong	29	8° 19.90’	4° 57.46’
UNI-21	Unical	44	8° 20.73’	4° 56.79’
UNI-22	Unical	44	8° 20.73’	4° 56.78’
UNI-23	Unical	33	8° 20.82’	4° 56.83’
UNI-24	Unical	35	8° 20.82’	4° 56.84’
UNI-25	Unical	30	8° 20.82’	4° 56.83’
UNI-26	Unical	60	8° 20.77’	4° 56.85’
UNI-3	Unical	28	8° 21.12’	4° 57.08’
UNI-4	Unical	25	8° 21.11’	4° 56.15’
UNI-5	Unical	32	8° 20.78’	4° 56.59’
UNI-6	Unical	41	8° 20.77’	4° 56.61’
UNI-7	Unical	41	8° 20.76’	4° 56.61’
UNI-8	Unical	42	8° 20.76’	4° 56.61’
UNI-9	Unical	30	8° 20.76’	4° 56.57’

The fruit edible volume is an important index of the horticultural quality, potential yield and market value of each accession.

2.3. Data analysis

The data obtained for all traits observed were subjected to descriptive statistics, one-way analysis of variance (ANOVA) and correlation analysis for quantitative traits, while frequency distribution was assessed for qualitative traits. The general linear model (GLM) procedure was specified for the analysis of variance (ANOVA). Multivariate analysis was performed using principal component analysis (PCA) to determine the relative importance of traits accounting for variability among the papaya accessions. The aforementioned statistical analyses were conducted using SAS v.9.1 (SAS Institute Inc., NC, USA). A cluster analysis specifying the nearest neighbor option based on Euclidean distances was used to explore relationships among the accessions and implemented with the PASW Statistics Release 18 (2009).

3. Results

3.1. Quantitative horticultural traits

The mean value and coefficient of variation among quantitative traits and mean squares obtained from analysis of variance indicated significant ($p < 0.001$) variation in the morphological and horticultural traits studied except the fruit central cavity diameter ($p < 0.123$) among the accessions studied (*table II*). Thus, there was significant ($p < 0.001$) variation in the leaf length, petiole length, [leaf petiole / blade length] ratio, fruit length, fruit diameter, [fruit diameter / central cavity diameter] ratio and fruit edible volume among the papaya accessions of the districts from which collection was made. Mean fruit length of papayas was greatest (27.2 cm) in the Akpanim location and lowest (20.7 cm – 22.0 cm) in the Goldie, Ebrutu and Ekong locations. Mean fruit diameter was greatest (12.3 cm) for papayas of the Bataba, Orok Orok and

Table II.
Mean ± standard error, coefficient of variation (%) and mean squares of quantitative traits studied among 60 papaya accessions in Nigeria (n = 60).

Character	Leaf length (cm)	Petiole length (cm)	[Petiole / leaf length] ratio	Fruit length (cm)	Fruit diameter (cm)	Central cavity diameter (cm)	[Fruit diameter / central cavity diameter] ratio	Fruit edible volume (cm^3)
Mean ± SE	48.9 ± 0.91	100.3 ± 2.26	2.1 ± 0.04	24.2 ± 0.54	11.5 ± 0.21	7.0 ± 0.19	1.7 ± 0.03	843.3 ± 44.64
Minimum	34.4	57.4	1.3	16.3	7.8	3.4	1.4	329.4
Maximum	63.2	132.2	2.7	34.2	15.8	11.2	2.6	1903.0
CV (%)	14.5	17.5	13.9	17.3	14.4	20.9	13.5	41.0
Mean square	250.26***	1532.58***	0.41***	52.37***	8.21***	24.77 ns	0.15***	358742.34***

***: F-ratio significant at the p < 0.001 level; ns: not significant.

Unical locations. Mean petiole length was greatest (121.8 cm) in the Orok Orok location and lowest in Akpanim (79.5 cm). Mean leaf length, on the other hand, was greatest (57.5 cm) in Akpanim and lowest (45.4 cm) in the Bataba and Goldie locations (results not shown).

The mean petiole length was 100.3 cm and ranged from 57.4 cm in accession INYE-7 to 132.2 cm in the UNI-22 and OROK-2 accessions. Mean leaf length was 48.9 cm and ranged from 34.4 cm in accession INYE-7 to 63.2 cm in UNI-26. The mean [petiole length / leaf length] ratio was 2.1. Among the fruit characteristics, the mean fruit length was 24.2 cm, which ranged from 16.3 cm in UNI-9 to 34.0 cm in UNI-24. The mean fruit diameter was 11.5 cm and ranged from 7.8 cm in UNI-11 to 15.8 cm in the accession UNI-25. Mean central cavity diameter was 7.0 cm and ranged from 3.4 cm in UNI-11 and GOLD-2 to 11.2 cm in UNI-26. The mean [fruit length / diameter] ratio was 2.1 and ranged from 1.45 in accession UNI-12 to 3.5 in DAH-3. The mean [fruit diameter / central cavity diameter] ratio was 1.7 and ranged from 1.4 in UME-4, EHW-4 and UNI-26 to 2.6 in the GOLD-2 accession. The mean fruit edible volume was 843.3 cm^3 and ranged from 329.4 cm^3 in UME-4 to 1873.3 cm^3 in UNI-24. The coefficient of variation among these traits ranged from 13.5% to 20.9% except for fruit edible volume, where it was as high as 41.0%.

Correlation analysis (*table III*) showed a highly significant positive correlation between leaf blade length and petiole length (r = 0.63, p < 0.0001), the [petiole / length] ratio and petiole length (r = 0.61, p < 0.0001) and fruit length (r = 0.34, p < 0.0001). Fruit length was highly correlated with fruit edible volume (r = 0.85, p < 00001) and the [fruit length / fruit diameter] ratio (r = 0.63, p < 0.0001). The fruit central cavity diameter was also very highly significantly correlated with fruit diameter (r = 0.87, p < 0.0001). Fruit edible volume was positively correlated with fruit diameter (r = 0.64, p < 0.0001) and leaf blade length (r = 0.37, p < 0.0001). Leaf blade length was also positively correlated with fruit length (r = 0.44, p < 0.0001). On the other hand, the [fruit length / fruit diameter] ratio was highly negatively correlated with fruit diameter (r = –0.47, p < 0.0001) and central cavity diameter (r = –0.51, p < 0.0001). The [fruit diameter / central cavity diameter] ratio was also negatively correlated with central cavity diameter (r = –0.73, p < 0.0001) and fruit diameter (r = –0.33, p < 0.0001). Fruit length was positively correlated with fruit diameter (r = 0.38, p < 0.0001).

3.2. Qualitative horticultural traits

There was a significant variation in qualitative traits observed among the accessions studied (*table IV*).

Table III.
Correlation matrix of nine quantitative characters assessed in 60 accessions of papaya in Nigeria.

Quantitative characters studied	Petiole length (cm)	Leaf blade length (cm)	[Leaf petiole / leaf length] ratio	Fruit length (cm)	Fruit diameter (cm)	Central cavity diameter (cm)	[Fruit length / fruit diameter] ratio	[Fruit diameter / central cavity diameter] ratio
Leaf blade length (cm)	0.63***	–	–	–	–	–	–	–
[Leaf petiole / leaf length] ratio	0.61***	-0.22	–	–	–	–	–	–
Fruit length (cm)	0.34***	0.44**	-0.00	–	–	–	–	–
Fruit diameter (cm)	0.09	0.13	-0.03	0.38**	–	–	–	–
Central cavity diameter (cm)	0.13	0.06	0.08	0.22	0.87***	–	–	–
[Fruit length / fruit diameter] ratio	o.23	0.25	0.03	0.63***	-0.47***	-0.51***	–	–
[Fruit diameter / central cavity diameter] ratio	-0.14	0.07	-0.23	0.13	-0.33**	-0.73***	0.40**	–
Fruit edible volume (cm^3)	0.22	0.37**	-0.10	0.85***	0.64***	0.32*	0.25	0.26*

***, **, * indicate significance at the $p < 0.001$, 0.01 and 0.05 levels, respectively.

3.3. Tree trunk and leaf characteristics

Analysis of tree habit showed that 75.0% of the accessions studied were single-stemmed, 16.7% double-stemmed and 8.3% had multiple stems. Generally, the leaf petiole was pale to deep green, accounting for 82.0% of samples, while 15.0% were pink and 3.0% red purple. The stem color was generally gray or light gray in 46.7%, grayish-brown in 35.0% and light yellow in 18.3% of the accessions studied.

3.4. Flower and fruit characteristics

Fruit shape (*figure 2*) was elongated in 20.0%, elliptic in 16.7%, club in 13.3% and pear in 10.0% of the accessions studied. Oblong and plum-shaped fruits accounted for 8.3% each, acorn-shaped in 6.7% of cases. Other shapes such as lengthened cylindrical, oval, blossom-end and globular shapes were found in 3.3%, respectively, among the accessions studied. Oblong blocky and reniform shapes were also found in some 1.7% of cases, respectively. Mature fruit skin color was generally yellowish-green (49.7%) or yellow (50.3%). Fruit flesh color (*figure 3*) was generally bright yellow (58.3%), deep yellow (22.0%) or light yellow (14.7%). A reddish-orange flesh color was observed in only 5.0% of accessions studied. The fruit stalk-end shape was generally flattened (71.7%), depressed in 26.7% and pointed in only 1.6% of accessions studied. The fruit central cavity (*figure 3*) was largely star-shaped, as observed in 71.7%, and irregular, slightly star-like and round-shaped in 10%, 10% and 6.7%, respectively, among the accessions studied. An angular shape was rarely observed and found in only 1.6% of cases. Flower size ranged from generally small (33.3%), to intermediate (28.3%) to generally large (38.4%) among the accessions studied.

3.5. Principal component analysis

With the exclusion of four highly correlated quantitative variables, principal component (PC) analysis was done using 17 variables (*table V*). The first seven PC axes accounted for some 73.47% of total variation among the accessions studied. The first PC axis, which made up 15.90% of total variation, was mainly correlated with fruit length (0.568), fruit edible volume (0.508), the [fruit length / fruit diameter] ratio (0.375) and petiole length (0.310) (*figure 4*). The second PC axis, accounting for 13.26% of total variation, was strongly correlated with fruit diameter (0.418), the [fruit length/ fruit diameter] ratio (–0.367), fruit shape (0.340) and the [fruit diameter / central cavity diameter] ratio (–0.337). The [leaf petiole length / leaf blade length] ratio (–0.477) and petiole length (–0.407) were strongly correlated with the third PC axis, which accounted for 11.23% of total variation. The fourth PC axis, making up 9.92% of total variation, was strongly correlated with tree habit (–0.431), stem color (–0.365), shape of the fruit central cavity (0.392) and fruit flesh color (0.357). The fifth PC axis, making up 8.67% of total variation, was mainly correlated with flower size (–0.479) and fruit stalk-end shape (0.420).

3.6. Cluster analysis

In order to classify the accessions based on similarity indices of horticultural traits, single linkage cluster analysis was used to generate five cluster groups (*figure 5*) with specific characteristics (*table VI*). ANOVA showed significant variation in leaf length ($p < 0.04$), fruit length ($p < 0.001$), fruit diameter ($p < 0.001$), central cavity diameter ($p < 0.01$) and fruit edible volume ($p < 0.001$) among the five clusters. Each cluster can be described.

– Cluster 1 (n = 5)

These accessions are characterized by mean leaf petiole in excess of 1.0 m (100.6 cm) and mean leaf blade of 51.7 cm. These accessions have a large fruit diameter (13.4 cm) and central cavity diameter (7.99 cm). Fruit edible volume is large (1296 cm^3), fruit shape usually oblong and flesh color generally deep yellow. The [fruit length / fruit diameter] ratio is 2.14, flower size is generally small, and the stalk-end generally depressed; the fruit central cavity is usually star-shaped and tree habit is single-stemmed. This cluster is most distant from cluster 2 (distance = 1384.6) and cluster 5 (distance = 1008.9), while closer to cluster 3 (distance = 608.1) and cluster 4 (distance = 613.9).

– Cluster 2 (n = 18)

This cluster has the lowest mean fruit length (21.2 cm) and fruit diameter (9.9 cm). The

Table IV.
Frequency distribution of 12 qualitative traits assessed in 60 papaya accessions in Nigeria.

Character	Description state	% total
Stem color	1: gray	6.7
	2: light gray	40.0
	3: grayish-brown	35.0
	4: light yellow	18.3
Tree habit	1: single stem	75.0
	2: multiple stem	8.3
	3: double stem	16.7
Shape of mature leaf teeth	1: straight	73.3
	2: concave	15.0
	3: convex	11.7
Color of mature leaf petiole	1: pale green	40.3
	2: red purple	3.0
	3: pink	15.0
	4: deep green	41.7
Fruit shape	1: elliptic	16.7
	2: elongated	20.0
	3: oblong	8.3
	4: club	13.3
	5: pear shape	10.0
	6: lengthened cylindrical	3.4
	7: plum shape	8.3
	8: oval	3.3
	9: acorn	6.7
	10: oblong blocky	1.7
	11: blossom-end shape	3.3
	12: reniform	1.7
	13: globular	3.3
Fruit skin color	1: yellowish-green	49.7
	2: yellow	50.3
Fruit flesh color	1: light yellow	14.7
	2: deep yellow	22.0
	3: reddish-orange	5.0
	4: bright yellow	58.3
Shape of fruit central cavity	1: star shape	71.7
	2: angular shape	1.6
	3: irregular	10.0
	4: slightly star-like	10.0
	5: round	6.7
Stalk-end fruit shape	1: flattened	71.7
	2: depressed	26.7
	3: pointed	1.6
Skin color of immature fruit	1: green	70.0
	2: light green	30.0
Flower size	1: generally small	33.3
	2: generally intermediate	28.3
	3: generally large	38.4
Flower color	1: yellow	45.0
	2: white	55.0

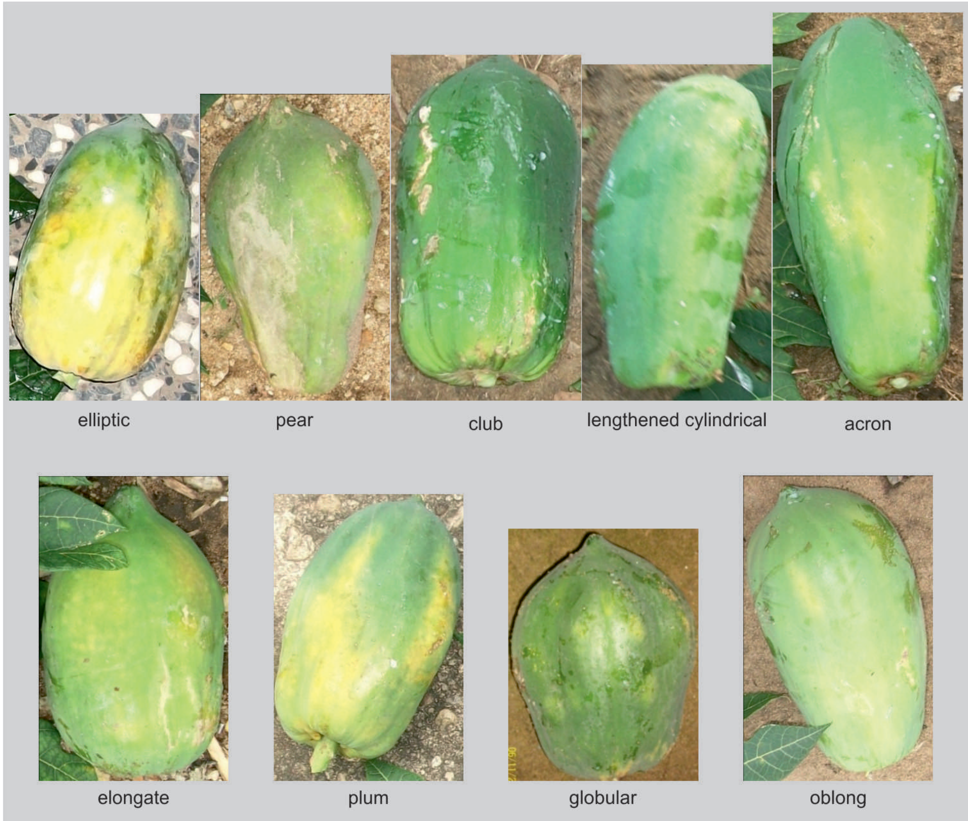

Figure 2.
Variation in fruit shapes showing elliptic, pear, club, lengthened cylindrical, acorn, elongated, plum, globular and oblong types among papaya accessions in Nigeria.

mean [fruit length / fruit diameter] ratio is 2.19 and fruit edible volume is lowest in this group (496 cm^3). The fruit shape of accessions in this group is generally club, the central cavity is angular-shaped with reddish-orange flesh color and the stem is grayish-brown; flower size is generally intermediate. Cluster 2 is closest to cluster 5 (distance = 375.8) and most distant from cluster 4 (distance = 994.6).

– Cluster 3 (n = 20)

This cluster consists of accessions with a short mean leaf petiole of 101.8 cm, leaf length of 50.4 cm and a [leaf petiole / leaf blade] ratio of 2.02. Mean fruit length is 25 cm and mean fruit diameter is 12.2 cm. The [fruit length / fruit diameter] ratio is 2.07 and accessions have a mean edible volume of 944 cm^3. Flower color in this group is usually light yellow and the mature leaf petiole color is reddish-purple. Fruit is generally pear-shaped with reddish-orange flesh color and the central cavity is star-shaped. Cluster 3 is closest to cluster 5 (distance = 400.9) and farthest from cluster 4 (distance = 1219.3).

– Cluster 4 (n = 4)

Accessions in this cluster have a mean petiole length of 115 cm, leaf blade length of 55.6 cm, fruit length of 33.5 cm, fruit diameter of 13.8 cm, central cavity diameter of 8.37 cm and mean fruit edible volume of 1715 cm^3. The fruit shape is club; the central cavity has an irregular shape; petiole color is pink and flesh color is bright yellow. Flower size is generally intermediate, stem color is light gray, and leaf teeth are convex. Accessions in this cluster are distantly related to accessions in the other clusters (distance = 1219.3–1994.6), except to those in cluster 1 (distance = 613.9).

– Cluster 5 (n = 13)

This cluster has accessions with a mean petiole length of 95.3 cm, leaf blade length of

45.1 cm and central cavity diameter of 6.60 cm. Fruit of accessions in this cluster is generally lengthened cylindrical with a mean length of 22.3 cm and diameter of 11.1 cm. Flower size is generally intermediate; flesh color is reddish-orange and the fruit central cavity is generally angular. Mean fruit edible volume is 710 cm^3.

4. Discussion

This study was conducted to assess genetic diversity in papaya accessions in Nigeria as a first step towards developing an effective genetic improvement program for papaya in Nigeria. Although Nigeria has the largest area planted to papaya in the world, it also has one of the lowest yields recorded globally[3]. This could be due largely to use of unselected and low-yielding planting materials grown by farmers. This in turn could be due to low attention given to the papaya breeding program, and consequently unavailability of high-yielding and selected locally adapted varieties for planting by farmers. In our study, horticultural and morphological traits related to fruit quality and yield potentials were evaluated.

A significant variation in these traits was observed among the accessions studied in Nigeria and the accessions were classified into five major cluster groups. It appeared that accessions in cluster 1 and cluster 4 with large fruit diameter (~13.4 cm – 13.8 cm), central cavity diameter (~8.0 cm – 8.4 cm), and club, oblong, elliptic and globular-shaped fruits reflected the characteristics of fruits produced from female plants. The large fruit edible volume obtained for these two clusters (~1296 cm^3 – 1715 cm^3) also indicated high fruit quality and edible proportion yield for these accessions, that made up only 15% of the accessions studied. The fruit edible volume classification provided in our study showed that accessions in this cluster range from large to very large. Female plants are known to produce large round-shaped fruits of good quality with a large seed cavity [21]. Hermaphrodite plants, on the other hand, produce small to medium elongated fruits of good quality but with a smaller seed cavity [5, 21].

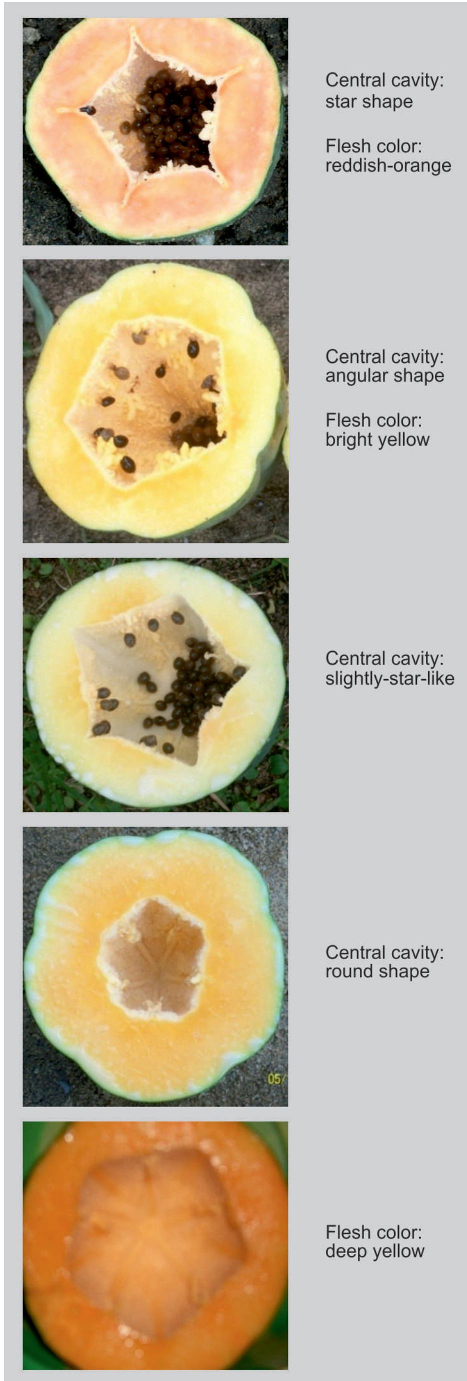

Figure 3.
Variation in shape of the fruit central cavity showing star shape, angular shape, slightly star-like and round shape among papaya accessions in Nigeria; and reddish-orange, bright yellow and deep yellow papaya flesh color.

The large fruit edible volume also indicated that these accessions have large yield potentials that can be exploited for both local consumption and commercial production for export. These accessions could be

Table V.
Principal component analysis showing the eigenvalue, proportion and cumulative proportion of 17 characters assessed among 60 papaya accessions in Nigeria.

Axes of the principal component analysis				Fruit length (cm)	Fruit diameter (cm)	[Fruit diameter / central cavity diameter] ratio	Fruit edible volume (cm^3)	Fruit shape	Fruit skin color	Fruit flesh color	Stalk-end fruit shape	Shape of fruit cavity	[Fruit length / fruit diameter] ratio
Axis	Eigenvalue#	Proportion (%)	Cumulative proportion (%)										
PC 1	2.70	15.90	15.90	0.568	0.183	0.169	0.508	– 0.107	– 0.263	0.046	0.051	0.106	0.375
PC 2	2.25	13.26	29.16	– 0.024	0.418	– 0.337	0.098	0.340	0.057	0.301	0.268	0.009	– 0.367
PC 3	1.91	11.23	40.39	0.104	0.348	0.075	0.283	– 0.143	0.306	0.202	0.237	0.165	– 0.179
PC 4	1.47	9.92	50.30	– 0.094	– 0.334	0.329	– 0.111	0.182	0.025	0.357	0.055	0.392	0.212
PC 5	1.32	8.67	58.97	– 0.061	– 0.023	– 0.158	– 0.023	0.198	0.116	0.060	0.420	0.299	0.110
PC 6	1.15	7.73	66.70	– 0.074	0.052	0.402	0.173	0.199	0.019	0.271	– 0.290	0.012	– 0.112
PC 7	1.05	6.77	73.47	0.022	– 64	– 0.054	– 0.019	– 0.498	0.500	0.137	0.107	– 0.233	0.068

Axes of the principal component analysis	Petiole length (cm)	[Leaf petiole / leaf length] ratio	Stem color	Leaf petiole color	Flower size	Tree habit	Leaf teeth shape
PC 1	0.310	0.083	– 0.086	0.049	– 0.052	– 0.059	– 0.038
PC 2	0.236	0.240	– 0.283	0.253	0.093	– 0.043	– 0.128
PC 3	– 0.407	– 0.477	0.154	– 0.169	– 0.222	– 0.121	– 0.049
PC 4	– 0.080	– 0.110	– 0.365	0.197	0.065	– 0.431	– 0.122
PC 5	0.129	0.307	– 0.158	0.321	– 0.479	0.242	– 0.265
PC 6	– 0.066	0.058	0.007	0.338	– 0.259	0.445	0.450
PC 7	0.257	0.083	– 0.091	0.175	0.075	– 0.256	0.470

cloned by grafting to retain their yield potentials and attain uniformity on the field. It is known that planting by seeds increases variability; therefore, vegetative propagation by stem cutting could be done to maintain uniformity, productivity and profitability.

Accessions in cluster 2, cluster 3 and cluster 5 appeared to be largely hermaphrodite plants with a small central cavity (~6.3 cm – 7.4 cm), compared with (~8.0 cm – 8.4 cm), and fruit edible volume (~496 cm^3 – 944 cm^3), compared with (~1296 cm^3 – 1715 cm^3) in cluster 1 and cluster 4. Accessions in cluster 3 have elongated and pear-shaped medium length fruits and central cavity, indicating traits of hermaphrodite: elongata type. However, accessions in cluster 5 with largely cylindrical-shaped fruits indicated that they are largely hermaphrodite: pentandra type. The characteristics of accessions in cluster 2, though reflective of fruits produced from hermaphrodite plants, also showed the resemblance of fruits produced from bisexual flowers. Bisexual flowers are also known to produce a few elongated poor-quality fruits [21], as reflected by the very low fruit edible volume in some of the accessions in this cluster. The low proportion of female plants (15%) against the large proportion of hermaphroditic plants (85%) recorded in our study showed that growers here have greater preference for hermaphroditic papaya plants. This is in consonance with earlier observations that most growers prefer fruits from hermaphroditic rather than female plants [5].

This study showed that, while flesh color was predominantly reddish-orange in cluster 2, cluster 3 and cluster 5, composed mainly of hermaphroditic plants, it was predominantly deep and bright yellow in accessions in cluster1 and cluster 4. In the trade classification, as in Australia, red- or pink-colored flesh cultivars are referred to as 'papaya' and distinguished from the yellow-fleshed cultivars known as 'paw paw'. Fruits from female plants were yellow fleshed while hermaphrodite plants were predominantly of reddish-orange-colored flesh.

There was significant genetic variability among the accessions studied in all the phenotypic horticultural traits considered in our study, which was useful for classification of samples into distinct clusters. For instance, there was more than two-fold variation among accessions in mean fruit length, fruit diameter and even three-fold variation in fruit central cavity diameter. This variability provides opportunity for selection of interesting parents to be used in further breeding or vegetative propagation to multiply accessions with outstanding yield, fruit shape and quality for commercial plantations. Fruit shape is an important component in the production of uniform fruits, for which the market will pay premium prices [22]. There was significant variation among the accessions studied in terms of fruit shape and it is important to exploit this variation for genetic improvement and commercial purposes. The papaya germplasm has been shown to exhibit considerable phenotypic variation for many horticulturally important traits, including fruit size, fruit shape, flesh color, flavor and sweetness, length of juvenile period, plant stature, stamen carpelloidy, and carpel abortion [14].

Such accessions as in cluster 1 and cluster 4 could be recommended for multiplication as clones for commercial planting to maintain the uniformity of fruit shape and large fruit edible volume which are indices of high quality and indicate high market value. It appeared from this study that papaya accessions in Nigeria exhibit high variability in many important horticultural traits, a possible consequence of use of seeds by farmers. As observed in other crops, farmers tend to obtain seeds from neighbors and self-owned farms from interesting parent trees or individuals for new plantings or farm expansion [23]. Open-pollinated dioecious varieties of papaya that form the basis of Australia's Queensland industry also tend to be highly variable in characteristics such as fruit shape, taste, size, flesh color, firmness and yield [24].

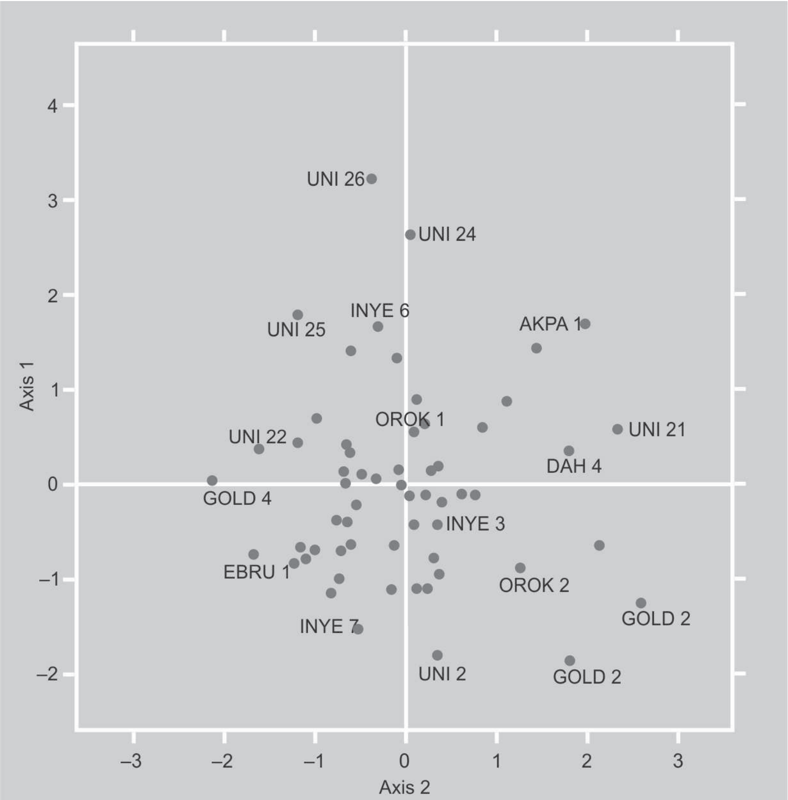

Figure 4.
Scatter plot of papaya accessions on principal component axes 1 and 2 (PC1 and PC2) accounting for 29.2% of total variation.

The results obtained from multivariate analysis, where seven principal component (PC) axes were responsible for 73.5% of total variability, showed that only a few characteristics will not be adequate to define genetic diversity among papaya accessions. The most important direct quantitative horticultural traits to be considered include fruit length, fruit diameter, petiole length, leaf blade length and central cavity diameter. Derived parameters include the fruit edible volume, [fruit length / fruit diameter] ratio and [fruit diameter / fruit central cavity diameter] ratio. Qualitative traits found to be important in our study include fruit shape, tree habit, stem color, flesh color, flower size and shape of the fruit central cavity. The significant relationship between leaf blade length, fruit length, fruit diameter and the

Figure 5.
A single linkage cluster dendrogram based on the rescaled distance option showing relationships among 60 papaya accessions in Nigeria. Two broad groups are defined comprising hermaphrodite and female plants, further reclassified into five clusters.

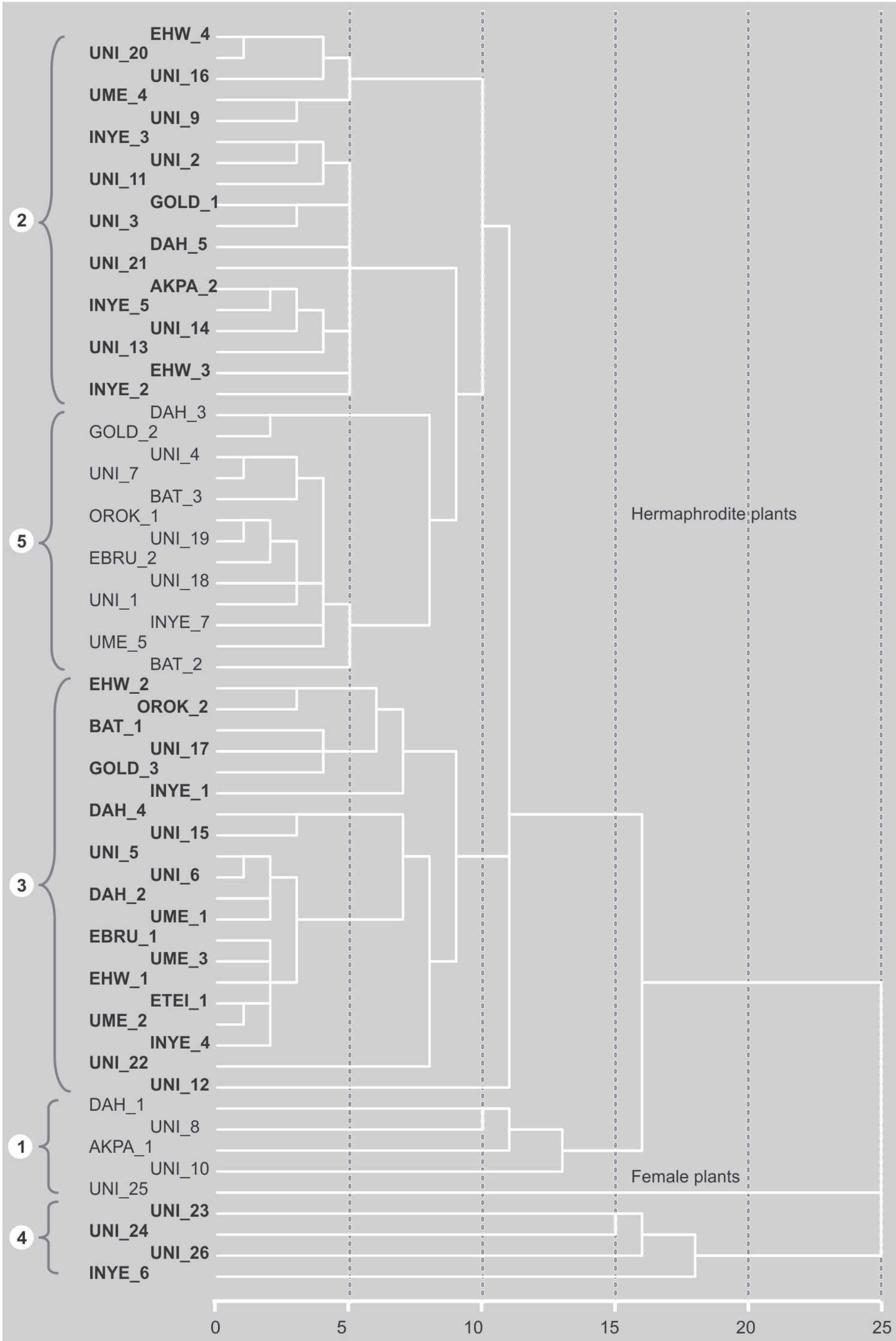

Table VI.
Membership, mean values and mean square of trait characteristics among five cluster groups of 60 papaya accessions in Nigeria.

Cluster	Number of accessions	Petiole length (cm)	Leaf blade length (cm)	[Leaf petiole / leaf blade] ratio	Fruit length (cm)	Fruit diameter (cm)	[Fruit length / fruit diameter] ratio	Central cavity diameter (cm)	[Fruit diameter / cavity diameter] ratio	Edibility constant	Fruit edible volume (cm^3)
1	5	100.6	51.7	1.98	28.0	13.4	2.14	7.99	1.74	0.71	1296
2	18	99.3	47.8	2.08	21.2	9.9	2.19	6.26	1.62	0.70	496
3	20	101.8	50.4	2.02	25.0	12.2	2.07	7.36	1.67	0.70	944
4	4	115.0	55.6	2.07	33.5	13.8	2.45	8.37	1.70	0.75	1715
5	13	95.3	45.1	2.12	22.3	11.1	2.05	6.60	1.74	0.70	710
df		4	4	4	4	4	4	4	4	4	4
Mean square		320.44	121.29	0.03	158.22	23.61	0.16	6.67	0.04	0.00	1642404.97
F		1.05	2.70	0.35	21.92	19.36	0.95	3.69	0.70	0.50	168.34
P– value		0.391	0.040	0.840	0.000	0.000	0.444	0.010	0.598	0.735	0.000

Cluster	Number of accessions	Flower color	Stem color	Mature leaf petiole color	Fruit shape	Fruit skin color	Fruit flesh color	Stalk-end fruit shape	Central cavity shape	Flower size	Tree habit	Immature fruit skin color	Mature leaf teeth shape
1	5	1	3	3	3	2	2	2	1	1	1	1	1
2	18	1	3	3	4	2	3	1	2	2	1	1	1
3	20	1	3	2	5	2	3	1	1	2	1	1	1
4	4	2	2	3	4	1	4	1	3	2	1	1	2
5	13	2	3	2	6	1	3	1	2	2	2	1	2
df		4	4	4	4	4	4	4	4	4	4	4	4
Mean square		0.52	0.88	1.98	11.79	0.33	3.02	0.22	2.13	0.85	.637	.065	.101
F		2.23	1.20	1.04	1.05	1.35	2.32	0.86	1.20	1.18	1.09	0.29	0.20
P– value		0.077	0.320	0.394	0.392	0.265	0.069	0.496	0.322	0.330	0.369	0.883	0.937

fruit edible volume gives an indication that yield potential of any accession is strongly related to its leaf characteristics. Interestingly, Asudi *et al.* also reported that seven PC axes accounted for 72.9% of total variation observed in 60 accessions from Kenya [19].

The highly significant correlation observed between leaf petiole, blade length, fruit length and edible volume in this study indicated strong physiological relationships and dependence of fruit size and quality on efficiency of photosynthesis and assimilate partitioning. Strong correlation among fruit and leaf traits was also reported by Asudi *et al.* [20] and Ocampo *et al.* [21]. This strong correlation indicates that environmental factors such as the nutrition regime might play a significant role in fruit size and quality.

Our results will therefore be useful for seed multiplication purposes that will significantly improve papaya production in Nigeria. Although fruit shape and horticultural traits as studied in our work are important for genetic improvement, further efforts should include agronomic characteristics such as disease resistance, which may also be contributing to the low yields experienced in Nigeria papaya production. Although papaya is generally regarded as a cross-pollinated species, self-fertilization does not result in inbreeding depression and inbred lines have been used to advantage to help fix useful genetic characteristics in both gynodioecious and dioecious lines [22]. Breeding objectives therefore should include tolerance to *Phytophthora*, improved fruit quality, long shelf life and yield. Of particular importance is the fruit edible volume (FEV) index developed in our study, which provides a reliable guide to yield potential and fruit quality. This index could be used in a papaya improvement program as a selection criterion along with other indices in selection of improved cultivars.

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Evaluación de la diversidad genética de las características hortícolas y morfológicas en el seno de muestras de material de papaya (Carica papaya) en Nigeria.

Resumen — **Introducción**. A pesar de que Nigeria posea la superficie más grande plantada de papayos (*Carica papaya*) en el mundo, se estima que tiene uno de los rendimientos más flojos. El buen conocimiento de la variabilidad genética disponible sería una primera etapa para la explotación de este cultivo, de modo a desarrollar otros cultivares mejorados. Hasta ahora, no existía ningún informe sobre la diversidad genética de las muestras de material de los papayos disponibles en Nigeria. **Material y métodos**. Se evaluaron sesenta muestras de material de papayos obtenidos a partir de diez distritos del sur de Nigeria empleando 21 variables definidas a partir de los descriptores para el papayo publicados por el IBPGR. Los datos se sometieron a estadísticas descriptivas, a un análisis de la varianza, a un análisis de variaciones múltiples, entre las cuales un análisis de compuestos principales (ACP) y un análisis de conglomerados. **Resultados**. El análisis de varianza mostró una variación significativa entre las muestras de material en cuanto a la longitud, el diámetro y el volumen comestible del fruto, así como en cuanto a la longitud del pecíolo de las hojas, y a la forma, el color de la carne y la forma de la cavidad central del fruto. Los siete primeros ejes del ACP representaron el 73,47% de la variación total y se generaron cinco grupos a partir del análisis de conglomerados. Las muestras de material se clasificaron en dos grandes grupos correspondientes a las plantas hembra (15%) y a las plantas hermafroditas (85%). Se encontró una fuerte correlación muy significativa entre la longitud del limbo y la longitud del pecíolo y entre algunas características del fruto, tales como la longitud, el diámetro y el volumen comestible de los frutos, una variable definida por primera vez en el presente estudio. Hubo un predominio de frutos con carne amarilla entre las plantas hembra y con carne de color rojo-naranja entre las plantas hermafroditas. **Discusión y conclusiones**. Cada uno de los cinco grupos puestos de manifiesto contiene muestras de material que podrían emplearse como progenitores para una selección futura o en clon para una propagación vegetativa. Nuestro estudio reveló una variación significativa que podría explotarse para la mejora genética del papayo en Nigeria. Se recomienda que se proyecte una mejora genética enfocada, de modo a explotar la variabilidad genética disponible.

Nigeria / *Carica papaya* / variación genética / métodos estadísticos