# Phenotypic Variability of Morphological and Nutritional Parameters of Pepper (*Capsicum* Spp) Accessions in the Derived Savanna Agro-Ecology of Nigeria

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## Summary

Variability studies on newly collected accessions and identification of superior genotypes enhances their suitability for breeding programmes. This study was aimed to estimate variation and assess the mean performance of pepper accessions collected across Nigeria. The study evaluated eighteen pepper genotypes and the experiment was laid out in a randomized complete block design with three replicates. Analysis of variance showed significant ($P < 0.01$) differences among accessions for all measured, except for number of fruits per plant. Correlation coefficients ranged from -0.27 to 0.84 and the strongest relationship was observed between stem colour and fruit length (r = 0.84, $P < 0.001$). Strong significant ($P < 0.001$) correlations between several traits were observed and fruit yield was either positively or negatively associated with other traits. Results from principal component analysis showed that the first six principal components accounted for 86 % of the total variability among the accessions. Cluster analysis differentiated the accessions and formed three distinct groups which were not in accordance with their source of collection. Accession NHPP-0144 combined high fruit yield with other desirable agronomic traits. Other promising accessions were NHPP-0137, NHPP-0319, NHPP-0332 and NHPP-0334 which possess favourable genes for yield potential and quality traits, a basis for future selection in pepper breeding programmes.

## Key words

breeding programme, pre-breeding, qualitative traits, quantitative traits, selection, variation

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## Introduction

Pepper (*Capsicum* spp.) is an economically important vegetable crop belonging to the family *Solanaceae* and the genus *Capsicum* (Pickersgill, 1997). It is considered the first spice to have been used by human beings with archaeological evidence (Hill et al., 2013). The genus *Capsicum* has five cultivated species (*C. annuum, C. frutescens, C. chinense, C. pubescens* and *C. baccatum*) which are either hot or sweet pepper. Nonetheless, *C. annuum* sweet and pungent fruits are the most widely cultivated and economically important worldwide (Rodrigues et al., 2012). Pepper has been identified as a vital commercial vegetable crop, mainly cultivated for spice and value-addition in processed products (Kumar and Rai, 2005). It is rich in vitamins with pleasant flavour and colour, which makes it an indispensable chief constituent in soups accounting for about 40 % of average daily in-take from meals in Nigeria (Dagnoko et al., 2013).

Pepper processing industry has shown interest in breeding programmes that focus on the nutritional and physicochemical properties of pepper fruits Maciel et al. (2016) to improve marketing by adding value due to nutritional benefits (Corrêa et al., 2018). In view of this, pepper improvement for nutritive value and yield has been the goal of some breeding programmes (Wall et al., 2001). Paucities of pepper genotypes specifically suitable for processing, especially regarding characteristics such as total soluble solids, titratable acidity and fruit pH have been reported (Geleta et al., 2005; Lanes et al., 2007; Ferrao et al., 2011; Faria et al., 2012). The magnitude of genetic variation within the pepper germplasm plays a vital role in its improvement and aids breeding programmes in developing elite genotypes through careful selection of superior parents with desirable genes. Therefore, it is crucial to evaluate existing pepper accessions in order to identify, select and develop novel pepper lines with desired horticultural traits and nutritive value. Phenotypic variability regarding vegetative growth, flowering and yield related traits of *C. annuum* in Peru (Ortiz et al., 2010), Brazil (Do Rêgo et al., 2011), India (Sood et al., 2011; Datta et al., 2013), Mexico (Hill et al., 2014), Argentina (Occhiuto et al., 2014) and Eritrea (Saleh et al., 2016) have been reported and the results obtained from these research are useful for selection of genotypes which combine favourable alleles useful in breeding programmes. In Nigeria, the National Horticultural Research Institute (NIHORT), Ibadan, plays a major role in the collection, conservation and distribution of vegetable germplasm and executes long term breeding projects in many fruits and crop vegetables including peppers which have now become an important cash crop for smallholder farmers' across the country. The institute has diverse collection of pepper accessions (Idowu-Agida et al., 2010; Ikoro et al., 2018) without documented information on their characterization for efficient utilization, which is an indispensable prerequisite for successful breeding.

So far, only morphological characterizations of few pepper accessions from the Institute's gene bank have been reported (Adetula and Olakojo, 2006). However, limited traits were considered with no information on the nutritional and physicochemical properties which are less influenced by environment (Berg et al., 1993). In view of the fact that the Institutes' makes germplasm accessions and elite lines accessible to researchers for further improvement, there is a need for documentation on utilization of these accessions in order to maximize the potential of the genetic resources. Therefore, the aim of this study was to estimate the extent of variation and mean performance of some NIHORT'S pepper accessions based on morphological, nutritional and physicochemical properties, as well as to select superior accessions with favourable genes suitable for breeding programmes.

## Materials and methods

The experimental material consisted of eighteen pepper genotypes which include sixteen germplasm accessions collected from the gene bank of the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria and two commercial varieties planted by farmers in Ogbomoso area of Oyo State used as local check (Table 1). These genotypes were evaluated in replicated field trial at the Teaching and Research Farm of Ladoke Akintola University of Technology, Ogbomoso, Nigeria (8°10' N, 4°10' E, and altitude 341 m above sea level). The seeds of each genotype were sown in nursery trays filled with sterilized top soil for six weeks. They were watered regularly and were hardened before they were transplanted to the field. Transplanting was done on ridges measuring 4 m in length, spaced at 0.40 m and 0.75 m apart. The experiment was laid out in a randomized complete block design replicated three times. Fertilizer was applied two weeks after transplanting at 130 kg N ha, 80 kg P ha and 110 Kg K ha using NPK 15:15:15, urea and muriate of potash (Grubben and Tahir 2004). Other cultural and agronomic practices such as weeding and insect control were carried out as and when due.

### Data Collection

Data were recorded on seedling vigour and seedling height (SDH) 7 days after planting, stem colours were recorded on young plants before transplanting and were coded as1 = green; 2 = green with purple stripes; 3 = purple, leaf length and leaf width (LW), height at first branching (BH), plant height (BH), fruit pedicel length (PL), node colours were recorded at plant maturity where 1 = green, 3 = light purple, 5 = purple; 7 = dark purple. Number of days to 50 % flowering (DTF), flower diameter (FD), number of days to fruiting (DTFR), number of days to maturity (DTM), fruit length (FRL), fruit width (FRW), weight of 1000 seeds (WOTS), number of fruits per plant (NOFPP) and fruit yield were calculated in t ha$^{-1}$. Fruit samples from each of the evaluated genotypes were also analyzed for nutritional and physicochemical properties including capsaicin (CAPS), β-carotene (BTC), vitamin C (VIT C), fruit pH, total soluble solids (TSS) and titratable acidity (TA).

### Determination of β-carotene, Capsaicin and Vitamin C

A total of 10-15 representative matured pepper fruit were harvested randomly from the 18 genotypes evaluated, packed in polyethylene bags, kept in an ice box (to prevent moisture loss), and transported to Product Development Laboratory of NIHORT, Nigeria. All chemicals used were of analytical grades and analyses were done in triplicate for each sample. β-carotene (mg 100 g$^{-1}$) content was calculated according to Rodriguez-Amaya and Kimura (2004) formula. The capsaicinoids (mg 100 g$^{-1}$) were extracted from powdered dried fruits.

**Table 1.** Description of qualitative traits and sources of the pepper accessions used in this study

| S/N | Accession | Collection source | Node colour | Stem colour |
|---|---|---|---|---|
| 1 | NHPP-0135 | Nigeria / Katsina | Green | Green |
| 2 | NHPP-0137 | Nigeria / Katsina | Green | Green |
| 3 | NHPP-0139 | Nigeria / Katsina | Green | Green |
| 4 | NHPP-0140 | Nigeria / Katsina | Light purple | Green |
| 5 | NHPP-0144 | Tanzania / World Vegetable Center | Purple | Purple |
| 6 | NHPP-0145 | Tanzania / World Vegetable Center | Light purple | Green + purple |
| 7 | NHPP-0316 | Nigeria / Kano | Light purple | Green |
| 8 | NHPP-0317 | Nigeria / Kano | Purple | Green + purple |
| 9 | NHPP-0319 | Nigeria / Kano | Green | Green |
| 10 | NHPP-0320 | Nigeria / Kano | Green | Green |
| 11 | NHPP-0323 | Nigeria / Kano | Green | Green |
| 12 | NHPP-0331 | Nigeria / Kano | Purple | Green + purple |
| 13 | NHPP-0332 | Nigeria / Kaduna | Green | Green |
| 14 | NHPP-0334 | Nigeria / Kaduna | Purple | Green + purple |
| 15 | NHPP-0335 | Nigeria / Kaduna | Green | Green |
| 16 | NHPP-0589 | Nigeria / Kaduna | Purple | Green + purple |
| 17 | Hausa Local | Nigeria / Ogbomoso | Green | Green |
| 18 | Yoruba Local | Nigeria / Ogbomoso | Purple | Green + purple |

To determine the vitamin C content (mg 100 g$^{-1}$) of the pepper fruits, standard solution of ascorbic acid (5 ml) was pipetted into 100 ml conical flask and the volume of dye used was recorded as ($V_2$ml) (Ibitoye, 2005).

### Determination of Fruit pH, Total Titratable Acidity and Total Soluble Solids

The pH of pepper fruits was measured by mixing 10 g with 90 ml of distilled water. This was then ground with mortar and pestle to allow proper dissolution and the pH was determined using a pH meter. Total titratable acidity (% TA) was determined following the method of Association of Official Analytical Chemists (AOAC, 2005). Ten milliliters of aliquot were mixed with two drops of phenolphthalein indicator in a test tube and thoroughly shaken. The mixture was titrated against 0.1 M NAOH until there was a change in color to persistent pink end point and acidity was calculated (James, 2013). Total soluble solids (TSS) content of all pepper was determined using a digital refractometer (Model, PAL-Tea, ATAGO, Tokyo, Japan) and were expressed as °Brix according to the AOAC (2005). All the readings were performed at 20 °C after filtration through hydrophilic cotton.

### Data Analyses

The quantitative and qualitative data were subjected to analysis of variances (ANOVA) to test the presence of significant differences among the pepper accessions with PROC GLM in SAS (SAS Institute, 2010). The means were separated with Fisher's least significant difference (LSD) as described by Snedecor and Cochran (1989) and level of significance was set at $P < 0.05$. Pearson's correlation coefficients were computed to determine the strength of associations between traits. Principal Component Analysis (PCA) was computed to identify traits that describe the variations among the accessions and principal components with eigenvalues >1 were selected. The relatedness among the accessions was further examined by hierarchical cluster analysis with Centroid linkage method. All data analyses were performed using SAS (SAS Institute, 2010).

## Results

Anthocyanin coloration was observed on the nodes of 50 % of the accession, but the intensity varied, only 31 % of the accession had the strong purple pigmentation while nodes of other accessions were green in colour.

On the other hand, 69 % of the accession had green stem colour followed by green + purple (38 %) and purple (6 %). Moreover, the pepper fruits varied extensively (Fig. 1). Results of the analysis of variance revealed that the pepper accessions mean squares were significant ($P < 0.001$) for all the morphological traits, nutritional and physicochemical parameters except for number of fruits per plant (Table 2). Considering the twenty (20) qualitative and quantitative parameters measured, coefficient of variation (CV) was > 20 % for fifteen parameters. The vegetative growth indicators, fruit related parameters and the nutritional properties of the accessions displayed abundant variability. The seedling height ranged from 6.2 cm (NHPP-0332) to 20.7 cm (NHPP-0144) with a mean of 13.0 cm (Table 3).

The width of the leaves ranged from 2.8 cm (NHPP-0317) to 6.2 cm (NHPP-0332) with a mean of 4.5 cm. Pedicel length was between 1.9 cm (NHPP-0137) and 4.3 cm (NHPP-0144) with a mean of 3.1 cm. The branching height from the soil level was between 4.5 cm (NHPP-0135) and 9.6 cm (NHPP-0144) with a mean of 6.7 cm. The plants were vigorous with a mean height of 34.8 cm at flowering. Accession NHPP-0334 was the tallest (48.0 cm) while accession NHPP-0319 was the shortest (21.4 cm). The number of days to 50 % flowering varied between 42 days (NHPP-0144) and 69 days (NHPP-0316) with an average of 55 days while it took between 41 days (NHPP-0331 and NHPP-0589) to 70 days (NHPP-0332) for first fruit formation or 54 days on the average. The mean number of days to fruit maturity was 88 days ranging from 63 days (NHPP-0137) to 96 days (NHPP-0139, NHPP-0136, NHPP-0332 and NHPP-0335). The fruit length varied from 1.4 cm (NHPP-0316) to 7.7 cm (NHPP-0144) with a mean of 3.6 cm while fruit width ranged from 0.6 cm (NHPP-0137) to 2.9 cm (NHPP-0319 and NHPP-0320) with a mean width of 1.5 cm. The weight of 1000 seeds ranged from 3.0 g (NHPP-0139) to 11.4 g (NHPP-0320) with a mean weight of 8.1 g. The mean number of fruits per plant was 9 fruits and the highest was recorded for accession NHPP-0137 (21 fruits) while the lowest was for accession NHPP-0135 (2 fruits). The pepper fruit yield of the evaluated accessions ranged from 0.02 t ha$^{-1}$ (NHPP-0332) to 1.41 t ha$^{-1}$ (NHPP-0334) with a mean yield of 0.5 t ha$^{-1}$.

Considering the two common varieties planted by farmers in the environs used as local checks in this study, the Hausa local was significantly ($P < 0.05$) superior to the Yoruba local in performance for traits such as: seedling height, leaf width, fruit width, weight of 1000 seeds, capsaicin, vitamin C and titratable acidity, while the latter had better performance for number of days to first fruiting, fruit length, number of fruits per plant and β-carotene.

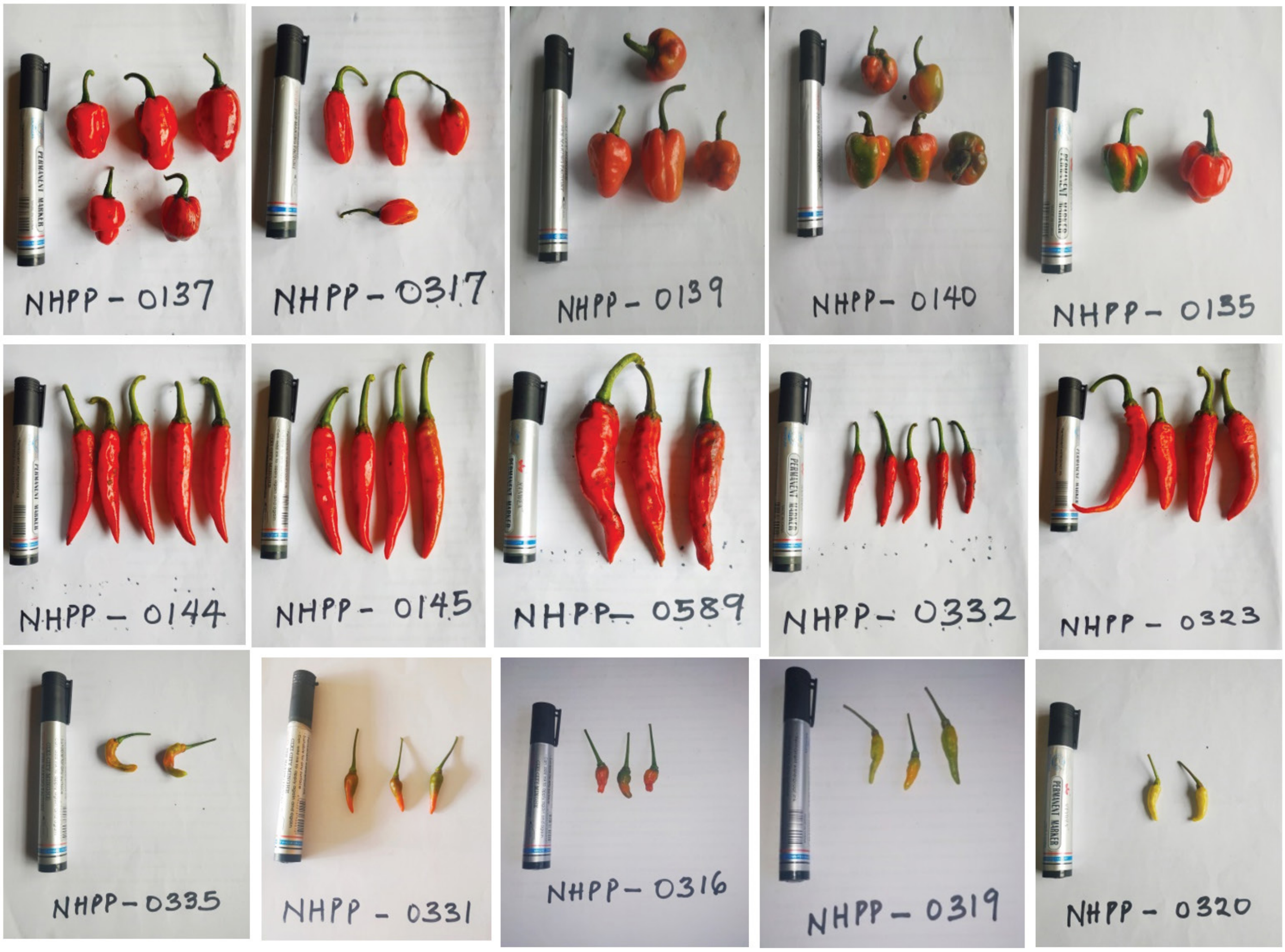

**Figure 1.** Fruit morphology diversity of some evaluated pepper accessions

**Table 2.** Mean squares for morphological traits, nutritional and physicochemical properties of pepper accessions evaluated

| Source | df | Seedling height (cm) | Leaf width (cm) | Pedicel length (cm) | Branch height (cm) | Plant height (cm) | Flower diameter (cm) | Number of days to 50 % flowering | Number of days to first fruiting | Number of days to maturity | Fruit length (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Replication | 2 | 12.12 | 0.23 | 0.03 | 1.16 | 336.75** | 0.01 | 218.39** | 120.84 | 11.68 | 0.40 |
| Accession | 17 | 54.58*** | 2.97*** | 1.24*** | 6.93*** | 186.34** | 0.09*** | 146.20** | 245.21*** | 199.12*** | 12.52*** |
| Error | 34 | 6.17 | 0.63 | 0.22 | 1.08 | 52.87 | 0.02 | 36.15 | 42.12 | 43.96 | 0.60 |
| CV (%) |  | 19.05 | 17.55 | 15.15 | 15.57 | 21.29 | 7.93 | 10.89 | 12.19 | 7.74 | 21.17 |

| Source | df | Fruit width (cm ) | Weight of 1000 seeds (g) | Number of fruits per plant | Fruit yield (t $ha^{-1}$) | Capsaicin (mg 100 $g^{-1}$) | Vitamin C (mg 100 $g^{-1}$) | β-carotene (mg 100 $g^{-1}$) | Fruit pH | Total soluble solid (°Brix) | Titratable acidity (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Replication | 2 | 0.02 | 1.94 | 247.66* | 0.27 | 167.38* | 331.67* | 0.01* | 0.01 | 0.11 | 0.00 |
| Accession | 17 | 1.92*** | 22.92*** | 103.37 | 0.63*** | 62495.65*** | 20392.74*** | 9.77*** | 0.23*** | 0.72** | 0.33*** |
| Error | 34 | 0.12 | 1.64 | 58.97 | 0.20 | 40.05 | 95.32 | 0.00 | 0.01 | 0.11 | 0.02 |
| CV (%) |  | 21.98 | 14.95 | 82.95 | 90.80 | 5.49 | 4.34 | 1.95 | 1.17 | 6.38 | 10.22 |

Note: CV = Coefficient of variation; *, **and *** indicates significance at 0.05, 0.01 and 0.001 probability levels, respectively

**Table 3.** Mean performance of morphological traits, nutritional and physicochemical parameters of pepper accessions evaluated

| Accession | SDH (cm) | LW (cm) | PL (cm) | BH (cm) | PH (cm) | FD (cm) | DTF | DTFR | DTM | FRL (cm) | FRW (cm) | WOTS (g) | NOFPP | Fruit yield | CAPS | VIT C | BTC | Fruit pH | TSS | TA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NHPP-0135 | 12.5 | 4.4 | 3.1 | 4.5 | 40.3 | 1.5 | 65 | 65 | 87 | 2.3 | 0.8 | 6.7 | 1.7 | 0.04 | 33.2 | 243.6 | 1.8 | 8.0 | 6.0 | 1.7 |
| NHPP-0137 | 8.7 | 5.9 | 1.9 | 5.9 | 26.3 | 1.7 | 57 | 57 | 63 | 1.6 | 0.6 | 8.3 | 21.5 | 0.07 | 492.7 | 99.2 | 1.2 | 7.9 | 5.0 | 1.7 |
| NHPP-0139 | 16.7 | 4.3 | 3.1 | 5.8 | 37.7 | 1.6 | 58 | 60 | 96 | 2.5 | 0.8 | 3.0 | 7.4 | 0.12 | 42.7 | 216.9 | 1.9 | 7.4 | 5.0 | 1.5 |
| NHPP-0140 | 9.8 | 4.8 | 3.3 | 6.9 | 40.3 | 1.6 | 56 | 58 | 92 | 2.7 | 1.7 | 8.4 | 8.0 | 0.19 | 483.2 | 144.2 | 1.0 | 8.1 | 4.0 | 1.0 |
| NHPP-0144 | 20.7 | 3.6 | 4.3 | 9.6 | 38.7 | 1.8 | 42 | 44 | 89 | 7.7 | 1.5 | 9.9 | 10.8 | 1.08 | 29.2 | 213.1 | 2.2 | 7.7 | 5.0 | 1.5 |
| NHPP-0145 | 14.1 | 5.1 | 3.1 | 6.4 | 39.8 | 1.4 | 55 | 58 | 92 | 2.3 | 1.6 | 8.3 | 14.2 | 0.35 | 47.7 | 270.8 | 1.4 | 7.6 | 4.5 | 1.7 |
| NHPP-0316 | 16.6 | 4.5 | 2.8 | 5.1 | 38.8 | 1.6 | 69 | 61 | 96 | 1.4 | 1.1 | 5.0 | 3.0 | 0.03 | 75.2 | 248.6 | 1.1 | 8.5 | 5.0 | 1.8 |
| NHPP-0317 | 15.4 | 2.8 | 3.4 | 9.3 | 36.0 | 1.8 | 47 | 44 | 80 | 6.3 | 1.3 | 5.5 | 15.1 | 0.91 | 104.2 | 124.7 | 2.0 | 8.1 | 5.5 | 0.8 |
| NHPP-0319 | 9.3 | 4.8 | 2.6 | 6.3 | 21.4 | 1.4 | 56 | 54 | 86 | 2.7 | 2.9 | 10.2 | 12.9 | 1.30 | 141.7 | 368.1 | 0.4 | 7.9 | 6.0 | 0.5 |
| NHPP-0320 | 14.3 | 4.0 | 2.9 | 7.1 | 24.4 | 1.5 | 55 | 50 | 84 | 2.5 | 2.9 | 11.4 | 4.8 | 0.42 | 30.7 | 330.3 | 1.1 | 8.1 | 5.5 | 1.3 |
| NHPP-0323 | 7.2 | 5.4 | 2.5 | 5.1 | 32.8 | 1.5 | 62 | 60 | 94 | 2.7 | 0.8 | 5.0 | 4.6 | 0.04 | 29.2 | 79.7 | 2.1 | 8.8 | 5.0 | 1.1 |
| NHPP-0331 | 18.1 | 5.1 | 4.2 | 8.3 | 45.8 | 2.0 | 48 | 41 | 85 | 5.7 | 2.0 | 8.9 | 6.5 | 0.83 | 44.7 | 269.2 | 3.6 | 8.1 | 6.0 | 1.4 |
| NHPP-0332 | 6.2 | 6.2 | 2.3 | 5.4 | 29.4 | 1.4 | 59 | 70 | 96 | 1.8 | 0.7 | 10.9 | 2.8 | 0.02 | 30.7 | 304.2 | 6.8 | 8.0 | 6.0 | 1.5 |
| NHPP-0334 | 16.1 | 4.3 | 4.1 | 8.4 | 48.0 | 1.9 | 45 | 42 | 85 | 6.9 | 2.0 | 8.3 | 12.5 | 1.41 | 64.2 | 324.2 | 2.8 | 8.2 | 4.5 | 0.8 |
| NHPP-0335 | 10.5 | 3.7 | 2.6 | 4.9 | 22.4 | 1.5 | 59 | 59 | 96 | 2.5 | 2.6 | 11.2 | 4.4 | 0.39 | 62.7 | 174.7 | 3.1 | 8.0 | 6.0 | 0.7 |
| NHPP-0589 | 12.3 | 3.5 | 3 | 7.9 | 34.6 | 1.7 | 48 | 41 | 88 | 6.2 | 1.0 | 9.1 | 15.2 | 0.74 | 115.2 | 154.2 | 2.1 | 8.5 | 5.0 | 1.0 |
| **Mean** | **13.0** | **4.5** | **3.1** | **6.7** | **34.8** | **1.6** | **55.1** | **54.0** | **88.1** | **3.6** | **1.5** | **8.1** | **9.1** | **0.5** | **114.2** | **222.9** | **2.2** | **8.1** | **5.3** | **1.3** |
| Local check | | | | | | | | | | | | | | | | | | | | |
| Hausa Local | 8.2 | 6.3 | 3.1 | 7.3 | 25.1 | 1.6 | 58 | 53 | 94 | 2.8 | 2.8 | 14.4 | 3.8 | 0.6 | 218.7 | 264.7 | 2.3 | 8.4 | 5.0 | 1.7 |
| Yoruba Local | 18.1 | 3.2 | 3.2 | 6.2 | 33.2 | 1.7 | 54 | 42.3 | 94 | 5.1 | 1.2 | 9.6 | 17.6 | 0.2 | 30.7 | 215.3 | 6.9 | 7.8 | 5.0 | 1.3 |
| LSD $_{(0.05)}$ | 4.1 | 1.3 | 0.8 | 1.7 | 12.1 | 0.2 | 10 | 10.8 | 11 | 1.3 | 0.6 | 2.1 | 12.7 | 0.7 | 10.5 | 16.2 | 0.1 | 0.2 | 0.7 | 0.3 |

Note: SDH = Seedling height, LW = Leaf width, PL = Pedicel length, BH = Branch height, PH = Plant height, FD = Flower diameter , DTF = Number of days to 50 % flowering, DTFR = Number of days to first fruiting, DTM = Number of days to maturity, FRL = Fruit length, FRW = Fruit width, WOTS = Weight of 1000 seeds, NOFPP = Number of fruits per plant, YIELD = Fruit yield (t ha$^{-1}$), CAPS = Capsaicin (mg 100 g$^{-1}$), VIT C = Vitamin C (mg 100 g$^{-1}$), BTC = β-carotene (mg 100 g$^{-1}$) Fruit pH, TSS = Total soluble solid (°Brix), TA = Titratable acidity (%)

Comparing the mean performance of the better checks with the accessions from NIHORT, 25.0 % of the evaluated accessions were significantly ($P < 0.05$) higher for vitamin C; 12.5 % of the accessions had significantly ($P < 0.05$) longer pedicels and fruits, higher branches and capsaicin content coupled with shorter number of days to maturity. Only 6.3 % of the accessions had significantly ($P < 0.05$) taller plants, wider flowers, higher fruit yield with shorter number of days to 50 % flowering.

The accessions evaluated in this study expressed significant variation for pungency. Capsaicin contents were between 29.2 mg 100 $g^{-1}$ (NHPP-0323) and 492.7 mg 100 $g^{-1}$ (NHPP-0137) with a mean of 114.2 mg 100 $g^{-1}$. The vitamin C content of the pepper accessions was between 79.7 mg 100$g^{-1}$ (NHPP-0323) and 368.1 mg 100 $g^{-1}$ (NHPP-0319) with a mean of 222.9 mg 100 $g^{-1}$. The β-carotene content of the pepper fruits ranged between 0.4 mg 100 $g^{-1}$ (NHPP-0319) to 6.8 mg 100 $g^{-1}$ (NHPP-0332) with a mean of 2.2 mg 100 $g^{-1}$.

Furthermore, the evaluated accessions had a considerable variation for total soluble solids and titratable acidity with the former varying between 4.0 °brix (NHPP-0140) and 6.0 °brix (NHPP-0135, NHPP-0319, NHPP-0331, NHPP-0332 and NHPP-0335) with an average of 5.3 °brix and the latter ranging from 0.5 mg 100 $g^{-1}$ (NHPP-0319) to 1.8 mg 100 $g^{-1}$ (NHPP-0316) with an average of 1.3 mg 100 $g^{-1}$.

Correlation coefficients (r) observed between pairs of traits ranged from -0.27 to 0.84 (Table 4). The strongest positive relationship was observed between stem colour and fruit length ($r = 0.84$, $P < 0.001$) while the association between fruit length and number of days to first fruit was negative but strong. Number of days to 50 % flowering had positive significant ($P < 0.001$) correlation with number of days to first fruiting ($r = 0.68$). Fruit length had negative significant ($P < 0.001$) correlation with number of days to 50 % flowering ($r = -0.69$) and number of days to first fruiting ($r = -0.71$). Fruit width was negatively associated with number of days to first fruiting. The stem colour showed negative association with flowering and fruiting traits but had a positive correlation with fruit length ($r = 0.84$). Similarly, plant height had significant negative correlation with flowering and fruiting traits but positive correlation with fruit length and stem colour. Number of days to maturity and number of days to first fruiting were positively correlated. Branch height had negative relationship with number of days to flowering, maturity and first fruit but had a positive association with fruit length ($r = 0.70$) and stem colour ($r = 0.66$). Node colour showed negative correlation with number of days to flowering and first fruit while its associations with fruit length ($r = 0.73$), stem colour ($r = 0.75$), plant and branch heights were positive. Seedling height was positively correlated with fruit length ($r = 0.56$), stem colour ($r = 0.62$), node colour ($r = 0.50$) branch and plant height but had negative correlation with number of days to flowering and first fruit. Flower diameter had positive association with fruit length ($r = 0.65$), branch and plant height as well as stem and node colour but had negative correlation with number of days to flowering and first fruit. Likewise negative correlation with number of days to flowering and first fruit was recorded for pedicle length. However, the trait had positive relationship with seedling, branch and plant heights, stem and node colours as well as fruit length ($r = 0.72$) and flower diameter ($r = 0.60$). Leaf width was positively correlated with only number of days to first fruiting, other correlated traits were negative. The weight of 1000 seeds had significant correlation with fruit width ($r = 0.58$). Number of fruits per plant also showed negative association with number of days to flowering, maturity and first fruit but had positive relationships with fruit yield, node and stem colours. Fruit yield was significantly correlated with flower diameter, fruit related traits, growth parameters, stem and node colours but like other measured traits, fruit yield was significantly ($P < 0.001$) negatively associated with number of days to flowering ($r = -0.63$) and first fruiting ($r = -0.54$). Considering the nutritional parameter, capsaicin was negatively correlated with stem colour (-0.30), seedling height (-0.38) and number of days to maturity (-0.41) but positively correlated with leaf width. Vitamin C is positively correlated with weight of 1000 seeds (0.36), fruit width (0.49) and yield but had a negative association with capsaicin (-0.39). β-carotene is associated with number of days to maturity and negatively correlated with capsaicin (-0.35) as well.

The relative discriminating power of the principal axes as indicated by the eigenvalues was high for axis 1 (11.87) and as low as 1.11 for axis 6. The first six principal components (PC) with eigenvalues >1 contributed to a cumulative variation of 86.4 % (Table 5). In view of traits with the highest coefficients in each of the PCs fruit length, stem colour, branch height, node colour, flower diameter, pedicle length and fruit yield were the most important traits explaining variability within the pepper accessions in PC1. Plant height at flowering, number of days to maturity and seedling height had the highest coefficients in PC2. Vitamin C content of the pepper fruit was considered as the most important parameter that contributed to the total genetic variance as revealed by PC3. In PC4, leaf width and capsaicin were the traits that made substantial contribution to total variation among the accessions. The highest contributors to variation in PC axis 5 were weight of 1000 seeds and β-carotene.

The cluster analysis grouped evaluated pepper accessions into three main clusters (Fig. 2). Cluster I accounted for 33.3 % of the total accessions including one of the commercial variety that was used as a local check (Yoruba local). The accessions in this group were superior for eight morphological traits; number of fruits per plant and fruit yield inclusive, coupled with early flowering, maturity and fruiting. Also this cluster was distinguished by anthocyanin coloration on the nodes and green + purple stem colour irrespective of their diverse collection sources. Cluster II had five accessions accounting for 27.8 % of the total with mainly green colour nodes and stems except for accession NHPP-0316, which had light purple node colour. This cluster comprised of accessions that flowered and matured late with the lowest values for other morphological traits and even capsaicin content in comparison to the other clusters but with high titratable acidity. Clusters III had seven accessions including a commercial variety that was used as a local check (Hausa local) representing 38.9 % of the total. This group had accessions with high capsaicin and vitamin C content as well as high values for yield related parameters, but with low β-carotene, titratable acidity and the plants were short. The accessions in this cluster had majorly green nodes, only two accessions (NHPP-0145 and NHPP-0140) had light purple node colour. Their stem colours were all green except for NHPP-0145 with green + purple stem colour. The node and stem colour, which are qualitative traits less influenced by environment, aid the differentiation of the accessions.

**Table 4.** Correlation coefficients (r) between morphological traits and nutritional parameters of pepper

| | DTF | DTFR | FRL (cm) | FRW (cm) | SC | PH (cm) | DTM | BH (cm) | NC | SDH (cm) | FD (cm) | LW (cm) | PL (cm) | WOTS (g) | YIELD (tha$^{-1}$) | NOFPP | CAPS | VIT C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DTFR | 0.68*** | | | | | | | | | | | | | | | | | |
| FRL | -0.69*** | -0.71*** | | | | | | | | | | | | | | | | |
| FRW | -0.15 | -0.29* | 0.05 | | | | | | | | | | | | | | | |
| SC | -0.64*** | -0.63*** | 0.84*** | -0.07 | | | | | | | | | | | | | | |
| PH | -0.35** | -0.35** | 0.39*** | -0.22 | 0.38** | | | | | | | | | | | | | |
| DTM | 0.17 | 0.27* | -0.11 | 0.06 | -0.08 | 0.01 | | | | | | | | | | | | |
| BH | -0.58*** | -0.64*** | 0.70*** | 0.24 | 0.66*** | 0.22 | -0.30* | | | | | | | | | | | |
| NC | -0.55*** | -0.54*** | 0.73*** | -0.06 | 0.75*** | 0.39*** | 0.01 | 0.59*** | | | | | | | | | | |
| SDH | -0.44*** | -0.57*** | 0.56*** | 0.00 | 0.62*** | 0.50*** | -0.05 | 0.37** | 0.50*** | | | | | | | | | |
| FD | -0.41*** | -0.58*** | 0.65*** | -0.01 | 0.49*** | 0.37** | -0.26 | 0.53*** | 0.57*** | 0.51*** | | | | | | | | |
| LW | 0.23 | 0.36** | -0.45*** | 0.01 | -0.41*** | -0.11 | -0.05 | -0.16 | -0.27* | -0.48*** | -0.24 | | | | | | | |
| PL | -0.44*** | -0.55*** | 0.72*** | 0.22 | 0.63*** | 0.51*** | 0.14 | 0.51*** | 0.61*** | 0.65*** | 0.60*** | -0.25 | | | | | | |
| WOTS | -0.21 | -0.17 | 0.08 | 0.58*** | 0.03 | -0.24 | -0.02 | 0.18 | -0.06 | -0.20 | -0.11 | 0.17 | 0.04 | | | | | |
| YIELD | -0.63*** | -0.54*** | 0.60*** | 0.50*** | 0.44*** | 0.16 | -0.19 | 0.52*** | 0.52*** | 0.35** | 0.33** | -0.14 | 0.48** | 0.24 | | | | |
| NOFPP | -0.50*** | -0.36** | 0.24 | -0.11 | 0.30* | 0.06 | -0.50*** | 0.21 | 0.30* | 0.19 | 0.14 | -0.10 | -0.06 | -0.01 | 0.42*** | | | |
| CAPS | 0.05 | 0.09 | -0.24 | -0.01 | -0.30* | -0.13 | -0.41*** | 0.01 | -0.17 | -0.38** | 0.01 | 0.29** | -0.24 | 0.11 | -0.11 | 0.23 | | |
| VIT C | -0.01 | 0.00 | -0.04 | 0.49*** | -0.02 | -0.03 | 0.18 | 0.03 | -0.03 | 0.13 | -0.14 | 0.11 | 0.17 | 0.36** | 0.27* | -0.19 | -0.39*** | |
| BTC | -0.09 | -0.05 | 0.18 | -0.22 | 0.19 | 0.02 | 0.28* | -0.06 | 0.25 | 0.04 | 0.05 | -0.01 | 0.05 | 0.24 | -0.12 | -0.02 | -0.35** | 0.09 |

Note: SDH = Seedling height, LW = Leaf width, PL = Pedicel length, BH = Branch height, SC = Stem colour, NC = Node colour, PH = Plant height, FD = Flower diameter, DTF = Number of days to 50 % flowering, DTFR = Number of days to first fruiting, DTM = Number of days to maturity, FRL = Fruit length, FRW = Fruit width, WOTS = Weight of 1000 seeds, NOFPP = Number of fruits per plant, YIELD = Fruit yield (t ha$^{-1}$), CAPS = Capsaicin (mg 100 g$^{-1}$), VIT C = Vitamin C (mg 100 g$^{-1}$), BTC = β-carotene (mg 100 g$^{-1}$), *, **and *** indicates significance at $P < 0.05$, 0.01 and 0.001 levels, respectively

**Table 5.** Principal component analysis of the contribution of quantitative and qualitative traits to total variation among pepper accessions

| Parameter | Eigenvectors | | | | | |
|---|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 |
| Number of days to 50 % flowering | -0.26 | 0.13 | -0.01 | -0.06 | -0.14 | 0.07 |
| Number of days to first fruiting | -0.27 | 0.07 | -0.02 | 0.01 | -0.07 | 0.03 |
| Fruit length (cm) | 0.28 | 0.02 | -0.01 | -0.02 | 0.12 | -0.03 |
| Fruit width (cm) | 0.04 | -0.23 | 0.44 | -0.03 | -0.15 | -0.08 |
| Stem colour | 0.25 | 0.07 | -0.03 | -0.01 | 0.15 | -0.10 |
| Plant height at flowering (cm) | 0.14 | 0.34 | -0.13 | 0.32 | -0.11 | 0.06 |
| Number of days to maturity | -0.06 | 0.32 | 0.25 | -0.21 | 0.08 | 0.32 |
| Branch height (cm) | 0.25 | -0.10 | 0.04 | 0.14 | 0.05 | -0.11 |
| Node colour | 0.26 | 0.14 | -0.05 | 0.08 | 0.17 | 0.13 |
| Seedling height (cm) | 0.20 | 0.27 | 0.00 | -0.08 | -0.15 | -0.29 |
| Flower diameter (cm) | 0.22 | 0.08 | -0.11 | 0.19 | 0.04 | -0.27 |
| Leaf width (cm) | -0.18 | -0.08 | 0.09 | 0.45 | 0.18 | 0.01 |
| Pedicel length (cm) | 0.23 | 0.19 | 0.12 | 0.17 | -0.06 | -0.14 |
| Weight of 1000 seeds | 0.00 | -0.27 | 0.36 | 0.02 | 0.34 | -0.01 |
| Fruit yield (t ha$^{-1}$) | 0.23 | -0.19 | 0.22 | 0.06 | -0.11 | 0.02 |
| Number of fruits per plant | 0.14 | -0.24 | -0.29 | -0.03 | 0.09 | 0.13 |
| Capsaicin (mg 100 g$^{-1}$) | -0.06 | -0.30 | -0.25 | 0.29 | 0.01 | 0.04 |
| Vitamin C (mg 100 g$^{-1}$) | 0.01 | 0.04 | 0.48 | 0.10 | -0.10 | 0.05 |
| β-carotene (mg 100 g$^{-1}$) | 0.01 | 0.18 | 0.07 | -0.14 | 0.64 | 0.03 |
| Eigenvalue | 11.87 | 3.44 | 3.02 | 2.12 | 1.76 | 1.11 |
| Proportion of Variation (%) | 43.98 | 12.75 | 11.17 | 7.86 | 6.52 | 4.13 |
| Cumulative Variation (%) | 43.98 | 56.73 | 67.9 | 75.76 | 82.28 | 86.41 |

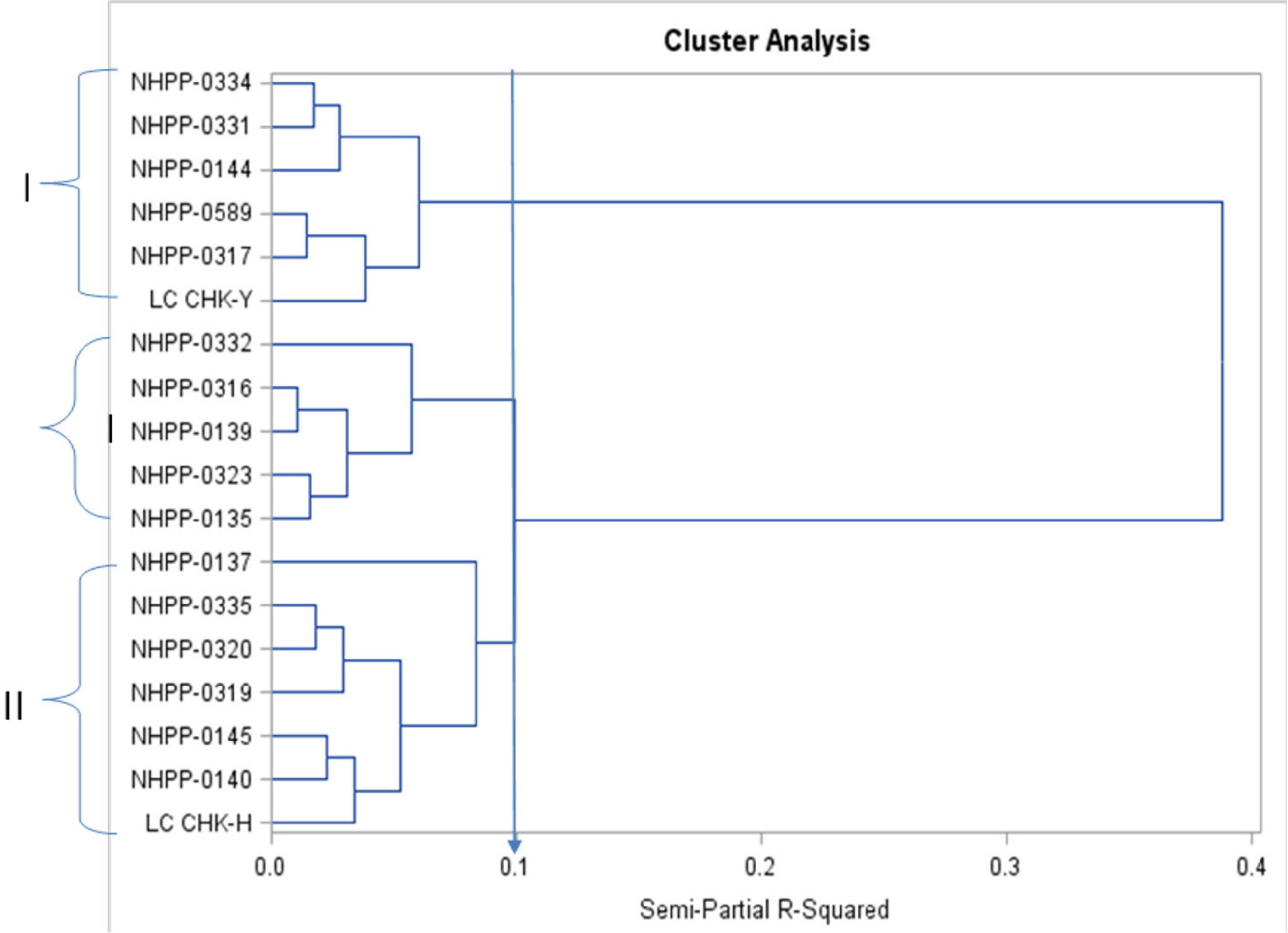

**Figure 2.** Dendrogram based on agronomic traits, nutritional and physicochemical parameters of pepper accessions generated by centroid hierarchical cluster analysis

## Discussion

Pre-breeding activities greatly improves the accessibility and utilization of genetic resources. Screening pepper accessions is vital for the determination of their potential and exploitation in breeding programmes and related researches (Abu et al., 2011). Variability among the evaluated pepper accessions was first observed as anthocyanin coloration (purple pigmentation) attributed to flavonoid compounds (Pimenta et al., 2012) on nodes for half of the accessions followed by the stem for few accessions. According to Kato et al. (2012) anthocyanin act as UV filter on the leaves, aids resistance to pathogens, and regulates photosynthesis in plants.

The coefficient of variation which indicates experimental precision was < 20 % for most of the parameters measured indicating good accuracy and reliability of the results obtained (Kolawole and Olayinka, 2022). The observed variations among the pepper accessions for growth, fruit and yield related traits as well as nutritional and physicochemical parameters indicated the presence of substantial variability essential for effective selection in agreement with the previous report (Cebula et al., 2015). Therefore, superior accessions can be identified and selected for genetic improvement and development of high yielding varieties with high content of desired nutritional parameters.

The wide range in mean performance of the accessions for morphological traits agrees with the reports of Nandadevi and Hosamani (2003) and Shukri et al. (2015). In this study, the mean yield of the pepper accessions was lower than that reported by Abu-Ngozi et al. (2019). The variation in the yield of the accessions may be linked to phenotypic differences that are evidenced by the differences in the fruit length and width, consistent with the reports of Abu et al. (2015) and Silva et al. (2017). The higher numbers of fruits recorded in some of the accessions translated to higher yield indicating that these accessions can be used as parental lines in pepper breeding programmes due to their prolificacy. Abu-Ngozi et al. (2019) report that parental lines with high fruiting ability are essential for developing improved genotypes with high performance in line with the breeders' objectives.

The performances of the accessions were attributable to their inherent genetic potentials and few accessions combined desirable traits. The genetic make-up of accession NHPP-0137 aided early maturity without fruit abortion and the pepper fruits had high capsaicin content. Earliness to maturity could also have enabled the accession to produce more pods per plant, which contributed to a high number of fruits per plant. Accession NHPP-0144 had better capacity to absorb sufficient nutrients from the soil which enhanced the growth parameters. This accession also displayed early acclimatization to the growing environment and ability of to withstand transplanting disruption (Nkansah et al., 2011) which eventually resulted into early flowering. The shortest pepper accession (NHPP-0319) had wide fruits; high TSS and vitamin C content which are considered best quality traits with higher market demand. Accession NHPP-0320 also had wide fruits and the highest weight for 1000 pepper seeds. Similarly, accession NHPP-0332 exhibited wide leaves (vegetative growth) which are responsible for increased photosynthetic capacity and assimilate partitioning that results in higher seed weight and appreciable β-carotene content. These two accessions are desirable because large pepper fruits attract premium price and they possess greater capacity for photosynthate storage coupled with lower respiration rate (Barrera et al., 2008). However, there is a need to improve these accessions for yield related traits. Accession NHPP-0334 had the tallest plant without lodging, longer fruit and the highest fruit yield and may be characterized as suitable for breeding purposes considering enhanced yield and productivity. This accession maximizes photosynthetic capacity and assimilates partitioning with its height in consonance with the report of Sam-Aggrey and Bereke-Tsehai (2005) who found positive impact of vegetative growth on yield and yield components.

Knowledge on the morphological traits of pepper accession is of limited value if it is not accompanied by extensive and detailed documented reports on the nutritional and physicochemical properties of the evaluated accessions. This information is an essential criterion for selection of genotypes because vegetables with antioxidant properties are linked to the prevention of certain cancers and diverse non-communicable diseases (Alvarez-Parrilla et al., 2012; Mateos et al., 2013). The principal chemical components that boost commercial value of pepper are capsaicinoids (pungency) and carotenoids (contributes fruit colour). Accession NHPP-0137 had the smallest fruit width (0.6) and length (1.6 cm) but with the highest concentration of capsaicinoids, which corroborates the report of Andrade et al. (2020). The content of capsaicin in this accession is higher than the value reported by Simonovska et al. (2014). Capsaicin which is responsible for pungency in pepper has been described as an important pharmaceutical property (Kurita, 2002) useful in the prevention of chronic and age-related diseases.

Additionally, pungency in pepper varies depending on the genotype and fruit phenological stage (De, 2003; Maksimova et al., 2016). Accession NHPP-0319 was superior for vitamin C content. The value of vitamin C concentration for this accession was higher than previous reports of Kumar et al. (2003) and Topuz and Ozdemir (2007) who worked on Indian pepper genotypes and that of Balkaya and Karaagac (2009) who worked on Turkish pepper genotypes. This is an indication that these pepper fruits contain sufficient vitamin C required to meet the recommended daily amounts (Padilha et al., 2015). Vitamin C in human diet comes majorly from fruits and vegetables and it is the most important and powerful water-soluble antioxidant among the bioactive compounds (Lee and Kader, 2000; Sesso et al., 2008) that mops up dangerous free radicals in the body, thereby preventing diseases. In comparison to some fruit vegetables, higher vitamin C contents have been reported in pepper fruits (Bosland and Votava, 2000; Finger et al., 2010).

The transition of chloroplasts into chromoplasts during fruit ripening is responsible for the change in color at maturity (Hornero-Méndez and Minguez-Mosquera, 2000). All the evaluated pepper accession fruits turned red when ripe as impacted by the presence of carotenoid which increases with fruit ripening due to synthesis of capsanthin, capsorubin, â-cryptoxanyhin and zeaxanthin (Ha et al., 2007). Accession NHPP-0332 had the dietary precursor of vitamin A which is higher than the values reported by Dubey et al. (2015) and Alam et al. (2018) but within the range that would supply 100 % of the recommended dietary allowance (RDA) of vitamin A in adults (Wall et al., 2001).

The TSS of pepper fruits comprise total sugars and organic acids which are critical to the overall sensory quality and can be used to determine the maturity of peppers (Tadesse et al., 2002). Few accessions stood out among all and fall in the range of minimum (6 and 6.5°Brix) recommended level of sugar for red pepper (Tadesse et al., 2002) probably as a result of increased accumulation of glucose and fructose during fruit ripening (Nielsen et al., 1991). The content of TSS in these accessions was higher than the report of Corrêa et al. (2018) but comparable to the reports of Rinaldi et al. (2008) and Sediyama et al. (2014).

Additionally, the value of fruit pH found in this study for all accessions was higher than in previous reports (Estrada et al., 2000; Castro et al., 2005). A consistent guide to fruit ripening is TA or the ratio of TSS to TA which depicts analytical measurement for quality. These values represent the amount of organic acids (citrate and malate) within the fruit whose accumulation is responsible for flavor in pepper depending on the state of maturity (Beckles, 2012; Figueroa et al., 2015). The TA of accession NHPP-0316 was the most outstanding, whereas accession NHPP-0319 had the highest TSS/TA ratio, hence better flavour and consumption priority.

Plausible explanation for differences in the results from this study may be due to accessions diversity, environmental conditions, maturity stage and production system (Melo et al., 2006). The wide range in mean performance of the accessions for nutritional and physicochemical parameters indicates inherent genetic diversity. These diversities can therefore be exploited for the nutritional improvement of pepper in an attempt to combat micronutrient deficiencies.

Correlations among traits are useful in breeding programmes for indirect selection for a primary trait, through a secondary trait and it also allows the improvement of several traits using just a few (Bonny, 2011). This study shows desirable linear association between pepper fruit yield, flowering traits, growth parameters and traits related to fruiting in conformity with previous reports (Sharma et al., 2010; Shumbulo et al., 2017; Orobiyi et al., 2018). Hence, pepper fruit yield can be improved through selecting accessions with these traits. More than ten morphological traits had significant strong negative association with number of days to 50 % flowering and first fruiting, which implies that those traits may be considered as secondary traits when selecting for earliness in pepper breeding. The relationship between number of fruits per plant and fruit yield is in line with the report of Tembhurne et al. (2010) and may be considered as a criterion for selection of accessions for fruit yield. The positive correlation between flower diameter and growth parameters (seedling, branch and plant heights) indicates that taller plants produce wide flowers.

On the other hand, the negative association of flower diameter with number of days to flowering and fruiting implies that wide flowers are associated with earliness. Interestingly, out of the three nutritional parameters measured, capsaicin had a negative relationship with seedling height and number of days to maturity. Negative associations between nutraceuticals and morphological traits have been reported (García-González et al., 2020). The negative coefficients between vitamin C and capsaicin as well as β-carotene and capsaicin disagree with the reports of Sora et al. (2015) and Kantar et al. (2016). Bigger fruits were associated with vitamin C; wide leaves and late maturity had relationship with capsaicin; likewise, late maturity was connected with β-carotene. The association between these traits shows the possibility of improving multiple traits which may aid selection index in pepper improvement programmes.

Previously, diversity studies using principal component analysis were used in pepper breeding to understand the most essential traits which explained the observed variability among the studied accessions (Portis et al., 2004; Bozokalfa et al., 2009; Rohami et al., 2010; Lahbib et al., 2012., Ilic et al., 2013). From this study, the contributions of the first six principal components to total genetic variation were higher than was observed by Bozokalfa et al. (2009). It can be deduced that traits listed in PCs 1 and 2 accounted for majority of the variability among the pepper accessions.

The cluster analysis revealed the relationship among the diverse pepper accessions and they were classified into three main clusters indicating divergence based on their morphological traits, nutritional and physicochemical parameters. Therefore, accessions identified as superior for specific desired traits belonging to different clusters can be selected and considered useful as parental lines in hybridization programmes (Lin et al., 2013) to produce viable and potential segregants population in pepper breeding.

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