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Original Article

Variations in agromorphological characteristics of IPGRI Cowpea (*Vigna unguiculata* (L.) Walp.) accessions

Ekemini Obok[1*], Macauley Ittah[1], Isong Ekurisong[2], and Francis Nwagwu[1]

[1] *Department of Crop Science, University of Calabar, Calabar, Nigeria*

[2] *Cross River State College of Education, Akamkpa, Nigeria*

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Abstract

Cowpea (*Vigna unguiculata* (L.) Walp.) remains an important crop in the tropics. One of its challenges remains the selection and improvement of genotypes to meet location–specific needs. We studied ten cowpea accessions in Akamkpa and Ikom, Cross River State, Nigeria. Principal component and biplot analyses associated high yield with growth, flowering, pod and seed traits. Seed weight per plot and number of seeds per plot were phenotypically correlated ($r_p = 0.99$, $p \leq 0.01$). Number of seeds per plot and number of seeds per pod were genotypically correlated ($r_g = 1.00$, $p \leq 0.01$). TVu–980 did not flower at Akamkpa and TVu–1019 did not grow at Ikom. TVu–992, TVu–53, TVu11, TVu–3629 and TVu–980 (only at Ikom) cowpea accessions showed promising agromorphological attributes for possible crop improvement programmes in Ikom and Akamkpa.

Keywords: cowpea, genotypic correlation, multivariate analysis, phenotypic correlation, principal component analysis

1. Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) grows in the tropics (Agyeman, Berchie, Osei–Bonsu, Nartey, & Fordjour, 2014), as sole crop or intercrop (Albuquerque, Oliva, Alves, Uchôa, & de Melo, 2015; Asiwe, Nkuna, & Motavalli, 2021a). Cowpea has a rich nutrient profile (Dominguez–Peries, Nelson, Valdemar, Miguel, & Ana, 2016). Through symbiosis with *Rhizobium*, cowpea fixes and enriches the soil with atmospheric nitrogen; and decreases soil erosion and weeds as a smoother crop (Nwagwu, Athanasius, Michael, Obok, & Ibrahim, 2022; Ola, Dodd, & Quinton, 2015).

Nigeria (2,606,912 tonnes), the Republic of Niger (2,376,727 tonnes) and Burkina Faso (630,965 tonnes) are top ranked in cowpea production (Food and Agriculture Organization of the United Nations Statistics Division [FAOSTAT], 2020). Cowpea thrives under 280 – 4100 mm rainfall and 22 – 28°C (Craufurd, Summerfield, Ellis, & Roberts, 1997). Weevils (*Callosobruchus maculatus* F.), leafhoppers (*Empoasca* spp), aphids (*Aphis craccivora)*, cowpea thrips (*Megaluro thripssjostedti*), blister beetles (*Hycleu slugens)* and green stink bugs (*Nezara viridula)* attack cowpea (Adebayo, Olaniran, & Akanbi, 2007; Centre for Agriculture and Bioscience International [CABI], 2015; Tiroesele, Thomas, & Seketeme, 2015).

Cowpea is an excellent food crop with a range of demands (Ayalew & Yoseph, 2022). Thus, developing high yielding and location–specific cultivars is the key to success. This requires selecting genotypes with desirable agromorphological characteristics (Abua, Iwo, & Obok, 2014) based on genetic and environmental factors. Cowpea's productivity can be limited by unpredictable rainfall patterns, poor soil, over–dependence on agrochemicals, unimproved seeds, pests, and diseases (Ajadi, Adeniyi, & Afolabi, 2011; Challinor *et al.*, 2014; Omomowo & Babalola, 2021; Ren *et al.*, 2014; Savary *et al.*, 2019).

Cowpea improvement is of strategic importance to its yields (Omomowo & Babalola, 2021). There are 16,460 International Institute of Tropical Agriculture [IITA] cowpea collections; few have been studied. The need to explore

*Corresponding author
Email address: e.e.obok@unical.edu.ng

additional cowpea germplasm for productivity enhancement is imminent. Cowpea improvement is possible with knowledge of genetic diversity (Bello *et al.*, 2021, Doumbia, Akromah, & Asibuo, 2013; Stoilova & Pereira, 2013) from multivariate analysis (Ponsiva, Sabarinathan, Senthilkumar, Thangavel, & Manivannan, 2019). Therefore, we evaluated agromorphological traits of cowpeas in Akamkpa and Ikom environments, in Cross River State, Nigeria, and explored the extent of these variations essential for potential cowpea improvement in these areas.

2. Materials and Methods

2.1 Site

Experiments were conducted in Akamkpa (5°5'15" N 8°21'30" E) and Ikom (5°57'40" N 8°42'39" E), Cross River State, Nigeria, between 28 August 2018 and 30 November 2018, at the Teaching and Research Farm, College of Education and farmers' demonstration plots, respectively.

2.2 Soil analysis

Topsoil samples (20 cm depth) were analysed for soil pH (IITA, 1982), texture (Gee & Bauder, 1986), total N (Bremner & Mulvaney, 1982), organic carbon (Nelson & Sommers, 1982), available P (Bray & Kurtz, 1945; Murphy & Riley, 1962), exchangeable bases, exchangeable acidity, effective cation exchange capacity (ECEC) and base saturation (BS) (Anderson & Ingram, 1993).

2.3 Planting materials

Ten IPGRI cowpea accessions were studied (Figure 1), Nigeria: TVu–7, TVu–11, TVu–53, TVu–980, TVu–1505, TVu–3629 and TVu–7954, India: TVu–992, USA: TVu–1019, and Cameroon: TVu–11273. These were obtained from the IITA (descriptors: https://my.iita.org/accession2/search.jspx?q =TVu)

2.4 Experimental design and field management

Randomised complete block design with three replications was used. Treatment plot measured 2.5 m × 2.5 m (6.25 m^2) with 1 m alleys. Two seeds per hill were planted (50 cm × 50 cm) and thinned (10 days after) to one stand (40,000 stands ha^{-1}). NPK (15:15:15) was applied at planting as a starter dose (15 kg N ha^{-1}). Insect pest and weed control was done as recommended by Omoigui *et al.* (2018).

2.5 Data collection

Data were collected from the net plot (50 cm × 150 cm, 8 tagged plants) on days to 50% flowering, number of flowers per plant, plant height, number of branches, leaf length, leaf width, peduncle length, plant population per plot, number of internodes per vine, number of nodes per vine, vine thickness, number of pods per plant, pod length, pod weight, number of seeds per pod, number of seeds per plot, total seed weight per plot and 100–seed weight (12% moisture content) (International Board for Plant Genetic Resources [IBPGR], 1983; National Plant Genetic Resources Laboratory [NPGRL], 2018).

2.6 Data analysis

Data were subjected to a two–way analysis of variance (ANOVA) using GenStat 16th edition (VSN International Limited, Rothamsted Experimental Station, Hemel Hempstead, UK) with Duncan's New Multiple Range test (DNMRT) (α = 0.05). Principal component analysis (PCA) and cluster analysis (Euclidean Distance) were done using Paleontological Statistics (PAST) software package (version 4.03) (Hammer, Harper, & Ryan, 2001). Cluster analysis reduces the number of discrete variable components by grouping them into a dendrogram based on a suitable coefficient of similarity (Tatineni, Cantrell, & Davis, 1996) and statistically congregates samples into clusters (Hair, Anderson, Tatham, & Black, 1995; Aremu, 2007). Genotypic (r_g) and phenotypic (r_p) correlation coefficients were computed using Plant Breeding Tools (PBTools, 2014):

Figure 1. IPGRI cowpea accessions used in the study

$$r_g = \frac{COV_g\,(x,y)}{\sqrt{V_g x \times V_g y}}$$

Here COV_g (x, y) is the genotypic covariance between characters x and y; $V_g x$ represents the genotypic variance of character x; $V_g y$ is the genotypic variance of character y.

$$r_p = \frac{COV_p\,(x,y)}{\sqrt{V_p x \times V_p y}}$$

Here COV_P (x, y) means the phenotypic covariance between characters x and y; $V_p x$ stands for the phenotypic variance of character x; $V_p y$ represents the phenotypic variance of character y.

3. Results and Discussion

3.1 Soil properties and weather conditions

The soil pH at Akamkpa and Ikom were 4.8 (strongly acidic) and 5.5 (moderately acidic), respectively (Table 1). Organic carbon (1.7%), carbon–nitrogen ratio (10.63) Ca^{2+} (16.93 cmol (+) kg^{-1}), Na^+ (1.67 cmol (+) kg^{-1}), K^+ (0.86 cmol (+) kg^{-1}), Al^{3+} (0.98 cmol (+) kg^{-1}) and H^+ (0.84 cmol (+) kg^{-1}) and clay contents (180 g kg^{-1}) were higher at Akamkpa. Ikom had higher total N (0.18 %), available P (31 mg kg^{-1}), Mg^{2+} (5.46 cmol (+) kg^{-1}), ECEC (23.01 cmol (+) kg^{-1}), BS (92.09%), sand (813 g kg^{-1}) and silt (67 g kg^{-1}) contents. Both locations had sandy loam soil and the weather conditions were relatively similar. Soil pH at both locations was below the range (6.6 – 7.6) reported by Joe and Allen (2008) to encourage maximum root length, plant height, nodulation, number of pods per plant and seed size. Whereas a soil pH between 6.0 and 7.5 is ideal for P–availability, pH below 5.5 limits P–availability because of fixation by aluminium, iron, or calcium. Based on Bray and Kurtz (1945) critical levels, P was high in Akamkpa ($\geq 25 \leq 30$ mg kg^{-1}) and highest in Ikom (> 30 mg kg^{-1}). Though ECEC and organic carbon fell within their desired ranges, 5 – 25 cmol (+) kg^{-1} and 1 – 2%, respectively, soil fertility status was poor. Apparently, these factors influenced sprouting of seeds and establishments of seedlings. TVu–1019 originated from the USA (Arkansas), an area relatively cold between August (22°C) and November (9°C average temperature). TVu–1019 failure to grow in Ikom corroborates with Khan, Bari, Khan, Shan, & Zada (2010) report that environmental variations can prevent germination and growth of cowpeas; and with Angelotti, Barbosa, Barros, and dos Santos (2020) and Barros *et al.* (2021) who report that temperatures of 29 °C (day)/23 °C (night) lead to higher seed weight while 32 °C (day)/29 °C (night) lead to flower abortion in certain cowpea cultivars. Photoperiod upsets cowpea flowering in West and Central Africa (Ishiyaku, Singh, & Craufurd, 2005). This explains TVu–980 not flowering at Akamkpa (25 – 29°C). Our findings could assist crop breeders and farmers to group photoperiodic sensitive cowpeas according to their reproductive and maturity periods as opined by Zannou, Struik, Richards, Tossou, and Zoundjihekpon (2015).

3.2 Agromorphological differences

The analysis of variance showed significant ($p \leq 0.05$) agromorphological differences among the cowpea accessions (Table 2). TVu–992 had the tallest plant height (PH) ($p \leq 0.05$) at Akamkpa (95.7 cm) and Ikom (114.6 cm) while TVu–3629 (17 cm) and TVu–7 (9.4 cm) were the shortest ($p > 0.05$), respectively. Leaf length (LL) followed a similar trend for TVu–992. LL ranged from 5.3 cm (TVu–1019) to 13.1 cm (TVu–992) at Akamkpa and 10.2 cm (TVu–7954) to 15.2 cm (TVu–992) at Ikom. TVu–11 had the highest ($p \leq 0.05$) number of branches (NB) at Akamkpa and Ikom with the lowest ($p < 0.05$) from TVu–53 (1.9) and TVu–992 (2.2), respectively. Overall, narrow leaves (i.e., leaf width (LW)) were reported at Akamkpa (2.1 – 7.7 cm) and broader leaves at Ikom (5.5 – 7.8 cm). TVu–3629 had higher peduncle length (PdL) at both locations. TVu–1505 had the highest average plant population per plot (PP) (15.7) while TVu–1019 and TVu–7 recorded the lowest (1.0 – 2.0). Number of internodes (NI) were higher at Ikom (10.4 – 17.8) than at Akamkpa (2.8 – 7.3). TVu–11 (Ikom – 21.8) and TVu–992 (Akamkpa – 14.6) outperformed other accessions in number of nodes (NN). TVu–11273 had the thickest vines (VT) ($p \leq 0.05$) at Akamkpa (1.3 cm) and Ikom (1.5 cm). TVu–1019 and TVu–1505 at Akamkpa had similar ($p > 0.05$) VT (< 1.0) with TVu–7, TVu–7954, TVu–980 and TVu–992.

Based on days to 50% flowering (D50F), TVu–992 flowered earlier at Ikom (37.2 days) and late at Akamkpa (52.7 days) (Table 3). TVu–11 and TVu–3629 consistently

Table 1. Soil properties and weather conditions at experimental locations

Soil property	Akamkpa	Ikom
pH in water	4.8	5.5
Organic C (g/kg)	1.70	1.25
Total N (g/kg)	0.16	0.18
C:N	10.63	6.94
Available P (mg/kg)	28.96	31.00
Exchangeable cations (cmol/kg)		
Ca^{2+}	16.93	1.87
Na^+	1.67	0.90
K^+	0.86	0.43
Mg^{2+}	1.73	5.46
†CEC	21.19	8.66
Acidic cations (cmol/kg)		
Al^{3+}	0.98	0.80
H^+	0.84	0.45
Exchange acidity (cmol/kg)	1.82	1.25
††ECEC (cmol/kg)	23.01	9.91
Base saturation (%)	92.09	87.39
Particle size distribution (g/kg)		
Sand	783.0	813.0
Silt	37.0	67.0
Clay	180.0	120.0
USDA textural class (SPAW, 2007)	Sandy loam	Sandy loam
†††Weather (1st August – 30th November 2018)		
Temperature (°C)	25 – 29	26 – 30
Rainfall (mm)	213 – 650	60 – 566
Humidity (%)	81 – 88	68 – 88
Ultraviolet index	5 – 6	5 – 7
Sun hours	216 – 359	309 – 359

†CEC = cation exchange capacity; ††ECEC = effective cation exchange capacity; C:N = carbon-to-nitrogen ratio; USDA = United States Department of Agriculture; †††Source: World Weather Online, Zoomash Limited, London, Hackney, United Kingdom.

Table 2. Growth traits of IPGRI cowpea accessions grown at Akamkpa and Ikom

Location accession	Plant height (cm)	Leaf length (cm)	Number of branches	Leaf width (cm)	Peduncle length (cm)	Plant population per plot	Number of internodes	Number of nodes	Vine thickness (cm)
Akamkpa									
TVu-1019	14.8e-g	5.3e	1.7fg	2.7e	7.7i	1.0i	2.8fg	5.9fg	0.9c-g
TVu-11	28.0d-f	9.8d	**13.5a**	5.2d	9.0g-i	13.7a-d	**7.3d-f**	12.8c-f	1.0bc
TVu-11273	41.9cd	10.9b-d	4.5b-d	6.6a-d	9.1f-i	15. 0ab	4.9fg	8.9ef	**1.3a**
TVu-1505	20.6ef	12.1b-d	5.2bc	7.1a-c	13.5a-c	**15.7a**	4.4fg	10.8d-f	0.9b-g
TVu-3629	32.1de	12.3b-d	5.2bc	**7.7ab**	**14.7ab**	14.7a-c	5.9ef	13.3c-e	1.0b-e
TVu-53	28.6d-f	12.8bc	1.9f	6.8a-d	11.3c-h	12.0b-f	4.5fg	11.3d-f	1.0b-d
TVu-7	9.4fg	6.3e	4.1b-e	2.1e	8.3hi	2.0i	2.4fg	6.0fg	0.8g
TVu-7954	22.7ef	10.7b-d	3.0d-f	5.2d	9.7e-i	12.7a-e	3.1fg	8.9ef	0.8e-g
TVu-980	26.3d-f	10.1d	4.0b-e	6.2a-d	12.9a-d	13.0a-d	5.0fg	11.2d-f	0.9c-g
TVu-992	**95.7b**	**13.1ab**	2.3ef	6.2a-d	8.2hi	13.0a-d	5.9ef	**14.6b-e**	0.8fg
Ikom									
TVu-11	21.0ef	12.4b-d	**13.6a**	6.9a-d	12.3a-f	11.0d-g	**17.8a**	**21.8a**	1.0b-f
TVu-11273	52.3c	11.2b-d	4.5b-d	7.0a-d	10.2d-i	**13.0a-d**	15.5ab	17.6a-d	**1.5a**
TVu-1505	23.3d-f	11.1b-d	5.4b	6.9a-d	12.2a-g	8.7f-h	17.3a	21.3ab	1.0b-g
TVu-3629	17.0e-g	11.7b-d	4.1b-e	7.2a-c	**15.1a**	11.3c-g	12.5bc	15.0a-e	1.0b-g
TVu-53	17.3e-g	12.8bc	3.2c-f	**7.8a**	11.6b-g	6.7h	11.7b-d	15.2a-e	1.1b
TVu-7	22.4ef	10.5b-d	3.3b-f	6.2a-d	9.5e-i	1.7i	13.4a-c	19.2a-c	0.9c-g
TVu-7954	21.9ef	10.2cd	3.7b-f	5.5cd	9.4e-i	9.3e-h	12.3bc	15.1a-e	0.8d-g
TVu-980	18.3e-g	11.2b-d	4.1b-e	6.0b-d	12.7a-e	9.3e-h	11.3b-d	14.2b-e	0.8d-g
TVu-992	**114.6a**	**15.2a**	2.2ef	7.3ab	10.0d-i	8.0gh	10.4c-e	13.1c-f	0.9c-g

Duncan New Multiple Range test (α = 0.05): Mean values in columns with same letters differ non-significantly. Highest mean values per location are in bold font type.

Table 3. Yield and yield components of IPGRI cowpea accessions (only flowering types) grown at Akamkpa and Ikom

Location accession	Days to 50% flowering	Number of flowers	Number of pods per plant	Pod length (cm)	Pod weight (g)	Number of seeds per pod	Number of seeds per pod	Total Seed weight per Plot (g)	100-Seed weight (g)
Akamkpa									
TVu-11	36.0d	**28.9b**	**22.5b**	13.7ab	0.8b	11.4cd	**563.0b**	**47.9c**	8.5bc
TVu-3629	36.0d	20.1b-d	15.3bc	10.9b	1.1b	**11.5cd**	472.0bc	33.0cd	7.4c
TVu-53	43.7bc	20.2b-d	13.0c	10.9b	1.0b	8.6de	45.3d	3.7e	8.2c
TVu-992	**52.7a**	5.8de	3.0d	**16.1ab**	**1.6b**	16.9b	24.0d	1.9e	**8.6c**
Ikom									
TVu-11	37.3cd	**47.3a**	**34.7a**	15.2ab	1.0b	10.1cd	765.3b	81.5b	10.6b
TVu-3629	38.3b-d	20.3b-d	21.1b	14.5ab	1.5b	12.7c	**1738.7a**	**178.1a**	10.5b
TVu-53	44.7b	25.3bc	15.9bc	13.8ab	1.2b	6.4e	179.7cd	15.8de	9.5bc
TVu-980	**58.7a**	21.6bc	15.9bc	18.2ab	2.5ab	19.1b	180.0d	13.9de	8.0c
TVu-992	37.2cd	11.8c-e	3.8d	**25.8a**	**5.8a**	**24.3a**	156.7d	19.6de	**12.7a**

Duncan New Multiple Range test (α = 0.05): Mean values in columns with same letters differ non-significantly. Highest mean values per location are in bold font type.

flowered earlier (36 – 38 days) at both locations. TVu–980 flowered late (58.7 days) and was similar ($p > 0.05$) to TVu–992 at Akamkpa. Profuse flowering associated with higher number of pods per plant (NPP) was noted with TVu–11 with the highest number of intact flowers at both locations. TVu–992 had scanty flowers, the lowest NPP (3.0 – 3.8), the longest and heaviest pods ($p \leq 0.05$) across locations. TVu–3629 had the highest number of seeds per pod (NSPd) (11.5 seeds) at Akamkpa and was significantly ($p \leq 0.05$) different from TVu–992 with the highest NSPd (24.3 seeds) at Ikom. The number of seeds per plant (NSPt) and the total seed weight per plot (SW) followed the same trend. TVu–3629 and TVu–11 topped in both NSPt and SW at Ikom and Akamkpa, respectively. TVu–992 had the highest ($p \leq 0.05$) mean values of 100–seed weight (100SW) at both locations.

Location predicts weather conditions and these invariably have effects on cowpea production. We reported location–specific variations in agromorphological traits of cowpea. Cowpea requires well–drained sandy loam soil (Omoigui *et al.*, 2018); this aligned with the soil textures at Ikom and Akamkpa. Soils at Akamkpa and Ikom were acidic and high P fixation is associated with acid soils. Pulses require P for nodulation; liming increases P availability to crops (Bello *et al.*, 2018). This could give further explanation for the poor performance of cowpea in acidic soils. Previous studies have reported variations in cowpea characteristics in Benin and Ghana (Bello *et al.*, 2021). Stoilova and Pereira (2013) reported significant differences in PL, PW, NSPd, and

100SW, which were consonant with our findings (Tables 2 and 3).

3.3 Principal component analysis (PCA)

Using Kaiser criterion, principal components (PCs) with eigenvalues greater than 1 were retained (Table 4). Four PCs accounted for 93.60% of the total variability in Akamkpa. Variables rotated with factor loading cut off of ≥ 0.25 (approximately 0.30) were considered and included in each of the PCs. Positive rotated factor loadings indicate that a variable and a principal component are positively correlated and vice versa. 100SW (0.29), NSPd (0.29), PW (0.274) and PL (0.29), D50F (0.28), NF (0.27), NPP (0.26), NN (0.29) and NI (0.28) had higher positive influence on PC1 (55.92%) in Akamkpa. These variables in PC1 describe reproductive growth (flowering), seed set and seed yield attributes of the cowpea accessions. PH (0.32), LL (0.38) and LW (0.34) and PP (0.28) positively influenced PC2 (17.15%) which could describe vegetative growth (leaf area, leaf area index, leaf efficiency and potential for photosynthesis etc.) with respect to plant density. PC3 (14.74%) was greatly influenced by PdL (0.40), NB (0.25), PP (0.34) and VT (0.33) which could describe the seed pod carrying capacity of the plants with respect to plant architecture. PC4 (5.79%) describes vine firmness in relation to plant architecture. PC4 was positively influenced by PH (0.36) and VT (0.63).

At Ikom, positive influences on PC1 (41.42%) were LL (0.27), D50F (0.33), NF (0.27), NPP (0.26), NSPd (0.32), 100SW (0.36), PL (0.35) and PW (0.28). In PC2 (25.26%), positive influences came from PdL (0.27), NB (0.37), NI (0.35), NN (0.32), NPP (0.30) and NSPt (0.25). The highest positive factor loading in PC3 (11.94%) came from VT (0.50) followed by LW (0.43), PH (0.39), LL (0.34) and NI (0.29). NB (0.39), NN (0.31) and NF (0.28) had positive loadings on PC4 (8.99%).

3.4 Cluster analysis

At Akamkpa, five clusters were identified using hierarchical clustering with unweighted pair group method with arithmetic mean (UPGMA) (Euclidean distance = 50; cophenetic correlation coefficient = 0.99). The clusters were and accessions were A (TVu–11273, TVu–1505, TVu–7954, TVu–980, TVu–7 and TVu–1019). Other clusters had one accession each: B (TVu–53), C (TVu–992), D (TVu–11) and E (TVu–3629). Four clusters (Euclidean distance = 150; cophenetic correlation coefficient = 0.98) were observed at Ikom. These were A (TVu–3629), B (TVu–11273, TVu–1505, TVu–7954, TVu–7), C (TVu–53, TVu–980 and TVu–992) and D (TVu–11) (Figure 2).

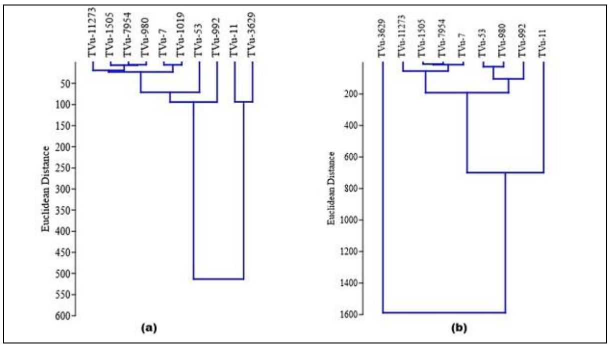

Figure 2. Cluster analysis at (a) Akamkpa and (b) Ikom. The cophenetic correlation coefficients were 0.99 (Akamkpa) and 0.98 (Ikom)

Table 4. Principal component analysis matrix for growth and yield components of IPGRI cowpea accessions grown at Akamkpa and Ikom

Trait	Akamkpa				Ikom			
	PC 1	PC 2	PC 3	PC 4	PC 1	PC 2	PC 3	PC 4
Plant Height (PH)	0.17	**0.32**	-0.29	**0.36**	0.10	-0.32	**0.39**	0.01
Leaf Length (LL)	0.21	**0.38**	0.13	-0.06	**0.27**	-0.18	**0.34**	0.11
Number of Branches (NB)	0.15	-0.35	**0.25**	0.20	0.06	**0.37**	0.15	**0.39**
Leaf Width (LW)	0.19	**0.34**	**0.30**	-0.04	0.18	0.04	**0.43**	-0.21
Peduncle Length (PdL)	0.09	0.18	**0.40**	-0.56	0.21	**0.27**	-0.16	-0.28
Plant Population per Plot (PP)	0.19	**0.28**	**0.34**	0.11	0.10	0.19	0.22	-0.31
Number of Internodes (NI)	**0.28**	0.00	0.14	0.24	-0.13	**0.35**	**0.29**	0.18
Number of Nodes (NN)	**0.29**	0.19	0.03	-0.07	-0.16	**0.32**	0.20	**0.31**
Vine Thickness (VT)	0.06	0.00	**0.33**	**0.63**	-0.07	0.12	**0.50**	-0.35
Days to 50% Flowering (D50F)	**0.28**	0.04	-0.25	-0.06	**0.33**	0.00	-0.14	0.08
Number of Flowers per Plant (NF)	**0.27**	-0.24	0.04	-0.11	**0.27**	0.24	0.00	**0.28**
Number of Pods per Plant (NPP)	**0.26**	-0.28	0.07	-0.09	**0.26**	**0.30**	-0.07	0.17
Pod Length (PL)	**0.29**	-0.02	-0.23	0.00	**0.35**	-0.11	0.02	0.12
Pod Weight (PW)	**0.27**	0.09	-0.28	-0.07	**0.28**	-0.28	0.10	0.09
Number of Seeds per Pod (NSPd)	**0.29**	0.02	-0.25	-0.01	**0.32**	-0.15	-0.04	0.10
Number of Seeds per Plot (NSPt)	0.24	-0.32	0.15	-0.07	0.23	**0.25**	-0.14	-0.33
Total Seed Weight per Plot (SW)	0.23	-0.34	0.14	-0.02	0.23	0.24	-0.13	-0.33
100-Seed Weight (100SW)	**0.29**	-0.04	-0.19	-0.06	**0.36**	-0.01	0.03	0.06
Eigenvalue	10.07	3.09	2.65	1.04	7.46	4.55	2.15	1.62
Variance (%)	55.92	17.15	14.74	5.79	41.42	25.26	11.94	8.99

PC = Principal Component. Values ≥0.25 (i.e., 0.3 approx.) with bold font type show positive trait influence in each of the PCs.

3.5 Discriminant analysis biplot of PC1 and PC2

TVu–992 and TVu–53 accession were included in quadrant 1 (Q1). These accessions could be of interest in terms of vegetative growth, exhibiting high seed quality and yields, despite their prolonged initiation of flowering. Quadrants 2 (Q2) and 3 (Q3) contained inferior accessions and as such could not be suitable choices in terms of growth and yield attributes. TVu–3629 and TVu–11 were in quadrant 4 (Q4) with distinguished reproductive capacity (profuse flowering) and high productivity (seed quantity and quality). At Ikom, in Q1 were TVu–11 and TVu–3629 with high growth rate (field establishment and plant architecture), profuse flowering and high pod quality (seed bearing capacity) despite showing delayed flower initiation. TVu–1505 and TVu–11273 in Q2 had attributes which could place them as choice accessions in the point of view of providing rapid ground cover (as cover crops) and better support for podding due to their greater number of nodes, internodes and firmer vines. Nonetheless, they performed poorly in terms of seed yield attributes. Apparently, these qualities can be exploited in hybridization to improve accessions in Q1 and Q4 (TVu–53, TVu–980 and TVu–992). Q4 had accessions with exceptional performance in terms of pod and seed qualities. In terms of growth and yield traits, accessions TVu–7 and TVu–7954 in Q3 performed poorly (Figure 3).

Cluster analysis provides a logical means of expressing the closeness existing between groups (Rahman, Rahman, & Begum, 2013). Our PCA results were similar to those of Nkomo, Sedibe, and Mofokeng (2020) in phenotyping cowpeas for drought tolerance. Top performing genotypes can be grouped by similarities and dissimilarities in agromorphological characters (Govindaraj, Vetriventhan, & Srinivasan, 2015; Niveditha, Sudharani, Rajesh, & Nirmala, 2016); this could aid in plant breeding. It has been established that selective breeding will allow the breeder to select for groups of several traits, to produce varieties with superior agronomic characteristics. Based on this, Q1 and Q4 at both locations had accessions within PC1 and PC2 (TVu–992, TVu–53, TVu11, TVu–3629 and TVu–980 (only at Ikom)) brought together presenting desirable traits, especially high growth and yield traits.

Yield traits, if not highly heritable, could greatly be influenced by the environment. Asiwe, Sekgobela, and Modiba (2021b) reported significant genotype, genotype x location interactions in cowpea yield. However, using only yield as a basis for selection is not a robust measure. Thus, selection efficiency can be enhanced by exploiting the relationship between yield and other yield–related traits. This observation has been reported in legumes, e.g., groundnut (Mubai *et al.*, 2020).

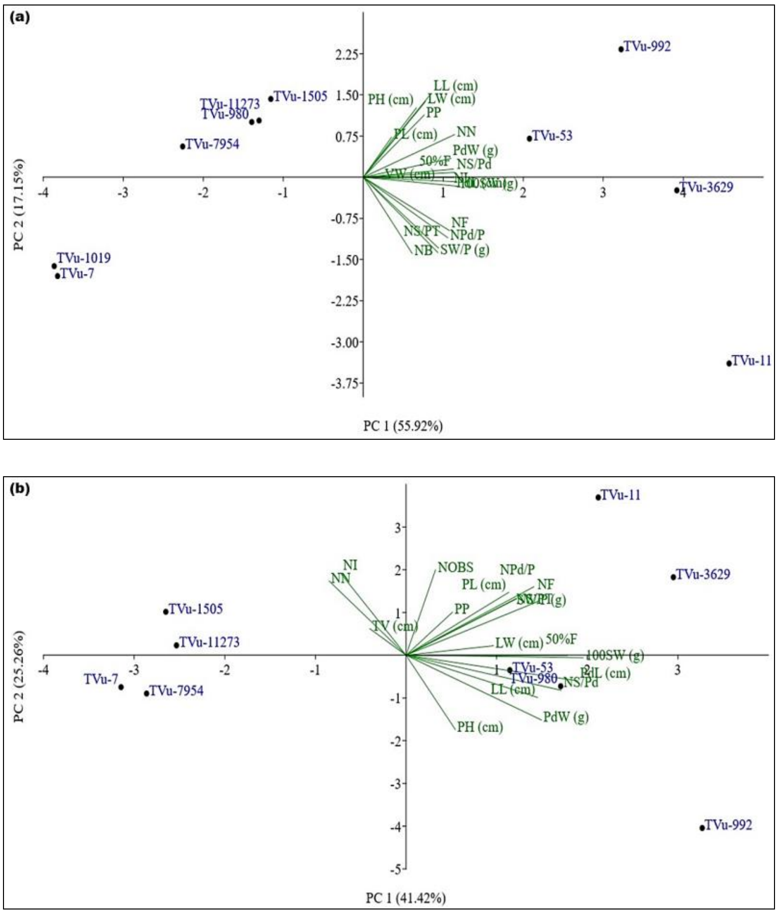

Figure 3. Discriminant analysis biplot of PC1 and PC2 at (a) Akamkpa and (b) Ikom

3.6 Phenotypic and genotypic correlations

LL correlated with PH ($r_p = 0.57, p \le 0.01$; $r_g = 0.58$, $p \le 0.01$). Phenotypic correlation existed between PW and PL ($r_p = 0.91$, $p \le 0.01$), SW and NSPt ($r_p = 0.99$, $p \le 0.01$) at Akamkpa and likewise at Ikom. There was a perfectly significant genotypic correlation between SW and NSPt ($r_g = 1.00$, $p \le 0.01$). Low and moderate significant positive genotypic correlations were observed between 100SW and SW at Ikom ($r_g = 0.17$, $p \le 0.01$) and Akamkpa ($r_g = 0.41$, $p \le 0.01$) (Tables 5 and 6).

The following growth traits should be considered: PH, LL, NB, PdL, PP, VT and NN. In terms of yield, PL, PW, NSPt, SW and 100SW should be considered. The positive phenotypic and genotypic correlations between LL and PH indicate an association between tall accessions and efficiency

Table 5. Phenotypic (r_p) and genotypic (r_g) correlation coefficients of growth traits of IPGRI cowpeas at Akamkpa (upper diagonal) and Ikom (lower diagonal)

Trait	PH	LL	NB	LW	PL	PP	NI	NN	VT
	r_p r_g	r_p r_g	r_p r_g	r_p r_g	r_p r_g	r_p r_g	r_p r_g	r_p r_g	r_p r_g
Plant Height (PH)		**0.57****	-0.14	0.39	-0.18	0.39	0.51	0.66	-0.09
		0.58**	-0.17	0.39	-0.24	0.39	0.64	0.75	0.03
Leaf Length (LL)	**0.57****		-0.00	**0.92***	0.53	0.88	0.59	**0.82***	0.29
	0.58**		-0.03	0.94	0.56	0.90	0.66	0.91	0.34
Number of Branches (NB)	-0.10	**0.40****		0.07	0.04	0.31	0.64	0.32	0.32
	-0.11	**0.40***		0.04	-0.02	0.30	0.76	0.34	0.35
Leaf Width (LW)	0.40	0.96	0.43		0.72	0.92	0.63	0.77	0.48
	0.40	0.98	0.43		0.74	0.97	0.71	0.79	0.53
Peduncle Length (PdL)	0.13	0.84	0.50	0.90		**0.57****	0.28	0.43	0.16
	0.12	0.86	0.51	0.92		0.61	0.30	0.48	0.15
Plant Population per Plot (PP)	0.26	0.64	0.53	0.67	**0.74****		0.70	0.76	0.48
	0.27	0.68	0.56	0.71	**0.78****		**0.77****	0.85	0.52
Number of Internodes (NI)	0.14	0.75	**0.72***	0.83	0.80	0.68		**0.88****	0.42
	0.17	0.86	0.78	0.94	0.91	0.82		0.98	0.50
Number of Nodes (NN)	0.12	0.75	0.69	0.83	0.79	0.57	0.99		**0.13****
	0.16	0.89	0.76	0.98	0.93	0.70	0.99		**0.11****
Vine Thickness (VT)	0.31	**0.79***	0.41	0.89	0.76	0.75	0.83	**0.79****	
	0.30	0.82	0.42	0.92	0.78	0.80	0.94	**0.93****	

* and ** = significant at 95% and 99% confidence level respectively.

Table 6. Phenotypic (r_p) and genotypic (r_g) correlation coefficients of yield traits of IPGRI cowpeas at Akamkpa (upper diagonal) and Ikom (lower diagonal)

Trait	D50F	NF	NPP	PL	PW	NSPd	NSPt	SW	100SW
	r_p r_g	r_p r_g	r_p r_g	r_p r_g	r_p r_g	r_p r_g	r_p r_g	r_p r_g	r_p r_g
Days to 50% Flowering (D50F)		0.45	0.37	0.96	0.96	0.93	0.15	0.15	0.95
		0.50	0.42	0.98	0.97	0.94	0.16	0.16	0.98
Number of Flowers per Plant (NF)	-0.16		0.99	0.53	0.25	0.36	0.80	0.81	0.69
	-0.12		1.00	0.53	0.24	0.35	0.85	0.90	0.78
Number of Pods per Plant (NPP)	-0.47	-0.04		0.48	0.18	0.32	0.86	0.88	0.63
	-1.00	-1.00		0.49	0.18	0.32	0.97	1.00	0.73
Pod Length (PL)	0.33	-0.14	-0.29		**0.91****	0.97	0.35	0.36	0.96
	1.00	-1.00	**-1.00***		**0.93****	0.98	0.32	0.35	1.00
Pod Weight (PW)	-0.12	-0.69	0.82	-0.25		0.96	0.09	0.06	0.86
	0.26	-1.00	-1.00	-1.00		0.97	0.07	0.04	0.89
Number of Seeds per Pod (NSPd)	0.12	-0.60	0.04	-0.30	0.90		0.29	0.28	0.89
	0.12	-0.63	-1.00	-1.00	1.00		0.28	0.28	0.92
Number of Seeds per Plot (NSPt)	-0.44	0.15	-0.17	-0.53	-0.42	-0.29		**0.99****	0.42
	-0.45	0.15	-1.00	-1.00	-0.83	-0.30		**1.00***	0.41
Seed Weight per Plot (SW)	-0.48	0.16	-0.20	-0.56	-0.39	-0.27	**1.00****		**0.42****
	-0.49	0.17	-1.00	-1.00	-0.75	-0.28	**1.00****		**0.41****
100-Seed Weight (100SW)	-0.86	-0.21	0.24	-0.23	0.61	0.37	0.12	**0.16****	
	-0.88	-0.24	-1.00	-1.00	1.00	0.38	0.12	**0.17****	

* and ** = significant at 95% and 99% confidence level respectively.

of leaf interception of photosynthetically active radiation for assimilate buildup. Meanwhile, our results showed that phenotypic correlations apparently reflect genotypic correlations. High genotypic correlation implies that genes that contribute to the traits are correlated. Karim, Siddique, Sarkar, Hasnat, and Sultana (2014) and Ahmad, Khalil, Iqbal, & Rahman (2010) reached the same conclusion in rice and wheat, respectively. In summary, having knowledge of the nature and magnitude of association among cowpea traits is considered essential in the improvement of cowpea production.

4. Conclusions

This study has identified TVu–992, TVu–53, TVu11, TVu–3629 and TVu–980 as choice cowpea accessions for possible improvement and cultivation at Akamkpa and Ikom. Important traits such as the number of seeds per plot, number of seeds per pod and number of days to 50% flowering have also been identified to play significant roles in enhancing cowpea productivity and should be considered in subsequent breeding programmes.

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