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Breeding Potential and Multivariate Analyses of Morphological and Yield Traits in Industrial Sugarcane (*Saccharum officinarum* L.) Accessions in a Humid Tropical Agroecology

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Authors' contributions

This work was carried out in collaboration between both authors. Author MAI designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author EEO managed the analyses of the study, subsequent drafts and the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Sugarcane (*Saccharum officinarum* L.) is propagated mostly by vegetative method. Although vegetative propagation conserves plant germplasm; it poses challenges in crop breeding. This field study assessed the breeding potential of twelve industrial sugarcane accessions in a humid tropical agroecology of Nigeria. The experiment was laid-out in a randomised complete block design with three replications. Accessions AKWA-005, B70607, C01001, CP65-357, DB37/45 and F141 produced flowers; an indicative trait of their suitability as prospective materials for hybridization. Accession DB37/45 had the highest Brix value of 16.3%, followed by B61208 with 15.7%, accession C01001 had the highest cane yield (58.9 t ha^{-1}) and longest stalks (150 cm); these further highlighted the potentials of C01001, DB37/45, CP65-357, B61208 and AKWA-005 for yield improvement in sugarcane through selection. Whereas principal component and hierarchical cluster analyses (Ward's method) grouped HAT4, F141 and IMO-002 together, the other

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accessions formed a separate but distinct grouping. These groupings provided a background information as an aid to selection of similar accessions. Cluster analysis and linear correlation identified significant (*P* = .05) positive associations between the following traits: stalk girth, stalk length and cane yield. Thus, these traits can be simultaneously selected for and improved in sugarcane. Overall, accession C01001, DB37/45, CP65-357, B61208 and AKWA-005 are recommended for inclusion in the breeding for adaptable lines of sugarcane in the humid tropical agroecology.

Keywords: Brix; correlation; heritability; principal component analysis; Saccharum officinarum L.

1. INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) has many domestic and industrial uses because the stem is rich in sugar, mainly sucrose. Sucrose is the table sugar consumed by most people all over the world. It is an ingredient in the making of many medicines and beverages; it is also used as a sweetener in confectionery and related industries. It is the energy source of the ethanol used as fuel by 80% of the eco-friendly cars in Brazil; about 5.4 billion gallons of fuel were produced from sugarcane in 2006 [1]. Chopped and dried sugarcane stalks are used as cattle feed. Sugarcane is a perennial plant in the family *Poaceae* (grass family); it has jointed fibrous stalks and can grow up to six metres in height. It is cultivated mostly by vegetative method; ensuring that the genotypes are conserved for generations.

However, the demerit of the vegetative propagation is the non-exploitation of segregation and recombination of genes associated with sexual reproduction, which are crucial for the uncovering of possible inherent genetic variation in the species. Sexual reproduction produces new gene combinations leading to the variation in the genotypes and phenotypes of the progeny; in contrast, in most asexual reproduction processes, the progenies are identical to their parents. Other demerits of vegetative reproduction in some species include non-flowering, reduced flowering and poor seed set, which hinder their breeding potential. Also, due to the associated genetic uniformity of vegetatively propagated crops, pests and diseases attack could be very devastating. Sugarcane is grown in most tropical countries [2]. The total world production was about 1.7 million MT, on land area of 23.8 million hectares; of which Brazil produced more than 300,000 MT; India 285, 000 MT and China 114, 000 MT, in 2009 [3]. Nigeria is one of the sugarcane producers in Africa; the crop is produced for domestic sugar used although the sugar is grossly inadequate, the country augments by import of over $500 million worth of brown sugar from Brazil annually [4], this situation can be remedied.

The genotype, environment and the interaction between genotype and environment have separate and combined roles to play in determining the phenotypic value of a plant. Since vegetatively propagated crops are often highly genetically alike; any variation within the lines is mostly induced by environmental effect. This could make intra-varietal selection ineffective unless there was germplasm contamination that resulted from a mechanical mixture of lines and/or mislabelling of the varieties. Meanwhile, inter-varietal selection in vegetatively propagated species would be effective, in that, a single plant selected from a population can form the basis for developing a new variety; and either one or two cycles of selection are enough to produce a fixed genotype.

Alternative methods of breeding vegetatively propagated or clonal crops are through mutation breeding technique. Successes have been recorded in the improvement in rhizome yield and oleoresin content in ginger [5] and increased cane yield and red rot resistance in sugarcane through gamma ray radiation [6]. In another breeding effort in sugarcane research, disease-free plantlets have been developed through tissue culture technique [7]. Generally, agricultural productivity has dwindled greatly in Nigeria, the country produces only about 5% of world palm oil and groundnut [8], against 50% and 30% respectively in the 1960s; this trend has affected the production of other crops, including sugarcane. Development in the sugar industry has been very slow due to over-dependency on sugar importation, in spite of the availability of land, manpower and other resources for sugarcane production [9].

There are several factors that hinder sugarcane production in Nigeria and North Africa [10]. The factors are insufficient investment, low capital outlay, lack of good market network and space for agricultural land, biotic (pest and diseases) and abiotic (mostly environmental) stress factors. Whereas, the economic and political concerns identified in sugarcane production can be amended through appropriate policies, the biotic and abiotic factors are issues that should trigger sugarcane breeding efforts. The goals of sugarcane breeding programmes emphasise on increase sugar yield, plant biomass (height, plant girth and number of stalks per plot) and resistance to pests and diseases. There is need to identify the most suitable genotypes for cultivation in each of the agroecologies of Nigeria.

Developing exotic cultivars of industrial sugarcane with high sugar yields for the humid tropical agroecology of Nigeria is very necessary. The more widely adaptable the cultivar, the more productive the venture. In varietal trials, the breeder finds the most adaptable variety based on some desirable traits. Multivariate analysis tools, such as principal component, factor and cluster analyses, discrimination and classification can be applied to study multiple characters simultaneously [11-13]. Selection for yield potential is useful for the improvement of crops and it is usually the main objective of breeding programmes [13]. Varietal development is a continuous process that involves evaluation for high yield, better quality, response to fertilizer, resistance to diseases and other pests and tolerance to abiotic stress depending on the objective of the breeding programme. The objective of this study was to evaluate twelve accessions of industrial sugarcane for morphological and yield traits in a humid tropical ecology for breeding purpose.

2. MATERIALS AND METHODS

Twelve industrial sugarcane accessions namely, AKWA-005, B61208, B70607, C01001, C0504, CP65-357, DB37/45, EBON-006, F141, HAT4, IMO-002 and TRITON, were obtained from the National Cereals Research Institute (NCRI), Badeggi, Niger State, Nigeria. The accessions were grown in the field trials in the 2014 and 2015 cropping seasons in the Teaching and Research Farm of the Faculty of Agriculture, Forestry and Wildlife Resources Management, University of Calabar, Nigeria. Calabar (Latitude 4.5° N; Longitude 8.0° E) is a rainfed region of Nigeria; the average rainfall ranges from 2000 to 3500 mm. The mean daily temperature is from 27 to 35°C with the relative humidity ranging from 70 to 85% annually. The area has rainfall, almost all year round, with an exception of a 10 to 15 days dry spell within the first and second weeks in August. Rainfall markedly intensifies soil erosion and coastal flooding in this area [14]. The weather, vegetation and the other conditions qualify Calabar as a humid tropical ecology. The physical and chemical compositions of the soil at the experimental site are presented in Table 1.

Table 1. Physical and chemical soil properties of the experimental site (0 – 30 cm soil depth)

Parameter	Value
Physical properties	
Particle Size (%)	
Clay	10.2
Silt	38.6
Sand	50.3
Soil Texture	Sandy loam
Chemical properties	
Soil pH in H_2O	6.0
Organic Carbon (g kg^{-1})	8.0
Available Phosphorus (mg kg^{-1})	5.5
Total Nitrogen (g kg^{-1})	0.6
Exchangeable bases (cmol kg^{-1})	
Ca^{2+}	0.9
Mg^{2+}	0.6
K^+	0.1
Na^+	0.4
Cation Exchange Capacity	4.0

The sugarcane accessions were planted in the field in a randomized complete block design (RCBD) in three replicates. The main plot was 23 m x 44 m, each plot was 5 m x 1.5 m, between row spacing was 1.5 m and within row spacing was 1 m. The same-aged cane cuttings for planting had three nodes. Standard agronomic practices for sugarcane cultivation were carried out. Data collected were on sprouting percentage (SPR%) at 21 days after planting (DAP) and establishment percentage (EST%) at five months after planting (MAP). Flowering behaviour (FLBEH), scored as flowering = 1 and non-flowering = 0; flowering cycle (FCY) were set as early flowering =139-168 DAP, medium flowering = 169 - 200 DAP and late flowering = 201 - 245 DAP; flowering intensity was scored as shy = 0, medium = 1 and profuse = 2; and Sexuality (SEX) was in three categories; no-flower (NF), staminate (male) and pistillate (female) plants. Yield traits were Brix value (^{o}Bx) measured with hand held refractometer at 12 MAP, stalk length (SLNG), stalk girth (SGTH) and number of millable stalks per plot (MLST). Cane yield (YIELD) was the weight of millable stalks in tonnes per hectare (t ha^{-1}). Heritability (H_B^2) in broad sense was estimated [15] from which genetic advance was calculated [16].

Analysis of variance (ANOVA) of the morphological characteristics was computed with the GenStat 8.1 package [17], significant differences between means were compared using Duncan's New Multiple Range Test (DNMRT) at the 95% confidence level. The multivariate analyses were computed with Past 3 package [18], principal components with Eigenvalues greater than one were discussed [19]; Pearson's (linear) correlation coefficients were also calculated.

3. RESULTS AND DISCUSSION

Some morphological characteristics in the 12 industrial sugarcane accessions are presented in Table 2. The sprouting percentage ranged from 50 to 100%, all the cane-setts planted of C01001 and DB37/45 sprouted in the humid tropical agroecology. The establishment percentage in the sugarcane accessions followed the pattern in sprouting; at 5 MAP, all the stands (100% establishment) of DB37/45 were still growing. AKWA-005, B70607, C01001, CP65-357, DB37/45 and F141 produced flowers within 168 DAP. AKWA-005, C01001 and DB37/45 were declared as early flowering accessions. B70607 and CP65-357 were medium flowering accessions and F141 was a late but profusely flowering accession with an intensity of 2.00, followed by AKWA-005 with an average flowering intensity of 1.50. C01001, CP65-357 and DB37/45 had an intensity of 1.33, while B70607 had an intensity of 1.00. Flowering behaviour, flowering cycle and flowering intensity are very important traits in plant breeding and they determine planting time, ease and suitability for crossing either an individual plant or a group of plants. The flowering intensity also determines the nature of sexuality in plants. Sugarcane accessions (C01001 and CP65-357), which were considered 'shy' in flowering intensity, shed pollen very poorly. These accessions could be exploited as female plants during hybridization, thus eliminating the need for artificial emasculation. AKWA-005, B70607, C01001, CP65-357, DB37/45 and F141 accessions, produced flowers in this study and are considered as suitable accessions for hybridization.

The Brix values (^{o}Bx) ranged from 11.7% (EBON-006) to 16.3% (DB37/45). The Brix values in this experiment are comparable to the sucrose content in some vegetables, such as watermelon and pineapple [20]. The stem girth ranged from 5.5 cm (F141) to 8.2cm (DB37/45). The stem girth for DB37/45 and B61208 were not significantly different (P = .05). The stalk length of 150.3 cm recorded for C01001 was the longest, but this was not significantly (P = .05) longer than the 140.3 cm which was documented for AKWA-005 (Table 3). The number of millable stalks per stool ranged from 3.8 (HAT4) to 8.3 (CP65-357) with an overall average of 6.3 millable stalks per stool. Six accessions (B70607, C01001, CP65-357, EBON-006, F141 and IMO-002) produced more millable stalks than the group's average (Table 3). The cane yield ranged from 9.4 t ha^{-1} (HAT4) to 58.9 t ha^{-1} (C01001). The average cane yield was 33.85 t ha^{-1}. Five accessions namely, AKWA-005, B70607, C01001, CP65-357 and EBON-006, produced higher cane yields, above the overall average. C01001 cane yield (58.9 t ha^{-1}) was significantly (P = .05) different from other accessions (Table 3).

Table 4 presents the genetic parameters of the morphological and yield traits of the industrial sugarcane accessions. The broad sense heritability was generally low for stem length (24%) and cane yield (18.2%); moderate for the sprouting percentage (63%), establishment percentage (58%), Brix value (50%), number of millable stalks per stool (41%) and stalk girth (43%). Since sugarcane is mostly cultivated vegetatively *via* its clones, heritability is literally fixed and would have minimal importance, with an exception to flowering clones which can be propagated *via* their seeds. It is established that the magnitudes of the phenotypic coefficient of variability (PCV) and heritability are affected by the environment and the effect is evident in the phenotype [21-23]. High PCV and heritability values imply low interference of the environment on the trait under consideration and *vice versa*. In this study, the heritability of cane yield was low, suggesting that environmental factors highly influence the trait, and mass selection as a breeding method would be very slow as far as breeding for cane yield is concerned.

The principal component and Eigenvalues of the industrial sugarcane accessions in the humid agroecology are presented in Table 5. Six of the principal components (PC) had Eigenvalues greater than 1.0; these were grouped from PC1 (705.18) to PC6 (1.05). The PC1 loaded 82.62% of the variations among the morphological and yield traits on the sprouting (%), establishment (%) and stalk length. The PC2 loaded 10.77% of the variation on the stalk length and stalk yield per hectare.

Table 2. Morphological traits of industrial sugarcane accessions grown in the humid tropical agroecology

Variety	SPR%	EST%	FLBEH	FCY	FLINT	SEX
AKWA-005	88.9[a]	88.9[a]	1	Early	1.50	Male
B61208	94.4[a]	94.5[a]	0	NF	0.00	NF
B70607	83.3[a]	86.1[ab]	1	Medium	1.00	Male
C01001	100.0[a]	94.4[a]	1	Early	1.33	Fem
C0504	91.7[a]	86.1[ab]	0	NF	0.00	NF
CP65-357	88.9[a]	88.9[a]	1	Medium	1.33	Fem
DB37/45	100.0[a]	100.0[a]	1	Early	1.33	Male
EBON-006	88.9[a]	88.9[a]	0	NF	0.00	NF
F141	63.9[b]	66.7[bc]	1	Late	2.00	Male
HAT4	50.0[c]	50.0[d]	0	NF	0.00	NF
IMO-002	61.1[b]	61.1[c]	0	NF	0.00	NF
TRITON	91.7[a]	91.7[a]	0	NF	0.00	NF

Key: [a]Means with the same letter under the same heading are not significantly different at 5% probability level of DNMRT; SPR% = sprouting percentage; EST% = percentage of the plants growing per plot; FLBEH = Flowering behaviour; FCY = Flowering cycle; FLINT = Flowering intensity SEX = Sexuality; NF = Non-flowering; Fem = female

Table 3. Yield traits of industrial sugarcane accessions grown in the humid tropical agroecology

Variety	BRIX	SGTH	SLNG	MLST	YIELD
AKWA-005	11.8[e]	7.1[bc]	140.3[ab]	6.1[c]	36.2[bc]
B61208	15.7[ab]	8.1[a]	130.8[b]	4.8[e]	33.5[bc]
B70607	13.1[cd]	5.6[d]	139.1[b]	7.7[b]	35.1[bc]
C01001	13.8[c]	7.1[bc]	150.3[a]	7.3[b]	58.9[a]
C0504	13.3[cd]	7.4[b]	117.6[c]	5.6[d]	24.4[c]
CP65-357	14.8[b]	6.3[cd]	131.0[b]	8.3[a]	42.1[b]
DB37/45	16.3[a]	8.2[a]	126.7[bc]	5.7[d]	35.6[bc]
EBON-006	11.7[e]	6.7[cd]	130.6[b]	6.5[bc]	46.2[b]
F141	12.3[de]	5.5[d]	114.8[cd]	6.7[bc]	28.6[c]
HAT4	13.4[cd]	6.1[cd]	98.6[d]	3.8[f]	9.4[d]
IMO-002	12.5[d]	6.0[cd]	111.3[cd]	7.1[b]	27.2[c]
TRITON	14.7[b]	7.7[b]	130.2[b]	6.1[c]	29.0[c]

Key: Means with the same letter under the same heading are not significantly different at 95% confidence level using DNMRT; BRIX = Brix value (^{o}Bx) (%); SGTH = Stalk girth (cm); SLNG = Stalk length (cm); MLST = number of millable stalk per stool; YIELD = Cane yield (t ha^{-1})

Table 4. Genetic parameters of morphological and yield traits of industrial sugarcane accessions grown in the humid tropical agroecology

Trait	Mean	σ_g^2	σ_e^2	σ_p^2	GCV	PCV	H_B^2	GA	GAM (%)
SPR%	83.6	219.9	129.2	349.1	17.7	22.3	63	24.25	29.02
EST%	83.1	189.8	135.6	325.3	16.6	21.7	58	21.55	25.93
BRIX	13.6	1.8	1.8	3.6	10.3	14.6	50	1.95	14.37
SGTH	6.8	0.6	0.8	1.4	11.4	17.4	43	1.05	15.38
SLNG	126.8	-276.9	1433.0	1156.2	13.1	26.3	24	16.81	13.26
MLST	6.3	1.1	1.5	2.6	16.3	25.5	41	1.36	21.57
YIELD	33.9	59.7	268.5	328.2	22.8	53.5	18	6.79	20.06

Key: $\sigma_g^2 = Genetic\ variance$; $\sigma_e^2 = Environmental\ variance$; $\sigma_p^2 = Phenotypic\ variance$; GCV= Genotypic coefficient of variability; PCV = Phenotypic coefficient of variability; GA = Genetic advance; $H_B^2 = Heritability\ in\ the\ broad\ sense$ (%); GAM = Genetic advance as percentage of the mean; SPR% = sprouting percentage; EST% = percentage of the plants growing per plot; BRIX = ^{o}Bx value (%); SGTH = Stalk girth (cm); SLNG = Stalk length (cm); MLST = number of millable stalk per stool; YIELD = Cane yield (t ha^{-1})

Principal component analysis has been used to show that spike yield, tillering, seed weight and seed yield were important traits in the breeding of wheat (*Triticum aestivum*) [12,24]. Similar relationships have been reported in some rice (*Oryza sativa* L.) genotypes, demonstrating that tillering, seed weight and seed yield were important traits for selection breeding [13]. In this study, the clonal reproductive attribute in sugarcane propagation must be considered in the choice of the method of breeding the crop. Although wheat, rice and sugarcane are in the family *Poaceae*; wheat and rice are seed propagated, while sugarcane is mainly cultivated by stem cuttings; stalk characteristics are valuable traits to be focused on in sugarcane breeding.

In the scatter plot of the principal component analysis (Fig. 1), HAT4, IMO-002 and F141 were captured on the left axis (II and III quadrants) of the ellipsis, while the following accessions; AKWA-005, B61208, B70607, C01001, C0504, CP65-357, DB37/45, EBON-006 and TRITON, were captured on the right axis (I and IV quadrants). The latter accessions demonstrated association with useful traits, such as, stalk length, stalk girth and number of millable stalks. The accessions on the right axis are the planting materials to be used for the improvement of yield traits in this population.

Table 5. Principal component and Eigenvalues of industrial sugarcane accessions grown in the humid tropical agroecology

Trait	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8
SPR%	0.60	0.05	0.42	-0.66	-0.03	0.17	0.04	-0.05
EST%	0.57	0.09	0.36	0.70	-0.09	-0.20	-0.05	0.01
FLBEH	0.01	0.03	-0.02	0.07	-0.03	0.18	0.48	-0.12
FLINT	0.00	0.05	-0.01	0.11	-0.08	0.22	0.81	0.14
BRIX	0.02	-0.02	0.11	0.19	0.78	0.58	-0.12	-0.08
SGTH	0.02	-0.02	0.07	-0.08	0.28	-0.20	0.04	0.91
SLNG	0.47	0.43	-0.76	-0.04	0.13	-0.03	-0.03	0.01
MLST	0.01	0.04	-0.08	0.12	-0.54	0.69	-0.29	0.34
YIELD	-0.32	0.89	0.31	-0.02	0.00	-0.02	-0.04	0.00
Eigen Value	***705.18***	***91.93***	***50.44***	***3.04***	***1.36***	***1.05***	***0.36***	***0.07***
Variance (%)	***82.62***	***10.77***	***5.91***	***0.33***	***0.16***	***0.12***	***0.10***	***0.00***

Key: PC = Principal component; SPR% = sprouting percentage; EST% = percentage of the plants growing per plot; FLBEH = Flowering behaviour; FLINT = Flowering intensity, BRIX = Brix value (^{o}Bx); SGTH = Stalk girth (cm); SLNG = Stalk length (cm); MLST = number of millable stalk per stool; YIELD = Cane yield (t ha^{-1})

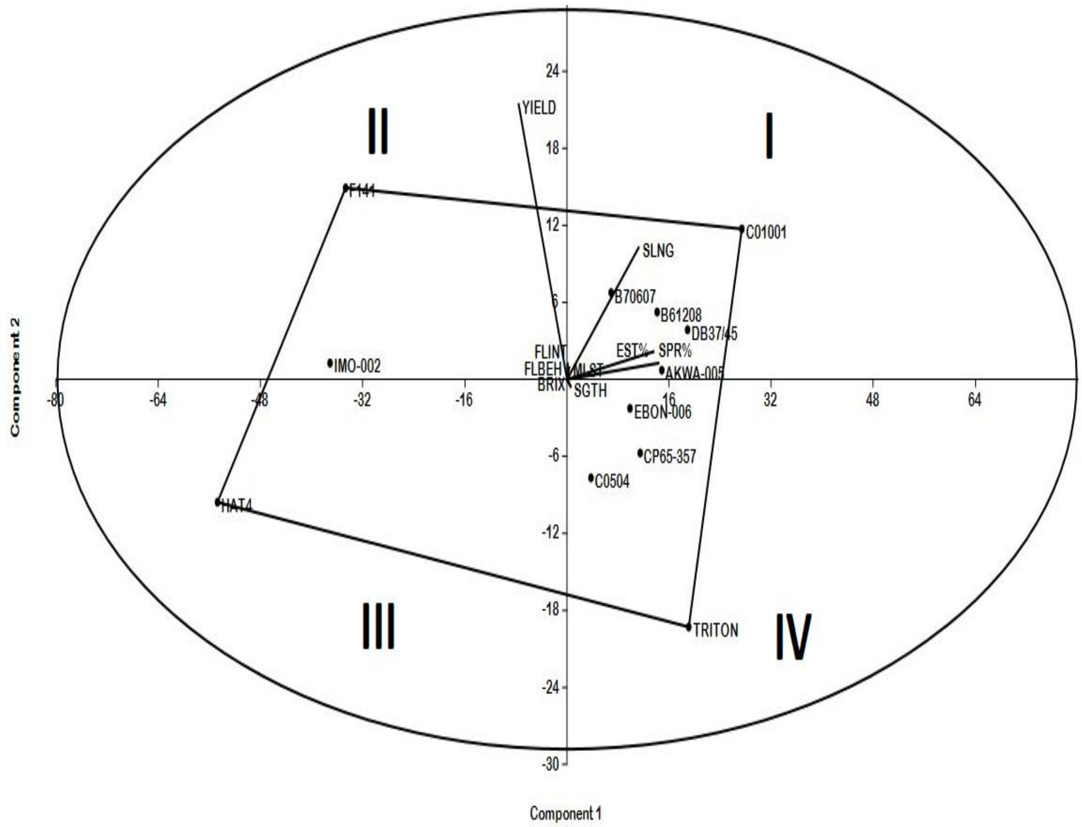

Fig. 1. Diagram showing scatter plot of the PCA with 95% ellipsis of industrial sugarcane accessions grown in the humid agroecology.

Key: SPR% = sprouting percentage; EST% = percentage of the plants growing per plot; FLBEH = Flowering behaviour; FLINT = Flowering intensity, BRIX = Brix value (^{o}Bx); SGTH = Stalk girth (cm); SLNG = Stalk length (cm); MLST = number of millable stalk per stool; YIELD = Cane yield (t ha^{-1})

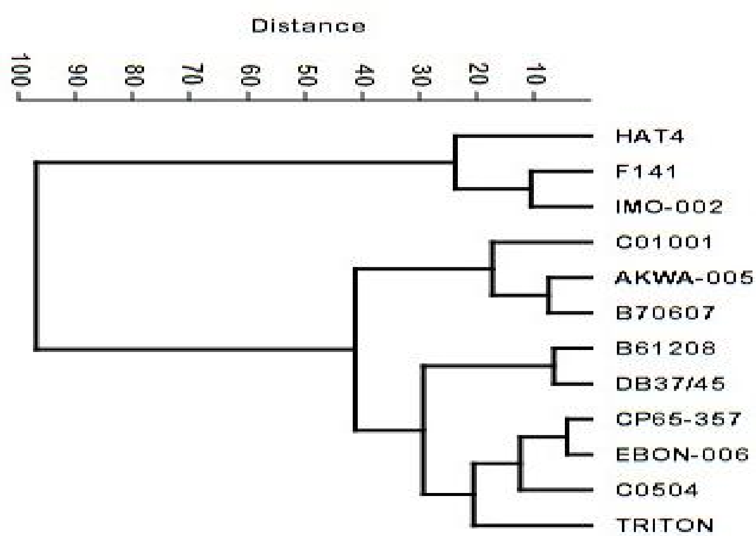

Fig. 2. Dendrogram showing Ward's algorithm clustering of industrial sugarcane accessions grown in the humid tropical agroecology

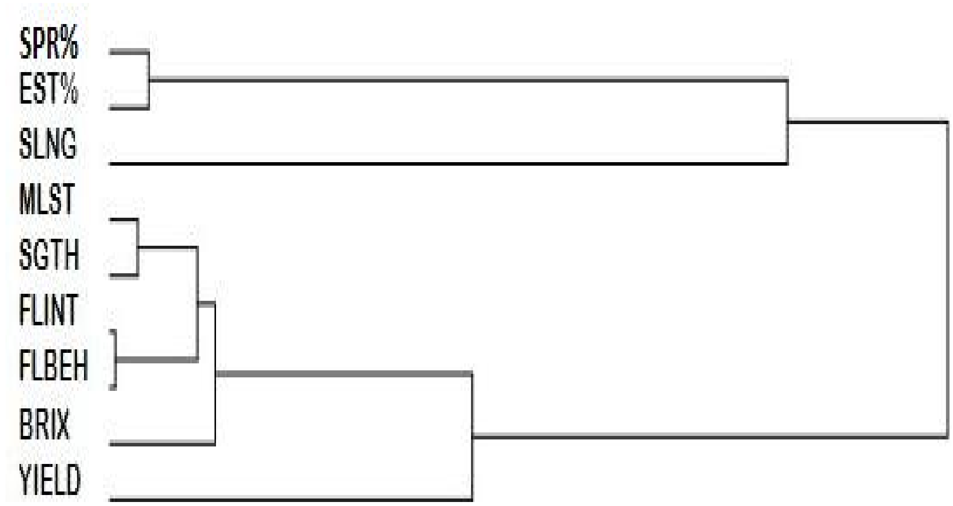

Fig. 3. Dendrogram showing the relationship between traits of industrial sugarcane grown in the humid tropical agroecology

Key: SPR% = Sprouting percentage; EST% = percentage of the plants growing per plot; FLBEH = Flowering behaviour; FLINT = Flowering intensity, BRIX = Brix value (^oBx); SGTH = Stalk girth (cm); SLNG = Stalk length (cm); MLST = number of millable stalk per stool; YIELD = Cane yield (t ha^{-1})

Fig. 2 shows the clustering similarity between the genotypes and the magnitude of deviation among the twelve industrial sugarcane accessions in the study. These accessions were partitioned into two major clusters, HAT4, F141 and IMO-002 were in the first cluster and C01001, B70607, AKWA-5, C0504, DB37145, B61208, TRITON, CP65-357 and EBON-006 in the second cluster. Accessions C01001, B70607 and AKWA-5 were in a sub-cluster of the second cluster. The accessions in the same cluster (more so in sub-cluster) share closer genetic association than accessions in different and distanced clusters. It has been reported that there is phylogenetic diversity and similarity in sugarcane genotypes in a study of genetic variation [25]. The cluster analysis has confirmed the observation in scatter plot of the principal component analysis (Fig. 1); implying that HAT4, F141 and IMO-002 were morphologically different from the other nine accessions.

The growth and yield traits were also subjected to single linkage clustering analysis. The stalk length, sprouting percentage and establishment percentage were in a cluster different from cane yield, flowering behaviour, flowering intensity, Brix value and stalk girth (Fig. 3). Variates in the same cluster are closer and can be improved simultaneously in a breeding programme.

Table 6. Correlation matrix showing morphological traits association in industrial sugarcane accessions

Trait	EST%	FLBEH	FLINT	BRIX	SGTH	SLNG	MLST	YIELD
SPR%	0.988*	0.253	0.140	0.455	0.727	0.800*	0.223	-0.620
EST%		0.300*	0.185	0.465	0.690	0.814	0.253	-0.606
FLBEH			0.958*	0.057	-0.204	0.510	0.554*	0.165*
FLINT				-0.027	-0.235	0.378*	0.477*	0.296
BRIX					0.623*	0.112	-0.179*	-0.264*
SGTH						0.309	0.411*	0.523*
SLNG							0.510*	0.470*
MLST								0.801*

*Key: SPR% = Sprouting percentage; EST% = Percentage of the plants growing per plot; FLBEH = Flowering behaviour; FLINT = Flowering intensity, BRIX = Brix value (%); SGTH = Stalk girth (cm); SLNG = Stalk length (cm); MLST = Number of millable stalk per stool; YIELD = Cane yield (t ha^{-1}); * = 95% confidence level*

The linear correlation matrix of some growth and yield traits are presented on Table 6. The cane yield per hectare had significant positive and high correlation (r = 0.80, *P* = .05) with the number of millable stalks per stool and positive but moderate correlation (r = 0.47, *P* = .05) with the stalk length and the stalk girth (r = 0.52, *P* = .05). Also, the stalk girth had positive but moderate correlation (r = 0.41, *P* = .05) with the number of millable stalks per stool. The Brix value also had positive correlation (r = 0.62, *P* = .05) with the stalk girth but very low negative correlation (r = -0.18, *P* = .05) with the number of the millable stalks per stool. The trend in correlation between traits compares with the linear linkage clustering in this study. Traits that have significant positive correlation can be improved simultaneously in a breeding programme [23]; the traits include stalk yield, stalk girth and the stalk length. Brix measures concentration of sugar in millable stalks, therefore had little to no relevance with traits evaluated in weight basis.

4. SUMMARY AND CONCLUSION

Sugarcane is primarily grown by vegetative method. Vegetative propagation method does pose challenges on sugarcane improvement and the breeding methods available are limited by this method, especially hybridization e.g. most clonal genotypes may not flower at all. Thus, selection can only be done among varieties and a mixture of germplasm because vegetative propagation will fail to create the expected genetic variation within a genotype for selection to be effective.

In this study, six (AKWA-005, B70607, C01001, CP65-357, DB37/45 and F141) out of the twelve sugarcane accessions produced flowers. This means that these sugarcane accessions can be used in making crosses. Also, backcross selection method could be recommended for quick improvement of yield and yield-related traits. Flowering is necessary to time planting and hybridization (crossing) and these accessions were grouped as follows: AKWA-005, C01001 and DB37/45 as early flowering types, B70607 and CP65-357 as medium flowering types and F141 as a late flowering type.

The broad sense heritability values of stem length and cane yield were low, and those of sprouting and establishment per cent, Brix value, number of millable stalks and stalk girth were moderate. If clonal selection is the method of choice in the breeding of these accessions, then heritability would not be important because the genetic make-up of the progeny of vegetatively propagated plant is fixed and matches with that of the parent plants. In respect of the multivariate analyses, most of the variations in the growth and yield traits were due to heterogeneity in the traits, such as sprouting and establishment per cent and stalk length.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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