Journal of Tropical Agriculture 58 (2): 147-157, 2020

Estimation of genetic parameters in agronomic characters and maturity index of sugarcane (*Saccharum* spp)

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Received 1 November 2018; received in revised form 18 November 2019; accepted 6 December 2020

Abstract

Varietal improvement in sugarcane is often targeted at high yield and sucrose quality. Effective genetic improvement of the crop requires understanding of the various attributes contributing to the existing diversity through genetic analysis. Hence, the objectives of this study were to evaluate sugarcane cultivars in the plant and ratoon crop cycles with a view to estimate the variance components, heritability and genetic gain of the characters and also to determine the association between them, both at phenotypic and genotypic levels. In the present investigation, twelve cultivars of sugarcane were evaluated in the two crop cycles in 2013 and 2014. The experiment was laid out in a randomized complete block design with three replications at Ibadan, Nigeria. Data were recorded on formative, vegetative and yield characters. Brix per cent (BP) was recorded at 9, 10, 11 and 12 months after planting (MAP) and denoted as BP9, BP10, BP11 and BP12. Data were subjected to analysis of variance for each crop and across crop cycles. Significant variations ($p<0.001$) existed among the cultivars, crop cycles and cultivars × crop cycles for all the formative, vegetative, yield characters and BP. Phenotypic variance for all the characters were higher than their respective genotypic variance. Estimates of heritability and genetic gain for the characters ranged from 23.3 % to 95.9 %, and from 10.4 to 23.0, respectively. However, days to flower initiation (DFI), stalk diameter (STD) and millable stalk (MBS) had high genetic gain across crop cycles. Additive gene action controlled inheritance of number of tillers and stalk, stalk diameter, total stalk at harvest, DFI, and brix per cent at 9 and 11 MAP, while both additive and non-additive genes governed inheritance of number of nodes, MBS, mean stalk weight and BP12. Phenotypic correlations in plant crop cycle were mostly positive and significant whereas both positive and negative correlations existed in ratoon crop cycle. Positive phenotypic and genotypic correlations existed among BP9, BP10 and BP11 in both crop cycles. The results of the study indicated that meaningful selection of genotypes for sugarcane improvement should be carried out at the formative growth phase or at maturity phase using yield and brix per cent attributes.

Key words: Brix per cent, Ratoon, *Saccharum,* Sucrose, Sugarcane.

Introduction

Sugarcane (*Saccharum* spp) is a perennial crop of Poaceae family in Andropogonae tribe of plants (Malavolta, 1994) grown mainly for cane and sucrose. It originated in Papua New Guinea. The commonest species of botanical genus *Saccharum* is *Saccharum officinarum* while two other sugar-bearing species of the genus are *S. sinense* and *S. barberi*. The genus also has three non-sugar-bearing species, namely, *S. robustum, S. spontaneum* and *S. edule.* A sugarcane plant contains 5 to 20 tillers per stand. It re-grows after each harvest and stem is a succession of nodes and internodes. The plant can grow up to 5 metres (Bigman, 2001). The stem has the capacity to store crystallizable sucrose in the pith, under the hard waxy bark. The major product of the crop is sugar. It can be converted into energy such as combustible material, charcoal or biofuel. Its bye-products are also used in industries for

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medicine, pharmaceuticals, confectioneries, beverages, electricity and motor fuels, while the leaves are good fodder for livestock (Wada et al., 2017).

Most sugarcane varieties currently grown are hybrids of several genotypes belonging to the common species in genus *Saccharum* (Sreenivasan and Jalaja, 1983). The varieties are cultivated in a wide range of environmental conditions all over the world. Variation in performance and use is expected with respect to variety, cultivation conditions, as well as the intention for cultivating the crop. Farmers prefer high cane yielding and early maturing varieties while the industries demand those with high sucrose. For this reason, varietal improvement of the crop is often targeted at high cane yields and high sucrose quality. Cane yield and sucrose quality of the crop are affected by several biotic and abiotic factors as well as physiological factors (Clarke, 1996). Breeders have directed their efforts to address the needs of farmers in spite of varying climate and edaphic conditions, and also for industrial use in terms of high sucrose content. Varietal differences in growth and maturity rates are important for breeders or farmers to make effective and informed harvest scheduling decisions (Caldron et al., 1996; Donaldson et al., 2008). Harvesting age is one of the most important physiological factors affecting sugarcane productivity. The optimum age to harvest varies from variety to variety and depends on the maturity time at which it develops highest sucrose content in the cane. Based on the age at harvest the crop can be early maturing (10-12 months), medium maturing (12 months) or late maturing (14-16 months) (Sreenivasan and Jalaja, 1983; Caldron et al., 1996; Donaldson et al., 2008). However, early maturing varieties may be harvested when they may not have reached their peak sucrose content, but have higher sucrose content than other late maturing varieties (Khan et al., 2017).

Time of maturity depends on characteristics associated with growing periods and plant physiological conditions during maturation. Variation in the association between physiological parameters with yield of plant and ratoon crops is also helpful in deciding the ratooning potential of the crop (Muschow et al., 1993; Gilbert et al., 2004). Climatic elements such as temperature, solar radiation, relative humidity and amount of rainfall, which jointly decide environment, account for a major variation in suitable harvest age of the crop (Jorge et al., 2010; Gomathi et al., 2013). Similarly, the type of crop (plant or ratoon) and management practices, which differ with both the crop's physiological status and the environmental conditions to a certain extent, may affect the genetic expression of the cultivars evaluated.

Estimation of the heritability and genetic advance offers reliable guidance for rapid and effective selection in a breeding programme. Heritability of a character gives insight into the expected performance of genotypes for the character (Tazeen et al., 2009). On the other hand, genetic advance, which measures the response of the characters to selection, explains the degree of gain obtained in a character under a particular selection pressure. Genetic parameters had been used to determine the relationships among agronomic characters in genetically diverse population for enhanced progress in crop improvement (Soomoro et al., 2006; Ogunniyan and Olakojo, 2014; Ogunniyan et al., 2015). High heritability and high genetic advance indicate the presence of additive genes in the trait and therefore suggests the importance of such characters in crop improvement through selection.

Sugarcane breeders began generation of hybrids from *S. officinarum* and other species in the 18th century but genotypic performance and consumer's preference vary with changes in the environment and consumer's requirements. This makes continuous improvement of the crop inevitable. However, effective genetic improvement of the crop requires demystification of the various attributes or characters of the existing diversity through genetic analysis. Hence, the objectives of this study were to evaluate the plant and ratoon crops of sugarcane with a view to estimate the variance components, heritability and genetic gain of the characters. The association between characters, both at phenotypic and genotypic levels were also estimated.

Material and Methods

Experimental Material

The experimental material comprising of 12 cultivars of sugarcane obtained from Sugar Research Institute, University of Ilorin, Nigeria were evaluated in two crop cycles at Ibadan representing a Forest-Savannah Transition agro-ecology of Nigeria from 2013 to 2014. Total amount of rainfall received at the experimental location was 1921.9 cm in 2013 and 1836.7 cm in 2014. Mean temperature was 26.6 °C and 25.7 °C in 2013 and 2014, respectively. The plots were irrigated to complement soil water during water shortage for ratoon crop cycle.

Field Layout and Agronomy

The experiment was laid out in a randomized complete block design with three replications. Each plot comprised of four rows of 5 m length and 1.5 m width (4 rows × 5 m × 1.5 m) representing unit plot size of 36 m^2. The plots were separated by 3 m and replicates were 4.5 m apart. The planting was done in November 2012 and October 2013, whereas the ratoon crop cycle was between October 2013 and September 2014.

Pest and disease free, six months old cane setts that had three eyes each were planted by laying horizontally end-to-end in rows in the ploughed and harrowed field. NPK fertilizer was applied at the rate of 150 kg N, 60 kg P and 90 kg K in two equal split doses at planting and 10 weeks after planting (WAP). The plots were kept weed free throughout the experiment by applying herbicide (as pre-emergence at 5.0 1 ha^{-1} each of paraquat and atrazine, two days after planting) and two hoe weeding operations at 4 WAP and 12 WAP. Stalks of the canes were harvested from the two middle rows of the plots at 52 WAP by cutting the canes at 5 cm above the ground.

Data Collection

Total stand per plot was counted at 3, 8 and 12 WAP. Ten randomly selected millable stalks of the cane were sampled for brix per cent. Stalk height was measured from the ground to the top visible dew-lap leaf using metre rule, and **s**talk diameter was measured using a pair of Vernier caliper, while stalk weight per plot was measured using weighing scale. Harvested cane stalks were bundled per plot and weights were expressed as t ha^{-1}. Internodes were counted and inter-nodal length was measured with metre rule at harvest.

Data Analysis

The data collected were analyzed separately for plant crop and ratoon crop for analysis of variance (ANOVA) using SAS software(SAS, 2009). The data pooled over two years (plant and ratoon crop cycles) were also subjected to ANOVA. Mean separation was conducted using Least Significant Difference wherever significant differences were detected in the F-test between crop cycles and Duncan Multiple Range Test among cultivars within crop cycles. Phenotypic (σ^2p) and genotypic (σ^2g) variances were estimated followingBaye (2002). The mean values were used for genetic analyses to determine phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV), according to Singh and Chaudhury (1985) as:

$$\text{GCV}(\%) = \frac{\sqrt{\sigma^2 g}}{x} \times 100$$

$$\text{PCV}(\%) = \frac{\sqrt{\sigma^2 p}}{x} \times 100$$

where, σ^2g = genotypic variance, σ^2p = phenotypic variance and x = sample mean.

Genotypic and phenotypic correlation coefficients between pairs of characters were calculated from the genotypic, phenotypic and environmental covariance to determine inter-character associations according to Sharma (1998), as:

$$\text{Genotypic correlation} = \frac{COV_{gxy}}{\sqrt{\sigma^2 gx \text{ x } \sigma^2 gy}}$$

and

$$\text{Phenotypic correlation} = \frac{COV_{pxy}}{\sqrt{\sigma^2 gx \text{ x } \sigma^2 gy}}$$

where COV_{gxy} and COV_{pxy} are genotypic covariance (GV) between two characters (x and y), and phenotypic covariance of the progeny means between the two characters, respectively. $\sigma^2 g_x$ was genotypic variance of the first character while $\sigma^2 g_y$ was the genotypic variance (PV) of the second character. $\sigma^2 p_x$ and $\sigma^2 g_y$ were the phenotypic variances for the first and second character, respectively. The calculated phenotypic correlation coefficients were tested for their significance using *t*-test. Broad sense heritability (h^2_b) estimate of each trait was computed according to the procedure outlined by Falconer (1989) as:

$$\text{Heritability } (h^2_b) = \frac{\sigma^2 g}{\sigma^2 p}$$

Where $\sigma^2 g$ = genotypic variance and $\sigma^2 p$ = phenotypic variance. Expected genetic advance percentage of mean (GAM) was calculated according to Shukla et al.(2006) as:

$$\text{GAM} = \frac{k.\sigma^2 g}{\mu} \times 100$$

where, k is standardized selection differential constant (2.06) at 5% selection intensity, σ^2p is phenotypic standard deviation and h^2_b is broadsense heritability. Heritability was rated low (when the estimate was less than 40%); medium (40-59%), high (60-79%) and very high (> 80%). The GAM was rated as low (when the estimate was less than 10%), medium (10-20%) and high (> 20%)(Singh, 2001).

Results and Discussion

Analysis of variance for establishment, maturity, yield and brix per cent of the sugarcane cultivars

Mean squares and coefficients of variation (CV_S)

Table 1. Mean square and coefficient of variation for formative, vegetative, yield characters and brix per cent for plant and ratoon crop of sugarcane cultivars evaluated in Ibadan, Nigeria in 2013 and 2014

Parameter	Plant crop cycle		Ratoon crop cycle		Cultivar × ratoon crop cycles			
	Mean square Cultivar (df=11)	Coefficient of variation (%)	Mean square Cultivar (df=11)	Coefficient of variation (%)	Mean square Crop (df=1)	Mean square Cultivar (df=11)	Mean square Cultivar × crop (df=11)	Coefficient of variation (%)
Formative Phase								
GMC	387.00***	22.47	15710.13***	20.12	112575.13***	8699.19***	7397.94***	20.01
TLC	2121,73***	20.83	14993.00***	19.46	210060.01***	11927.50***	5187.23***	20.80
STC	543.38***	21.84	2142.20***	26.78	1662A2.72***	2080.56***	603.03^{ns}	26.72
Vegetative phase								
NND	9.38***	7.50	20.32***	9.02	46.14***	18.14***	11.57***	8.24
SHT	11.46^{ns}	10.86	0.33***	6.48	17.02^{ns}	5.42^{ns}	6.36^{ns}	14.39
STD	0.41***	6.34	0.42***	7.80	1.00^{ns}	0.66***	0.18***	7.06
INL	7.94***	11.19	244.05^{ns}	10.02	463.80^{ns}	122.59^{ns}	129.39^{ns}	13.23
Yield component								
TSC	1212.82***	16.21	1845.01*	22.06	14734.72***	2503.81***	554.02^{ns}	15.07
MSW	0.80**	20.13	0.38***	23.43	2.29***	0.79***	0.38***	19.59
TSW	503.91*	21.82	1482.70***	22.42	12329.47***	1034.08***	952.53***	19.70
MBS	10.35***	13.97	24.61***	14.80	4.01^{ns}	21.41***	13.56***	14.42
Flowering and brix per cent								
DFI	30191.61***	0.06	558.17***	0.65	1330.42***	17227.82***	13521.96***	0.46
BP9	11.08***	5.95	11.04***	5.08	21.51***	17.65***	4.47***	5.56
BP10	5.15***	2.31	1.86***	1.16	0.26^{ns}	4.19***	2.82***	1.83
BP11	2.20***	3.15	3.55***	3.16	0.004^{ns}	4.37***	1.38***	3.16
BP12	3.49***	3.64	1.44***	4.40	6.81***	6.27***	3.98***	4.02

GMC, TLC, STC, NND, SHT, INL, TSC, MSW, TSW, MBS and DFI are germination count, tiller count, stalk count, number of nodes/plant, stalk height, internode length, total stalk count, mean stalk weight, total stalk weight, millable stalk and days to flower initiation. BP9, BP10, BP11 and BP12 mean brix per cent at 9, 10, 11 and 12 weeks after planting, respectively, CV - coefficient of variation for the agronomic characters for the plant crop and first ratoon crop cycles as well as pooled values for the two crop cycles are shown in Table 1. Significant variations existed in the cultivars for all the growth parameters at the formative and maturity phases except stalk height (SHT). All the yield contributing characters and brix per cent (BP) in the plant crop significantly varied between cultivars. Significant variation that existed in the cultivars for the formative and vegetative parameters in each crop cycle and across cycles indicated that selection of superior cultivars for the characters could be achieved effectively in each cycle and across crop cycles. Similarly, days to flowering and brix per cent are important criteria to be considered during breeding for cane yield and quality in sugarcane. The significant variation in the characters across growth phases indicated that there was a rich pool of variability to be used for improvement of the crop. Chang (1996) also observed that mean yield performance of sugarcane cultivars could be used in selecting superior genotypes.

Coefficient of variation ranged from 6.3% for stalk diameter (STD) to 21.8% for total stalk count (TSC) in the vegetative phase while the CV ranged from 14.0% for millable stalk (MBS) to 20.0% for total stalk weight (STW) among the yield characters. It was also shown that BP10 had least CV (2.3%) whereas BP9 had the highest (6.0%) among the BP. Significant differences existed among cultivars for all the parameters considered in the ratoon crop cycles. The CV for the characters considered in the formative stage were greater than 20.0% whereas all the vegetative parameters at maturity as well as BPs had CV lower than 10.0% in the ratoon crop cycle.The CV was relatively higher in the formative phase and in yield contributing characters than the stalk height, diameter and internode length, which were considered in the vegetative phase in each crop and across crops. However, days to flower initiation (DFI)and BP had least CV suggesting that selection was more suitable in the formative phase or with yield contributing characters.

The analysis of the pooled data showed that there were significant variations among the cultivars for all the formative, yield, flowering parameters and BP, except SHT and INL. The crop (plant and ratoon) cycles had significant effects ($p<0.001$) for all the characters in the formative stage as well as BP9 and BP12. The effect of crop cycles was significant for all the yield characters also except MBS. Combined ANOVA further showed significant differences for GMC and TLC ($p<0.001$) among the formative phase parameters and only STD ($p<0.01$) among growth parameters at maturity. All the yield characters except TSC had significant variation ($p<0.001$) due to cultivars × crop cycles.

The interaction effects on all the BP were highly significant. The CVs for all the parameters considered in this study across crop cycles were less than 15.0% except for GMC, TLC, stalk count (STC), mean stalk weight (MSW) and days to flower initiation (DFI) which ranged between 19.6% for MSW to 30.5% for DFI. Significant effects of cultivars × crop cycles on the yield characters and brix per cent were indicative of consequences of environment and difference in ratoonability of the cultivars. On the other hand, non-significant variation for brix per cent at 10 and 11 MAP across crop cycles showed that sucrose accumulation of the cultivars did not vary with years or ratooning. The result corresponded with that of Jamoza (2013), who found that significant genotype × environment interactions existed for cane yields but not for brix per cent of sugarcane.

Means, variance, heritability and genetic gain for establishment, maturity, yield and Brix per cent of the sugarcane cultivars

Mean values were higher in the plant crop than ratoon crop for number of nodes (NND), MSW, DFI, BP9 and BP12, while values for the GMC, TLC, stalk count (STC), TSC and TSW were higher in the ratoon crop cycles (Table 2). Mean values of the plant characters in the formative phase and yield components were higher in the ratoon cycles due to

Table 2. Mean yield, variances, heritability and genetic gain for formative, vegetative, yield characters and brix per cent of plant and ratoon crops of sugarcane cultivars evaluated in Ibadan, Nigeria in 2013 and 2014

Character	Crop	Mean	Phenotypic Variance	Genotypic Variance	Environmental Variance	Phenotypic CV (%)	Genotypic CV (%)	Broadsense Heritability	Genetic Gain
GMC	Plant	27.17^{*}	129.00	116.58	12.42	41.80	39.74	90.37	77.82
	Ratoon	106.25	5236.71	4999.34	237.37	68.11	66.55	95.47	93.94
TLC	Plant	57.17^{*}	707.24	659.96	47.29	46.52	44.94	93.31	89.42.
	Ratoon	165.20	4997.67	4653.22	344.44	42.79	41.29	93.11	82.08
STC	Plant	31.06^{*}	180.46	147.87	32.60	43.25	39.15	81.94	73.00
	Ratoon	61.45	714.07	543.81	170.26	43.49	37.95	76.16	68.23
NND	Plant	21.39^{*}	3.13	2.27	0.86	8.27	7.05	72.58	12.36
	Ratoon	19.78	6.77	5.71	1.06	13.16	12.09	74.36	13.87
SHT(m)	Plant	3.33^{ns}	3.85	2.04	0.02	58.81	5.61	90.91	21.10
	Ratoon	2.36	3.11	2.10	0.01	14.04	13.52	92.75	26.83
STD (cm)	Plant	2.78^{ns}	0.14	0.13	0.01	13.68	13.17	92.77	26.13
	Ratoon	2.48	0.14	0.13	0.01	15.04	14.35	90.35	28.18
INL (cm)	Plant	12.12^{ns}	62.65	12.03	0.86	13.42	11.76	76.82	21.23
	Ratoon	14.42	98.66	17.31	1.35	17.75	24.19	67.55	20.87
TSC	Plant	54.53^{*}	104.27	336.18	68.10	36.87	33.63	83.16	63.17
	Ratoon	83.14	615.00	378.25	236.76	29.83	23.39	61.50	37.79
MSW (g)	Plant	1.23^{*}	0.27	0.25	0.02	42.03	40.39	92.37	79.97
	Ratoon	0.87	0.23	0.21	0.01	40.63	38.29	88.83	74.34
TSW ($g/36m^2$)	Plant	50.82^{*}	167.97	126.95	41.02	25.50	22.17	75.58	39.70
	Ratoon	76.99	494.23	397.94	99.30	28.88	25.81	79.91	47.53
MBS	Plant	9.28^{ns}	3.45	2.89	0.56	20.02	18.33	83.78	34.56
	Ratoon	9.81	8.20	7.51	0.69	29.38	27.11	91.54	55.40
DFI (days)	Plant	257.88^{*}	163.87	163.87	0.09	38.90	38.90	100.00	80.14
	Ratoon	249.28	186.06	185.17	0.89	35.47	35.46	99.52	81.22
BP9 (%)	Plant	19.09^{*}	3.69	3.26	0.43	10.07	9.46	88.29	18.31
	Ratoon	17.99	3.68	3.40	0.28	10.66	10.25	92.45	20.31
BP10 (%)	Plant	18.96^{*}	1.72	1.65	0.06	6.91	6.78	96.26	13.71
	Ratoon	19.08	1.62	1.60	0.02	4.12	4.07	97.36	8.27
BP11 (%)	Plant	20.45^{ns}	0.73	0.60	0.14	4.19	3.78	81.17	7.01
	Ratoon	20.46	1.18	1.04	0.14	5.31	4.99	88.19	9.65
BP12 (%)	Plant	21.48^{*}	1.16	0.96	0.20	5.02	4.56	82.47	8.53
	Ratoon	20.87	2.25	1.97	0.28	7.19	6.73	87.51	12.96

GMC, TLC, STC, NND, SHT, INL, TSC, MSW, TSW, MBS, DFI, BP9, BP10, BP11 and BP12 are significant ($p=0.05$), germination, tiller count, stalk count, number of nodes/plant, stalk height, internode length, total stalk count, mean stalk weight, total stalk weight, millable stalk, days to flower initiation, brix per cent at 9, 10, 11 and 12 weeks after planting.

the higher tiller counts which eventually culminated in the total cane yield. This result could be explained by the observation that the plants in the ratoon crop cycle established more rapidly than in the plant crop. Hence, food materials were utilized more effectively by the plants which had well developed root and shoot systems at early stage. However, plants in the main crop require longer time for initial adaptation to the micro-environment where they were grown before effective uptake and utilization of plant nutrients or solar radiation. Khan et al. (2013) found that higher number of tillers contributed to higher sugar yields in sugarcane genotypes. Similarly, Ogunniyan et al. (2018) had reported higher productivity of ratoon crop over the plant crop cycle of sugarcane.

The phenotypic variances for all the parameters were higher than their respective genotypic variance indicating influence of environmental conditions under which the crop was grown. However, the PV and GV were similar for DFI and BP9. Variances were higher for the ratoon crop than plant crop cycle, but the parameters were similar for STD, MSW, BP9 and BP10. The PCV and GCV were higher in plant crop than ratoon crop cycle except for STC, MSW and BP10 where the parameters were not significantly different. Variance estimates for the characters at the formative stage as well as the yield and brix per cent at the later stage of maturity were higher for the ratoon crop than the plant crop cycle. This variation might have been due to environmental effects and differences in ratoonability of the cultivars and supported the view that selection was more effective in ratoon cycle than plant crop cycle. Phenotypic variance for all the characters were higher than their respective genotypic variance indicating the effect of environment or differences in their ratoonability which might have affected performance of the cultivars. However, DFI and BP at 9 MAP showed similar variance in the plant and ratoon crop cycles. Thus, effect of environment and crop cycle was negligible on the expression of the characters or biochemical activities in the plant.

Heritability varied for the parameters between crops (Table 2). It was lower in the plant crop than ratoon crop cycle for GMC, NND, SHT, TSW, MBS, BP9 and BP12, not significantly different in both the plant and ratoon crop cycles for TLC, DFI and BP10 but higher in the ratoon than the plant crop cycle for the remaining parameters. The parameter ranged from 72% and 74% for NND in the plant and ratoon crop, respectively to 100% for DFI in both crops. The genetic gain ranged from 7.0 to 89.4 in the plant crop, and from 9.7 to 93.9 in the ratoon crop cycle. The genetic gain was consistently lowest for BP11 and highest for TLC in the two crop cycles. Heritability estimates were higher in most of the parameters in ratoon crop than the plant crop cycle portending adaptation of the cultivars to the environmental conditions in the ratoon. The asexual mode of reproduction of the crop caused high to very high heritability estimates for all the characters in each of the two crop cycles.

Mean and estimates of genetic parameters for the characters of the two crop cycles are shown in Table 3. The phenotypic and genotypic variance for all the characters were higher than their corresponding error variance (EV) except for MSW. The PV for cultivar × crop cycle was higher than GV for GMC, NND, TSW, MBS, DFI, BP10 and BP12. Conversely, PV and GV estimates were lower than EV for STC, NND and TSC, but similar to EV for INL. Furthermore, it was found that PCV was higher than the GCV for all the characters. Estimates of heritability and genetic gain ranged from 23.3% for INL to 95.9% for DFI, and from 10.4 for BP11 to

Table 3. Mean, variances, heritability and genetic gain for formative, vegetative, yield characters and brix percentage from combined analysis of plant and ratoon crops of sugarcane cultivars evaluated in Ibadan, Nigeria in 2013 and 2014

Character	Mean	Phenotypic Variance	Genotypic Variance	Cultivar × Crop Variance	Environmental Variance	Phenotypic CV (%)	Genotypic CV (%)	Broadsense Heritability	Genetic Gain
GMC	66.71	1449.86	216.87	1170.54	62.45	0.44	0.17	28.96	13.03
TLC	111.18	1987.92	1123.38	766.61	97.93	0.37	0.28	70.51	13.34
STC	46.25	346.76	246.26	49.79	50.71	0.90	0.75	85.02	14.21
NND	20.59	3.02	1.09	1.45	0.48	9.59	5.77	50.20	12.05
SHT (m)	2.85	1.06	0.16	0.06	0.97	16.19	6.21	28.74	17.82
STD (cm)	2.60	0.11	0.08	0.02	0.01	50.29	43.10	87.44	19.99
INL (cm)	13.27	21.57	11.13	4.39	4.82	3.59	0.82	23.26	13.29
TSC	68.83	417.30	324.97	16.12	76.21	0.82	0.72	91.87	14.21
MSW (g)	1.05	0.13	0.07	0.06	0.01	45.84	33.00	65.83	17.85
TSW (g/36 m^2)	63.91	172.35	33.59	123.67	13.08	1.27	0.36	31.89	13.11
MBS	9.54	3.57	1.31	1.95	0.31	8.82	5.34	50.66	1956
DFI(days)	253.58	2871.30	617.64	2253.44	0.22	0.31	0.14	95.51	23.04
BP9 (%)	18.54	2.94	2.20	0.57	0.18	9.25	7.99	88.67	12.85
BP10 (%)	19.02	0.70	0.23	0.45	0.02	19.94	11.40	46.67	12.32
BP11 (%)	20.46	0.73	0.50	0.16	0.07	19.53	16.15	82.41	10.42
BP12 (%)	21.17	1.04.	0.38	0.54	0.12	16.31	9.85	50.46	12.15

GMC, TLC, STC, NND, SHT, INL, TSC, MSW, TSW, MBS and DFI are germination count, tiller count, stalk count, number of nodes/plant, stalk height, internode length, total stalk count, mean stalk weight, total stalk weight, millable stalk and days to flower initiation; BP9, BP10, BP11 and BP12 - mean brix per cent at 9, 10, 11 and 12 weeks after planting, respectively; SE and CV are standard error and coefficient of variation.

23.0 for DFI, respectively. Only DFI, STD and MBS had genetic gain equal to or greater than 20.0% across crop cycles.

Genetic gains for the characters were similar for plant and ratoon crop cycles suggesting selection based on certain characters such as number of nodes per plant, internode length, days to flower initiation and brix per cent at 9 MAP Genetic gain for characters in the formative phase, particularly GMC and TLC, flowering and yield characters (for instance MSW and STC) were consistently high. Therefore, these characters were critical for selection in both the crop cycles. Estimates of heritability and genetic gain were high for TLC, STC, STD, TSC, DFI, BP9 and BP11 signifying additive gene action controlling inheritance of the characters. On the other hand, both additive and non-additive gene actions governed inheritance of NND, MBS, MSW, BP12 because of their high heritability and medium genetic gain.

Genetic correlation among establishment, maturity, yield and Brix percentage of the sugarcane cultivars
Various significant levels of positive and negative phenotypic correlations existed among the parameters considered for each of the two crop cycles (Table 4). In the plant crop cycle in 2013, germination count had significant correlation with stalk count (0.58^{*}) only while the latter correlated with TSC (0.65^{*}) and BP at 10 WAP (-0.76^{**}); stalk diameter and mean stalk weight correlated with days to flower initiation (0.71^{**}). Contrary to the significantly positive phenotypic correlations in the plant crop, both positive and negative correlations existed in ratoon crop in 2014. The GMC had highly significant phenotypic correlation with STC, STD, TSC, MSW, MBS and BP10 in the ratoon crop. MBS had positive significant phenotypic correlations with all other characters except STC, SHT and MSW. The MSW had negative phenotypic correlations with BP9 and BP10 while MBS had negative phenotypic correlation with BP11 (-0.56^{*}). The BP9, BP10 and BP11 had significant phenotypic correlations with BP12 in the ratoon crop cycle in 2014.

In the plant crop cycle, GMC had positive genotypic significant correlations ($p<0.05$) with STC and TSW while STC significantly correlated with STD (-0.68^{**}) and TSC (0.77^{**}) only (Table 5). SHT exhibited significant correlations ($p<0.05$) with MBS and BP9, STD correlated with DFI (0.74^{**}) only while INL correlated with TSC (0.62^{*}) and TSW ($0.87(0.77^{**}$). The TSC had significant correlation with TSW (0.65^{*}) and BP10 (-0.67^{*})

Table 4. Phenotypic correlations among formative, vegetative, yield and brix per cent in plant crop in 2013 (above diagonal) and ratoon crop in 2014 (below diagonal) of sugarcane cultivars evaluated in Ibadan, Nigeria in 2013 and 2014

Character	GMC	STC	SHT	STD	INL	TSC	MSW	TSW	MBS	DFI	BP9	BP10	BP11	BP12
GMC		0.58^{*}	0.02	-0.01	0.31	0.41	0.09	0.46	0.13	0.24	-0.20	-0.32	-0.18	-0.26
STC	0.70^{**}		-0.08	-054	0.19	0.65^{*}	-0.30	0.14	0.32	-0.37	0.13	-0.37	-0.29	-0.76^{**}
SHT	0.17	0.48		0.02	0.06	0.07	-0.39	-0.17	0.54	-0.27	-0.51	-0.18	-0.23	0.45
STD	-0.71^{**}	-0.52	-0.02		0.39	-0.19	-0.22	0.42	-0.27	0.71^{**}	-0.11	0.03	0.41	0.47
INL	0.36	0.00	0.04	-0.48		0.54	-0.43	0.64^{*}	-0.37	0.20	-0.09	-0.29	0.22	0.15
TSC	0.73^{**}	0.82^{***}	0.27	-049	0.27		-0.34	0.65^{*}	-0.21	0.00	-0.17	-0.63	-0.32	-0.45
MSW	-0.56^{*}	-0.11	0.46	0.54	-0.42	-0.45		-0.14	-0.22	0.71^{**}	0.11	0.10	0.01	0.02
TSW	0.21	0.39	0.66^{*}	0.21	0.27	0.25	0.43		-0.52	0.38	-0.18	-0.29	-0.03	0.02
MBS	0.68^{**}	0.51	0.01	-0.69^{**}	0.62^{*}	0.65^{*}	-0.54	0.90^{***}		-0.43	-033	-0.24	-0.34	-0.22
DFI	-0.47	-0.58^{*}	0.03	0.60^{*}	-0.23	-0.51	0.25	0.01	-0.54		-014	-0.16	0.18	0.20
BP9	0.47	0.16	-0.36	-0.22	0.09	0.35	-0.59^{*}	-0.43	0.28	0.03		0.67^{*}	0.66^{*}	-0.21
BP10	0.70^{**}	0.50	0.30	-0.52	0.27	0.56^{*}	-0.57^{*}	0.00	0.47	0.04	0.60^{*}		0.65^{*}	0.22
BP11	-0.27	-0.16	0.25	0.50	-0.45	-0.25	0.40	0.06	-0.56^{*}	0.59^{*}	0.24	0.09		0.24
BP12	0.33	-0.02	0.06	0.04	0.14	0.21	-0.32	-0.13	-0.02	0.32	0.75^{**}	0.60^{*}	0.56^{*}	

GMC, TLC, STC, NND, SHT, INL, TSC, MSW, TSW, MBS and DFI are germination count, tiller count, stalk count, number of nodes/plant, stalk height, internode length, total stalk count, mean stalk weight, total stalk weight, millable stalk and days to flower initiation.
BP9, BP10, BP11 and PB 12 mean brix per cent at 9, 10, 11 and 12 weeks after planting, respectively.

Table 5. Genotypic correlations among formative, vegetative, yield and brix per cent in plant crop in 2013 (above diagonal) and ratoon crop in 2014 (below diagonal) of sugarcane cultivars evaluated in Ibadan, Nigeria in 2013 and 2014

Character	GMC	STC	SHT	STD	INL	TSC	MSW	TSW	MBS	DFI	BP9	BP10	BP11	BP12
GMC		0.61^{*}	0.49	-0.01	0.45	0.51	0.07	0.57^{*}	0.22	0.25	-0.19	-0.36	-0.23	-0.28
STC	0.79^{**}		-0.18	-0.68^{**}	0.21	0.77^{**}	-0.37	0.15	0.42	-0.41	0.20	-0.41	0.42	-0.37
SHT	0.18	0.65^{*}		-0.01	0.25	-0.25	-0.44	-0.24	0.60^{*}	-0.28	-0.59^{*}	-0.27	-0.27	0.49
STD	0.77^{**}	-0.70^{**}	0.00		0.45	-0.25	0.21	0.42	-0.27	0.74^{**}	-0.11	0.05	0.46	0.48
INL	0.92^{***}	-0.63^{*}	0.16	-0.98^{***}		0.62^{*}	-0.52	0.87^{***}	-0.53	0.23	-0.10	-0.29	0.23	0.19
TSC	0.96^{***}	0.98^{***}	0.42	-0.31	0.98^{***}		-0.43	0.65^{*}	-0.25	0.00	-0.23	-0.67^{*}	-0.34	-0.54
MSW	-0.65^{*}	-0.22	0.51	0.58^{*}	0.96^{***}	-0.67^{*}		-0.19	-0.21	0.74^{**}	0.12	0.14	0.01	0.03
TSW	0.21	0.48	0.81^{***}	0.16	-0.71^{**}	0.09	0.47		-0.61^{*}	0.44	-.026	-0.33	-0.03	0.01
MBS	0.71^{**}	0.56^{*}	0.05	-0.77^{**}	0.98^{***}	0.93^{***}	0.64^{*}	-0.61^{*}		-0.47	-0.49	-0.25	-0.34	-0.25
DFI	-0.47	-0.65^{*}	0.03	-0.63^{*}	-0.57^{*}	-0.67^{*}	0.28	0.00	-0.56^{*}		-0.15	-0.17	0.20	0.22
BP9	0.45	0.11	-0.37	-0.27	0.22	0.42	-0.72^{**}	-0.57^{*}	0.29	0.04		0.75^{**}	0.91^{***}	-0.25
BP10	0.71^{**}	0.58^{*}	0.32	-0.55	0.60^{*}	0.74^{**}	-0.62^{*}	-0.02	0.50	0.04	0.62^{*}		0.73^{***}	0.25
BP11	-0.26	-0.22	0.27	0.56^{*}	-0.24	-0.40	0.41	0.10	-0.62^{*}	0.63^{*}	0.29	0.10		0.37
BP12	0.32	-0.07	0.05	0.06	0.49	0.31	-0.40	-0.13	-0.03	0.35	0.77^{**}	0.63^{*}	0.67^{**}	

GMC, TLC, STC, NND, SHT, INL, TSC, MSW, TSW, MBS and DFI are germination count, tiller count, stalk count, number of nodes/plant, stalk height, internode length, total stalk count, mean stalk weight, total stalk weight, millable stalk and days to flower initiation; BP9, BP10, BP11, and BP12 mean brix per cent at 9, 10, 11 and 12 weeks after planting, respectively

while MSW had positive correlation with DFI and TSW was negatively correlated with MBS. This showed positive correlations among BP9, BP10 and BP11. Genotypic correlation in the ratoon crop in 2014 between GMC, STC, STD, INL, TSC, MBS and BP10 were positive and highly significant. The STD had high significant correlation with GMC and STC ($P<0.01$); INL had significant negative correlations with STC and STD while TSC had highly significant and positive correlations with GMC (0.96^{***}), STC (0.98^{***}) and INL (0.98^{***}). The MSW had negative correlation with GMC and TSC. Similarly, TSW was highly correlated with SHT and INL while MBS correlated with all the formative, vegetative and yield parameters except SHT. The DFI also correlated with STC, STD, INL, TSC and MBS. Correlations among BP9, BP10, BP11 and BP12 were positive in the ratoon crop. In the formative phase, most of the characters significantly correlated with one another. The GMC phenotypically correlated with STC while TSC had phenotypic correlation with TSW showing that cane yield depended on crop establishment among other factors. The results obtained for genotypic correlations were almost similar to those for phenotypic correlations. Hence, decisions could be made without recurrence to the environment. This was proved with the preponderance of non-significant environmental correlations among the characters for each of the cycles. However, correlations among BP9, BP10 and BP11 were more of genotypic than phenotypic nature. This meant that genetic factors played more significant roles than environmental parameters or crop cycle in the sucrose accumulation of the cultivars. Correlations among phenotypic characters indicated biological processes that were of considerable interest and could be the result of genetic, functional and physiological or developmental nature (Soomoro et al., 2006).

Unlike phenotypic and genotypic correlation estimates, significant environmental associations ($p<0.05$) existed among a few pairs of characters of the crop for either plant or ratoon crop cycles (Table 6). For plant crop cycle in 2013, environmental correlations existed between STD and TSW (0.56^{*}) and DFI (0.64^{*}), TSC and TSW (0.67^{*}), MSW with DFI (0.64^{*}) and BP10 (-0.67^{*}) and between BP9 and BP11 (0.57^{*}) only. The GMC had significant correlations with MSW (0.60^{*}) and BP9 (0.58^{*}) for ratoon crop in 2014, while TSW correlated with STD (0.56^{*}) and TSC (0.66^{*}) and BP9 correlated with GMC (0.58^{*}) and MSW (0.61^{*}) only. According to the result of this study, quality of sugarcane with respect to sucrose was basically due to genetic factors and environment did not have significant influence on the changes in the sucrose

Table 6. Environmental correlations among formative, vegetative, yield and brix per cent in plant crop in 2013 (above diagonal) and ratoon crop in 2014 (below diagonal) of sugarcane cultivars evaluated in Ibadan, Nigeria in 2013 and 2014

Character	GMC	STC	SHT	STD	INL	TSC	MSW	TSW	MBS	DFI	BP9	BP10	BP11	BP12
GMC		0.41	-0.09	0.05	-0.45	-0.20	0.30	-0.07	0.47	0.22	-0.30	0.17	0.18	-0.15
STC	0.29		0.06	0.49	0.01	0.08	0.14	0.10	0.15	-0.34	-0.33	-0.13	0.29	0.20
SHT	-0.01	-0.50		0.09	0.08	-0.09	0.04	0.04	0.04	-0.24	0.06	-0.31	0.00	0.04
STD	0.05	0.39	-0.15		0.07	0.29	0.30	0.56*	-0.28	0.64*	-0.18	-0.20	0.08	0.49
INL	-0.10	0.51	-0.08	0.02		0.23	0.01	-0.11	0.31	0.19	-0.02	-0.40	0.19	-0.10
TSC	-0.01	0.50	-0.31	0.37	-0.22		0.31	0.67*	-0.04	0.00	0.18	-0.37	-0.19	-0.01
MSW	0.60*	0.41	0.06	0.10	-0.06	0.22		0.18	-0.28	0.64*	0.00	-0.67*	0.01	-0.06
TSW	0.31	0.08	-0.33	0.56*	0.00	0.66*	0.22		0.16	0.36	0.18	-0.06	-0.04	0.05
MBS	0.31	0.33	0.29	0.16	0.50	-0.25	0.37	-0.02		-0.40	0.63*	-0.27	-0.37	-0.07
DFI	-0.42	-0.18	-0.27	0.04	0.15	0.37	-0.53	0.32	-0.31		-0.13	-0.15	0.17	0.18
BP9	0.58*	0.51	-0.25	0.29	-0.10	0.19	0.61*	0.43	0.10	-0.22		-0.25	-0.57*	0.02
BP10	0.34	-0.01	0.07	-0.06	0.14	-0.14	0.24	0.18	0.02	-0.05	0.31		0.11	-0.07
BP11	-0.50	0.15	0.02	0.04	0.12	0.22	0.29	-0.17	-0.01	-0.02	-0.25	-0.07		-0.32
BP12	0.54	0.23	0.10	-0.11	-0.16	-0.07	0.24	-0.16	0.04	0.02	0.55*	0.31	-0.27	

GMC, TLC, STC, NND, SHT, INL, TSC, MSW, TSW, MBS and DFI are germination count, tiller count, stalk count, number of nodes/plant, stalk height, internode length, total stalk count, mean stalk weight, total stalk weight, millable stalk and days to flower initiation; BP9, BP10, BP11 and BP12 mean brix per cent at 9, 10, 11 and 12 weeks after planting, respectively.

as the plant aged. The brix per cent at 9 MAP had significant negative genotypic correlation with cane yield as has also been observed in early maturing cultivars (Ahamed et al., 2010; Sanghera et al., 2015). It has been shown that early maturing cultivars produced highest sucrose at 9 MAP, hence this might be responsible for the significant correlation of only BP9 with TSW while BP status at other stages did not correlate with cane yield.

This study concluded that meaningful selection for sugarcane improvement should be carried out at the formative or maturity phase and based on the brix per cent attributes. Ratoon crop cycle provided more reliable conditions for improvement of yield attributes, especially total stem count, mean stem weight, total stem weight and millable stalk, in the crop. Genes played more significant roles in the sucrose content of the cultivars than crop cycles. Tiller count, stalk count, stalk diameter, total stalk count, days to flower initiation, and brix per cent at 9 and 11 MAP were governed by additive gene actions, while both additive and non-additive gene actions governed inheritance of number of nodes, millable stalk, mean stalk weight and brix per cent at 12 MAP. These characters were suitable and reliable selection indices due to their high heritability and medium genetic gain. It was therefore advisable for sugarcane breeders to give attention to these characters for improvement.

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