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RESEARCH ARTICLE

Identification of principal traits for ratooning ability associated with cane yield and juice quality in sugarcane genotypes from advanced varietal evaluation trials

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Abstract:
Any new sugarcane variety should have both high yield and superior juice quality to ensure profitability for both farmers and sugar mills. Varieties with good ratooning ability (RA) give additional income to the farmers without replanting. In the national varietal development program, eight elite genotypes were evaluated in Randomized Block Design along with two standards during 2017-18 (as plant crop) and 2018-19 (as ratoon crop) at ICAR-Sugarcane Breeding Institute, Coimbatore. Eight Sugareane genotypes from advanced varietal Trial (AVT) were evaluated to study the relationship among yield, juice quality and its Component traits traits for their RA. PCA was carried out using eleven quantitative traits to identify the important traits contributing to high ratoonability in terms of cane yield and sugar yield. Three principal components with eigen value more than one explained 80.93 % of the total variation. Results on PCA indicated that single cane weight, juice sucrose %, CCS %, cane yield and sugar yield were strongly associated and dominant in explaining the existing variability among the genotypes. of the eght test genotypes evaluated Co 12009 and VSI 12121 were identified as excellent ratooners as they recorded high cane yield, such as sugar yield combining appreciable field stand in the ratoon crop. These genotypes have high RA for juice quality traits sucrose% and CCS%. These two genotypes with good flowering intensity could be used in hybridization as parents for identifying hybrid progenies with better retainability.

Keywords: Principal component analysis; Sugar yield; Sucrose; CCS %; NMC

Introduction

Sugarcane is the most important cash crop in the world mainly used as a source of sugar and allied industrial byproducts. It is widely cultivated in tropical and subtropical conditions in the world. Sugarcane is a clonally propagated crop which is initially grown as plant crop and subsequently as many ratoon crops. The cost incurred in seed material and planting operations can be saved by raising a ratoon crop (Shanthy et al. 2014). Hence, ratooning is a common practice in sugarcane cultivation throughout the world (Ram and Sahi 2012). In India, approximately 40% of the total area of sugarcane is occupied by ratoon crop (Danawale et al. 2012). Reduction in cane yield commonly occurs in the following/subsequent ratoon crops which may be due to diseases, insect damage and poor management practices. Despite the release of high yielding varieties and advanced cane production technologies, low cane productivity is the major reason for yield decline in ratoon crops (Gomathi et al. 2013). The genotypes identified with superior performance for ratooning ability is expected to either maintain or increase the yield in ratoon crops as compared to plant crop. Generally two to more ratoon crops are undertaken by majority of cane growing farmers to get high income from sugarcane cultivation (Shrivastava et al. 1992). Reduced cane yield has been reported with an increase in the number of ratoons which ultimately hinders the income of the farmer (Ricaud and Arceneaux 1986 and Johnson et al. 1993). Significant difference in the ratooning ability (RA) % of sugarcane genotypes has been observed for cane yield and component traits thereby giving an opportunity for selection (Tripathi et al. 1982; Chapman et al. 1992, El-Hinnawy and Masri 2009a). Genotypes having poor RA % show either high reduction in cane yield from plant crop to first ratoon or between the first and in the subsequent ratoon crops.

Among the agronomic traits, high ratooning ability has been recognized as an important breeding objective in sugarcane breeding programmes (Bazacott 1962; Skinner 1972). Breeding behaviour of ratooning ability was studied in Lousiana breeding programs, across plant cane, first ratoon crop and second ratoon crops in 210 clones derived from a cross between L 65-69 × CP 65-357. a good unber of clones with high ratooning ability for each of the individual yield component traits has been reported (Dunckelman 1982). Although a large number of published reports are available on the causes of ratoon failure in Sugarcane but the information relating to breeding behaviour of RA in breeding population is very less. Studies conducted in the past have indicated that sugarcane cultivars with good ratooning potential are characterized by rapid canopy development, development of adequate number of stalks at an early growth stage coupled with high cane weight at the time of harvest (Sundara et al. 1992; Sundara 1996; Gomathi et al. 2013). Therefore, investigations directed towards evaluation of ratooning ability of genotypes would be of immense benefit in sugarcane varietal development programmes. Significant differences among genotypes have been reported for cane yield in the ratoon crop giving ample scope for selection (Tripathi et al. 1982; Chapman et al. 1992). Studies reported differences for ratooning ability among genotypes from plant to fourth ratoon crop indicating potential for simultaneous screening (Zhou and Shoko 2012).

Statistical tools to compare genotypes for ratoon yield and associated traits across crop cycles would enhance selection for sugarcane clones with potential for multiratooning. The objective of the present study was to identify principal traits for efficient phenotypic characterization of genotypes that would enhances simultaneous selection of clone for high plant crop yield and ratooning ability in sugarcane.

Materials and Methods

Eight genotypes from avt (Advanced Varietal Trial) were evaluated in a Randomized Block Design along with three standards during 2017-18 (as plant crop) and 2018-19 (as ratoon crop) at ICAR-Sugarcane Breeding Institute, Coimbatore. Each genotype was planted in 8 rows of 6 meter length and 1.2 meter spaceing between the rows. Standard agronomic practices were adopted for raising a good plant crop. After the harvest of plant crop, ratoon management operations were carried out with the same set of genotypes. Gap filling was not done in the ratoon crop as it would interfere with our present objective of evaluating the potential of ratooning ability of genotypes. The observations on tiller count at 120 days, NMC at 300 days, cane height (cm), cane diameter (cm), single cane weight (kg), cane yield (tonnes/hectare), juice brix % and juice sucrose % were recorded at harvest. Juice purity % was calculated as: (Sucrose % / Brix %)x100 and CCS % were estimated using the formula: (Sucrose % × 1.022) – (Brix % × 0.292). CCS yield (tonnes/hectare) as: (Cane yield × CCS %) / 100. Number of millable canes (NMC) was recorded and expressed as thousands per hectare (‘000/ha). Ratooning Ability % was estimated as RA = (RC/PC)x100, for all the genotypes based on plant crop (PC) and ratoon crop (RC) mean values of all the traits studied (Milligan et al. 1996). Using least significant difference at 5% level of probability, means were compared between genotypes. In this study, multivariate statistical technique called Principal Component Analysis (PCA) was employed using MINITAB software that facilitates identification of principal cane yield and juice quality characters to ensure optimal selection gains for ratoonability in sugarcane.

Results and Discussion

Ratooning ability % was estimated for eleven traits Pertaining to cane yield, juice quality and their component traits in this study. The test genotypes differed significantly for all the traits except number of tillers at 120 days, cane diameter and juice brix% (Table 1).

Comparative performance of AVT genotypes for ratooning ability % of cane yield and its component traits

The performance of ratoon crop for number of millable canes (NMC) at 300 days exceeded unity in genotype Co 12009 and significantly surpassed both the standards Co 86032 and CoC 671. The reason could be the higher tiller survival rate at 120 days as well as higher conversion of tillers at establishment phase into millable canes during grand growth and maturity phase in Co 12009. Increase in stalk population has been reported in the clones from advanced selection stages in the first ratoon crop compared to the plant crop while it decreased in the second ratoon crop (El-Hinnawy and Masri 2009a). Physiological studies on RA % in sugarcane varieties (Gomathi et al. 2013) have reported differences between plant and ratoon crop for growth parameters in formative phase when compared to the grand growth and maturity phase. cane height of all genotypes except Co 12007 and CoM 12085 increased in the ratoon crop as seen by their higher RA % values compared to the standards Co 86032 (103.23%) and CoC 671 (95.10%). The genotypes did not differ significantly in their RA % for cane diameter. None of the genotypes performed better than the standards in terms of RA % for cane diameter. However, two genotypes *viz.,* Co 12009 and CoM 12085 were found to be on par with the standard CoC 671 for cane diameter in the ratoon crop. The genotypes varied significantly with regard to RA % for single cane weight and it ranged from 63.17% (Co 12008) to 103.80% (Co 12009). Two genotypes (Co 12009 and VSI 12121) recorded higher values of RA % for single cane weight than the standard Co 86032 (94.80) behaving as good ratooners by virtue of their high cane yield combining higher stalk population and taller canes at harvest in the ratoon crop. The comparative performance of Co 12009 and VSI 12121 for cane parameters indicated that the increase in RA % values for single cane weight is due to cane height rather than cane diameter.

Co86032, a popular cultivar in peninsular India recorded higher RA for cane yield (81.74%) as compared to the other standard CoC671 (76.66%) Of the eight test clones evaluated VSI 12121 and Co 12009 were found to be excellent ratooners by recording highest cane yield in the ratoon crop with their ratooning ability (RA) estimates greater than unity (>100%) of 111.66% and 110.30% respectively. In addition, the genotypes Co 12012 and Co 12019 recorded higher cane yield than the check variety Co 86032 in the ratoon crop. Overall, Co 12009 and VSI 12121 were the best ratooners in terms of higher RA % estimates for all cane characters except cane diameter. Earlier studies have reported that improved cane yield in the ratoon crops as compared to the plant crop was mainly due to an increase in millable cane number rather than single cane weight and cane diameter during early selection stages (Tripathi et al. 1982; Jamil et al. 2007). Although, Co 12012 emerged as one among the top three high yielding entries in this trial but it recorded lower RA % for NMC at 300 (84.62%) as compared to the other test genotypes. Higher RA % of 93.86 % observed for cane yield in Co 12012 than the standards Co

Table 1. Ratooning ability % of cane yield, juice quality and its components traits of sugarcane genotypes

S. No.	Entries	No. of tillers ('000/ha) at 120 days	NMC ('000/ha) at 300 days	Cane Ht. (cm)	Cane Dia. (cm)	SCW (Kg)	Brix %	Sucrose %	CCS %	Purity %	Cane yld t/ha	CCS YLD t/ha
1	Co 12007	94.63	77.63	99.91	89.02	83.44	103.03	101.27	100.48	98.30	70.82	71.26
2	Co 12008	94.58	83.65	111.06	91.12	63.17	101.56	100.43	99.91	98.89	76.94	76.88
3	Co 12009	106.02	101.01	104.16	95.41	103.80	108.31	109.11	109.47	100.75	110.30	120.88
4	Co 12012	96.08	84.62	108.34	94.19	91.52	108.69	114.58	117.47	105.45	93.86	110.01
5	Co 12019	97.95	94.98	135.45	94.83	85.86	106.76	107.39	107.69	100.58	85.63	92.15
6	Co 12024	99.93	96.88	107.14	91.29	77.48	104.97	103.52	102.87	98.61	83.04	85.39
7	CoM 12085	97.42	94.28	97.87	95.09	94.04	110.79	107.21	105.61	96.76	78.34	82.82
8	VSI 12121	94.12	92.51	112.28	91.28	97.29	109.04	107.37	106.63	98.44	111.66	119.04
Standards												
9	Co 86032	96.91	87.80	103.23	99.62	94.80	106.16	107.86	108.64	101.60	81.74	88.80
10	CoC 671	98.31	76.79	95.10	95.85	81.94	110.17	110.35	110.43	100.10	76.66	85.30
	GM	97.60	89.02	107.16	93.77	87.33	106.95	106.91	106.92	99.95	86.90	93.25
	CD	N/A	14.47	13.84	N/A	13.73	N/A	7.30	7.85	2.23	10.46	14.08
	CV	6.11	8.99	7.58	7.38	9.05	3.58	3.99	4.29	1.30	6.89	8.68

86032 and CoC 671 is by virtue of superiority for cane height and single cane weight in the ratoon crop. In addition, Co 12009 and Co 12019 demonstrated their potential as good ratooners by their high single cane weight and taller canes in the ratoon crop. Another genotype VSI 12121, exhibited superiority in the ratoon crop with high cane yield due to its high millabe cane population at 300 days, taller canes and high single cane weight. High ratoon cane yield observed in the genotype Co12012 was primarily contributed by cane height pollowed by cane diameter and single cane weight. Recent investigations on ratooning ability have reported that high cane yield in the ratoon crop was due to an increase in cane rength, single cane weight and NMC copaned to the plant crop (Songri et al. 2020).

Potential of sugarcane genotypes for ratooning ability of sugar yield and juice quality traits

Ratooning ability (RA) varied significantly among genotypes between plant crop and the ratoon crop cycles in respect of juice sucrose %, CCS %, juice purity % and sugar (CCS) yield. This finding is in agreement with the earlier studies on RA % of sugarcane genotypes under three crop cycles (Masri and Amein 2015). Among the check varieties, CoC 671 recorded the highest RA % values for all juice traits followed by the other standard Co 86032. An important observation here is that the comparative values in the ratoon and plant crop for juice quality traits exceeded unity for all the genotypes studied. Earlier studies have reported that juice quality traits are not affected by ratooning (El-Hinnawy and Masri 2009b). The test clone Co 12012 recorded the highest RA % for juice sucrose % (114.58) followed by Co 12009 (109.11), which was higher than the standard Co 86032 (107.86). Similar trend was observed for juice purity % and CCS%. Commercial cane sugar (CCS) yield is a derived estimate based on cane yield and commercial cane sugar percent. High estimates of RA % for CCS yield was recorded by Co 12009 (120.88), VSI 12121 (119.04) and Co 12012 (110.01) which was higher than the check vaniety Co 86032 (88.80). This obseration on hight ratooning ability estimates for sugar yield from this study was in agreement with the candiles reports (mehareb et al. 2015; Abu-Ellail et al. 2019; Arbelo et al. 2021). Comparative performance of the eight test genotypes highlighted the superiority of Co 12009 and VSI 12121 as excellent ratooners because of their high cane yield and sugar yield in the ratoon crop.

Principal component analysis (PCA) for Ratooning Ability (RA) %

In varietal development programs, breeders are interested to identify promising genotypes with multiple or more desirable traits. Selection for RA % assumes greater importance as yield is the most affected trait during ratooning. Since ratoon crops are harvested in sequence after the plant crop, selection for cane yield and sugar yield with high RA% could be ideal in different ratoon crops *viz.,* first ratoon, second ratoon crops etc. But these analyses do not give precise directions on the traits to be given importance that would enhance selection efficiency for ratooning ability (Raza et al. 2017). The main purpose of employing PCA analysis is to understand the relationship between the variables by dividing the total variance of all the studied traits into a few uncorrelated new variables called principal components (Willy and Lieberman, 2011). RA % of Eleven traits was studied using PCA in this study. Three principal components showed Eigen value >1 contributing to 80.93% of the total variation (Table 2). Principal component 1 (PC1) with an eigen value of 4.90 accounted for a maximum variation of 40.80 %. Eigen vector of PC1 showed positive values for CCS yield (0.908), single cane weight (0.848), cane yield (0.837), sucrose % (0.653), CCS % (0.636), diameter (0.600), NMC at 300 days (0.596) and tiller population at 120 days (0.567). Major factors for variation in PC 2 is mainly due to the contribution from CCS % (0.751), sucrose % (0.739), purity % (0.612) and brix % (0.525) Earlier studies employing PCA have also mentioned juice quality traits such as 270 days brix, 300 days brix and 300 days sucrose % as major eigen vectors contributing to 31.11% variation through PC1 (Zhou et al. 2015). The third principal component (PC 3) with an eigen value of 1.50 explained 12.52 % of the total variation. Cane height (0.908), purity % (0.306) and were identified as major contributing traits in PC3, while the remaining variables had no discriminatory power. Thus, the results on PCA analysis revealed tiller population at 120 days, NMC at 300 days, single cane weight, cane diameter, juice sucrose % and CCS %, cane yield and CCS yield as the important traits explaining the maximum variation in respect of RA % among the sugarcane genotypes from advanced selection stages involved in this study.

Table 2. Eigen value, % of total variation and Eigen vectors for the principal components.

Traits	PC1	PC2	PC3
Tiller at120 days	0.567	-0.500	-0.413
NMC 300 days	0.596	-0.760	0.140
Cane Ht.	0.040	-0.135	0.908
Cane Dia.	0.600	0.051	-0.404
SCW	0.848	-0.064	-0.279
Brix %	0.554	0.525	-0.152
Sucr %	0.653	0.739	0.072
CCS %	0.636	0.751	0.131
Purity %	0.438	0.612	0.306
Cane yld t/ha	0.837	-0.321	0.159
CCS YLD t/ha	0.908	-0.080	0.180
Eigen value	4.90	3.31	1.50
% of variation	40.80	27.62	12.52
Cumulative % variation	40.80	68.41	80.93

Scree plot was constructed with number of components in the X-axis and eigen value in the Y-axis to know the components to be used in PCA (Fig 1). Based on the plotted graph, three

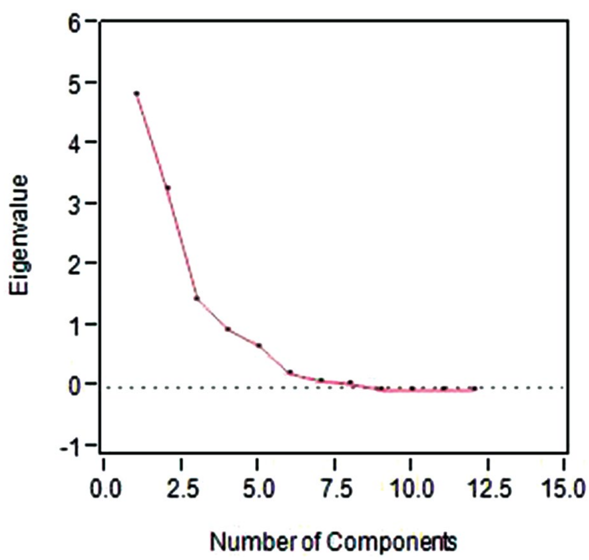

Figure 1. Scree plot of components hersus eigen values

component traits *viz.,* NMC at 300 days, sucrose % and CCS % that contributed to total variation were identified. Further, score plot depicting the varieties was made using the observations of PC1 and PC2 (Fig 2). Of the eight genotypes under investigation, Co 12009, VSI 12121 and Co 12019 were Identified as good ratooner with high cane yield and sugar yield through PCA. These genotypes have the potential to give superiou progenies for high ratoon cane yield and sugar yield when used as parents in sugarcane hybridization

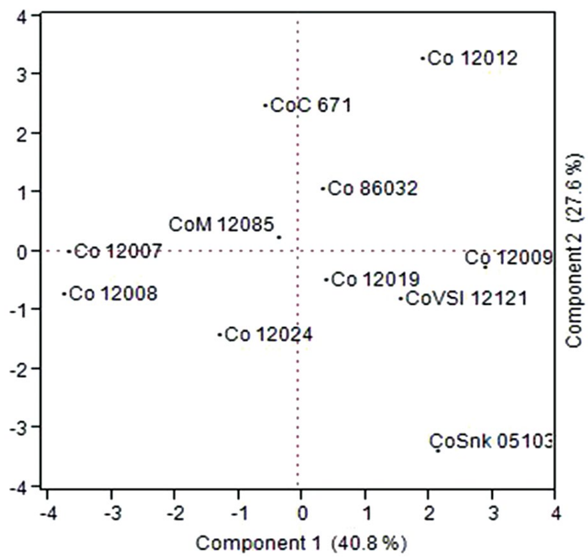

Figure 2. Scree plot for first and second components for 11 traits

programmes. Additional studies are required to identify genotypes with multi-ratooning potential by testing them across crop cycles involving more than two ratoon crops.

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References

Abu-Ellail FFB, Abd El-Azez YM, Bassiony NA. 2019. Assessment of ratooning ability and genetic variability of promising sugarcane varieties under middle Egypt conditions. Electronic Journal of Plant Breeding. 10(1): 143-154.

Arbelo OC, Sandhu H, Momotaz A, Davidson W, Sandoya G, Baltazar M, Barreto E, LaBorde C. 2021. Selection via cane yield and ratooning ability of sugarcane genotypes in sandy soils in Florida. Sugar Tech. https://doi.org/10.1007/s12355-021-00973-9.

Buzacott JH. 1962. The defects for which the majority of seedlings are discarded during selection. Proceedings International Society Sugar Cane Technologists Congress. 11: 410-413.

Chapman LS, Ferraris R, Ludlow MM. 1992. Ratooning ability of cane varieties: Variation in yield and yield components. Proceedings of Australian Society of Sugar Cane Technologists. 14: 130-138.

Danawale NJ, Dhage AB, Gaikwad DD, Gawari KM. 2012. Physiological studies on ratoonability of promising sugarcane genotypes. International Journal Forestry & Crop Improvement. 3(2): 95-98.

Dunckelman JW. 1982. Breeding Behavior of Ratooning Ability in Sugarcane. LSU Historical Dissertations and Theses. 3714.

EL-Hinnawy HH, Masri MI. 2009a. Crop cycle effects on Genetic variability, heritability and yield of sugarcane. Journal of Agricultural Science, Mansoura University. 34(6): 6755-6767.

El-Hinnawy HH, Masri MI. 2009b. Ratooning ability and indirect response to selection in sugarcane. Egyptian Journal Plant Breeding. 13: 39-52.

Gomathi R, Rao PNG, Rakkiyappan P, Sundara B.P. Shiyamala S. 2013. Physiological studies on ratoonability of sugarcane varieties under tropical Indian condition. American Journal of Plant Sciences. 4: 274-281.

Jamil MS, Afghan S, Majid MA, Rasool A. 2007. Ratooning performance of different sugarcane varieties. Pakistan Sugar Journal. 22: 38-47.

Johnson JL, Heagler AM, Zapata HO, Ricaud R. 1993. The impact of succession planting and a third ratoon crop on economic efficiency in sugarcane production in Louisiana. American Society of Sugar Cane Technologists. 13: 28-32.

Masri MI, Amein MMM. 2015. Yield potential and ratooning ability of some sugar cane genotypes. Journal of Plant Breeding and Crop Science. 7(8): 262-274.

Mehareb EM, Abou-Elwafa SF, Galal MOA. 2015. Comparative performance of sugarcane genotypes for ratoonability in early clonal selection stages. Journal of Sugarcane Research. 5(2): 2015.

Milligan SB, Gravois KA, Martin FA. 1996. Inheritance of sugarcane ratooning ability and relationship of younger crop traits to older crop traits. Crop Science. 36: 45-50.

Ram B, Sahi BK. 2012. Evaluation of exotic and Indian clones of sugarcane for ratoonability during winter. Journal of Sugarcane Research. 2(2): 48-53.

Raza I, Farooq MA, Masood MA, Abid S, Anwar MZ, Hassan M, Mustafa R. 2017. Exploring relationship among quantitative traits of sugarcane varieties using principal component analysis. Science, Technology and Development. 36: 142-146.

Ricaud R, Arceneaux A. 1986. Some factors affecting ratoon cane yield and longevity in Louisiana. Proceedings of International Sugar Cane Technologists. 19: 18-24.

Shanthy TR, Bhaskaran A, Boobalan R. 2014. Constraints and opportunities in sugarcane ratoon management – A performance analysis. Journal of Sugarcane Research. 4(2): 48-55.

Shrivastava AK, Ghosh AK, Agnihotri VP. 1992. Sugar cane ratoons. Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi.

Skinner JC. 1972. Selection in sugarcane: A review. Proceedings International Society Sugar Cane Technologists Congress. 14: 149-162.

Songsri P, Nata J, Bootprom N, Jongrungklang N. 2020. Performances of elite sugarcane genotypes for agro-physiological traits in relation to yield potential and ratooning ability under rain-fed conditions. Journal of Agronomy. 19: 1-13.

Sundara B, Sankaranarayanan P, Batcha MBGR. 1992. Varietal characteristics affecting ratooning potential of Sugarcane. Sugarcane. 6: 1-4.

Sundara B. 1996. "Studies on multi-ratooning potential of sugarcane varieties", 58th Annual Convention, STAI, 14-16 September pp. 3-8.

Tripathi BK, Gill SS, Misa GP, Lai S. 1982. Screening of sugarcane (*Saccharum* spp hybrids) genotypes for ratooning ability. Indian Sugar. 32: 577-580.

Wiley E, Lieberman B. 2011. Phylogenetics: Theory and Practice of Phylogenetic Systematics. John Wileyand Sons, New York.

Zhou H, Yang R, Li YR. 2015. Principal component and cluster analyses for quantitative traits in GT sugarcane germplasm (*Saccharum* Spp. Hybrids). International Journal of Agricultural Innovative Research. 3: 1686-1690.

Zhou MM, Shoko MD. 2012. Simultaneous selection for yield and ratooning ability in sugarcane genotypes using analysis of covariance. South African journal of plant and soil. 29(2): 93-100.