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RESEARCH ARTICLE

Natural flowering patterns and key traits influencing flowering propensity in diverse sugarcane (*Saccharum* spp.) clones at Coimbatore

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Abstract

A study was conducted to analyze the natural flowering behavior of sugarcane clones focusing on identification of the cane characteristics that influence flowering propensity. The findings revealed that clones originating from subtropical agro-climatic zones exhibited the highest flowering propensity and flowered early, whereas those from tropical zones demonstrated a lower flowering propensity and flowered later. A positive correlation was found between the days required to form visible internodes and flowering propensity. Eleven key characters studied collectively explained 40.94% of the variation, as observed in the principal component analysis. A scatter plot analysis identified 22 genotypes with high flowering potential, including diverse genotypes Co 8209, 97 R 401, CoLk 94184, CoJ 89, LG 99190 and LG 72120, which exhibited 100% flowering propensity. These genotypes can be utilized in crossing programs to enhance seedling populations for varietal selection. The study's findings provide valuable insights into the characteristics influencing sugarcane flowering, enabling the development of more efficient breeding programs and ultimately leading to increased sugar production.

Keywords: Sugarcane, Flowering propensity, Principal component analysis, Agronomic and physiological traits, National hybridization garden.

Introduction

Flowering and subsequent seed formation are essential prerequisites for achieving desirable recombination through hybridization in crop improvement programs. The flowering phenomenon is crucial for generating variation in classical breeding programs. While many crops in India flower profusely in the locations where breeding programs are conducted, sugarcane is an exception, exhibiting poor flowering and inadequate seed sets in most breeding locations. This limitation necessitates sugarcane breeders to visit the ICAR-Sugarcane Breeding Institute in Coimbatore, where the favorable climate promotes flowering, to make targeted crosses.

Flowering in sugarcane is considered a blessing for sugarcane breeders, and on the other hand, it causes significant yield losses in commercial cultivation. The single cane weight was the character that was reduced slightly with age after flowering, while the sucrose % in the juice was not affected until after 3 months of flowering and the fiber content was increased marginally three months after flowering (Gururajarao and Nareshkumar 2003). Flowering and flowering intensity in sugarcane is vastly variable and erratic in tropical environments due to changing weather conditions. Sugarcane flowering is affected by many plant and environmental factors like temperature, photoperiod, moisture and nutrition (Moore and Nuss 1987), humidity, altitude and latitude. The floral induction time of the sugarcane crop was about 6 months of age (Clements 1975).

Panje and Srinivasan (1959) opined that sugarcane clones were bound with respect to flowering to definite

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photoperiods of latitudes of their origin and that the capacity of latitudinal tolerance of flowering varies among individuals. The clones that were displaced latitudinally flower every year or nearly every year than those that were displaced farther. Elevation from mean sea level plays an important role in sugarcane flowering in places whose latitudes are farther from the equator, possibly by regulating temperature variations. Many authors have studied the effect of altitude on sugarcane flowering (Pollock 1981 and Nayamuth et al. 2003). Jeswiet (1927) observed good flowering in mountainous regions, especially at 500 m. However, Torrecilla et al. (2010) reported a negative correlation between altitude and pollen fertility.

Another important stimulus that plays a critical role in sugarcane flowering is photoperiod. Sugarcane requires a reduction in day length from 12 hours 55 minutes to 12 hours or 12 hours 30 minutes for flowering. Photoperiods of 9, 11, and 14 hours considerably reduced the number of panicles that emerged in quite a lot of sugarcane clones (*Saccharum spp.*), as compared to a photoperiod of 12.5 hours (Pavani et al. 2023). Increasing the duration of the photoperiod resulted in an increased delay of panicle emergence and 4 weeks of this treatment caused maximum delay when inflorescences were just beginning to form or up to 1.25 cm long (James and Smith 1969). Dark treatment of four hours in a photoperiodic chamber induced flowering one month earlier than the control (Srivastava et al. 2006). Experiments in South Africa established that a continuous application of nitrogen significantly increased flowering as well as panicle and fuzz weight in photoperiod-treated sugarcane clones while it significantly reduced the amount of viable pollen and viable seed per gram of fluff (Brunkhorst 2003). Hurriedly decreasing day length is responsible for sparse flowering in most of the genotypes by dropping the number of photo-inductive days (Ahamed et al. 2019). A light intensity of 1399 lux tended to decrease the panicle emergence in a more significant number and significantly delayed the panicle emergence than a light intensity of 86 lux (James and Smith 1969).

The transition from the vegetative stage to the reproductive stage is reverted back when there is any deviation from ambient temperature and light, revealing the complexity in spatial and temporal expression patterns of gene circuits of the sugarcane flowering. Similarly, when the daytime temperature exceeded 31°C during the induction and initiation period of the flowering, the intensity was very much reduced in traditional breeding plots (Shanmugavadivu and Rao 2009). Temperature much below the normal reduces the pollen viability in both emerging and developing inflorescence and it also reduces the flowering intensities by hindering floral organization. Low temperature resulted in variation in flowering among genotypes and was also responsible for reduced fuzz viability (Ahamed et al. 2019). Knowledge of the transcriptomic background of circadian, photoperiod, and gibberellin pathways in sugarcane is required to understand variable responses in floral development (Pavani et al. 2023). Because of the complexity of sugarcane flowering, the understanding of this process has been elusive.

In countries closer to the equator, most varieties will flower every year because the climatic conditions are favorable every year to induce floweringIn India, breeding materials from different sugarcane research stations located in different latitudes from Thiruvalla (9.39°N; 76.58°E in Kerala) to Ludhiana (30.91°N; 75.85°E in Punjab) are accumulated in ICAR-Sugarcane Breeding Institute, Coimbatore which is situated in the tropical part of the country (Durai et al. 2014). Here, the clones from the sub-tropical region flower first, followed by the tropical ones. In order to make the crosses with a very high seed setting, it is essential to study flowering propensity. This is more significant in the context of developing true seed propagation technology where true seeds of sugarcane crops are used for commercial cultivation. A lot of literature is available on the climatic factors responsible for sugarcane flowering (Pavani et al. 2023). Among the plant characters, Coleman (1969) reported that 2 to 4 well-exposed internodes were sufficient to respond to flowering stimulus in sugarcane. However, the information on other plant characteristics which are essential for flowering induction to happen is meagre. Therefore, the present study was conducted with the objective of identifying plant agronomical and physiological characteristics essential for sugarcane flowering.

Materials and methods

The material comprised of 226 sugarcane genotypes (Table 1) from various breeding centers, including both domestic and exotic clones, planted in the National Hybridisation Garden, ICAR-SBI, Coimbatore, a centralized facility for the sugarcane breeders of the country to effect crosses of their choice during the years 2020 and 2021. The parental clones from different sugarcane breeding centers of the country located in the tropical and the subtropical parts of the country, interspecific hybrids developed using unutilized accession of *Saccharum* complex and related genera, exotic hybrids from Canal Point, Lyallpur Natal, Queensland and Sau Paulo and genetic stocks were taken for the present study. The genotypes were planted in nonreplicated rows where each entry occupied a single row of 6 m in length. Recommended agronomic practices were followed to ensure a good crop. The crop was maintained in pests and disease-free conditions. Observations on the number of days required for node formation were taken during the initial phase of crop growth. Data on agronomic and physiological characters like cane length, cane thickness, number of nodes, number of leaves, leaf length and leaf breadth and

number of tillers were taken during the flowering induction time (between the last week of June and the first of week of July around 180 days after planting) from five randomly selected competitive plant. Plant height, cane diameter, cane weight, brix%, sucrose%, wax, total number of stalks and number of flowering stalks were taken at maturity. Flowering propensity was calculated based on the number of canes flowered to the total number of canes in a particular genotype. It was scored on 1 to 5 scale with less than 10% flowered clones as very low propensity, 11 to 30% as low propensity, 31 to 60% as medium propensity, 61 to 80% as high propensity and above 80% as very high propensity. Statistical analyses were accomplished using JMP 2009 (JMP, Version 9.0.0. SAS Institute Inc., Cary, NC). For multifactorial comparison, principal component analysis (PCA) was used to display the correlations between the various agronomic and physiological traits and their relationship with different sugarcane clones. The bivariate correlation among the studied parameters and simple linear regression between the number of days to form internode and flowering propensity (%) were done through the Microsoft Excel 2013 version.

Results and discussion

Influence of weather parameters on flowering propensity

Fig. 1 shows monthly temperature (°C) and rainfall (mm) for years 2020 and 2021. The mean temperature for the years 2020 and 2021 was 27.07 and 25.85°C, respectively. The mean rainfall was about 1.58 and 2.16 mm, for the years 2020 and 2021, respectively. Notably, there was a slight decrease in the mean flowering percentage of the clones under study from 78.99% in 2020 to 76.7% in 2021, which may correlate with changes in specific weather conditions, such as an increase in rainfall and a decrease in temperature in the year 2021. This suggests that weather parameters could have a significant impact on the flowering patterns in sugarcane.

Diversity in flowering of tropical and subtropical clones

A minimum of 10 inductive nights is required for flowering and a maximum flowering occurs after 15 inductive nights (Coleman 1963). The heated environment produced more profuse flowering, increased panicle availability, and increased pollen stain-ability, which was directly correlated with pollen fertility, resulting in high germination of fluff (Berding 1981). In the present case in Coimbatore, the flowering commenced from the second fortnight of October and the peak and high propensity of flowering was found during the November month. The flowering in sugarcane germplasm in Alexandria, Egypt, commenced in November and ended in June and most of the germplasm flowered during December at the three seasons and, followed by

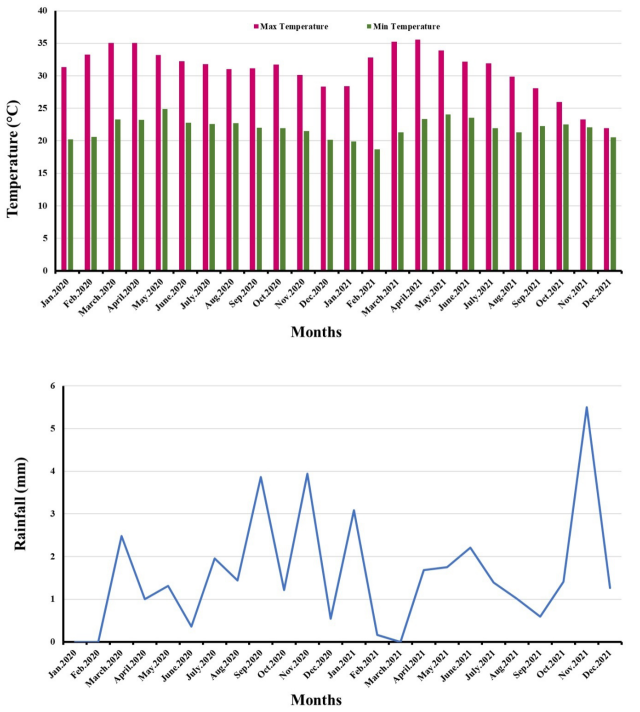

Fig. 1. Graphical representation of monthly temperature (°C) ad rainfall (mm) for the year 2020 and 2021

Table 1. Biological materials taken for the study

S. No	Origin	No. of parents
1	Tropical Co canes (Coimbatore)	59
2	CoS and UP (Shahjahanpur)	20
3	BO and CoP (Pusa)	14
4	Subtropical Co canes (Karnal)	20
5	CoH (Uchani)	17
6	CoLk and LG (Lucknow)	14
7	CoN (Navsari)	05
8	CoJ (Jalandhar)	09
9	CoPant (Pantnagar)	06
10	ISH	12
11	Exotic clones	08
12	CoA (Anakapalle)	07
13	CoM and M (Padegaon)	06
14	CoSnk (Sankeshwar)	02
15	CoV (Vuyyuru)	03
16	CoBln (Buralikson)	03
17	CoSe (Seorahi)	05
18	R (Rudrur)	03
19	CoC (Cuddalore)	08
20	CoOr (Nayagarh)	02
21	CoJaw (Powarkheda)	01
22	CoT (Perumalapalee)	01

February at the plant crop, January and February at the first ratoon crop and January and March at second ratoon crop (Marva et al. 2018). Most of the clones studied at Coimbatore were either very high-intensive flowerers (93) or high-intensive flowers (58) (Table 2). This may be due to the fact that the population studied was a breeding pool where only flowering clones were kept and those with poor flowering ability were removed from the parental pool periodically.

Among the 226 clones studied, 93 showed 100% flowering propensity (Fig.2). Four exotic clones viz., CP 44-101, CP 61-23, NCo 310 and SP 80-1842 showed cent per cent flowering propensity. Genetic stocks having all the stalks flowered were HR 83-144, HR 8365, ISH 1, ISH 150, ISH 229, ISH 287, ISH 41 and ISH 43. Among the 80 Indian canes showing 100% flowering propensity, most of the clones 52 in number, were from subtropical origin and only 28 clones were from tropical India, mostly from Coimbatore (14) followed by Navsari (4). Other than these locations, the origin of the tropical canes with 100% flowering propensity were Anakapalle (2), Padegaon (2), Sankeshwar (2) and Vuyyuru (2), Rudurur (1) and Cuddalore (1). Clones with a lower range of flowering propensity were mostly from the tropical center. There are clones that show very low flowering propensity but possess good desirable traits, such as Co 419, CoC 671, 87R 40 and CoSe 98231, which can be used in a breeding program for developing new varieties. Modern sugarcane cultivars are derived from interspecific crosses between *S. officinarum* and *S. spontaneum* genotypes, followed by several cycles of intercrossing and selection. They are polyploid aneuploid hybrids with unequal contribution from *S. officinarum* (80–90%) and *S. spontaneum* (10–20%) parental genomes and a small percentage of recombinant chromosomes (D'Hont 2005; Piperidis et al. 2010). Selvi et al. (2006) opined that sugarcane varieties selected and cultivated in the subtropical belt of India retained more of *Saccharum spontaneum* alleles and among the different species of the *Saccharum* genus, *S. spontaneum* flowers freely (Kandasamy et al. 1983). The higher propensity of flowering in subtropical sugarcane may be due to the larger quantity of *S. spontaneum* alleles in them. Among the 30 clones having less than 50% flowering propensity, 19 were from Coimbatore. Only six clones out of 30 were from Subtropical centers like Buralikson (2), Jalandhar (2), Shajahanpur (1) and Lucknow (1). Berding (1981) reported that in the heated environment, the late-season group flowered significantly less than the mid-season flowering ones. The clones, which usually flower early in the season, responded most to the heated night, followed by those that flower during the middle of the season. In the natural environment, flowering in the mid-season group significantly exceeded the other two groups of clones. In the present study, the subtropical clones that flowered early in the season had high flowering propensity when compared to their subtropical counterparts, which flowered later in the season. These results were in agreement with Panse and Srinivasan (1959), who opined that those who were displaced to the south of their origin flowers early and vice versa.

Principal Component Analysis

Principal component analysis (PCA) is one of the widely used tools in many experimental procedures for deducing information looked for from a large number of data sets for a better understanding of the population. This procedure also aids in minimizing the variables and demonstrates the relationship among them (Mundaragi et al. 2017). In the present study, PCA was executed for 17 traits taken in the field experiment. The number of principal components calculated from the correlation matrix is 17 which was similar to the number of traits observed. The first six principal components determined 72.11 percent of the variation in the population (Table 3). Latent roots (Eigenvalues) of the principal components having more than unity

Table 2. Classification of parents based on flowering propensity

Very low propensity (13): Co 419, Co 8013, Co 86249, Co 87252, Co 91019, Co 0120, Co 0121, Co 0327, CoC 671, CoH 76, 87 R 40, CoSe 98231 and Q 65
Low propensity (6): Co 7201, Co 7204, Co 94007, Co 98014, CoBln 03174, LG 95053
Moderate propensity (23): Co 740, Co 6304, Co 8353, Co 86002, Co 86019, Co 85246, Co 87272, Co 94008, Co 94012, Co 98007, Co 98010, Co 99006, Co 0237, CoA 92081, CoBln 9104, CoC 8201, CoC 90063, CoJ 64, CoJ 72, CoLk 7901, CoM 0235, CoS 87216 and CoT 8201
High propensity (33): BO 106, BO 128, BO 130, Co 976, Co 62198, Co 86010, Co 86032, Co 89010, Co 93020, Co 97015, Co 98008, Co 0118, Co 0240, Co 06037, NB 94-545, CoA 93082, CoA 09321, C 81615, CoH 70, CoJ 84291, CoM 9217, MS 6847, CoN 91132, CoOr 03152, CoOr 05546, CoPant 84214, CoPant 90224, CoS 8119, CoS 8436, ISH 228, ISH 306, CP 52-1 and CP 52-68
Very high propensity (151): Co 617, Co 775, Co 1148, Co 1307, Co 7314, Co 7706, Co 7717, Co 7915, Co 8208, Co 8209, Co 8210, Co 8340, Co 8316,Co 8371, Co 85002, Co 86011, Co 87023, Co 87267, Co 88028, Co 88013, Co 88025, Co 89003, Co 89029, Co 89036,Co 90018, Co 92002, Co 92007, Co 92008, Co 92013, Co 92006, Co 93003, Co 97009, Co 98006, Co 2000-10, Co 0238, Co 0331, Co 05010, Co 06033, Co 06035, Co 06036, HR 83-144, HR 83-65, 69 A 591, CoA 7602, CoA 90081, CoA 07321, CoBln 04174, C 79218, CoC 8001, CoSi 6, CoC 85061, CoH 12, CoH 13, CoH 14, CoH 15, CoH 56, CoH 92, CoH 98, CoH 99, CoH 104, CoH 106, CoH 110, CoH 119, CoH 128, CoH 133,CoH 7803, CoJ 46, CoJ 80, CoJ 83, CoJ 87, CoJ 88, CoJ 89, CoJaw 70, CoLk 8002, CoLK 8102, CoLK 94184, LG 72115, LG 72120, LG 99122, LG 99190, LG 01014, LG 01030, LG 02100, LG 04602, LG 04605, CoM 6806, CoM 9206, CoM 9220, CoN 98133, CoN 05071, CoN 05072, CoN 07072, CoP 06436, BO 91, BO 92, BO 108, BO 109, BO 89, BO 139, BO 141, BO 146, BO 147, BO 32, CoPant 88220, CoPant 84212, CoPant 90223, CoPant 92227, 85 R 186, 97 R 401, CoS 510, CoS 767, CoS 8408, CoS 88216, CoS 90265, CoS 90269, CoS 91269, CoS 92263, CoS 93278, CoS 95255, CoS 96260, CoS 96275, CoS 97261, CoS 99259, CoS 07231, UP 0097, UP 9530, CoSe 92423, CoSe 95423, CoSe 95436, CoSe 96436, CoSnk 03-44,CoSnk 05-103, CoV 89101, CoV 92102, CoV 94101, ISH 1, ISH 41, ISH 43, ISH 50, ISH 69, ISH 100, ,ISH 101, ISH 150, ISH 229, ISH 287, CoL 9, CoL 29, CP 44-101, CP 61-23, SP 80-1842 and NCO 310

Table 3. Eigen value and 5 of total variance for principal components

Principal component	Eigen value	Total variance	Cumulative Eigen value	Cumulative Per cent
PC 1	4.847	28.512	4.847	28.51
PC 2	2.114	12.432	6.961	40.94
PC 3	1.746	10.269	8.707	51.21
PC 4	1.405	8.267	10.112	59.48
PC 5	1.183	6.956	11.295	66.44
PC 6	0.965	5.677	12.260	72.11
PC 7	0.921	5.42	13.181	77.53
PC 8	0.784	4.61	13.965	82.14
PC 9	0.656	3.857	14.621	86.00
PC 10	0.588	3.458	15.209	89.46
PC 11	0.526	3.096	15.735	92.55
PC 12	0.480	2.824	16.215	95.38
PC 13	0.333	1.957	16.548	97.33
PC 14	0.235	1.384	16.783	98.72
PC 15	0.149	0.877	16.932	99.60
PC 16	0.057	0.335	16.989	99.93
PC 17	0.012	0.07	17.001	100.00

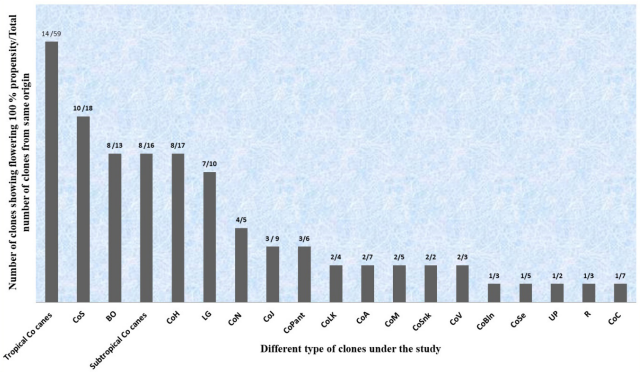

Fig. 2. Origin of sugarcane clones showing 100% flowering propensity

explained 75.9% of the variability, are the most significant, with PC1 being the most important due to its focus on leaf-related parameters (Sumbele et al. 2021). Alemu et al. (2022) reported 75.63% of the total variation accounted by

Table 4. Trait contribution to Principal components and total contribution to PC1 and PC 2

Characters	PC1	PC2	PC3	PC4	PC 5	Total contribution to PC 1 and PC 2
Flowering Propensity%	2.31	2.52	0.76	0.14	35.08	2.37
No of days to form visible node	7.61	3.52	2.04	0.64	0.81	6.37
Stalk length at induction period	12.78	1.47	4.86	2.97	0.20	9.34
Stalk diameter at induction period	11.21	3.24	1.77	3.13	1.43	8.79
No of nodes at induction period	8.79	0.82	8.47	3.46	6.82	6.37
Number of tillers at induction period	0.21	9.19	1.49	0.45	27.74	2.94
Single Cane Weight (kg) at maturity	11.42	3.01	0.21	8.02	0.19	8.87
Number of leaves at induction period	0.06	8.16	2.32	43.74	0.00	2.52
Leaf length at induction period	2.79	0.88	9.68	0.44	15.36	2.21
Leaf width at induction period	5.84	10.83	6.53	6.90	1.23	7.35
SPAD at induction period	0.00	1.73	2.53	9.02	1.90	0.53
Leaf area at induction period	5.10	21.89	3.42	9.45	3.48	10.20
Stalk length at maturity	11.33	1.28	7.81	0.00	0.49	8.27
Stalk diameter at maturity	10.24	1.17	3.28	5.22	0.09	7.48
Brix at maturity	4.24	16.36	16.40	1.64	3.19	7.92
Pol% at maturity	5.21	13.75	17.81	1.04	2.00	7.80
Wax at maturity	0.87	0.18	10.59	3.77	0.03	0.65

were considered as major and the principal components whose eigenvalues were below the unity were usually not considered. The Eigenvalues of major principal components varied from 4.847 (PC1) to 1.183 (PC 5). The first two major principal components explained 40.94 percent of the variation. In a similar study, Ong'ala et al. (2016) reported that among the 19 traits studied, the PCA identified only 10 traits, viz., germination counts at 30 and 45 days after planting, tiller counts at three, five and seven months after planting, brix at 12, 13 14,15,16 months after planting and population, contributed to 80.8% of variations. The analysis revealed that the first four principal components, which together the first three categories while studying the morphological diversity of sugarcane (*Saccharum officinarum* L.) genotypes at Finchaa Sugar Estate, Ethiopia. The study aimed to assess the genetic diversity of 196 sugarcane genotypes. Using agro-morphological trait data and an eigenvalue threshold of ≥1, the top five principal components in the PCA accounted for 81.74% of the total variation (Tolera et al. 2023). In the recent study, principal component analysis of BMC clones, considering twelve traits with a cumulative variance of 81.67%, distilled these traits into three principal components. Similarly, for BM clones, twelve traits with a cumulative variance of 87.88% were also reduced to three

main components (Venkatarayappa et al. 2024).

The first principal component explained 28.51% of the variation, which was mainly contributed by cane yield contributing traits viz., plant height at 180 days after planting (12.78%), single cane weight (11.42%), stalk length at 360 days (11.33%) and cane diameter (10.24%). The second principal component described 12.43 percent of the variation determined by moistly the physiological triats like leaf area (21.89%) and leaf width (10.83%). The third principal component explained (10.27%) of the variation contributed by sugar traits viz., sucrose% (17.81%), brix (16.40 %) and wax (10.59) while the fourth principal component explained 8.27% of the variation given by a number of leaves. The fifth principal component explained 6.96% of the variation provided majorly by flowering propensity (35.08%), tillers at 180 days after planting (27.74%) and leaf length (15.36%) (Table 4). It was noted by Rakesh et al. (2019) that stalk height and stalk girth were found to be the most effective variables contributing 28.64 and 17.98%, respectively, for PC1, whereas cane yield (37.69%), single cane weight (25.98%) and plant height (10.49%) were best explained by PC2. Similarly, internode length, the number of internodes, single cane weight, the volume of juice and recovery were effective variables for PC3 with a contribution of 27.53, 23.39, 22.35 and 16.42%, respectively in sugarcane varieties cultivated in Northern Karnataka.

The total contribution of given traits in explaining the variations retained by the first two principal components was estimated as per Kassambara (2017). Considering the variation of the variables being uniform, the expected *per se* value would be 5.88%. In the present study eleven variables viz., leaf area, plant height at 180 days after plating, single cane weight, cane thickness at induction period, stalk length at 360 days after planting, brix%, sucrose%, cane diameter at 360 days after plating, leaf width, number of nodes at inductive phase of flowering and number of days required to form visible internode contributed higher than the expected *per se* variability in PC 1 and PC 2 (Table 3).

The association of traits among the first two major principal components was utilized to construct a bi-plot graph. Biplot can be used to observe the character relationship and the trait profiles of the genotypes (Fig. 3). When two vectors form an acute angle then the characters representing those two vectors are considered to be positively correlated. Similarly, the characters whose vectors form right angles are known to be not correlated. For those characters whose vectors for obtuse angle are said to be in negative correlation in the present study, flowering propensity was positively correlated with no. of days required for node formation. The length of the vector of a trait indicates the extent to which the trait is represented in the bi-plot. The short vector depicts the lesser variation among the genotypes studied. This may also be due to a

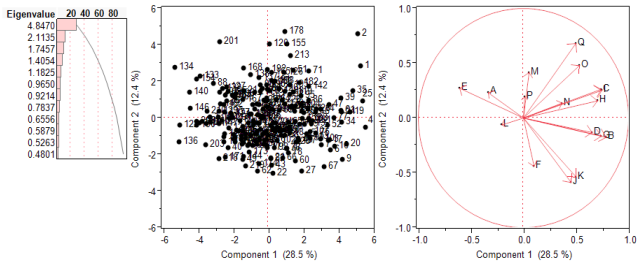

Fig. 3. Projection of the variables on the Principal components 1 and 2. Where, A=flowering propensity; B =Stalk length at induction stage =Cane thickness at induction stage ; D = No of nodes at induction stage; E=No of days to form visible node; F=Number of tillers at induction stage; G=Stalk length at maturity; H=Cane thickness at maturity; I=Cane weight at maturity; J=Brix% at 360 days; K=Sucrose% at 360 days; L=Wax; M=No. leaves at induction stage; N=Leave length at induction stage ; O=Leaf width at induction stage; P=SPAD value at induction stage ; Q=Leaf area at induction stage

weak correlation of particular traits with others (Yan and Foregeau-Reid 2018).

The results of the correlation analysis revealed that flowering propensity was positively correlated with the number of days required for visible node formation (Fig. 4). However, none of the traits measured during the flowering induction period or at maturity showed a positive correlation with flowering propensity. Instead, flowering propensity was significantly and negatively correlated with stalk length, cane diameter, and number of nodes during the induction period, as well as with stalk length and sucrose content at maturity. This suggests that other factors may be influencing flowering propensity, and further investigation is needed to identify the factors that positively affect flowering propensity in sugarcane. Sumbele et al. (2021) found significant and positive correlations in the sugarcane germplasm collection from Cameroon between plant height and stalk height, relative leaf area and leaf width, relative leaf area and leaf length, internode thickness and leaf width, relative leaf area and internode thickness, as well as relative leaf area and internode length. The number of days required for mode formation showed negative and significant inter-correlation with stalk length, stalk diameter, number of nodes and number of tillers at induction period and stalk length, stalk diameter, cane weight brix%, and sucrose% at maturity. It showed an insignificant positive correlation with wax, number of leaves and SPAD value taken at the induction period. Inter-correlation among different traits, number of millable stalks, cane length, cane thickness and number of internodes per stalk and their highly positive association with sugarcane yield was reported earlier by Yahaya et al. (2009). Kumar and Kumar (2014), while studying character association among sugarcane genotypes, observed that the cane yield had a positive significant correlation with germination percentage, number of millable canes, number of stools/plants, cane thickness and number of green leaves

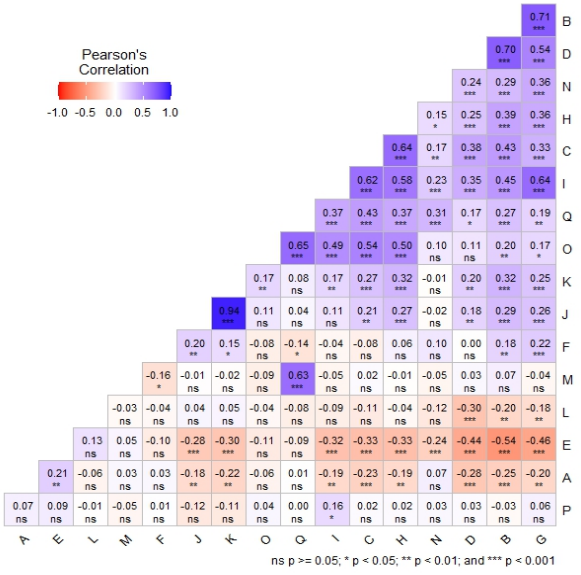

Fig. 4. Correlation analysis of traits with flowering propensity in sugarcane. Where, A=flowering propensity; B =Stalk length at induction stage;C =Cane thickness at induction stage; D=No of nodes at induction stage; E=No of days to form visible node; F=Number of tillers at induction stage; G=Stalk length at maturity; H=Cane thickness at maturity; I=Cane weight at maturity; J=Brix % at 360 days; K=Sucrose % at 360 days; L=Wax ; M=No. leaves at induction stage; N=Leave length at induction stage ; O=Leaf width at induction stage; P=SPAD value at induction stage ; Q=Leaf area at induction stage

and positive but non-significant correlation with the top weight. Further, they reported the negative correlation between cane yield and brix value. Khan et al. (2019), while studying morphological and quality traits in sugarcane, reported that brix% and sucrose% were positively and highly significantly correlated. In a study involving 29 genotypes germinating in a glasshouse and evaluated in field conditions alongside two local checks, PCA and correlation analysis revealed significant correlations among plant height, cane length, internodal length, and tiller number (Saleem et al. 2023).

Identification of diverse parents

Scatter plots showed redundancy in the materials taken for the study (Fig. 5). However some genotypes are more diverse from each other as they were spread over the scatter plot. The genotypes Co 8371 (G1), MS 68/47 (2), Co 86010 (G25), CoM 0265 (G 19), Co 98010 (G 20), Co 86002 (G 9), Co 7204 (G67), Co 62198 (G27), Co 98014 (G60), CoLk 94184 (G22), CoJ 89 (G203), LG 99190 (136), BO 92 (G146), CoS 87216 (G140), LG 72120 (G134), ISH 101 (G201), Co 8209 (G178), 97 R 401 (G213), Co 92006 (G71), CoC 671 (G4), ISH 229 (G155) and Co 94008 (G168) were present at distance from other genotypes with respect to PC1 and PC2 and hence they were considered as more diverse. The information thus obtained from the analysis could be utilized to formulate the appropriate crossing scheme to develop clones of the best commercial

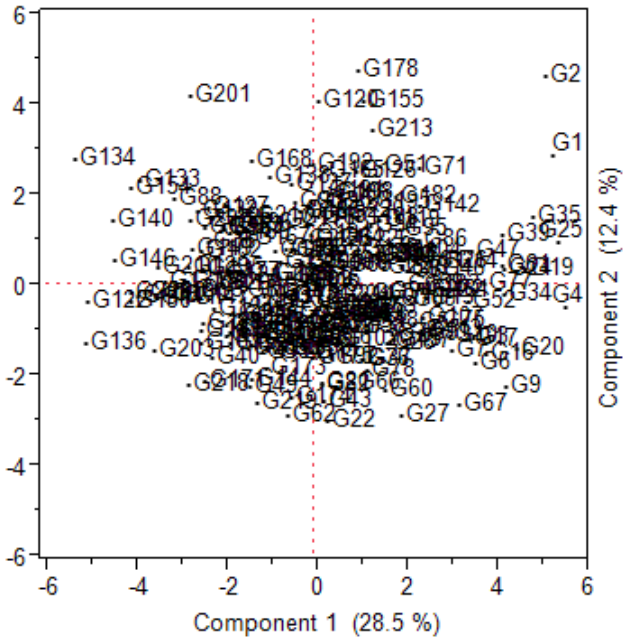

Fig. 5. Projection of the genotypes on the principal component 1 and 2

merits, suitable for cultivation in different environments.

When our objective is to get a good number true seeds, we can go for involving intensive flowerers in the crossing program. Co 8209 (G178) and 97 R 401 (G213) from the first quarter, CoLk 94184 (G22) from the second quarter, CoJ 89 (G203) and LG 99190 (G136) from the third quarter and LG 72120 (G134) from the fourth quarter were found with 100% flowering propensity (Table 5). However, it is observed from earlier work that when the intensive flowerers are used as parents in the hybridization, most of the progenies are found to be flowering ones, which are not desired in commercial varieties. However, the resulting population will likely exhibit a range of flowering propensities from low to high. Therefore, it is essential to identify recombinant progenies by raising a large population that combines shy flowering with desirable economic traits, which can then be advanced for varietal development. Non-flowering genotypes may be obtained by using the parents like CoM 0265 (G19), CoC 671 (G4), Co 98010 (G 20) Co 98014 (G60) and Co 7201 (G67). By selecting genotypes from different quarters of scatter plots and effecting crosses among them may yield superior progenies with diverging genetic backgrounds. Considering other economic traits, including resistance to biotic and abiotic stress, these clones may be utilized in the crossing program to have a greater number basal population for varietal selection or true seed production for commercial cultivation of sugarcane. Diversity analysis of 31 sugarcane accessions for identifying diverse clones, including two local checks, identified four main groups based on morpho-physiological traits. Each group was further divided into two subgroups to reveal varying degrees of similarity among the

Table 5. Possibles exploitation of diverge sugarcane parents for sugarcane improvement.

Parents	Position of Quarter in scatter plot	Flowering propensity	Pollen fertility	Economic characters which can be exploited
Co 8371 (G1)	1	86.90	35.70	Smut and drought tolerance
MS 68/47 (2)	1	77.20	59.71	Smut and red rot resistance
Co 86010 (G25)	1	69.44	37.40	Drought and smut tolerance
CoM 0265 (G 19)	1	33.18	21.12	Drought and smut tolerance
Co 8209 (G178)	1	100.00	39.10	Drought tolerance
97 R 401 (G213)	1	100.00	49.96	Adaptability to wide-row planting
Co 92006 (G71)	1	90.00	8.40	Smut tolerance
ISH 229 (G155)	1	100.00	53.00	Smut resistance
CoC 671 (G4)	2	14.65	37.89	High sucrose content
Co 98010 (G 20)	2	40.38	42.10	Stability over varied environments
Co 86002 (G 9)	2	57.27	56.20	Smut tolerance
Co 7204 (G67)	2	19.05	0.00	Early high sucrose accumulation
Co 62198 (G27)	2	78.20	65.00	Smut resistance
Co 98014 (G60)	2	21.82	32..96	Early high sucrose accumulation
CoLk 94184 (G22)	2	100.00	18.77	Red rot resistant
CoJ 89 (G203)	3	100.00	20.45	High cane yield
LG 99190 (G136)	3	100.00	17.90	High sugar
BO 92 (G146)	4	84.85	53.80	Red rot resistant
CoS 87216 (G140)	4	60.00	57.00	Resistant to smut, wilt and early borer
ISH 101 (G201)	4	92.06	48.00	Moderately resistant to red rot
Co 94008 (G168)	4	51.57	71.21	Smut, drought and salinity tolerance

*Parents with less than 20% pollen fertility may be utilized as safe female, 20-40 as female, 40-60 as both female and male, 60-80 as males and more than 80% as strong male in the crosses

accessions (Saleem et al. 2023).

The clones from the breeding centers located in the subtropical zone were found to flower early in the season and have high flowering propensity and vice versa. Among the different characters studied, days to form visible internode had a positive correlation with flowering propensity. Leaf area, stalk length and stalk diameter during the induction period and stalk length during maturity contributed maximum to the total diversity. Among the 17 variables studied 11 contributed higher than the expected *per se* variability in PC 1 and PC 2, which explained the 40.94% of the variation. Diverse parents with very high flowering propensity identified in the study may be utilized to effect crosses in order to get assured and profuse seedling production. The study's findings offer insights into the factors affecting sugarcane flowering, which can help create more effective breeding programs and ultimately boost sugar production.

Authors' contribution

Conceptualization of research (AAD); Designing of the experiments (AAD, VS); Contribution of experimental materials (AAD); Execution of field/lab experiments and data collection (AAD, RA); Analysis of data and interpretation (AAD, RA, CP); Preparation of manuscript (AAD, RA, CP).

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