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RESEARCH ARTICLE

Studies on association of coefficient of coancestry with progeny performance in sugarcane

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Abstract:
The utilization of superior parental lines and identification of superior families enhance the genetic gain in sugarcane. To identify the superior parental lines and superior progenies, 1889 progenies derived from twenty crosses involving genetically diverse historical parents were evaluated for juice quality and yield attributing traits.The historical parental lines were selected based on coefficient of coancestry from the tropical and subtropical parents maintained at National Hybridization Garden. Based on progeny performance, families of Co 99006 × CoSe 92423 and Co 86032 × 85R186 were found superior for number of millable canes, , Co 86032 × 85R186 and Co 8371 × CoT 8201 for cane thickness and CoSe 95422 × Co 775 and Co 8371 × CoV 92102 for sucrose content. Parental lines such as Co 86002, Co 99006 and CoLk 98184, Co 775, 85R186 and BO 130 were identified for HR Brix; Co 419 and Co 89010, CoS 510, CoV 92102 and CoSe 92423 for cane thickness; and CoLk 94184, BO 91 and BO 32 for number of millable canes. The estimates of coefficient of coancestry was negatively correlated with HR Brix and cane thickness suggesting that parental cross combination with lesser value of coefficient of coancestry or inbreeding coefficient resulted in produce the heterotic progenies. This study based on the historic parental lines selected based on the coefficient of coancestry and inference limited to only to this experimental material. The evaluation of families derived from the population parental cross combination and parental lines in replication family block design permits the estimation of BLUP based breeding values and helpful in selection of superior parental lines and superior progenies.

Keywords: Coefficient of coancestry; Inbreeding coefficient; HR brix; Number of millable canes

Introduction

Sugarcane is a C_4 crop with high biomass production potential anda pillar of age old agro based rural economy in India. Sugarcane serves as raw material for production white sugar, ethanol and cogeneration, besides the traditional and indigenous sweetners such as jaggery and khandsari (Canilha et al. 2012; Dotaniya et al. 2016; Singh et al. 2018). Sugarcane cultivated in 5.06 million hectors in India during 2019 with annual production of 405.42 million tonnes and productivity of 80.10tonnes/hectors (FAOSTAT, 2020). India's requirement of sugar by 2050 is projected around 48 million tonnes of sugar with projected production of 550 million tonnes of sugarcane (ICAR, 2015) and considering the biotic and abiotic stresses, it is required to evolve the superior varieties combined with high cane yield and sucrose content. Therefore, identification and utilization of elite and superior breeding parental lines to enhance the genetic gain for cane yield and sucrose content.

Sugarcane is a complex polyploid aneuploid genome and its genome derived from interspecific and intergeneric hybridization (Raghavan, 1952; Bremer, 1962, Srinivasan et al. 1987; Premachandran et al. 2011). During varietal selection process, the elite plant types in F_1 population are selected and propagated through clonal propagation. Modern sugarcane varieties contains 6-12 copies of chromosome, highly heterozygous combined with gametic sterility hinders the selection of elite of parental lines for hybridization programmes. The average performance of progenies depends on the breeding value of the parents and the estimation of breeding values from the pedigree requires the estimate of coefficient of coancestry (Henderson 1984). Coefficient of Coancestry/parentage of two parents is defined as probability of two gametes from each parents containing alleles are identical by descent. It is identical with inbreeding coefficient of the progeny. Coefficient of Coancestry ranges from '0' to '1'; where '0' indicate absolute heterozygosity and '1' inferred as absolute homozygosity (Falconer, 1960; Crow and Kimura 1970). The selection of parental combination based on coefficient of coancestry help to produce the superior heterotic progenies and helpful to enhance the genetic gain.

ICAR-Sugarcane Breeding Institute, Coimbatore mandated with development of superior sugarcane varieties for cane yield and sucrose content combined with tolerance to biotic and abiotic stresses, suitable for cultivation in tropical, subtropical and coastal India. This institute evolved more than 3000 'Co' varieties, maintaining more than 600 parents in National Hybridization Garden, effecting more than 600 crosses and supplying more than 25 kg of fluff to different sugarcane research stations in India and evaluating more than twenty thousand seedlings in ground nursery (Nair 2008). In this study, coefficient of coancestry of the historic and popular parental lines which are commonly used as parents in tropical and subtropical crosses were used in the hybridization programmes. The seedlings from these crosses were raised in ground nursery and evaluated for the progeny performance. We identified the superior parental combinations and superior parental lines for cane yield attributing traits and sucrose content. Further, evaluation of families derived popular parental lines in replicated trials and parents permits the estimation of breeding values and identification of superior parental lines, certainly helps in enhancing the genetic gain in sugarcane.

Materials and Methods

The 'Coefficient of coancestry' was estimated for twenty one crosses as described by Falconer (1960). Sugarcane genotypes, which were popularly used as male and female parents for effecting the tropical and subtropical crosses in National Hybridization Garden were used in the study. The estimate of 'Coefficient of Coancestry' for 20 crosses is given in table 1 and the crosses were effected during 2014-15 in National Hybridization Garden. A total of 1888 progenies belongs to 20 families were raised in ground nursery during 2015-16 at ICAR-Sugarcane Breeding Institute, Coimbatore with a spacing of 90 × 30 cm and recommended package of practices were adopted.

Table 1: Estimates of 'Coefficient of coancestry' selected cross combinations

Sl No	Crosses	Coefficient of coancestry
1	CoH 99 × CoS 8436	0.37
2	Co 98010 × Co 89003	0.18
3	MS 68/47 × Co 0314	0.18
4	Co 1148 × BO 91	0.80
5	Co 99006 × Co 94008	0.37
6	Co 7314 × 85R186	0.26
7	Co 8371 × Co 775	0.27
8	Co 0120 × CoPant 97222	0.36
9	Co86002 × BO 130	0.60
10	Co 86032 ×85R186	0.32
11	Co 8371 × CoT 8201	0.20
12	Co 0240 × CoS 88216	0.27
13	Co 8371 × CoV 92102	0.24
14	BO91× BO32	0.82
15	Co 89010 × CoSe 92423	0.88
16	Co 8371 × Co 94008	0.19
17	Co 7314 × Co 0233	0.44

Table 1 Contd...

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18	Co 86010 × CoSe 92423	0.37
19	BO 91 × BO130	0.46
20	Co 99006 × 85R186	0.29

Recording of observations

Number of millable canes, cane thickness and HR Brix were recorded at 360 days during November 2016 in all the progenies. Progenies having NMC ≥5 /clump, cane thickness ≥2.5 cm and HR Brix ≥19 were considered as selectable progenies. The selection differential was estimated as deviation of mean of selectable progenies from the population mean in the particular cross.

Statistical analysis

Statistical analysis was done by using ggplot2 package of 'R' software (https://www.r-project.org/). Significance of family mean and population means of parental lines tested using 't' test assuming unequal variance'. The skewness and kurtosis was estimated by using SPSS 16.

Table 2. Selection differential for number of millable canes (NMC), Cane Diameter and HR Brix in different familiesin ground nursery

Sl No	Families	N	NMC			Cane Diameter			HR Brix		
			X_0	X_1	S	X_0	X_1	S	X_0	X_1	S
1	Co 99006 × CoSe 92423	50	6.44±3.35	9.45±3.59	3.01	2.60±0.02	2.89±0.04	0.29	20.7±0.88	21.63±3.36	0.93
2	Co 86032 × 85R186	262	4.79 ±0.50	7.64±1.36	2.85	2.60±0.21	3.14±0.02	0.54	19.2±0.39	20.46±0.64	1.26
3	CoSe 95422 × Co 775	52	6.54±2.72	9.23±2.50	2.69	2.20±0.02	2.66±0.02	0.46	15.69±1.86	20.00±1.75	4.31
4	Co 8371 × CoT 8201	270	7.14±1.50	9.62±0.02	2.48	2.40±0.01	2.94±0.46	0.54	17.37±1.50	20.10±2.28	2.73
5	Co 89010 × CoSe 92423	110	4.25±0.57	6.71±1.87	2.46	2.68±0.01	2.8±0.03	0.12	17.68±1.13	20.28±1.02	2.60
6	Co 8371 × CoV 92102	260	6.03±0.94	8.41±1.02	2.38	2.86±0.01	3.01±0.09	0.15	17.36±0.48	20.23±0.78	2.87
7	Co 0240 × CoS 88216	110	6.53±1.35	8.83±4.40	2.30	2.54±0.01	2.78±0.03	0.24	19.45±0.64	20.69±0.36	1.24
8	Co 97015 × Co 1148	50	7.08±4.28	9.38±4.07	2.30	2.31±0.03	2.83±0.5	0.52	19.18±1.07	21.38±0.76	2.20
9	Co 419 × CoS 510	72	6.78±2.47	9.05±2.20	2.27	2.72±0.03	2.93±0.12	0.21	19.72±1.00	21.23±3.20	1.51
10	Co 8371 × Co 775	436	6.82±0.82	9.01±1.89	2.19	2.39±0.01	2.84±0.09	0.45	20.96±0.40	21.70±2.68	0.74
11	CoLk 94184 × BO 130	66	10.36±6.98	12.52±5.98	2.16	2.13±0.01	2.54±0.01	0.41	19.07±3.60	20.88±2.50	1.81
12	Co 86002 × BO130	562	6.20±0.48	8.13±4.98	1.93	2.39±0.01	2.72±0.02	0.33	19.7±0.26	20.88±1.49	1.18
13	BO 91 × BO 32	120	8.33±1.81	9.70±2.20	1.37	2.16±0.01	2.63±0.02	0.47	17.68±0.56	20.25±0.30	2.57

N: size of family; X_0: Family mean; X_1: Selectable progeny mean; S = Selection differential ($\times_1$- $\times_0$)

Results and Discussion

a) Family performance

Estimation of genetic gain requires selection intensity, which is corresponds to 10 percent selection differential (Miller et al. 1978). The genetic gain and selection differential are positively correlated and higher values of selection differential are desirable. The highest selection differential was observed for number of millable canes in families of Co 99006 × CoSe 92423 and Co 86032 × 85R186 (Table 2). The families of Co 86032 × 85R186 and Co 8371 × CoT 8201 recorded the highest selection differential for cane thickness. For HR Brix content, the highest selection differential was recorded by CoSe 95422 × Co 775 and Co 8371 × CoV 92102 indicating the presence good genetic variations in the families evaluated under this experiment.

Families derived from common female and male parents were pooled and the best performing parental lines for NMC, cane diameter and HR Brix were identified based on progeny performances. Significance of parental line performances was tested using 't' test assuming unequal variances. From this study, Co 86002, Co 99006 and CoLk 98184 were identified as best female parents for HR Brixor sucrose content (Table 3). Families of Co 86002 as female parent recorded significantly higher mean sucrose content (19.46%) as compared to population mean (19.13%). Similarly, Co 99006 derived families recorded average of 20.70% of sucrose content as compared to population mean. Families derived from the crosses of BO 91 and CoSe 95422 recorded HR Brix value of 17.62 and 15.69, significantly lower than the population mean. Among the male parents (Table 4), Co 775, 85R186 and BO 130 were identified as the best male parents based on mean HR Brix values of families. Family mean of Co 775 and BO 130 crosses recorded 20.24% and 19.65% of HR Brix significantly higher than population mean. Family mean of crosses involving BO 32 (17.68), CoT8201 (17.37) and CoV 92102 (17.41) as male parents recorded the significantly lower mean for HR Brix.

With regards to cane thickness, families of crosses involving Co 419 and Co 89010 as female parent

Table 3. Identification of best female parents based on family performance

Sl No	Families	Family size	Progeny mean		
			NMC	Cane Diameter (cm)	HR Brix
1	BO 91	122	8.73^{**}	2.18^{**}	17.62^{**}
2	Co 0240	142	6.47^{ns}	2.55^{ns}	19.45^{**}
3	Co 419	102	6.35^{ns}	2.73^{**}	18.88^{ns}
4	Co 7219	40	5.22^{**}	2.68^{ns}	19.28^{ns}
5	Co 8371	986	6.69^{ns}	2.53^{ns}	18.93^{ns}
6	Co 86002	818	5.85^{**}	2.47^{ns}	19.46^{**}
7	Co 89010	106	4.40^{**}	2.69^{**}	18.39^{ns}
8	Co 97015	46	6.86^{ns}	2.37^{ns}	19.18^{ns}
9	Co 99006	48	6.44^{ns}	2.60^{ns}	20.70^{**}
10	CoLk 94184	60	10.67^{**}	2.13^{**}	19.28^{ns}
11	CoSe 95422	56	6.54^{ns}	2.20^{**}	15.69^{**}
	Mean	1888	6.42	2.47	19.13

recorded the higher mean values for cane thickness as compared to the population mean. The families of from Co 419 recorded the cane diameter of 2.73 cm and Co 89010 recorded 2.69 cm, significantly higher than the populations mean (2.47 cm). The progenies of crosses involving BO 91 (2.18 cm), CoLk 94814(2.13 cm) and CoSe 95422 (2.20 cm) as male parents recorded the lower mean values for cane thickness. Among male parents, progenies involving CoS 510, CoV 92102 and CoSe 92423 as male parents recorded the significantly higher mean values for cane diameter. The family mean for cane thickness for CoS 510 was 2.72 cm, CoV 92102 was 2.84 cm and CoSe 92423 was 2.68 cm significantly higher than population mean (2.66 cm). The lowest mean values for cane thickness was observed in progenies derived from crosses involving BO 32 (2.18 cm), BO 130 (2.37 cm) and Co 1148 (2.37 cm) as male parents.

Number of millable canes is positively correlated with cane yield. From this study, subtropical male parents such as CoLk 94184 and BO 91 are highly contributing to the number of millable canes. The progenies derived crosses involving CoLk 94184 and BO 91 as female parents recorded the significant higher mean millable canes of 10.67 and 8.73 respectively. The progenies of male parent such as BO 32 and Co 7201 significantly contributing to the number of millable canes and their progenies recorded the significantly higher mean NMC of 8.56 and 7.20 as compare population mean.

b) Correlation between juice quality and cane yield attributing traits with coefficient of coancestry

The relationship between coefficient of coancestry over juice quality and cane yield related parameters by regression analysis of HR Brix, cane thickness and number of millable canes on Coefficient of Coancestry (Fig 1). The HR Brix value of both the family mean (-0.4582) and selectable progeny

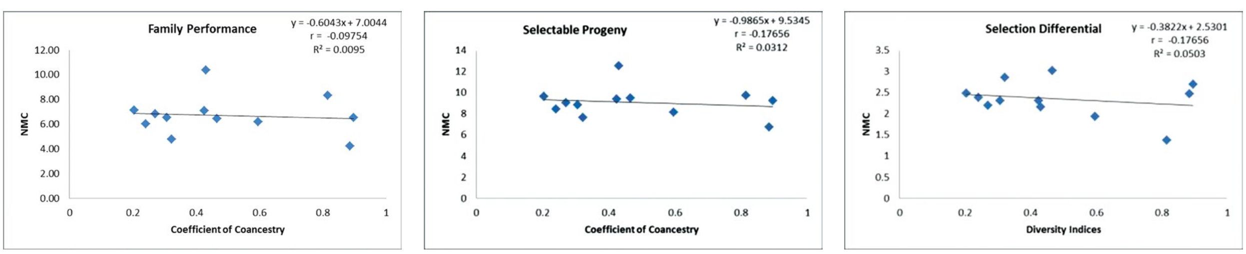
Table 4. Identification of best male parents based on family performance

Sl No	Families	Family size	Progeny mean		
			NMC	Cane Diameter (cm)	HR Brix
1	BO 32	116	8.56**	2.18**	17.68**
2	85R186	322	4.87**	2.60^{ns}	19.32*
3	BO 130	598	6.63^{ns}	2.37**	19.65**
4	Co 1148	48	6.87^{ns}	2.37^{ns}	19.18^{ns}
5	Co 62198	44	6.77^{ns}	2.41^{ns}	19.46^{ns}
6	Co 775	504	6.76^{ns}	2.37**	20.24**
7	CoS 510	76	6.78^{ns}	2.72**	19.73^{ns}
8	CoS 88216	108	6.47^{ns}	2.55^{ns}	19.45^{ns}
9	CoSe 92423	184	5.11**	2.68**	18.77^{ns}
10	CoT 8201	266	7.20*	2.41*	17.37**
11	CoV 92102	276	6.03^{ns}	2.84**	17.41**
	Mean	1888	6.42	2.47	19.13

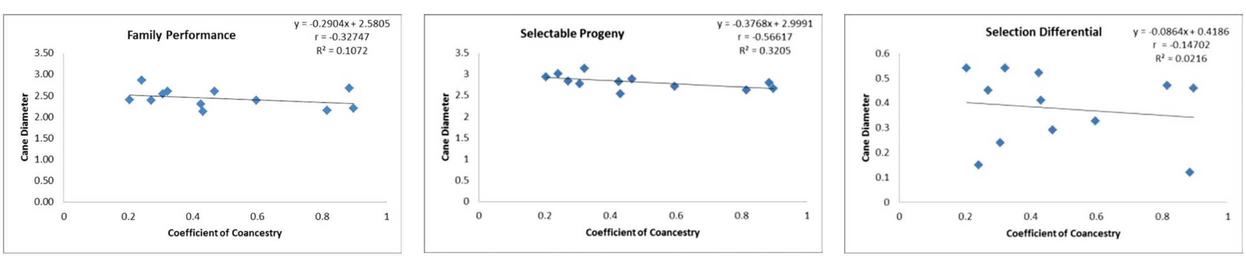
mean (-0.3282) were negatively associated with Coefficient of Coancestry. The correlation between Coefficient of Coancestry and selection differential was moderately high (-0.4892) for HR Brix. Coefficient of Coancestry explains 21% and 10.77% of total phenotypic variability of sucrose content in families and selectable progenies respectively. Similarly, negative association was also observed for cane thickness and Coefficient of Coancestry (-0.5662) in selectable progenies explaining 32.05% of total phenotypic variability. Our studies showed that Coefficient of Coancestry does not show any association for number of millable canes.

C. Skewness and kurtosis

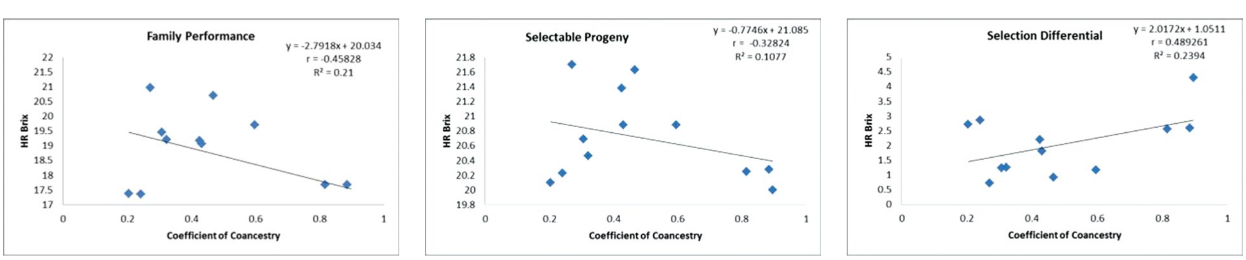
Skewness and kurtosis are third and fourth degree statistics depicts the nature and number of gene action, more powerful than first- and second degree statistics. Kurtosis indicates the relative number of genes controlling the trait under investigation. Shapiro-Wilk's test showed significant deviation from normal distribution for HR Brix, cane diameter and number of millable canes in seedling population derived from diverse crosses. In our studies, the HR Brix showed positively skewed mesokurtic distribution, negatively skewed mesokurtic distribution was observed for cane thickness (Fig 2) and negatively skewed leptokurtic distribution for number of millable canes.



a) Number of millable cane

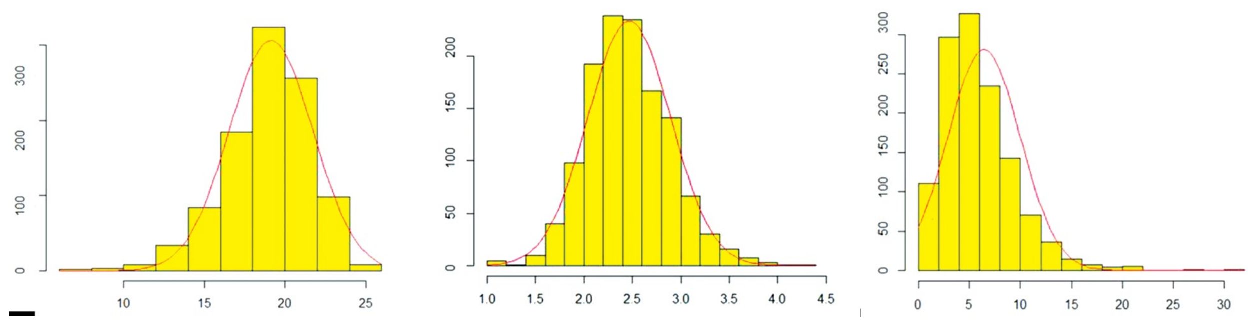


b) Cane diameter



c) HR Brix

Figure 1. Relationship between coefficient of coancestry with number of millable cane (NMC), cane diameter and HR Brix in ground seedlings derived from diverse crosses.



HR Brix　　Cane diameter　　Number of millable canes

Figure 2. Frequency distribution and estimates of skewness and kurtosis for HR Brix, cane diameter and number of millable canes in ground nursery seedlings derived from diverse crosses

Sugarcane is a C_4 crop with high biomass production potential, mainly used in industries as raw material for production of sugar, ethanol and cogeneration. The sugarcane breeding mainly focused on development of superior varieties with high CCS yield combined with tolerance to biotic and abiotic stresses. The selection for CCS yield is focused in advanced breeding trials, early selection strategies mainly focusses on sucrose content (Jackson and Rae 2001) and cane yield attributing traits such as number of millable canes, single cane weight, stalk length, which are having high correlation index with cane yield (Miller et al. 1978). The progeny performance depends on the breeding values of parental lines and pedigree based breeding values estimated from coefficient of coancestry (Henderson 1984). In our studies, the coefficient of coancestry was estimated for 21 cross combination involving popular and historical parental lines, often frequently used in the tropical and subtropical crosses in India.

The average performance of families depends on the combining ability effects or breeding value of parents (Miller 1977; Wu et al. 1980; Alarmelu et al. 2010; Mbuma et al. 2020) and genetic gain is advantageous through family selection (Zhou and Lichakane 2012; Mbuma et al. 2020). In our studies, it showed the high selection differential of millable canes in families of Co 99006 × CoSe 92423 and Co 86032 × 85R186, cane thickness in families of Co 86032 × 85R186 and Co 8371 × CoT 8201 and, for HR Brix in families of CoSe 95422 × Co 775 and Co 8371 × CoV 92102. The selection differential is a function of selection intensity, directly correlated with genetic gain (Miller et al. 1978) and selection from these families helpful in selecting superior plant types. From our studies, high combining parental lines such as Co 86002, Co 99006 and CoLk 98184 as female parents and Co 775, 85R186 and BO 130 male parents for HR Brix; Co 419 and Co 89010 as female parents and CoS 510, CoV 92102 and CoSe 92423 as male parents cane thickness; and CoLk 94184 and BO 91as female parents and BO 32 and Co 7201 as male parents for number of millable canes. The Utilization of breeding lines with high combining ability helpful in selecting of heterotic plant types from ground nursery (Alarmelu et al. 2010).

The coefficient of coancestry defines the probability of two gametes received from parents are identical by descent. This defines the coancestry of two parents and identical with inbreeding coefficient (Folconer, 1960). The inbreeding coefficient value 'zero' indicates the highest level of heterozygosity or random mating population and that value 'one' suggests homozygous lines (Crow and Kimura 1970). From our studies it showed that coefficient of coancestry was negatively correlated with

HR Brix and cane thickness. It is inferred that parental cross combination with higher value of coefficient of coancestry or inbreeding coefficient resulted in reduced trait values in the progenies for sucrose and cane thickness. The increased inbreeding coefficients or coefficient of coancestry results in the increased level of homozygosity and accumulation of more number of alleles in homzygosity status (Falconer 1960; Crow and Kimura 1970) and produces less heterotic progenies. Therefore, the genetically diverse crosses or cross combinations with smaller value of coefficient of coancestry produces the superior heterotic segregants in progenies for sucrose and cane thickness. The similar results of reduced vigour for yield and juice quality parameters due to inbreeding depression were reported in sugarcane (Ferreira et al. 2005; Azeredo et al. 2015).

Sugarcane progenies are highly heterozygous-heterogenous population and classical genetic analysis is very difficult due to complexity of genome. However, the frequency distribution, estimates of sekewness and kurtosis are other ways of inferring the genetics of the traits. Skewness and kurtosis are third and fourth degree statistics which depict the nature and number of gene action 'and are' more powerful than first- and second degree statistics (Choo and Reinbergs, 1982; Xu, 2010). Kurtosis indicates the relative number of genes controlling the trait under investigation (Robson 1956). Fisher et al. (1932) outlined the theoretical basis of skewness and skewed distribution for a given traits indicates non-additive gene action and influence of environment (Pooni et al.1977; Roy 2000). Positive skewness is caused by complementary gene interactions and negative skewness is caused by duplicate gene interactions (Snape and Riggs, 1975). Complete ambi directional epistasis however produces kurtosis while distributions stays symmetrical around mean (Pooni et al. 1977). From our studies, the Shapiro-Wilk's test showed significant deviation from normal distribution for HR Brix, cane diameter and number of millable canes. Sucrose or HR Brix was positively skewed mesokurtic distribution, negatively skewed mesokurtic distribution for cane thickness and negatively skewed leptokurtic distribution for number of millable canes. It has been demonstrated in other crops and also theoretically inferred that skewed mesokurtic distribution is due to ambidirectional epistatic genes, negatively skewed mesokurtic distribution is due to ambidirectional epistatic genes and negatively skewed leptokurtic distribution is due to fewer genes with major epistatic gene action (Pooni et al. 1977; Roy 2000; Kelker and Kelker 1986).

Conclusion

Genetically diverse crosses based on the Coefficient of Coancestry derived progenies were evaluated for juice quality and cane yield attributing traits. The set of cross combinations and parental lines having high potential for improving the sucrose and yield potential was identified. The correlation of coefficient of coancestry with cane yield and juice quality attributing traits revealed that genetically diverse parental lines produce the heterotic selectable progenies. The frequency distribution, skewness and kurtosis showed significant deviation from the normal distribution and complex gene actions manifesting the traits. However, these studies are based on limited number of historical parental lines and families cannot be generalized for all parental lines. There are many popular parental lines such as Co 86032, Co 0238, Co 05011, Co 0239, Co 11015, CoM 0265, CoVc 14061, Co 12009, Co 06022, Co 10026, Co 0212 and many other parental lines and families are required to evaluate over years and seasons to identify the superior parental lines and superior families. The replicated family block evaluation with inclusion of parental lines permits estimation of BLUP based breeding values of parental lines, which is helpful in selection of superior parental lines and families in sugarcane crop improvement programmes.

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