Received: 28 Nov 2022 | Revised: 21 Jun 2023 | Accepted: 22 Jun 2023

Electronic Journal of Plant Breeding

Research Article

Estimation of genetic variability, character association and path coefficient using sugarcane segregating population

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Abstract
An experiment was conducted to explore variation and the association among 13 sugarcane yield and juice quality attributes through correlation and path coefficient analysis. Phenotypic coefficient of variation (PCV) was found higher than genotypic coefficient of variation (GCV) for all the traits. Moderate to high GCV, PCV along with high heritability and genetic advance were recorded for several agronomic traits, indicated wider range of variability in population. Results showed that cane yield exhibited highly significant positive correlation with CCS yield, number of millable canes, number of tillers, single cane weight, germination per cent, cane height and cane diameter at both genotypic and phenotypic levels. Path analysis revealed that three characters namely CCS yield, sucrose per cent and number of millable canes exerted positive direct effect on cane yield at both the levels. CCS yield exerted highest indirect effect on cane yield via number of millable canes, single cane weight and number of tillers on cane yield. These indirect effects could be the major cause of concern for the positive correlation of these characters with cane yield thus should be considered at the time of selection.

Keywords: Heritability, Correlation, Direct effect, Indirect effect, *Saccharum*, Selection criterion

INTRODUCTION

Sugarcane is a perennial, monocotyledonous member of the genus *Saccharum,* tribe *Andropogoneae*, sub-tribe *Saccharineae* and family Poaceae. There are three cultivated species namely *Saccharum officinarum* (noble cane, 2n=80), *Saccharum barberi* (2n = 82-124), and *Saccharum sinense* (2n= 111-120) and two wild species *viz. Saccharum spontaneum* (2n = 40-128) and *Saccharum robustum* (2n= 60-194) (Gupta *et al*., 2010). Sugarcane is widely cultivated in India after nobilization because of high sucrose content and adaptability to adverse environmental conditions (Tabassum *et al.,* 2021). Sugarcane cultivation occurs in most of the states of India. Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Bihar and Andhra Pradesh are the major producer (Anonymous, 2018). All plant parts of the cane and by-product of sugar industry are useful for various purposes like food, fodder, energy, bio-fuel etc. It is widely cultivated in tropical and subtropical countries for sugar and biomass production and in India it is the main source of sugar production in the form of crystal sugar, *gur* and *khandsari*. Genetic variability is pre-requisite for plant breeders to exercise selection for the improvement of different traits (Gnanasekaran *et al*., 2020). Genotypic and phenotypic coefficients of variation provide a broad idea about the amount and nature of variability present in a population, whereas, heritability estimates are useful in predicting the transmission of characters from the parents to their offspring. Genetic advance as percent of mean along with heritability largely determine the success of selection (Kumar *et al.,* 2021). is the most useful estimate of genetic gain under selection. Higher sugarcane yield with high sucrose content is one of the most important and complex breeding objectives in most of the cane breeding programmes. Being a complicated trait, yield is influenced both directly and indirectly by its numerous components (Priya *et al.,* 2022). The correlation coefficient analysis is used for the identification of characters which are positively correlated with yield, so that one can accumulate optimum combination of these characters in a common genotype. But in order to determine the contribution of various characters towards cane yield it is important to partition the correlation between cane yield and the yield contributing characters into a series of direct and indirect effects depicting the specific forces which are contributing to develop a given correlation between concerned characters (Verma *et al.,* 2021). Further, complex characters can be studied better by knowing the direct and indirect effect of interrelated components through path analysis (Ali *et al.,* 2021). Therefore, the experiment was conducted to assess the genetic variability among the sugarcane genotypes and to decipher the magnitude of relationship among the sugarcane yield and juice quality parameters by measurement of character association path analysis for dividing it into direct and indirect effects.

MATERIALS AND METHODS

The experiment was performed by evaluating 142 sugarcane clones, five check varieties (CoPant 97222, Co 0238, Co S8436, Co J64 and Co S767) along with two parental varieties (Co 1148 and BO 91) in augmented block design II (Federer and Ragavarao, 1975) for two seasons (both plant crops) at Sugarcane Breeding Block, N. E. Borlaug Crop Research Centre, G. B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand. Each entry was allotted to a five-row plot measuring 5.0 m long and row to row spacing was kept to 0.90 m. After that F-test was carried out to test homogeneity of variances over two season (Lal, 2018), pooled analysis of variance was carried out by considering seasons as replication and further correlation and path coefficient analysis was carried out on the data recorded for 13 cane yield and juice quality characters *viz.,* germination per cent (recorded 45 days after planting), number of tillers (thousand per hectare, recorded at 120 days after planting), number of millable canes (thousand per hectare, recorded at 300 days after planting), cane height (m), cane diameter (cm), single cane weight (kg), polarity per cent (used to estimate sucrose per cent), brix per cent, sucrose per cent, purity per cent, commercial cane sugar per cent, cane yield (t/ha) and commercial cane sugar yield(t/ha). Cane yield (t/ha) was calculated by multiplying the number of millable canes per hectare with average cane weight i.e., single cane weight. All these traits were measured at harvesting, i.e., 360 days after planting. Genotypic and phenotypic coefficients of variability were calculated as per the method of Burton and De Vane (1953). Heritability in broad sense (h^2_b) was estimated as per Lush (1949) and genetic advance (GA) was calculated as per Johnson *et al.* (1955). GCV and PCV were categorized as low (0-10 percent), moderate (10-20 percent) and high (above 20 percent) according to Sivasubramanian and Menon (1973), while heritability in broad sense was categorized as low (0-30 percent), moderate (31-60 percent) and high (above 60 percent) as suggested by Robinson *et al.* (1949). Genetic advance as per cent of mean was categorized as low (0-10 percent), moderate (11-20 percent) and high (above 20 percent) as given by Johnson *et al.* (1955). The phenotypic and genotypic correlation coefficients were obtained as per (Johnson *et al.,* 1955) and its significance was tested as suggested by Senedecor and Cochran, 1967. Path coefficient analysis was done according to the procedure given by Wright (1921) and further elaborated by Dewey and Lu (1959). Statistical package used for the estimation was “variability” package (Popat *et al.,* 2020) in R-studio. All the thirteen, cane yield and juice quality characters were considered in path coefficient analysis to estimate their direct and indirect effects. R-stastistical software package, “metan” (Olivoto and L’ucio, 2020) and illustration software “affinity designer” (Anonymous, 2022) were used to draw figures and illustrations.

$$Germination\ \% = \frac{Number\ of\ buds\ germinated}{Number\ of\ buds\ planted} \times 100$$

$$Purity\ \% = \frac{Juice\ Sucrose}{Juice\ Brix} \times 100$$

$$CCS\ \% = [S - (B - S)\ x0.40]\ x0.73$$

Where, S = Sucrose percent in juice and B = Brix percent in juice

$$CCSyield\ (t/ha) = \frac{Available\ sugar(\%)in\ cane \times Cane\ yield\ (t/ha)}{100}$$

RESULTS AND DISCUSSION

Analysis of Genetic Variability: The results of genetic variability parameter are presented in **Table 1**. Moderate PCV (16.760) and GCV (13.962) values with high H^2b (69.398 %) and GAM (23.959 %) were recorded for germination percent. Earlier, Pandey *et al.* (2018) reported moderate GCV and PCV values for germination percent. High PCV (21.200), moderate GCV (16.485) along with high H^2b (60.464 %) and high GAM (26.406 %) were obtained for no. of tillers. Gowda *et al.* (2016) also reported higher PCV with moderate GCV along with high H^2b and GAM for no. of tillers in their experiment. No. of millable canes showed high PCV (22.819), moderate GCV (19.087) with high H^2b (69.968 %) and GAM (32.890 %). For single cane weight, moderate values of PCV (18.883) and GCV (15.438) were recorded with high H^2b (66.840 %) and GAM (26.000 %). Moderate PCV (15.807) and low GCV (9.145) along with moderate H^2b (33.472 %) and GAM (10.900 %) values were obtained for cane height. Similarly, for cane diameter, moderate PCV (13.329) and GCV (10.403) estimates with high H^2b (60.922 %) and moderate value of GAM (16.727 %) were recorded. Similar results had been previously reported by Ranjan and Kumar, (2017) for both cane height and cane diameter.

https://doi.org/10.37992/2023.1402.074

Table 1. Genetic variability parameters studies in sugarcane

S.No.	Characters	GCV	PCV	H^2b (%)	GA	GAM
1	Germination percent	13.962	16.760	69.398	9.753	23.959
2	No of tillers (000/ha)	16.485	21.200	60.464	22.274	26.406
3	NMC (000/ha)	19.087	22.819	69.968	22.196	32.890
4	Single cane weight (kg)	15.438	18.883	66.840	0.292	26.000
5	Cane height (m)	9.145	15.807	33.472	0.234	10.900
6	Cane diameter (cm)	10.403	13.329	60.922	0.383	16.727
7	Brix percent	3.192	4.756	45.051	0.910	4.414
8	Polarity percent	5.331	8.465	39.669	5.463	6.917
9	Sucrose percent	4.829	8.221	34.511	1.109	5.844
10	Purity percent	3.669	7.229	25.761	3.534	3.836
11	CCS percent	6.194	11.084	31.227	0.954	7.130
12	Cane yield	23.541	26.464	79.129	32.449	43.138
13	CCS yield	24.287	27.211	79.666	6.368	44.657

NMC-Number of millable canes, CCS- Commercial cane sugar, GCV-Genotypic coefficient of variation, PCV- Phenotypic coefficient of variation, H^2b- Heritability in broad sense, GA- Genetic advance, GAM- Genetic advance as percent of mean

For brix percent, low PCV (4.756) and GCV (3.192) values with moderate H^2b (45.051 %) and low GAM (4.414 %) were recorded. Tyagi *et al.* (2011) recorded same results of PCV, GCV and GAM for brix percent. Low PCV (8.465) and GCV (5.331) values along with moderate H^2b (39.669 %) and low GAM (6.917 %) were recorded for polarity percent. For sucrose percent, low values of PCV (8.221), GCV (4.829), moderate estimates of H^2b (34.511 %) with low GAM (5.844%) were recorded. Patil and Patel, (2017) observed same results as lower GCV, PCV, GAM and moderate H^2b for this trait. For purity percent, low values of PCV (7.229), GCV (3.669), H^2b (25.76 %) and GAM (3.836 %) were recorded. For purity percent, low values of all the four estimates were also observed previously by Pandey *et al.* (2018). For CCS percent, moderate PCV (11.084), low GCV (6.194), moderate H^2b (31.227 %) and low GAM (7.130 %) were recorded. For cane yield, high PCV (26.464), GCV (23.541), H^2b (79.129 %) and GAM (43.138 %) values were recorded. for CCS yield GCV (27.211), PCV (24.287), H^2b (79.666 %) and GAM (44.657 %) were also recorded high. For these traits, all the four estimates were also observed as high earlier by Anbanandan and Eswaran (2018).

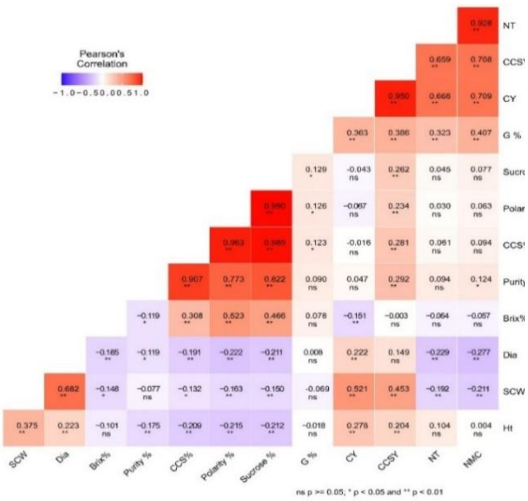
A crucial review of PCV and GCV values revealed that PCV were higher than GCV for all the traits studied and the closeness between GCV and PCV values indicated that the traits are less influenced by the environment. High values of both PCV and GCV were observed for cane yield and CCS yield, indicated that selection might be effective on these characters and their phenotypic expression is a good indication of their genotypic potential. The high H^2b with high GAM was recorded for cane yield, CCS yield, germination percent, no. of tillers, no. of millable canes and single cane weight. It indicated that these traits are governed by additive gene action and least influenced by the environmental effect. Therefore, selection for these characters will be effective for improvement in successive generations. High estimates of H^2b and moderate GAM recorded for cane diameter, also indicated the importance of additive gene action in the inheritance of this trait, but it requires cautious selection to improve this character. Similar results were also reported by Shimelis (2018), Ranjan and Kumar (2017) and Negi *et al.* (2017) for cane yield, CCS yield and germination percent.

Correlation and Path Coefficient Analysis: Sugarcane yield is a complex trait which depends on less complex, simply inherited yield contributing traits which are also interlinked in their action. Selection for one such trait may simultaneously bring change in the other related traits. The traits showing a close connection with cane yield and among themselves, if selected together, not only facilitate improvement of themselves but sugarcane yield also. So, the knowledge of magnitude and direction of association among traits may provide useful insight for the prediction of correlated response, in the construction of selection indices and in the detection of traits having no values in themselves but may become indicators of useful characters under consideration (Johnson *et al.,* 1955). Path coefficient analysis was conducted to partition correlation coefficients into direct and indirect effects, as correlation coefficient do not provide a reliable estimate of relative direct and indirect contribution of different traits towards sugarcane yield. Path coefficient is a standardized partial regression coefficient which provides a mean for the estimation of direct and indirect effects of one variable on the other.

Estimates of correlation coefficients: Correlation coefficients at both phenotypic and genotypic levels were calculated and the results are presented in

Fig. 1 and **Fig. 2**, respectively**.** Cane yield showed highly significant positive association (at both genotypic and phenotypic levels) with CCS yield (rg=0.982, rp=0.950), no. of millable canes (rg=0.753, rp=0.709), no. of tillers (rg=0.727, rp=0.688), weight of single cane (rg=0.549, rp=0.521), germination percent (rg=0.433, rp=0.363), cane height (rg=0.281, rp=0.278) and cane diameter (rg=0.207, rp=0.222). It showed highly significant negative association with brix percent (rg=-0.206, rp=-0.151), non-significant association with polarity per cent (rg=0.038, rp=-0.067) and sucrose percent (rg=0.092, rp=-0.043). Whereas with purity per cent (rg=0.293) and CCS per cent (rg=0.153), it recorded highly significant positive correlation at genotypic level which was found non-significant at phenotypic level.

Germination per cent exhibited significant positive correlation with no. of tillers (rg=0.478, rp=0.323), no. of millable canes (rg=0.526, rp=0.407), polarity per cent (rg=0.362, rp=0.126), sucrose per cent (rg=0.393, rp=0.129), CCS per cent (rg=0.395, rp=0.123) and CCS yield (rg=0.493, rp=0.386) genotypically and phenotypically. No. of tillers showed significant positive correlation with no. of millable canes (rg=0.991, rp=0.928) and CCS yield (rg=0.731, rp=0.659). No. of millable canes exhibited significant positive correlations with purity percent (rg=0.410, rp=0.124) and CCS yield (rg=0.768, rp=0.708). Likewise, weight of single cane recorded significant positive correlation with cane height (rg=0.374, rp=0.375), diameter of cane (rg=0.769, rp=0.682) and CCS yield (rg=0.507, rp=0.453). Cane height exhibited



(0.119), polarity

Fig. 1. Phenotypic correlation among 13 cane yield and juice quality characters of sugarcane in heatmap.

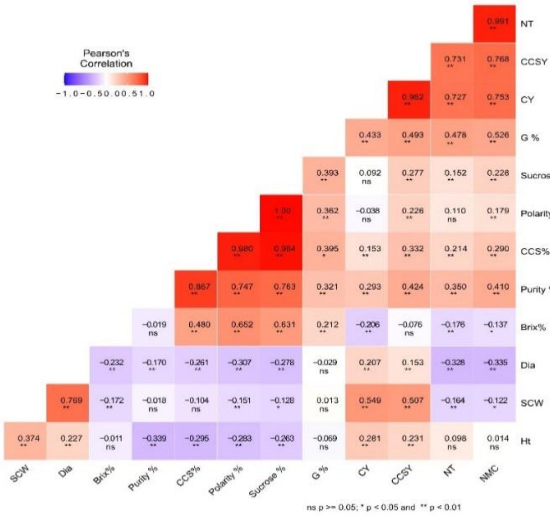


Fig. 2. Genotypic correlation among 13 cane yield and juice quality characters of sugarcane in heatmap

significant positive correlations with cane diameter (rg=0.227, rp=0.223) and CCS yield (rg=0.234, rp=0.204), diameter of cane recorded significant positive correlations with CCS yield (rg=0.153, rp=0.149). Brix percent recorded significant positive associations with polarity percent (rg=0.652, rp=0.523), sucrose percent (rg=0.631, rp=0.466) and CCS percent (rg=0.480, rp=0.308), polarity per cent exhibited significant positive correlations with sucrose per cent (rg=1.000, rp=0.990), purity per cent (rg=0.747, rp=0.773), CCS per cent (rg=0.980, rp=0.963) and CCS yield (rg=0.226, rp=0.234). Sucrose percent showed significant positive correlation with purity percent (rg=0.763, rp=0.822), CCS percent (rg=0.984, rp=0.985) and CCS yield (rg=0.277, rp=0.262). Purity per cent exhibited significant positive correlations with CCS percent (rg=0.867, rp=0.907) and CCS yield (rg=0.424, rp=0.292). CCS percent showed significant positive correlation with CCS yield (rg=0.332, rp=0.281) at both the levels.

The experimental findings of the present study showed that sugarcane yield possessed highly significant positive association with seven yield contributing characters namely germination percent, no. of tillers, no. of millable canes, single cane weight, cane height, cane diameter and CCS yield at both the levels. It suggests that improvement of these component characters ultimately improve sugarcane yield. These findings are in accordance with earlier results obtained by Swamygowda and Saravanan, (2016) and Kumar and Kumar (2014) by estimation of correlations between cane yield and yield attributing characters. CCS yield exhibited highly significant positive phenotypic as well as genotypic association with all studied traits except brix percent, which found to be non-significantly associated with CCS yield. CCS yield is the product of cane yield and available sugar and cane yield is known to positively impacted by good germination percent, more no. of tillers and millable cane, cane height, single cane weight and cane diameter. It revealed that indirect improvement of CCS yield could be possible if the above mention characters increased significantly, as this will improve cane yield and further CCS yield. Highly significant positive correlation of germination percent with no. of tillers, no. of millable canes and CCS percent at both genotypic as well as phenotypic level indicated that higher germination leads to more tillers as well as millable canes. The results are in agreement with the earlier reports of Agrawal and Kumar (2018) from correlation study using 16 sugarcane genotypes and Verma *et al.* (2021) by studying 24 diverse origin varieties of sugarcane. Cane height and cane diameter were reported to have positive and significant correlation with single cane weight, suggesting that both of these plays important role in cane weight and it can be increased by improving the said characters.

Among juice quality characters, brix percent exhibited positive and highly significant correlation with polarity percent and sucrose percent, whereas polarity percent recorded positive and highly significant association with purity percent, sucrose percent and CCS per cent, sucrose percent showed highly significant positive correlation with purity percent and CCS percent both genotypically and phenotypically. These results revealed that all the juice quality characters exerted positive and significant effect on the other remaining quality characters thus aid in the performance of those characters. These results were found similar of the earlier reports of Ahmed *et al.* (2010) and Tahir *et al.* (2014) for brix, polarity and purity percent among each other.

Estimates of path coefficient: Path coefficients were calculated considering sugarcane yield as dependent variable and the rest twelve characters as independent variable. The phenotypic path coefficients are presented in **Table 2.**

Direct effects: Path coefficients for cane yield at phenotypic level depicted that CCS yield (0.870) recorded highest positive direct effect on cane yield, followed by sucrose per cent (0.736), number of millable canes (0.129), single cane weight (0.119), polarity per cent (0.035) and number of tillers (0.007) whereas, CCS per cent (-0.558) exhibited highest negative direct effect on cane yield followed by brix per cent (-0.349), purity per cent (-0.335) and cane diameter (-0.011). Remaining characters showed very low direct effects on cane yield.

Indirect effects: Germination percent conferred highest positive indirect effect via CCS yield (0.376), sucrose percent (0.156) and no. of millable canes (0.058). Similarly, no. of tillers recorded positive indirect effect through CCS yield (0.598), no. of millable canes (0.122), sucrose percent (0.057) and brix percent (0.035). No. of millable canes recorded highest indirect effect in positive direction via CCS yield (0.598), followed by sucrose percent (0.092) and highest negative indirect effects through CCS per cent (-0.085). Other characters namely no. of tillers, cane diameter, brix per cent, polarity per cent showed positive but very little indirect effects through no. of millable canes. Weight of single cane exerted indirect effect in positive direction via CCS yield (0.413) followed by CCS per cent (0.067) and highest indirect effect in negative direction via sucrose percent (-0.103). Cane height also recorded higher positive indirect effect via CCS yield (0.181) followed by CCS per cent (0.128) and higher indirect effect in negative direction via sucrose percent (-0.165). Diameter of cane recorded highest positive indirect effect via CCS yield (0.130) followed by CCS percent (0.117), weight of single cane (0.085), brix 0.070) and purity percent (0.043) but negative indirect effects were observed via sucrose percent (-0.169) and weight of single cane (-0.038). Similarly, brix per cent exhibited recognizable positive indirect effects through sucrose percent (0.376), purity percent (0.031) and negative indirect effect via CCS percent (-0.197) and CCS yield (-0.022). Polarity percent exerted highest positive indirect effect via sucrose percent (0.730), CCS yield (0.198), whereas, highest negative indirect effect through CCS (-0.539), purity (-0.256) and brix percent (-0.196). Sucrose percent exerted higher indirect effect in positive direction via CCS yield (0.228) and higher indirect effect in negative direction through CCS (-0.550), purity (-0.270) and brix percent (-0.178). Purity percent exhibited higher indirect effect in positive direction via sucrose percent (0.594), CCS yield (0.280) and negative indirect effect through CCS percent (-0.501). CCS percent exhibited higher indirect effects in positive direction through sucrose percent (0.725), CCS yield (0.253) and negative indirect effects via purity (-0.301) and brix percent (-0.123). CCS yield exhibited highest positive indirect effect through sucrose percent (0.192), negative indirect effects through CCS (-0.162) and purity percent (-0.107) and very little indirect effects via rest of the characters. The residual effect was recorded to be 0.056.

The results of genotypic path coefficients analysis are presented in **Fig. 4.**

Direct effects: At genotypic level path coefficient analysis for cane yield revealed that only three characters namely sucrose per cent (7.767), CCS yield (1.094) and number of millable canes (0.096) recorded positive direct effect on cane yield, while, CCS yield (-6.697) exerted highest negative direct effect on cane yield followed by brix per cent (-1.789), purity per cent (-0.274), number of tillers (-0.136), polarity per cent (-0.059), single cane weight (-0.029), cane diameter (-0.012), germination per cent (-0.011) and cane height (-0.006).

Table 2. Phenotypic path matrix exhibiting direct and indirect effects of yield contributing characters on cane yield in sugarcane

Characters	Germ	NT	NMC	SCW	Ht	Dia	Brix%	Polarity%	Sucrose%	Purity%	CCS%	CCSY
Germ	**-0.0005**	-0.0002	-0.0002	0.0000	0.0000	0.0000	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0002
NT	0.0028	**0.0072**	0.0069	-0.0013	0.0007	-0.0019	-0.0007	0.0004	0.0006	0.0012	0.0008	0.0050
NMC	0.0588	0.1229	**0.1291**	-0.0225	0.0009	-0.0387	-0.0110	0.0132	0.0161	0.0263	0.0198	0.0946
SCW	0.0020	-0.0216	-0.0208	**0.1193**	0.0441	0.0854	-0.0186	-0.0189	-0.0168	-0.0070	-0.0145	0.0567
Ht	0.0001	-0.0003	0.0000	-0.0012	**-0.0033**	-0.0007	0.0003	0.0008	0.0007	0.0007	0.0008	-0.0007
Dia	0.0001	0.0031	0.0035	-0.0084	-0.0026	**-0.0118**	0.0024	0.0029	0.0027	0.0015	0.0025	-0.0018
Brix%	-0.0438	0.0357	0.0297	0.0544	0.0264	0.0701	**-0.3495**	-0.1960	-0.1788	0.0323	-0.1236	0.0092
Polarity%	0.0073	0.0020	0.0036	-0.0056	-0.0083	-0.0089	0.0200	**0.0356**	0.0353	0.0272	0.0344	0.0081
Sucrose %	0.1566	0.0575	0.0920	-0.1038	-0.1658	-0.1694	0.3768	0.7308	**0.7364**	0.5941	0.7251	0.1929
Purity %	-0.0519	-0.0548	-0.0685	0.0196	0.0711	0.0439	0.0310	-0.2561	-0.2706	**-0.3355**	-0.3010	-0.1079
CCS%	-0.1151	-0.0593	-0.0859	0.0679	0.1283	0.1171	-0.1976	-0.5399	-0.5501	-0.5012	**-0.5587**	-0.1627
CCSY	0.3760	0.5983	0.6382	0.4139	0.1817	0.1306	-0.0229	0.1984	0.2281	0.2801	0.2535	**0.8706**
CY (Correlation)	0.3633	0.6685	0.7096	0.5212	0.2783	0.2226	-0.1519	-0.0678	-0.0433	0.0477	-0.0169	0.9508

Note: Germ- Germination %, NT-No of tillers (000 /ha), N.M.C. – Number of Millable Canes (000/ha), SCW- Single cane weight (Kg), Ht – Cane Height (m), Dia – Cane Diameter (cm), CCS- Commercial cane sugar, CY- Cane yield (t/ha), CCSY - C.C.S. yield(t/ha)
RESIDUAL EFFECT = 0.0565

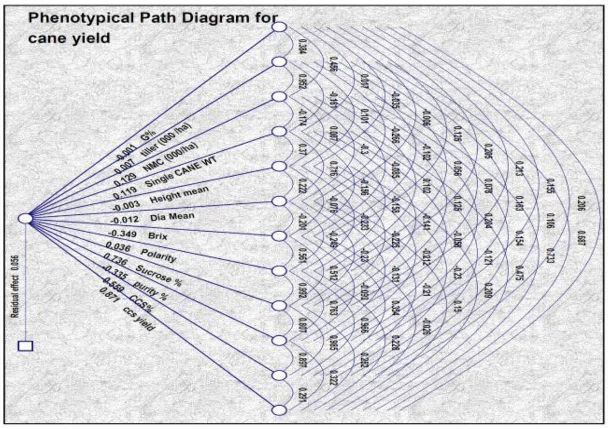


Fig. 3. Phenotypic path diagram for cane yield depicting direct and indirect effects of various cane yield contributing and juice quality characters in sugarcane

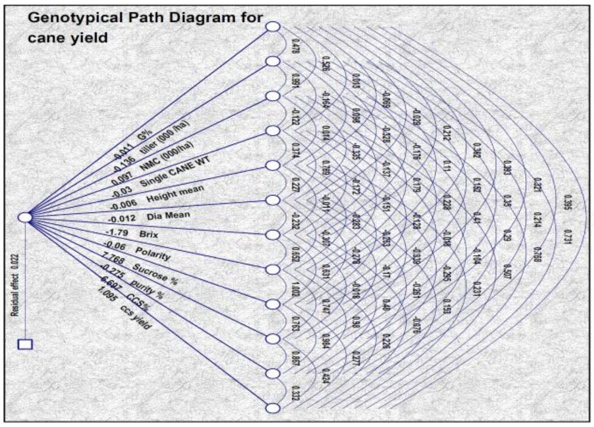


Fig. 4. Genotypic path diagram for cane yield depicting direct and indirect effects of various sugarcane yield contributing and juice quality characters in sugarcane

Indirect effects: Germination per cent exhibited highest positive indirect effect through sucrose per cent (3.051) followed by CCS yield (0.540) and no. of millable cane (0.051) while, highest negative indirect effect via CCS percent (-2.644) followed by brix percent (-0.380), purity percent (-0.088), no. of tillers (-0.065) and polarity percent (-0.021). No. of tillers recorded higher positive indirect effects through sucrose percent (1.182), CCS yield (0.800), brix percent (0.315), no. of millable cane (0.096) and higher negative indirect effects through CCS percent (-1.432) and purity percent (-0.096). No. of millable cane exerted highest positive indirect effect via sucrose percent (1.772) followed by CCS yield (0.840), brix percent (0.245) and highest negative indirect effects through CCS percent (-1.945) followed by no. of tillers (-0.135), purity percent (-0.112) and polarity percent (-0.010). Likewise, weight of single cane exhibited highest positive indirect effect via CCS percent (0.694) followed by CCS yield (0.554), brix percent (0.308), no. of tillers (0.022) and highest negative indirect effect via sucrose per cent (-0.991) and no. of millable canes (-0.011). Cane height recorded higher positive indirect effect via CCS percent (1.976), CCS yield (0.253), purity percent (0.093), brix percent (0.019), polarity percent (0.016) and higher

https://doi.org/10.37992/2023.1402.074

negative indirect effect via sucrose percent (-2.046), no. of tillers (-0.013) and weight of single cane (-0.011). Cane diameter exhibited highest positive indirect effect through CCS percent (1.745), brix percent (0.414), CCS yield (0.167), purity percent (0.046), no. of tillers (0.044) and polarity percent (0.018). Negative indirect effects were recorded through sucrose percent (-2.161), no. of millable cane (-0.032) and weight of single cane (-0.022). Brix percent exhibited higher positive indirect effects via sucrose percent (4.898), no. of tillers (0.024) and highest negative indirect effect through CCS percent (-3.215) followed by CCS yield (-0.082), polarity percent (-0.038) and no. of millable cane (-0.013). Polarity percent exerted highest positive indirect effect through sucrose percent (7.780), CCS yield (0.247), no. of millable cane (0.017) and highest negative indirect effect through CCS percent (-6.565), brix percent (-1.167), purity percent (-0.205) and no. of tillers (-0.015). Similarly, sucrose percent exerted higher positive indirect effect through CCS yield (0.303), no. of millable cane (0.022) and higher negative indirect effect through CCS percent (-6.586), brix percent (-1.128), purity percent (-0.209), polarity percent (-0.059) and no. of tillers (-0.020). Purity percent recorded highest positive indirect effect via sucrose percent (5.928) followed by CCS yield (0.464), no. of millable cane (0.039) and brix percent (0.033) while, highest negative indirect effect exerted via CCS percent (-5.805) no. of tillers (-0.047) and polarity percent (-0.044). CCS per cent exerted higher positive indirect effects through sucrose per cent (7.639), CCS yield (0.363), no. of millable cane (0.028) and highest negative indirect effect via characters namely brix percent (-0.859), purity percent (-0.238), polarity percent (-0.058) and no. of tillers (-0.029). CCS yield exhibited positive indirect effects only through three characters namely sucrose percent (2.154), brix percent (0.135), no. millable cane (0.074) and via remaining eight characters negative indirect effects were showed in which CCS percent (-2.223) exerted highest effect followed by purity percent (-0.116), no. of tillers (-0.099) and weight of single cane (-0.015). The residual effect was recorded to be 0.022.

The path coefficient analysis is helpful to understand the actual factor responsible for the association between characters, as it divides the correlation between characters into direct contribution and indirect contribution through other characters. It was observed that sucrose percent, CCS yield and no. of millable canes showed higher direct effects in positive direction on sugarcane yield. The results were found in accordance with the earlier results obtained by Verma *et al.* (2021). Sucrose percent conferred positive indirect effects through no. of millable canes and CCS yield conferring that these indirect effects are the main reason of positive association between these traits. While, CCS yield exerted higher positive indirect effect through no. of millable cane and sucrose percent that contributed in the direct effects via these characters. CCS yield exhibited recognizable indirect effect on cane yield in positive direction through all the traits studies except via brix percent, indicated important role of this character in the correlation at both genotypic and phenotypic levels. Swamygowda and Saravanan, (2016) also recorded that CCS yield exhibited positive indirect effect on sugarcane yield via no. of millable cane, germination percent, length and diameter of cane.

Table 3. Genotypic path matrix exhibiting direct and indirect effects of yield contributing characters on cane yield in sugarcane

Characters	Germ	NT	NMC	SCW	Ht	Dia	Brix %	Polarity %	Sucrose %	Purity %	CCS %	CCSY
Germ	**-0.0114**	-0.0054	-0.0060	-0.0001	0.0008	0.0003	-0.0024	-0.0041	-0.0045	-0.0037	-0.0045	-0.0056
NT	-0.0651	**-0.1364**	-0.1352	0.0223	-0.0134	0.0447	0.0241	-0.0150	-0.0208	-0.0477	-0.0292	-0.0997
NMC	0.0510	0.0961	**0.0969**	-0.0118	0.0014	-0.0325	-0.0133	0.0174	0.0221	0.0397	0.0282	0.0745
SCW	-0.0004	0.0049	0.0036	**-0.0296**	-0.0111	-0.0228	0.0051	0.0045	0.0038	0.0005	0.0031	-0.0150
Ht	0.0004	-0.0006	-0.0001	-0.0023	**-0.0062**	-0.0014	0.0001	0.0018	0.0016	0.0021	0.0018	-0.0014
Dia	0.0003	0.0040	0.0040	-0.0093	-0.0027	**-0.0121**	0.0028	0.0037	0.0034	0.0021	0.0031	-0.0018
Brix%	-0.3800	0.3158	0.2450	0.3085	0.0190	0.4149	**-1.7898**	-1.1671	-1.1287	0.0331	-0.8593	0.1353
Polarity%	-0.0215	-0.0066	-0.0107	0.0090	0.0169	0.0183	-0.0389	**-0.0596**	-0.0597	-0.0445	-0.0584	-0.0134
Sucrose %	3.0518	1.1826	1.7729	-0.9915	-2.0464	-2.1617	4.8988	7.7803	**7.7677**	5.9281	7.6399	2.1545
Purity %	-0.0883	-0.0962	-0.1127	0.0050	0.0930	0.0467	0.0051	-0.2054	-0.2097	**-0.2748**	-0.2383	-0.1165
CCS%	-2.6444	-1.4320	-1.9454	0.6941	1.9764	1.7452	-3.2152	-6.5654	-6.5868	-5.8059	**-6.6970**	-2.2239
CCSY	0.5402	0.8004	0.8409	0.5548	0.2530	0.1673	-0.0827	0.2470	0.3037	0.4640	0.3636	**1.0948**
CY (Correlation)	0.4337	0.7276	0.7532	0.5492	0.2818	0.2071	-0.2063	0.0380	0.0921	0.2939	0.1531	0.9825

Note: Germ- Germination %, NT-No of tillers (000 /ha), N.M.C. – Number of Millable Canes (000/ha), SCW- Single cane weight (Kg), Ht – Cane Height (m), Dia – Cane Diameter (cm), CCS- Commercial cane sugar, CY- Cane yield (t/ha), CCSY - C.C.S. yield(t/ha)
RESIDUAL EFFECT = 0.0219

On sugarcane yield, negative direct effects were recorded by germination percent, cane height and diameter, brix, purity and CCS percent at both genotypic and phenotypic level. The negative direct effect of brix percent resulted in negative association between brix percent and sugarcane yield. Non-significant association between cane yield and sucrose percent mainly due to the higher negative indirect effect of CCS percent through sucrose percent inspite of that sucrose percent exerted higher direct effects on sugarcane yield at genotypic and phenotypic levels. These results were found to be similar to the earlier findings of Kumar and Kumar, (2014) in their correlation and path coefficient study with fifteen characters. Traits with higher negative direct and indirect effects indicate that they are not the determinants for cane yield. The residual effects at both the levels were recorded to be very low which, indicates that the characters under study contributed to almost all the cane yield directly or indirectly via other character under study.

Path analysis revealed that CCS yield exerted higher direct effect in positive direction on sugarcane yield, revealing it as main cause of positive association between them. No. of tillers, no. of millable cane and weight of single cane were also exerted direct positive effect on cane yield. Study of indirect effects revealed that CCS yield showed highest indirect effect on sugarcane yield through no. of millable cane, no. of tillers and weight of single cane. Further, no. of millable canes also exerted considerable indirect effect on cane yield through no. of tillers. These indirect effects reported as the major cause of concern for positive correlation of these traits with cane yield thus should be considered at the time of selection. These findings indicated that sugarcane genotypes selected on the basis of no. of tillers, no. of millable canes, weight of single cane and CCS yield will ultimately improve sugarcane yield. Pandyal and Patel, (2017) and Ali *et al.* (2021) concluded that more emphasis in selection should be given to cane height, weight of single cane, no. of tillers and no. of millable canes for sugarcane yield improvement.

If the correlation coefficient between characters is similar to its direct effect on that character, it represents a true relationship between them and a direct selection *via* this character will be potent. If the correlation is positive and the direct effect is negative or negligible then the indirect effects appear as the real reason of correlation between those traits (Tyagi and Lal, 2007). Results of present study showed that the correlation coefficient between sugarcane yield and sucrose percent was observed as non-significant but path analysis revealed that sucrose percent exerted high magnitude of direct effect on cane yield. But it was observed that indirect effect of CCS percent via sucrose percent on sugarcane yield was higher and negative. Therefore, it reduced the magnitude of correlation of sucrose percent with sugarcane yield. It was observed that the juice quality characters like brix percent, polarity percent, sucrose percent and CCS percent were exhibited significant association among each other but these characters were found to be negatively or non-significantly correlated with cane yield. Krishna and Kamat (2017) also observed highly significant positive correlation among brix percent, purity percent, CCS percent and polarity percent. Results also indicated that most of the quality characters were found to be positively correlated with CCS yield and some of them also showed positive association with yield contributing characters like no. of tillers and no. of millable canes. Therefore, in order to select high yielding clones with improved juice quality characters it is suggested that selection should be based upon no. of tillers, no. of millable cane and CCS yield.

Generally, selection is not based on one trait but it is practiced simultaneously for various contributing parameters in order to improve the economic value of a complex, polygenic trait like cane yield which depends on a number of independent traits. It referred as multi character selection which is expected to give more speedy improvement in the economic value of the dependent trait. In present study, it was observed that seven characters namely germination percent, no. of tillers, no. of millable cane, weight of single cane, cane height and diameters and CCS yield exhibited highly significant positive association with sugarcane yield. Path analysis revealed that CCS yield exerted higher direct effect on sugarcane yield positively, revealing the main cause of the positive association between them. No. of millable cane, weight of single cane and no. of tillers were also exerted direct effect on sugarcane yield in positive direction. CCS yield recorded highest indirect effect on sugarcane yield via no. of millable cane, weight of single cane and no. of tillers on sugarcane yield, no. of millable cane also exerted considerable indirect effect on cane yield through no. of tillers, indicated that plant selection based on no. of tillers, no. of millable cane and single cane weight would increase sugarcane yield. Most of the quality characters were found to be positively correlated with CCS yield and some of them also showed positive association with yield contributing characters like no. of tillers and no.of millable cane. Therefore, for the selection of high yielding clones with improved juice quality characters it is suggested that selection should be based upon no. of tillers, no. of millable cane and CCS yield.

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