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Genetic Variations and Selection Coefficients for Agronomic, Physiological and Quality Traits towards Sugarcane Improvement for Waterlogged conditions

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ABSTRACT: Sugarcane production and quality is highly affected by various biotic and abiotic stresses. Among abiotic stresses, water logging or submerged condition is an important factor affecting cane and sugar yield, globally. For crop improvement under waterlogged conditions, the genetic variability in sugarcane needs to be explored under specific stress. To determine the contribution of different agronomic, physiological and quality traits towards cane and sugar present study was conducted under waterlogged conditions using 44 diverse sugarcane clones/varieties. Analysis of variation revealed significant difference among clones for all the characters under study. High phenotypic and genotypic coefficients of variation were observed for the total chlorophyll (32.86 % and 31.24%), while single cane weight recorded high PCV (23.96%) only. High heritability (broad sense) was observed for number of internodes (92.89%) followed by total chlorophyll (90.38%), stalk length (84.92%) cane yield (73.55%) and commercial cane sugar (t/ha) (69.65%). Similarly high genetic advance (percent mean) was observed only for total chlorophyll (61.18%) under waterlogged environment. Cane yield had shown significant correlation with single cane weight (0.41, 0.251), stalk diameter (0.365, 0.280), number of internodes (0.296, 0.236) and dry biomass (0.361, 0.224) at phenotypic and genotypic level, respectively. Path analysis revealed high positive direct effect of number of millable canes (0.349) (phenotypic) and leaf area (2.646) (genotypic) on cane yield while stalk diameter had highest positive significant indirect effects on cane yield *via* dry biomass (0.159) and number of millable canes (2.53) at phenotypic and genotypic levels, respectively. The traits exhibiting positive association with cane yield and quality should be given due emphasis in development of sugarcane varieties for the waterlogging conditions.

Keywords: Sugarcane, Genetic variability, Correlation and Path analysis.

INTRODUCTION

Sugarcane (*Saccharum* spp. hybrid complex) is one of the leading industrial crops in the world where India holds position of second largest sugarcane producing country with an area of about 5.06 million hectares and production of 405.42 million tones after Brazil (FAO 2021). In Punjab, sugarcane occupies an area of about 96 thousand hectares with an average cane yield of 836 quintals per hectare (Anonymous, 2020). It is a primary commodity for sugar production that provides nearly 80% of the world's overall sugar production along with ethanol production as renewable bio-fuel. It is also used for manufacturing of chemicals, paper, bio-manure, paper board factories and cogeneration plants.

Sugarcane production and quality is highly affected by various biotic and abiotic stresses. Among abiotic stresses, waterlogging or submerged condition is an important factor affecting cane yield and sugar, globally. In India, 11.60 million hectares area is affected by waterlogging stress and 10-20% of this area is under sugarcane cultivation which is one of the reasons of poor sugarcane productivity or recovery of sugar. Under waterlogging the soil pores fill with water and causes oxygen deficiency (*i.e.* hypoxia and anoxia conditions) resulting shift of aerobic respiratory metabolism pathway into anaerobic pathway and production of reactive oxygen species *viz*., radical superoxide, hydroxyl radical, singlet oxygen and hydrogen peroxidase have started as soon as plants experience stress (Garnczarska *et al*., 2004). The reactive oxygen species trigger lipid peroxidation and leads to discharge of cellular material, breakdown of proteins, deactivation of enzymes, damaging of DNA, membrane damage and damages the oxidative processes and causes cell death. Being a moderately tolerant to waterlogging conditions, duration of waterlogging and physiological stage determines the loss in yield and quality of sugarcane (Deren *et al*., 1991). The waterlogging affects on cane expansion and inhibition in growth of characters *i.e*., plant height, total biomass and number of tillers. The reduction in crop growth under water logging is due to number of factors *i.e*., closing of stomata which results in lower transpiration rate, low photosynthesis rate due to decrease in leaf area, whereas increase in respiration rate in submerged organs (Gomathi *et al.,* 2014). Mean yield loss of sugarcane due to waterlogging stress is approximately 15-25% and in some cases, this limit can exceed 40% according to the period of flooding and stage of crop (Gomathi and Chandran 2009). In Punjab, most of sugarcane is cultivated in catchment areas alongside the rivers Ravi, Beas and Sutlej are highly affected by waterlogging (Sanghera and Jamwal 2019). It can be better exploited for sugarcane production and better sugar recovery if specific varieties be developed for these specified adaptations.

For improvement of sugarcane under waterlogged conditions, the genetic variability in sugarcane needs to be explored under specific stress. The heterozygous and polyploid nature of sugarcane has resulted in generation of greater genetic variability. The information on the nature and the magnitude of variability present in the genetic material is of prime importance for a breeder to initiate any effective selection program. Knowledge of genotypic and phenotypic coefficients of variation along with heritability as well as genetic advance is very useful to improve any trait of interest because this would help in knowing whether or not the desired objective can be achieved from the material (Gomathi *et al.,* 2014; Sanghera and Jamwal 2019). While under the stress, genotype behave differently and show diverse response compared to normal conditions. The genetic tolerance of genotype plays an important role in coping up with the stress through modifying its morphological, physiological and biochemical traits. The effect of these traits ultimately influences the economic traits which is cane yield and sucrose accumulation in sugarcane. Hence, it is necessary to study the association and path coefficients of different traits with economically important traits *viz*., cane yield and sugar. This will help the breeders to design the selection strategies for developing the waterlogging stress tolerance sugarcane varieties. In past, very scanty information/research has been documented on exploiting the waterlogging aspect in sugarcane agriculture particularly in Punjab state representing North-west zone of the country under sub-tropical conditions. Taking into account of all the above concerns especially waterlogging conditions in river basin areas of the state, the present study was planned to examine the extent of genetic variability parameters, association and path coefficients of different cane yield components, physiological and quality traits of sugarcane clones under waterlogging condition of Punjab.

MATERIAL AND METHODS

The experiment was conducted at PAU Regional Research Station (RRS), Kapurthala (31.38ºN longitude and 75.38ºE latitude) during 2019-2020. The minimum and maximum mean weekly temperature varied from 5.1°C to 27.6°C and from 12.7°C to 44.4°C, respectively. The total rainfall during crop season was 984.9mm. Forty-four diverse sugarcane clones/varieties developed at RRS Kapurthala except five varieties *viz*., Bo-91, Bo-153, Bo-154, CoP-2061 and CoP-9437 were introduced from Dr Rajendra Prasad Central Agricultural University, Pusa (Samastipur), Bihar were involved in the present investigation. The experiments were carried out in Randomized Complete Block Design with two replications in waterlogged conditions. In each replication, each clone/variety was planted in a plot of 4 rows of 4 m length maintaining inter row spacing of 90 cm. The seed rate was 12 buds per running meter row length. The standard agronomic practices as per package of practices of the sugarcane were followed to raise the ideal crop stand except irrigation under waterlogged conditions. Under waterlogging, submerged conditions was imposed at tillering stage, formative/grand growth stage and maturation stage.

The observations on different cane yield and component traits, physiological and quality traits were recorded at appropriate stages for each clone/variety in each replication under waterlogging. The data were recorded for germination (%) after 45 days, number of millable canes (NMC) (000/ha), stalk length (cm), stalk diameter (cm), single cane weight (kg), number of internodes, cane yield (t/ha) and juice quality traits were recorded at harvest which included brix (%), sucrose (%), purity (%), commercial cane sugar (CCS) (%), extraction (%) and commercial cane sugar (CCS) (t/ha) at time harvesting. The physiological traits including average internode length (cm), leaf area (cm^2), number of stomata and dry biomass (g/plant) were recorded. The total chlorophyll in leaves

The data were statistically analyzed according to randomized complete block design using software CPCS1 (Cheema and Singh 1990). The phenotypic and genotypic coefficients of variation, heritability (broad sense) and genetic advance (percent mean) were measured. The phenotypic and genotypic coefficients of variation were measured as per Burton and Devane (1953); Johnson *et al.* (1955). Heritability (%) in broad sense was measured with the formula proposed by Allard (1960). Genetic advance for each trait was measured using formula proposed by Miller *et al.* (1958). The phenotypic and genotypic correlation coefficients were calculated as proposed by Al-Jibouri et al. (1958). Path coefficient analysis was carried out as per Dewey and Lu (1959).

RESULTS AND DISCUSSION

The analysis of variance for 18 agronomic, physiological and quality traits revealed mean sum of squares for genotypes were found significant for all cane yield, physiological and quality traits recorded in this study (Table 1). The results indicated that clones have sufficient genetic variability for all the traits under waterlogged conditions which further opened the possibility to identify specific clones suitable under waterlogging conditions through selection (Punia, 1982). Similar results were reported by Krishna *et al*. (2017) where significant analysis of variance for cane yield and quality traits has been observed under waterlogging conditions. The range for cane yield varied between 43.51 to 73.66 t/ha, number of millable canes varied from 55.76 to 96.89 thousand/ha, while sucrose varied from 13.27 to 17.26 per cent, commercial cane sugar (%) lied between 9.08 to 12.05 per cent and sugar yield (CCS) (t/ha) ranged from 4.57 to 8.76 t/ha (Table 2). Simple analysis of variance and range is unable to explain all the inherent genetic variability in the genotypes for the given trait. Therefore, selection and identification of suitable genotypes depends on the magnitude of inherent variability for a particular trait. Hence, it is essential to study the estimates of genetic parameters such as coefficients of genotypic and phenotypic variability, heritability and genetic advance (Sanghera *et al*., 2018).

Table 1: Analysis of variance for sugarcane yield, its components, physiological and quality traits under waterlogged conditions.

Sr. No.	Traits	Mean Squares			
		S.V.	Replications	Clones	Error
		d.f.	1	43	43
Cane yield and component traits					
1	Germination (%)		53.339	129.510*	23.228
2	NMC (000/ha)		29.011	196.312*	41.628
3	Stalk length (cm)		2.227	1110.163*	90.506
4	Stalk diameter (cm)		0.003	0.132*	0.033
5	Single cane weight (kg)		2.800	0.113*	0.036
6	Number of internodes		102.878	10.196*	0.376
7	Cane yield (t/ha)		28.943	105.409*	16.068
Physiological traits					
1	Avg internode length (cm)		6.367	3.640*	2.095
2	Leaf area (cm^2)		4023.273	9382.465*	1362.133
3	Number of stomata		171.401	29.900*	12.805
4	Dry biomass (g/plant)		274.182	50825.120*	9402.554
5	Total chl (mg/g)		0.009	0.520*	0.026
Juice quality traits at harvest					
1	Brix (%)		1.217	2.570*	1.254
2	Sucrose (%)		1.923	2.053*	0.986
3	Purity (%)		4.153	11.246*	6.328
4	CCS (%)		0.122	1.095*	0.615
5	Extraction (%)		2.830	13.572*	4.951
6	CCS (t/ha)		0.429	1.835*	0.328

***** Significant at 5% level of significance
NMC: Number of millable canes, CCS: Commercial cane sugars, Total Chl: Total chlorophyll

Table 2: Genetic variability parameters for cane yield, its components, physiological and quality traits in sugarcane under waterlogged conditions.

Traits	Range	PCV (%)	GCV (%)	Heritability (H^2_{bs}) (%)	GA (% mean)
Cane yield and its component traits					
Germination (%)	31.58 - 67.26	19.53	16.29	69.59	28.00
NMC (000/ha)	55.76 - 96.89	15.12	12.19	65.01	20.25
Stalk length (cm)	176.50 - 277.20	11.00	10.14	84.92	19.24
Stalk diameter (cm)	2.20 - 3.36	10.54	8.15	59.85	12.99
Single cane weight (kg)	0.67 - 1.74	23.96	17.16	51.31	25.32
Number of internodes	12.57 - 21.50	13.25	12.77	92.89	25.34
Cane yield (t/ha)	43.51 - 73.66	13.46	11.54	73.55	20.39
Physiological traits					
Avg. internode length (cm)	8.39 - 14.50	15.40	7.99	26.94	8.55
Leaf area (cm^2)	263.00 - 567.00	18.59	16.06	74.65	28.59
Number of stomata	25.00 - 41.33	14.00	8.86	40.03	11.54
Dry biomass (g/plant)	581.50 - 1336.25	17.39	14.42	68.78	24.64
Total chl (mg/g)	0.54 - 2.60	32.86	31.24	90.38	61.18
Quality traits					
Brix (%)	14.72 - 19.17	8.24	4.40	28.43	4.83
Sucrose (%)	13.27 - 17.26	8.06	4.78	35.12	5.83
Purity (%)	85.46 - 96.55	3.32	1.75	27.84	1.91
CCS (%)	9.08 - 12.05	8.71	4.61	28.04	5.03
Extraction (%)	36.11 - 48.83	6.70	4.57	46.55	6.43
CCS (t/ha)	4.57 - 8.76	16.89	14.10	69.65	24.23

PCV: Phenotypic coefficient variance; GCV: Genotypic coefficient variance; GA: Genetic advance; H^2_{BS}: Broad sense Heritability; NMC: Number of millable canes; Total chl: Total chlorophyll and CCS: Commercial cane sugar

Genetic Variability parameters. The extent of genetic variability decides the improvement of any trait. The range of mean values and analysis of variance represents tentative estimates of the variation present among different genotypes for the given character. The genotypic and phenotypic coefficient of variation was computed after partitioning of variance along broad sense heritability and genetic advance per cent mean (Table 2). The results indicated the phenotypic coefficient of variation (PCV) were higher than genotypic coefficient of variation (GCV) which revealed that the variations in the genotypes is not due to genetic makeup but it was due to environmental variations under waterlogging. But the difference between PCV and GCV is low for most of traits indicating high prospects for genetic progress through selection under waterlogging conditions. Similar observations were reported by Ram (2005); Behou and

Pene (2020). The genotypic coefficient of variation alone couldn't provide estimate of degree and magnitude of improvement that can be expected by phenotypic selection. Hence heritability along with genetic advance is more effective and reliable in predicting the response to selection by providing more genetic information about the trait. It also indicates the possibility and extent of improvement that can be achieved through selection for a particular trait.

Cane yield and its component traits. Cane yield is depended upon its component traits for improvement in sugarcane. Under waterlogging conditions, cane yield is highly influenced through its yield related traits. Under this study moderate PCV and GCV for cane yield and six related traits was recorded except high PCV for single cane weight (23.96 %) and low GCV for stalk diameter (8.15%) (Table 2). High broad sense heritability (>60%) was recorded for all cane yield traits except stalk diameter (59.85%) and single cane weight (51.31%) whereas moderate genetic advance (20-30%) was recorded for all cane yield traits except for stalk diameter (12.99%) and stalk length (19.24%) (Table 2). These results are in conformity with the findings of Krishna et al. (2017) who recorded moderate genotypic and phenotypic coefficient of variation under waterlogging for germination, number of millible cane, cane yield (t/ha), sugar yield (CCS t/ha) stalk length (cm) and high broad sense heritability for all the traits and moderate genetic advance for germination and number of millable canes. Identical results had been documented by Agrawal and Kumar (2017); Belwal and Ahmad (2020b); Krishna *et al.* (2017); Kumar *et al.* (2017) who reported moderate PCV and GCV along with high to moderate heritability and moderate genetic advance for various traits under waterlogged conditions. These values suggest that selection of these traits should be effective in later segregating generations *i.e.* by hybridization programme to exploit heritability for developing improved waterlogging tolerant clones.

Physiological traits. Five physiological traits were recorded under waterlogging where total chlorophyll recorded high phenotypic (32.86 %) and genotypic (31.24%) coefficient of variation along with high broad sense heritability (90.38%) and high genetic advance (61.18%) (Table 2). High GCV and PCV for the trait indicated that selection might be effective on traits investigated and their expression might be relevant to the genotypic potential (Pene and Behou 2019). High heritability coupled with high genetic advance indicated that the trait was controlled by additive gene action. The substantial improvement can be expected by practicing selection for these traits comprised high heritability (broad sense) and genetic advance (percent mean). Leaf area and dry biomass recorded high heritability but moderate PCV, GCV and genetic advance (Table 2). Similarly, Krishna *et al.* (2017) recorded high heritability and moderate PCV, GCV and genetic advance for leaf area index under waterlogging.

Cane quality traits. Sugar is the end product of the sugarcane whose extraction is determined by the quality traits of sugarcane. Abiotic stresses interfere with sugar production by affecting purity, higher acidity, and the sucrose content of the stalk. So, it becomes crucial to identify those quality traits which impact more on sugar recovery from sugarcane under waterlogging conditions. Lower magnitude of phenotypic and genotypic coefficient of variation along with moderate to low heritability (broad sense) and low genetic advance was observed for all cane quality traits except commercial cane sugars (CCS t/ha) which recorded moderate magnitude of PCV (16.89 %), GCV (14.10 %) and genetic advance (24.23%) but high broad sense heritability (69.65%) (Table 2). Similar results of low PCV and GCV for quality traits under waterlogged conditions are in accordance with Kumar *et al. (*2017) and for sucrose (%) with Belwal and Ahmad (2020b). Agrawal and Kumar (2017) also observed low PCV and GCV for brix (%), purity (%) and low GCV for stalk diameter and CCS (%) under waterlogged conditions. Low genotypic coefficient of variation indicated that the parental clones used in the development have narrow genetic background. Earlier workers (Agrawal and Kumar 2017; Belwal and Ahmad 2020b) reported lower estimate of heritability and genetic advance under waterlogged conditions for brix (%) and CCS (%) which are in confirmation with the present findings. Lower value could be due to the environmental influence on the expression of these traits as is also indicated by differences in phenotypic and genotypic coefficient of variation values. The direct selection could not be much effective for these traits. The low levels of genetic advance obtained for some agronomic and quality traits could be attributed to low levels of genotypic coefficient of variation.

Association analysis. Cane yield is a complex trait determined by number of contrasting traits and environment in which crop is grown. Selection based on strongly correlated contrasting traits is more efficient than direct selection for such complex trait. Stronger the correlation between the traits and yield, greater the likelihood of success in the selection programme. The correlation coefficient is a statistical measure that helps to evaluate the degree and direction of relationship between two or more traits. Once the significant genetic association between easily observable traits and yield is identified, the selection process will be accelerated because genetic association provides information on the correlated response to selection.

Under waterlogging conditions phenotypic and genotypic correlation coefficient of cane yield was found positively significant with stalk diameter (0.281 and 0.365), single cane weight (0.251 and 0.400), number of internodes (0.236 and 0.296) and dry biomass (0.224 and 0.361). While, germination (%) (0.320) and leaf area (0.256) have recorded significantly positive correlation at genotypic level with cane yield (Table 3).

For quality traits, commercial cane sugar (t/ha) had significantly positive phenotypic and genotypic correlation coefficient with most of the quality traits *i.e*., brix (%) (0.425 and 0.532), sucrose (%) (0.535 and 0.630), purity (%) (0.240 and 0.375) and CCS (%) (0.591 and 0.606) under waterlogging (Table 4). Identical results for significant and positive correlation of cane yield with single cane weight, stalk length and brix (%) are in confirmation with earlier findings of Kumar *et al.* (2018), while with germination (%), number of millable canes, sucrose (%) and CCS (t/ha) are in agreement with Belwal and Ahmad (2020a). Krishna and Kamat (2017) also reported significant positive correlation of cane yield with germination (%), number of millable canes, stalk length, single cane weight, stalk diameter, leaf area index and CCS (t/ha) under waterlogged conditions. Palachai *et al.* (2019) also reported positive correlation between single cane weight and cane yield under waterlogging. The genotypic correlation coefficients were found to be higher in magnitude than the corresponding phenotypic correlation coefficients. This showed that there was an inherent correlation among the studied traits, which was depressed due to the effect of environment and eventually resulted in low phenotypic expression. Based on the association analysis, traits such as cane yield, stalk diameter, single cane weight, leaf area, dry biomass and CCS (t/ha) were reported as important and these traits should be selected for improvement of yield under waterlogged environment. These traits were also suggested to be important under waterlogged conditions by Kumar *et al.* (2017); Krishna and Kamat (2017); Belwal and Ahmad (2020a).

Path coefficient analysis. The knowledge of correlation among traits determines the efficiency of selection in any breeding programme. The association analysis shows just the magnitude of association between the traits without revealing the underlying cause of the relationship. As many traits are included in the analysis, the path coefficient analysis divides the correlation values into direct and indirect effects and that enable a detailed interpretation of the particular cause in an attempt to develop a given correlation. The direct and indirect effects of traits analyzed at phenotypic and genotypic level under waterlogged conditions are presented in Tables 5 & 6. In this study, stalk diameter, single cane weight, number of internodes, dry biomass and leaf area are significantly associated with cane yield therefore their direct and indirect involvement at phenotypic and genotypic level is estimated by path coefficient analysis.

Path coefficient analysis of yield related traits with cane yield and quality traits with commercial cane sugar (t/ha) (CCS) under waterlogging are presented in Table 5 and 6, respectively. The significance of path analysis can be better explored for the traits which have shown significant association with cane yield. The germination has shown significant correlation with cane yield (0.320) at genotypic level where high positive direct effect (1.181) of germination has been observed while average internode length (0.535) has highest positive indirect while number of millable canes NMC (-0.603) have negative indirect effect. The stalk diameter showed significant association with cane yield (0.281 and 0.365) at phenotypic and genotypic level, respectively. It has shown positive (0.321) direct effect at phenotypic level while negative direct effect was calculated at genotypic level (-0.3464) on cane yield.

The positive indirect effect of leaf area (1.996) and number of millable canes (1.373) has been recorded via stalk diameter on cane yield at genotypic level. Similarly, single cane weight have significant phenotypic (0.251) and genotypic (0.400) correlation with cane yield. Whereas the positive direct effect (0.034) of single cane weight at phenotypic level and negative at genotypic level (-0.294) has been observed. The stalk diameter (0.221) has indirect effect on single cane weight and cane yield at phenotypic level. At genotypic level stalk diameter have shown highest negative (-3.684) indirect effect whereas leaf area (1.891) and NMC (1.484) have shown positive indirect effect on SCW and cane yield. The significant correlation of number of internodes with cane yield at phenotypic (0.236) and genotypic (0.296) level has been observed. The number of internodes have positive direct effect (0.310) at phenotypic level and negative direct effect (-1.431) at genotypic level. The dry biomass has significant correlation with cane yield at phenotypic (0.224) and genotypic (0.361) level. The path analysis revealed positive phenotypic (0.106) and genotypic (1.161) direct effect of dry biomass on cane yield. The leaf area (1.283) and NMC (1.088) have shown positive indirect effect whereas stalk diameter (-2.765) has shown negative indirect effect on dry biomass with cane yield. Under waterlogging, all quality traits have shown significant association with commercial cane sugars (t/ha) at phenotypic and genotypic level except for extraction percentage at phenotypic level (0.086). The highest positive direct effect of brix (3.402) followed by purity (1.237) while highest negative direct effect of sucrose (-3.517) has been observed on CCS (t/ha). The highest positive indirect effect of brix (3.936) and negative indirect of sucrose (-4.47) have been observed for CCS (%) on CCS (t/ha). Contrary Viradiya *et al.* (2015) reported highest direct effect of CCS (t/ha) and sucrose percentage on cane yield while highest indirect effect was via single cane weight on cane yield. Similar results reported by Belwal and Ahmad (2020b); Somu *et al.* (2020); Kumar *et al.* (2016) where CCS (%), brix (%), purity (%), single cane weight, number of millable canes, extraction (%), stalk length and stalk diameter exhibited positive direct effect, while negative direct effect by germination (%) on cane yield under waterlogged conditions.

The residual (unexplained) variation in the path analysis was 0.73 and 0.53 under waterlogged environment on phenotypic and genotypic correlations, respectively among component traits of cane yield, while among quality traits it was 0.64 (phenotypic) and 0.67 (genotypic) under waterlogged environment examined for all the clones. This residual variation showed that among the clones, there was still unexplained and unrecognized variation that could not be revealed by above traits considered. Yet more component traits of cane yield and physiological and quality traits are required to disclose the same.

Table 3: Phenotypic (Below Diagonal) & Genotypic (Above Diagonal) correlation coefficient among cane yield, its components and physiological traits under waterlogged conditions.

Traits	Germination (%)	NMC (000/ha)	Stalk length (cm)	Stalk diameter (cm)	SCW (kg)	Number of internodes	Avg. internode length (cm)	Leaf area (cm^2)	Number of stomata	Dry biomass (g/plant)	Total chl (mg/g)	Cane yield (t/ha)
Germination		0.321**	0.062	0.166	0.069	0.207	-0.336**	-0.028	-0.01	-0.034	-0.118	**0.320****
NMC	0.249*		-0.038	-0.730**	-0.790**	-0.085	0.087	-0.251*	-0.052	0.579**	-0.276**	**0.179**
Stalk length	0.052	-0.014		0.05	0.422**	0.439**	0.121	-0.167	0.033	0.320**	0.141	**0.157**
Stalk diameter (cm)	0.05	-0.423**	-0.011		1.064**	0.044	0.089	0.754**	0.064	0.798**	0.155	**0.365****
SCW (kg)	0.025	-0.472**	0.356**	0.690**		0.389**	-0.198	0.715**	-0.082	0.743**	0.361**	**0.400****
Number of internodes	0.188	-0.122	0.372**	0.01	0.265*		-0.934**	-0.252*	-0.085	0.13	0.065	**0.296****
Avg. internode length (cm)	-0.009	0.240*	0.202	-0.045	-0.042	-0.474**		0.254*	-0.234*	0.03	0.023	**0.004**
Leaf area (cm^2)	0.019	-0.195	-0.146	0.435**	0.359**	-0.197	0.169		0.073	0.485**	0.229*	**0.256***
Number of stomata	-0.022	0.121	0.03	-0.051	-0.072	-0.04	0.084	-0.07		0.158	-0.295**	**0.148**
Dry biomass (g/plant)	-0.073	0.363**	0.277**	0.496**	0.553**	0.109	0.006	0.362**	0.151		0.207	**0.361****
Total chl (mg/g)	-0.116	-0.184	0.109	0.126	0.169	0.044	-0.026	0.203	-0.155	0.157		**-0.064**
Cane yield (t/ha)	**0.165**	**0.139**	**0.148**	**0.281****	**0.251***	**0.236***	**0.016**	**0.153**	**0.081**	**0.224***	**-0.068**	

* Significant at 5% level of significance; ** Significant at 1% level of significance; NMC: number of millable canes; SCW: Single cane weight and Total chl: Total chlorophyll

Table 4: Phenotypic (Below Diagonal) and Genotypic (Above Diagonal) correlation coefficient among juice quality traits under waterlogged conditions.

Traits	Brix (%)	Sucrose (%)	Purity (%)	CCS (%)	Extraction (%)	CCS (t/ha)
Brix (%)		0.950**	0.007	1.157**	0.063	0.532**
Sucrose (%)	0.919**		0.324**	1.271**	0.136	0.630**
Purity (%)	-0.260*	0.139		0.573**	0.199	0.375**
CCS (%)	0.761**	0.897**	0.284**		0.265*	0.606**
Extraction (%)	0.152	0.114	-0.106	0.055		0.237*
CCS (t/ha)	0.425**	0.535**	0.240*	0.591**	0.086	

***** Significant at 5% level of significance ** Significant at 1% level of significance

Table 5: Estimates of direct (Bold) and indirect effects of cane yield, its components and physiological traits on cane yield (t/ha) under waterlogged conditions.

Traits		Germination (%)	NMC (000/ha)	Stalk length (cm)	Stalk diameter (cm)	SCW (kg)	Number of internodes	Avg. internode length (cm)	Leaf area (cm^2)	Number of stomata	Dry biomass (g/plant)	Total chl (mg/g)	Correlation with cane yield (t/ha)
Germination (%)	P	**-0.002**	0.087	0.001	0.016	0.001	0.058	-0.001	0.002	-0.001	-0.008	0.011	**0.165**
	G	**1.181**	-0.603	0.086	-0.575	-0.020	-0.296	0.535	-0.074	0.009	-0.039	0.117	**0.320***
NMC (000/ha)	P	-0.001	**0.349**	0.000	-0.136	-0.016	-0.038	0.016	-0.020	0.005	-0.038	0.017	**0.139**
	G	0.379	**-1.879**	-0.052	2.530	0.232	0.122	-0.138	-0.665	0.049	-0.672	0.273	**0.179**
Stalk length (cm)	P	0.000	-0.005	**0.011**	-0.004	0.012	0.115	0.014	-0.015	0.001	0.029	-0.010	**0.148**
	G	0.074	0.071	**1.375**	-0.175	-0.124	-0.628	-0.192	-0.443	-0.032	0.371	-0.140	**0.157**
Stalk diameter (cm)	P	0.000	-0.148	0.000	**0.321**	0.024	0.003	-0.003	0.045	-0.002	0.053	-0.012	**0.281***
	G	0.196	1.373	0.069	**-3.464**	-0.312	-0.063	-0.142	1.996	-0.061	0.926	-0.153	**0.365***
SCW (kg)	P	0.000	-0.165	0.004	0.221	**0.034**	0.082	-0.003	0.038	-0.003	0.059	-0.016	**0.251***
	G	0.081	1.484	0.580	-3.684	**-0.294**	-0.556	0.315	1.891	0.078	0.862	-0.357	**0.400***
Number of internodes	P	0.000	-0.043	0.004	0.003	0.009	**0.310**	-0.032	-0.021	-0.002	0.012	-0.004	**0.236***
	G	0.244	0.160	0.603	-0.152	-0.114	**-1.431**	1.486	-0.666	0.081	0.151	-0.065	**0.296***
Avg. internode length (cm)	P	0.000	0.084	0.002	-0.014	-0.001	-0.147	**0.068**	0.018	0.003	0.001	0.003	**0.016**
	G	-0.397	-0.163	0.166	-0.310	0.058	1.336	**-1.591**	0.672	0.222	0.035	-0.023	**0.004**
Leaf area (cm^2)	P	0.000	-0.068	-0.002	0.140	0.012	-0.061	0.012	**0.104**	-0.003	0.038	-0.019	**0.153**
	G	-0.033	0.472	-0.230	-2.613	-0.210	0.360	-0.404	**2.646**	-0.069	0.563	-0.227	**0.256***
Number of Stomata	P	0.000	0.042	0.000	-0.017	-0.002	-0.012	0.006	-0.007	**0.041**	0.016	0.015	**0.081**
	G	-0.012	0.098	0.046	-0.223	0.024	0.122	0.373	0.193	**-0.948**	0.183	0.292	**0.148**
Dry biomass (g/plant)	P	0.000	-0.127	0.003	0.159	0.019	0.034	0.000	0.038	0.006	**0.106**	-0.015	**0.224***
	G	-0.040	1.088	0.440	-2.765	-0.218	-0.186	-0.048	1.283	-0.149	**1.161**	-0.205	**0.361***
Total chl (mg/g)	P	0.000	-0.064	0.001	0.041	0.006	0.014	-0.002	0.021	-0.006	0.017	**-0.095**	**-0.068**
	G	-0.139	0.518	0.194	-0.536	-0.106	-0.093	-0.037	0.605	0.279	0.240	**-0.991**	**-0.064**

P=Phenotypic level; G=Genotypic level; Residual at phenotypic level=0.73; Residual at genotypic level=0.53; Number of millable canes, SCW: Single cane weight and Total chl: Total chlorophyll

Table 6: Estimates of direct (Bold) and indirect effects of different juice quality traits on commercial cane sugar (t/ha) under waterlogged conditions.

Traits		Brix (%)	Sucrose (%)	Purity (%)	CCS (%)	Extraction (%)	Correlation with CCS (t/ha)
Brix (%)	P	**-0.620**	0.613	0.039	0.383	0.009	**0.425***
	G	**3.402**	-3.339	0.008	0.451	0.010	**0.532***
Sucrose (%)	P	-0.570	**0.667**	-0.021	0.451	0.007	**0.535***
	G	3.231	**-3.517**	0.400	0.496	0.021	**0.630***
Purity (%)	P	0.161	0.093	**-0.150**	0.143	-0.006	**0.240***
	G	0.023	-1.138	**1.237**	0.224	0.030	**0.375***
CCS (%)	P	-0.471	0.599	-0.043	**0.503**	0.003	**0.591***
	G	3.936	-4.470	0.709	**0.390**	0.040	**0.606***
Extraction (%)	P	-0.094	0.076	0.016	0.028	**0.060**	**0.086**
	G	0.215	-0.479	0.246	0.103	**0.151**	**0.237***

Residual at phenotypic level under E_1=0.64; Residual at genotypic level under E_2=0.67; P=Phenotypic level; G=Genotypic level; CCS=Commercial cane sugars

CONCLUSIONS

It is evident from present study that sugarcane is suitable cultivation under waterlogging conditions within some catchment areas under rivers basins in Punjab but lack of suitable varieties poses a hindrance in increasing the cane yield and sucrose. Information generated on genetic variability for different agronomic, physiological and quality traits under waterlogging can help to develop of tolerant varieties. The present results suggest that the sugarcane yield is significantly associated with single cane weight, stalk diameter, number of internodes and dry biomass for higher cane yield under waterlogging conditions. Most of the yield and quality related traits have shown moderate to low heritability and genetic advance. Path analysis revealed high positive direct effect of number of millable canes and leaf area on cane yield while stalk diameter had highest positive significant indirect effects on cane yield *via* dry biomass and number of millable canes. In sugarcane varietal development programme selection for these traits in association with commercial traits would lead to a significant improvement in cane and sugar yield under water logged conditions to harness economic returns for sugar industry and farming community.

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