Pak. J. Bot., 50(4): 1441-1450, 2018.

FIELD EVALUATION OF DIVERSE SUGARCANE GERMPLASM IN AGROCLIMATIC CONDITIONS OF TANDOJAM, SINDH

MUHAMMAD TAHIR KHAN*, IMTIAZ AHMED KHAN, SHAFQUAT YASMEEN, NIGHAT SEEMA AND GHULAM SHAH NIZAMANI

Biotechnology Group, Plant Breeding and Genetics Division, Nuclear Institute of Agriculture (NIA), Tandojam, 70060, Pakistan
**Corresponding author's email: tahir-khan@mail.com*

Abstract

Sugarcane (*Saccharum officinarum*) is the major source of sugar in Pakistan. Development of new high yielding cane varieties is crucial to enhance its production to meet the ever-increasing demands of sugar. In this study, 41 sugarcane genotypes were evaluated in randomized complete block design in field conditions, with three replications. Seven quantitative characteristics of the crop including stalk height, number of tillers per plant, cane girth, length of the internodes, number of internodes per stalk, weight per stool, and the cane yield were analysed; whereas seven quality related traits (brix%, CCS%, fiber%, sucrose%, purity%, sugar recovery, and sugar yield) were also investigated. The dependency of cane and sugar yield on these parameters was determined through correlation and scatter plot analysis. The analysis of variance revealed significant differences among genotypes for all the characteristics studied. NIA223P3 showed substantial superiority recording highest cane yield of 63.33 t ha^{-1} against 51.66 t ha^{-1} of the check (Thatta-10). CSSG-272 surpassed all of the genotypes under study in terms of sugar yield (5.86 t ha^{-1}), while, least sugar yield was observed in S2003SPSG-12 (1.76 t ha^{-1}). Maximum cane height was recorded in BL4P70 (262.0 cm), whereas NIA86-223 exhibited the highest cane girth (2.5). Moreover, regarding juice quality related traits, TSG-21 performed exceptionally good with CCS%, brix%, and sucrose% values of 11.58%, 20.5%, and 16.35%, respectively. Lowest qualitative parameters were, on the other hand, observed in NIA223P3 (CCS%, sucrose%, purity, and sugar recovery values of 5.49%, 9.18%, 68.32%, and 5.16%, respectively). Scatter plots of the data and the correlation analysis depicted that the cane weight, tillers per plant, internode length, and plant height contributed the most towards the cane yield. It was also seen that the quantitative traits were highly correlated with other quantitative traits however, negative correlations were observed among quantitative and qualitative characteristics.

Key words: Correlation, Field evaluation, Genotypes, Scatter matrix, Sugarcane.

Introduction

Sugarcane (*Saccharum officinarum* L.) is world's largest crop with respect to total production. Brazil, India, China, Thailand, and Pakistan are the top cane growing countries of the world. Pakistan, ranked fifth in cane production, is South Asia's biggest per capita consumer of sugar (Azam & Khan, 2010). Therefore, sugarcane is one of the most important cash crops of Pakistan (Memon *et al.*, 2010; Khan *et al.*, 2017a). Being major source of sugar in the country, sugarcane is responsible for meeting the needs of the second largest industry of Pakistan by more than 99% (Williams & Rehman, 2016). Apart from sugar, it also produces numerous byproducts *viz.* alcohol for pharmaceutical industry, bagasse for paper, ethanol for biofuel production, and press mud for organic matter engenderment (Almazan *et al.*, 2001; Szczerbowski *et al.*, 2014; Khan *et al.*, 2017c). Its share in the total agricultural value addition is 3.1 % and 0.6 % in GDP of the country (Ministry of Finance, Pakistan, 2015).

Sugarcane's paramountcy as a crop commodity is increasing in Pakistan over the years. Drop in competing crops i.e. rice and cotton has caused an upsurge in sugarcane cultivation by more than 3 percent in previous years as per reports of Sugar Crops Research Institute, Mardan (SCRI, 2015). High tariffs and support prices for sugarcane has made it a more looked-for agricultural choice for growers (Williams & Rehman, 2016). It is being grown in Punjab, Sindh, and Khyber Pakhtunkhwa (KPK) provinces of the country. Currently, 84 sugar mills are operating in the country, out of which Punjab, Sindh, and Khyber Pakhtunkhwa (KPK) have 45, 32, and 7 sugar mills respectively (SCRI, 2015).

Total area under sugarcane cultivation in Pakistan is approximately 1.1 million hectares. Punjab shares 62 % of the total area, whereas Sindh and KPK account for 28, and 10%, respectively. Annual production of the sugarcane in Pakistan is 62.8 million tonnes, however, the per hectare yield is far lower than other cane growing countries (FAOSTAT, 2014, 2015). Average yield of cane in Pakistan is around 54.96 t/ha, well below the world average. The per hectare yield of the cane growing provinces is 54, 56, and 41 t/ha for Punjab, Sindh, and KPK, respectively (SCRI, 2015). Moreover, Sugar recovery in Pakistan stays at 9.41 % as per recent reports, in comparison to India's 11.05% and Australia's 13.8 % sugar recovery (Khan *et al.*, 2013; FAOSTAT, 2014; Singh *et al.*, 2016).

There are numerous reasons of low yield in the country however, the major cause is the plantation of unapproved and low yielding varieties, while other factors include the limitation of irrigation resources, lack of technology adoption, irregular use of fertilizers, and poor management practices. Therefore, there is still considerable potential of sugarcane improvement in Pakistan in contrast to other top growing nations (Bahadar *et al.*, 2002; Soomro *et al.*, 2006; Williams & Rehman, 2016). Thus, it is extremely important to develop new cane varieties through varietal development programs to meet the increasing needs for ever-escalating population of the country.

Sugarcane varietal development program in Pakistan is hampered by several factors which include the unavailability of new genetic resources, flowering deterrents, pollen sterility, and the subtropical climate (Khatri *et al*., 2002; Seema *et al*., 2017). The lack of new high yielding, and tolerant varieties has limited the crop's potential in Sindh province as well. Moreover, it has been reported by several researchers that a variety loses its potential agronomic vigor, as well as biotic and abiotic stress tolerance over time as the new races or biotypes of diseases and insects can adopt themselves to attack the previously resistant varieties, thus making them susceptible (Bonman *et al.*, 1992; Khush, 1995; Karyeija *et al.*, 2000).

Therefore, it is essential to develop new genotypes, evolved at agroclimatic conditions of the province which could perform well under the same environments. Continuous breeding efforts are essential for an agricultural country like Pakistan. New varieties can have better performance in terms of yield, vigour, and stress tolerance; and they can help in fulfilling the ever-increasing food desiderata for growing population (Rogers *et al*., 2015; Khan *et al.,* 2017b*;* Yasmeen *et al.*, 2017). This study was initiated to evaluate the exotic and local germplasm, as well as mutated genotypic collection in order to find the best performing genotypes which could lead to development of novel varieties, resistant to biotic and abiotic stresses.

Materials and Methods

In this study, 41 genotypes were tested along with a control (Thatta-10). The trials were conducted at experimental farm of Nuclear Institute of Agriculture (NIA), Tandojam, Sindh. The study area is located at latitude and longitude of 25.25º and 68.33º, respectively. The annual rainfall of the region is 145 mm, 75% of which occurs in monsoon period of summer season (Kazi *et al.*, 2015). Trials were conducted in randomized complete block design (RCBD), with three replications. The size of each plot was 8 x 10m, while distance between furrows was maintained at one meter.

Sowing was done in the month of September, whereas the crop was harvested in the first week of November. NPK fertilizer was applied at the rate of 128-63-70 kg ha^{-1}, and recommended agronomic practices were followed throughout the growth period (Khan *et al.*, 2005). Several qualitative and quantitative parameters were recorded at maturity to evaluate the performance of the genotypes against the check variety. Three culms were randomly analysed from each row for this purpose. Seven major quantitative characters of the crop including stalk height, number of tillers per plant, cane girth, length of the internodes, number of internodes per stalk, weight per stool and cane yield were analysed. Moreover, brix %, CCS %, fiber %, sucrose %, purity %, sugar recovery, and sugar yield were also investigated as qualitative traits of the cane crop. Sugar analysis was done following the protocols of Khan *et al.*, (2015).

Statistix version 8.1 was used for statistical analysis of the data. One-way analysis of variance (ANOVA) was done for the characteristics under study, comparing the means at a confidence level of $p \leq 0.05$ through Tuckey's test. SPSS version 21 was used on windows operating system for assessing correlation of the variables, while scatter plots were developed for cane and sugar yield modulating factors through OriginLab, version 2016.

Results and Discussion

The germplasm under study, showed high variability in quantitative and qualitative characters. Significant differences were observed among the genotypes in this regard (Tables 1 and 2). Data of the quantitative characters of the evaluated genotypes have been presented in Table 3, whereas Table 4 shows data for juice quality related traits of the trials. Height of the plants in the trial ranged from 98.3 cm to 262.0 cm. The highest cane height was recorded in BL4P70 (262.0 cm) followed by NIA223P3 (255.33) and 1026P33 (248.0 cm). Least cane height was, on the other hand, recorded by the clones NIA-09P3 (98.33cm). Cane girth also considerably varied among the genotypes under study. Maximum values for girth were recorded by NIA86-223 (2.5 cm) while least values were presented by TSG-13 (2.06 cm).

Tillering potential of a variety is one of the most important characteristics considering yield potential. Many of the sugarcane genotypes showed excellent tillering potential (NIA-09P3, CSSG-272, SPSG-2875, TSG-13, and Thatta-10) whereas some of the genotypes showed a few tillers e.g. only 2.66 tillers were recorded for S2003SPSG-12 on average. Internode parameters are also major traits regarding quantitative performance of the clones. Highest numbers of internodes were observed in BL4P70 (26.66) however Thatta-10 recorded the longest internode of 14.83 cm. Conversely, shortest internodes were seen in Ghulabi-95 (5.66 cm). Similarly, least number of internodes were observed in NIA-09P3 (11.33). The internode parameters are significant contributors towards cane height, consequently, cane height for Ghulabi-95 as well as NIA-09P3 was among the lowest in the study.

Table 1. Analysis of variance (mean squares) for different quantitative characters in sugarcane germplasm

Source	df	Stalk height	Number of tillers	Girth	Internodes length	Number of internodes	Weight per stool	Cane yield
Rep	2	2918.67	3.38889	0.11817	3.1567	4.9127	0.49008	49.008
Germplasm	41	5848.31**	3.10492**	0.02280**	10.9265**	23.2925**	3.07515**	307.515**
Error	82	150.32	0.29133	0.00809	0.3397	0.3111	0.20553	20.553
Total	125							
Grand mean		177.15	5.0159	2.2508	9.5278	18.770	3.8373	38.373
CV		6.92	10.76	4.00	6.12	2.97	11.81	11.81

Table 1. Analysis of variance of the genotypic pool under study was done through Statistix version 8.1 on windows operating system.
41 genotypes were subjected to the statistical analysis through this platform

Table 2. Analysis of variance (mean squares) for different qualitative characters in sugarcane germplasm

Source	df	Brix %	CCS %	Fiber %	Sucrose %	Purity %	Sugar recovery	Sugar yield
Rep	2	0.47151	0.14887	1.8251	0.42174	0.4927	0.13053	0.71362
Germplasm	41	7.39862**	5.32559**	10.2057**	7.54630**	19.0845**	4.70157**	2.69508**
Error	82	0.54037	0.33973	1.2864	0.51761	2.2663	0.30017	0.26491
Total	125							
Grand mean		17.467	9.0314	12.868	13.293	75.867	8.4894	3.4400
CV		4.21	6.45	8.81	5.41	1.98	6.45	14.96

Table 2. Analysis of variance of the genotypic pool under study was done through Statistix version 8.1 on windows operating system.
41 genotypes were subjected to the statistical analysis through this platform

Table 3. Assessment of quantitative traits of sugarcane germplasm under agroclimatic conditions of Tandojam

Genotype	Plant height (cm)	Tillers per plant	Cane girth (cm)	Internode length (cm)	Internodes per stalk	Cane weight per plant (kg)	Cane yield (t/ha)
NIA-09P3	98.33u	6.66a	2.26c-g	8.66i	11.33n	4.16ef	41.66ef
NIA-03	100.33u	4.66de	2.26c-g	7.33jk	13.66l	4.33ef	43.33ef
S-2003-QSG-22	126.67rs	3.66f	2.26c-g	10.00fg	12.66m	2.66hi	26.66hi
AEC-1	106.33tu	4.33ef	2.16f-h	6.66k	16.00k	3.66fg	36.66fg
HS-12	149.33o-q	5.33cd	2.20e-h	7.33jk	20.33ef	4.66de	46.66de
BL4P70	262.00a	5.66bc	2.20e-h	12.66c	26.66a	5.50bc	55.00bc
NIA-223P4	241.67bc	5.66bc	2.36a-d	11.33de	21.33cd	4.83c-e	48.33c-e
CSSG-272	199.33f-h	6.66a	2.26cde-g	10.66ef	18.66h	5.66ab	56.66ab
QSSG-239	188.00h-j	4.66de	2.26c-g	8.66i	21.66c	2.66hi	26.66hi
BL4P36	167.33k-o	5.66bc	2.16f-h	8.66i	19.33gh	3.66fg	36.66fg
GT-11	194.67g-i	3.66f	2.33b-e	11.66d	16.66jk	3.66fg	36.66fg
QSG-23	199.33f-h	5.66bc	2.30b-f	8.66i	22.66b	3.33gh	33.33gh
SIKH	231.33c-e	4.66de	2.43ab	10.66ef	21.66c	4.16ef	41.66ef
NIA86-223	217.67d-f	4.66de	2.50a	11.66d	18.66h	3.33gh	33.33gh
GT-7	164.67l-o	4.66de	2.30b-f	9.33g-i	17.66i	4.16ef	41.66ef
NIA223P3	255.33ab	6.33ab	2.43ab	9.33g-i	21.66c	6.33a	63.33a
SPSG-2875	202.00f-h	6.66a	2.20e-h	13.66b	18.66h	4.66de	46.66de
S2003-US637	178.00i-m	3.66f	2.23d-g	10.66ef	16.66jk	2.66hi	26.66hi
SGNIA-10	177.00i-m	3.66f	2.13gh	9.00hi	19.66fg	2.66hi	26.66hi
1026P33	248.00a-c	4.66de	2.26c-g	12.00cd	20.66de	3.66fg	36.66fg
Ghulabi-95	100.33u	4.66de	2.16f-h	5.66l	17.66i	3.33gh	33.33gh
CP67-500	111.33s-u	5.00c-e	2.23d-g	6.66k	16.66jk	3.66fg	36.66fg
S47-US-183	170.67j-n	3.66f	2.23d-g	8.66i	19.66fg	2.33i	23.33i
S2003SPSG-12	143.33p-r	2.66g	2.40a-c	7.66j	18.66h	2.16i	21.66i
CP-718	122.67st	4.66de	2.30b-f	7.66j	16.00k	3.33gh	33.33gh
S2003-HOSG-4	199.33f-h	3.66f	2.16f-h	9.33g-i	21.33cd	2.16i	21.66i
SPSG-26	213.67e-g	3.66f	2.30b-f	10.66ef	20.00e-g	2.33i	23.33i
NIA-SP96-345	183.33h-l	5.66bc	2.26c-g	9.33g-i	19.66fg	4.16ef	41.66ef
SPSG-449	122.00st	5.00c-e	2.30b-f	7.33jk	16.66jk	3.16gh	31.66gh
S2006SP-18	131.00q-s	4.33ef	2.20e-h	7.00jk	18.66h	3.66fg	36.66fg
S04-CSSG-234	167.33k-o	6.33ab	2.20e-h	8.66i	19.33gh	3.66fg	36.66fg
S06SPSG-24	184.67h-k	4.33ef	2.16f-h	10.66ef	17.33ij	2.33i	23.33i
CSSG-32	155.33n-p	5.66bc	2.16fgh	9.33g-i	16.66jk	4.16ef	41.66ef
LRK-2004	231.33c-e	5.66bc	2.26c-g	10.66ef	21.66c	4.16ef	41.66ef
GT-7	164.67l-o	4.66de	2.30bcdef	9.33g-i	17.66i	4.16ef	41.66ef
TSG-13	199.33f-h	6.66a	2.06h	10.66ef	18.66h	4.66de	46.66de
TSG-14	236.67b-d	5.66bc	2.26c-g	9.66gh	20.66de	5.66ab	56.66ab
TSG-21	198.33f-h	5.66bc	2.16f-h	9.00hi	22.00bc	4.33ef	43.33ef
TSG-16	162.00m-p	4.66de	2.23d-g	9.33g-i	17.33ij	4.66de	46.66de
LRK-2001	178.00i-m	4.66de	2.20e-h	10.66ef	16.66jk	3.66fg	36.66fg
BL4P36	167.33k-o	5.66bc	2.16fgh	8.66i	19.33gh	3.66fg	36.66fg
Thatta-10	190.33h-j	6.66a	2.20e-h	14.83a	19.66fg	5.16bcd	51.66b-d
SD	10.01	0.44	0.07	0.47	0.45	0.37	3.70
HSD	19.91	0.87	0.14	0.94	0.90	0.73	7.36

Table 3. The table presents the data for various quantitative characteristics of the germplasm population against the check i.e.,Thatta-10. Different letters in the same column represent that the difference is significant at $p<0.05$

NIA223P3 was observed to have the highest yield potential of 63.33 tons per hectare (t/ha), followed by CSSG-272 and TSG-14 (56.66 t/ha). The cane yield of a variety is contributed by numerous traits which include the cane weight, number of tillers per plant, cane height, girth, and number of internodes (Rahman *et al.*, 1992; Khan *et al.*, 2005). The maximum cane yield of NIA223P3 was indeed a result of combinatorial effect of all of the mentioned characteristics as it had shown a good blend of such traits (Table 3). Similar reports have been published by other researchers as well (Quebedeaux & Martin, 1986; Balsalobre *et al.*, 2016).

Regarding qualitative traits of the genotypes, TSG-21, S47-US-183, and AEC-1 performed exceptionally good when compared to the other genotypes, in terms of CCS%, brix%, sucrose%, purity, and sugar recovery. The CCS%, brix%, and sucrose% values for TSG-21, and S47-US-183 were recorded to be 11.58, 20.5, 16.35; and 11.48, 20.5, 16.35, respectively. Moreover, these genotypes also recorded highest purity, and sugar recovery among the genetic pool studied. Lowest values for the five aforementioned qualitative parameters were observed in NIA223P3, which recorded CCS%, brix%, sucrose %, purity, and sugar recovery values of 5.49, 13.33, 9.18, 68.32, and 5.16%, respectively. Fiber percent, which depicts the energy potential of the genotypes in the crushing process, was observed to be highest for TSG-16 (16.43), whereas the lowest fiber percentage was seen in NIA-03 (9.49 %).

Sugar yield potential is the most important parameter in cane varietal selection. Many of the genotypes tested in this study produced sugar yield values higher than control (Thatta-10), which demonstrates the importance of varietal screening for new lines. Highest sugar yield was observed in CSSG-272 (5.86 t/ha) which was extremely promising against the sugar yield potential of check variety Thatta-10 (4.96 t/ha). TSG-14 followed CSSG-272 in terms of this parameter harvesting 5.55 t/ha of sugar, whereas TSG-21 recorded the sugar yield of 5.02 t/ha. Lowest sugar yield was recorded by S2003SPSG-12 (1.76 t/ha).

The variations observed among different genotypes of the sugarcane evaluated in this study were in agreement with several previous studies (Khan *et al.*, 2004, 2013; Yasmin *et al.*, 2011). The genetic composition of a variety dictates its yield and agronomic potential. Das *et al.*, (1996), Keerio *et al.*, (2003), Kadam *et al.*, (2004), and Sohu *et al.*, (2008) also proposed similar behaviour of various genotypes grown in same agroclimatic conditions and reported differences among various agronomic characters including the mentioned yield components. Moreover, our results were also in alignment with Das *et al.*, (1996) and Sugimoto *et al.*, (2012) who reported that the qualitative traits were purely genetic characters. Arain *et al.*, (2011) also evaluated 12 genotypes against same check *viz.* Thatta-10 in the agroclimatic conditions of Sindh, and reported that no sugarcane clone could surpass the check. However, contrarily our results indicated the check variety to be surpassed by many genotypes in numerous characteristics. The evaluated promising genotypes can replace the current varieties under cultivation in the province through further evaluation and selection.

Sugarcane screening and selection is extremely tricky because of the fact that it is very difficult to achieve high cane yields, and sugar recovery, in the same genotype. It has been observed over the years that improvement in one trait results in impact on many others (Chaudhary & Joshi, 2005). Sugar, as well as cane yield, both are crucial parameters for the two major stake holders *viz.* the farmers, and the sugar mills of the country. To have an insight in to the interrelations of different variables of the cane crop, correlation analysis was done in this study.

Results of the correlation study, were quite interesting obtained from the analysis of the variations in various parameters (Table 5). Plant height showed highest correlation with the internode length (0.841) and the number of internodes per stalk (0.707). Cane girth was not observed to be highly correlated to other traits however, it showed significant negative correlation with brix %, sucrose %, and purity. Whereas, number of tillers of the genotypes showed very significant correlation with the cane weight (0.767). It was evident from results of the correlation analysis that most of the quantitative traits had extremely negative correlation with the qualitative characters which explicates the difficulty in cane breeding, and the results we obtained.

Most of the qualitative traits were seen to be highly correlated to each other. In many of the cases, observed correlation was even very close to 1 - the maximum correlation value. CCS% recorded the correlation of 0.996, 0.986, 0.974, and 0.965 with the sugar recovery, sucrose%, brix%, and purity%. Brix%, and purity% also showed similar trends showing highest correlation with sucrose % (0.995) and sugar recovery (0.965), respectively. Similarly, sugar recovery was significantly correlated with sucrose and brix % recording the correlation values of 0.986, and 0.974, respectively. Parallel findings regarding the qualitative traits' correlation were reported by Sangwan & Singh (1983) as well. Moreover, our finding are also confirmed by the reports of Soomro *et al.*, (2006) and Khan *et al.*, (2012).

Cane yield and sugar yield are the most important parameters under consideration in varietal selection programs. Quantitative parameters under study, which contributed the most towards cane yield were observed to be cane weight, and tillers per plant with correlation values of 1 and 0.767 (significant at $p<0.01$), respectively. Internodes' length also significantly contributed towards cane yield (0.320). Most of the qualitative traits, on the other hand, showed negative effects on cane yield to some extent. However, sugar yield, the other major parameter of concern, was observed to be contributed by both the quantitative as well as qualitative parameters. It showed strongest correlation with the cane yield and cane weight (0.797). Other traits which were significantly correlated to sugar yield at a level of $p<0.01$ included tillers per plant (0.726), CCS% (0.403), brix% (0.412), sucrose% (0.396), and sugar recovery (0.403), whereas purity contributed by correlation value of 0.314 at a level of $p<0.05$ (Table 5).

Table 4. Assessment of qualitative traits of sugarcane germplasm under agroclimatic conditions of Tandojam.

Genotype	Brix %	CCS %	Fiber %	Sucrose %	Purity %	Sugar recovery	Sugar yield (t/ha)
NIA-09P3	17.66d-g	9.47d-i	10.667j-l	13.51d-g	76.49c-h	8.90d-i	3.93e-i
NIA-03	18.66cd	10.45bc	9.49l	14.51cd	77.75a-f	9.82bc	4.53c-e
S-2003-QSG-22	16.33hi	8.23lm	11.98f-k	12.18h-j	74.57hi	7.73lm	2.17q-s
AEC-1	20.00ab	11.28ab	11.57g-k	15.85ab	79.24ab	10.61ab	4.12d-h
HS-12	17.66de-g	9.27f-k	12.46fg-j	13.51d-g	76.49c-h	8.70f-k	4.31c-g
BL4P70	16.16hi	8.05l-n	12.41f-j	12.01h-j	74.32hi	7.56l-n	4.42c-f
NIA-223P4	14.50jk	6.37pq	16.24ab	10.35kl	71.35jk	5.98pq	3.08j-p
CSSG-272	18.66cd	10.31cd	10.667j-l	14.51cd	77.75a-f	9.68cd	5.86a
QSSG-239	18.16c-f	9.35e-j	15.18a-c	14.01c-f	77.15b-g	8.78e-j	2.48o-s
BL4P36	16.66g-i	8.45j-m	12.41f-j	12.51g-j	75.08g-i	7.94j-m	3.11i-p
GT-11	14.66j	6.88op	11.57g-k	10.51k	71.67jk	6.47op	2.51n-s
QSG-23	18.50c-e	9.64c-h	14.97a-d	14.35c-e	77.55a-f	9.06c-h	3.21i-o
SIKH	16.66g-i	8.52i-l	11.77g-k	12.51g-j	75.08g-i	8.01j-l	3.54g-l
NIA86-223	14.66j	6.88op	11.76g-k	10.51k	71.67jk	6.47op	2.28p-s
GT-7	17.16f-h	8.93g-l	11.76g-k	13.01f-h	75.61f-i	8.40g-l	3.74e-j
NIA223P3	13.33k	5.49q	15.77ab	9.18l	68.32l	5.16q	3.52g-m
SPSG-2875	18.66cd	10.29c-e	10.81i-l	14.51cd	77.75a-f	9.67c-e	4.82b-d
S2003-US637	18.50c-e	10.19c-f	10.493kl	14.35c-e	77.55a-f	9.57c-f	2.73lm-r
SGNIA-10	19.16bc	10.14c-f	15.18a-c	15.01bc	78.34a-e	9.53c-f	2.69m-r
1026P33	16.83g-i	8.64i-l	11.98f-k	12.68g-j	75.34f-i	8.12i-l	3.18i-o
Ghulabi-95	18.66cd	10.08c-f	12.41f-j	14.51cd	77.75a-f	9.48c-f	3.35h-n
CP67-500	18.16c-f	9.77c-g	11.57g-k	14.01c-f	77.15b-g	9.18c-g	3.58g-k
S47-US-183	20.50a	11.48a	13.06e-h	16.35a	79.75a	10.80a	2.68m-r
S2003SPSG-12	16.66g-i	8.19lmn	14.97a-d	12.51g-j	75.08g-i	7.70lmn	1.76s
CP-718	19.00bc	10.33cd	12.62f-i	14.85bc	78.14a-e	9.71cd	3.44h-m
S2003-HOSG-4	17.00f-h	8.79h-l	11.77g-k	12.85f-i	75.57f-i	8.27h-l	1.91rs
SPSG-26	16.33hi	8.37k-m	10.537kl	12.18h-j	74.57hi	7.87k-m	1.96rs
NIA-SP96-345	17.00f-h	8.80h-l	11.76g-k	12.85f-i	75.57f-i	8.27h-l	3.67f-j
SPSG-449	17.33e-h	8.92g-l	13.13d-h	13.18e-h	76.04d-h	8.38g-l	2.82k-q
S2006SP-18	15.66ij	7.52m-o	13.68c-f	11.51jk	73.49ij	7.07m-o	2.74k-r
S04-CSSG-234	19.33a-c	10.52bc	13.27d-g	15.18a-c	78.53a-c	9.88bc	3.86e-j
S06SPSG-24	16.83g-i	8.19lmn	16.10ab	12.68g-j	75.31f-i	7.70lmn	1.92rs
CSSG-32	16.66g-i	8.57i-l	11.29h-l	12.51g-j	75.91e-i	8.05i-l	3.56g-l
LRK-2004	17.23f-h	8.99g-l	11.77g-k	13.08f-h	75.08g-i	8.45g-l	3.74e-j
GT-7	17.16f-h	8.93g-l	11.76g-k	13.01f-h	75.61f-i	8.40g-l	3.74e-j
TSG-13	19.23bc	10.26c-e	14.62a-e	15.08bc	78.42a-d	9.65c-e	4.79b-d
TSG-14	17.00f-h	7.25n-p	14.52b-e	11.81ij	69.69kl	6.81n-p	5.55ab
TSG-21	20.50a	11.58a	12.44f-j	16.35a	79.74a	10.88a	5.02a-c
TSG-16	17.66d-g	8.81h-l	16.43a	13.51d-g	76.49c-h	8.28h-l	4.10d-h
LRK-2001	17.66d-g	8.98g-l	14.97a-d	13.51d-g	76.49c-h	8.44g-l	3.31h-o
BL4P36	16.66g-i	8.45j-m	12.41f-j	12.51g-j	75.08g-i	7.94j-m	3.11i-p
Thatta-10	18.66cd	9.62c-h	16.10ab	14.51cd	77.75a-f	9.04c-h	4.96bc
SD	0.60	0.47	0.92	0.58	1.22	0.44	0.42
HSD	1.19	0.94	1.84	1.16	2.44	0.88	0.84

Table 4. The table represents the data for various qualitative characteristics of the germplasm population against the check i.e., Thatta-10. Different letters in the same column represent that the difference is significant at $p<0.05$

Table 5. Pearson's correlation coefficients among various parameters in sugarcane germplasm.

		Plant height	Girth	Tillers per plant	Number of internodes	Internodes length	Weight per stool	CCS %	Brix %	Sucrose %	Fiber %	Purity %	Sugar recovery	Sugar yield	Cane yield
Plant height	**Pearson correlation**	**1**	**0.186**	**0.262**	**0.707****	**0.841****	**0.301**	**-0.333***	**-0.290**	**-0.309***	**0.163**	**-0.347***	**-0.333***	**0.087**	**0.301**
	Sig. (2-tailed)		0.240	0.094	0.000	0.000	0.053	0.031	0.063	0.047	0.302	0.024	0.031	0.584	0.053
	Sum of Squares & Cross-products	79926.93	29.278	481.677	3563.902	2905.602	551.808	-803.890	-824.294	-885.992	545.088	-1585.03	-755.557	149.02	5518.082
	Covariance	1949.437	0.714	11.748	86.924	70.868	13.459	-19.607	-20.105	-21.610	13.295	-38.659	-18.428	3.635	134.587
Girth	**Pearson correlation**	**0.186**	**1**	**-0.153**	**0.092**	**0.169**	**0.070**	**-0.542****	**-0.573****	**-0.571****	**-0.025**	**-0.561****	**-0.542****	**-0.270**	**0.070**
	Sig. (2-tailed)	0.240		0.334	0.564	0.285	0.660	0.000	0.000	0.000	0.877	0.000	0.000	0.083	0.660
	Sum of Squares & Cross-products	29.278	0.312	-0.556	0.913	1.152	0.253	-2.583	-3.218	-3.235	-0.162	-5.060	-2.428	-0.916	2.526
	Covariance	0.714	0.008	-0.014	0.022	0.028	0.006	-0.063	-0.078	-0.079	-0.004	-0.123	-0.059	-0.022	0.062
Tillers per plant	**Pearson correlation**	**0.262**	**-0.153**	**1**	**0.236**	**0.268**	**0.767****	**0.015**	**0.054**	**0.028**	**0.030**	**-0.061**	**0.015**	**0.726****	**0.767****
	Sig. (2-tailed)	0.094	0.334		0.133	0.086	0.000	0.924	0.732	0.860	0.851	0.702	0.924	0.000	0.000
	Sum of Squares & Cross-products	481.677	-0.556	42.434	27.376	21.370	32.386	0.842	3.566	1.855	2.292	-6.409	0.794	28.699	323.862
	Covariance	11.748	-0.014	1.035	0.668	0.521	0.790	0.021	0.087	0.045	0.056	-0.156	0.019	0.700	7.899
Number of internodes	**Pearson correlation**	**0.707****	**0.092**	**0.236**	**1**	**0.380***	**0.243**	**-0.224**	**-0.108**	**-0.152**	**0.368***	**-0.278**	**-0.224**	**0.054**	**0.243**
	Sig. (2-tailed)	0.000	0.564	0.133		0.013	0.120	0.153	0.496	0.336	0.016	0.075	0.153	0.736	0.120
	Sum of Squares & Cross-products	3563.902	0.913	27.376	318.331	82.824	28.149	-34.144	-19.381	-27.568	77.606	-80.019	-32.083	5.806	281.495
	Covariance	86.924	0.022	0.668	7.764	2.020	0.687	-0.833	-0.473	-0.672	1.893	-1.952	-0.783	0.142	6.866
Internodes length	**Pearson correlation**	**0.841****	**0.169**	**0.268**	**0.380***	**1**	**0.320***	**-0.369***	**-0.314***	**-0.355***	**0.027**	**-0.431****	**-0.369***	**0.101**	**0.320***
	Sig. (2-tailed)	0.000	.285	0.086	0.013		0.039	0.016	0.043	0.021	0.863	0.004	0.016	0.526	0.039
	Sum of Squares & Cross-products	2905.602	1.152	21.370	82.824	149.329	25.384	-38.425	-38.529	-44.029	3.959	-85.056	-36.110	7.466	253.843
	Covariance	70.868	0.028	0.521	2.020	3.642	0.619	-0.937	-0.940	-1.074	0.097	-2.075	-0.881	0.182	6.191
Weight per stool	**Pearson correlation**	**0.301**	**0.070**	**0.767****	**0.243**	**0.320***	**1**	**-0.207**	**-0.170**	**-0.198**	**0.074**	**-0.297**	**-0.207**	**0.797****	**1.000****
	Sig. (2-tailed)	0.053	0.660	0.000	0.120	0.039		0.187	0.280	0.210	0.640	0.056	0.188	0.000	0.000
	Sum of Squares & Cross-products	551.808	0.253	32.386	28.149	25.384	42.027	-11.472	-11.111	-13.008	5.693	-31.144	-10.781	31.353	420.271
	Covariance	13.459	0.006	0.790	0.687	0.619	1.025	-0.280	-0.271	-0.317	0.139	-0.760	-0.263	0.765	10.251
CCS %	**Pearson correlation**	**-0.333***	**-0.542****	**0.015**	**-0.224**	**-0.369***	**-0.207**	**1**	**0.974****	**0.986****	**-0.278**	**0.965****	**0.996****	**0.403****	**-0.207**
	Sig. (2-tailed)	0.031	0.000	0.924	0.153	0.016	0.187		0.000	0.000	0.075	0.000	0.000	0.008	0.187
	Sum of Squares & Cross-products	-803.890	-2.583	0.842	-34.144	-38.425	-11.472	72.780	83.578	85.424	-28.014	132.902	68.410	20.846	-114.723
	Covariance	-19.607	-0.063	0.021	-0.833	-0.937	-0.280	1.775	2.038	2.084	-0.683	3.242	1.669	0.508	-2.798

Table 5. (Cont'd.).

		Plant height	Girth	Tillers per plant	Number of internodes	Internodes length	Weight per stool	CCS %	Brix %	Sucrose %	Fiber %	Purity %	Sugar recovery	Sugar yield	Cane yield
Brix %	**Pearson correlation**	**-0.290**	**-0.573****	**0.054**	**-0.108**	**-0.314***	**-0.170**	**0.974****	**1**	**0.995****	**-0.109**	**0.929****	**0.974****	**0.412****	**-0.170**
	Sig. (2-tailed)	0.063	0.000	0.732	0.496	0.043	0.280	0.000		0.000	0.491	0.000	0.000	0.007	0.280
	Sum of Squares & Cross-products	-824.294	-3.218	3.566	-19.381	-38.529	-11.111	83.578	101.114	101.599	-12.977	150.780	78.563	25.131	-111.112
	Covariance	-20.105	-0.078	0.087	-0.473	-0.940	-0.271	2.038	2.466	2.478	-0.317	3.678	1.916	0.613	-2.710
Sucrose %	**Pearson correlation**	**-0.309***	**-0.571****	**0.028**	**-0.152**	**-0.355***	**-0.198**	**0.986****	**0.995****	**1**	**-0.122**	**0.958****	**0.986****	**0.396****	**-0.198**
	Sig. (2-tailed)	0.047	0.000	0.860	0.336	0.021	0.210	0.000	0.000		0.440	0.000	0.000	0.009	0.210
	Sum of Squares & Cross-products	-885.992	-3.235	1.855	-27.568	-44.029	-13.008	85.424	101.599	103.133	-14.689	157.176	80.296	24.438	-130.077
	Covariance	-21.610	-0.079	0.045	-0.672	-1.074	-0.317	2.084	2.478	2.515	-0.358	3.834	1.958	0.596	-3.173
Fiber %	**Pearson correlation**	**0.163**	**-0.025**	**0.030**	**0.368***	**0.027**	**0.074**	**-0.278**	**-0.109**	**-0.122**	**1**	**-0.179**	**-0.278**	**-0.141**	**0.074**
	Sig. (2-tailed)	0.302	0.877	0.851	0.016	0.863	0.640	0.075	.491	0.440		0.257	0.075	0.374	0.640
	Sum of Squares & Cross-products	545.088	-0.162	2.292	77.606	3.959	5.693	-28.014	-12.977	-14.689	139.478	-34.101	-26.330	-10.079	56.931
	Covariance	13.295	-0.004	0.056	1.893	0.097	0.139	-0.683	-0.317	-0.358	3.402	-0.832	-0.642	-0.246	1.389
Purity %	**Pearson correlation**	**-0.347***	**-0.561****	**-0.061**	**-0.278**	**-0.431****	**-0.297**	**0.965****	**0.929****	**0.958****	**-0.179**	**1**	**0.965****	**0.314***	**-0.297**
	Sig. (2-tailed)	0.024	0.000	0.702	0.075	0.004	0.056	0.000	0.000	0.000	0.257		0.000	0.043	0.056
	Sum of Squares & Cross-products	-1585.03	-5.060	-6.409	-80.019	-85.056	-31.144	132.902	150.780	157.176	-34.101	260.782	124.917	30.786	-311.443
	Covariance	-38.659	-0.123	-0.156	-1.952	-2.075	-0.760	3.242	3.678	3.834	-0.832	6.361	3.047	0.751	-7.596
Sugar recovery	**Pearson correlation**	**-0.333***	**-0.542****	**0.015**	**-0.224**	**-0.369***	**-0.207**	**0.996****	**0.974****	**0.986****	**-0.278**	**0.965****	**1**	**0.403****	**-0.207**
	Sig. (2-tailed)	0.031	0.000	0.924	0.153	0.016	0.188	0.000	0.000	0.000	.075	0.000		0.008	0.188
	Sum of Squares & Cross-products	-755.557	-2.428	0.794	-32.083	-36.110	-10.781	68.410	78.563	80.296	-26.330	124.917	64.303	19.596	-107.809
	Covariance	-18.428	-0.059	0.019	-0.783	-0.881	-0.263	1.669	1.916	1.958	-0.642	3.047	1.568	0.478	-2.629
Sugar yield	**Pearson correlation**	**0.087**	**-0.270**	**0.726****	**0.054**	**0.101**	**0.797****	**0.403****	**0.412****	**0.396****	**-0.141**	**0.314***	**0.403****	**1**	**0.797****
	Sig. (2-tailed)	0.584	0.083	0.000	0.736	0.526	0.000	0.008	0.007	0.009	0.374	0.043	0.008		0.000
	Sum of Squares & Cross-products	149.021	-0.916	28.699	5.806	7.466	31.353	20.846	25.131	24.438	-10.079	30.786	19.596	36.841	313.534
	Covariance	3.635	-0.022	0.700	0.142	0.182	0.765	0.508	0.613	0.596	-0.246	0.751	0.478	0.899	7.647
Cane yield	**Pearson correlation**	**0.301**	**0.070**	**0.767****	**0.243**	**0.320***	**1.000****	**-0.207**	**-0.170**	**-0.198**	**0.074**	**-0.297**	**-0.207**	**0.797****	**1**
	Sig. (2-tailed)	0.053	0.660	0.000	0.120	0.039	0.000	0.187	0.280	0.210	0.640	0.056	0.188	0.000	
	Sum of Squares and Cross-products	5518.082	2.526	323.862	281.495	253.843	420.271	-114.723	-111.112	-130.077	56.931	-311.443	-107.809	313.53	4202.712
	Covariance	134.587	0.062	7.899	6.866	6.191	10.251	-2.798	-2.710	-3.173	1.389	-7.596	-2.629	7.647	102.505

Table 5. Pearson's correlation coefficients: The Pearson's correlation among various parameters in sugarcane germplasm was determined using SPSS v. 21. ** shows that the correlation is significant at the 0.01 level whereas * depicts that the correlation is significant at the 0.05 level (2-tailed)

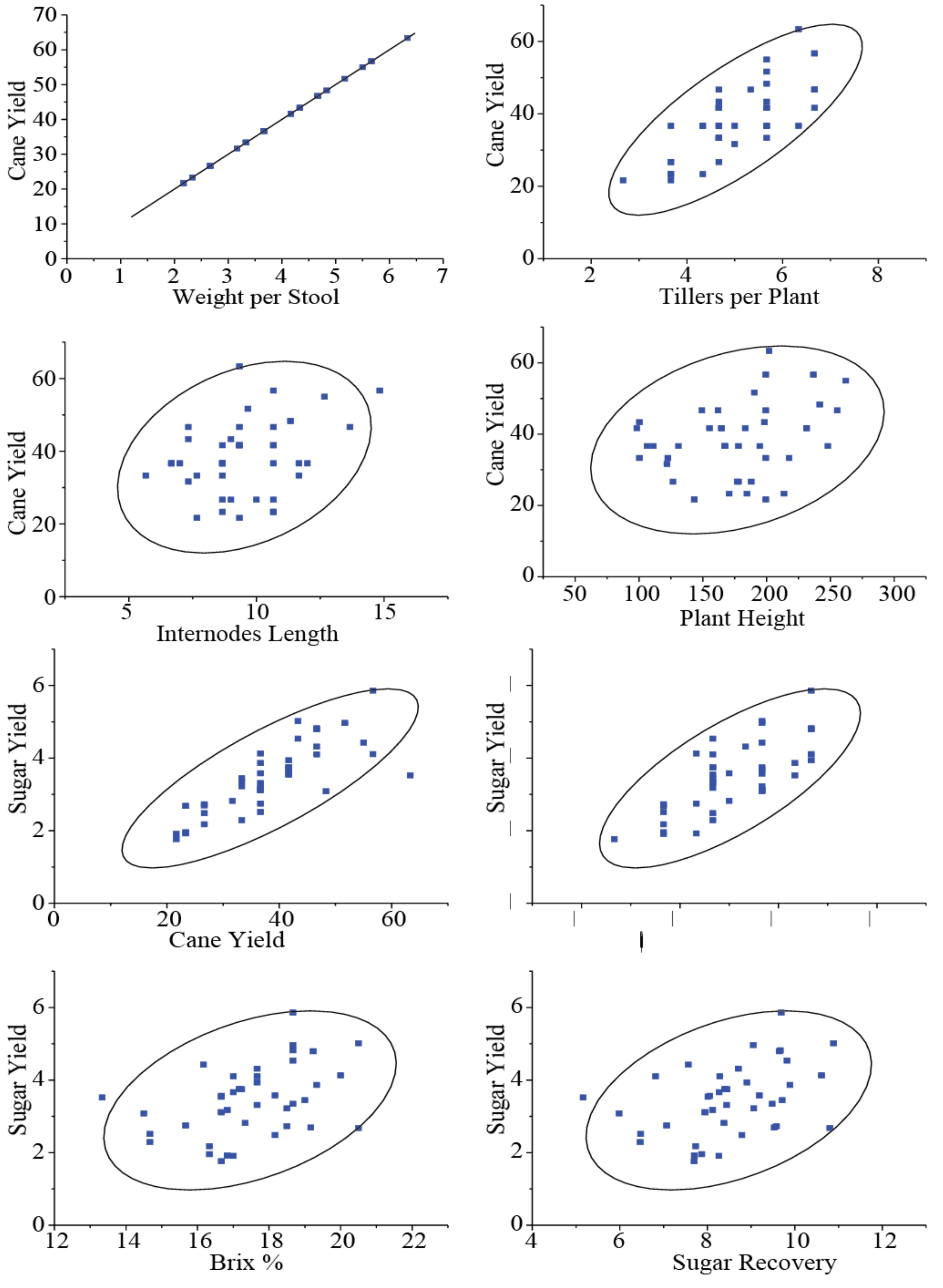

Fig. 1. The scatter plots of highly correlated parameters against cane and sugar yield were developed by subjecting the data to said analysis through computer operated program Origin, version 2016. Weight per stool, tillers per plant, internode length, and plant height highly contributed towards cane yield, whereas cane yield, tillers per plant, brix%, and sugar recovery were the major traits for higher sugar yield.

Yield is one of the most complicated cane traits (Cox *et al.*, 1996). Our observation of its strong dependence on stalk weight, tillers, and height was in accidence with many of the previous reports (Sharma & Agarwal, 1985; Khan *et al.*, 2012). Habib *et al.,* (1991) also published similar results however, they proposed a high role of stalk girth which we did not observe in our correlation analysis. Yield is determined by numerous agronomic, morphological, and physiological factors which further have intricate associations and interrelations (Khan *et al.*, 2012). Varietal selection on the basis of contributing components is advantageous as they have more heritability rather than the yield itself (Risch, 2000; Darvasi & Pisanté-Shalom, 2002).

Our observation of high correlation values of cane yield for tillers per plant, cane height, and weight per stool, and non-significant correlation with cane girth were in alignment with Khan *et al.,* (2013). Raman *et al.,* (1985) also reported that the number of stalks per stool, and height are essential factors for higher cane yield. Regarding sugar yield, we observed the significant and positive correlation with tillers per plant, weight of the stool, and cane yield, and negative correlation with the cane girth which is supported by Khan *et al.,* (2013). Soomro *et al.,* (2006) and Mahmood *et al.,* (1990) also reported highly significant and positive correlation among many of the dependent and independent traits. Moreover, Raza *et al.,* (2014) and Ahmed *et al.,* (2010) also mentioned similar correlation behaviours among sugarcane characters regarding cane and sugar yields, hence confirming our results. Correlation depicts the biological, genetic, physiological, and functional interrelations (Wagner & Schwenk, 2000). Based on our observations from the study, we concluded that tillers per plant, stool weight, and internodes length could serve the genotypic selection for both the cane and sugar yields. However, for higher sugar yields pol %, CCS % and recovery must also be given appropriate weightage.

Scatter plotting of cane and sugar yield was conducted in order to project the variables in scatter subspace between cane and sugar yield, and the parameters which contributed towards them the most (Fig. 1). Weight per stool, tillers per plant, internode length, and plant height were observed to be major components of cane yield. Whereas, cane yield, tillers per plant, brix%, and sugar recovery were seen as the major elements of higher sugar yield. Hence, sugar yield augmentation can only be achieved by incorporating promising quantitative and qualitative characters coupled together in the genotypes. Gunnula *et al.*, (2012) also analysed sugarcane crop data through scatter plot analysis and presented very similar results mentioning the strong relationship of stalk weight and height to cane yield as well as the sugar yield. Some other studies have also described strong relation of plant height to the ultimate crop yield (Jia *et al.*, 2011). Scatter plotting can be used to draw the pictographic representation of relationships between two variables, and the extent of variability among the factors under study (Suryanarayana & Mistry, 2016). Tyagi *et al.*, (2012) reported similar findings and presented very high association of cane weight, tillers, cane height, as well as number of internodes towards the cane yield. Moreover, their observations were similar to ours in terms of sugar yield as well, since they reported high dependence of sugar yield on cane weight, tillers, and sugar recovery. Furthermore, Johnson *et al.*, (2012) also reported similar findings for assessing association and interactions of sugarcane's parameters using scatter plotting.

We observed highest sugar yield of 5.86 t/ha for CSSG-272 genotype which surpassed the genotype NIA223P3 which had shown highest cane yield. Similar observations were seen for TSG-14, TSG-21, and SPSG-2875, which also produced good sugar yield as a result of better coalescence of various qualitative and quantitative traits. Hence, cane breeders are to look for excellent combinations of quantitative and qualitative traits which could benefit both the farmers and the sugar industry.

Conclusions

CSSG-272 surpassed all of the genotypes under study with its sugar yield of 5.86 t/ha, whereas, NIA223P3 recorded highest cane yield of 63.33 t/ha against 51.66 t/ha of the check (Thatta-10). Further evaluation of promising genotypes exhibiting improved qualitative and quantitative traits could lead to exploration of the best possible combinations for sugar recovery and cane yield, to serve the agricultural sector and sugar industry of the country.

References

Ahmed, A.O., A. Obeid and B. Dafallah. 2010. The influence of characters association on behavior of sugarcane genotypes (*Saccharum* spp.) for cane yield and juice quality. *World J. Agric. Sci.*, 6(2): 207-211.

Almazan, O., L. Gonzalez and L. Galvez. 2001. The sugarcane, its by-products and co-products. *Sugar Cane Int.*, 07: 3-8.

Arain, M.Y., R.N. Panhwar, N. Gujar, M. Chohan, M.A. Rajput, A.F. Soomro and S. Junejo. 2011. Evaluation of new candidate sugarcane varieties for some qualitative and quantitative traits under Thatta agro-climatic conditions. *J. Anim. Plant Sci.*, *21*(2): 226-230.

Azam, M. and M. Khan. 2010. Significance of the sugarcane crops with special reference to NWFP. *Sarhad J. Agric.*, *26*(2): 289-295.

Bahadar, K., M. Jamal, M. Sadiq, M. Suleman, H. Azim and M.S. Baloch. 2002. Genetic variation and ecological suitability of new sugarcane genotypes under the agro-climatic conditions of Bannu (NWFP). *Pak. Sugar J.*, 17(3): 15-17.

Balsalobre, T.W.A., M.C. Mancini, G. da S. Pereira, C.O. Anoni, F.Z. Barreto, H.P. Hoffmann, A.P. de Souza, A.F. Garcia and M.S. Carneiro. 2016. Mixed modeling of yield components and brown rust resistance in sugarcane families. *Agron. J.*, 108(5): 1824-1837.

Bonman, J.M., G.S. Khush and R.J. Nelson. 1992. Breeding rice for resistance to pests. *Annu. Rev. Phytopathol.*, 30(1): 507-528.

Chaudhary, R.R and B.K. Joshi. 2005. Correlation and path coefficient analyses in sugarcane. *Nepal Agric. Res. J.*, 6: 24-27.

Cox, M., T. Mcrae, B.JK and H. DM. 1996. Family selection improves the efficiency and effectiveness of a sugarcane improvement program. *Sugarcane*, 42.

Darvasi, A. and A. Pisanté-Shalom. 2002. Complexities in the genetic dissection of quantitative trait loci. *Trends Genet.*, 18(10): 489-491.

Das, P.K., B.C. Jena, N. Nayak and A.K. Parida. 1996. Correlation and path analysis of cane yield in sugarcane. *Coop. Sugar*, 27: 509-512.

FAOSTAT. 2014. Production of crops: Sugarcane. Retrieved November 10, 2015, from http://faostat3.fao.org/browse/ Q/QC/E

FAOSTAT. 2015. Production of crops: Sugarcane. Retrieved November 10, 2015, from http://faostat3.fao.org/ browse/Q/QC/E

Gunnula, W., M. Kosittrakun, T.L. Righetti, P. Weerathaworn, M. Prabpan, J.S. Caldwell and S. Sukchan. 2012. Evaluating sugarcane growth and maturity using ground-based measurements and remote sensing data. *Thai J. Agric. Sci.*, 45(1): 17-28.

Habib, G., K.B. Malik and M.Q. Chatha. 1991. Preliminary evaluation of exotic sugarcane varieties for some quantitative characters. *Pak. J. Agric. Res.*, 3(4): 320-326.

Jia, K., B. Wu, Y. Tian, Q. Li and X. Du. 2011. An effective biophysical indicator for opium yield estimation. *Comput. Electron. Agric.*, 75(2): 272-277.

Johnson, R.M., R.P. Viator and W.H. White. 2012. Precision agricultural techniques for identifying yield limiting factors in Louisiana sugarcane. *J. Am. Soc. Sugar Cane Technol.*, 32: 76-77. Retrieved from http://www.assct.org/journal/JASSCT PDF Files/volume 32/ag2012abstrracts.pdf

Kadam, U.A., R.R. Hasure, J.P. Patil and B.R. Kanse. 2004. Response of sugarcane varieties for different dates of harvesting under pre-seasonal conditions. *Coop. Sugar*, 35(6): 471-474.

Karyeija, R.F., J.F. Kreuze, R.W. Gibson and J.P.T. Valkonen. 2000. Two serotypes of Sweetpotato feathery mottle virus in Uganda and their interaction with resistant sweetpotato cultivars. *Phytopathology*, 90(11): 1250-1255.

Kazi, K.A., I. Bari, M. Ayaz and K. Noureen. 2015. Crop development in lower Sindh, 1-31, *Report of Pakistan Meteorological Department, Islamabad, Pakistan.*

Keerio, H.K., R.N. Panhwar, Y.M. Memon, M.Y. Arain and R.R. Qazi. 2003. Qualitative and quantitative performance of some promising and commercial sugarcane varieties under agro-climatic conditions of Thatta. *Pak. J. Appl. Sci*, 3(10-12): 670-673.

Khan, I.A., A. Khatri, G.S. Nizamani, M.A. Siddiqui, S. Raza and N.A. Dahar. 2005. Effect of NPK fertilizers on the growth of sugarcane clone AEC86-347 developed at NIA, Tando Jam, Pakistan. *Pak. J. Bot.*, 37(2): 355.

Khan, I.A., A. Khatri, M.A. Siddiqui, G.S. Nizamani and S. Raza. 2004. Performance of promising sugarcane clone for yield and quality traits in different ecological zones of Sindh. *Pak. J. Bot.*, 36(1): 83-92.

Khan, I.A., N. Seema, S. Raza and S. Yasmine. 2015. Comparative performance of sugarcane somaclones and exotic germplasm under agro-climatic conditions of Tando Jam. *Pak. J. Bot.*, 47(3): 1161-1166.

Khan, I.A., N. Seema, S. Raza, S. Yasmine and S. Bibi. 2013. Environmental interactions of sugarcane genotypes and yield stability analysis of sugarcane. *Pak. J. Bot*., 45(5): 1617-1622.

Khan, I.A., S. Bibi, S. Yasmin, A. Khatri, N. Seema and S. A. Abro. 2012. Correlation studies of agronomic traits for higher sugar yield in sugarcane. *Pak. J. Bot*., 44(3): 969-971.

Khan, M.T., N. Seema, I.A. Khan and S. Yasmine. 2017a. Applications and potential of sugarcane as an energy crop. In *Agricultural Research Updates* (Vol. 16, pp. 1-24). New York: Nova Science Publishers, Inc.

Khan, M.T., N. Seema, I.A. Khan and S. Yasmine. 2017b. Characterization of somaclonal variants of sugarcane on the basis of quantitative, qualitative, and genetic attributes. *Pak. J. Bot.*, 49(6): 2429-2443.

Khan, M.T., N. Seema, I.A. Khan and S. Yasmine. 2017c. The green fuels: evaluation, perspectives, and potential of sugarcane as an energy source. *Environ. Res. J.*, 10(4):

Khatri, A., I.A. Khan, M.A. Javed, M.A. Siddiqui, M.K.R. Khan, M.H. Khanzada and R. Khan. 2002. Studies on callusing and regeneration potential of indigenous and exotic sugarcane clones. *Asian J. Plant Sci.*, 1(1): 41-43.

Khush, G.S. 1995. Modern varieties - their real contribution to food supply and equity. *GeoJournal*, 35(3): 275-284.

Mahmood, T., M.S. Nazir, M. Ashfaq and C.N. Ahmad. 1990. Correlation studies in sugarcane. *J. Agric. Res.*, 22(1): 21-26.

Memon, A., A.M. Khushk and U. Farooq. 2010. Adoption of sugarcane varieties in the sugarcane growing areas of Pakistan. *Pak. J. Agric. Res.*, 23(3): 122-131.

Ministry of Finance, Government of Pakistan. 2015. Pakistan Economic Survey 2014-15. Islamabad. Retrieved from http://www.finance.gov.pk/survey/chapters_15/02_Agricultre.pdf

Quebedeaux, J.P. and F.A. Martin. 1986. A comparison of two methods of estimating yield in sugarcane. *Report of projects-Louisiana Agricultural Experiment Station, Department of Agronomy (USA).*

Rahman, S., G.S. Khan and I. Khan. 1992. Coordinated uniform national varietal trial on sugarcane. *Pak. J. Agric. Res.*, 13(2): 136-140.

Raman, K., S.R. Bhat and B.K. Tripathi. 1985. Ratooning ability of sugarcane genotypes under late harvest conditions. *Indian Sugar*, 35: 445-448.

Raza, S., S. Qamarunnisa, I. Jamil, B. Naqvi, A. Azhar and J.A. Qureshi. 2014. Screening of sugarcane somaclones of variety BL4 for agronomic characteristics. *Pak. J. Bot.*, 46(4): 1531-1535.

Risch, N.J. 2000. Searching for genetic determinants in the new millennium. *Nature*, 405(6788): 847-856.

Rogers, J., P. Chen, A. Shi, B. Zhang, A. Scaboo, S.F. Smith and A. Zeng. 2015. Agronomic performance and genetic progress of selected historical soybean varieties in the southern USA. *Plant Breed.*, 134(1): 85-93.

Sangwan, R.S. and R. Singh. 1983. Correlation and path coefficient analysis of commercial characters in sugarcane (*Saccharum* species complex). *Indian Sugar Crop. J.*,7(1):

Seema, N., M.T. Khan, I.A. Khan and S. Yasmeen. 2017. Genetic itemization of exotic sugarcane clones on the basis of quantitative and qualitative parameters. *Pak. J. Bot*., 49(4): 1471-1478.

Sharma, M.L. and T. Agarwal. 1985. Studies on the cane and sugar yield contributing characters in sugarcane cultivars. *Indian Sugar*, 35(2): 91-101.

Singh, P., S.K. Pathak, M.M. Singh, V. Mishra and B.L. Sharma. 2016. Impact of high sugar early maturing varieties for sustainable sugar production in sub tropical India. *Sugar Tech*., 1-5.

Sohu, I.A., A.H. Memon and B.A. Abro. 2008. Performance of promising sugarcane varieties in comparison with commercial varieties. *Life Sci. Int. J.*, 2(3): 760-764.

Soomro, A.F., S. Junejo, A. Ahmed and M. Aslam. 2006. Evaluation of different promising sugarcane varieties for some quantitative and qualitative attributes under Thatta (Pakistan) conditions. *Int. J. Agric. Biol.*, 8(2): 195-197.

Sugar crops research institute (SCRI). 2015. Sugarcane statistics. *Report of SCRI, Mardan, Pakistan*. Retrieved March 2, 2017, from http://scri.gkp.pk/Statistics.html

Sugimoto, A., Y. Terajima, T. Terauchi, W. Ponragdee, S. Ohara, S. Tagane, T. Sansayawichai, T. Ishida, S. Ando and M. Matsuoka. 2012. Developing new types of sugarcane by hybridization between commercial sugarcane cultivars and wild relatives. *Plant Genet. Resour. Food Agric. Asia Pacific Impacts Futur. Dir.*, 11.

Suryanarayana, T.M.V and P.B. Mistry. 2016. Principal component regression for crop yield estimation. Springer, NY, USA.

Szczerbowski, D., A.P. Pitarelo, A. Zandoná Filho and L.P. Ramos. 2014. Sugarcane biomass for biorefineries: comparative composition of carbohydrate and non-carbohydrate components of bagasse and straw. *Carbohydr. Polym.*, 114: 95-101.

Tyagi, V.K., S. Sharma and S.B. Bhardwaj. 2012. Association pattern among cane and sugar yields pattern of association among cane yield, sugar yield and their components in sugarcane (*Saccharum officinarum* L.). *J. Agric. Res. J. Agric. Res.*, 50(501). Retrieved from http://apply.jar.punjab.gov.pk/upload/1374743226_94_545__1p1(3).pdf

Wagner, G.P. and K. Schwenk. 2000. Evolutionarily stable configurations: functional integration and the evolution of phenotypic stability. In *Evolutionary Biology* (pp. 155-217). Springer, USA.

Williams, D. and M.S.U. Rehman. 2016. Pakistan Sugar: Annual Report 2016. *Gain Rep. USDA Foreign Agric. Serv. Glob. Agric. Inf. Network, GAIN Rep. Number PK1608*.

Yasmin, S., I. Khan, A. Khatri, N. Seema, M.A. Siddiqui and S. Bibi. 2011. Plant regeneration from irradiated embryogenic callus of sugarcane. *Pak. J. Bot.*, 43: 2423-2426.

Yasmeen, S., M.T. Rajput, I.A. Khan and S.S. Hasseny. 2017. Induced mutations and somaclonal variations in three sugarcane (*Saccharum officinarum* L.) varieties. *Pak. J. Bot*., 49(3): 955-964.

(Received for publication: 15 May 2017)