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Original Article

Screening of promising sugarcane genotypes in relation to agroecological conditions of Tandojam district of Sindh, Pakistan

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Abstract

Worldwide, sugarcane is the major sugar-producing crop and the sugar industry ranks second largest industry of Pakistan. Field experiments were conducted during the sugarcane cultivation seasons of 2016-2017 and 2017-2018 at Sugarcane Research Institute, Tandojam, Pakistan. Seventeen sugarcane genotypes (G1 to G17) were studied to select potential genotypes having better agronomic and quality performances. Results of both studied years indicated that the maximum sprouting (66%) was noted by G1 followed by G8 (64%) in the first season, while G10 recorded the highest sprouting of 62.66% in the second year. The lengthiest cane length of 3 and 2.7 m was observed by G1 in two consecutive seasons, respectively. The maximum number of nodes was recorded in G15 (29.67) and G12 (40.67) in the 1st and 2nd years of study, respectively. Regarding cane girth, G1, during the first of study, while G1 and G2 performed better in the second year of study. With respect to quality attributes of studied genotypes, the highest brix percentage (23.66 and 23.62) was recorded by G13 and G12 in the first season. In the case of second year, the maximum brix percentage of 23.77 and 23.63 was recorded by G11 and G4, respectively. The highest cane yield of 126.33 t ha^{-1} was recorded by G1 in the first season, and in the next season, both G1 (138.6 ha^{-1}) and G2 (124.6 t ha^{-1}) produced the maximum cane yield. Among the tested genotypes, G1, G2, G4, G11, G12, and G13 were observed as promising genotypes with the best potential for yield and quality attributes to fulfill the needs of growers and industry.

Keywords: Climate, Genotypes, Growth, Performance, Quality, Sugarcane, Yield

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Introduction

Sugarcane (*Saccharum officinarum* L.) is one of the main crops produced in tropical to subtropical regions in around 120 countries throughout the globe and accounts for almost 80% of global sugar production (FAOSTAT, 2019; ISO, 2023). It is commonly considered one of the most substantial and resourceful reservoirs of biomass for biofuel production. In addition to sugar and biofuel, sugarcane is generally used to produce bagasse, molasses, falernum, ethanol, and rum (ISO, 2023). With respect to Pakistan, agriculture is an important sector and plays a vital role in the economics of the country as it contributes 22.9% of the national gross domestic product (GDP) and directly supports the country's population (Pakistan Economic Survey, 2023). Sugarcane, among the field crops of the country, is the foremost crop with respect to total production and one of the major cash crops of Pakistan (Khan et al., 2018). Over the country, it delivers the raw materials to the 2nd largest sugar industry and provides employment to millions of rural farming and non-forming communities. Its share of GDP and agriculture's value addition were recorded at 0.9% and 3.7%, respectively, in the year. During 2022-2023, sugarcane was cultivated over an area of 1319 thousands hectares with a production of 91.111 million tons (Pakistan Economic Survey, 2023). Among the sugar-producing countries in the world, Pakistan has been one of the top eight sugar producers for the last three years (USDA, 2023).

For commercial cane sugar production, variety plays a fundamental role; therefore, cultivation of better-quality varieties is a prerequisite for utmost profit. It is a fact that among the various countries of the world yield increased significantly owing to varietal perfection. According to Finlay and Wilkinson (1963), the best varieties are those with the highest yield and stability potential. In Pakistan, despite productive soil and suitable climatic conditions, production and average yield are limited. This could be attributed to many factors, but a key factor to be considered is the lack of improved varieties because bad effects are observed on production by using poor-quality cane cultivars as seed sources (Mian, 2006). The way out for improvement of decreased cane yield and improved sugar recovery is the cultivation of high yielding varieties (Chattha et al., 2006). As reported by Sundara et al. (1992), through the cultivation of improved sugarcane cultivars, profit and production can be increased. Simultaneously, implementation of better crop management techniques and plantation of high potential-varieties, could improve production (Gill, 1995).

The agronomic desirable parameters for a sugarcane breeding program include a deep root system, leaf angle, prolonged greening, more biomass, an erect canopy, and the non-flowering nature of the crop. Cane-yielding attributes consist of cane weight, number of millable canes, and number of tillers. Similarly, with respect to quality traits, sugar content and sugar recovery are among the most important traits in commercial sugarcane breeding programs, and these characters are significantly influenced by environmental elements (Singh et al., 2003; Khan et al., 2012; Meena et al., 2022). Furthermore, insect, disease and herbicide resistant, improved tolerance to drought, salt and cold, sugar production and accumulation along with higher biomass are areas of interest and concern to be focused while working on sugarcane germplasm for breeding and variety developments (Budeguer et al., 2021). To augment cane and sugar yield, the knowledge of associated characters is essential (Tahir et al., 2014). Therefore, knowledge about different quality traits plays a crucial role in developing a variety with good potential under climate change circumstances. A wide range of environmental and social issues relate to sugar production and processing, and sugar crop growers, processors, energy and food companies are seeking ways to address concerns related to sugar production, biofuels, and sustainability (ISO, 2023). Many phenotypic traits, the tedious breeding practices, and the complex genome of sugarcane substantially hinder the genetic improvement efficiency (Voss-Fels et al., 2021).

Over the past many years, it has become obvious that human activities, including deforestation, and the of burning of fossil fuels, are adversely influencing the world's climatic conditions through an increase in drought, variations in rainfall intensity, and extreme temperatures (IPCC, 2013). It is reported that agriculture is the main vulnerable sector, and adverse impacts are observed on crops' yield and their production through such fluctuations in environmental elements (Parry et al., 2004; Attavanich and McCarl, 2014; Miao et al., 2015). Climate change is supposed to have vital consequences producing sugarcane crop throughout the world, particularly in developing countries, because of more vulnerability to natural disasters,

reduced adaptive capacity, very poor mitigating strategies and forecasting systems (Zhao and Li, 2015). Poor agronomic practices, lack of finance, water shortage, labor cost, improper fertilization, mechanical maintenance, inputs cost, transportation, and poor-quality seeds are the major constraints responsible for low yield of sugarcane crop (Thibane et al., 2023). It is very crucial to quantify the sensitivity of sugarcane crops to climate change to secure future crop production. The introduction of new germplasm could advance the successful development of improved sugarcane cultivars to boost productivity under the scenario of climate change. It is need of time to evaluate high-yielding and high-quality sugarcane varieties (Huang et al., 2018).

It was hypothesized that various sugarcane genotypes may perform differently under the climatic conditions of Tandojam District, Pakistan. Keeping in view the above facts, the present study was conducted to identify the relationship of different characteristics with cane yield as an appropriate and efficient selection strategy that could be adopted to select the better performing genotypes for further selection and breeding programs to provide quality cane to factories for crushing, consequently increasing the profitability of growers.

Material and Methods

Experimental location and particulars

The present study was conducted during two successive growing seasons (2016-2017 and 2017-2018) of the sugarcane crop under the National Uniform Yield Trial (NUYT) in the experimental field of the Sugarcane Research Institute, Tandojam, Pakistan. Seeds (setts) of seventeen promising sugarcane genotypes were collected from the sugarcane research institutes throughout Pakistan (Table 1). All the genotypes were tested to explore their adaptability under the agro-ecological conditions of Tandojam District with respect to their potential regarding growth, yield, and quality attributes. The experiment was conducted under a randomized complete block design (RCBD) with three replications. The weather data for both cropping seasons are presented in figures 1 and 2.

Table-1. Information about genotypes and their source.

S. No.	Names of the genotype	Source of genotypes
Genotype 1	PS-TJ-41, PS= Pa Suruan, Tj= Tandojam	Sugarcane Research Institute, Tandojam.
Genotype 2	Ganj Bux	Sugar crops research institute, Larkana
Genotype 3	S-2008-AUS-130, S= Sugarcane 2008, AUS=Australia	Sugarcane Research Institute, Ayoub Agriculture Research Institute AARI, Faisalabad
Genotype 4	S-2008-AUS-134, S= Sugarcane 2008, AUS=Australia	Sugarcane Research Institute, Ayoub Agriculture Research Institute AARI, Faisalabad
Genotype 5	SLSG-771, SL =Srilanka, SG=Shakarganj	Shakarganj Sugarcane Research Institute, Jhang
Genotype 6	SLSG-96061, SL =Srilanka, SG=Shakarganj	Shakarganj Sugarcane Research Institute, Jhang
Genotype 7	CPSG-2730, CP=Canal Point, SG=Shakarganj	Shakarganj Sugarcane Research Institute, Jhang
Genotype 8	CPSG-2525, CP=Canal Point SG=Shakarganj	Shakarganj Sugarcane Research Institute, Jhang
Genotype 9	HOCP-810, HO=Homa (USA), CP=Canal Point	Shakarganj Sugarcane Research Institute, Jhang
Genotype 10	HOCP-840, HO=Homa (USA), CP=Canal Point	Shakarganj Sugarcane Research Institute, Jhang
Genotype 11	HOCP-846, HO=Homa (USA), CP=Canal Point	Shakarganj Sugarcane Research Institute, Jhang
Genotype 12	HOCP-832, HO=Homa (USA), CP=Canal Point	Shakarganj Sugarcane Research Institute, Jhang
Genotype 13	MS-2003-CP-368, MS=Mardan station, CP=Canal Point	Sugar crops research institute Mardan Khyber Pakhtunkhwa
Genotype 14	MS-2003-CP-380, MS=Mardan station, CP=Canal Point	Sugar crops research institute Mardan Khyber Pakhtunkhwa
Genotype 15	S- 9883-CSSG-155, S=Selection CSSG= common wealth Shakarganj sugarcane	Sugar crops research institute, Mardan Khyber Pakhtunkhwa
Genotype 16	MS-2003-CP-389, MS=Mardan station, CP=Canal Point	Sugar crops research institute Mardan Khyber Pakhtunkhwa
Genotype 17	Th-1312, Th=Thatta	National sugar tropical & horticulture research institute

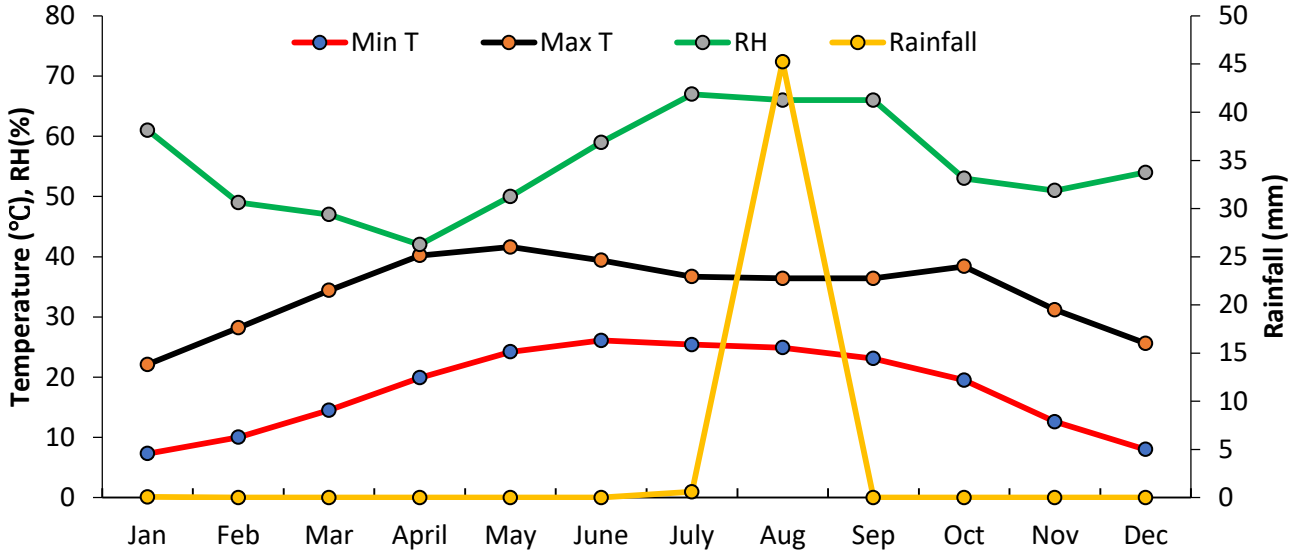

Figure-1. Weather conditions of the Tandojam District of Sindh, Pakistan, during the first year of experimentation.

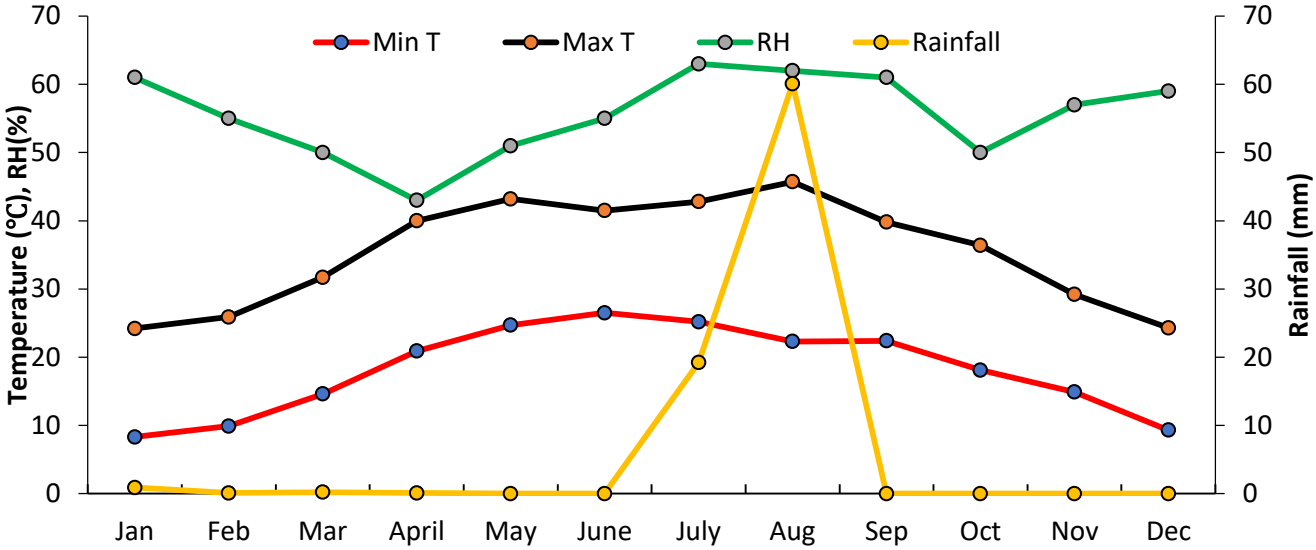

Figure-2. Weather conditions of the Tandojam District of Sindh, Pakistan, during the second year of experimentation.

Soil analysis

Before planting the setts, soil samples were collected from five locations in the experimental field at depths of 0-30 cm and 30-45 cm with the help of a soil auger. The samples were air-dried, ground, sieved (2 mm), and placed in plastic containers. Later, various physical and chemical properties of soil were tested following procedure suggested by Ryan et al. (2001). The soil texture was measured by the Bouyoucos hydrometer method. Electrical conductivity (EC) and soil pH were measured in 1:2 soil/distilled water using EC and pH meters, respectively. Organic matter content was determined by following the procedure of Walkley and Black (1934). The details of the physicochemical characteristics of soil are presented in Table S1. As per the USDA classification system, soil was predominantly found as silty clay loam to clay loam in nature, as determined by the soil textural triangle. The soil was alluvial in nature and belonged to the Miani (*Typic Camborthids*) soil series.

Crop husbandry

Sugarcane is a deep-rooted crop, so keeping that in

mind, a well-worked, friable, and fully pulverized seedbed was prepared. The experimental land was prepared well before planting setts. Deep plowing was done, particularly to break the hard pan of the experimental soil. After deep plowing, the Goble disc harrow was applied crosswise, followed by precise leveling and crosswise ploughing with a cultivator. The dimensions of each experimental unit were 4.8 × 8 cm, with a seed rate of 75,000 double-budded setts per hectare. During the first year of experimentation, setts were planted on October 7, 2016, and harvested on December 16, 2017, while setts were planted on October 12, 2017, and harvested December on 25, 2018, in the second year of experimentation. Throughout the course of experimentation, a total of 27 irrigations were applied to fulfill the water requirements of crops (Table S2).

It is very important to use proper doses of balanced fertilizers to exploit the maximum yield potential of cane crop. However, 225 kg of nitrogen (N), 115 kg of phosphorus (P), and 100 kg of potassium (K) per hectare were applied as a recommended and optimum dose to achieve economically maximum cane and sugar yields. All the P and K with 1/3rd of N were applied at planting time, and the remaining N was applied in two equal doses at the first earthing up (3.5 months after planting) and the second earthing up (1.5 months after the first earthing up). The herbicide (CLIO Combo) post-emergence pack of Clio 35 ml/ac + Atrazine 500 ml/ac used in 100 liters of water to target broad and narrow leaves of weeds was applied. Insecticide Regent 80 WG at 45 g/acre was applied to seed setts before sowing. The second application of regent was done through the fertigation method 30-40 days after sowing. All the crop husbandry practices were kept normal and uniform throughout the course of experimentation.

Data collection

Growth and yield attributes

Data regarding sprouting percentage was collected after 45 days of sowing, when emergence was completed. The number of seedlings that emerged in each plot was counted manually and converted into a percentage by using the following formula:

Germination percentage = (Number of germinated buds / Total number of buds) × 100

The cane height was measured from the surface of the soil to the tip of the last internode with the help of a measuring tape. The number of nodes was counted manually from a randomly selected stalk. A Vernier caliper was used to record the data on cane girth. The cane girth was measured from the bottom, mid, and top portions of the stalk, and the average of the three values was used for further analysis. The number of tillers per stool was recorded after completion of germination up to 120 days of crop age. The whole plant was harvested, leaves were removed and weighted using the electric weighing machine.

Quality attributes

The brix (total soluble solids, TSS) percentage was determined by means of brix hydrometer. For this purpose, a cylinder of 200 ml capacity, already cleaned, was filled with sample can juice. The hydrometer was placed in it and allowed to settle, and a reading was recorded. The temperature of the juice was noted, and the hydrometer reading was corrected accordingly. For the determination of sucrose contents (POL), a digital polarimeter was used. Purity is the ratio of sucrose to brix and is presented in percentage. The following formula was used to estimate the purity percentage.

Purity percentage = POL / TSS × 100

Commercial cane sugar (CCS) and recovery percentage were determined by means of the digital polarimeter according to the laboratory manual for Queensland sugar mills.

Statistical analysis

A statistical package called “Statistics 8.1” was used to analyze the collected data of growth, yield, and quality parameters. Microsoft Excel was used to calculate the means and standard errors for the graphical presentation. The ANOVA technique (Fisher’s analysis of variance) was applied to demonstrate the significance of the data. By following Steel et al. (1997), differences between treatments were assessed with a 5% probability using the least significant difference (LSD) test. The statistical program “RStudio (v2023.06.1-524) by Boston, Massachusetts USA” was used for Pearson’s correlation coefficient between attributes and the multi trait genotype ideotype distance index.

Results

Findings of the current experimentation revealed that the sprouting percentage (%) differed significantly (Table 2). The maximum sprouting percentage of 66% was recorded in G1 followed by G8 with a sprouting percentage of 64.33% during the first year

of experimentation. Whereas data for the next season depicted that G10 produced the maximum sprouting percentage of 62.66%, followed by G1 and G2 (62%). However, the minimum sprouting (55.33%) in the first season was recorded by G9 and G13, similarly, in the second year, G15 expressed minimum sprouting of 52%. It is evident from the data that sugarcane genotypes performed differently with respect to cane length, and statistically significant differences were recorded (Table 2). The highest cane lengths of 3 m and 2.73 m were recorded by G1 during the first and second years of study, respectively. The lowest cane length was noted by G7 (2.16 m) and G15 (1.37 m) in the first and second years of cultivation, respectively (Table 2).

The performance of genotypes regarding the number of nodes per cane varied significantly (Table 2). Overall, G15 consisted of the highest number of nodes (29.67), followed by G11 (27.67) in the first year of crop cultivation. The data regarding the second year of crop revealed that the highest number of nodes per cane were produced by G12 (40.67), followed by G7 with nodes of 35.67. The results of the cane girth were found to be statistically significant (Table 2). The maximum cane girth (3.5 cm) was observed in G1, followed by G17 (3.17 cm) and G2 (3 cm), and the least cane girth of 2.17 cm was observed in G6 during the first season. The data pertaining to the second year of crop depicted that G1 and G2 produced the highest cane girth of 3 cm, followed by G7 and G17, with cane girths of 2.83 cm and 2.63 cm, respectively. The least cane girth of 1.9 cm was noted in G10 in the second season of the crop (Table 2).

Among the number of tillers per stool, statistically non-considerable variations were observed (Table 3). However, the higher number of tillers per stool was documented in G17 (7.39), followed by G1, G9 and G13 with the same number of tillers (7.00) in the first season. Similarly, according to the second year's findings, the higher number of tillers per stool was noticed in G1 (7.17) and G2 (7), while the least number of tillers (5.33) were observed in G12 (Table 3). The recorded data for cane yield apparently showed that the highest cane yield of 126.33 and 138.6 t ha^{-1} was produced by the G1 followed by G2 (125 and 124.6 t ha^{-1}) during the first year and second year of experimentation, respectively (Table 3). G10 produced the minimum cane yield of 106.14 t ha^{-1} during the first year and 103 t ha^{-1} during the second year of study (Table 3).

The outcomes of genotypes with respect to brix percentage were recorded as statistically significant. Data showed that the highest brix percentage was recorded by G13 (23.66%), followed by G12 (23.62%), during the first year of study. During the second year of trail, G11 and G4 performed better with brix percentages of 23.77 and 23.63, respectively (Table 3). The minimum brix percentages of 20.17 and 19.23 was found in G7 and G17 in the first and second years of crop cultivation, respectively (Table 3). The results regarding the sucrose contents (POL) are summarized in Table 3. The highest POL was recorded in G13 (20.11%) and G12 (20.05%) during the first years of the study, while G2 and G7 performed poorly with POLs of 17.25% and 17.29%, respectively. During the second year of study, G4 (20.58%), G11 (20.61%), and G15 (20.61%), produced the maximum POL percentage while minimum POL percentages of 17.85 and 18.15 were observed in G16 and G6, respectively (Table 3).

The findings of the experimentation with respect to purity percentage, commercial cane sugar percentage, and recovery percentage are presented in Table 4. Regarding the purity percentage, significant variations were recorded among the genotypes. According to the findings, the maximum purity percentage of 86.66 was recorded in G13, followed by G12 (86.64%), and a minimum purity percentage of 84.24 in G7 during the first year of study. The G4, G11, and G15 performed better with a purity percentage of 86.70, 86.71, and 86.72, respectively, in the second year of study, and the minimum purity percentage was found in G16 (84.97%). The highest commercial cane sugar percentage of 14.02 was recorded in both the G12 and G13, which was statistically similar during the first year of experimentation, while minimum values were observed G2 (11.54%) and G7 (11.50%). In the second year of study, G11 and G15 produced the highest commercial cane sugar percentage of 14.13, and the lowest performance was observed in G16 (12.11%) and G6 (12.32%). With respect to recovery percentage, genotype 12 was at the top among all the genotypes with a value of 13.63%, followed by G13 (13.48%) during the first year of study. G7 performed very poorly during the first year of the trail, and the minimum recovery percentage was 9.67. During the second year of experimentation, the highest recovery percentage was observed in G4 (13.73), followed by G15 (13.70%). The minimum recovery percentage of 10.60% was recorded in G17, followed by G16 with a recovery percentage of 11.73 (Table 4).

Table-2. Mean data of sprouting percentage, cane length, number of nodes and cane girth of sugarcane genotypes cultivated during crop cultivation seasons of 2016-2017 and 2017-2018.

Genotypes	Sprouting (%)		Cane length (m)		No. of nodes		Cane girth (cm)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
G1	66.0 a	62.0 ab	3.0 a	2.73 a	27.0 abc	28.0 efg	3.50 a	3.00 a
G2	62.33 abc	57.0 ef	2.4 e	2.1 cde	26.67 bc	31.0 cdef	3.00 ab	3.00 a
G3	62.0 abc	55.0 f	2.47 de	2.0 de	24.0 de	29.0 defg	2.50 cde	2.60 abc
G4	64.0 ab	60.67 abc	2.59 c	1.8 ef	23.0 fg	28.33 efg	2.67 cd	2.10 efg
G5	62.0 abc	59.0 ef	2.7 b	1.5 fg	27.0 abc	31.0 cdef	2.37 efg	2.23 cdef
G6	59.33 ef	62.0 ab	2.42 de	2.07 de	23.33 fg	24.0 g	2.17 g	2.17 def
G7	63.0 abc	58.67 cde	2.16 fg	2.5 ab	20.67 g	35.67 abc	2.70 bc	2.83 ab
G8	64.33 ab	55.0 f	2.17 fg	2.13 bcde	23.0 fg	29.33 defg	2.53 cd	2.57 bcd
G9	55.33 f	59.0 ef	2.6 c	1.80 ef	27.33 abc	37.67 ab	2.67 bc	2.00 fg
G10	58.33 def	62.66 a	2.37 ef	1.83 ef	20.67 g	30.33 cdef	2.57 cd	1.90 g
G11	57.00 ef	60.00 abcd	2.28 ef	2.03 de	27.67 ab	35.33 abc	2.77 bc	2.47 bcde
G12	55.67 f	59.67 bcd	2.17 fg	2.0 de	23.0 fg	40.67 a	2.80 b	2.27 cdef
G13	55.33 f	61.0 ab	2.4 e	1.97 de	23.0 fg	34.33 bcd	2.43 def	2.33 cdef
G14	57.33 ef	57.33 ef	2.5 d	1.8 ef	26.67 bc	33.67 bcde	2.63 cd	2.43 bcd
G15	55.67 f	52.0 g	2.0 g	1.37 g	29.67 a	28.67 defg	2.57 cd	1.93 fg
G16	58.0 cde	55.33 f	2.17 fg	2.33 bcd	24.67 def	26.0 fg	2.57 cd	2.17 def
G17	58.33 cde	54.33 ef	2.38 ef	2.47 abc	25.0 cd	31.33 cdef	3.17 ab	2.63 abc
LSD	6.5	3.4	0.30	0.38	4.02	5.96	0.45	0.42

In each column, means followed by same alphabet are not significantly different at 0.05% probability level.

Pearson's correlations of various growth, yield, and quality traits of sugarcane genotypes are presented in Figure 3: 3A and 3B represent the outcomes of first and second year of cultivation of sugarcane genotypes. During the first year of study, a positive relationship of sprouting is observed with growth and yield parameter, including cane length (0.43), girth (0.29), number of tillers (0.15), and yield (0.61) except number of nodes (-0.2) which were negatively linked (Figure 3A). Can yield is moderately and positively linked with cane length (0.49), cane girth (0.49), and tillers (0.54). The quality parameters were very poorly or negatively linked with yield parameter. With respect to relationship among quality parameters, they are strongly linked with each others. The recovery percentage was very strongly correlated with brix (0.77), POL (0.76), purity (0.73), and CSS (0.77). In second year findings, growth and yield parameters were poorly or negatively linked with each others and with quality attributes as well, while quality attributes were perfectly linked (Figure 3B).

Table-3. Mean data of number of tillers per stool, cane yield and brix percentage and POL percentage of sugarcane genotypes cultivated during crop growing seasons of 2016-2017 and 2017-2018.

Genotypes	No. of tillers/stool		Cane yield (tons/ha)		Brix (%)		POL (%)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
G1	7.00 a	7.17 a	126.33 a	138.6 a	21.53 abc	21.60 ef	18.37 bcd	18.45 ef
G2	6.33 a	7.00 a	125.0 ab	124.6 ab	20.23 e	22.43 bcde	17.25 e	19.28 bcde
G3	6.33 a	6.43 a	116.0 de	108.3 fgh	21.07 bcde	22.40 bcde	18.14 bcde	19.25 bcde
G4	6.67 a	6.66 a	120.3 bc	109.33 fgh	22.10 abc	23.73 a	19.31 bcde	20.58 a
G5	6.33 a	6.23 a	112.33 efg	107.0 gh	21.83 abc	22.83 abcd	18.67 bcde	19.68 abcd
G6	6.00 a	6.16 a	110.42 fgh	117.0 cd	20.83 cde	21.30 f	17.55 cde	18.15 f
G7	6.67 a	6.66 a	115.62 de	108.0 fgh	20.17 e	21.77 def	17.29 e	18.61 def
G8	6.30 a	6.33 a	117.12 cd	111.0 efg	21.25 bc	21.53 ef	18.16 bcde	18.38 ef
G9	7.00 a	6.66 a	110.32 fgh	111.33 ef	21.67 abc	21.90 cdef	18.40 bcde	18.75 cdef
G10	6.13 a	6.00 a	106.14 fgh	103.0 h	22.03 abc	23.37 ab	18.88 bcde	20.21 ab
G11	6.00 a	6.00 a	107.21 fg	120.3 bc	20.70 cde	23.77 a	17.55 cde	20.61 a
G12	5.35 a	5.33 a	108.46 fg	101.7 fgh	23.62 a	22.93 abc	20.05 a	19.78 abc
G13	7.00 a	7.00 a	123.24 abc	109.10 gh	23.66 a	23.13 ab	20.11 a	19.98 ab
G14	6.10 a	6.00 a	110.32 fgh	110.0 fgh	22.20 abc	23.27 ab	19.23 abc	20.11 ab
G15	6.67 a	6.66 a	106.33 fgh	111.33 ef	20.47 de	23.77 a	17.36 de	20.61 a
G16	6.16 a	6.00 a	108.0 fg	109.67 fgh	22.61 ab	21.0 f	19.47 ab	17.85 f
G17	7.39 a	7.33 a	118.12 cd	115.0 de	21.58 abc	19.23 g	18.35 bcde	16.08 g
LSD	2.19	2.12	3.69	4.29	1.67	1.06	1.67	1.06

In each column, means followed by same alphabet are not significantly different at 0.05% probability level.

Table-4. Mean data of purity percentage (%), CCS (%) and recovery percentage (%) of sugarcane genotypes cultivated during crop growing seasons of 2016-2017 and 2017-2018.

Genotypes	Purity (%)		CCS (%)		Recovery (%)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
G1	85.32 cdef	85.39 ef	12.49 bcd	12.54 ef	12.53 c	12.34 ef
G2	85.26 ef	85.93 bcde	11.54 e	13.15 bcde	11.80 f	12.80 d
G3	85.09 cdef	85.91 bcde	12.15b cde	13.13 bcde	12.32 de	12.73 d
G4	85.71 abcd	86.70 a	12.91 abcd	14.10 a	13.11 c	13.73 a
G5	85.52 abcde	86.18 abcd	12.71 bcde	13.44 abcd	12.45 d	13.22 c
G6	84.77 def	85.18 f	11.98 cde	12.32 f	13.04 c	12.02 fg
G7	84.24 f	85.50 def	11.50 e	12.67 def	9.67 h	12.25 ef
G8	85.15 cdef	85.34 ef	12.29 bcde	12.50 ef	11.78 f	12.17 ef
G9	84.43 bcde	85.59 cdef	12.59 bcde	12.76 cde	12.49 d	12.37 e
G10	85.68 abcd	86.49 ab	12.86 abc	13.83 ab	12.53 d	13.33 c
G11	84.75 def	86.71 a	11.86 cde	14.13 a	11.04 g	13.47 abc
G12	86.64 ab	86.24 abc	14.02 a	13.52 abc	13.63 a	13.17 c
G13	86.66 a	86.36 ab	14.04 a	13.66 ab	13.48 ab	13.21 c
G14	85.71 abcde	86.44 ab	12.98 ab	13.76 ab	13.25 bc	13.40 bc
G15	84.53 def	86.72 a	11.72 de	14.13 a	12.07 ef	13.70 ab
G16	86.0 abc	84.97 f	13.28 ab	12.11 f	13.06 c	11.73 g
G17	85.37 cdef	83.56 g	12.53 bcde	10.82 g	12.37 de	10.60 h
LSD	0.09	0.70	1.21	0.77	0.33	0.32

In each column, means followed by same alphabet are not significantly different at 0.05% probability level.

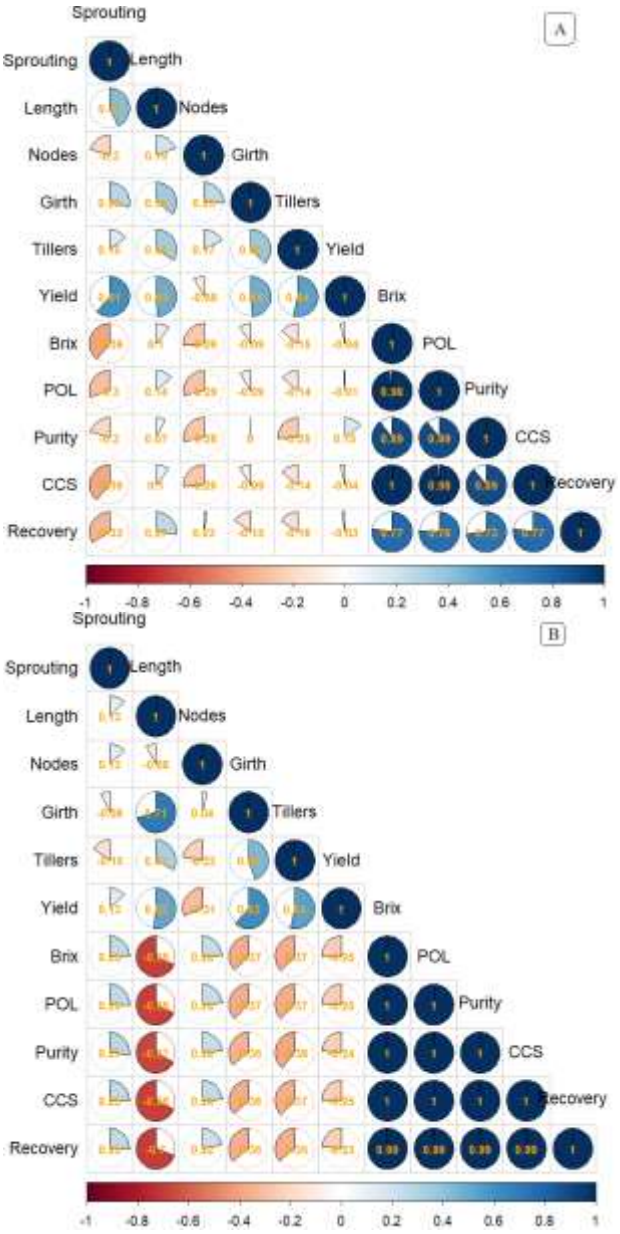

Figure-3. Pearson's correlation among growth, yield and quality attributes of sugarcane genotypes during first (A) and second (B) years of crop cultivation.

Selection of genotypes based on MGIDI index and genetic gain

Based on results of multi trait genotype ideotype distance index (MGIDI), three genotypes i.e., G1, G2 and G13 were selected as found to be superior to rest of genotypes evaluated in this study (Figure 4). Results of the genetic gain based on MGIDI index revealed that MGIDI was the most efficient index to select genotypes with desired characteristics. All the traits expressed a positive selection gain, with highest value of expected genetic gain observed was 7.59 (yield), followed by 0.453 (tillers) and 0.355 (nodes) (Table 5).

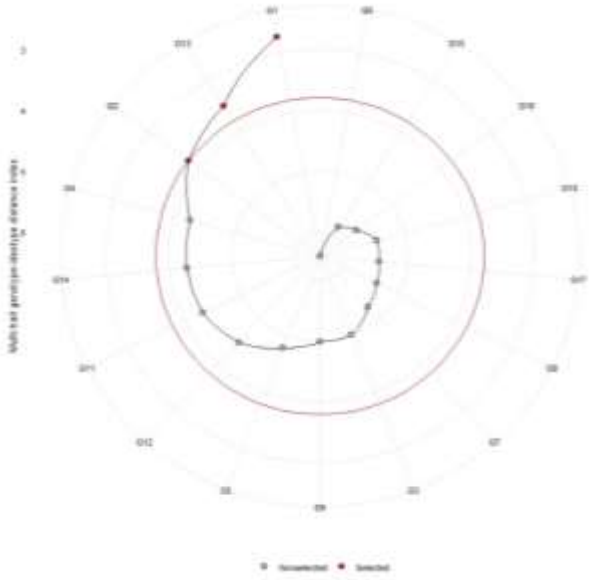

Figure-4. Selection of superior genotypes based on MGIDI index.

Figure 5 represents the strengths and weaknesses of three selected sugarcane genotypes, calculated by factors contribution to the MGIDI indices. The MGIDI was classified into 3 contributing factors, where the factors that major contribution were plotted near the center, while factors with less contribution were at the edges of Figure 5. FA1 has the higher contribution towards the Brix, POL, purity, CCS, and recovery, hence G1, G13 and G2 have lower values for these mentioned traits. While contribution of FA1 was lowest for length, girth, tillers, and yield, hence G1 and G13 are best performing for these traits. Likewise, FA2 has higher contribution for G2, and contributing poorly to G13 and followed by G1, which shows that G13 and G1 are best performing for sprouting, length, nodes, girth, tiller, and yield attributes of sugarcane plant (Table S3).

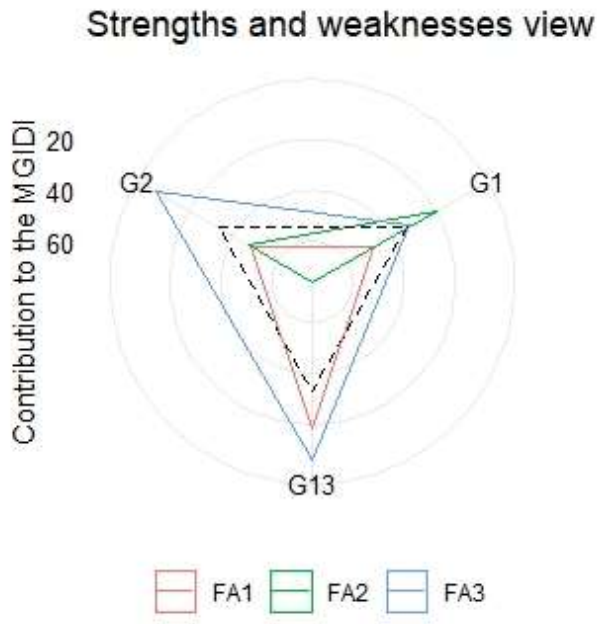

Figure-5. The strengths and weaknesses of the three selected genotypes are shown as the proportion of each factor on the computed MGIDI.

Table-5. Genetic gain values/selection of differential for all studied variables based on MGIDI index.

Variables	Factor	SD/Expected genetic gain	Objective
Brix	FA1	0.02	Increase
POL	FA1	0.017	Increase
Purity	FA1	0.0539	Increase
CCS	FA1	0.0151	Increase
Recovery	FA1	0.0305	Increase
Length	FA2	0.0566	Increase
Girth	FA2	0.258	Increase
Tillers	FA2	0.453	Increase
Yield	FA2	7.59	Increase
Sprouting	FA3	0.273	Increase
Nodes	FA3	0.355	Increase

Discussion

An integrated impact of environmental factors and genetic makeup defines the phenotype. Our findings explore important differences with respect to growth, yield, and quality attributes of sugarcane genotypes cultivated in the agroecological environment of Tandojam District of Sindh Province, Pakistan. Significant variations were recorded among all the traits that were under consideration during the experimentation, expect number of tillers per stool. Sprouting, an initial phase of crop growth, ensures the required number of plants in a specific area and directly influences the crop yield, the ultimate output of the crop. The variation in sprouting trait might be more linked to genetic makeup than environment, as reported by Xu et al. (2023), that the high heritability indicated that genetic factors played a predominant role in determining trait variation. It is also stated that seasonal changes in temperature and relative humidity had a significant impact on the emergence and sprouting parameters (Bashir et al., 2000). However, Mohanthy and Nayak (2011) and Patel and Patel (2014) recorded the highest sprouting percentage in setts with more buds.

The differences in cane length might be due to the genetic makeup as well as the effect of relative humidity on crop growth, because during the second year of plantation, relative humidity was slightly higher, which ranged from 42-66% throughout the year. This shows that the studied genotypes are appreciably longer than commonly referred. The variation in plant height among different genotypes might be attributed to variations in the portioning of photosynthesis among different genotypes. Shahzad et al. (2016) and Suman et al. (2011) also reported significant variations in cane length due to genetic makeup. The seasonal effect on the number of nodes per cane might be due to the optimum temperature, which ranged from 26-42℃, and increased humidity, which ranged from 42-66% throughout the year. Including the effect of atmospheric conditions, the differences in origin also affected the number of nodes per cane. Similarly, (Bughio et al., 2018) also reported variation in the number of nodes per cane in exotic and indigenous varieties of sugarcane. Similarly, (Hassan et al., 2017) reported major dissimilarities in cane girth in different sugarcane clones. That may be due to the genetic background of the genotypes. Moore and Botha (2013) also concluded that sugarcane tillers are basically related to the inherited characteristics of cultivars. It is also observed in the number of tillers per stool that there was no significant effect of atmospheric conditions during both seasons.

All the developments in agriculture are mainly focused on yield enhancement, which benefits the grower as well as the economic growth of the country. Sarwar et al. (2016) also reported similar

findings as observed in the current experimentation: both G1 (138.6 t ha^{-1}) and G2 (124.6 t ha^{-1}) produced the maximum yield as compared to the rest of the genotypes. It is evident from the results of both seasons that G1 and G2 have the potential to produce more yield in higher relative humidity (65%) as well as even in the increased atmospheric temperature (25℃). The findings of the current experiments with respect to yield are in line with the outcomes of Hagos et al. (2014). Arain et al. (2011) also stated that genetically improved clones found better yield and sugar content. Therefore, maximum cane yield by G1 and G2 might be attributed to their improved genetic makeup and adaptability under the agroclimatic conditions of the region. Saleem et al. (2023) reported the significant variations among the morphophysiological traits, including plant height, cane length, number of tillers, internodal distance, and brix percentage of 29 genotypes of sugarcane.

The variations in the brix percentage might be due to a change in weather conditions during both seasons. Elamin et al. (2007) and Getaneh et al. (2016) reported that brix percentage has a direct relationship with atmospheric conditions. Baloch (2016) also observed a disparity in the brix percentage of sugarcane clones. Among the qualitative traits of sugarcane, POL is one of the most important, because it shows the amount of sucrose present in the juice (Da-Silva et al., 2017; Cervi et al., 2018). This character also demonstrates the productivity potential and longevity of the genotypes. Our results are in accordance with the recommendations of SASTA (2009) who recommended that the POL percentage of cane range between 14 and 21%. The differences in POL percentage among the evaluated genotypes reflect the genetic formation inherent to each genotype. These results are also in agreement with the findings of Maule et al. (2001), who studied the behavior of sugarcane varieties and verified the differences among the cultivars.

The changing trends in purity percentage among the genotypes might be due to the timely harvest because it is observed that in late harvesting, purity decreases to some extent owing to environmental variations during the growth period of the crop in both years. Our findings are in line with the study of Sajjad and Khan (2009). Khalid et al. (2014) also observed the highest purity of 84.97% by the clone MS-99-HO-93 and the lowest (79.8%) by the clone MS-99-HO-388. These differences in CCS percentage might be due to environmental differences during both years of study as well as the autumn plantation of genotypes. According to the studies of Mitr (2007), that several factors are involved in the CCS percentage of sugarcane, i.e., varieties, planting season, nutrients, water management, diseases, insect pests, lodging, time of harvesting, crop duration, transportation, and duration of post-harvest management. It is well known that the CCS increases during the maturation stage of the sugarcane crop (Bull, 2000). Similarly, this can be augmented by high radiation, cool temperature, and dry weather conditions (Kingston, 2002). The differences among the studied genotypes regarding recovery percentage may be attributed to their genetic structure and might be due to the environmental changes, as high relative humidity was recorded during the growth period of the crop (Ahmad et al., 2011; Mehareb and Galal, 2017). Similar results were also reported by Sarwar et al. (2011). The increasing trend in sugar recovery due to the longer growth season was also observed by Mohamed and El-Taib (2007). The outcomes of the current experimentation are supported by the findings of Gashaw et al. (2016) that considerable variations are present among the phenotypic characteristics of sugarcane genotypes.

Conclusion

Field experiments were conducted consecutively during the sugarcane cultivation seasons of 2016-2017 and 2017-2018 at the Sugarcane Research Institute, Tandojam, Pakistan, to observe the variations among the seventeen genotypes of sugarcane with respect to growth, yield, and quality parameters. G1 (PS-TJ-41), G2 (Ganj Bux), and G13 (MS-2003-CP-368), were found to be comparatively superior in yield and quality attributes. These genotypes are recommended to be considered for further cultivation and propagation under the agroclimatic conditions of Tandojam Districts of Sindh and the regions having similar agroecological circumstances to boost the net outputs.

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Contribution of Authors

Hisbani WA: Conceived idea, designed and conducted the experiment, collected & analyzed data and prepared the first draft
Khan S: Conceived idea, analyzed the collected data and prepared first draft & submitted the final draft as a corresponding author
Jamro MMUR & Soomro NA: Contributed in writing the manuscript and draft preparation
Hafeez B: Review of literature & edited the draft
Ibrar D: Review of manuscript, software and data analysis
Rais A & Gul S: Manuscript write up and review
Irshad S & Hameed M: Analyzed the collected data and prepared first draft

References

Ahmad ZA, Ahmad AM and Osman MSH, 2011. Optimum inter row spacing and number of ploughings for two promising sugarcane varieties. Egypt. J. Agric. Res. 89(1): 301-316.

Arain MY, Panhwar RN, Gujar N, Chohan M, Rajput MA, Soomro AF and Junejo S, 2011. Evaluation of new candidate sugarcane varieties for some qualitative and quantitative traits under Thatta agro-climatic conditions. J. Anim. Plant Sci. (2)1: 226-230.

Attavanich W and McCarl BA, 2014. How is CO_2 affecting yields and technological progress? A statistical analysis. Clim. Chang. 124: 747–762.

Baloch AB, 2016. Effect of different potassium levels on the cane yield and recovery of sugarcane varieties. Thesis submitted to Sindh Agriculture University, Tandojam, Pakistan

Bashir S, Saeed M, Ghaffar A, Ali Z and Khan RMZ, 2000. Analysis of economic aspects of raising autumn sugarcane at different planting patterns and seeding densities. Int. J. Agric. Biol. 2: 322-325.

Budeguer F, Enrique R, Perera MF, Racedo J, Castagnaro AP, Noguera AS and Welin B, 2021. Genetic Transformation of Sugarcane, Current Status and Future Prospects. Front. Plant Sci. 12: 768609. doi: 10.3389/fpls.2021.768609

Bughio N, Panhwar RN, Chohan M, Junejo S and Unar GS, 2018. Cane yield and quality appraisal of Thatta 2109 sugarcane variety in different varietal testing trials in Sindh. Pak. Sug. J. 28(3): 8-14.

Bull T, 2000. The sugarcane plant, In: P.M. Hoogarth and P.G. Allsopp, (Eds), Manual of Cane Growing. Bureau of Sugar Experiment Stations, Indooroopilly, Australia. pp. 71–91.

Cervi RG, Rodrigues SA, Filho EK and De-Oliveira PA, 2018. Influence of cutting stages and sugarcane varieties on sucrose content in a Brazilian power plant with mechanized harvesting. J. Agri. Sci. Tech. 8(4): 220-227.

Chattha AA, Rafique M, Afzal M, Ahmed F and Bilal M, 2006. Prospects of sugar industry & sugarcane cultivation in Punjab. Proceedings of 41th Annual Convention of Pakistan Society of Sugar Technologists held at Rawalpindi on August 21-22, 2006. p. 173-181.

Da-Silva VSG, Da-Oliviera MW, Da-Silva AC, Da-Silva AF, Galvao ER and Salva MDB, 2017. Agro industrial quality of plant cane first and second ratoon in sugarcane varieties. Aust. J. Crop Sci. 11(9): 1216.

Elamin EA, El-Tilib MA, Elnasikh MH, Ibrahim SH, Elsheikh MA and Babiker EE, 2007. Influence of phosphorus and potassium fertilization on quality of sugar of two sugarcane varieties grown on three soil series of Sudan. J. Applied Sci. 7(16): 2345-2350.

FAOSTAT, 2019. Food and Agriculture Organization of the United Nations, Statistics Division. Forestry Production and Trade. Available online: http://www.fao.org/faostat/en/#data/FO (accessed on 4 April 2019).

Finlay KW and Wilkinson GN, 1963. The analysis of adaptation in plant breeding program Aust. J. Res. 13: 742-54.

Gashaw ET, Mekbib F and Ayana A, 2016. Genetic Diversity among Sugarcane Genotypes Based on Qualitative Traits. Advances in Agriculture. 2016: 8909506. http://dx.doi.org/10.1155/2016/8909506

Getaneh A, Tadesse F, Ayele N and Bikill M, 2016. Agronomic performance evaluation of sugarcane varieties under Finchaa Sugar Estate agro-ecological conditions. African. J. Agri. Res. 11(44): 4425-4433.

Gill MB, 1995. Physio agronomic studies on flat versus pit plantation of autumn and spring sugarcane (*Saccharum officinarum* L.). M.Sc.

Thesis, Department of Agronomy, University of Agriculture, Faisalabad. pp. 49- 89.

Hagos, Mengistu HL and Mequanint Y, 2014. Determining optimum harvest age of sugarcane varieties on the newly establishing sugar project in the tropical areas of Tendabo Ethiopia. Adv. Crop Sci. Tech. 2(5): 156.

Hassan MU, Fiaz N, Mudassir MA and Yasin M, 2017. Exploring the ratooning potential of sugarcane (*Saccharum Officinarum* L.) genotypes under varying harvesting times of plant crop. Pak. J. Agric. Res. 30: 303-309.

Huang Y, Shang H, Xu Y, Jiang H, Xu S and Zhang M, 2018. Quantitative evaluation of variation in defoliation traits among sugarcane genotypes. PLoS ONE. 13(5): e0196071. https://doi.org/10.1371/journal.pone.0196071

IPCC, 2013. Annex I: Atlas of Global and Regional Climate Projections. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovermental Panel on Climate Change; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013; pp. 1311–1393.

ISO, 2023. https://www.isosugar.org/sugarsector/sugar (accessed on July 20, 2023).

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

Khan MT, Khan IS, Yasmeen S, Seema N and Nizamani GS, 2018. Field evaluation of diverse sugarcane germplasm in agro climatic conditions of Tandojam, Sindh. Pak J. Bot. 50: 1441-1450.

Kingston G, 2002. Recognising the impact of climate on CCS of sugarcane across tropical and subtropical regions of the Australian sugar. Proc. Aust. Soc. Sug. Technol. 24: 145−152.

Maule RF, Mazza JA and Martha Jr GB, 2001. Productivity of Sugarcane Cultivars in Different Soils and Harvesting Periods. Scientia Agrícola. 58(2): 295-301.

Meena MR, Appunu C, Arun Kumar R, Manimekalai R, Vasantha S, Krishnappa G, Kumar R, Pandey SK and Hemaprabha G, 2022. Recent Advances in Sugarcane Genomics, Physiology, and Phenomics for Superior Agronomic Traits. Front. Genet. 13: 854936.

Mehareb EM and Galal MOA, 2017. Ratooning ability inheritance for some promising Egyptian sugarcane varieties. Indian J. Sugarcane Tech. 32(2): 50-59.

Mian AM, 2006. Sugarcane variety composition in Pakistan. Proceedings of Seminar on Agriculture. Organized by Pakistan Society of Sugar Technologists held at Faisalabad on 19th June 2006. pp. 107- 121.

Miao R, Khanna M and Huang H, 2015. Responsiveness of Crop Yield and Acreage to Prices and Climate. Am. J. Agric. Econ. 98: 191–211.

Mitr PRD, 2007. Sugarcane Quality Management. Mitr Phol Sugarcane and Sugar Research and Development Co., Ltd., Chaiyaphum, Thailand.

Mohamed BD and El-Taib ABA, 2007. Evaluation of some spring planted sugarcane genotypes under different growing seasons:1- quality traits performance. Assiut. J. Agri. Sci. 38(1): 1-15.

Mohanthy M and Nayak PK, 2011. Economizing seed cane quantity by reducing sett size and bud number with sett treatment in sugarcane cultivation. Indian J. Sugarcane Technol. 26(2): 59- 60.

Moore PH and Botha FC, 2013. Sugarcane: physiology, biochemistry and functional biology. Oxford: John Wiley & Sons pp. 55- 84.

Khalid M, Rahman HU, Rabbani MA, Farhatullah and Khan A, 2014. Qualitative and quantitative assessment of newly selected sugarcane varieties Sarhad J. Agric. 30(2): 187-191.

Pakistan Economic Survey, 2023. Government of Pakistan 2022-2023. Chapter 2: Agriculture. Pp. 21.

Parry ML, Rosenzweig C, Iglesias A, Livermore M and Fischer G, 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Glob. Environ. Chang. 14: 53–67.

Patel D and Patel R, 2014. Influence of sett size, seed rate and sett treatment on yield and quality of sugarcane. Bioscan. Int. J. Life Sci. 9(1): 55- 57.

Ryan J, Estefan G and Rashid A, 2001. Soil and Plant Analysis Laboratory Manual. International Center for Agricultural Research in the Dry Areas (ICARDA), Islamabad, Pakistan. 172p.

Sajjad M and Khan FA, 2009. Genetic Diversity among Sugarcane Cultivars in Pakistan. American-Eurasian J. Agric. Environ. Sci. 6(6): 730-736.

Saleem B, Uzair M, Noman M, Attia KA, Zhang M,

Alwahaibi MS, Zahra N, Naeem MK, Mohammed AA, Fiaz S, Kimiko I and Khan MR, 2023. Evaluation of sugarcane promising clones based on the morphophysiological traits developed from fuzz. PeerJ 11: e15646. http://doi.org/10.7717/peerj.15646

Sarwar M, Mehmood A and Ahmad N, 2016. Performance of promising sugarcane varieties/clones at farmer's field in Punjab. Pak. Sugar J. 31(4): 06-08.

Sarwar MA, Ahmad S, Fiaz N, Hussain F and Chattha AA, 2011. Evaluation of approved sugarcane varieties through hydraulic press method. Int. J. Agric. Appl. Sci. 3(1): 14-17.

Shahzad S, Khan FA, Iqbal MZ, Khaliq I and Ahmed N, 2016. Characterization of local and exotic sugarcane genotypes on the basis of morphological and quality related attributes. Pak. J. Agri. Sci. 53: 121-128.

Singh A, Bhatnagar PK, Khan AQ and Shrotria PK, 2003. Association of quality character with cane and commercial cane sugar yields in sugarcane. Sugar Tech. 5: 197- 198.

SASTA, 2009. Cane Testing Service Tongaat- Hulett Sugar Limited – Technical Engineering Group-Laboratory Manual including the Official Methods ISBN 978-0-620-43586-4 - 5th Edition, August 2009.

Steel RGD, Torrie JH and Dockey DA, 1997. Principles and Procedures of Statistical Analysis: A Biometrical Approach. 3rd Ed McGraw Hill Book Co. Inc., New York, USA. 336-352.

Suman A, Ali K, Arro J, Parco AS, Kimbeng CA and Baisakh N, 2011. Molecular diversity among members of the *Saccharum* complex assessed using trap markers based on lignin-related genes. Bioenergy Res. 5: 197-205.

Sundara B, Sankaranarayanan P and Batcha MBGR, 1992. Varietal characteristics affecting ratooning potential of sugarcane. Sugarcane. (6): 1-4.

Tahir M, Khalil IH, Mc-Cord PH and Glaz B, 2014. Character association and selection indices in sugarcane. American. J. Exp. Agri. 4: 336.

Thibane Z, Soni S, Phali L and Mdoda L, 2023. Factors impacting sugarcane production by small-scale farmers in KwaZulu-Natal Province-South Africa. Heliyon 9: e13061. https://doi.org/10.1016/j.heliyon.2023.e13061

USDA, 2023. Sugar: World Markets and Trade. https://apps.fas.usda.gov/psdonline/circulars/sugar.pdf (accessed on 4 September 2023).

Voss-Fels KP, Wei X, Ross EM, Frisch M, Aitken KS, Cooper M and Hayes BJ, 2021. Strategies and considerations for implementing genomic selection to improve traits with additive and non-additive genetic architectures in sugarcane breeding. Theor. Appl. Genet. 134: 1493–1511.

Walkley A and Black IA, 1934. An examination of Degtjareff method for determining soil organic matter and proposed modification of chronic acid titration method. Soil Sci. 37: 29-37.

Xu Z, Kong R, An D, Zhang X, Li Q, Nie H, Liu Y and Su J, 2023. Evaluation of a Sugarcane (*Saccharum* spp.) Hybrid F_1 Population Phenotypic Diversity and Construction of a Rapid Sucrose Yield Estimation Model for Breeding. Plants. 12(3): 647.

Zhao D and Li YR, 2015. Climate Change and Sugarcane Production: Potential Impact and Mitigation Strategies. Int. J. Agro. 2015: 547386. http://dx.doi.org/10.1155/2015/547386