Quality Coefficient on Gene Differentiation and Phenotype: Clone Assessment of *Saccharum officinarum* Linn

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ABSTRACT

The production of superior sugarcane varieties can be achieved through crossbreeding between superior parent plants based on the desired advantages. Research examined the diversity of superior clones of SB04, SB11, SB19, and SB20 and identified the clones with the highest productivity potential. The first ratoon research was carried out from August 2020 to July 2021. Data analysis used descriptive-analytic methods, regression tests, and genetic diversity assessment. The observation was made on agronomic variables and potential productivity. Based on the result, the genetic diversity of the superior clone SB04 showed close similarity to the heterozygous combination PS862. The superior clone SB11 showed a tendency to inherit traits similar to Cenning. The superior clones SB19 and SB20 lean towards the VMC71-238 variety and the combination of PSBM01 and VMC71-238. The superior clones SB04, SB11, SB19, and SB20 produced higher weight, yield, and sugarcane crystal content compared to the characteristics of their two parents. Clones SB04, SB11, SB19, and SB20 produced high crystal content, ranging from 8.47 to 15.26 tons/ha, higher than their parent plants. SB19 had the highest yield, namely 15.26 tons/ha. Although some clones dominate crystal production, other clones inherit traits from both parents but are less dominant in overall productivity.

Keywords: Clone; Coir levels; Gene differentiation; Productivity; Superior

INTRODUCTION

Sugarcane, a nutritious plant from the grass family, is fresh and easy to cultivate on a wide scale (Bhatt, 2020; Rosales, 2021). It is regarded as one of the world's premier food crops (Ali et al., 2019). It has become a significant industrial commodity in Indonesia in the pursuit of sugar self-sufficiency. According to the Directorate General of Plantations, sugarcane production demonstrated a decreasing trend from 2015-2019, with yields of 2,497,997 tons, 2,204,619 tons, 2,121,671 tons, 2,174,400 tons, and 2,450,000 tons, respectively (Uchtiawati et al., 2020).

The primary factor contributing to low sugar productivity in Indonesia is the scarcity of high-yielding sugarcane varieties (Sulaiman et al., 2019). Most superior varieties cultivated by farmers mature slowly, leading to an imbalance in the optimal composition of plant maturity (Pathirana et al., 2020). The low sugar productivity in Indonesia results in a decrease in potential productivity at

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harvest. The suboptimal maturity of harvested sugarcane is due to the simultaneous planting of early, middle, and late-ripening varieties (Calderan-Rodrigues et al., 2021). Such conditions can lead to a decline in productivity, particularly yield, because the optimum level of maturity inherited genetically varies across varieties. Consequently, the potential yield for sugar also differs (Cursi et al., 2022). Environmental factors can also influence low potential productivity (Montaldo et al., 2021; Neto et al., 2020). Insufficient water supply, salt stress, high temperatures, low humidity levels, and nutrient deficiencies can all decrease the potential productivity of high-yielding sugarcane varieties.

This critical and intricate issue in the sugarcane-based industry necessitates intensive, comprehensive, and sustainable research (Restu et al., 2021; Amna et al., 2020). The productivities of sugarcane should be complemented by government regulations that promote the growth and development of a healthy, honest, fair, modern, and globally competitive sugar industry. The breeding and collection of high-yielding varieties can enhance the quality and quantity of sugarcane production (Ali et al., 2019; Hamida & Parnidi, 2019; Restu et al., 2021). The production of superior varieties can be achieved through cross-breeding between superior parent plants based on desired advantages. Cross-breeding between clones can increase the diversity of F1 progeny to form new clones. Additionally, cross-breeding can be conducted between superior varieties and clones based on the desired potential superiority. The expectation is that the resulting offspring or F1 or clones will exhibit high productivity potential and resistance to pests and diseases.

Cross-breeding in previous studies has yielded several superior clones with high potential productivity, resistance to pests and diseases, and high coir content (Anwar et al., 2021; Prabowo et al., 2021). These clones include SB01, SB03, SB04, SB11, SB12, SB19, and SB20. To date, these seven clones have undergone superiority testing in multiple locations, including Plantcane and Ratoon One, as well as in the superiority test of Ratoon Two. Each variety of plant species possesses specific morphological descriptions, and numerous publications have explored the identification of varieties based on morphological characteristics (Tesfa et al., 2024). Newly created superior varieties require periodic review at least every 10 years due to the potential decline in resistance of commercial varieties to new pests and diseases and the emergence of more productive varieties (Begna, 2020).

By relevant regulations, the assembly of various stages of selection and superiority tests serves as the benchmark for producing new high-yielding sugarcane varieties (Heliyanto & Abdurrakhman, 2022). Clones that pass the selection and multi-location productivity potential tests and demonstrate resistance to pests and diseases can be submitted to the Minister of Agriculture of the Republic of Indonesia by the rules stipulated in the online application. The superior clones that are created and produced must possess both special and general advantages over existing superior varieties and embody the character and productivity potential of the two parent plants. These special and general advantages include superior sugarcane weight per hectare, yield, and crystal content per hectare, resistance to pests and diseases, and high coir content (Heliyanto & Abdurrakhman, 2022).

Genes govern quantitative variables related to morphological and physiological characteristics and result from growth processes. These variables are regulated by several genes, referred to as multiple genes or polygenes (Napier et al., 2023). Each gene exerts a minor effect, while environmental influences have a substantial impact (Montaldo et al., 2021). Quantitative variables can be measured using specific units of measure and are controlled by many genes, thus characterizing them as polygenic characters (Meena et al., 2022). Each gene unit has a minor influence on expressing the phenotype, which is termed a minor gene (Das & Bansal, 2019). The selection of quantitative variables can be conducted based on statistical data. Data testing involves calculating the mean, variance, and standard deviation (Mertler et al., 2021).

Qualitative variables are typically discrete, reflecting the observed plant phenotype, and can be visually distinguished (Uchtiawati et al., 2020). One or more genes regulate these variables (Anwar et al., 2021). If controlled by a single gene, it is referred to as a monogenic character, and if controlled by several genes, it is termed an oligogenic variable (Campuzano et al., 2020). Each gene plays a significant role in expressing the phenotype and is a major gene (Zhang et al., 2021). These variables are differentiated based on the presence or absence of environmental influences. Data collection for these variables is conducted through observation techniques (Reckling et al., 2021).

Qualitative variables serve as the primary characteristics of a species due to their minimal environmental influence and ease of transmission to offspring (Komape, 2019). Selection activity is deemed effective if the original population has two conditions: substantial phenotypic diversity and a sufficiently high heritability value (Saini et al., 2020). The effectiveness of selection activities on a character increases with the heritability value of that character (Tena et al., 2023). While there is no standard heritability value, several scientific journal articles suggest that a heritability value is considered low if it is less than 20 %, moderately high if it is between 20-50 %, and high if it is greater than 50 % (Kumari et al., 2020; Netoet al., 2020; Prabowo et al., 2021). These values are highly dependent on the method and population studied.

Breeders often regard the purported genetic progress as a percentage above the average value of the population (Snowdon et al., 2021). The genetic aligns with the explanation provided by the previous finding that Genetic Gain (KG) (%) is the product of differential selection values and heritability, which determines the efficiency of the selection system. Consequently, selection will be effective if a high genetic progress value is supported by one of the high heritability values (Barreto et al., 2019), resulting in high heritability.

This study has identified variations in crystallization productivity among sugarcane clones, but there is still a gap in the deeper understanding of the genetic mechanisms underlying this quality differentiation. While previous studies have focused more on identifying superior clones based on agronomic outcomes, this study needs to explore further how specific interactions between genes and the environment contribute to different phenotypic expressions. In addition, further studies are needed on how epigenetic factors influence the stability and inheritance of these superior traits in subsequent generations to ensure continued high productivity and adaptation to changing environmental conditions.

MATERIALS AND METHODS

Study area

The study was carried out from August 2020 to July 2021 at the Center for Sugar Cane Research and Development (P3T) at the Faculty of Agriculture, University of Muhammadiyah Gresik, in collaboration with Gempolkrep PG PT Perkebunan Nusantara X (PTPN X) in Sambiroto Village, Sooko

District, Mojokerto Regency. Geographically, Mojokerto Regency is situated between 111°20'13" to 111°40'47" east longitude and 7°18'35" to 7°47'0" south latitude. Sooko district is located at an altitude of 64 meters above sea level with an average air temperature of approximately 29.8°C and air humidity ranging from 74.3 - 84.8 %. The soil type at the site is alluvial, containing N content of 0.11 %, P_2O_5 of 30 ppm, K_2O of 30 ppm, K_2O of 154 ppm, organic C of 1.08 %, organic matter of 1.86 %, pH of 5.79, and moisture content of 0.29. The average rainfall recorded in Sooko District in 2018 was 227 mm.

Description of Clones

The clones of sugar used were SB04, SB11, SB19, and SB20 clones. Ratoon cane 1 underwent maintenance in August 2020 and was harvested in July 2021. The data on hablur (sugar) is presented in Table 6. The four superior clones were planted in a plant cane manner in July 2019 and harvested in August 2020. The crystal content was very high, with values of 9.41 tons/ha, 10.76 tons/ha, 11.63 tons/ha, and 8.92 tons/ha, respectively. Ratoon cane 2 was harvested in August 2022. The hablur (sugar) produced by ratoon cane 2 was very high. The crystals produced had yields of 10.05 tons/ha, 9.73 tons/ha, 10.21 tons/ha, and 11.18 tons/ha, respectively.

Methodology and Data Analysis

The data about the four clones were analyzed using descriptive, analytical, diagnostic, and differential diagnostic methods. Analytical descriptions encompass all the natural traits or characters of the organism (natural character), while diagnostic descriptions contain only important traits (essential traits), which serve as distinctive identifiers. Differential diagnostic descriptions distinguish sugarcane clones from each other by mentioning the different varieties being compared. The description guidelines adhere to PP No. 19 of 2021 concerning Genetic Resources and the Release of Plantation Plant Varieties, PP No. 38 of 2019 concerning the Release of Plant Varieties, and Ministerial Decree No. 1/KPTS/Kb020/1/2018 Amendment to the Decree of the Minister of Agriculture No. 318/KPTS. Kb,020.10.2015 concerning Guidelines for Production, Certification, Distribution, and Supervision of Sugarcane Seeds.

The research utilized both qualitative and quantitative analysis methods. Quantitative variables, which are governed by genes and pertain to morphological and physiological traits, were measured, including stem height, stem diameter, yield, crystal content, and harvest weight (Patra, 2022). Conversely, qualitative variables are discrete and visually observed to distinguish plant phenotypes. One or more genes also control these variables and can be either monogenic or oligogenic. The presence or absence of environmental influences distinguishes these variables. Data collection was conducted through observation techniques. The research design for the ratoon cane was a randomized block design (RBD) consisting of six clones (SB04, SB11, SB19, SB20, PS881, and BL) as treatments and three replicates. The experimental plot size was 10 x 8 meters. The pedigree selection was conducted in 2013, and the clones underwent several laboratory tests for excellence, including Green House, Pot trial, and Polybags. Furthermore, the clones underwent preliminary and multi-location tests in several dry land typologies, paddy fields, and agro-climates until 2018. Productivity tests were conducted in multi-locations plant cane in 2019, followed by ratoon cane one in 2020 and ratoon cane two in 2021. The data were analyzed using ANOVA with a 5 % LSD test, regression analysis, genetic diversity assessment, and analytical description.

Genetic Diversity and Regression Test

The regression value is utilized to ascertain the extent of influence that several independent variables exert on the dependent variable, and the values of the dependent variables can be a predictor if all the independent variables have known values. Regression analysis is employed to predict the value of one or more response variables (dependent variables) based on several predictor variables (independent variables). If x1, x2, . . ., xp are predictor variables with p variables that have a relationship with a response variable Y, then a general linear regression model with one response variable can be represented as follows:

$$Y = a + b1X1 + b2X2 \quad (1)$$

Y = dependent variable (variable value to be predicted)
A = constant
b1,b2,…, bn = regression coefficient value
X1,X2,…, Xn = independent variable

Genetic diversity is a variation within a population due to diversity among individuals as members of the population (Filho et al., 2021).

$$\sigma^2 g = (M3 - M2) / rl \quad (2)$$

$$\sigma^2 gxe = (M2 - M1) / r \quad (3)$$

$$\sigma^2 e = M1 / rl \quad (4)$$

$$\sigma^2 p = \sigma 2 g + \sigma 2\, gxe / l + \sigma^2 e \quad (5)$$

and

$$KKG = \frac{\sqrt{\sigma^2 g}}{\bar{x}} x\ 100\% \quad (6)$$

The breadth or narrowness of the genetic diversity value of a trait is determined based on the genetic variance and standard deviation of gene variance according to the following formula:

σ^2 g > 2 $\sigma\sigma^2$ g: broad genetic diversity,

σ^2 g < 2 $\sigma\sigma^2$ g : narrow genetic diversity (Tolera et al., 2023).

RESULTS AND DISCUSSION

Kinship

Grouping analysis to determine the relationship between the sugarcane varieties studied was carried out based on the morphological traits description in Figure 1.

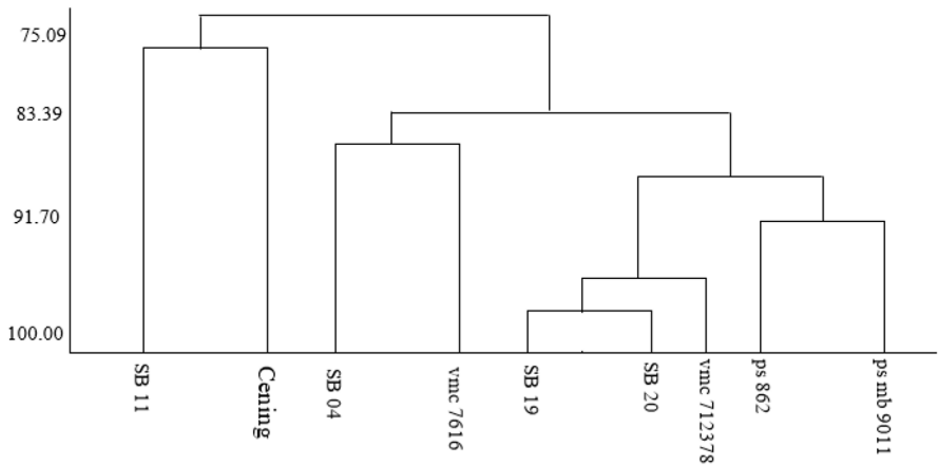

Figure 1. Dendrogram of the Relationship between Sugarcane *(Saccharum officinarum* Linn*)* Clone SB04, Clone SB11, Clone SB19, Clone SB20, and the Parental Varieties

Figure 1 depicts two groups or clusters of sugarcane varieties *(Saccharum officinarum* Linn*)* based on their morphological traits, with a similarity value of 75.09 %. Group I comprise sugarcane varieties Cenning and SB 11, while Group II includes varieties VMC 76-16, PSBM901, PS862, VMC71-238, and clones SB04, SB19, and SB20. The agglomerative coefficient values indicate the degree of similarity between sugarcane varieties. Clones SB04, SB19, and SB20 exhibit a closeness of 88.85 to variety VMC711 but not to clone SB11 or variety Cenning.

Genetic Diversity, Potential Productivity, and Coefficient of Genetic Diversity

The diversity value for quantitative variables can be determined based on the coefficient of genotypic diversity (GST) and the coefficient of phenotypic diversity (PST). These values ascertain the potential for selection progress for the trait under examination. The coefficient value of genetic diversity is presented in Table 1.

Table 1. The Coefficient Value of Genetic Diversity (GST) and Coefficient of Phenotypic Diversity (PST)

CHARACTER	GST (%)	PST (%)	Adms
Stem Height	29.181	29.297	Slightly Low
Rod Diameter	0.092	0.100	Low
Number of segments	2.204	2.430	Low
Brix	2.866	2.902	Low
Sugarcane Weight	104.745	231.351	hight
Yield	0.356	0.361	Low
Crystal	9.773	21.802	low

All the traits observed in this study exhibited high heritability estimates, except the percentage of stem weight and crystal content. A high heritability value signifies a strong correlation between phenotype and genotype. In this context, genetic factors exert a greater influence than environmental factors on the manifestation of the trait or phenotype. The environmental influence suggests that the action of additive genes is highly prominent, as proposed by Yadav et al. (2023). Most traits display broad genetic and phenotypic diversity, as evidenced by the diverse GST and PST scores. High diversity ensures the effectiveness of the selection made on the population.

As per the data presented in Table 1, the clones SB04, SB11, SB19, and SB20 exhibited high genetic diversity values in a broad sense. A higher GST value indicates a greater potential for successful technical culture improvement across various multi-location productivity potential tests for these clones in dry land and rice fields, thereby leading to optimal productivity.

A high GST value also results in a wider variability of traits, which can subsequently enhance genetic progress. A large coefficient of genetic diversity suggests that genetic manipulation of a trait with that coefficient has a high probability of success. Conversely, a trait with a small coefficient of genetic diversity will have a lower likelihood of successful improvement (Luo et al., 2022).

The clones SB04, SB11, SB19, and SB20 exhibited high PST values. A high FCF value suggests that environmental factors significantly influence the observed diversity. If the PST value is low and the GST value is high, it implies that genetic factors predominantly influence diversity. Conversely, a high PST value and a low GST value indicate that environmental factors largely influence diversity.

The observed high phenotypic diversity can be attributed to substantial environmental diversity (Zan et al., 2020). This high phenotypic diversity is due to significant environmental and genetic diversity resulting from segregation (Khan et al., 2021). The displayed diversity is the phenotype resulting from differences in genotypes.

A low genetic variance value in a population results from environmental variance exceeding phenotypic variety (Tolera et al., 2023). The absence of genetic variance does not mean that no genes affect the appearance of the diversity of clones SB04, SB11, SB19, and SB20. However, these genes are only expressed because dominant environmental factors cover them.

The yield diversity trait of clones SB04, SB11, SB19, and SB20 exhibited relatively high GST and comparatively low PST values. However, the crystal content and stem weight trait demonstrated high values for both GST and PST. The diverse traits of these clones displayed narrow variability. This narrow variability suggests that each individual in the population tends to be homogeneous, reducing the likelihood of obtaining a superior new generation (Hoarau et al., 2022). The high GST and PST values were particularly evident in the crystal content and stem weight traits. Despite both coefficients of diversity yielding high values, the PST value surpassed the GST value. This indicates that environmental factors exert a greater influence on the diversity of crystal content and stem weight in sugarcane clones SB04, SB11, SB19, and SB20.

Based on empirical evidence, the execution of multi-location tests to evaluate the potential productivity of plant cane and ratoon clones SB04, SB11, SB19, and SB20 in dry land and paddy fields is essential for determining their optimal productivity potential and stability.

The analysis of quantitative variables for clones SB04, SB11, SB19, and SB20, as presented in Table 1, revealed high GST values for the crystal content and stem weight per hectare. The yield trait exhibited a relatively high GST value. The crystal content and stem weight per hectare traits demonstrated a high FCF value, while the yield character showed a relatively low PST value. The genetic diversity analysis indicated high GST values, particularly for the crystal content and stem weight per hectare traits. The observed traits had KK values ranging from 27-28262 %. A greater coefficient of diversity on observed traits suggests a wider distribution of clone data (Ahmed et al., 2019; Alarmelu et al., 2021). The environment exerts varying influences on the observed variables. The Coefficient of Genetic Diversity (GST) and Phenotype (PST) are expressed in percentages (%). The GST and PST values for yield traits were 27 % and 65 %, respectively; for crystal content, they were 28262 % and 266 %; and for stem weights, they were 9536 % and 117%. Most GST and PST calculations displayed high criteria, while the yield trait showed relatively high criteria.

These results suggest that productivity in terms of crystal content and weight of sugarcane per hectare is high and is influenced more by genetic factors than environmental factors and vice versa. The high and low PST values describe the diversity of the visual traits of the four superior clones tested.

The genetic diversity of the four clones (SB04, SB11, SB19, and SB20), when planted in the limited environmental conditions of Mojokerto's alluvial dry land, exhibited varied responses. The observed differences in the genetic diversity of each clone were consistent with the traits of their parent varieties (Khan et al., 2022). The findings of this study highlight the suitability of each clone to its respective growing area typology, thereby contributing to an increase in productivity potential, particularly in sugarcane weight, yield, and crystallization optimization. Each clone aligns with Barreto et al.'s assertion that qualitative traits can be visually discerned (Barreto et al., 2021), and that these qualitative characteristics remain relatively stable despite changing environmental conditions (Xu et al., 2021). The qualitative trait of each clone plays a crucial role in germplasm conservation. The genetic diversity trait of each clone is manifested in the four superior clones selected and tested for their superiority. This ensures that the superior clones that pass the selection and have been tested for superiority are distinct and can be differentiated from one another.

The results of the genetic diversity test for each clone corroborate previous studies, which stated that there were trait differences between sugarcane clones, as evidenced by examining the morphological traits of each clone (Ahmed et al., 2019; Hamida & Parnidi, 2019). This study demonstrated that each clone could develop unique traits but tended to thrive in dry environmental conditions in Mojokerto's alluvial soils.

Potential Productivity Analysis

The potential advantages of the SB04 clone's productivity are presented in Table 2, showing that the productivity value of SB04 was higher than its parent, namely the PS 862 variety. The SB04 clone tends to inherit the trait description of the PS 862 parent.

Table 2. Comparison of SB04 Clone Production with its Parents Polycross

Varieties	Variable			
	Yields (%)	Crystal (ku/ha)	Rod Weight (ku/ha)	Maturity
SB04	9.25	134.12	1450	Middle–Slow
Tetra (PS 862)	9.45±1.51	91.0±16.3	993±1.02	Early-Middle

SB11 clone has high potential productivity compared to its parents, as shown in Table 3. As indicated in Table 3, the SB11 clone demonstrated higher potential productivity than the Cenning parent across all variables, although it did not surpass the VMC76-16 parent. The SB11 clone tends to inherit the descriptive trait of a.

Table 3. Comparison of SB11 Clone Production with its Parents

Varieties	Variable			
	Sugar Content (%)	Crystal (ku/ha)	Rod Weight (ku/ha)	Maturity
SB11	8.63	80.47	933	Slow
Parent (VMC76-16)	10.02±0,52	88.27±19.9	1105±182	early-middle
Parent (Cenning)	10.97	71.14	775	early-middle

The SB19 clone has high potential productivity, which is presented in Table 4. As indicated in Table 4, the SB19 clone demonstrated higher potential productivity than the VMC71-238 parent across all assessment criteria, although the yield value was not superior to that of the parent. The SB19 clone tends to inherit the descriptive trait of the parent.

Table 4. Comparison of SB19 Clone Production with its Parent

Varieties	Variable			
	Yield (%)	Crystal (ku/ha)	Rod Weight (ku/ha)	Maturity
SB19	11.25	152.62	1650	Early
Parent (VMC71-238)	10	110	1100	early-middle

The SB20 clone exhibited high potential productivity, as presented in Table 5. As indicated in Table 5, the SB20 clone demonstrated higher potential productivity than both parents across all variables, except for the yield value, which was lower than the parent's yield. The SB20 clone tends to inherit the descriptive trait of VMC 71-238.

Table 5. Comparison of the Production of SB20 Clones with their Parents

Varieties	Variable			
	Sugar Content (%)	Crystal (ku/ha)	Rod Weight (ku/ha)	Maturity
SB20	8.14	125.36	1540	Early
Parent (VMC71-238)	10.02±0.52	88.27±19.9	1105±182	early-middle
Parent (PSBM-901)	9.93±1.002	69.5±16.3	704±162	early-middle

The analysis presented in Tables 2 to 5 reveals that the four clones (SB04, SB11, SB19, and SB20) tend to inherit morphological traits from their respective parents. Kinship mapping can be utilized to determine the diversity of germplasm for plant breeding purposes. The SB04 clone inherits traits from its heterozygous polycross parent, PS 862, and exhibits a tall stem stature but is susceptible to collapsing in strong winds. It has a yield potential of 13.41 tons/ha. The SB11 clone inherits a trait from Cenning and features a dense and tall clump stature with straight stems exhibiting reddish cylindrical segments. The stems have a waxy coating, but it does not affect their color. The yield productivity potential is 8.04 tons/ha.

The SB19 clone inherits characteristics from VMC 71-238 and has an upright stature with straight stems featuring green cylindrical segments with a thick wax coating. It has pest and disease-resistance properties and a yield productivity potential of 15.26 tons/ha. The SB20 clone inherits traits from the combination of its parents, VMC71-238 and PSBM 901, with a yield potential of 12.53 tons/ha. These percentage values for the morphological characters and productivity can serve as a reference for genetic studies and kinship analysis between the four tested clones, which are deemed superior for alluvial soils in Mojokerto and multiple locations.

The four superior clones under investigation exhibited variations in their physical traits. These variations were attributed to the inheritance of morphological traits from their parent varieties and their predisposition towards specific parent varieties. The morphological included agronomic potential and sugarcane production (Cursi et al., 2022). Qualitative traits are defined as traits that exhibit qualitative differences and can be easily categorized (Tesfa et al., 2024). Simple genes typically govern these traits (Budeguer et al., 2021). This analysis aimed to ascertain the genetic relationship among the four clones (SB04, SB11, SB19, and SB20) in a quantifiable manner. Regression analysis indicated that the observed values were a consequence of genetic and environmental influences.

The productivity of these clones was found to be optimal under environmental conditions conducive to their growth. These four superior clones (SB04, SB11, SB19, and SB20) are undergoing further testing to evaluate the stability of their productivity across multiple locations with varying soil types, including vertisol, alluvial, regosol, and grumusol. Despite these ongoing tests, their productivity continues to surpass that of older varieties and controls.

This study aimed to investigate the productivity potential of superior clones SB04, SB11, SB19, and SB20 in the Sambiroto Mojokerto plantation when planted as plant cane instead of ratoon cane. The study was conducted on dry land with a 75 % conversion per hectare and one type of alluvial soil. The results of the 5 % LSD test are presented in Table 6.

Table 6. Productivity Potential of Plant cane and Ratoon cane one Clone SB04, SB11, SB19, SB20, Conversion 75%, LSD 5%

Varieties	Plant Period	Harvest Time	Ripeness	Productivity				
				Brix (%)	Weights (q/ha)	Yield (%)	Crystal (ton/ha)	Conversion 75 %/ Ha (ton/ha)
Plant Cane								
SB04	07B 2019	08B 2020	Middle-slow	21	1256	7.49	9.41	7.32 a
SB11			Slow	23	1223	8.80	10.76	8.72 ab
SB19			Preliminary	20	1473	7.90	11.63	8.92 b
SB20			Preliminary	22	1130	7.90	8.92	7.52 a
PS 881			Preliminary	22	1216	9,06	11.02	8.27 a
BL			Slow	19	1264	7.52	9.51	7.13 a
LSD 5%								1.33
Ratoon Cane 1								
SB04	08B 2020	07B 2021	Middle-slow	25	1450	9.25	13.41	11.60 b
SB11			Slow	22	933	8.63	8.04	10.93 ab
SB19			Preliminary	24	1650	9.25	15.26	11.63 b
SB20			Preliminary	22	1540	8.14	12.53	9.90 ab
PS 881			Preliminary	22	1360	9.30	12.64	10.50 b
BL			Slow	20	1363	8.53	11.62	9.73 a
BNT 5%								2.49

Note: In the same column followed by different letters indicates significantly different based on the 5% LSD test.

Table 6 shows the potential productivity of clones SB04, SB11, SB19, and SB20 by plant cane and one type of alluvial soil.

As per the analysis in Table 6, the SB04, SB11, SB19, and SB20 clones exhibited high productivity potential. However, the productivity potential of each clone varies when evaluated based on indicators such as sugarcane weight, yield, and crystal production per hectare (Mehdi et al., 2024).

The disparity in the potential productivity of each clone can be attributed to the differing potential productivity inherited from each parent. This affects metabolic processes, particularly cell division, enlargement, and elongation (Pocovi et al., 2020). The process of converting sap into sucrose also varies. The converting aligns with the findings of (Ahmed et al., 2019; Kumari et al., 2020), which suggest that the productivity potential of superior varieties is not uniform.

In 2013, a plant breeding process was conducted at the Perning Mojokerto field using parent plants, including PL 55, Cenning, BM 90-1, VMC.71.238, BM 90-1, VMC 76-16, BL, and PS 862. The goal was to produce new superior varieties based on genetic diversity and breeder preferences (Anwar et al., 2021). The Hablur clones SB04, SB19, and SB20 demonstrated higher productivity than their parent plants and the PS 862 variety and exhibited early to mid-maturity. Clone SB11 produced a higher crystal content than its parent plants and the slow-ripening Bululawang variety. However, a 5 % LSD test did not reveal a significant difference compared to the other clones.

The crystals produced in this study were minimal, as the conversion rate was 75 % of the one-hectare area (Table 6). These results are consistent with previous findings (Heliyanto & Abdurrakhman, 2022) (3). Interestingly, one of the clones possesses a unique feature of feather covering on its back, which is around 20-25 % between the segments of the stem. (4) They are well-adapted for cultivation in the D3 agroclimatic type, characterized by alluvial soil topology in dry Raton cane 1 land. These clones display both early and late maturity types and have the potential to produce high fiber content while being resistant to fire blight disease. (5) Future research should extend to determining productivity superiority in different agroclimatic conditions, such as C2 and C3 types, and soil typologies, including chromosols, vertosols, and podzolic. DNA testing should also be conducted to ascertain the precise reasons for the high productivity traits. Furthermore, resistance to fire blight disease and fiber content testing should be carried out in various settings. (6) The crystal content and stem weight traits had a high coefficient of gene differentiation (Gst) and phenotypic differentiation coefficient (Pst), namely crystal content of 28262 % and 266 % and stem weight of 9536 % and 117 %, respectively. The four superior clones have the advantage of high crystal content, resistance to smut disease, and high coir content, which are potential renewable bioenergy sources.

The regression value is utilized to ascertain the extent of influence that several independent variables exert on the dependent variable. It can also predict the value of the dependent variable if all the independent variables have known values. The results of the regression test are presented in Table 7.

Table 7. Regression Value

Predictor	Coef	SE	t stat	p-value
Constant	0.335	2.202	-0.15	0.887
X1	0.39223	0.09475	4.14	0.014
X2	0.00032	0.000247	1.29	0.265
S	0.2553			
R-Sq	81.10%			
R-Sq(adj)	71.60%			
Sig. F	0.048			

This study used the multiple linear regression equation model: $Y = a + b_1X_1 + b_2X_2$. By examining the regression model and the results of the multiple linear regression, we can derive an equation that represents the factors influencing sugarcane productivity. This equation provides a mathematical representation of how various factors contribute to the overall productivity of sugarcane.

$Y = 0.33 + 0.392X_1 + 0.00032X_2$. As indicated in Table 7, the calculated F value is 0.335, with a significance level of 0.048. The results of analysis suggests that the probability is less than the tolerable significance level (0.048 < 0.05). Consequently, the yield variable has a significant positive effect on clone productivity. The coefficient of determination is utilized to determine the percentage of the effect of the yield variable on productivity. According to the regression test results in Table 7, the coefficient of determination (R square) is 81.10 %. This demonstrates that productivity is influenced by internal factors by 81.10 %, and external factors influence 18.9 %.

Based on the analysis presented in Table 7, the four superior clones (SB04, SB11, SB19, and SB20) exhibited high productivity. The superior clones was substantiated by the productivity data from two planting periods, namely the plant cane (PC) and the ratoon cane I (RC1), which were analyzed using multiple linear regression analysis. Sugarcane production is influenced by several factors, such as the fact that it does not operate independently and affects productivity. The production components utilized were data on sugarcane stalk production per planting level and resulting sugar production data, which were analyzed using correlation analysis. The research analysis results support the first hypothesis that variable (X1) has a partially positive effect on crop production, as indicated by the regression coefficient X1 of 0.392. Essentially, every unit increase in a variable (X1) will enhance productivity by 0.392 units. Variable (X2) also has a partially positive effect on plant productivity, as indicated by the regression coefficient X2 of 0.00032. The variable analysis implies that every

Table 8. Resistance to Fire Wounds and Coir Content of Superior Clones SB04, SB11, SB19, SB20 in Plant cane and Ratoon Cane One

Varieties	Plant Period	Harvest Time	Observation Attack (%)	Inoculation Attack (%)	Coir rate (%)	POL (%)
Plant Cane (Corsample)						
SB04	07 B 2019	08 B 2020	0.58	-	15.25	10.68
SB11			0.00	-	16.30	11.30
SB19			0.00	-	16.95	11.05
SB20			0.00	-	17.20	11.76
PS 862				-	-	-
BL				-	-	-
Ratoon Cane 1(Laboratory)						
SB04	08 B 2020	07 B 2021	0.58	-	14.80	-
SB11			0.00	-	15.81	-
SB19			0.00	-	16.45	-
SB20			0.00	-	16.23	-
PS 862				-	13.47	-
BL				-	13-14	-
Plant Cane (Polybag) age up to 6 months						
SB04	08 B 2022	02 B 2023	-	7.41	-	-
SB11			-	7.41	-	-
SB19			-	3.70	-	-
SB20			-	3.70	-	-
PS 862			-	14.81	-	-
BL			-	22.22	-	-

unit increase will augment crop production by 0.00032 units. A probability value smaller than 5 % (0.048 < 0.05) indicates that variables X1 and X2 positively increase sugarcane productivity. The results of this analysis illustrate that 81.10 % of the productivity of clones SB04, SB11, SB19, and SB20 is influenced by genetic factors, while environmental factors influence 18.9 %.

The resistance to fire injury and coir content of superior clones SB04, SB11, SB19, and SB20 are presented in Table 8. As indicated in Table 8, the four clones demonstrated resistance to smut disease, as observed in both plant cane and ratoon cane until natural harvest. Moreover, they were also tested with a smut disease inoculant on cane plants up to the age of 6 months on polybag media, with only indicators of attack appearing at 6 months of age. Another supporting trait was that these four superior clones have the potential to produce high coir content in both plant cane and ratoon cane harvest methods, making them a potential source of bioenergy. The findings of this study corroborate that these four clones meet the requirements as candidates for new superior varieties, which aligns with previous studies (Kristini et al., 2022; Uchtiawati et al., 2020).

CONCLUSIONS

The genetic diversity among the four clones of *Saccharum officinarum* Linn is characterized by differences in morphological and agronomic traits, with their genetic superiority traits varying upon crossing, such as weight, yield, and crystallization. These clones exhibit high crystallization productivity exceeding 8-15 tons/ha due to superior genetic and morphological traits that cause differences in productivity. The superior clones of SB04, SB11, SB19, and SB20 resulted in higher sugarcane weight, yield, and crystal content than the two parents. SB04 yielded 13.41 tons/ha of crystals, SB11 produced 8.47 tons/ha of crystals, SB19 yielded 15.26 tons/ha of crystals, and SB20 produced 12.53 tons/ha of crystals, which were higher than those of their parent plants. The test results revealed a significant difference related to the dominance of the potential productivity variable; there were dominant clones in crystal production and some inherited traits from both parents that were high but not dominant.

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AUTHORS CONTRIBUTIONS

SB designed and conceived the experiments. WNL and AEP conducted the experiment. SB, WNL, and AEP contributed to sample preparation and interpretation of results. WNL and GSS primarily prepared this manuscript. All authors provided critical feedback and contributed to the research development, analysis, and manuscript.

COMPETING OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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