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Agronomic performance and sugar yield potential of seven promising sugarcane (*Saccharum officinarum* L.) clones in second ratoon cultivation

Kinerja agronomis dan potensi hasil gula tujuh klon tebu (*Saccharum officinarum* L.) harapan pada budidaya keprasan kedua

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ABSTRACT
The decline in sugarcane productivity and the imbalance between sugar production and national consumption are largely attributed to the genetic degradation of long-cultivated commercial varieties and suboptimal ratoon management. This study evaluates the agronomic performance and sugar yield potential of seven promising sugarcane (*Saccharum officinarum* L.) clones in their second ratoon cycle. The research was conducted at the Sugarcane Research and Development Center (P3T) in collaboration with PG Krembung, PT Perkebunan Nusantara X (PTPN X), in Watesari Village, Sidoarjo, Indonesia. A randomized block design (RBD) with one factor and nine treatments was employed. Statistical analysis comprised ANOVA at a 5% significance level, Least Significant Difference (LSD) test, genetic diversity analysis, and heritability estimation. The results revealed significant differences among the clones in stalk diameter, brix, stalk weight, yield, and sugar content. The JW01 UMG NX clone exhibited the highest stalk diameter (33.31 mm) and sugar recovery (11.64%), while the SB19 UMG NX clone demonstrated the highest stalk weight (165.28 tons/ha), brix (23.78 °Bx), and yield (18.79 tons/ha). Genetic diversity was low across all measured traits, but heritability values were high, suggesting a strong genetic influence. These findings indicate that JW01 UMG NX and SB19 UMG NX are highly productive and hold strong potential as candidates for new superior varieties (NSV) to support national sugar self-sufficiency.

ABSTRAK
Penurunan produktivitas tebu dan ketidakseimbangan antara produksi serta konsumsi gula nasional sebagian besar disebabkan oleh degradasi genetik pada varietas komersial yang telah lama dibudidayakan serta pengelolaan keprasan yang kurang optimal. Penelitian ini bertujuan untuk mengevaluasi kinerja agronomis dan potensi hasil gula dari tujuh klon tebu (*Saccharum officinarum* L.) harapan pada siklus keprasan kedua. Penelitian dilakukan di Pusat Penelitian dan Pengembangan Tebu (P3T) bekerja sama dengan PG Krembung, PT Perkebunan Nusantara X (PTPN X), di Desa Watesari, Sidoarjo, Indonesia. Rancangan acak kelompok (RAK) dengan satu faktor dan sembilan perlakuan digunakan dalam penelitian ini. Analisis statistik mencakup ANOVA pada taraf kepercayaan 5%, uji Beda Nyata Terkecil (BNT), analisis keragaman genetik, dan estimasi heritabilitas. Hasil penelitian menunjukkan perbedaan signifikan antar klon pada parameter diameter batang, brix, bobot batang, hasil tebu, dan rendemen gula. Klon JW01 UMG NX memiliki diameter batang terbesar (33.31 mm) dan hasil tebu tertinggi (11.64%), sedangkan klon SB19 UMG NX menunjukkan bobot batang tertinggi (165.28 ton/ha), brix tertinggi (23.78 °Bx), dan rendemen gula tertinggi (18.79 ton/ha). Keragaman genetik tergolong rendah pada semua karakter yang diukur, tetapi nilai heritabilitasnya tinggi, menunjukkan pengaruh genetik yang kuat. Temuan ini mengindikasikan bahwa klon JW01 UMG NX dan SB19 UMG NX memiliki produktivitas tinggi dan berpotensi kuat sebagai kandidat varietas unggul baru (VUB) untuk mendukung swasembada gula nasional.

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INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is a key plantation crop that serves as the primary raw material for sugar production. The increasing national sugar consumption aligns with population growth and changing dietary patterns. According to the Central Bureau of Statistics, Indonesia's population reached 278 million in 2023, continuing to rise from previous years (Badan Pusat Statistik [BPS], 2024). However, in the same year, sugar production declined, with output dropping from 2.40 million tons in 2022 to 2.23 million tons in 2023, marking a 7.01% decrease (168.41 thousand tons). The limited availability of new superior varieties has contributed to the low productivity of sugarcane (Fasheh et al., 2022). Many commercially grown sugarcane varieties have experienced declining productivity due to genetic degradation resulting from prolonged cultivation, ultimately leading to reduced growth and yield (Nurazizah et al., 2022).

Over time, superior sugarcane varieties gradually lose their vigor, disrupting optimal plant maturation cycles (Ranjiith & Francesco, 2022). Additionally, extended ratoon cropping negatively affects growth quality and overall productivity. Several factors influence ratoon yield, including genetic traits, agronomic management, and environmental conditions (Pissolato et al., 2021). Periodic evaluations of superior sugarcane varieties are essential every 10 years to maintain resistance to new pests and diseases while introducing more productive varieties (Begna, 2020). One of the strategies to address this issue is the development of new superior varieties through artificial crossbreeding. Sugarcane breeding programs aim to produce superior varieties adapted to diverse environmental conditions while maximizing desired agronomic traits (Cursi et al., 2022).

The breeding process is complex and time-consuming, typically requiring 10 to 15 years to develop a new variety (Gazaffi et al., 2016). Our group initiated artificial crossbreeding and selection in Perning, Mojokerto. After successfully developing seven promising sugarcane clones (JW01 UMG NX, SB03 UMG NX, SB04 UMG NX, SB11 UMG NX, SB12 UMG NX, SB19 UMG NX, and SB20 UMG NX), further selection and performance evaluations were conducted until 2019. Multi-location productivity trials across different agroclimatic and soil conditions were carried out until 2024. By 2022, these clones were undergoing multi-location productivity assessments and morphological description validation (Budi et al., 2022). The availability of these candidate superior sugarcane varieties is expected to provide farmers with improved planting options, support the national sugar self-sufficiency program, and enhance farmer incomes, as the expected sugar yield surpasses 8 tons per hectare (Budi et al., 2022). Despite these advancements, limited research has been conducted on evaluating the agronomic performance and sugar yield potential of promising sugarcane clones specifically in the second ratoon cycle. Additionally, there is a lack of comprehensive studies assessing the adaptability and productivity stability of these clones across various agroclimatic conditions and soil types, particularly in grumusol soil with an E3 climate classification.

The seven promising clones are currently undergoing stability testing for productivity across different soil types (vertisol, alluvial, regosol, and grumusol) and climatic conditions (D3, C3, E3). Watesari Village is one of the selected locations for multi-location trials, aiming to evaluate the productivity of these clones in grumusol soil under E3 climatic conditions. The objective of this evaluation is to assess agronomic differences in productivity potential and stability among clones (Wati et al., 2024). Ratoon persistence in superior sugarcane varieties is a crucial target in breeding programs and is highly valued by breeders (Abu-Ellail et al., 2019). Therefore, this study aims to evaluate the agronomic performance, sugar yield potential, and ratoon persistence of seven promising sugarcane clones in their second ratoon cycle. The findings will contribute to identifying clones with superior productivity and adaptability, supporting their potential release as new superior varieties.

MATERIALS & METHODS

Study site

This study was conducted at the Sugarcane Research and Development Center (P3T) in collaboration with PG Krembung, PT Perkebunan Nusantara X (PTPN X), located in Watesari Village, Balongbendo District, Sidoarjo Regency, Indonesia (7°25'31"S, 112°32'45"E). The research was carried out from May to August 2024. The experimental site is characterized by grumusol soil and is classified under an E3 climate type. This classification follows the Schmidt-Ferguson climate classification system, which is widely used for determining agroclimatic suitability for crop cultivation in tropical regions. The E3 climate is particularly important in sugarcane production due to its seasonal moisture variation, which influences ratooning ability and sugar accumulation in cane stalks (Budi et al., 2022). This location was selected as part of a multi-location trial program aimed at evaluating the agronomic performance and sugar yield potential of second ratoon sugarcane clones under varying environmental conditions. The grumusol soil in this area, which is clay-rich with moderate organic matter, plays a crucial role in nutrient retention and influences root development and stalk elongation (Ismail & Jamin, 2022).

Plant material

The plant materials used in this study consisted of seven promising sugarcane clones obtained through artificial crossbreeding, developed to enhance agronomic traits and improve ratooning ability. These clones included JW01 UMG NX (*PL 55 × VMC 71-238*), SB03 UMG NX (*PL 55 × Cening*), SB04 UMG NX (*Polycross PS 862*), SB11 UMG NX (*VMC 7616 × Cening*), SB12 UMG NX (*PSBM 901 × VMC 71-238*), SB19 UMG NX (*PL 55× VMC 71-238*), and SB20 UMG NX (*PSBM 901 × VMC 71-238*). These clones were selected due to their high sugar yield potential and resistance to environmental stressors (Apriliyanto et al., 2024). Two widely cultivated commercial sugarcane varieties, PS 862 and Bululawang, were included as controls because of their proven agronomic stability in Indonesia (Wibisono et al., 2022). All clones and varieties used in this study were in their second ratoon cycle at 46 weeks after ratooning (WAR).

Experimental design

A randomized block design (RBD) was used to minimize variability in field conditions. The experiment consisted of nine treatments, representing the seven promising sugarcane clones and two control varieties, each replicated three times, resulting in 27 experimental units. Each unit consisted of three sample plants, totaling 81 sample plants. The experimental plot size was 10 × 10 meters, with a planting distance of 30 × 120 cm. Standard agronomic practices, including fertilization, irrigation, and pest management, were applied uniformly to all plots, ensuring that observed differences were attributed solely to genetic factors (Budi et al., 2022).

Observed parameters

The study assessed various agronomic and yield-related traits. Growth parameters were recorded at 46–50 WAR, including stalk length (cm), number of internodes, and stalk diameter (mm). Stalk length was measured from the base of the plant to the uppermost visible internode, while the number of internodes was manually counted for each plant (Muliandari et al., 2021). Stalk diameter was measured at the basal region using a digital caliper to ensure precision. Yield-related traits were recorded at 50 WAR, including Brix percentage (%), stalk weight (kg/plant), sugar recovery (%), and sugar yield (tons/ha). The Brix percentage, an indicator of sugar content in cane juice, was measured using a hand refractometer (SPAD 502-Plus, Atago, Japan). Prior to measurement, the refractometer was calibrated, and juice samples were extracted from the stalks (Amal et al., 2023). Stalk weight was determined using a digital balance and converted into tons per hectare to estimate total cane yield (Lira et al., 2017). Sugar recovery (%) was calculated using the formula:

$$\textit{Sugar recovery}\,(\%) = \text{Juice Extraction Factor} \times \text{Brix Value} \quad (1)$$

as suggested by previous studies (Harjanti et al., 2024). Sugar yield (tons/ha) was estimated by multiplying stalk weight with sugar recovery percentage (Budi et al., 2022).

Data analysis

Statistical analyses were performed using analysis of variance (ANOVA) at a 5% significance level to determine significant differences among clones. If significant effects were detected, a Least Significant Difference (LSD) test at 5% was applied for post-hoc comparisons (Pissolato et al., 2021). Genotypic and phenotypic variability were assessed using the genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) to evaluate the degree of genetic diversity within the clones (Rahayu et al., 2022). Furthermore, heritability estimates were calculated to determine the extent of genetic control over observed agronomic traits (Kumar et al., 2023). ANOVA and LSD analysis were conducted using Ms. Excel (Microsoft Corporation, USA).

RESULTS & DISCUSSIONS

Stalk length (cm)

The analysis of variance (ANOVA) at a 5% significance level (Table 1) indicated that stalk length did not differ significantly among the treatments or across the observation period from 46 to 50 weeks after ratooning (WAR). This lack of significant variation may be attributed to the genetic characteristics of each promising clone and commercial sugarcane variety. Additionally, environmental factors, such as limited water availability, could have influenced sugarcane growth by restricting cell elongation and overall plant development. The ratooning ability of sugarcane varieties is largely influenced by parental genetic factors, which are selected to produce offspring with growth characteristics equal to or superior to their parents. According to Syarifuddin et al. (2023), genetic material plays a crucial role in determining the inherited traits of each clone. Moreover, environmental factors, particularly water availability, significantly affect stalk elongation. A shortage of water supply disrupts cell expansion, reduces gas exchange, and limits CO_2 absorption by leaves, ultimately lowering the plant's photosynthetic efficiency (de Aquino et al., 2017). Drought stress leads to stomatal closure, restricting gas exchange in an effort to conserve moisture (Bhandari et al., 2023). Additionally, water deficiency impairs enzyme and hormone activity, which further affects plant growth (Yusuf, 2020).

Table 1. Mean stalk length (cm) at 46–50 weeks after ratooning (WAR) (n = 3)

Treatment	46 WAR	47 WAR	48 WAR	49 WAR	50 WAR
K1 (JW01 UMG NX)	278.97	282.22	285.70	290.33	297.36
K2 (SB03 UMG NX)	272.87	276.28	278.70	282.31	286.52
K3 (SB04 UMG NX)	253.60	257.02	259.82	263.96	268.73
K4 (SB11 UMG NX)	288.30	291.58	294.13	298.89	303.29
K5 (SB12 UMG NX)	296.94	300.10	303.23	307.18	311.94
K6 (SB19 UMG NX)	282.62	286.48	289.94	294.53	299.08
K7 (SB20 UMG NX)	283.92	287.66	290.58	295.18	299.40
K8 (PS 862)	279.70	282.28	284.04	285.83	290.31
K9 (Bululawang)	280.70	283.42	286.14	289.78	293.97
LSD 5%	ns	ns	ns	ns	ns

Note. Values in the columns are means. Different letters indicate significant differences based on Least Significant Difference (LSD) test at 5%; ns = not significant.

The soluble acid invertase (SAI) enzyme plays an essential role as an energy source for cell growth and elongation in sugarcane. The inhibition of invertase activity can increase sucrose accumulation, which is required for cell suspension growth in sugarcane (Sanjaya et al., 2020). Furthermore, auxin is a critical plant hormone that regulates growth by promoting cell division, elongation, and vascular differentiation (Chen et al., 2022). Mature sugarcane plants have been shown to exhibit similar physiological responses to growth regulation (Wang et al., 2013).

Number of internodes

The analysis of variance (ANOVA) results presented in Table 2 indicate that the number of internodes did not differ significantly among the treatments or across the observation periods. The process of internode formation continued between 46 and 50 weeks after ratooning (WAR), with an average increase of 3–4 internodes per plant. This consistent internode formation contributes to an increase in stalk length and overall productivity in sugarcane.

Table 2. Mean number of internodes per plant at 46–50 weeks after ratooning (WAR) (n = 3)

Treatment	46 WAR	47 WAR	48 WAR	49 WAR	50 WAR
K1 (JW01 UMG NX)	20.11	20.78	21.78	22.67	23.67
K2 (SB03 UMG NX)	20.00	20.44	21.00	21.89	22.89
K3 (SB04 UMG NX)	20.33	20.67	21.44	22.11	23.11
K4 (SB11 UMG NX)	20.44	20.89	21.56	22.22	23.22
K5 (SB12 UMG NX)	20.33	20.78	21.67	22.33	23.33
K6 (SB19 UMG NX)	20.44	21.22	22.22	23.00	24.00
K7 (SB20 UMG NX)	21.11	21.56	22.22	23.00	23.89
K8 (PS 862)	19.56	19.78	20.33	21.11	22.11
K9 (Bululawang)	21.11	21.33	21.67	22.22	23.22
LSD 5%	ns	ns	ns	ns	ns

Note. Values in the columns are means. Different letters indicate significant differences based on Least Significant Difference (LSD) test at 5%; ns = not significant.

As shown in Table 2, the increase in the number of internodes was not statistically significant across the treatments and observation periods. This result is likely due to the fact that the sugarcane plants had already entered the maturation phase, which typically occurs when sugarcane reaches 10 to 12 months of age (Andeva et al., 2018). The variations in mean internode number among different clones and varieties may be influenced by genetic factors, as morphological traits and parental lineage play a crucial role in determining growth characteristics. Genetic diversity is a key outcome of plant breeding programs and is reflected in the variation observed among clones (Siahaan et al., 2020).

Incomplete internode formation may be attributed to disruptions in cellular activity, leading to the development of shorter internodes. Water stress is a major limiting factor in sugarcane growth, as a lack of sufficient water availability results in reduced stalk elongation compared to plants grown under optimal moisture conditions (Zhao et al., 2013). Furthermore, nutrient availability plays a critical role in both sucrose formation and stalk development. According to Andeva et al. (2018), sugarcane plants with adequate nutrient supply exhibit optimal growth and internode elongation. In contrast, excessive nutrient leaching can lead to substantial nutrient loss, surpassing the rate of plant absorption, ultimately affecting plant development (Febrianto et al., 2022).

Stalk diameter (mm)

The Least Significant Difference (LSD) test at 5% significance level (Table 3) indicated that stalk diameter (mm) showed significant differences ($p < 0.05$) across all treatments and observation periods from 46 to 50 weeks after ratooning (WAR). Among the evaluated clones, JW01 UMG NX exhibited the largest stalk diameter at 33.31 mm, while SB03 UMG NX had the smallest diameter at 25.22 mm. The variation in stalk diameter across different clones may be attributed to genetic factors, as the inherited characteristics from parent plants influence stalk size. The significant variation in stalk diameter across treatments and observation periods may be influenced by enzyme activity and optimal growing conditions. The availability of soluble acid invertase (SAI) and cell wall invertase (CWI) enzymes plays a crucial role in plant growth by providing energy for cell elongation and expansion (Larasati & Budi, 2023). These enzymes hydrolyze sucrose into hexoses (glucose and fructose), which serve as energy sources for actively growing plant tissues (Husain et al., 2023). In addition to enzymatic factors, stalk diameter expansion is also influenced by the synthesis of uridine-5-diphosphate glucose (UDPG), a key product of photosynthesis that supports stalk thickening. Auxin, a major plant hormone, further contributes to cell enlargement, particularly in the apical meristem region, thereby influencing stalk diameter (Sharfina et al., 2021). The interaction between genetic variation and optimal environmental conditions results in different stalk diameter outcomes across clones and varieties (Nurazizah et al., 2022). The stalk diameter of each clone and variety serves as an important indicator of the plant's ability to store juice, which directly affects sucrose accumulation. Sugarcane stalks with larger diameters typically contain higher juice content, which translates to greater sugar yield during factory processing (Rahmah et al., 2023). Therefore, selecting sugarcane clones with genetically superior stalk diameter is a crucial factor in improving sugar production efficiency.

Table 3. Mean stalk diameter (mm) at 46–50 weeks after ratooning (WAR) (n = 3)

Treatment	46 WAR	47 WAR	48 WAR	49 WAR	50 WAR
K1 (JW01 UMG NX)	32.16[c]	32.65[c]	32.65[c]	33.05[c]	33.31[c]
K2 (SB03 UMG NX)	24.14[a]	24.60[a]	24.76[a]	24.92[a]	25.22[a]
K3 (SB04 UMG NX)	31.19[c]	32.12[c]	32.49[c]	32.71[c]	32.94[c]
K4 (SB11 UMG NX)	28.52[b]	28.89[b]	29.14[b]	29.30[b]	29.55[b]
K5 (SB12 UMG NX)	27.83[b]	28.40[b]	28.53[b]	28.72[b]	28.96[b]
K6 (SB19 UMG NX)	31.79[c]	32.67[c]	32.97[c]	33.09[c]	33.29[c]
K7 (SB20 UMG NX)	31.78[c]	32.33[c]	32.51[c]	32.66[c]	32.75[c]
K8 (PS 862)	28.24[b]	28.85[b]	28.96[b]	29.17[b]	29.39[b]
K9 (Bululawang)	31.31[c]	31.87[c]	32.09[c]	32.28[c]	32.49[c]
LSD 5%	1.15	1.19	1.17	1.16	1.15

Note. Values in the columns are means. Different superscript letters indicate significant differences based on Least Significant Difference (LSD) test at 5%.

Brix content (°Bx)

The Least Significant Difference (LSD) test at 5% significance level (Table 4) revealed that Brix content showed significant differences ($p < 0.05$) at 49 and 50 weeks after ratooning (WAR). The sugarcane clones JW01 UMG NX, SB03 UMG NX, SB19 UMG NX, and SB20 UMG NX exhibited the highest Brix values, exceeding 23°Bx, just before harvest at 49 WAR. However, after harvesting at 50 WAR, Brix content declined in several promising clones and commercial sugarcane varieties. This reduction in Brix levels after harvest may be influenced by genetic factors, environmental conditions, and delayed milling after harvesting. The seven promising clones tested exhibited significant variation in Brix content, which is primarily influenced by morphological traits inherited from their parental lines. Each clone tends to inherit distinct agronomic potential and productivity characteristics from its parent variety (Budi et al., 2024). Morphological attributes, such as internode structure, fiber content, and juice accumulation, play a crucial role in determining sucrose content and sugar yield (Cursi et al., 2022). Moreover, a stable environmental condition enhances enzymatic activity, optimizing plant productivity.

The sucrose produced during photosynthesis is accumulated and stored in somatic cells as part of the sink mechanism. This process is regulated by key enzymes such as sucrose phosphate synthase (SPS) and sucrose phosphate phosphatase (SPP), which control sucrose translocation (Nurnasari & Djumali, 2019). As sugarcane enters the maturation phase, the SPS enzyme activity increases, primarily influenced by temperature fluctuations between day and night. Optimal sugarcane growth and sucrose formation occur at temperatures ranging between 24°C and 32°C (Kiswanto & Wijayanto, 2014). Dissolved solids, including sucrose, glucose, fructose, and other soluble sugars, contribute to the measured Brix content (Bitibalyo & Mustamu, 2021). The variability in Brix values determines the maturity classification of sugarcane, which is typically categorized into early-maturing, mid-maturing, and late-maturing types (Riajaya & Kadarwati, 2017).

Table 4. Mean Brix content (°Bx) at 49–50 weeks after ratooning (WAR) (n = 3)

Treatment	49 WAR (Before harvest)	50 WAR (After harvest)
K1 (JW01 UMG NX)	23.22[cd]	19.99[b]
K2 (SB03 UMG NX)	23.11[cd]	20.88[c]
K3 (SB04 UMG NX)	22.67[c]	19.29[b]
K4 (SB11 UMG NX)	20.44[ab]	18.19[a]
K5 (SB12 UMG NX)	20.67[b]	19.39[b]
K6 (SB19 UMG NX)	23.78[d]	21.92[de]
K7 (SB20 UMG NX)	23.22[cd]	21.72[d]
K8 (PS 862)	22.67[c]	22.67[e]
K9 (Bululawang)	19.89[a]	19.89[b]
LSD 5%	0.72	0.83

Note. Values in the columns are means. Different superscript letters indicate significant differences based on Least Significant Difference (LSD) test at 5%.

Delayed milling after harvest leads to weight loss and an increase in reducing sugars due to water loss through evaporation (Antika & Ingesti, 2020). This phenomenon occurs as a result of increased respiration rates, causing Brix levels to decline over time. Additionally, the reduction in total soluble solids (TSS) in sugarcane juice is attributed to the enzymatic degradation of sucrose by microbial activity (Rahayu et al., 2022). Mechanical damage to harvested sugarcane facilitates microbial colonization, particularly by Leuconostoc mesenteroides, a bacteria known for consuming sugars and producing dextran. The accumulation of dextran in sugarcane juice increases viscosity, which negatively impacts sugar extraction efficiency and overall sugar quality during factory processing (Amal et al., 2023).

Sugarcane productivity

The Least Significant Difference (LSD) test at a 5% significance level (Table 5) revealed significant differences ($p < 0.05$) in stalk weight, sugar recovery, and sugar yield among the tested sugarcane clones and commercial varieties. SB19 UMG NX exhibited the highest stalk weight (165.28 tons/ha) and sugar yield (18.79 tons/ha). Meanwhile, JW01 UMG NX recorded the highest sugar recovery at 11.64%. The high productivity levels observed in these clones indicate their stable performance in the second ratoon cycle, potentially outperforming the plant cane or first ratoon. These results further support the selection of these promising clones as candidates for new superior sugarcane varieties. Stalk weight is primarily influenced by genetic and environmental factors. Sugarcane clones or varieties with higher stalk weight contribute significantly to improving total productivity (Djumali et al., 2019). The ratooning ability of sugarcane can be enhanced through direct selection of genotypes with high ratooning productivity. The recommended ratooning cycle is limited to a maximum of three ratoon generations, ensuring the availability of high-quality seed cane to meet national demand (Kadarwati et al., 2016).

Genetic factors also play a crucial role in determining ratoon vigor. During the germination phase of ratoon crops, higher abscisic acid (ABA) levels are observed in genotypes with strong ratooning ability compared to those with weak ratooning potential (Bashir et al., 2012). The primary objective of sugarcane breeding programs is to achieve national sugar self-sufficiency. Globally, sugarcane-producing countries focus on improving sugar yield through genetic enhancement. Sugarcane breeders have successfully developed new varieties with desirable traits, including high ratooning ability, resistance to pests and diseases, and optimal fiber content, ultimately maximizing sugar yield (Acreche et al., 2015). The evaluation of sugarcane productivity components aims to assess the stability of agronomic traits and sugar recovery rates. The observed variability in sugar recovery among clones helps determine their maturity classification. Additionally, conducting a second ratoon cycle evaluation is essential for selecting promising clones that can be nominated as new superior sugarcane varieties (Mahardianti et al., 2024).

Table 5. Mean stalk weight (tons/ha), sugar recovery (%), and sugar yield (tons/ha) at 50 WAR (n = 3)

Treatment	Stalk weight (tons/ha)	Sugar recovery (%)	Sugar yield (tons/ha)
K1 (JW01 UMG NX)	147.32[g]	11.64[c]	17.14[d]
K2 (SB03 UMG NX)	120.56[c]	9.60[ab]	11.57[b]
K3 (SB04 UMG NX)	137.22[f]	9.13[a]	12.52[c]
K4 (SB11 UMG NX)	111.95[a]	9.38[ab]	10.50[a]
K5 (SB12 UMG NX)	125.28[e]	9.01[a]	11.28[ab]
K6 (SB19 UMG NX)	165.28[h]	11.37[c]	18.79[e]
K7 (SB20 UMG NX)	111.67[a]	10.15[b]	11.33[b]
K8 (PS 862)	116.67[b]	10.33[b]	12.05[bc]
K9 (Bululawang)	121.67[d]	8.94[a]	10.88[ab]
LSD 5%	0.86	0.86	0.83

Note. Values in the columns are means. Different superscript letters indicate significant differences based on Least Significant Difference (LSD) test at 5%.

Planting sugarcane without considering its maturity classification may result in suboptimal sugar recovery, as the genetic variation among clones and varieties influences the optimal harvest time (Budi et al., 2024). Moreover, global climate change has led to rising environmental temperatures, impacting photosynthesis, respiration, water balance, and membrane stability in sugarcane leaves, which consequently reduces sugarcane yield (Cao et al., 2022). To address these challenges, sugarcane breeding programs focus on selecting genotypes with drought tolerance, high sugar content, and pest resistance. These strategies are crucial in mitigating the negative effects of climate-induced stress on sugarcane production (Zhao & Li, 2015). The development of new superior sugarcane varieties with high sugar recovery potential is a key solution in ensuring sustainable sugar production (Mastur et al., 2015). The ability of promising clones to maintain high sugar yield in the second ratoon cycle is a critical factor in sugarcane breeding. The evaluation of clone potential plays a crucial role in improving sugar yield, ensuring the selection of genotypes best suited to specific soil typologies and agroclimatic conditions (Djumali et al., 2019). The seven promising clones tested in this study, derived from elite parental crosses, are ready for release as new superior varieties, replacing older commercial varieties that have been cultivated for over a decade. Prolonged cultivation of commercial sugarcane varieties leads to genetic degeneration, resulting in increased susceptibility to pest and disease infestations and a gradual decline in sugar productivity (Setyawati et al., 2017). To overcome this challenge, sugarcane breeders must continuously develop hybridization and selection programs to produce new clones with improved yield, higher sugar content, and greater environmental adaptability (Kumar et al., 2023). Over the past five years, conventional breeding techniques have led to the successful development of numerous high-yielding sugarcane varieties with superior resistance to biotic and abiotic stress factors (Mehdi et al., 2024).

Genetic diversity and heritability

The analysis of genetic diversity and heritability, presented in Table 6, indicates that genetic variability was categorized as low, while heritability values were classified as high across all observed variables. The genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) for all measured traits were less than 5%, categorizing them as low variability. Meanwhile, heritability values exceeded 0.5 for all variables, indicating a high level of heritability. Genetic diversity reflects the extent to which a particular trait can vary due to environmental and genetic factors. Understanding genetic variation is crucial in facilitating the selection process for developing new elite sugarcane clones (Apriliyanto et al., 2024). The low PCV values observed in this study indicate that the phenotypic expression of the studied traits is relatively uniform, suggesting a high degree of genetic stability in the evaluated clones (Simanjuntak & Ardiarini, 2024). A broad genetic diversity in sugarcane is essential for breeders aiming to develop high-yielding clones with improved sugar content and productivity. The high heritability values across all measured traits suggest that the genetic influence from both male and female parent lines significantly affects the inheritance of these traits.

Table 6. Genetic diversity and heritability

Observed Variable	GCV (%)	Category	PCV (%)	Category	H^2	Category
Stalk length (cm)	0.32	Low	0.02	Low	224.30	High
Number of internodes	0.17	Low	0.22	Low	0.59	High
Stalk diameter (mm)	0.96	Low	0.68	Low	1.97	High
Brix (°Bx)	0.73	Low	0.72	Low	1.03	High
Stalk weight (tons/ha)	1.56	Low	1.50	Low	1.08	High
Sugar recovery (%)	0.90	Low	0.86	Low	1.08	High
Sugar yield (tons/ha)	2.50	Low	2.47	Low	1.03	High

Note. GCV classification: Low (<5%), Medium (5–14%), High (>14.5%). PCV classification: Low (0–10%), Medium (10–20%), High (>20%). Heritability (H^2) classification: Low (<0.20), Medium (0.20–0.50), High (>0.50)

As a result, these clones and varieties are highly recommended for cultivation, as they demonstrate strong genetic potential for maximizing sugarcane productivity. Furthermore, high heritability values indicate substantial variability within these traits, providing strong opportunities for further breeding programs (Nurazizah et al., 2022). Additionally, high heritability is crucial for the success of selection programs, as it ensures that targeted traits are reliably passed on to the next generations (Lira et al., 2017). The findings of this study confirm that the seven promising clones have strong heritable traits, making them excellent candidates for commercial release as new superior sugarcane varieties.

CONCLUSIONS

This study confirms the high productivity, strong ratooning ability, and genetic stability of seven promising sugarcane clones in the second ratoon cycle. SB19 UMG NX exhibited the highest stalk weight and sugar yield, while JW01 UMG NX had the highest sugar recovery, demonstrating their potential for commercial cultivation. Despite low genetic variability, high heritability values indicate that these clones possess desirable traits for breeding programs. The findings highlight the importance of optimal harvesting and milling practices to maintain sugar quality and prevent sucrose degradation. Overall, these promising clones offer superior alternatives to existing commercial varieties, supporting efforts toward higher sugarcane productivity and national sugar self-sufficiency. Future research should focus on multi-location trials and long-term evaluations to ensure their adaptability and sustainability in diverse agroclimatic conditions.

REFERENCES

Abu-Ellail, F. F. B., El-Azez, Y. M. A., & Bassiony, N. A. (2019). Assessment of ratooning ability and genetic variability of promising sugarcane varieties under middle Egypt conditions. *Electronic Journal of Plant Breeding*, *10*(1), 143–154. https://doi.org/10.5958/0975-928X.2019.00017.6

Acreche, M. M., Saez, J. V., & Chalco Vera, J. (2015). Physiological bases of genetic gains in sugarcane yield in Argentina. *Field Crops Research*, *175*, 80–86. https://doi.org/10.1016/j.fcr.2015.02.002

Amal, F. I., Sihmawati, R. R., Wulandari, A., & Wardah, W. (2023). Pengaruh umur simpan tebu terhadap kualitas nira tebu (*Saccaharum officinarum* L.). *Heuristic*, 209–2014. https://doi.org/10.30996/heuristic.v20i2.10159

Andeva, N., Indrawati, W., & Kusumastuti, A. (2018). Produktivitas tebu (*Saccharum officinarum* L.) asal bibit bud chips (ujung, tengah, pangkal) akibat aplikasi mulsa bagasse. *Jurnal Agro Industri Perkebunan*, *6*(2), 99. https://doi.org/10.25181/jaip.v6i2.815

Antika, L., & Ingesti, P. S. V. R. (2020). Analisis lama waktu pangkal batang tebu (*Saccharum officinarum* L.) tertinggal di lahan terhadap nilai rendemen. *Vigor: Jurnal Ilmu Pertanian Tropika Dan Subtropika*, *5*(1), 19–23. https://doi.org/10.31002/vigor.v5i1.2414

Apriliyanto, H., Budi, S., & Nur Lailiyah, W. (2024). Keragaan pertumbuhan dan produktivitas keprasan ii beberapa klon unggul tebu *(Saccharum officinarum* L.) di lahan kering Juwet Mojoagung Jombang. *TROPICROPS (Indonesian Journal of Tropical Crops)*, *7*(2), 108. https://doi.org/10.30587/tropicrops.v7i2.8409

Badan Pusat Statistik (BPS). (2024). Statistik tebu Indonesia 2023. https://www.bps.go.id/id/publication/2024/11/29/71e6450a9b235855ffc525c9/statistik-tebu-indonesia-2023.html

Bashir, S., Fiaz, N., Ghaffar, A., & Khalid, F. (2012). Ratooning ability of sugarcane genotypes at different harvesting dates. *International Sugar Journal*, *114*(1360), 273–276. https://www.researchgate.net/publication/258926437_Ratooning_ability_of_sugarcane_genotypes_at_different_harvesting_dates

Begna, T. (2020). Major Challenging constraints to crop production farming system and possible breeding to overcome the constraints. *International Journal of Research Studies in Agricultural Sciences*, *6*(7), 27–46. https://doi.org/10.20431/2454-6224.0607005

Bhandari, U., Gajurel, A., Khadka, B., Thapa, I., Chand, I., Bhatta, D., Poudel, A., Pandey, M., Shrestha, S., & Shrestha, J. (2023). Morpho-physiological and biochemical response of rice (*Oryza sativa* L.) to drought stress: A review. *Heliyon*, *9*(3), e13744.https://doi.org/10.1016/j.heliyon.2023.e13744

Bitibalyo, M., & Mustamu, Y. A. (2021). Kadar kemanisan tebu (*Saccharum officinarum* L.) di Kampung Wariori Indah Distrik Masni Kabupaten Manokwari. *Agrotek*, *9*(1), 39–44. https://doi.org/10.46549/agrotek.v9i1.192

Budi, S., Lailiyah, W. N., Prihatiningrum, A. E., & Supangkat, G. (2024). Quality coefficient on gene differentiation and phenotype: clone assessment of *Saccharum officinarum* Linn. *PLANT TROPIKA*, *12*(2), 170-185. https://journal.umy.ac.id/index.php/pt/article/view/22232

Budi, S., Prihatiningrum, A. E., Rejeki, E. S., & Lailiyah, W. N. (2022). Potensi produktivitas klon unggul harapan hasil persilangan buatan karya anak bangsa. Indomediapustaka

Cao, Z., Tang, H., Cai, Y., Zeng, B., Zhao, J., Tang, X., Lu, M., Wang, H., Zhu, X., Wu, X., Yuan, L., & Wan, J. (2022). Natural variation of HTH5 from wild rice, *Oryza rufipogon* Griff., is involved in conferring high-temperature tolerance at the heading stage. *Plant Biotechnology Journal*, *20*(8), 1591–1605. https://doi.org/10.1111/pbi.13835

Chen, X., Huang, Z., Fu, D., Fang, J., Zhang, X., Feng, X., Xie, J., Wu, B., Luo, Y., Zhu, M., & Qi, Y. (2022). Identification of genetic loci for sugarcane leaf angle at different developmental stages by genome-wide association study. *Frontiers in Plant Science*, *13*, 1–13. https://doi.org/10.3389/fpls.2022.841693

Cursi, D. E., Hoffmann, H. P., Barbosa, G. V. S., Bressiani, J. A., Gazaffi, R., Chapola, R. G., Fernandes Junior, A. R., Balsalobre, T. W. A., Diniz, C. A., Santos, J. M., & Carneiro, M. S. (2022). History and current status of sugarcane breeding, germplasm development and molecular genetics in Brazil. *Sugar Tech*, *24*(1), 112–133. https://doi.org/10.1007/s12355-021-00951-1

de Aquino, G. S., de Conti Medina, C., da Costa, D. C., Shahab, M., & Santiago, A. D. (2017). Sugarcane straw management and its impact on production and development of ratoons. *Industrial Crops and Products*, *102*, 58–64. https://doi.org/10.1016/j.indcrop.2017.03.018

Djumali, Heliyanto, B., & Khuluq, D. A. D. (2019). Evaluasi klon-klon tebu potensial di lahan kering. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy)*, *46*(3), 328–336. https://doi.org/10.24831/jai.v46i3.21082

Fasheh, M. F., Budi, S., & Nurlailiyah, W. (2022). Study of growth and production of seven clones of sugarcane (*Saccharum officinarum* L.) in alluvial soil in Sambiroto Village, Sooko District-Mojokerto. *Nabatia*, *10*(2), 57–65. https://doi.org/10.21070/nabatia.v10i2.1611

Febrianto, D. A., Budi, S., & Lailiyah, W. N. (2022). Uji pemberian dosis pupuk daun terhadap pertumbuhan dan hasil tanaman tebu (*Saccharum officinarum* L.) Terbakar. *JINTAN: Jurnal Ilmiah Pertanian Nasional*, *2*(2), 103. https://doi.org/10.30737/jintan.v2i2.2675

Gazaffi, R., Cursi, D. E., Chapola, R. G., Santos, J. M., Fernandes-Jr, A. R., Carneiro, M. S., Barbosa, G. V. S., & Hoffmann, H. P.

(2016). RB varieties: a major contribution to the sugarcane industry in Brazil. *Proceedings of the International Society of Sugar Cane Technologists*, *29*(September 2017), 1677–1682. https://www.researchgate.net/publication/320086488

Harjanti, R. S., Hamami, R. S., Kusumawati, A., Rizal, A., Mustangin, M., Suryaningrum, D. A., & Yunaidi, Y. (2024). Pengaruh kesegaran tebu (*Saccharum officinarum* L.) pada kualitas gula cetak merah. *Jurnal Agro Industri Perkebunan*, *12*(1), 29–40. https://doi.org/10.25181/jaip.v12i1.3384

Husain, M. J., Budi, S., & Suhaili. (2023). Evaluasi pertumbuhan klon tanaman tebu (*Saccharum officinarum* L.) ratoon I di Desa Watesari, Kecamatan Balongbendo, Kabupaten Sidoarjo. *Gema Agro*, *28*(2), 130–138. https://doi.org/10.22225/ga.28.2.8135.130-138

Ismail, N., & Jamin, S. F. (2022). Pola sebaran retensi dan ketersediaan hara pada toposekuen lahan jagung di Desa Pilolaheya, Kabupaten Bone Bolango. *Jurnal Ecosolum*, *11*(1), 1–13. https://doi.org/10.20956/ecosolum.v11i1.19556

Kadarwati, F. T., Santoso, B., & Khuluq, A. D. (2016). Improvement of cane yield and sugar yield of sugarcane (*Sacharrum officinarum* L.) through maintaining ratoon. In *Jurnal Penelitian Tanaman Industri* (Vol. 21, Issue 4, p. 199). https://doi.org/10.21082/littri.v21n4.2015.199-205

Kiswanto, & Wijayanto, B. (2014). Petunjuk teknis budidaya tebu. *Badan Penelitian Dan Pengembangan Pertanian Kementrian Pertanian*, 1–30.

Kumar, R., Sagar, V., Verma, V. C., Kumari, M., Gujjar, R. S., Goswami, S. K., Kumar Jha, S., Pandey, H., Dubey, A. K., Srivastava, S., Singh, S. P., Mall, A. K., Pathak, A. D., Singh, H., Jha, P. K., & Prasad, P. V. V. (2023). Drought and salinity stresses induced physio-biochemical changes in sugarcane: an overview of tolerance mechanism and mitigating approaches. *Frontiers in Plant Science*, *14*(August), 1–18. https://doi.org/10.3389/fpls.2023.1225234

Larasati, K., & Budi, S. (2023). Evaluasi karakter pertumbuhan dan komponen hasil 8 klon tanaman tebu (*Saccharum officinarum* L.) di Lahan Hollywood Gresik. *Journal of Agro Plantation (JAP)*, *2*(1), 113–123. https://doi.org/10.58466/jap.v2i1.1246

Lira, E. G., Amabile, R. F., Fagioli, M., & Montalvão, A. P. L. (2017). Genetic parameters, phenotypic, genotypic and environmental correlations and genetic variability on sunflower in the Brazilian Savannah. *Ciência Rural*, *47*(8), 1–7. https://doi.org/10.1590/0103-8478cr20160719

Mahardianti, D. S., Budi, S., & Lailiyah, W. N. (2024). Klon unggul baru dan dua varietas tanaman tebu (*Saccharum officinarum* L .) keprasan dua di Kebun Sidokampir – jombang. *Jurnal Tropicrops*, *7*(1), 46–56. http://dx.doi.org/10.30587/tropicrops.v7i1.7460

Mastur, Syafaruddin, & M, S. (2015). Role and management of sugarcane nitrogen nutrient to increase productivity. *Perspektif*, *14*(2), 73–86. https://media.neliti.com/media/publications/157916-ID-peran-dan-pengelolaan-hara-nitrogen-pada.pdf

Mehdi, F., Cao, Z., Zhang, S., Gan, Y., Cai, W., Peng, L., Wu, Y., Wang, W., & Yang, B. (2024). Factors affecting the production of sugarcane yield and sucrose accumulation: suggested potential biological solutions. *Frontiers in Plant Science*, *15*, 1–21. https://doi.org/10.3389/fpls.2024.1374228

Muliandari, N., Sudiarso, S., & Sumarni, T. (2021). Analisis pertumbuhan tanaman tebu (*Saccharum officinarum* L.) akibat aplikasi vermikompos dan plant growth promoting rhizobacteria (PGPR). *Jurnal Agro Industri Perkebunan*, *9*(2), 73–82. https://doi.org/10.25181/jaip.v9i2.1973

Nurazizah, S., Budi, S., & Lailiyah, W. N. (2022). Pertumbuhan berbagai klon tanaman tebu (*Saccharum officinarum* L.) di Kebun Juwet Dukuhdimoro, Mojoagung – Jombang. *Agroplantae: Jurnal Ilmiah Terapan Budidaya Dan Pengelolaan Tanaman Pertanian dan Perkebunan*, *11*(2), 87–100. https://doi.org/10.51978/agro.v11i2.463

Nurnasari, E., & Djumali,. (2019). Determination of soil moisture duration before harvesting that influences the sugar cane content. *Jurnal Ilmu Pertanian Indonesia*, *24*(2), 127–134. https://doi.org/10.18343/jipi.24.2.127

Pissolato, M. D., da Cruz, L. P., Silveira, N. M., Machado, E. C., & Ribeiro, R. V. (2021). Sugarcane regrowth is dependent on root system size: An approach using young plants grown in nutrient solution. *Bragantia*, *80*, 1-10. https://doi.org/10.1590/1678-4499.20210039

Rahayu, R., M, Warkoyo, Harini, N & Anggriani, R. (2022). Efektivitas pemakaian mesin magic sugar cane terhadap penurunan kualitas nira pada sistem tebang angkut. *Jurnal Ilmiah Teknologi Pertanian*, *12*(1), 33–40. https://ojs.unud.ac.id/index.php/agrotechno/article/download/84304/44208

Rahmah, K., Budi, S., & Agustina, R. (2023). The effect of liquid organic fertilizer on genetic potential between clones of sugar cane (*Saccharum officinarum* L.) ratoon 2. *Gontor Agrotech Science Journal*, *9*(2), 172–185. https://doi.org/10.21111/agrotech.v9i2.8920

Ranjiith, P., & Francesco, C. (2022). Management and utilization of plant genetic resources for a sustainable agriculture. *Plants*, *11*(15), 1-36. https://doi.org/10.3390/plants11152038

Riajaya, P. D., & Kadarwati, F. T. (2017). Kesesuaian Tipe kemasakan varietas tebu pada tipologi lahan bertekstur berat, tadah hujan, dan drainase lancar. *Buletin Tanaman Tembakau, Serat & Minyak Industri*, *8*(2), 85–97. https://media.neliti.com/media/publications/54537-ID-kesesuaian-tipe-kemasakan-varietas-tebu.pdf

Sanjaya, W. T. A., Giyanto, ., Widyastuti, R., & Santosa, D. A. (2020). Keanekaragaman enzim invertase, pengembangan strain unggul dan teknologi produksinya. *Jurnal Bioteknologi & Biosains Indonesia (JBBI)*, *7*(1), 146–165. https://doi.org/10.29122/jbbi.v7i1.3705

Setyawati, I., Wibowo, R., Magfiroh, I. (2017). Mutu tebu industri gula Indonesia. *Mutu Tebu Industri Gula Di Indonesia*, *1*, 94–100. https://repository.unej.ac.id/bitstream/handle/123456789/83968/F. P_Prosiding_Illia Seldon_MUTU TEBU INDUSTRI.pdf?sequence=1&isAllowed=y

Sharfina, F. D., Mulyana, N. R., Rahmadhana, N., Nurita, F. D., Rahayu, Y. S., & Dewi, S. K. (2021). perbandingan aktivitas auksin alami dengan auksin sintetis terhadap pertumbuhan akar sawi hijau (*Brassica juncea* L.) secara hidroponik. *Inovasi Riset Biologi Dalam Pendidikan Dan Pengembangan Sumber Daya Lokal*, *2014*, 725–733. https://semnas.biologi.fmipa.unp.ac.id/index.php/prosiding/article/view/183

Siahaan, H. S. W., Sari, A. K., & Waluyo, B. (2020). Keragaman karakter morfologi dan komponen hasil beberapa klon F1 hasil seleksi pendahuluan tebu (*Saccharum officinarum* L.). *Jurnal Produksi Tanaman*, *8*(1), 1028–1034. https://protan.studentjournal.ub.ac.id/index.php/protan/article/view/1482

Simanjuntak, A. I., & Ardiarini, N. A. (2024). Potensi pengembangan genotipe bunga matahari (*Helianthus annuus* L.) melalui keragaman genetik dan pendugaan nilai heritabilitas. *Produksi Tanaman*, *12*(04), 247–257. https://doi.org/10.21776/ub.protan.2024.012.04.04

Syarifuddin, M. K., Budi, S., & Lailiyah, W. N. (2023). Uji pertumbuhan dan hasil klon tanaman tebu (*Saccharum officinarum* L.) di Desa Budung Sidorejo Kecamatan Sumobito – Jombang. *TROPICROPS (Indonesian Journal of Tropical Crops)*, *5*(2), 116. https://doi.org/10.30587/tropicrops.v5i2.5179

Wang, J., Nayak, S., Koch, K., & Ming, R. (2013). Carbon partitioning in sugarcane (*Saccharum species*). *Frontiers in Plant Science*, *4*, 1-16. https://doi.org/10.3389/fpls.2013.00201

Wati, D. D. K., Suhaili, S., Budi, S., & Jumadi, R. (2024). Evaluasi keragaan agronomi 7 klon dan 2 varietas tanaman tebu *(Saccharum officinarum* L.) ratoon II lahan Jatisari. *TROPICROPS (Indonesian Journal of Tropical Crops)*, *7*(2), 84. https://doi.org/10.30587/tropicrops.v7i2.8407

Wibisono, V. B., Avivi, S., Ubaidillah, M., & Sri Hartatik. (2022). Morphological, physiological and molecular characteristics of tolerant sugarcane to waterlogging stress. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy)*, *50*(2), 217–224. https://doi.org/10.24831/jai.v50i2.40760

Yusuf, E. Y. (2020). Pengaruh genotip cekaman kekeringan dan tingkat netralisasi aluminium terhadap komponen hasil kedelai. *Jurnal Agro Indragiri*, *5*(1), 12–22. https://doi.org/10.32520/jai.v5i1.1452

Zhao, D., Glaz, B., & Comstock, J. C. (2013). Sugarcane leaf photosynthesis and growth characters during development of water-deficit stress. *Crop Science*, *53*(3), 1066–1075. https://doi.org/10.2135/cropsci2012.09.0554

Zhao, D., & Li, Y. R. (2015). Climate change and sugarcane production: potential impact and mitigation strategies. *International Journal of Agronomy*, *2015, 1-10*. https://doi.org/10.1155/2015/547386