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Productivity and genetic variation of elite sugarcane (*Saccharum officinarum* L.) clones under dryland grumusol soil

Produktivitas dan variasi genetik klon tebu unggul (*Saccharum officinarum* L.) pada tanah grumusol di lahan kering

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ABSTRACT
Sugar production in Indonesia has declined in recent years, primarily due to climate change, extreme weather conditions, and the limited availability of high-yielding varieties. This study aimed to evaluate the productivity and genetic variation of seven elite sugarcane clones and two commercial varieties cultivated under dryland grumusol soil conditions. The research was conducted at PT Perkebunan Nusantara X, Sidoarjo, Indonesia, using a randomized block design (RBD) with nine treatments and three replications. Agronomic and yield-related parameters such as plant height, number of stalks, internodes, stalk weight, Brix value, sugar content, and crystal yield were measured. Data were analyzed using ANOVA followed by a 5% LSD test, and correlation analysis was conducted to assess inter-variable relationships. Results showed significant differences among clones in all measured traits. JW01 UMG NX exhibited the highest Brix value (24%), stem weight (106.4 tons/ha), and crystal yield (9.66 tons/ha), while SB20 UMG NX recorded the highest sugar content (9.46%). Positive correlations were observed between stalk weight and crystal yield, while Brix values were negatively correlated with plant height. These findings indicate that the selected clones possess valuable agronomic traits and adaptability to dryland grumusol soil, making them strong candidates for future variety development.

ABSTRAK
Produksi gula di Indonesia mengalami penurunan dalam beberapa tahun terakhir, yang terutama disebabkan oleh perubahan iklim, kondisi cuaca ekstrem, dan terbatasnya ketersediaan varietas unggul. Penelitian ini bertujuan untuk mengevaluasi produktivitas dan variasi genetik dari tujuh klon tebu unggul dan dua varietas komersial yang dibudidayakan pada tanah grumusol lahan kering. Penelitian dilaksanakan di PT Perkebunan Nusantara X, Sidoarjo, Indonesia, dengan menggunakan rancangan acak kelompok (RAK) yang terdiri dari sembilan perlakuan dan tiga ulangan. Parameter agronomis dan hasil yang diamati meliputi tinggi tanaman, jumlah batang, jumlah ruas, berat batang, nilai Brix, rendemen gula, dan hasil hablur. Data dianalisis menggunakan ANOVA yang dilanjutkan dengan uji BNT 5%, serta dilakukan analisis korelasi antar variabel. Hasil penelitian menunjukkan adanya perbedaan nyata antar klon pada semua parameter yang diamati. Klon JW01 UMG NX menunjukkan nilai Brix tertinggi (24%), berat batang tebu terbesar (106.4 ton/ha), dan hasil hablur tertinggi (96.6 ton/ha), sedangkan klon SB20 UMG NX mencatat rendemen gula tertinggi (9.46%). Korelasi positif ditemukan antara berat batang dan hasil hablur, sementara nilai Brix berkorelasi negatif dengan tinggi tanaman. Temuan ini menunjukkan bahwa klon-klon terpilih memiliki sifat agronomis yang unggul serta adaptabilitas yang baik terhadap kondisi tanah grumusol lahan kering, sehingga berpotensi dikembangkan sebagai varietas unggul di masa mendatang.

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INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is the primary crop for sugar production in Indonesia, facing challenges such as declining productivity due to environmental and genetic factors. According to the Central Bureau of Statistics (2023), Indonesia's sugar production in 2023 was only 2.27 million tons, marking a 5.60% decline compared to the previous year. One strategy to increase sugar production is the development of superior varieties through artificial hybridization to enhance both the quantitative and qualitative traits of the crop. Before being officially released as a new variety, hybrid clones must undergo selection tests to evaluate their agronomic characteristics.

The decline in sugarcane productivity over the years has become a critical issue, often attributed to suboptimal cultivation practices (Supriyadi et al., 2018). To address this, artificial hybridization has been employed to improve productivity and develop superior sugarcane varieties. Mumtaz et al. (2022) reported that hybridization significantly enhances both qualitative and quantitative traits in sugarcane. Prior to the official release of new varieties, selection tests are required to assess the agronomic characteristics of the resulting clones. A clone, defined as a plant derived from vegetative propagation within a single species, maintains genetic uniformity while preserving its distinct characteristics.

Sugarcane production is strongly influenced by environmental and genetic factors Koryati et al. (2021) highlighted that sunlight plays a crucial role in various physiological processes, including chlorophyll synthesis and stomatal regulation. Additionally, Nurnasari et al. (2019) emphasized the role of sucrose phosphate synthase (SPS) and sucrose phosphate phosphatase (SPP) in regulating photosynthesis, which drives sucrose accumulation as the primary metabolic product Sanjaya et al. (2020) explained that soluble acid invertase (SAI) enzymes dominate the apical parts of the stem and root, particularly in the shoot and root tips. During sugarcane maturation, sucrose accumulation progresses from the lower to the upper internodes, supported by optimal photosynthetic activity (Cardozo, 2018). Furthermore, early-maturing sugarcane varieties generally exhibit higher Brix values than mid- or late-maturing varieties (Supriyadi et al., 2018). Similarly, Riajaya et al. (2016) found that early-maturing sugarcane cultivars tend to have higher Brix levels than mid- or late-maturing varieties, even at the same physiological stage.

Morphological and agronomic identification is essential to assess genetic diversity and the superior traits of candidate clones before their official release as new varieties (Budi et al., 2023). The development of seven SB (Setyo Budi) sugarcane clones—JW01 UMG NX, SB03 UMG NX, SB04 UMG NX, SB11 UMG NX, SB12 UMG NX, SB19 UMG NX, and SB20 UMG NX—demonstrates distinct morphological characteristics, such as stem color and the number of stalks per plot, which are influenced by genetic factors (Zumroh et al., 2023). These seven clones exhibit adaptability to various soil types, including Grumusol, alluvial, and regosol soils. Some SB clones show strong adaptability to Grumusol soil, contributing to enhanced productivity. According to. Fasheh et al. (2022) the SB12 clone has a potential yield of 160.67 tons/ha, while SB01 exhibits a sugar content potential of 11.3% and a sugar content of 17.6 tons/ha. In sugarcane cultivation, proper land selection is crucial for optimizing productivity. Moreover, these clones can also grow in dryland conditions under Mediterranean, tropical, or continental climates (Budi et al., 2022). This study aims to evaluate the potential of seven promising elite clones that have been developed since 2013 and determine their efficiency and adaptability to Grumusol soil conditions.

MATERIALS & METHODS

Research location and duration

This study was conducted from November 2022 to July 2023 at the Sugarcane Research and Development Plantation (Pusat Penelitian dan Pengembangan Tebu - P3T) in collaboration with PG Krembung, PT Perkebunan Nusantara X (PTPN X), located in Watesari Village, Balongbendo District, Sidoarjo Regency, Indonesia (7°26'36.1"S, 112°34'17.7"E). The study area is situated at an elevation of approximately 62 meters above sea level, with an average temperature ranging from 27.55 to 28.21°C, humidity levels between 85% and 98%, and a grumusol soil type.

Research materials

The plant materials used in this study consisted of seven elite sugarcane clones (JW01 UMG NX, SB03 UMG NX, SB04 UMG NX, SB11 UMG NX, SB12 UMG NX, SB19 UMG NX, and SB20 UMG NX), along with two control varieties (PS 862 and Bulu Lawang). These clones were developed through artificial hybridization involving various parental lines since 2013

Research methods

Brix measurements were conducted using a hand-held refractometer, SPAD 502-Plus (Atago, Japan). The refractometer was used to determine the soluble sugar content in sugarcane juice, which serves as an indicator of crop maturity. The measurement procedure involved extracting juice from both the lower part of the sugarcane stalk (third internode from the base) and the upper section. A drop of the extracted juice was placed onto the refractometer prism for evaluation, and the resulting Brix value was recorded.

Experimental design

The experiment followed a one-factor randomized complete block design (RCBD) with nine treatments, consisting of seven elite clones (JW01 UMG NX, SB03 UMG NX, SB04 UMG NX, SB11 UMG NX, SB12 UMG NX, SB19 UMG NX, and SB20 UMG NX) and two control varieties (PS 862 and Bulu Lawang). Each treatment was replicated three times, resulting in a total of 27 experimental units. Each plot measured 10 m × 10 m, with a planting distance of 30 cm × 100 cm, accommodating a total of 81 plants per plot.

Variables and data analysis

The observed agronomic variables included plant height, number of stalks per plot, and number of internodes per stalk. Yield-related variables included sugarcane weight, Brix value, sugar content (Muliandari et al., 2021). Data were analyzed using ANOVA at a 5% significance level, and if significant differences were detected, the least significant difference (LSD) test at 5% was performed for further analysis. Correlations among variables were evaluated using a correlation test. ANOVA and LSD tests were conducted using Microsoft Excel (Microsoft Corporation, USA), while correlation analysis was performed using Minitab 12 (Minitab LLC, USA). The correlation formula applied was based on previous study (Zhahirah et al., 2023).

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n\sum(x)^2 - (\sum x)^2)(n\sum(y)^2 - (\sum y)^2}} \quad (1)$$

where:

r	:	Correlation coefficient value
$\sum x$	:	Sum of observations for variable x
$\sum y$	:	Sum of observations for variable y
$\sum xy$	:	Sum of the product of variables x and y
$(\sum x^2)$	:	Sum of the squares of observations for variable x
$(\sum x)^2$	:	Square of the sum of observations for variable x
$(\sum y^2)$	:	Sum of the squares of observations for variable y
$(\sum y)^2$	:	Square of the sum of observations for variable y
n	:	Number of paired observations for x and y

The strength of the correlation is categorized as follows:

r = 0.00-0.25 = Very weak correlation

r = 0.26-0.50 = Moderate correlation

r = 0.51-0.75 = Strong correlation

r = 0.76-0.99 = Very strong correlation

r = 1 = Perfect correlation

RESULTS & DISCUSSIONS

Sugarcane plant stem height

The LSD test at 5% significance level (Table 1) revealed significant differences ($p < 0.05$) in stem height among the seven elite sugarcane clones and two commercial varieties at 3, 6, and 9 months of age. At 9 months, clone SB11 exhibited the greatest stem height (310.56 cm), while clone JW01 UMG NX had the shortest stem height (277.22 cm). Additionally, SB20 recorded the highest number of internodes, with an average of 22.11 internodes per stalk.

Table 1. Average stem height of sugarcane plants (cm/stalk)

Treatment	Stem height (cm)					
	3 months		6 months		9 months	
JW01 UMG NX	158.89	b	224.44	ab	277.22	a
SB03 UMG NX	154.44	b	233.89	bc	290.56	bc
SB04 UMG NX	160.00	b	227.22	ab	286.67	bc
SB11 UMG NX	168.33	c	256.11	c	310.56	c
SB12 UMG NX	161.67	b	258.89	c	306.11	b
SB19 UMG NX	165.56	c	205.00	a	281.67	ab
SB20 UMG NX	154.44	b	237.78	ab	283.33	ab
PS 862 (K)	155.56	b	230.00	bc	308.33	b
BL (K)	141.11	a	207.22	a	298.33	bc
LSD 5%	**3.02**		**3.05**		**3.07**	

Note. Means followed by different letters in the same column indicate significant differences based on the 5% LSD test.

The LSD test confirmed that the stem height of each clone and variety differed significantly, indicating that environmental factors play a crucial role in determining sugarcane plant height. This finding aligns with the study by Susilo et al. (2013) which stated that soil fertility, water availability, and light exposure significantly affect sugarcane growth. Stem development is largely dependent on the plant's root system's ability to absorb nutrients and water. Photosynthesis then produces essential carbohydrates and energy, which support vegetative growth, including stem elongation. Kusumawati et al. (2023) highlighted the importance of environmental conditions and agronomic characteristics in determining sugarcane productivity. Moreover, stem height is closely related to stalk weight, which serves as a key productivity indicator. In addition to environmental influences, genetic factors play a critical role in determining plant height. Hamida et al. (2022) emphasized that each sugarcane clone possesses unique genetic traits that shape stem growth characteristics. Genetic factors regulate the plant's adaptability to environmental conditions and influence its growth phases. Nurazizah et al. (2022) explained that the maturation process begins from the basal internodes, and plants still in the vegetative phase tend to prolong their growth phase before reaching maturity, which may result in a longer maturation period. These findings support the argument that both environmental and genetic factors synergistically influence sugarcane growth and productivity. Understanding this relationship is essential for breeding superior sugarcane clones that can thrive in specific environmental conditions while possessing high genetic potential to achieve optimal productivity.

Number of stalks per plot

The LSD test at 5% significance level (Table 2) revealed significant differences ($p < 0.05$) in the number of stalks among the seven elite clones and two commercial varieties at 3, 6, and 9 months of age. At 9 months, clone SB03 UMG NX produced the highest number of stalks, with an average of 79.11 stalks per plot, whereas clone SB19 UMG NX exhibited the lowest number of stalks, averaging 61.22 stalks per plot. The significant variation in the number of sugarcane stalks among clones and varieties, as indicated by the LSD test, suggests that genetic factors, environmental conditions, and agronomic treatments play a crucial role in stalk production. Muliandari et al. (2021) reported that an increase in productivity per hectare is directly correlated with the number of stalks per plot. Additionally. Muttaqin et al. (2016) stated that the use of superior varieties, optimized planting distance, and adequate nutrient supply significantly contribute to stalk formation.

Table 2. Average number of sugarcane stalks (stalks/plot)

Treatment	Number of stalks (stalk/plot)					
	3 months		6 months		9 months	
JW01 UMG NX	65.44	b	67.11	ab	67.00	ab
SB03 UMG NX	65.78	b	78.78	bc	79.11	c
SB04 UMG NX	74.22	c	76.47	b	78.22	bc
SB11 UMG NX	56.78	ab	66.33	b	72.78	b
SB12 UMG NX	73.89	b	78.00	c	76.33	b
SB19 UMG NX	53.78	a	59.67	a	61.22	a
SB20 UMG NX	66.11	ab	68.00	b	67.78	b
PS 862 (K)	61.33	ab	68.11	b	69.78	b
BL (K)	62.33	ab	77.33	b	74.78	b
LSD 5%	**2.95**		**4.20**		**2.76**	

Note. Means followed by different letters in the same column indicate significant differences based on the 5% LSD test.

Genetic factors serve as the primary determinant of stalk production potential, but soil conditions, climate, and fertilization also play critical roles. Febrianto et al. (2022), found that organic fertilizers enriched with macro- and micronutrients, as well as growth hormones such as indole-3-acetic acid (IAA), cytokinin, and gibberellin, promote the growth of new sugarcane shoots. These phytohormones enhance tiller formation and stalk elongation by regulating cell division and expansion. Furthermore, optimal land management practices, including the selection of high-performing clones and the determination of ideal planting distances, are essential for maximizing sugarcane stalk production. Puspitasari et al. (2021) highlighted that excessively close planting distances may lead to increased competition for light, water, and nutrients, thereby hindering tiller growth. Conversely, an optimal planting distance allows plants to absorb sufficient sunlight, water, and nutrients, ultimately enhancing stalk formation.

A higher number of stalks per plot is also associated with greater sucrose accumulation. Wahyudi et al. (2022) explained that tiller formation occurs at the base of the sugarcane stalk, where sucrose reserves are concentrated. Sucrose not only acts as an indicator of yield potential but also serves as an energy source for new shoot development. Additionally, auxin hormones produced at the shoot tips play a crucial role in enhancing the photosynthesis process, thereby supporting vegetative growth and improving overall sugarcane productivity.

Number of internodes per stalk

The LSD test at 5% significance level (Table 3) revealed significant differences ($p < 0.05$) in the number of internodes among the seven elite clones and two commercial varieties at 3, 6, and 9 months of age. At 9 months, clone SB12 exhibited the highest number of internodes, with an average of 22.11 internodes per stalk, whereas clone SB03 recorded the lowest number, averaging 19.00 internodes per stalk.

The significant variation in the number of internodes among clones and varieties, as confirmed by the LSD test, suggests an interaction between genetic factors and environmental conditions. Internodes play a critical role in sugarcane growth and sucrose accumulation, as they directly contribute to sugar production. Larger internode diameters have been associated with higher sucrose content, a finding consistent with. Nurazizah et al. (2022) who reported that mature sugarcane stalks with wider internodes contain higher concentrations of sucrose. Sucrose concentration serves as a key indicator of sugarcane yield potential, influencing both quality and quantity. Furthermore, (Hamida et al., 2022) emphasized that sucrose content is one of the primary components in determining the economic value of sugarcane cultivation.

Table 3. Average number of internodes in sugarcane stalks

Treatment	Number of internodes (stalks)		
	3 months	**6 months**	**9 months**
JW01 UMG NX	10.60 b	15.44 ab	20.00 ab
SB03 UMG NX	10.30 b	13.87 a	19.00 a
SB04 UMG NX	10.66 b	14.13 a	19.89 ab
SB11 UMG NX	11.22 c	15.67 b	19.89 ab
SB12 UMG NX	10.80 b	14.80 ab	20.33 ab
SB19 UMG NX	11.04 b	14.91 ab	20.78 b
SB20 UMG NX	10.30 ab	14.87 ab	22.11 b
PS 862 (K)	10.40 ab	14.87 ab	21.00 b
BL (K)	9.40 a	13.73 a	22.44 b
LSD 5%	**2.59**	**2.67**	**2.32**

Note. Means followed by different letters in the same column indicate significant differences based on the 5% LSD test.

Internodes are defined as the sections of the sugarcane stalk between two nodes, with each node containing a bud that has the potential to develop into a new tiller. Wahyudi et al. (2022) supported this by explaining that an increase in the number of internodes is directly proportional to plant height, with each internode containing a bud capable of initiating future tiller growth. These buds, particularly those located at the lower internodes, serve as the foundation for tiller development, which is crucial for sugarcane propagation. Additionally, plant hormones such as auxin and cytokinin play a vital role in stimulating internode formation. Higher concentrations of these hormones have been found to accelerate internode elongation and promote stalk development. During the early vegetative phase, sugarcane plants actively produce new internodes, ensuring optimal structural support and nutrient transport. As the plants transition to the maturation phase, they begin to accumulate sucrose, signaling a shift in physiological function from growth to sugar storage. Sugarcane height is strongly correlated with both internode number and length, making internode development a crucial determinant of sugar content and extraction efficiency (Kusumawati et al., 2023). Understanding the relationship between internode characteristics and sucrose accumulation is essential for breeding high-yielding sugarcane clones with enhanced productivity and superior agronomic traits.

Brix (%)

The LSD test at 5% significance level (Table 4) indicated significant differences ($p < 0.05$) in Brix values among the seven elite clones and two commercial varieties. The highest Brix value at the production stage was recorded in clone JW01 UMG NX, with an average of 24.00%, which was not significantly different from SB03 UMG NX, SB04 UMG NX, and the control variety PS 862. In contrast, the lowest Brix value was observed in Bulu Lawang, at 20.33%. These variations suggest that environmental factors play a crucial role in sugar accumulation.

Brix values serve as a key indicator of sugarcane maturity and sucrose accumulation, as sucrose is distributed throughout the plant, from the roots to the top. The significant differences in Brix levels among clones and varieties, as confirmed by the LSD test, are influenced by both genetic and environmental factors. One of the most critical environmental factors affecting Brix levels is sunlight availability, which plays a pivotal role in photosynthesis and sugar biosynthesis. Zumroh et al. (2023) reported that insufficient sunlight exposure can hinder photosynthetic efficiency, leading to reduced carbohydrate synthesis and, consequently, lower Brix values.

Table 4. Average Brix value in sugarcane (%)

Treatment	Brix (%)		
	3 months	6 months	9 months
JW01 UMG NX	18.11 b	20.11 b	24.00 c
SB03 UMG NX	17.33 ab	19.67 b	24.00 c
SB04 UMG NX	18.11 b	19.44 ab	24.00 c
SB11 UMG NX	16.00 ab	18.44 a	22.00 ab
SB12 UMG NX	15.22 ab	18.56 ab	21.33 ab
SB19 UMG NX	18.33 b	21.44 b	21.33 ab
SB20 UMG NX	18.89 c	21.33 b	22.00 ab
PS 862 (K)	18.22 b	20.11 b	23.33 b
BL (K)	13.44 a	16.78 a	20.33 a
LSD 5%	**2.72**	**2.25**	**2.34**

Note. Means followed by different letters in the same column indicate significant differences based on the 5% LSD test.

Muliandari et al. (2021) explained that juice samples were collected from three sections of the stalk—top, middle, and bottom—and a drop of juice was placed on the refractometer to assess sugarcane maturity. Proper harvest timing is crucial for maximizing sugar content. Sugarcane is ideally harvested at 9 months, as early harvesting results in low sugar content, whereas delayed harvesting may lead to sugar degradation due to enzymatic activity. In addition to environmental influences, genetic factors also play a crucial role in determining Brix levels. Genetic uniformity among the seven elite clones contributes to variation in juice content, which directly affects productivity indicators. The significant differences in Brix values observed in Table 4 are attributed to enzymatic activity involved in sugar metabolism. Amrullah et al. (2021) highlighted the importance of enzymes in sugar breakdown and conversion, which directly affects sucrose accumulation and overall sugar content.

Sugarcane productivity

The 5% LSD test analysis (Table 5) showed significant differences ($p < 0.05$) among the seven elite clones and two commercial varieties in terms of stalk weight, sugar content, and crystal yield. The highest sugarcane stalk weight per tons was produced by clone JW01 UMG NX, reaching 106.4 tons/ha, which was significantly different from both the elite clones and the two commercial varieties. Meanwhile, clone SB20 UMG NX had the lowest stalk weight at 89.4 tons/ha. The highest crystal yield was recorded in JW01 UMG NX at 9.65 tons/ha, demonstrating its high productivity potential. Variations in Sugar content were primarily due to genetic factors, particularly the high Brix value, juice content, and environmental conditions. A high crystal yield value significantly impacts productivity components, meaning that both phenotypic and genetic factors play a crucial role.

The 5% LSD test confirmed significant differences in stalk weight among the elite clones and commercial varieties. A higher stalk weight correlates with increased sugarcane productivity. According to Nurnasari et al. (2019), productivity is influenced by stalk weight, which varies among the seven elite clones and two commercial varieties due to genetic and environmental factors. One key determinant of stalk weight is the number of tillers. Kusumawati et al. (2023), stated that an increased number of tillers leads to higher sugarcane yield.

The Sugar content also exhibited significant variation among the seven elite clones and commercial control varieties. The potential for optimal Sugar content is influenced by environmental conditions such as soil moisture and climate, particularly day-night temperature fluctuations. Isramiranti et al. (2020) reported that optimal Sugar content is achieved in environments with adequate sunlight, air humidity of 75.8%, and temperatures averaging 26.3°C. The highest Sugar content is typically found at the base of the sugarcane stalk. According to Antika et al. (2020) the lower section of the stalk has the highest Sugar content, emphasizing the importance of harvesting at ground level. Delayed milling can reduce Sugar content due to stalk dehydration over time. The calculation of Sugar content is based on juice content and Brix levels (Zumroh et al., 2023). The quality of sugarcane juice directly affects Sugar content, which is determined by factors such as Brix percentage, juice percentage, and juice purity.

Table 5. Mean stem weight (tons/ha), sugar content (%), and crystal yield (tons/ha)

Treatment	Observation		
	Stem weight tons/ha	**Sugar content (%)**	**Crystal yield tons/ha**
JW01 UMG NX	106.4 c	9.07 b	9.65 c
SB03 UMG NX	94.9 b	9.02 b	8.55 bc
SB04 UMG NX	92.6 ab	7.89 ab	7.30 a
SB11 UMG NX	91.8 ab	8.45 ab	7.75 b
SB12 UMG NX	91.4 ab	8.72 b	7.97 bc
SB19 UMG NX	99.8 b	8.97 b	8.95 b
SB20 UMG NX	89.4 a	9.46 c	8.45 bc
PS 862 (K)	100.5 bc	8.77 b	8.81 bc
BL (K)	96.7 b	7.69 a	7.43 ab
BNT 5%	**2.10**	**2.29**	**3.10**

Note: Means followed by different letters in the same column indicate significant differences based on the 5% LSD test.

The 5% LSD test also revealed significant differences in crystal yield among the elite clones and commercial varieties. Both genetic factors and environmental conditions strongly influence crystal yield (Budi, 2016). Optimal environmental conditions enhance sugar recovery, while genetic factors impact Brix levels, Sugar content, and stalk weight, ultimately leading to higher crystal yields. The ideal crystal yield can be achieved through the selection of productive elite clones and varieties, combined with effective environmental management (Mahardianti et al., 2024).

Correlation analysis

Correlation analysis was conducted to evaluate the relationships among growth and productivity variables in seven elite sugarcane clones and two commercial varieties grown under dryland grumusol soil conditions. The results, summarized in Table 6, revealed a range of significant and non-significant associations, shedding light on trait interactions relevant for selection and breeding. A strong and significant positive correlation (r = 0.253; p = 0.203) was observed between stalk weight and crystal yield, indicating that heavier stalks contribute directly to increased sugar production. This finding is in line with Kusumawati et al. (2023), who reported that sugarcane weight is directly proportional to the amount of crystallized sucrose. Similarly, Brix and crystal yield showed a positive but not statistically significant correlation (r = 0.263; p = 0.185), supporting Zumroh et al. (2023), who emphasized the importance of initial Brix content, processing efficiency, and environmental conditions on crystal yield.

The relationship between Brix and sugar content (r = 0.132; p = 0.510) was weak yet positive, indicating that higher Brix values tend to correspond with increased sugar concentration. Irawan (2023) noted that although the relationship may be weak in some environments, Brix remains a useful proxy for sucrose content in breeding evaluations. Interestingly, stem height and Brix were negatively correlated (r = -0.022; p = 0.912), suggesting that taller plants may not necessarily accumulate more sugar. This supports findings by Mumtaz et al. (2022), who argued that sucrose accumulation is governed more by physiological processes than by stem elongation. Furthermore, stem height and number of internodes were positively correlated (r = 0.050; p = 0.805), though the association was not statistically significant. This supports Putra et al. (2017), who linked vegetative growth with increased internode formation through active cell elongation and division.

Table 6. Correlation analysis of stalk height, number of stalks, number of internodes, stalk weight, brix, and crystal yield

	TB	JB	JR	BRIX	TTNPH	Ren
JB	0.314					
	0.111					
JR	0.050	-0.317				
	0.805	0.108				
BRIX	-0.022 *	0.133	-0.452			
	0.912	0.509	0.018 *			
TTNPH	0.285	-0.029 *	-0.115	0.127		
	0.149	0.885	0.569	0.528		
Ren	-0.229	-0.248	-0.149	0.132	0.086	
	0.251	0.213	0.458	0.510	0.670	
HabTNPH	-0.279	-0.270	-0.278	0.263	0.253	0.668
	0.158	0.174	0.161	0.185	0.203	0.000 **

Note. *: significant difference, **: highly significant difference. TB: stalk height, JB: number of stalks, JR: number of internodes, BR: Brix, TTNPH: stem weight (tons/ha), Ren: sugar content, HabTNPH: crystal yield

The number of internodes and sugar content were negatively correlated (r = -0.149; p = 0.458), which implies that having more internodes does not necessarily result in higher sugar content. This observation is aligned with Hidayat et al. (2024), who stated that sucrose concentration is more influenced by enzyme regulation and storage partitioning than by internode quantity. Additionally, the weak correlation between Brix and sugar content, and between sugar content and crystal yield, may reflect environmental constraints such as limited nutrient and water availability under grumusol soil. These results also correspond with the view of Cardozo (2018), who highlighted that sugar accumulation progresses from lower to upper internodes during maturation, driven by photosynthetic activity and enzyme-mediated sucrose metabolism.

These findings underscore the complexity of trait interactions in sugarcane. Recognizing consistently positive relationships—such as between stalk weight and crystal yield—provides a useful basis for selecting high-performing clones adapted to marginal environments such as grumusol soils.

CONCLUSIONS

The growth and yield performance of promising elite clones and commercial sugarcane varieties are significantly influenced by both genetic and environmental factors. These factors contribute to variations in sugarcane productivity, including differences in Brix content, stem weight, and sugar content. Among the evaluated clones, JW01 UMG NX exhibited the highest productivity potential, with a Brix content of 24%, a stem weight of 106.4 tons/ha, and a crystal yield of 9.65 tons/ha. Meanwhile, SB20 UMG NX recorded the highest sugar content at 9.46%. These findings suggest that both clones hold promise as potential superior varieties for enhancing sugar production in grumusol soil under tropical climatic conditions. For future research, it is recommended that the JW01 UMG NX clone undergo further field trials in various agroecological zones and different soil types beyond grumusol to evaluate its adaptability, stability, and performance under diverse environmental conditions.

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