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Genetic diversity and yields of promising sugarcane clones under ratoon crop in a rainfed land

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Abstract: This study examined the genetic diversity and yield of improved sugarcane clones in ratoon crops on rainfed land. Ten sugarcane clones (SB 01, SB 03, SB 04, SB 11, SB 12, SB 19, SB 20, and two control varieties, PS 881 and Bululawang) were evaluated during two ratoon cycles in East Java, Indonesia (7°27'28 "S 112°23'03 "E) from September 2021 to May 2023 with an alluvial soil type. The study employed a mixed model, specifically a multi-season randomized group design with one factor: clone, where ratoon represented the season and observed growth and production parameters. The analysis revealed significant genetic diversity among the clones in terms of stem length, stem diameter, productivity, and Brix characteristics. Productivity consistently increased in the second ratoon for all clones, with the highest increase in SB 11 (29.0%) and SB 04 (28.9%). Heritability values increased in the second ratoon cycle for most characters, mainly stem length (0.37 to 0.79), productivity (0.52 to 0.78), and Brix (0.69 to 0.95). Significant positive correlations were found between ratoon and productivity (0.70), rendemen (0.61), and Brix (0.32). Stem diameter was positively correlated with productivity (0.30), hablur (0.40) and Brix (0.34). Clones SB 01, SB 11, SB 12, SB 19, and SB 20 showed superior performance for growth and yield characters, with SB 01 achieving the highest sugar yield (12.3 tons.ha^{-1}). This study provides essential information for sugarcane breeding programs to develop superior varieties with high productivity and stability in ratoon crops on rainfed land.

Keywords: *Saccharum officinarum* L., superior sugarcane clones, Rainfed Sugarcane Cultivation, ratoon cane, genetic advance.

Introduction

Sugarcane (*Saccharum officinarum* L.) is a significant industrial crop that contributes substantially to global sugar production. In 2020, global sugarcane production reached 1.9 billion tons, with Brazil, India, and China as the primary producers (FAO, 2021). Indonesia is the world's ninth-largest sugarcane producer, with production expected to reach 31.4 million tons in 2020 (Statistics Indonesia). However, sugarcane productivity in Indonesia is still relatively low compared to other major producing countries. The average sugarcane productivity in Indonesia is only 67.4 tons per hectare, significantly lower than the average in Brazil, which stands at 75.1 tons.ha^{-1} ("FAO Stat. Program. Work 2020-2021," 2020). One of the factors contributing to the low productivity of sugarcane in Indonesia is the decline in yield in ratoon crops.
Genetic diversity is a crucial foundation for plant breeding programs, including those for sugarcane. This diversity is a valuable genetic resource for developing high-yielding varieties with desirable characteristics, such as high yield, resistance to pests and diseases, and adaptability to various environmental conditions. High genetic diversity in sugarcane has been reported in various studies, with genetic diversity coefficients ranging from 10-20% for essential characters such as sugarcane yield, yield, and other yield components (Budi and Lailiyah, 2023; Irsyad et al., 2016; Setyobudi et al., 2023; Singh

et al., 2017). The utilization of genetic diversity in sugarcane breeding programs is a crucial strategy for developing superior varieties with stable and optimal yield performance, both in plant cane and ratoon crops.
The evaluation of superior sugarcane clones is a crucial step in identifying potential genotypes that can provide optimal yields, not only in plant cane but also in ratoon crops. Ratoon crops, which grow from sugarcane stubble after the first harvest, play an essential role in the sugarcane production cycle and contribute significantly to total yield. Ratoon crops can contribute up to 40-50% of sugarcane production (Rahmah et al., 2023; Xu et al., 2021; Yadawad et al., 2022). However, sugarcane yields in ratoon crops often decline significantly compared to those in plant cane crops. Yield reductions in ratoon crops can range from 20-40%, depending on sugarcane variety and environmental conditions (Abu-Ellail et al., 2019). This reduction in yield can be attributed to various factors, including a decline in plant vigor, the accumulation of pests and diseases, and a decline in soil fertility (Viswanathan and Rao, 2011).
Evaluation of superior sugarcane clones for sugarcane yield in ratoon crops has been carried out in several previous studies. Rahmah et al. (2023) evaluated 9 improved sugarcane clones and found significant variation in sugarcane yield in ratoon crops, with stalk weights ranging from an average of 1.5 kg.stalk^{-1}. Similarly, Yadawad et al. (2022) evaluated 18 high-yielding sugarcane clones and identified several clones with high yield potential in ratoon crops, resulting in a 27% increase over plant cane yield. Sugarcane clones SB 01, SB 03, SB 12, SB 19, and SB 20 developed by the Indonesian Sugar Plantation Research Center (P3GI) have also shown high yield potential in early evaluations (Nurazizah et al., (2022); Zumroh et al., (2023)) and ratoon (Rahmah et al., 2023; Wahyudi et al., 2022).
This study aims to assess the genetic diversity of superior sugarcane clones available as genetic resources in sugarcane breeding programs and evaluate the sugarcane yield performance of these superior clones in ratoon crops, whether the first ratoon crop or the second ratoon crop. This evaluation is expected to identify superior sugarcane clones that exhibit stable and optimal yields in ratoon crops, making them candidates for further development as potential varieties. In addition, this research also aims to analyze the genetic and agronomic factors contributing to the differences in sugarcane yield performance between ratoon crops in the superior clones evaluated. The results of this study are expected to provide recommendations for sugarcane breeding programs to develop high-yielding and stable superior varieties in ratoon crops, thereby increasing the productivity and sustainability of the sugarcane industry.

Results and discussion

Genetic variability

Table 1 presents an analysis of variance for several sugarcane traits across different sources of variation. Significant genetic differences exist among clones (C) for all measured traits, with highly significant effects ($p<0.01$) for stalk length, stalk diameter, productivity, and Brix. At the same time, the leaf number shows significance at $p<0.05$. The interaction between ratoons and clones (R×C) also demonstrates significance across most traits, indicating that the performance of clones varies between ratoon generations. Ratoon effects (R) independently show high significance for stalk length, productivity, height, and Brix, suggesting that the harvest cycle strongly influences these characteristics. The analysis reveals substantial genetic variability among sugarcane clones that can be harnessed for crop improvement, particularly in terms of productivity traits.
The analysis of variance table 1 for sugarcane clones reveals several significant findings regarding genetic variation and agronomic traits. The most striking observation is the highly significant differences ($p<0.01$) among clones for nearly all measured characteristics, including stalk length (SL), stalk diameter (SD), productivity (P), and Brix content (B), with leaf number (LN) significant at $p<0.05$. This strong genetic component suggests substantial potential for selecting superior varieties in breeding programs. The ratoon effect (R) shows high significance for stalk length, productivity, height, and Brix, indicating that harvest cycle substantially influences these economically important traits, with first-generation ratoons likely differing from subsequent harvests. Furthermore, the significant interaction between ratoons and clones (R × C) for most traits demonstrates that genotypes respond differently across harvest cycles, a crucial consideration for varietal selection and crop management. The non-significant LSD values for height and Brix between ratoons and between clones suggest that these traits may be more stable across different genetic backgrounds and harvest cycles. Collectively, these results underscore the importance of both genetic factors and crop cycles in determining sugarcane performance, providing valuable insights for breeding programs aimed at developing improved varieties with consistent performance across multiple harvests.
Table 2 presents the average growth data of various traits of the ten sugarcane clones studied during the two ratoon cycles (RC 1 and RC 2). Based on stem length, most clones increased in the second ratoon, with clones SB 11 and SB 01 showing the highest increase (from 306.7 cm to 319.6 cm and 273.3 cm to 314.1 cm, respectively). For stem diameter, some clones, such as SB 12 and SB 03, showed significant increases in the second ratoon, while others were relatively stable. The number of leaves tended to decrease in the second ratoon for all clones, with the most apparent decrease seen in clone SB 20 (from 8.1 to 6.0 leaves). Based on the LSD test results, significant differences between clones (indicated by different capital letters in the vertical direction) were more pronounced in the first ratoon, indicating higher genetic variability at this stage. Overall, clones SB 12 and SB 11 exhibited better and more consistent growth performance across all three traits observed during both ratoon cycles, making them potential candidates for varietal selection.
Based on Table 2, several significant findings were identified regarding the growth of sugarcane clones during the two ratoon cycles. Analysis of stem length showed that most clones increased in the second ratoon, with SB 01 experiencing the most substantial increase from 273.3 cm to 314.1 cm (15%), indicating positive adaptation to ratoon. There was an interesting pattern for stem diameter where some clones (SB 12 and SB 03) significantly increased in the second ratoon,

Table 1. Mean Square for various traits of sugarcane clones

SOV	df	SL		SD		LN		P		R		H		B	
Ratoons (R)	1	1069		0.02		10.48	**	3590.27	**	2.07		43.64	**	26.27	**
Galat (a)	4	156		0.03		0.42		19.96		0.62		1.08		0.76	
Clones (C)	8	856	**	0.14	**	0.70	*	260.99	**	1.83	**	4.93	**	24.47	**
R x C	8	551	*	0.05	**	0.83	**	94.14	**	0.71	**	1.67	**	0.69	ns
Galat (b)	32	185		0.01		0.25		17.42		0.09		0.46		0.82	
C.V (a) (%)		4.16		5.95		10.00		4.10		9.00		10.86		4.28	
C.V (b) (%)		4.52		3.61		7.70		3.83		3.51		7.08		4.45	
LSD between R vs C (0.05)		22.62		0.16		0.83		6.94		0.51		1.13		ns	
LSD between two ratoons (0.05)		23.20		0.1941		0.91		7.32		0.76		1.31		ns	
LSD between two clones (0.05)		22.62		0.1630		0.83		6.94		0.51		1.13		ns	

Remarks: SOV = source of variation, C.V. = coefficient variation, df = degree of fredom, LSD = Least Significant Difference, SL = Stalk length, SD = Stalk diameter, LN = Leaf number, P = Productivity, R = Randemen, H = Hablur, B = Brix, * = Significant at 0.05 level, ** = Significant at 0.01 level, ns = not significant.

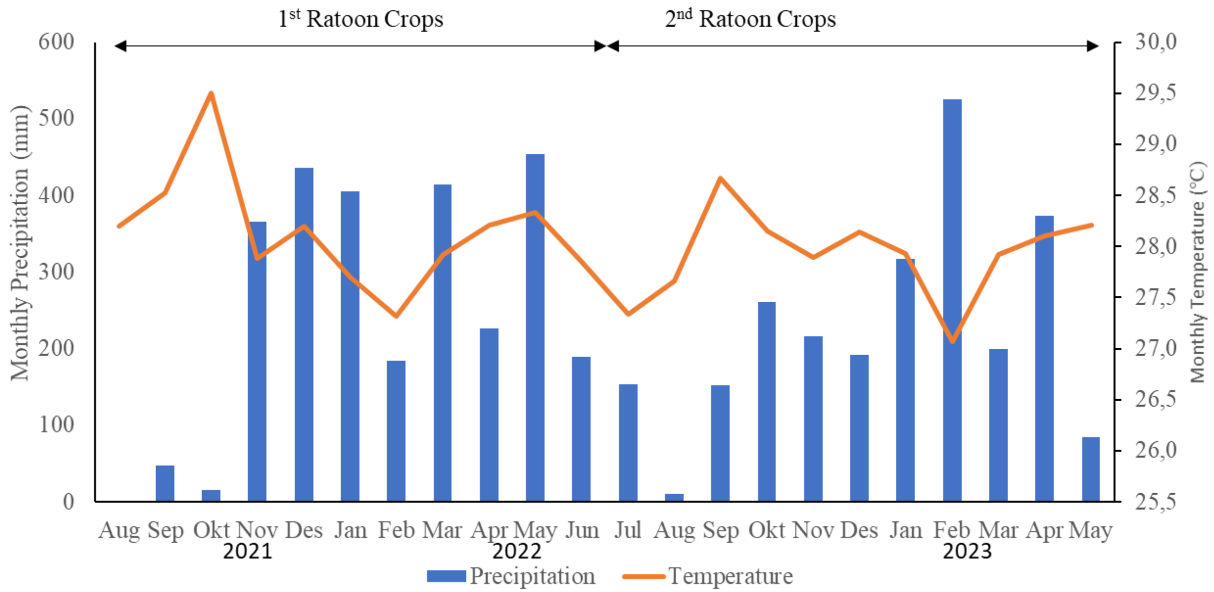

Figure 1. Map of the experiment location. Source: Juanda climate station, Meteorological Station Sidoarjo, (2024).

Table 2. Growth of mean for various traits of studied sugarcane clones.

Clones	Stalk leght (cm)		Stalk diameter (cm)		Leaf number	
	RC 1st	RC 2nd	RC 1st	RC 2nd	RC 1st	RC 2nd
SB 04	295.7 a ABC	308.4 a BC	2.8 a D	2.7 a AB	6.7 a AB	6.1 a A
SB 11	306.7 a BCD	319.6 a C	2.6 a BC	2.7 a AB	6.2 a A	6.1 a A
SB 12	325.0 a D	306.4 a BC	2.4 a A	2.7 b ABC	7.9 b CD	5.9 a A
SB 19	293.3 a AB	318.4 b C	2.9 a D	2.7 a AB	7.1 b BC	6.0 a A
SB 20	287.8 a AB	303.5 a BC	2.8 a CD	2.8 a BC	8.1 b D	6.0 a A
SB 01	273.3 a A	314.1 b C	3.2 b E	2.9 a C	7.1 b BC	6.1 a A
SB 03	316.1 a CD	306.8 a BC	2.5 a AB	2.8 b ABC	6.1 a A	6.0 a A
PS 881	293.9 a ABC	280.9 a A	2.5 a AB	2.6 a A	6.4 a AB	6.1 a A
Bululawang	274.8 a A	288.4 a AB	2.6 a B	2.7 a AB	6.6 a AB	5.8 a A
C.V (a) (%)	4.16		5.95		10.00	
C.V (b) (%)	4.52		3.61		7.70	
LSD between R vs C (0.05)	22.62		0.16		0.83	
LSD between two ratoons (0.05)	23.20		0.1941		0.91	
LSD between two clones (0.05)	22.62		0.1630		0.83	

while clones SB 04 and SB 20 maintained diameter stability. The decrease in the number of leaves in the second ratoon was consistent in almost all clones, with the most drastic reduction in clones SB 20 and SB 12, indicating physiological changes in plant energy allocation. Statistical testing through LSD showed significant differences between clones (indicated by capital letter variations), especially in the first ratoon, which reduced in the second ratoon, suggesting convergence of genetic performance as ratoon cycles increased. Comprehensively, clones SB 11 and SB 12 displayed the most promising and consistent growth performance for all three observed traits, making them excellent candidates for breeding programs or commercial planting. In contrast, clone PS 881 showed the lowest performance for stem length in the second ratoon, which may indicate low adaptability to repeated ratooning.

Table 3 presents some key findings on the productivity and quality of the various sugarcane clones examined. Plant productivity consistently increased in the second ratoon for all clones, with the most significant increase in SB 11 (29.0%) and SB 04 (28.9%), indicating a positive response to the ratoon cycle and good adaptation to growing conditions. Yield parameters showed a varied pattern, with some clones (PS 881, Bululawang, and SB 03) showing a significant increase in the second ratoon. In contrast, others (SB 20 and SB 19) experienced a slight decrease, indicating different genetic responses to sucrose accumulation. Hablur values representing sugar yield per hectare increased evenly across clones in the second ratoon, with SB 01 showing the highest performance (12.3 tons.ha-1), indicating superior biomass to sugar conversion efficiency. Brix content consistently increased in all clones in the second ratoon, with SB 19 reaching the highest value (24.3%), positively correlated with sugar production potential. Analysis of variance through LSD showed significant interactions between clones and ratoon for productivity, yield, and crush parameters but insignificant for Brix, suggesting that genetic factors influence soluble solids content more than ratoon cycle. Overall, clones SB 01, SB 19, and SB 20 displayed comprehensive superiority for all parameters analyzed, making them prime candidates for developing superior sugarcane varieties with high productivity and sugar quality.

Phenotypic and genotypic coefficient of variability, heritability and genetic advance

Table 4 presents the genetic, phenotypic, and environmental variance components, as well as important genetic parameters, of the various sugarcane traits studied across the two ratoon cycles. The analysis revealed that heritability (H^2) values varied across traits and ratoon cycles, with a significant increase in values at RC 2 for most characters, particularly stem length (from 0.37 to 0.79), productivity (from 0.52 to 0.78), and Brix (from 0.69 to 0.95). The coefficient of genetic variance (GCV) showed moderate to high variability in several traits, with the highest values in crush (13.34-7.13%) and number of leaves (8.46-0.81%). Expected genetic progress (GAM) was very high for hablur (22.09%) and brix (15.00%) in RC 1, and productivity (13.24%) and brix (25.11%) in RC 2, indicating substantial improvement potential through selection. A comparison of genetic (Vg) and phenotypic (Vp) variances showed varying environmental influences (Ve) on the expression

Table 3. Yield of mean for various traits of studied sugarcane clones

Clones	Productivity ($t.ha^{-1}$)		Randemen (%)		Hablur ($t.ha^{-1}$)		Brix (%)	
	RC 1st	**RC 2nd**	**RC 1st**	**RC 2nd**	**RC 1st**	**RC 2nd**	**RC 1st**	**RC 2nd**
SB 04	97.5 a AB	111.2 b A	8.1 a B	8.7 a ABC	7.9 a BC	9.6 b A	18.7	19.3
SB 11	99.4 a ABC	128.2 b C	8.2 a BC	8.5 a AB	8.2 a BC	10.8 b B	17.6	18.3
SB 12	102.9 a BCD	108.4 a A	8.7 a CD	8.9 a BC	9.0 a CDE	9.7 a A	19.2	20.3
SB 19	106.6 a CD	120.4 b BC	8.6 a BCD	8.5 a AB	9.4 a DE	10.2 a AB	21.8	24.3
SB 20	107.6 a D	127.4 b BC	8.9 a D	8.4 a A	9.8 a EF	10.7 a AB	21.7	23.3
SB 01	110.1 a D	124.2 b BC	9.8 a E	9.6 a D	10.8 a F	12.3 b C	21.7	23.7
SB 03	99.6 a ABC	111.0 b A	8.7 a CD	9.1 a C	8.4 a BCD	10.1 b AB	19.6	20.3
PS 881	95.2 a AB	103.4 a A	8.7 a CD	10.0 b D	7.8 a B	10.4 b AB	19.7	20.7
Bululawang	92.3 a A	120.1 b B	7.1 a A	8.7 b ABC	6.6 a A	10.5 b AB	16.7	18.7
C.V (a) (%)	4.10		9.00		10.86		4.28	
C.V (b) (%)	3.83		3.51		7.08		4.45	
LSD between R vs C (0.05)	6.94		0.51		1.13		ns	
LSD between two ratoons (0.05)	7.32		0.76		1.31		ns	
LSD between two clones (0.05)	6.94		0.51		1.13		ns	

Table 4. Variance components, heritability, genotypic and phenotypic coefficient of variance and genetic advance of studied traits

Characters	Vg		Vp		Ve		GCV (%)		PCV (%)		H^2		GAM (%)	
	RC 1st	**RC 2nd**	**RC 1st**	**RC 2nd**	**RC 1st**	**RC 2nd**	**RC 1st**	**RC 2nd**	**RC 1st**	**RC 2nd**	**RC 1st**	**RC 2nd**	**RC 1st**	**RC 2nd**
Stalk length (cm)	190.74	154.929	519.3	196.31	328.51	41.383	4.66	4.08	7.69	4.59	0.37	0.79	5.82	7.46
Stalk diameter (cm)	0.03	0.006	0.1	0.01	0.05	0.003	6.34	2.87	10.38	3.55	0.37	0.65	7.97	4.79
Leaf number	0.34	0.002	0.8	0.03	0.47	0.002	8.46	0.81	13.07	2.63	0.42	0.10	11.27	0.52
Productivity ($t.ha^{-1}$)	27.68	72.601	52.7	92.92	25.06	20.314	5.20	7.27	7.17	8.23	0.52	0.78	7.75	13.24
Randemen (%)	0.46	0.330	0.8	0.46	0.33	0.132	7.90	6.42	10.39	7.60	0.58	0.71	12.39	11.17
Hablur ($t.ha^{-1}$)	1.34	0.558	2.1	0.75	0.73	0.188	13.34	7.13	16.59	8.25	0.65	0.75	22.09	12.71
Brix (%)	2.95	6.855	4.3	7.23	1.32	0.373	8.76	12.52	10.53	12.85	0.69	0.95	15.00	25.11

Table 5. Correlation among all the studied traits.

	Ratoons	SL	SD	LN	P	R	H	B
Ratoons	1.00	0.24	0.10	-0.57 *	-0.99 *	0.25	0.99 *	0.32 *
SL	0.24	1.00	-0.03	-0.13	-0.25	0.02	0.24	0.11
SD	0.10	-0.03	1.00	-0.03	-0.06	0.26	0.13	0.34 *
LN	-0.57 *	-0.13	-0.03	1.00	0.60 *	0.05	-0.55 *	0.00
P	-0.99 *	-0.25	-0.06	0.60 *	1.00	-0.20	-0.98 *	-0.28 *
R	0.25	0.02	0.26	0.05	-0.20	1.00	0.29 *	0.54 *
H	0.99 *	0.24	0.13	-0.55 *	-0.98 *	0.29 *	1.00	0.36 *
B	0.32 *	0.11	0.34 *	0.00	-0.28 *	0.54 *	0.36 *	1.00

Remarks : * = Significant at 0.05 level, SL = Stalk length, SD = Stalk diameter, LN = Leaf number, P = Productivity, R = Randemen, H = Hablur, B = Brix.

of these traits, with higher $Vg.Vp^{-1}$ ratios in RC 2nd than RC 1st for most characters, suggesting better selection conditions in the second ratoon cycle.

Table 4 presents a comprehensive analysis of genetic and phenotypic parameters for various sugarcane traits across two ratoon cycles, highlighting several significant findings relevant to breeding programs. The pattern of increasing heritability (H^2) values from the first ratoon to the second ratoon in the majority of traits was a highly significant finding. In particular, stem length exhibited an increase in heritability from low (0.37) to high (0.79), productivity increased from medium (0.52) to high (0.78), and Brix levels rose from high (0.69) to very high (0.95). This indicates that selection in the second ratoon cycle can provide a more effective response than in the first.

The coefficient of genetic variance (GCV) exhibited a diverse pattern, with some traits, such as brix and stem diameter, decreasing from RC 1 to RC 2, while productivity increased from 5.20% to 7.27%. High to very high genetic advance (GAM) values for some economically important traits, such as productivity (13.24% in RC 2), crush (22.09% in RC 1), and brix (25.11% in RC 2), indicate the potential for substantial improvement through selection.

Comparison of variance components showed that genetic influence (Vg) on phenotypic expression (Vp) increased in the second ratoon cycle for most traits, reflected by higher $Vg.Vp^{-1}$ ratios. Overall, these data provide valuable information for sugarcane breeders, suggesting that selection for the improvement of economically important traits such as productivity, yield, crush, and Brix would be more effective in the second ratoon cycle, with particular attention to traits with high heritability and GAM values that promise significant genetic progress.

Trait associations

Table 5 presents the correlation analysis between the various sugarcane traits studied, with correlation coefficient values ranging from -0.57 to 0.79. Ratoon showed a significant positive correlation with productivity (0.70), yield (0.61), and Brix (0.32). Still, there is a significant negative correlation with several leaves (-0.57), indicating that ratoon plants have higher productivity and sugar quality even with fewer leaves. Stem diameter (SD) was significantly positively correlated with productivity (0.30), hablur (0.40), and brix (0.34), indicating the importance of this morphological character to sugarcane yield and quality. Productivity (P) showed the highest positive correlation with yield (0.79) and was also significantly correlated with brix (0.48), confirming the direct relationship between plant biomass and sugar production. Yield (R) was strongly associated with both yield (0.70) and brix (0.54), reflecting the intrinsic relationship between sugar content and other quality parameters. Hablur (H) and brix (B) also showed a significant positive correlation (0.66), confirming the link between soluble solids and sugar production potential. Stem length (SL) showed no significant correlation with other parameters, indicating that different genetic factors may influence this trait. Understanding these correlations is crucial for sugarcane breeding programs that aim to simultaneously improve productivity and sugar quality.

The correlation analysis in Table 5 reveals some significant findings regarding the relationship between various agronomic traits in sugarcane. The strong and significant positive correlation (0.70) between ratoon and productivity (P) indicates that the second ratoon crop tends to produce higher biomass than the first ratoon crop, which aligns with the increased productivity in the previous table. The significant negative relationship (-0.57) between ratoon and leaf number (LN) indicates a physiological phenomenon where sugarcane plants in advanced ratoon allocate more energy to stem formation than leaves. Productivity showed the highest positive correlation with ratoon (0.79), confirming the direct relationship between plant biomass and potential sugar production per hectare. Rendemen (R) was strongly correlated with hablur (0.70) and brix (0.54) but not significantly associated with productivity (0.25), indicating that genetic factors influence sugar content more than plant biomass. Stem diameter (SD) had a significant positive correlation with productivity (0.30), yield (0.40), and Brix (0.34), confirming the importance of this morphological character as a selection indicator in sugarcane breeding programs. Interestingly, stem length (SL) showed no significant correlation with yield parameters, indicating that stem elongation may not directly contribute to productivity or quality. An in-depth understanding of this correlation relationship provides a crucial foundation for selection strategies in breeding programs, primarily focusing on enhancing stem diameter and balancing productivity with sugar content.

Materials and methods

This research was conducted at the research farm of Gempolkrep Sugar Factory, Sidokampir Farm, Sumobito District, Jombang Regency, East Java, Indonesia (7°27'28 "S 112°23'03 "E) from September 2021 to May 2023. The altitude was 64 meters above sea level (asl), with an alluvial soil type, and average rainfall and air humidity during the study (Figure 1). The study used a mixed model: multi-season randomized group design with one factor being clone and ratoon as season. Clones consisting of seven sugarcane clones: SB 04, SB 11, SB 12, SB 19, SB 20, SB 01, SB 03, and control are two sugarcane varieties, PS 881 and Bululawang. Ratoon consists of the first cane ratoon (RC 1st) and the second cane ratoon (RC 2nd). Sugarcane clones are from the collection of the Sugarcane Research and Development Center (P3T), Faculty of Agriculture, Muhamadiyah University Gresik, Indonesia, with three replications. Each treatment in one replication consisted of 8 jurings with a juring length of 10 m and a distance to the center of 110 cm. Manure was applied to the juring as much as 5 tons.ha^{-1} or equivalent to 6.1 kg.juring^{-1} before planting. Planting was done in September 2021.

Plant maintenance included fertilization, weeding, hilling, irrigation, and pest and disease control. Fertilization was done twice with a total dose of 500 kg Phonska and 700 kg ZA.ha^{-1}. The first fertilization was done when the plants were 3-4 weeks old at a dose of 1 kg Phonska + 0.5 kg ZA.juring^{-1}. Fertilization II at 3 months after planting at a dose of 1 kg ZA.juring^{-1}. Fertilization is done in rows about 10 cm from the base of the plant stalk. Hilling was done twice by pulling the soil around the juring to the top of the juring. Fertilization I and II are done after fertilization I and II. Irrigation is done if there is no rain before fertilization. Pest and disease control is carried out according to the level of attack.

Observations of growth components were made before harvest by observing stalk length, number of leaves, and stalk diameter. Stalk length (cm) was measured on the primary plants of each sample clump from the soil surface to the first leaf triangle. Stalk diameter (cm) was measured in each clump of samples selected in primary plants or those with dominant dimensions. The number of leaves is done by counting the fully open leaves. Stalk weight (ton.ha^{-1}) is the weight of the sample plant measured from the soil surface to the breaking point of sugarcane (30 cm below the first leaf triangle). Plant samples were taken as many as 1 clump per juring, and each treatment in one replication was taken 4 juring. Observation of productivity components was carried out before harvest by observing stalk weight. Stalk weight observations were made by taking samples of plants used for growth observations. The yield component was observed before harvest by observing brix and pol to calculate the milking factor and nira value. Brix (percent soluble solids) was determined with a hydrometer. Plant samples were taken from stalk weight observations. Calculation of milking factor, yield, and hablur (H) is crystallized sucrose sugar according to the following formula:

Dairy factors $= \frac{Nira\ weight}{Stalk\ weight}$ (1)

$Rendemen = Dairy\ factor\ x\ nira\ value$ (2)

$Hablur = Randemen\ x\ Productivity$ (3)

Heritability test

Heritability test in the broad sense (H^2) considers total genetic diversity about environmental diversity. Heritability analysis is derived from Analysis of Variance (ANOVA) to obtain the center square value of clones and errors. Furthermore, the Estimated Center Square calculates the value of genotypic diversity (σ^2 g) and phenotype (σ^2 f). The formulation of the heritability test is based on the estimated central square. The environmental variance (σ^2 e) is equal to the centre-squared value of the error. While the variety of genotypes (σ^2 g) equals the value of center-squared genotypes minus center-squared error divided by the number of replicates. Phenotypic variance (σ^2 f) is the sum of genotypic (σ^2 g) and environmental (σ^2 e) variances (Malau, (2020)).

$H^2 = \frac{\sigma^2 g}{\sigma^2 g + \sigma^2 e}$ (4)

$H^2 = \frac{\sigma^2 g}{\sigma^2 f}$ (5)

Heritability values are described as follows H^2<0.2 low category; 0.2≤H^2≤0.5 medium category; and H^2>0.5 high category (Syukur et al., (2015)). Phenotypic diversity coefficient and genotypic diversity coefficient with the following formula:

$$\text{GCV} = \frac{\sqrt{\sigma^2 g}}{x} \text{ x } 100\%$$

$$\text{GCV} = \frac{\sqrt{\sigma^2 f}}{x} \text{ x } 100\%$$

Description: $\sqrt{\sigma^2 g}$ = standard deviation of genotype variance; $\sqrt{\sigma^2 f}$ = standard deviation of phenotypic variance; x = general mean. PCV and GCV are divided into 4 categories: 0<PCV or GCV<25% low category; 25%<PCV or GCV<50% rather low category; 50%<PCV or GCV<75% moderately high category; 75%<PCV or GCV<100% high category (Herawati, (2019)).

Genetic advance test

The genetic advance test is intended to determine how effective the crosses are. The following is the calculation of the genetic advance test (Syukur et al., (2015)).

$R = i\ x\ H^2\ x\ \sigma^2 f$ (6)

$GAM\ (\%) = \frac{R}{x}\ x\ 100\ \%$ (7)

Description: R = response to selection; i = intensity of selection in the study; H^2= heritability in the broadest sense; σ^2 f = standard deviation of phenotypes; GAM = genetic advance; x = population mean.

Criteria for expected genetic advance (GAM) >10% means high, if GAM 6.6 - 10% means quite high, if GAM 3.3 - 6.6% means rather low, and if GAM 0-3.3% means low (Wulandari et al., (2016)). In a broad sense, the estimated value of heritability is estimated using an analysis of variance components (Hanson, (1989)). Observations were made on the characters of stalk length, stalk diameter, number of leaves, and stalk weight.

Correlation analysis

According to (Sugiono, (2019)) the correlation formula is as follows:

$$r = \frac{n\Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{n\Sigma(x)^2 - (\Sigma x)^2 \, n\Sigma(y)^2 - (\Sigma y)^2}} \quad (8)$$

Description: n = Number of X and Y data pairs; Σx = Total number of X variables; Σy = Total number of Y variables; $\Sigma(x)^2$ = Square of the total number of X variables; $\Sigma(y)^2$ = Square of the total number of Y variables; Σxy = The product of the total number of X and Y variables.

To determine the strength of the weak relationship between the two variables, it can be categorized as follows, namely (±) 0.00-0.19 is stated to be very low, (±) 0.20-0.39 is stated to be low, (±) 0.40-0.59 is stated to be sufficient, (±) 0.60-0.79 is stated to be strong, (±) 0.80-1.00 is stated to be very strong. The (+) sign indicates the relationship between the two variables in the same direction, while the (-) sign indicates the opposite relationship of the two variables tested (Hayati, 2018)

Sugarcane productivity observations were made at harvest time by weighing the weight of harvested stalks from all nets other than the edge nets. Observations were made on the first ratoon crop, followed by the second ratoon crop (Figure 1). The results are expressed as the mean from three replicates in each individual. Data were analyzed using a two-way analysis of variance (ANOVA) with Smartstat software (Setiawan, (2023)). Multiple treatments were compared using Fisher's Least Significant Difference (LSD) range test at a 5% error level.

Conclusion

A study on the genetic diversity and yield of superior sugarcane clones in ratoon crops in rainfed areas revealed important findings that can significantly contribute to the development of superior sugarcane varieties. The results showed substantial genetic diversity among the ten evaluated sugarcane clones, with consistent productivity increases in the second ratoon for all clones, particularly SB 11 and SB 04, which exhibited the highest increase of approximately 29%. Heritability values increased in the second ratoon cycle for most characters, primarily stem length (0.37 to 0.79), productivity (0.52 to 0.78), and Brix content (0.69 to 0.95), indicating more effective selection conditions. Significant positive correlations were identified between ratoon and productivity (0.70), yield (0.61), and Brix (0.32). At the same time, stem diameter was positively correlated with productivity (0.30), hablur (0.40), and Brix (0.34), confirming the importance of these morphological characters as selection indicators in sugarcane breeding programs. Clones SB 01, SB 11, SB 12, SB 19, and SB 20 consistently demonstrated superior performance in all measured parameters, with SB 01 recording the highest sugar yield (12.3 t/ha). These clones are prime candidates for the development of superior sugarcane varieties with high sugar productivity and quality. However, this study was limited to two ratoon cycles and requires extension to different agroecological conditions for further validation before the commercial release of the varieties.

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