

Growth and Yield of Six Sugarcane Varieties (*Saccharum officinarum* L.)

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ABSTRACT

Sugarcane (*Saccharum officinarum* L.) is a plant that can grow on uplands and lowlands. Domestic demand for sugar continues to increase in line with population growth and industrial development, but domestic production has not kept pace. Efforts to increase sugarcane productivity and sugar production can be optimized through adaptive, high-yielding, superior sugarcane varieties. The purpose of this study was to determine the morphological characteristics of six sugarcane varieties and to determine their genetic variability. The research was conducted at the Jatimulyo Field, Faculty of Agriculture, Brawijaya University, Lowokwaru District, Malang City, East Java Province. This study used an observational approach to describe the morphological characteristics of six sugarcane varieties. The collected data were analyzed descriptively. Quantitative data were visualized in a table showing the mean, standard deviation, standard error, and coefficient of variation. This study revealed morphological differences among six sugarcane varieties, namely PSJT 941, PS 865, PS 862, Bululawang, PA 028, and Kidang Kencana. The study's results indicate significant morphological differences among varieties. PS 865 exhibits superior vegetative growth with the tallest plant height (224.33 cm) and stem diameter (39.33 mm), while PA 028 demonstrates highly stable characteristics with a coefficient of variation of 4.37%, indicating suitability across various environments. PS 862 and PSJT 941 exhibited longer roots and greater fresh weight, indicating adaptability to wetter conditions. Cluster analysis grouped the six varieties into two major clusters: Cluster 1 (Bululawang, Kidang Kencana, PSJT 941, PS 862) and Cluster 2 (PS 865, PA 032), showing differences in morphological structure.

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1. Introduction

Sugarcane (*Saccharum officinarum* L.) is a plant that can grow in high mountainous areas and towards lowlands. The existence of sugarcane has been known not only in these areas, but also in central and eastern Java since the 19th century. However, sugarcane can also be planted and grown in areas such as Kalimantan and Sumatra (Ridhoi, 2021). According to (Respati, 2020), sugarcane is planted in half of the smallholder plantation area

in Indonesia due to its high economic potential. National demand for sugar continues to increase in line with population and industrial growth, but domestic sugar production has not kept pace. The area of sugarcane plantations in Indonesia in 2021, including both large and smallholder plantations, reached 444,800,000 hectares, with most located on the island of Java, covering an area of 242,500,000 hectares. Sugarcane is an important plantation crop due to the sugar content in its stems (Sari & Sukmawan, 2018). The morphological characteristics of sugarcane are closely related to its yield potential and resistance to various environmental conditions. This plant can only grow in tropical climates because of the high glucose content in sugarcane, which is why it is widely cultivated and processed into sugar to meet the high sugar needs of the Indonesian people. This plant can only grow in tropical climates. Due to sugarcane's high glucose content in sugarcane, this plant is widely cultivated and processed into sugar to meet the needs of the Indonesian people with high sugar levels.

One of the determining factors in sugarcane productivity is the use of superior varieties implemented in a variety management programme based on land typology suitability, ripening characteristics, planting period, and harvesting period. The relationship between genetic and environmental factors in supporting plant growth and development begins at the start of the vegetative period (Arimbawa, 2016). Plant phenotype is the result of the interaction of genetics and the environment (Ariffin *et al.*, 2020). Efforts to achieve this target include sugarcane rehabilitation and variety management. In order to optimise sugarcane productivity and sugar production, superior, adaptive, high-yielding sugarcane varieties are selected. The morphological characteristics of sugarcane plants are closely related to their yield potential and resistance to various environmental conditions. Morphological differences among varieties not only reflect genetic diversity but also indicate adaptability to different agroecosystem conditions. Information on sugarcane growth phases and productivity is used in agroecosystem management and decision-making, including fertilization schedules, harvest times, and the development of marketing strategies (Wahyuni & Astuti, 2022). Previous studies have not discussed the growth comparisons among the varieties to be studied. Information on new varieties, such as PSJT 941 and PA 028, remains scarce. With climate change, there is no information on how these varieties respond to environmental conditions. Therefore, this research is important to provide the latest information on the comparative growth of sugarcane varieties widely cultivated by farmers. In addition, understanding the morphological characteristics of sugarcane varieties is crucial in supporting breeding and cultivation programmes. The purpose of this study was to determine the morphological characteristics of six sugarcane varieties and to determine their genetic diversity. This research is expected to contribute to increasing national sugar production through recommendations on suitable varieties for marginal and intensive land.

2. Methodology

The research was conducted at the Jatimulyo Field, Faculty of Agriculture, Brawijaya University, Lowokwaru District, Malang City, East Java Province, at an altitude of 476 metres above sea level. It was carried out from March to May 2025. The average air temperature in Lowokwaru District ranges from 22 to 25°C. The tools used for this research included a tape measure or ruler, a vernier caliper, a digital scale, an oven, a camera, and a notebook. The materials used in this study were sugarcane seeds collected from the Jatimulyo Garden of the Faculty of Agriculture, Brawijaya University, including the Bululawang, Kidang Kencana, PA 028, PSJT 941, and PS 865 varieties, goat manure, NPK fertiliser, and urea fertiliser.

This study used an observational approach to describe the morphological characteristics of six sugarcane varieties. The research was conducted through the following steps: (1) Preparation of tools and materials, during this stage, various tools and materials required for the study were meticulously prepared; (2) Observation, this stage involved examining the research materials to collect necessary morphological data. Observations included quantitative characteristics gathered through both visual and direct observation; (3) Documentation, the documentation stage aimed to record all research activities, in the form of both written notes and photographs, to ensure the data remains accessible and verifiable. The quantitative variables observed were plant height, number of leaves, fresh weight, stem diameter, number of tillers, and root length. This approach was chosen to gain an in-depth understanding of the characteristics of the six sugarcane varieties cultivated at the research site. Data were collected through direct observation and documentation. The collected data were analysed descriptively. Each quantitative variable was analysed using the centralisation parameters, mean and median, to provide an overview of the distribution of morphological characteristics for each variety.

3. Results and Discussion

According to (Mayasari Yamin *et al.*, 2024), differences in sugarcane plant performance are suspected to be due to differences in gene action that regulate the resulting plant phenotype. These differences are particularly useful as a basis for efforts to increase the frequency of genes for desired observed traits. The Bululawang variety is the result of a variety refinement first discovered in Bululawang District, South Malang. Bululawang is better suited to light soils (loam/sandy clay) with good drainage and sufficient N fertilization. The Kidang Kencana sugarcane variety shows satisfactory plant performance on loam-clay soils (medium to heavy texture) with sufficient water availability. Meanwhile, on land without irrigation, Kidang Kencana appears to show less good performance, so the suitability of the typology of the development area is on available land with sufficient soil moisture (irrigated rice fields). PS 862 shows good germination, initial growth characteristics, simultaneous shoot formation, upright stems, large diameter, small to medium holes, infrequent flowering, and a fiber content of around 12%. The PS 862 variety is suitable for cultivation on light to loamy soils (Regosol, Mediterranean, Alluvial). Sugarcane variety PS 865. This variety is very tolerant to stem borer and shoot borer pest attacks, so it is able to provide high sugarcane production even in conditions of high pest attacks. The PSJT 941 variety is resistant to waterlogged land conditions. PA 028 variety is well adapted to various types of land, including rice and dry fields, and is tolerant of less-than-ideal environmental conditions.

3.1. Quantitative Morphological Characteristics of Sugarcane Plants

Morphological characteristics need to be observed to see the appearance of sugarcane plants. Tables 1, 2, 3, 4, 5, and 6 show the results of measurements of quantitative characteristics of sugarcane plants of the PSJT 941, PS 865, PS 862, Bululawang, PA 028, and Kidang Kencana varieties in terms of plant height, number of leaves, fresh weight, stem diameter, number of tillers, and root length.

Table 1. Quantitative characteristics of sugarcane varieties PSJT 941

Characteristics	Mean	Range	Standard deviation	Standard Error	Coefficient of Variation
Plant height (cm)	181,67	80,0	40,10	23,15	22,08
Number of leaves	12,00	2,0	1,00	0,58	8,33
Fresh weight (g)	1833,33	80,0	404,15	233,33	22,04
Stem diameter (mm)	37,67	10,0	5,51	3,18	14,62
Number of tillers	6,33	5,0	2,52	1,45	39,74
Root length (cm)	13,00	2,0	1,00	0,58	7,69

Based on observations of the quantitative characteristics of PSJT 941 sugarcane varieties, the average plant height was 181.67 cm with a range of 80.0 cm, standard deviation of 40.10 cm, standard error of 23.15 cm, and coefficient of variation (CV) of 22.08%. For the number of leaves, the CV was 8.33%, indicating low variation and relatively uniform growth. For fresh plant weight, the average was 1833.33 grams, with a range of 800.0 grams, a standard deviation of 404.15 grams, a standard error of 233.33 grams, and a CV of 22.04%. Stem diameter had a CV of 14.62%, indicating moderate variation. The tiller characters showed a CV of 39.74%, the highest among all characters, indicating high heterogeneity in tiller production. Meanwhile, root length showed a CV of 7.69%, indicating high stability in this character.

Table 1. Quantitative Characteristics of Sugarcane Variety PS 865

Characteristics	Mean	Range	Standard deviation	Standard Error	Coefficient of Variation
Plant height (cm)	224,33	52,0	27,06	15,62	12,06
Number of leaves	11,67	3,0	1,53	0,88	13,09
Fresh weight (g)	1733,33	1200,0	602,77	348,01	34,78
Stem diameter (mm)	39,33	3,0	1,53	0,88	3,88
Number of tillers	11,67	5,0	2,89	1,67	24,74
Root length (cm)	11,00	2,0	1,00	0,58	9,09

Based on observations of the quantitative characteristics of PS 865 sugarcane plants, plant height showed an average value of 224.33 cm, with a range of 52.0 cm, a standard deviation of 27.06 cm, and a coefficient of variation (CV) of 12.06%. The number of leaves showed a CV of 13.09%, indicating that the number of leaves between plants varied at a moderate level. The stem diameter recorded a CV of only 3.88%, indicating excellent consistency in stem size between individual plants, making this characteristic quite stable in this variety. The number of suckers with a CV of 24.74% indicates a fairly high degree of diversity in the regenerative capacity of the plants. The average root length is 11.00 cm, with a range of 2.0 cm, a standard deviation of 1.00 cm, a standard error of 0.58 cm, and a CV of 9.09%, indicating low variation in this characteristic.

Table 2. Quantitative Characteristics of Sugarcane Variety PS 862

Characteristics	Mean	Range	Standard deviation	Standard Error	Coefficient of Variation
Plant height (cm)	168,00	44,0	22,27	12,86	13,26
Number of leaves	13,67	6,0	3,21	1,86	23,52
Fresh weight (g)	1033,33	500,0	251,66	145,30	24,35
Stem diameter (mm)	37,67	7,0	3,79	2,19	10,05
Number of tillers	8,33	10,0	5,77	3,33	69,28
Root length (cm)	12,67	8,0	4,04	2,33	31,91

Observations of the quantitative characteristics of the PS 862 sugarcane variety showed significant diversity between individual plants in several morphological parameters. Plant height showed a coefficient of variation (CV) of 13.26%, indicating that the variation in plant height was moderate. The number of leaves, with a CV of 23.52%, showed considerable variation between plants. For the plant's fresh weight, the average was 1033.33 grams, with a CV of 24.35%. This indicates moderate to high variation in the potential for fresh biomass yield. The stem diameter showed a CV of 10.05%, indicating low variation and stability in this characteristic. The tiller count had a very high CV of 69.28%, indicating substantial variation among plants in regenerative capacity. Meanwhile, the CV for root length was 31.91%, also indicating high variation in this parameter.

Table 4. Quantitative Characteristics of Bululawang Sugarcane Varieties

Characteristics	Mean	Range	Standard deviation	Standard Error	Coefficient of Variation
Plant height (cm)	155,00	29,0	15,72	9,07	10,14
Number of leaves	15,33	12,0	6,43	3,71	41,93
Fresh weight (g)	1133,33	400,0	208,17	120,19	18,37
Stem diameter (mm)	30,00	2,0	1,00	0,58	3,33
Number of tillers	9,33	7,0	3,79	2,19	40,56
Root length (cm)	11,67	5,0	2,52	1,45	21,57

Observations of the quantitative characteristics of Bululawang sugarcane varieties show varying levels of diversity in each morphological parameter observed. Plant height shows a coefficient of variation (CV) of 10.14%, indicating a low to moderate level of diversity. The number of leaves had a high CV of 41.93%, indicating considerable variation in the number of leaves between individual plants. Plant fresh weight had a CV of 18.37%, indicating moderate diversity in potential biomass yield. The stem diameter character showed a CV of 3.33%, indicating that the Bululawang variety had very uniform stem diameters across plants. The number of suckers had a CV of 40.56%, indicating that regenerative ability via suckers varied greatly among plants. Meanwhile, root length had a CV of 21.57%, indicating moderate diversity in rooting characteristics.

Table 5. Quantitative Characteristics of Sugarcane Variety PA 028

Characteristics	Mean	Range	Standard deviation	Standard Error	Coefficient of Variation
Plant height (cm)	207,67	18,0	9,07	5,24	4,37
Number of leaves	10,33	8,0	4,16	2,40	40,29
Fresh weight (g)	1400,00	600,0	346,41	200,00	24,74
Stem diameter (mm)	31,00	4,0	2,00	1,15	6,45
Number of tillers	12,67	3,0	1,53	0,88	12,06
Root length (cm)	12,67	1,0	0,58	0,33	4,56

Observations of the quantitative characteristics of the PA 028 sugarcane variety showed low to moderate levels of diversity in each of the morphological parameters observed. Plant height showed a coefficient of variation (CV) of 4.37%, indicating that plant height between individuals was relatively uniform and was an indicator of the vertical growth stability of this variety. The number of leaves per plant had a fairly high CV of 40.29%, indicating significant variation between plants in the number of leaves produced. The fresh weight of the plant showed a CV of 24.74%, indicating moderate diversity in plant biomass yield. The stem diameter had a CV of 6.45%, indicating that the stem size was relatively stable and uniform between plants. The number of tillers character obtained a KV of 12.06%, indicating low to moderate variation. Meanwhile, the root length character showed a very low KV of 4.56%, indicating high stability in the root system development of the PA 028 variety.

Table 6. Quantitative Characteristics of Kidang Kencana Sugarcane Variety

Characteristics	Mean	Range	Standard deviation	Standard Error	Coefficient of Variation
Plant height (cm)	189,67	20	10,21	5,90	5,38
Number of leaves	14,00	12	6,00	3,46	42,86
Fresh weight (g)	1600,00	500	275,86	159,02	17,24
Stem diameter (mm)	32,33	5	2,52	1,46	7,79
Number of tillers	8,67	5	2,52	1,46	29,06
Root length (cm)	10,00	4	2,00	1,15	20,00

Observations of the quantitative characteristics of Kidang Kencana sugarcane varieties reveal varying levels of diversity in morphological traits. Plant height shows a coefficient of variation (CV) of 5.38%, indicating low diversity and relatively uniform vertical growth. The number of leaves per plant had a very high CV of 42.86%, indicating significant variation in the number of leaves between individual plants. Plant fresh weight had a CV of 17.24%, indicating moderate diversity in plant biomass yield. Stem diameter had a CV of 7.79%, indicating low diversity and good stem size stability. The number of suckers showed a CV of 29.06%, with fairly high diversity in regenerative ability among plants. Meanwhile, root length had a CV value of 20.00%, indicating moderate variation in the root system character.



Figure 1. Comparison of the Morphological Characteristics of the Stems of Six Sugarcane Varieties

3.5 Principal Component Analysis of Sugarcane Plants

Principal Component Analysis (PCA) is used to identify relationships and determine which characters make the greatest contributions. The results of principal component analysis of six quantitative characters of sugarcane plants show five principal components, with eigenvalues ordered from largest to smallest, and differences in the percentage of diversity shown in Figure 2.

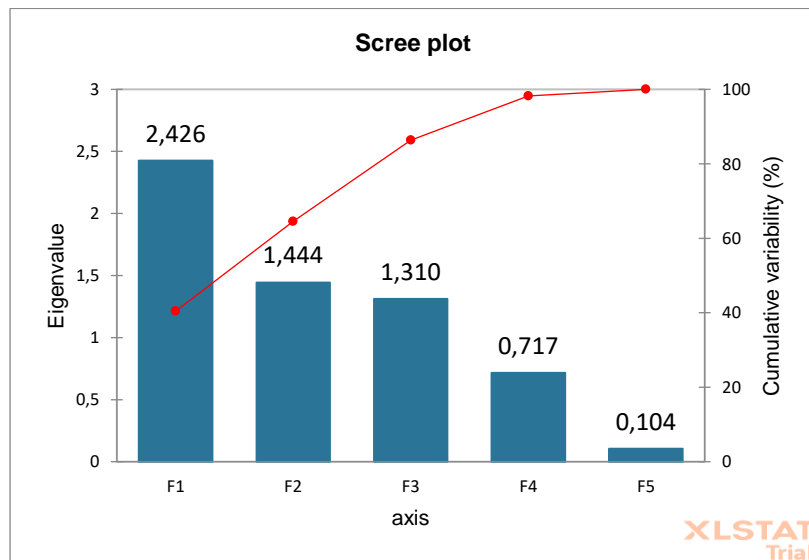


Figure 2. Scree Plot with Eigenvalues and Cumulative Diversity Based on Morphological Characteristics

The scree plot shows that the main components with eigenvalues greater than 1, indicated by the bars above the dotted line, are found in F1 to F3, so only three main components are used. The magnitude of the contribution of each character in the F variation can be known based on the factor loading value. The main components (PC) are determined based on eigenvalues >1, and the characteristics that contribute to diversity are determined by factor loadings >0.5. Eigenvalues less than one (<1) are not used in calculating the number of

principal components formed. The results of the principal component analysis or Principal Component Analysis (PCA) are based on 6 quantitative characteristics in 6 varieties of sugarcane plants at the research location, as shown in Table 7.

Table 7. Eigenvalues, Diversity, Cumulative Diversity, and Factor Loadings for 6 sugarcane varieties based on 6 quantitative characteristics

Characteristic	F1	F2	F3
Plant height	0,610*	-0,141	0,143*
Number of leaves	-0,520	-0,409	-0,196
Fresh weight	0,194*	-0,451	0,537*
Stem diameter	-0,117	0,066*	0,696*
Number of tillers	0,545*	0,077*	-0,352
Root length	-0,095	0,774*	0,211*
Eigenvalue	2,426	1,444	1,310
% Variability	46,870	27,820	25,300
% Cumulative	46,870	74,690	99,990

Description: *) characters contributing to the principal component of maximum variability

Component F1, with an eigenvalue of 2.426, contributes to a maximum diversity of 46.87%. The characteristics contributing to component F1 are plant height, fresh weight, and number of tillers. The first principal factor reflects the dimension of vertical vegetative growth and the potential for tiller propagation. This component is important for selecting varieties with high vigour and production potential. Component F2 with an eigenvalue of 1.44 contributes to a maximum diversity of 27.82%. The characteristics contributing to component F2 are stem diameter, number of tillers, and root length. Component F3 with an eigenvalue of 1.310 contributes to a maximum diversity of 25.30%. After analyzing the main components, the next step was to analyze the active variables such as plant height, number of leaves, fresh weight, stem diameter, number of shoots, and root length, which can be seen in Figure 3.

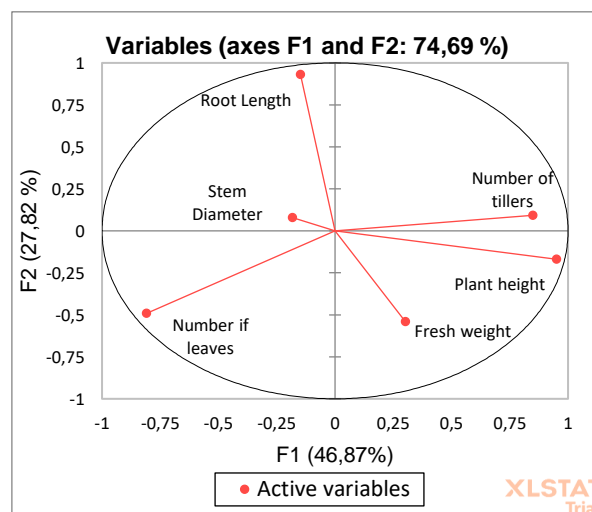


Figure 3. Biplot Clustering of Principal Component Analysis Based on Morphological Characteristics in Six Varieties of Sugarcane

Figure 3 shows the PCA biplot based on two principal components (F1 and F2) that cumulatively explain 74.69% of the morphological variation of six sugarcane plant

characteristics. The F1 axis (46.87%) separates varieties based on above-ground growth characteristics, with strong contributions from plant height, number of tillers, and fresh weight, all of which are positively correlated. Conversely, the number of leaves shows a negative correlation with this axis, indicating no relationship between leaf production and plant height and number of tillers. The F2 axis (27.82%) is mainly influenced by root length, which has a very high contribution to the vertical direction of the graph, and stem diameter, which has a smaller contribution. This shows that F2 separates varieties based on root system adaptation and stem rigidity. The relationship between vectors on the biplot also indicates a positive correlation between plant height and number of tillers, while the number of leaves tends to be in the opposite direction. Root length stands almost alone on the F2 axis, clarifying its role as a determinant of underground adaptation that is relatively independent of above-ground production dimensions.

3.6. Discussion

Sugar cane is one of the strategic commodities in Indonesia, which plays a role in the national economy (Ikka *et al.*, 2021). The increasing demand for sugar must be accompanied by the availability of superior sugarcane varieties. Sugarcane productivity can be optimised through a combination of superior genetics and a suitable growing environment (Irawan *et al.*, 2023). This is in line with the opinion of (Wahyudi *et al.*, 2022), who state that optimal genetic and environmental factors can support vegetative growth, which can increase productivity. High genetic diversity and heritability values are benchmarks for assembling a variety, as they reflect genetic progress. Furthermore, genetic factors are decisive in selection, where selection can be effective if genetics plays a greater role than the environment in trait inheritance (Meydina *et al.*, 2015). According to Meydina *et al.* (2015), extensive diversity can be influenced by genes that regulate plant physiological processes (Abadi *et al.*, 2021).

Based on growth data, the faster the sugar cane plant grows, the faster the plant parts, such as leaves, roots, flowers, and so on, are formed (Saptorini, 2019). According to (Muharram *et al.*, 2020), during the vegetative period, plants produce more growth hormones, so that they are able to stimulate the apical dominance of the plant, which then increases the height of the plant. Stem weight has a strong positive correlation in determining sugarcane productivity (Salsabila Kartika Zahra Maharani & Anna Kusumawati, 2024). The process of stem elongation is growth supported by the development of several plant parts, including leaf crown development, root development, and stem elongation (Ardiyansyah & Purwono, 2015). Plant breeding programmes play an important role in producing superior varieties that meet market criteria and have high yields. The success of a breeding programme is largely determined by the degree of diversity in the population. Mapping kinship will facilitate the determination of germplasm diversity when crossbreeding plants (Setyobudi *et al.*, 2023). Information on diversity will assist in selecting promising genotypes that can be used in future breeding programmes (Rifda *et al.*, 2020). Diversity in plants is divided into two types, namely genetic diversity caused by genetic factors and phenotypic diversity caused by genetic interactions with the environment (Nugroho *et al.*, 2022). Temperatures above 38°C affect photosynthesis in sugarcane plants and increase respiration frequency. This affects sugarcane productivity and juice quality. Genetic diversity is the difference in appearance caused by differences in the alleles of an individual's genes (Bhandari *et al.*, 2017). Genetic factors will not express their characteristics unless the necessary environmental factors are present. Conversely, improving environmental factors will not cause character development

unless the necessary genetic factors are present in the individual concerned (Syukur, Sujiprihati, & Yuniarti, 2018). The existence of diversity in agronomic characters provides information related to traits that can be expressed well so that they can be carried out more effectively. The sugarcane breeding process is inseparable from germplasm management programmes, as germplasm is a source of genetic diversity for a plant species. The collection of sugarcane germplasm with various varieties must be balanced with scientific information about the characteristics of each accession or variety. One of the efforts to explore information in germplasm collection empowerment is by characterising agronomic and morphological traits, so that superior sugarcane varieties or accessions can be classified (Chidambaram & Sivasubramaniam, 2017). The part of the sugar cane plant that is used is the stem. Sugarcane produces a relatively large biomass, and the storage of photosynthate in the form of high levels of sucrose is found in the stem (Erlina *et al.*, 2017).

Furthermore, principal component analysis is used to identify variables such as morphological, agronomic, and molecular traits that contribute most to diversity. Principal component analysis reduces many variables into several principal components without losing too much information. The characteristics contributing to component F3, namely plant height, are dominated by fresh weight, stem diameter, and root length. A stem diameter >30 mm is the preferred minimum threshold of the sugar industry due to its correlation with juice volume and ease of processing (Zainuddin *et al.*, 2020). The third factor indicates stem strength and the potential for biomass accumulation. Large stem diameter is generally associated with lodging resistance and sugarcane productivity. When combined with fresh weight and root length, this reflects high yield potential. After analysing the main components, the next step is to examine the active variables, including plant height, number of leaves, fresh weight, stem diameter, number of tillers, and root length.

4. Conclusion

Based on the research conducted, there is significant morphological diversity among varieties, especially in plant height, leaf number, fresh weight, stem diameter, tiller number, and root length. The PS 865 and PA 028 varieties exhibit superior, stable morphological characteristics with relatively low coefficient of variation (CV) values. The Bululawang and PS 862 varieties have specific local advantages, such as rapid regeneration and adaptation to certain environmental conditions. Principal Component Analysis (PCA) grouped morphological diversity into three main components (F1, F2, and F3) that cumulatively explained 99.96% of the total diversity. Component F1 represented vertical growth and number of tillers, F2 reflected root system adaptation, and F3 was related to stem diameter and fresh weight. Cluster analysis grouped the six varieties into two large clusters, namely Cluster 1 (Bululawang, Kidang Kencana, PSJT 941, PS 862) and Cluster 2 (PS 865, PA 032), which showed significant differences in morphological structure.

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