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Morphological variations of superior sugarcane cultivars (*Saccharum officinarum*) from Lampung, Indonesia

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Abstract. *Windiyani IP, Mahfut, Purnomo, Daryono BS. 2022. Morphological variations of superior sugarcane cultivars (*Saccharum officinarum*) from Lampung, Indonesia. Biodiversitas 23: 4109-4116.* Sugarcane (*Saccharum officinarum* L.) is the main crop for producing sugar and for various industries. The need for sugar is continuously increasing as the population grows and the diverse demands of industrial needs. One of the efforts to increase sugar production is by developing high-yielding sugarcane varieties. In doing so, performing morphological characterization is necessary so that superior sugarcane cultivars can be identified. This study aimed to determine the morphological variations and phenetic relationships of the crosses of sugarcane cultivars of the collections of PT. Gunung Madu Plantation in Lampung, Indonesia. Morphological observation of 15 sugarcane cultivars was carried out on 37 characters covering leaves, leaf midrib, internodes, stems, eyes, and agronomical aspects. The dendrogram was built using the UPGMA cluster using the Gower's General Similarity Coefficient algorithm, while the PCA analysis was performed using the Euclidean Distance algorithm using MVSP v.3.1 software. The results of the study showed that there were fairly high morphological variations among the sugarcane cultivars observed. The results showed the superior sugarcane cultivars of PT. GMP collections (i.e., GMP 1, GMP 2, GMP 3, GMP 4, GMP 5, GMP 6, and GMP 7) were not in one cluster due to differences between each parent. The principal component analysis of 37 characters showed that the total variation on axis I contributed 27.62% to the variation with an eigenvalue of 0.25, while axis II was 17.9% with an eigenvalue of 0.16. The information about morphological variations in this study suggests that morphological characters as taxonomic evidence are very good for identifying and analyzing local sugarcane cultivar variations and knowing the closeness of their kinship relationships.

Keywords: Morphological variations, plant breeding, sugarcane

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is one of the important plantation crops in the world as a raw material for sugar production and other beverages product (Kristanti et al. 2007). Globally, there are various cultivars of improved sugarcane which are inter-species hybrids of the genus Saccharum involving four species, i.e., three cultivated species namely *S. officinarum*, *S. barberi* and *S. sinense*; and one wild species, *S. spontaneum*. In addition to polypolidy, sugarcane is also a heterozygous plant with a very diverse number of chromosomes, ranging from 90-130. Of the total chromosomes in sugarcane cultivars, 80% were contributed by *S. officinarum*, 10% by *S. spontaneum*, and 10% by *S. barberi* and *S. sinense* (Khan 2017; Srivastava 2009).

In Indonesia, sugarcane has been developed to achieve self-sufficiency. The consumption of sugar in the country has been continuously increasing as the population grows as well as consumption per capita has increased 1.5 times, reaching 14.5 kg per capita per year. However, the increasing demand for sugar consumption is not in line with sugarcane production which is declining nowadays, for example there is a decrease from 2.19 million tons in 2017 to 2.17 million tons in 2018. According to estimates from the Ministry of Agriculture, the production of sugarcane in Indonesia fell by 4% in five years (Utama 2020).

One way to achieve sugar self-sufficiency is through plant breeding programs to develop sugarcane varieties with superior characteristics to improve the quality and quantity of sugarcane production. The selection of cross-breeds with good combining power is an initial effort to breed sugarcane to produce superior cultivars. Such plant breeding programs have also been developed by PT. Gunung Madu Plantations (GMP), a sugar producer company located in Lampung in Sumatra Island, Indonesia. Through its Research & Development Department, the company has carried out a variety cross-breeding programs so that the needs for high-yielding varieties can be met. PT. GMP has succeeded in releasing 7 high-yielding sugarcane cultivars from their own crosses, namely GMP 1, GMP 2, GMP 3, GMP 4, GMP 5, GMP 6, and GMP 7, through a long selection process (10-12 years) to produce the desired characteristics (PT. Gunung Madu Plantations 2015).

One of the efforts to extract information about the potential characteristics of those sugarcane varieties is by performing morphological characterization so that superior sugarcane cultivars can be identified. A morphological characterization is a process that can be used to determine the phenotypic character of a plant so that variations can be assessed quickly. According to Hidayati et al. (2016), characterization based on morphological characters (leaves, stems, tubers, fruits, roots) can determine the type of utilization of the characterized plants with the highest variation shown in the petiole. Color variation is also very important in the identification of cultivar differences (Oktavianingsih et al. 2019; Purnomo et al. 2020).

Identification of morphological characters is an important tool in the taxonomic basis and plant systematics (Mahfut et al. 2021). Morphological variability is an important data point that describes genetic variation and can be used to identify the range of variation and morphological similarity between cultivars using cluster analysis (Purnomo et al. 2015). Morphological and agronomic characters analyzed using multivariate statistical methods can be used to study genetic variation in hybrid sugarcane and germplasm resources (Zhou et al. 2015; Ongala et al. 2016). Multivariate analysis is the most popular type of analysis to estimate genetic variability to study variation patterns and genetic relationships between germplasm collections (Ajmal et al. 2013; Malik et al. 2014). This study was conducted to evaluate morphological variations and phenetic relationships of *S. officinarum* of several sugarcane cultivars including superior cultivars developed by PT. GMP Lampung. We expected the results of this study might be used as a basis for characterization and information on selection in future sugarcane breeding programs.

MATERIALS AND METHODS

Plant materials

The plant materials investigated in this study were fourteen cultivars of *S. officinarum*, which were *ex-situ* living collections of PT. Gunung Madu Plantations and one wild species, Glagah (*S. spontaneum*). These fifteen cultivars were GMP 1, GMP 2, GMP 3, GMP 4, GMP 5, GMP 6, GMP 7, ROC 01, ROC 14, ROC 15, SS 33, SS 113, SS 109, Irvine 93-552, and Glagah (*S. spontaneum*) as Operational Taxonomic Units (OTU's).

Morphological observation

Morphological characters, including quantitative and qualitative characters, were observed directly. In total, there were 37 characters based on the classification of leaves, leaf midrib, internode, stem, eye, and agronomy with the application of binary and multistate scoring (Table 1).

Table 1. Morphological characteristics of *S. officinarum* observed in this stud

No.	Characters	Scores
1.	Leaf curvature	0: < ⅓ leaf; 1: 1/3 - ½ leaf; 2: ½ - 2/3 leaf
2.	Leaf width	0: Narrow (<4cm); 1: Medium (4-5cm); Wide (>5cm)
3.	Leaf color	0: 5 GY 4/4; 1: 5 GY 5/4; 2: 5 GY ¾; 3: 7.5 GY 4/2
4.	Leaf triangle color	0: White; 1: Purple; 2: Green
5.	Leaf ears	0: No ears; 1: Ear length 1 times the width (weak); 2: Ear length 2-3 times the width (medium); 3: Ears equal to or more than 3 times the width (strong)
6.	Leaf ear position	0: Upright; 1: Oblique; 2: Curved
7.	Back fur position	0: Hairless; 1: Upright; 2: Lying down
8.	Width of dorsal hair area	0: Hairless; 1: < width of leaf midrib; 2: =/> width of midrib
9.	Peak distance of dorsal hair area	0: Hairless; 1: <1 cm; 2: =/> 1 cm
10.	Dorsal hair density	0: Hairless; 1: Infrequent; 2: Dense
11.	Leaf-sheath detachment	0: Difficult; 1: Medium; 2: Easy
12.	Leaf-sheath color	0: White; 1: Purple; 2: Green
13.	Segment arrangement	0: Straight; 1: Zigzag
14.	Segment shape	0: Cylindrical; 1: Barrel; 2: Spherical; 3: Conical; 4: Inverted conical; 5: Convex-concave
15.	Section cross-section	0: Round; 1: Flat
16.	Internode length (cm)	0: Long (>15); 1: Medium (13-15); 2: Short (<13)
17.	Root ring	0: Up above the eye, 1: Not above the eye
18.	Number of root points	0: <2 rows; 1: 2-3 rows, 2: >3 rows
19.	Eye grooves	0: None; 1: On some segments; 2: On all segments
20.	Rod color	0: 2.5 Y 5/4; 1: 2.5 Y 5/6; 2: 2.5 GY 5/4; 3: 2.5 GY 6/6; 4: 2.5 GY 7/6; 5: 5 Y 6/8; 6: 5 YR 4/4; 7: 7.5 YR 4/2; 8: 7.5 YR 4/4; 9: 7.5 YR 5/2
21.	Wax coating	0: Thick; 1: Medium; 2: Thin
22.	Stem diameter	0: Large (>3 cm); 1: Medium (2.5-3 cm); 2: small (<2.5 cm)
23.	Bar cracks	0: None; 1: One; 2: Two; 3: More than two
24.	The nature of the cork rods	0: No; 1: Yes
25.	Hole in stem	0: No; 1: Yes
26.	Eye position	0: On the former leaf midrib; 1: Above the former leaf midrib
27.	Eye shape	0: Round; 1: Elliptical; 2: Ovoid; 3: Inverted ovoid
28.	Crested hair	0: No, 1: Yes
29.	Eye wing edge	0: Wingless; 1: The same width; 2: The base is narrower
30.	Eye wing shape	0: Flat; 1: Scalloped
31.	Growth center	0: Below / in the middle of the eye; 1: Above the middle of the eye
32.	Basal fringe hair	0: No; 1: Yes
33.	Plant height (cm)	0: Long (>300); 1: Medium (250-300); 2: Short (<250)
34.	Population	0: Small (<8); 1: Medium (8-10); 2: Large (>10)
35.	Number of internodes	0: Many (>30 cm); 1: Few (<30 cm)
36.	The nature of the fall	0: Fall down; 1: Do not fall
37.	Pests and diseases	0: Less than 2 pests and diseases;1: More than 2 pests and diseases

Data analysis

The collected data were analyzed descriptively to identify the variations in the character of observed organs which were completed in MVSP (Multivariate Statistical Package) v.3.1 software to construct phenetic dendrogram and for Principal Component Analysis (PCA). Dendrogram was constructed by Gower's General Similarity Coefficient and Unweighted Pair Group with Mean of Arithmetic (UPGMA) clustering method (Singh 1999), while the PCA scattered plot was constructed using Euclidean Distance algorithm. Gower's General Similarity Coefficient was for mixed data analysis (ordinal and categorical) (Podani 1999). Furthermore, PCA (Principal Component Analysis) was performed to determine the characteristics of the operational taxonomic unit (OTU's) group of *S. officinarum*.

RESULTS AND DISCUSSION

Morphological variations of *Saccharum officinarum* at the study site

The results of the scoring of morphological characters are presented in Table 2. The explanation of the variations of characters is elaborated below.

Leaf variations

Saccharum officinarum had a green leaf triangle. Variations occurred in the character of the leaf arch, leaf width, leaf color, leaf ear, and leaf ear position. *S. officinarum* had 3 variations of narrow-leaf width (<4 cm), medium leaf width (4-5 cm), and wide leaf (>5 cm). Leaf color variations included 5 GY 4/4, 5 GY 5/4, 5 GY and 7.5 GY 4/2. Variations of leaf ear included earless, ear length was 1 times the width (weak), the ear length was 2-3 times the width (medium) and ear length was equal to or more than 3 times the width (strong). Variations in the position of the leaf ear had the character of an upright and oblique leaf ear. Most of the cultivars had a curved character of 1/3 of the leaf blade, the leaf color was 5 GY 4/4, the ear length was 1 time the width (weak), and the position of the leaf ear was upright.

Leaf midrib variations

The leaf midrib showed that there was variation in all characters. These variations were found in the character of the position of the dorsal hair, the width of the dorsal hair area, the distance to the peak of the dorsal hair area, the density of the dorsal hair, the loose nature of the leaf midrib and the color of the leaf midrib. The position of the hair on the back had 2 variations, namely hairless and lying down. Hairless variations were also found in the character of the width of the dorsal hair area and the distance between the crest and the dorsal hair area, each of which was dominated by most of the cultivars. Most of the cultivars had medium leaf midrib lose properties and green leaf midrib color.

Internode variations

The segment generally has a root ring that does not reach above the eye, and the number of roots is 2–3 rows. Variations were found in the character of the segment arrangement, the shape of the segment, the cross-section of the segment, the length of the segment, and the eye groove. The arrangement of segments had 2 variations, namely straight and zigzag. Most variations were found in the shape of the segment, namely cylindrical, barrel, spherical, conical, inverted conical, and convex-convex. Most of the cultivars had a cylindrical internode shape, a round cross-section, a medium internode length (13-15 cm), and no eye grooves.

Stem variations

The stem variation was found in the character of the color of the stem, the wax layer, the diameter of the stem, the nature of the cork of the stem, and the hole in the stem, while there was no variation in the character of the crack of the stem. All cultivars had no cracks in the stems. The highest variation among all morphological characters was found in the color variation on the stems, including 2.5 Y 5/4 color characters in GMP 1; color 2.5 Y 5/6 on ROC 14; color 2.5 GY 5/4 on GMP 5 and ROC 15; color 2.5 GY 6/6 on GMP 4; 2.5 GY 7/6 on SS 113, SS 109, Irvine 93-552 and Glagah; color 5Y 6/8 on GMP 7; color 5 YR 4/4 on GMP 6; color 7.5 YR 4/2 on ROC 01 and SS33; color 7.5 YR 4/4 in GMP 2 and color character 7.5 YR 5/2 in GMP 3. Most of the cultivars had a medium wax coating, a medium stem diameter (2.5-3 cm), no cork, and holes in the stem.

Eye variations

Saccharum officinarum had a central character growing above the middle of the eye. Variations occurred in the character of eye position, eye shape, crested hair, eye wing edge, eye wing edge shape, and basal hair edge. The position of the eye had 2 variations of characters, namely the character of the eyes on the former leaf midrib and on the former leaf midrib. There were variations in eye shape, namely round, elliptical, and ovoid. Most of the cultivars had the characteristics of eyes on the leaf midrib; the shape of the eyes was oval; there were crest hairs on the eyes; the wing edges were the same width; the shape of the wing edges of the eyes was flat; and there were basal hairs.

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Table 2. Morphological character scoring on 15 sugarcane cultivars of the collection of PT. GMP Lampung, Indonesia

	GMP 1	GMP 2	GMP 3	GMP 4	GMP 5	GMP 6	GMP 7	ROC 01	ROC 14	ROC 15	SS 33	SS 113	SS 109	Irvine 93-552	Glagah
D1	1	1	0	0	1	1	1	1	1	1	0	1	1	1	0
D2	2	2	1	0	1	2	1	1	1	2	1	2	2	1	0
D3	0	1	3	3	0	0	0	3	0	0	3	2	0	0	0
D4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
D5	0	1	1	3	1	2	1	1	1	1	2	1	1	1	0
D6	0	1	1	1	2	2	1	2	1	2	1	2	2	1	0
P1	0	0	2	2	0	0	2	0	2	0	0	2	0	2	2
P2	0	0	1	1	0	0	1	0	1	0	0	1	0	1	1
P3	0	0	2	2	0	0	2	0	2	0	0	2	0	2	2
P4	0	0	1	2	0	0	1	0	1	0	0	1	0	1	1
P5	1	0	2	1	1	1	1	0	1	2	2	1	1	1	0
P6	2	2	2	0	2	2	2	2	2	2	1	2	2	2	2
R1	0	1	0	0	1	1	0	1	0	1	1	1	1	1	0
R2	0	0	2	0	0	0	0	0	0	0	0	3	4	4	0
R3	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
R4	1	1	2	1	2	1	1	0	1	1	1	2	2	2	0
R5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
R6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
R7	0	1	0	0	2	1	0	0	0	1	1	0	1	0	1
B1	0	8	9	3	2	6	5	7	1	2	7	4	4	4	4
B2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	2
B3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B5	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1
B6	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0
M1	0	1	0	0	1	0	0	0	1	0	0	0	0	0	1
M2	2	2	2	0	2	2	2	0	2	1	2	2	1	2	1
M3	1	1	1	0	1	1	1	0	1	1	1	1	1	0	0
M4	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
M5	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0
M6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M7	1	0	0	0	0	0	1	1	1	1	1	1	1	0	0
A1	1	0	0	0	0	0	1	0	1	1	0	0	1	0	1
A2	2	2	2	2	2	2	2	2	1	1	2	2	2	2	2
A3	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1
A4	0	0	1	1	1	0	1	0	0	0	0	0	0	1	1
A5	1	0	0	0	1	1	1	0	0	1	1	1	1	1	0

Description: D1: Leaf curvature; D2: Leaf width; D3: Leaf color; D4: Leaf triangle color; D5: Leaf ears; D6: Leaf ear position; P1: Back fur position; P2: Width of dorsal hair area; P3: Peak distance of dorsal hair area; P4: Dorsal hair density; P5: Leaf-sheath detachment; P6: Leaf-sheath color; R1: Segment arrangement; R2: Segment shape; R3: Section cross-section; R4: Internode length (cm); R5: Root ring; R6: Number of root points; R7: Eye grooves; B1: Rod color; B2: Wax coating; B3: Stem diameter; B4: Bar cracks; B5: The nature of the cork rods; B6: Hole in stem; M1: Eye position; M2: Eye shape; M3: Crested hair; M4: Eye wing edge; M5: Eye wing shape; M6: Growth center; M7: Basal fringe hair; A1: Plant height (cm); A2: Population; A3: Number of internodes; A4: The nature of the fall; A5: Pests and diseases

Agronomical variations

There was variation in all agronomical characters. These variations were found in the character of plant height, population, number of segments, nature of laying down, pests and diseases. Most of the cultivars were tall (>300 cm), had a large population, a large number of segments, felling character, and had more than 2 pests and diseases.

Phenetic relationship of *Saccharum officinarum* based on morphological characters

The phenetic relationship of 15 cultivars was determined based on 37 characters. The dendrogram constructed showed two clusters at the phenon line of 60% similarity (Figure 1). Cluster I consisted of Glagah, which is a comparison plant (outgroup) separated from the other fourteen sugarcane cultivars. At the 65% phenon line (Figure 1), three clusters were formed, namely cluster I (Glagah), cluster II (Irvine 93-552, SS 113, ROC 14, GMP 7, GMP 4, and GMP 3) and cluster III (ROC 01, GMP 5, GMP 2, SS 33, SS 109, ROC 15, GMP 6, and GMP 1). Clusters II and III were grouped with a similarity coefficient of 65%. The close relationship between sub-clusters is caused by the parent-hybrid relationship. These results were further confirmed by the PCA method (Figure 2) to determine the role of each character in the clustering.

Table 3. Eigenvalues, percentage of variance, and character loading on the first two principal components

Character code	Character name	Character loading	
		PC 1	PC 2
D1	Leaf curvature	-0.15	0.08
D2	Leaf width	-0.22	-0.03
D3	Leaf color	0.18	-0.54
D4	Leaf triangle color	0.00	0.00
D5	Leaf ears	0.02	-0.26
D6	Leaf ear position	-0.11	-0.24
P1	Back fur position	0.47	0.11
P2	Width of dorsal hair area	0.30	0.07
P3	Peak distance of dorsal hair area	0.47	0.11
P4	Dorsal hair density	0.34	0.05
P5	Leaf sheath detachment	-0.01	-0.03
P6	Leaf sheath color	-0.10	0.10
R1	Segment arrangement	-0.19	-0.21
R2	Segment shape	0.16	-0.20
R3	Section cross section	0.00	-0.13
R4	Internode length (cm)	-0.01	-0.06
R5	Root ring	0.00	0.00
R6	Number of root points	0.00	0.00
R7	Eye grooves	-0.22	-0.02
B1	Rod color	0.09	-0.53
B2	Wax coating	0.02	0.00
B3	Stem diameter	0.03	0.04
B4	Bar cracks	0.00	0.00
B5	The nature of the cork rods	0.03	0.11
B6	Hole in stem	-0.06	0.04
M1	Eye position	-0.01	0.14
M2	Eye shape	-0.06	0.12
M3	Crested hair	-0.14	0.02
M4	Eye wing edge	0.03	0.03
M5	Eye wing shape	-0.04	-0.01
M6	Growth center	0.00	0.00
M7	Basal fringe hair	-0.10	0.04
	Eigen values	-0.03	0.30
	Percentage (%)	0.02	-0.06
	Cum. Percentage (%)	0.08	0.10

PCA was also used to determine the morphological characters that play a dominant role in group formation. The contribution value of each character to the grouping is represented in eigenvalues. Eigenvalues represent the contribution value of each character to the cultivar grouping, while the size indicates the influence of each character, which can be seen from the short length of the projection formed. Overall, the principal component analysis of 37 characters showed that the total variation on axis I contributed 27.62% to the variation of the 37 morphological characters used, with an eigenvalue of 0.25, while axis II was 17.9% with an eigenvalue of 0.16. The total percentage of the two axes was 45.52 variations of 37 characters (Table 3).

Based on the scatter diagram (Figure 2 and Table 3), the most important character in the grouping of cluster I, cluster II, and cluster III was leaf width (D2). In clusters I and II, most of the clusters had medium leaf width (4-5 cm). Most of the clusters had broad leaves (> 5 cm), the position of the dorsal hair area (P1), the width of the dorsal hair area (P2), the distance to the top of the dorsal hair area (P3), the density of the dorsal hair area (P4), and eye grooves (R7).

Discussion

Morphological variations of Saccharum officinarum

Saccharum officinarum mostly had high morphological variation. There were 32 variations of the 37 morphological characters observed. A fairly high variation indicates a fairly wide genetic diversity. High variation in morphological characters was also found in the research of kinship analysis of sugarcane germplasm based on morphological characters (Hamida and Parnidi 2019), morphological variability, and taxonomic relationship of *Sorghum bicolor* based on qualitative characters (Martiwi et al. 2020), and genetic diversity of jackfruit provenances based on morphological parameters (Palupi and Daryono 2021).

In general, morphological characters can be used as a source of taxonomic evidence and are the best data for delimiting a taxon because it uses characters that are easy to see, not hidden characters (Stace 1981). The results of this study indicate that morphological characters as taxonomic evidence are very well used to identify and analyze the diversity of local sugarcane cultivars and can determine plant kinship relationships. This shows that morphological markers are becoming increasingly useful and easier to use because of direct observations and can be measured in the field.

Phenetic relationship

Based on the grouping pattern in the dendrogram, there were clear differences between the morphology of wild and cultivated sugarcane species and their hybrids. In this case, Glagah which is known as wild sugarcane, showed a clear separation from other cultivar groups. This cluster separation at the 60% phenon line (Figure 1) is thought to be the age of the sugarcane plant and the difference in species between Glagah (*S. spontaneum*) and the sugarcane (*S. officinarum*) collections in PT. GMP. Sugarcane (*S. officinarum*) is believed to have originated from a complex introgression between *S. spontaneum*, *Erianthus aruninaceus*, and *Miscanthus sinesis* (Daniels and Roach 1987). At the 65% phenon line (Figure 1), three clusters were formed. Clusters II and III were grouped with a similarity coefficient of 65%. There were similarities between the two clusters, namely the color of the leaf triangle, root ring, number of roots, stem diameter, stem crack, and growth center. The distinguishing characteristics were in cluster II: in general, the position of the dorsal hairs was lying down, the width of the dorsal hair area was <1/4 the width of the midrib, and the distance to the top of the dorsal hair area =/> 1 cm, the density of the dorsal hairs were rare, and there was no eye groove. Meanwhile, in cluster III, there was no fur on the dorsal hair. The width of the dorsal hair area, the distance to the top of the dorsal hair area, the density of the dorsal hair, and eye grooves were found in some segments.

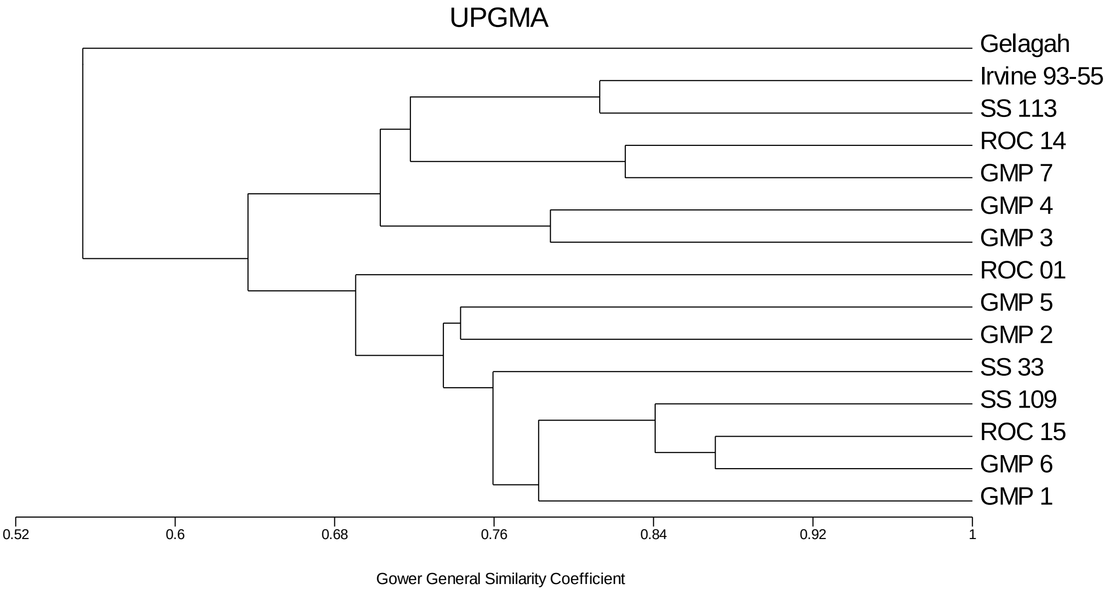

Figure 1. Dendrogram of phenetic relationship of 15 cultivars of *S. officinarum* using Gower's General Similarity Coefficient

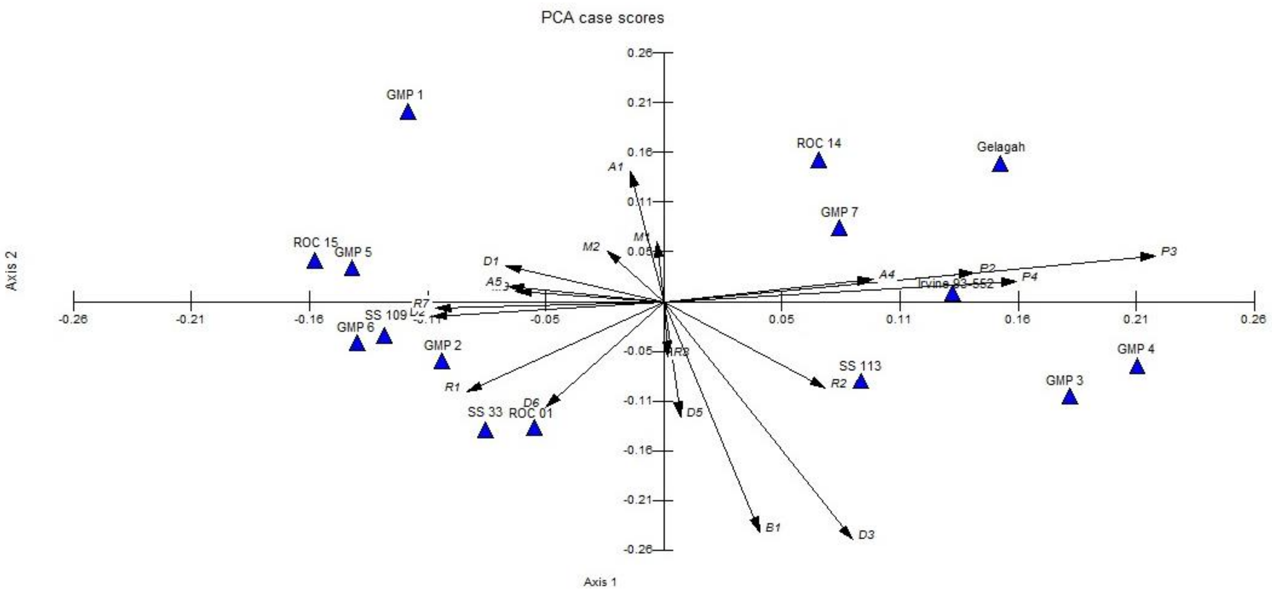

Figure 2. Principal Component Analysis using Euclidean Distance algorithm

Cluster analysis is a method used in grouping character sets. The clusters represent uncorrelated groups that may be useful for future heterotic breeding (Twumasi 2017). The superior sugarcane cultivars (GMP 1, GMP 2, GMP 3, GMP 4, GMP 5, GMP 6, and GMP 7) did not cluster in one cluster. The grouping was thought to be due to differences in male and female parents in each superior sugarcane cultivar. GMP 1 and GMP 2 were grouped in one cluster with a similarity coefficient of 73%. The morphological characters formed were thought to be due to similarities in the female parents. Likewise, GMP 5 and GMP 6 were closely related because of the similarity between male and female parents, with a similarity coefficient of 83%. In GMP 3 and GMP 4, with a similarity coefficient of 79%, it is suspected that the female parents were similar, while GMP 7 was in the same cluster as the male and female parents.

PCA is a useful technique for identifying the best genotypes based on quantitative and qualitative data, and is able to assess genetic variation, and describe and classify cultivars and populations (Thapa et al. 2009; Al-Naggar et al. 2020). A number of studies of morphological characters used cluster analysis and PCA with a degree of similarity of 60% and a variation of PCA of 75.4% (Hamida and Parnidi 2019), similarity coefficients ranging from 49.25% to 76.12% (Palupi and Daryono 2021), similarity coefficients ranging from 58% to 86% (Amzeri et al. 2021), and the PCA results of 57.91% from the total variation (Al-Naggar 2020). Singh (1999) stated that if the germplasm has a similarity index of 85% or more, then the germplasm is grouped into the same species.

The grouping pattern based on the dendrogram and scatter diagram showed the grouping of sugarcane cultivars based on the similarity of morphological characters. Cultivars that have many similar characters will have a greater similarity value, so that they are gathered in the same cluster or sub-cluster. The results of cluster analysis showed that the superior sugarcane cultivars of PT. GMP (i.e., GMP 1, GMP 2, GMP 3, GMP 4, GMP 5, GMP 6, and GMP 7) did not cluster in one cluster due to differences between each parent.

Morphological characters are influenced by environmental conditions to some extent. Cultivars have different phenotypes based on the characteristics of stems, internodes, buds, leaves, and measurable characteristics (Khan 2017). The above-ground morphological characters can be used for testing of distinctiveness, uniformity, and performance of sugarcane cultivars (Singh 2012), and can be used for property rights by plant breeders (Rae 2014), and are referred to as sugarcane descriptors for identification, release, and notification of cultivars (SAS Institute 2004).

The combination of cluster analysis and principal component analysis has been widely applied in plant systematic studies in various taxa at the taxonomic level, starting from the species level (Fitriana and Susandarini 2019; Singh et al. 2020), genus level (Alzahrani et al. 2021), and family level (Arogundade and Adedeji 2019). Our study suggests that grouping based on morphological characters as taxonomic evidence is very good for identifying and analyzing local sugarcane cultivar variations and knowing the closeness of their kinship relationships.

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