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Morphological diversity of banana (*Musa* sp.) accessions collected from Bengkulu Province, Indonesia

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Abstract Local banana germplasm accessions of Bengkulu Province, Indonesia, were studied to elucidate their similarity based on morphological performances using multivariate techniques. Low to medium correlation coefficients were found among 13 morphological characters of bananas, indicating that those traits are independent in nature. To facilitate interpretation of the results of principal component analysis, three PCAs, explaining 44.5% of the variability of the accessions, were adopted. PCA1 is characterized by pseudostem height, leaf blade length and peduncle length PCA2 is characterized by pseudostem color, bract apex shape, number of fruits and fruit length while PCA3 is characterized by peduncle length, fruit position, fruit length and immature fruit peel color. Using the three PCAs as the basis for clustering, the accessions can be grouped into four clusters to set apart their main habitats.

Keywords: Cluster analysis, Correlation analysis, Germplasm, Principal component analysis, Similarity

Introduction

Bananas are the most common and oldest fruit crop in the tropics. The crop is usually picked for direct consumption or transformed into various products. However, in certain African and Latin American nations, bananas serve as essential dietary staples. World banana consumption is recorded at more than 100 million tons per year, has increased by 1.21% in the last five years, and is predicted to reach 136 million tons in 2025 (Voora *et al*., 2020). Banana fruit contains both macro- and micro-nutrients needed for human health (USDA, 2020). In addition to the fruit, other parts of the plant, such as the roots, pseudostems, leaves, flowers, and even the peel of the fruit, can be used for various purposes. Banana flowers and male buds are usually consumed in the form of processed vegetables, jerky, chips, and others.

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Banana originates from Southeast Asia, including Indonesia, so this region is also a center of diversity (Daniells *et al*., 2001; Hapsari *et al*., 2018). There are at least 300 local banana accessions that have been identified throughout Indonesia (Poerba, 2016), and at least 137 of these accessions have been characterized (Poerba *et al*., 2018). Due to the fact that climate change, land conversion, habitat destruction, and lack of attention may endanger their existence, activities related to exploration, inventory, identification, and characterization of banana germplasm need to be carried out. Otherwise, they will be extinct, as occurred to several members of the *Dipterocarpaceae* (Dwiyanti *et al*., 2014; Liliwirianis *et al*., 2013; Primananda *et al*., 2022), *Amorphophallus decus, Dipterocarpus littoralis, Nepenthaceae,* and *Coelogyne pandurata* (Soto *et al*., 2011). By doing such activities, mitigation and conservation measures can be determined (Rosales *et al*., 2006), and further benefits of their existence can be developed (Slamet *et al*., 2020). Likewise, the germplasm can be used for the exchange of germplasm in order to implement the Convention on Biological Diversity of December 29, 1993, the International Treaty on Plant Genetic Resources for Food and Agriculture (2006), and the Nagoya Protocol (Buck and Hamilton, 2011).

Bengkulu Province, similar to several other areas in Indonesia, is home to a diverse array of local banana germplasm that thrives at different altitudes, including coastal, midland, and highland regions, as documented by Riandini (2020) and Riandini *et al*. (2018, 2021). Despite this diversity, there has been a lack of research focused on the primary characteristics of these germplasm varieties and their comparative similarities. The objective of this study was to assess the morphological diversity patterns and the extent of similarity among the banana germplasm found in Bengkulu Province.

Materials and methods

The study was carried out between March and June 2024, utilizing an exploratory survey across different altitudes in Bengkulu Province, Indonesia. The sampled accessions consisted of mature banana plants that had already produced fruit for consumption. Data were gathered both *in situ* and *ex situ* for thirteen morphological characteristics of the plants, following the guidelines outlined in the Descriptor for Banana (IPGRI, 1996). The *in situ* assessments were concentrated on the plant stature, pseudostem structure, and leaf, whereas *ex situ* evaluations were primarily concerned with the male buds and fruits.

Statistical analysis of the collected data was performed using SAS V9.4 (SAS Institute Inc., Cary, N.C.). PROC CORR was employed to assess the degree of closeness among traits. PROC PRINCOM was utilized using the correlation matrix to identify the variability pattern among accessions based on the traits studied. The Wards' minimum variance method in the Proc CLUSTER was employed to categorize accessions according to the primary features identified in the principal component analysis. The results of the cluster analysis were visualized using a dendrogram with the help of PROC TREE.

Results

Collected accessions

The distribution of 79 accessions identified in the surveyed regions (Figure 1). The data indicated that banana varieties in Bengkulu Province are found at varying elevations, encompassing coastal, midland, and highland areas. Additionally, the origin of these accessions, their respective elevations, local names, and their uses, highlighting the adaptability of bananas to a range of environmental conditions are shown in Table 1. The local names assigned to them appear to be a collective agreement, with some names derived from morphological characteristics, geographical origins, and sensory attributes. The utilization indicated the local use of the fruits.

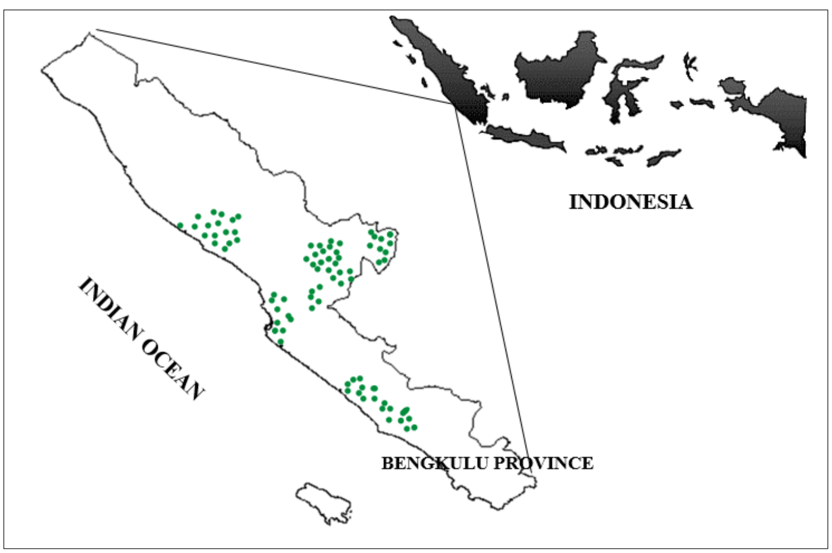

Figure 1. Distribution the collected banana accessions in Bengkulu Province

Table 1. Typical banana accessions collected in Bengkulu

No	Location	Elevation (m asl)	Accession Code	Local Name	Utilization
1	Lais	31	H101	Mas	Dessert
2	Lais	28	H102	Susu	Dessert
3	Lais	28	H103	Kepok	Cooking
4	Arga Makmur	164	H104	Ambon Kecil	Dessert
5	Arga Makmur	143	H105	Serindit	Dessert
6	Arga Makmur	135	H106	Jantan	Cooking
7	Arga Makmur	135	H107	Muli	Dessert
8	Arga Makmur	135	H108	Raja	Dual purposes
9	Arga Makmur	135	H109	Lidi	Dessert
10	Arga Makmur	135	H110	Kepok	Cooking
11	Arga Makmur	135	H111	Udang	Dual purposes
12	Arga Makmur	141	H112	Susu	Dessert
13	Arga Makmur	231	H113	Kepok Jawa	Cooking
14	Arga Makmur	231	H114	Ambon	Dessert
15	Padang Jaya	158	H115	Bawean	Cooking
16	Padang Jaya	221	H116	Nangka	Cooking
17	Padang Jaya	225	H117	Raja Nangka	Cooking
18	Tengah padang	21	H218	Jantan	Cooking
19	Tengah padang	21	H219	Muli	Dessert
20	Karang Tinggi	22	H220	Ambon	Dessert
21	Taba Penanjung	114	H221	Timun	Dessert
22	Taba Penanjung	115	H222	Masak Semalam	Dessert
23	Taba Penanjung	128	H223	Kepok	Cooking
24	Taba Penanjung	120	H224	Raja Seri	Dual purposes
25	Tengah padang	22	H225	Serindit	Dessert
26	Tengah padang	22	H226	Raja Seri	Dual purposes
27	Pasar Pedati	10	H227	Seribu	Dessert
28	Pasar Pedati	10	H228	Kepok	Dessert
29	Timur Indah	34	H229	Tanduk	Cooking
30	Timur Indah	34	H230	Masak Semalam	Dessert
31	Tebat Karai	445	H231	Jantan	Cooking
32	Tebat Karai	445	H232	Ambon	Dessert
33	Tebat Karai	445	H233	Mas	Dessert
34	Tebat Karai	446	H234	Raja Nangka Merah	Cooking
35	Tebat Karai	448	H235	Barangan Merah	Dessert
36	Tebat Karai	448	H236	Cavendis	Dessert
37	Ujan Mas	596	H237	Rotan	Dual purposes
38	Ujan Mas	596	H238	Susu	Dessert
39	Ujan Mas	596	H239	Nangka	Cooking
40	Ujan Mas	597	H240	Ambon Curup	Dessert
41	Ujan Mas	593	H241	Jogja	Dessert
42	Ujan Mas	593	H242	Mas	Dessert
43	Ujan Mas	595	H243	Kapagh	Dual purposes
44	Ujan Mas	595	H244	Rapit	Dessert

Table 1. *Continued*

No	Location	Elevation (m asl)	Accession Code	Local Name	Utilization
45	Ujan Mas	595	H245	Jantan	Cooking
46	Ujan Mas	595	H246	Keripit	Cooking
47	Ujan Mas	595	H247	Sabo	Cooking
48	Ujan Mas	595	H248	Rawas	Dual purposes
49	Ujan Mas	595	H249	Ruso	Dual purposes
50	Ujan Mas	595	H250	Masak Semalam	Dessert
51	Ujan Mas	595	H251	Seribu	Dessert
52	Pematang Donok	750	H252	Raja Nangka	Cooking
53	Pematang Donok	745	H253	Ambon	Dessert
54	Pematang Donok	750	H254	Susu	Dessert
55	Pematang Donok	748	H255	Lampung	Cooking
56	Tangsi Duren	980	H256	Jantan	Cooking
57	Tangsi Duren	972	H257	40 Hari	Dessert
58	Tangsi Duren	960	H258	Selendang	Dessert
59	Tangsi Duren	960	H259	Lenggang	Cooking
60	Tangsi Duren	960	H260	Coklat	Cooking
61	Lunjuk	28	H261	Barangan	Dessert
62	Niur Sukaraja	19	H362	Muli	Dessert
63	Talang Dantuk	16	H363	Serindit	Dessert
64	Lubuk Lagan	29	H364	Rajo Merah	Cooking
65	Lubuk Lagan	29	H365	Rawas	Dual purposes
66	Lubuk Lagan	29	H366	Kepok Putih	Cooking
67	Pasar Ngalam	10	H367	Jantan	Cooking
68	Lawang Agung	14	H368	Tanduk	Cooking
69	Pasar Ngalam	10	H369	Nangka	Cooking
70	Pasar Ngalam	10	H370	Raja Nangka	Cooking
71	Lubuk Lagan	29	H371	Kepal	Cooking
72	Lubuk Lagan	29	H372	Bawean	Cooking
73	Lawang Agung	14	H373	Kepok	Cooking
74	Napal Jungur	92	H374	Tanduk	Cooking
75	Napal Jungur	92	H375	Sabo	Cooking
76	Napal Jungur	92	H376	Ambon	Dessert
77	Cawang Seluma	276	H377	Lidi	Dessert
78	Cawang Seluma	292	H378	Mas Belanda	Dessert
79	Cawang Seluma	275	H379	Kapagh	Dual purposes

The relationship among traits

The results of the correlation analysis, as presented in Figure 2, show that the correlation coefficient between the 13 observed traits is generally relatively low. Exceptions were found in several pairs of traits whose relationships were moderately close with a range of r = 0.34 to r = 0.51. The closest relationship was shown by the pseudostem height - leaf blade length pair, followed by the pseudostem height - peduncle length pair, then the leaf blade length - peduncle length pair, and pseudostem height - bract apex shape.

	PH	PC	LBL	CMS	PL	BP	BAS	FP	NF	FL	FS	FPC	PCM
PH													
PC	-0,234												
LBL	0,508	-0,020											
CMS	-0,044	0,004	0,024										
PL	0,410	-0,135	0,409	0,045									
BP	0,076	0,029	-0,098	-0,117	-0,255								
BAS	0,336	-0,260	0,105	0,098	0,265	0,023							
FP	-0,116	0,089	-0,330	-0,054	-0,161	0,100	0,101						
NF	0,134	0,052	0,218	-0,023	0,275	-0,268	-0,148	-0,282					
FL	0,233	-0,366	0,126	0,071	0,030	-0,167	0,270	-0,103	-0,098				
FS	0,122	-0,229	0,023	0,104	0,111	-0,011	0,044	-0,254	0,093	0,296			
FPC	0,037	-0,114	-0,125	0,001	0,236	0,004	0,299	0,110	-0,024	-0,143	0,159		
PCM	-0,183	0,117	-0,097	-0,037	-0,088	0,148	0,139	0,135	-0,288	0,009	-0,039	-0,204	

Figure 2. Correlation Matrix (PH : pseudostem height; PC : pseudostem color; LBL : leaf blade length; CMS : color of midrib dorsal surface; PL : peduncle length; BP : bunch position; BAS : bract apex shape; FP : fruit position; NF : number of fruits; FL : fruit length; FS : fruit shape; FPC : immature fruit peel color; PCM : pulp color at maturity)

Principal component analysis

The relatively low degree of closeness between traits indicated that the morphological characteristics of the accessions tend to be independent. The results of the principal component analysis confirmed that the observed traits were multidimensional and it was not easy to determine a unique multi-character construct. Based on this phenomenon, only 3 principal component axes (PCA), namely PCA1, PCA2, and PCA3, were involved in the evaluation (Table 2). The contribution of the three axes to data variability is indicated by their eigenvalues, which overall reached 44.5%. A closer inspection and based on the vector loadings that contributed relatively large to each PCA revealed that PCA1 was more characterized by pseudostem height, leaf blade length, and peduncle length. This implies that accessions with high PCA1 values had prominent features of tall plant, long leaves, and long peduncle. PCA2 was more characterized by pseudostem color, bract apex shape, number of fruits, and fruit length, to indicate that accessions having large PCA2 values would have greener pseudostem, rounder bract apex, less fruit number, and longer fruit. Moreover, PCA3 was more characterized by peduncle length, fruit position, fruit length, and immature fruit peel color, where accession with higher PCA3 values would have long oeduncle, pendant and shorter fruits, and greener immature fruit peel.

By plotting PCA1 and PCA2 scores, the distribution of accessions on the graph formed from the two PCA axes becomes clearer (Figure 3a). Quadrant I characterized by accessions that have tall pseudostems with a green appearance, long leaf blades, long stems, rounded bract leaf apexes, and produce fewer but longer fruits, as typically shown by accessions 60 (H260), 47 (H274), and 68 (H268). Quadrant II represents accessions that have a short red-purple pseudostem, long leaf blade, long peduncle, pointed bract apex, produce more fruits but short in size, e.g. accessions 40 (H240), 37 (H237), and 34 (H234). Quadrant III is characterized by a short purple-red pseudostem, short leaf blade, short peduncle, pointed bract apex, and produces more short fruits. Accessions 28 (H228), 62 (H362), and 7 (H107) would be examples of quadrant III. Quadrant IV describes accessions with the characteristics of a short green pseudostem, short leaf blade, short peduncle, round bract apex, produce less long fruits, as represented by accessions 1 (H101), 2 (H102), and 21 (H221).

Table 2. Three principal component axes derived from the principal component analysis along with their loadings, eigenvalues, and percentage of variance explained

Plant traits	PCA1	PCA2	PCA3
Pseudostem height	**0.43**	0.10	0.12
Pseudostem color	-0.27	**-0.33**	0.16
Leaf blade length	**0.39**	-0.19	-0.01
Color of midrib dorsal surface	0.07	0.03	-0.13
Peduncle length	**0.42**	-0.06	**0.32**
Bunch position	-0.18	0.23	0.06
Bract apex shape	0.24	**0.48**	0.22
Fruit position	-0.27	0.29	**0.32**
Number of fruits	0.23	**-0.48**	0.08
Fruit length	0.26	**0.30**	**-0.48**
Fruit shape	0.23	0.12	-0.29
Immature fruit peel color	0.10	0.20	**0.56**
Pulp color at maturity	-0.19	0.25	-0.18
Eigenvalue	2.60	1.78	1.39
% Varians	20.04	13.74	10.75
Cummulative % varians	20.04	33.77	44.52

Bold values indicate correlation coefficients equal to or greater than 0.5 in absolute value

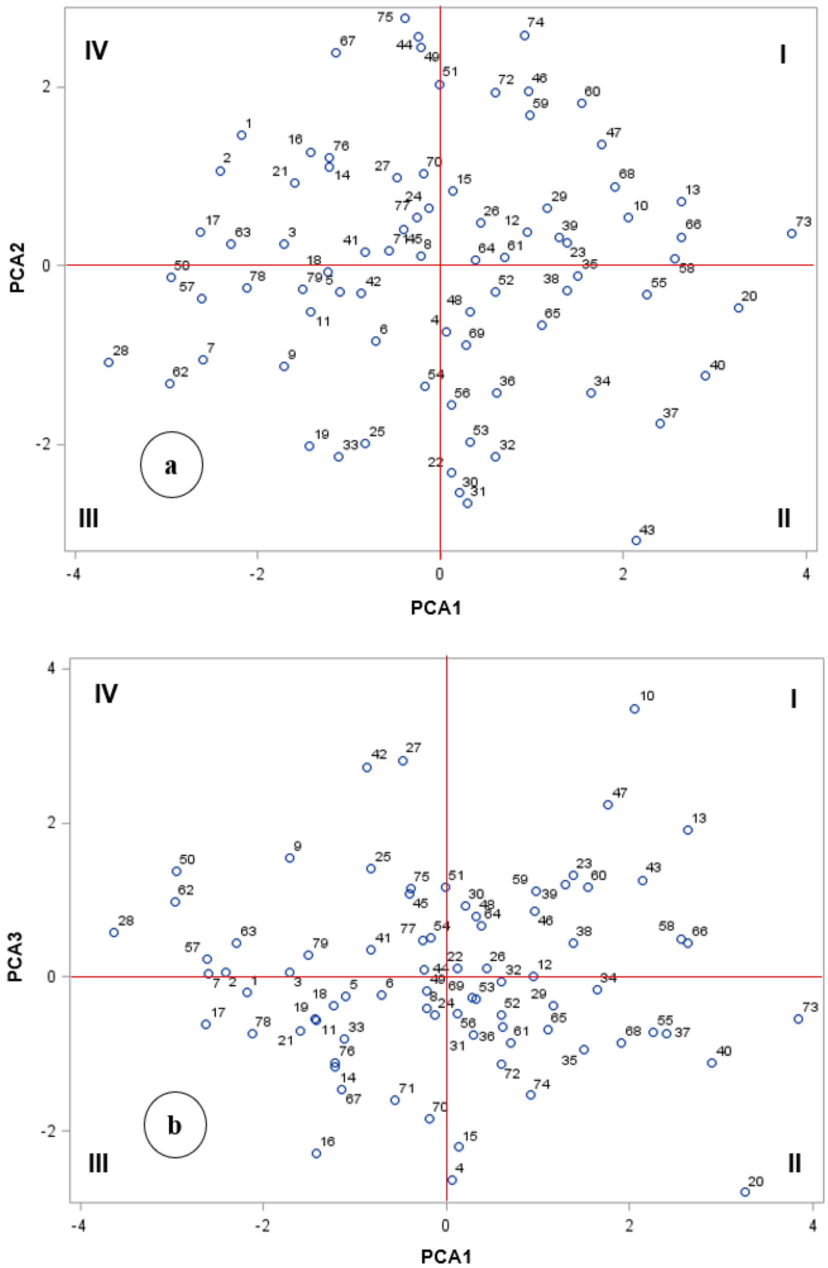

Figure 3. Distributin pattern of the collected banana accessions as plotted along the axes of PCA1 vs PCA2 (a) and PCA1 vs PCA3 (b)

The analysis of the graph constructed from the PCA1 and PCA3 axes revealed distinct groupings of accessions based on the observed traits, including pseudostem height, leaf blade length, peduncle length, fruit position, fruit length, and the color of immature fruit peels, as illustrated in Figure 3b. By segmenting the graph into four quadrants, it becomes possible to categorize the characteristics of each accession. Quadrant I is characterized by accessions exhibiting tall pseudostems, elongated leaf blades, extended peduncles, short and hanging fruits, along with greener immature fruit peels, represented by accessions 10 (H110), 13 (H113), and 47 (H247). In contrast, Quadrant II encompassed accessions with tall pseudostems, long leaf blades, long peduncles, fruits that are long and curve upwards, and light green immature fruit peels, as seen in accessions 20 (H220) and 40 (H240). Quadrant III included accessions 16 (H116), 17 (H117), and 78 (H378), which are characterized by short pseudostems, short leaf blades, short peduncles, long upward-curving fruits, and light green immature fruit peels. Finally, Quadrant IV is defined by accessions with short pseudostems, short leaf blades, short peduncles, short and hanging fruits, and green immature fruit peels, exemplified by accessions 9 (H109) and 50 (H250).

Accessions similarity

The application of cluster analysis through Ward's method on three PCAs categorized the accessions into several clusters, as shown in the dendrogram (Figure 4). By applying a Semipartial R-Square threshold of 0.1, the collected accessions are classified into four clusters, as follows:

Cluster I included H243, H240, H237, H234, H373, H366, H258, H368, H255, H361, H252, H365, H235, and H220. These accessions are characterized by high and large pseudostem with a green yellow appearance, long leaf blade and peduncle, rounder bract apex, produce long but fewer fruits. Such accessories are commonly found at midland and highland areas.

Cluster II consisted of accessions H374, H372, H260, H259, H246, H375, H251, H249, H244, H247, H113, H110, H242, H227, H225, H109, H238, H239, H223, H364, H248, H377, H245, H241, H226, H229, H112, H224, and H108. These accessions exhibited a fairly tall and large pseudostem posture, green pseudostem, rather long leaf blade and peduncle, medium bract apex, and rather long fruits. The accessions typically thrive in both midland and highland.

Cluster III consisted of accessions H369, H256, H236, H254, H230, H231, H253, H232, H222, H233, H219, H106, H111, H218, and H105 with characteristics of pseudostem height, leaf blade length, and medium peduncle length, green-red pseudostem color, slightly pointed bract apex shape, quite a lot of number of fruits, and medium fruit length. Most accessions grow in both midland and coastland.

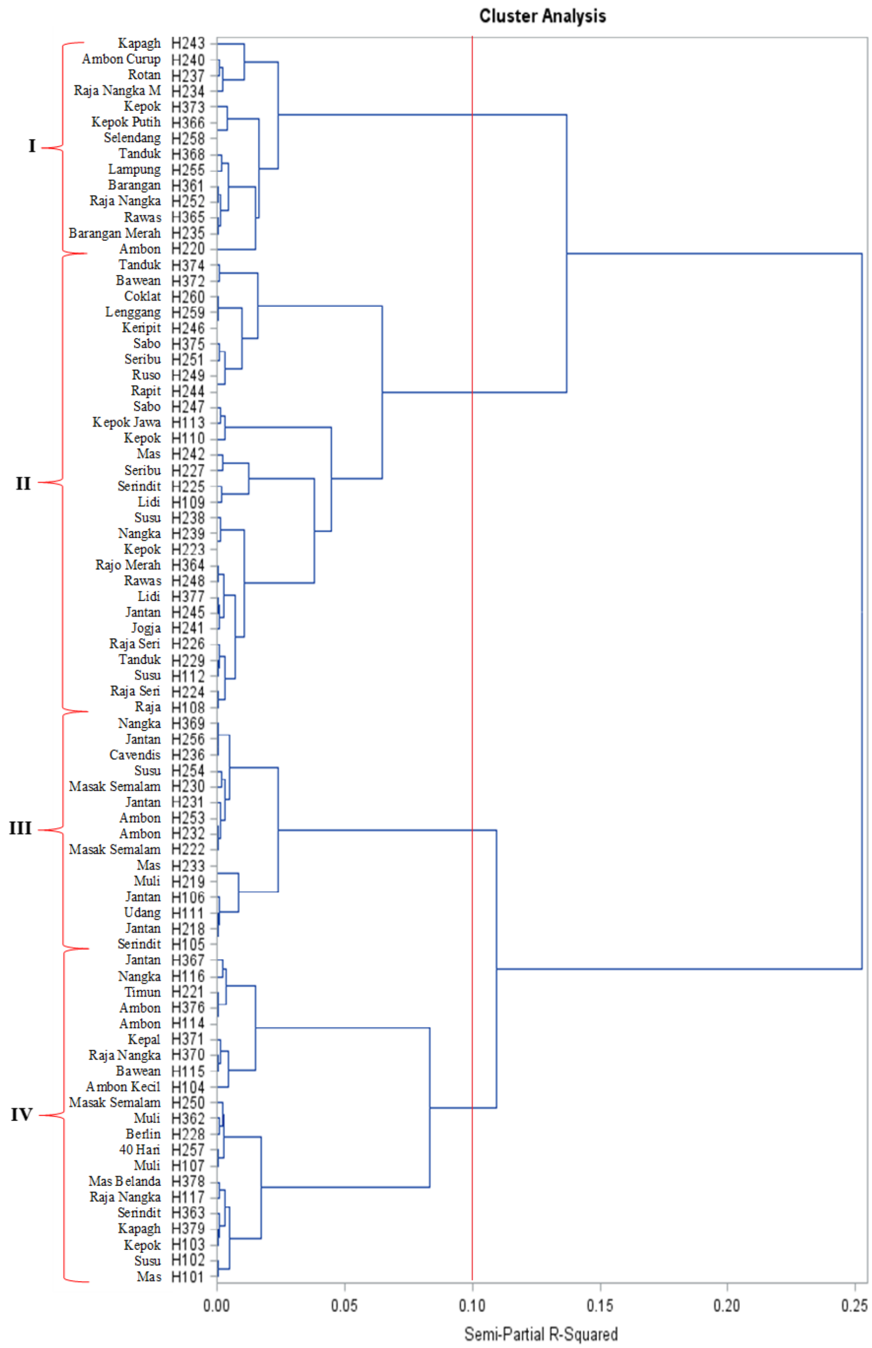

Figure 4. Dendrogram of 79 banana accession generated by Ward's method of cluster analysis on three PCAs

Cluster IV consisted of accessions H367, H116, H221, H376, H114, H371, H370, H115, H104, H250, H362, H228, H257, H107, H378, H117, H363, H379, H103, H102, and H101 with characteristics of shorter pseudostem height, leaf blade length, and peduncle length, red pseudostem color, tapered bract apex shape, many number of fruits, and short fruit length. Accessions grow in coastlands.

Discussion

This study showed that Bengkulu Province has various types of bananas with diverse morphological characteristics and spread across various elevations. Of the 79 accessions collected, variability can be found in plant posture, organ color, and flower and fruit characteristics. Similar findings were also reported by Poerba and Ahmad (2013), Tak *et al*. (2015), Calberto *et al*. (2018), and Zulfahmi *et al*. (2024).

The presence of banana accessions across elevations suggested their remarkable ability to adapt to a wide range of tropical conditions. This adaptability is evident that bananas thrive from coastal regions with elevated temperatures (Hastuti *et al*., 2019; Aeberli *et al*., 2021) to highland regions where temperatures are considerably lower (Hastuti *et al*., 2019). Poor growth of banana plants is only found in several accessions that grow in areas with altitudes above 2,000 meters above sea level, due to very low temperatures (Kamira *et al*., 2016).

The correlation analysis conducted on 13 observed traits indicated that the interrelationships among these traits exhibit a generally low level of association, indicating the independency of performances among the traits. A few exceptions were found on certain pairs of traits having medium correlation, specifically between pseudostem height and leaf blade length, pseudostem height and peduncle length, leaf blade length and peduncle length, as well as pseudostem height and bract apex shape. These observations aligned with the findings reported by Soares *et al*. (2012).

When the observed traits are independent of each other, it is not easy to conceptualize them as a common trait (construct) that is a group of variables that are similar in the information that they provide. As a result, the dimensionality resulting from principal component analysis cannot be reduced to a more simplified dimension (Linting *et al*., 2011; Johnson *et al*., 2023). Principal component analysis of the 13 observed traits also agrees with these notions. The first three principal component axes (PCA) selected can show the distribution pattern of all accessions according to the characteristics of each PCA.

When the observed traits exhibit independence from one another, it becomes challenging to conceptualize them as a unified construct that encompasses a set of variables sharing similar informational content. Consequently, the dimensionality derived from principal component analysis cannot be effectively simplified. This perspective is further supported by the principal component analysis conducted on the 13 observed traits, which indicates that the first three PCAs selected are capable of illustrating the distribution patterns of all accessions based on the characteristics represented by each PCA.

Cluster analysis using three PCA showed that accessions can be categorized into four clusters with unique traits determined by the loadings of PCA. Accessions in cluster I predominantly inhabit high plain habitats, while accessions in cluster II, cluster III, and cluster IV are found at lower elevations. Grouping germplasm accessions based on PCA scores is a widely used method for clustering (Ramli *et al*., 2009; Ramli *et al.,* 2010; Opara *et al*., 2010). The current findings can serve as a guide for managing and conserving the banana germplasm in Bengkulu Province, as well as for their development for various uses. This suggested that more research is required to assess the usefulness of each component of the plant.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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