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Research Paper

MORPHOLOGICAL CHARACTERISTICS AND TOTAL FLAVONOID CONTENT IN PEEL EXTRACTS OF FOUR BANANA CULTIVARS FROM INDONESIA (*Musa* spp.)

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ARTICLE HIGLIGHTS

- Wild banana morphology links to high peel flavonoid content.
- Klutuk banana peel has the highest antioxidant potential.
- Morphological traits can predict nutraceutical value in bananas.
- Banana peel waste is a valuable source of natural antioxidants.
- Conservation of wild germplasm is crucial for bioactive compounds.

Article Information

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ABSTRACT

Banana is a commodity with high genetic diversity in Indonesia, often leading to identification issues due to synonymy and homonymy. Accurate morphological characterization is essential for germplasm management and breeding programs. Concurrently, high consumption of banana generates significant banana peel waste, which is a potential source of bioactive compounds like flavonoids. This study aimed to characterize the morphology of four banana varieties (Cavendish, Kepok, Raja, Klutuk) from the Yogyakarta Banana Germplasm Garden and analyze the total flavonoid content (TFC) in banana peels. Morphological characterization was conducted following the IPGRI descriptor list, and TFC was measured spectrophotometrically and expressed as mg Quercetin Equivalent per gram (mgQE/g). The results revealed distinct morphological profiles for each variety, with the wild-type Klutuk banana exhibiting the tallest pseudostem and seedy fruit. The TFC analysis showed a significant variation, where Klutuk peel had the highest content (0.453 mg QE/g), followed by Kepok (0.386 mg QE/g), Cavendish (0.146 mg QE/g), and Raja (0.139 mg QE/g). The high flavonoid content in the morphologically distinct Klutuk variety suggests a correlation between its wild morphological traits and enhanced production of defensive phytochemicals. These findings underscore the value of morphological data for identifying cultivars with high nutraceutical potential, promoting the utilization of banana peel waste as a source of natural antioxidants.

Keywords: banana peel, germplasm, morphological characteristics, *Musa* spp., TFC

INTRODUCTION

Bananas are crucial economic and food commodity in Indonesia. The country's extensive production and harvest area have established it as a center of banana distribution in Southeast Asia. A key institution for conservation and research is the Yogyakarta Banana Plasma Nutfah Garden, which maintains over 300 banana accessions to support the nation's farmers (Kebun Plasma Nutfah Pisang 2016). However, accurate identification is significantly challenging due to the high genetic diversity of bananas. Problems of synonymy (different cultivars sharing the same name) and homonymy (the same cultivar having different names) are common. Detailed morphological characterization is therefore essential, serving as a primary tool for accurate identification and as a foundation for assembling superior varieties by identifying valuable agronomic traits (Riandini *et al.* 2018).

Alongside its agricultural importance, the banana industry generates substantial waste, with banana peels constituting about 30% of the fruit's weight. Currently, this by-product is underutilized in Indonesia, often discarded or used as animal feed. This represents a missed economic opportunity, as banana peels are a rich source of antioxidant phytochemicals, particularly flavonoids like anthocyanin, delphinidin, and cyanidin (Seymour 1993). Promisingly, peels from popular Indonesian cultivars such as kepok, raja, and klutuk have demonstrated strong antioxidant activity, with IC50 values of 9.702 ppm, 46.86 ppm, and 1.92 μg/mL, respectively (Jami'ah *et al.* 2018; Rahmi *et al.* 2021; Nofianti *et al.* 2021). While the antioxidant potential of banana peels is recognized, the critical link between the morphological identity of a cultivar and the flavonoid content of its peel remains unexplored. Previous studies have treated these aspects in isolation by describing morphology for taxonomy or analyzing peel chemistry without rigorous cultivar-specific morphological data. This has created a knowledge gap where valuable phenotypic markers for high-value biochemical traits are unknown.

Our research directly addresses this gap by integrating detailed morphology with biochemical analysis to investigate a potential correlation. To this end, we selected four commercially significant and genetically distinct cultivars, including the globally dominant Cavendish (AAA), and three locally important Indonesian varieties, Kepok (ABB), raja (AAB), and Klutuk (BB). This selection provides a representative sample across different genomic groups and consumption patterns, enabling a robust comparative analysis to determine if morphological characteristics can serve as visual indicators for a cultivar's nutraceutical potential. Therefore, this study aimed to: 1) perform a detailed morphological characterization of these four banana varieties from the Yogyakarta Banana Plasma Nutfah Garden and 2) analyze the flavonoid content of their peel extracts. The ultimate goal was to determine if a correlative relationship exists, thereby contributing to the better utilization of both Indonesia's banana genetic resources and its agro-industrial waste.

MATERIALS AND METHODS

Morphological Observation of Bananas

Morphological observation was carried out on four 42-day-old banana accessions, including Cavendish, Kepok, Raja, and Klutuk. Each accession consisted of three individuals planted in the Yogyakarta banana germplasm garden area according to the designated planting zones. The tools used included stationery, label paper, and measuring instruments such as rulers, tape measures, and cameras. Morphological observations were carried out following the *Musa* Descriptor List (IPGRI 1996) (Table 1). Qualitative morphological data were presented in descriptive form.

Measurement of Total Flavonoid Levels Equivalent to Quercetin

The measurement of total flavonoids in banana peels was carried out by preparing banana peel samples, producing the banana peel extracts, and determining the total flavonoid content.

Preparation of Banana Peel Samples

Fourteen-week-old bananas were harvested. The peels were separated from the fruits, cleaned, air-dried, and ground using a blender. The resulting peel powder was stored at room temperature.

Making Banana Peel Extract

Banana peel powder was macerated in 96% ethanol (1:1 w/v). The macerate was filtered using a Buchner funnel and concentrated with a rotary evaporator to produce a thick extract, which was stored at 4°C for subsequent total flavonoid content analysis (Uckaya *et al.* 2022).

Total Flavonoid Content (TFC) Levels Equivalent to Quercetin

Banana peel extract samples (100 mg) were dissolved in 100 mL of methanol. Then, 1 mL of the sample solution was mixed with 3 mL of methanol, 0.2 mL of 10% $AlCl_3$, 0.2 mL of potassium acetate, and diluted with distilled water to a final volume of 10 mL. The mixtures were incubated at room temperature in the dark for 30 minutes. Absorbance was measured at a wavelength (λ) of 431 nm. A quercetin standard solution with concentrations ranging from 10 – 50 mg/L was prepared to construct a calibration curve. Total flavonoid content was calculated using the quercetin linear regression equation, $y = ax + b$ (Ahmad *et al.* 2015).

Table 1 Qualitative characters of bananas

No	Character	Subcharacter
1	Leaf habitus	(1) erect; (2) intermediate; (3) drooping; (4) other (e.g., very drooping, specify in descriptor).
2	Pseudostem height (m)	Measured from the base of the pseudostem to where the bunch stalk emerges (1) ≤ 2; (2) 2.1 – 2.9; (3) ≥ 3.
3	Pseudostem aspect/ diameter (cm)	Measured at a pseudostem height of 100 cm (1) slender; (2) normal; (3) robust.
4	Pseudostem color	Observe the color of the pseudostem after one layer of the outer leaf sheath is removed (1) green yellow; (2) medium green; (3) green; (4) dark green; (5) greenish-red; (6) red; (7) reddish-purple; (8) blue; (9) chimerical; (10) other.
5	Pigmentation on the pseudostem	Observe the pigmentation color that appears on the pseudostem (1) pink-purple; (2) red; (3) purple; (4) other.
6	Sap color	Observed on the sliced pseudostem (1) watery; (2) milky; (3) reddish-purple; (4) other.
7	Number of suckers	Number of shoots >30 cm tall on plants that were not desuckered (no desuckering occurred)
8	Blotches at the petiole base	(1) sparse; (2) small; (3) large; (4) extensive; (5) without pigmentation.
9	Blotches color	Observed at the base of the petiole base (1) brown; (2) dark brown; (3) brownish black; (4) blackish purple; (5) other.
10	Petiole canal leaf	The leaf stalk is cut and the cross-section is observed to be (1) open with margins spreading; (2) wide with erect margins; (3) straight with erect margins; (4) margins curved inward; (5) margins overlapping.
11	Leaf blade length (cm)	Measured at the maximum point of leaf length (1) ≤ 170; (2) 171 – 220; (3) 221 –260; (4) ≥ 261.
12	Leaf blade width (cm)	Measured at the maximum point of leaf width (1) ≤ 70; (2) 71 – 80; (3) 81 – 90; (4) ≥ 91.
13	Petiole length (cm)	Measured from the pseudostem to the lamina (1) ≤ 50; (2) 51 – 70; (3) ≥ 71.
14	Color of leaf upper and lower surface	Observed on the upper and lower surfaces of leaves (1) greenish-yellow; (2) medium green; (3) green; (4) dark green; (5) dark green with reddish-purple (presence of large blotches of reddish-purple); (6) blue; (7) other.
15	Wax on leaves (lower surface)	Wax coating (1) very little/no visible sign of wax; (2) few wax; (3) moderately waxy; (4) very waxy.
16	Shape of leaf blade base	(1) both sides rounded; (2) one sided rounded, one side pointed; (3) both sides pointed.
17	Color of midrib dorsal and ventral surface	Observed on the dorsal and ventral surfaces (1) yellow; (2) light green; (3) green; (4) pinkish-purple; (5) reddish-purple; (6) purple to blue; (7) other.
18	Peduncle length (cm)	Measured from the leaf crown to the first hand of fruit (1) ≤ 30; (2) 31 – 60; (3) ≥ 61.
19	Peduncle hairiness	(1) hairless; (2) slightly hairy; (3) very hairy, short hairs; (4) very hairy, long hairs (>2 mm).
20	Bunch position	(1) hanging vertically; (2) slightly angled; (3) hanging at angle 45 ∘ ; (4) horizontal; (5) erect.
21	Rachis position	(1) falling vertically; (2) at an angle; (3) with a curve; (4) horizontal; (5) erect.
22	Male bud type	Observed at harvest time (1) present (normal); (2) degenerating before maturity; (3) absent.
23	Male bud shape	(1) like a top; (2) lanceolate; (3) shape between lanceolate and oval (intermediate); (4) ovoid; (5) rounded.
24	Male bud length (cm)	Measured at harvest at the maximum point of heart length
25	Male bud diameter (cm)	Measured at harvest at the maximum point of heart diameter

No	Character	Subcharacter
26	Bract apex shape	Observed in bracts that are made flat (1) pointed; (2) slightly pointed; (3) intermediate (shaped between slightly sharp and blunt); (4) obtuse; (5) obtuse and split.
27	Color of the bract external face	(1) yellow; (2) green; (3) red; (4) red purple; (5) purple brown; (6) purple; (7) blue; (8) pinkish-purple; (9) orange-red; (10) other.
28	Color of the bract internal face	(1) whitish; (2) yellow or green; (3) orange-red; (4) red; (5) purple; (6) purplish brown; (7) pinkish purple; (8) other.
29	Bract scars on rachis	Observed after the bracts and flowers fall from the racisis (1) prominent; (2) less prominent.
30	Bract base color	Observed on the inside of the bracts (1) the color fades toward the base of the bracts (pigmentation disappears at the base of the bracts; (2) homogeneous color (pigmentation to the base of the bracts).
31	Wax on the bracts	Observed on the outer surface of the bractea (1) very little or none; (2) little; (3) waxy; (4) very waxy.
32	Number of fruits/comb	Observed on the mid-hand of the bunch (1) ≤ 12; (2) 13 – 16; (3) ≥ 17.
33	Fruit length (cm)	Measured as the internal arc of the fruit, without pedicel
34	Fruit shape (longitudinal curvature)	Observed longitudinal curve of the fruit (1) straight; (2) straight at the distal part; (3) curved (sharp curve); (4) 'S' shape; (5) other.
35	Transverse section of fruit	Observed when the fruit is ripe (1) pronounced ridges; (2) slightly ridged; (3) rounded.
36	Fruit apex	Observed on the distal part of the fruit: (1) pointed; (2) lengthily pointed; (3) blunt-tipped; (4) bottle-necked; (5) rounded.
37	Mature fruit peel color	(1) yellow; (2) bright yellow; (3) orange; (4) grey spots; (5) brown/rusty-brown; (6) orange-red, red or pink/pinkish-purple; (7) reddish-purple; (8) black; (9) other.
38	Fruit flesh color	The color was observed
39	Presence of seed	(1)< 5; (2) 5 – 20; (3) >20.

Source: IPGRI (1996).

RESULTS AND DISCUSSION

Morphological Characterization Description

The exploration of genetic resources as an effort for plant improvement requires characterization of diversity as fundamental prerequisites. Currently, banana characterization is primarily based on morphological traits. Through plant morphology, the external form and organs of the plant can be observed, which allow visual differentiation among banana plant species. Morphological characters reflect the expression of an individual genetic traits.

Genes affect physiological processes in plants by regulating enzyme synthesis and the formation of compounds that support plant growth and development (Taiz *et al.* 2006). However, the observation of morphological characters often leads to confusion in classification because these traits are strongly influenced by environmental factors.

The parts of the plant body most susceptible to morphological changes due to environmental influences include leaves, stems, and flowers. In banana plants, these traits are described using detailed banana descriptors. Morphological characterization of banana plants is essential to support the development and selection of superior banana varieties (Lukmanasari *et al.* 2023). Previous studies have shown that morphological descriptors such as pseudostem color and blotching, leaf orientation, pseudostem diameter, and fruit number are highly effective in distinguishing *Musa* cultivars. These traits demonstrate high heritability and repeatability, making them reliable for classification. This is consistent with findings published in Genetic Resources and Crop Evolution, which reported that quantitative morphological traits, including pseudostem girth, number of fruits, and fruit size, exhibit high heritability (> 0.8) and high repeatability (> 2.0), underscoring their value in cultivar differentiation. Such traits are particularly useful for breeding programs and germplasm characterization, as they serve as consistent markers for identifying and classifying banana varieties (Ortiz 1997).

Cluster analysis of bananas in East Java classified local cultivars based on 15 qualitative and 9 quantitative morphological traits, including the number of hands per bunch, pseudostem diameter, and petiole length. These morphological variations demonstrate strong potential for supporting future breeding programs (Sa'diyah *et al.* 2025). Furthermore, ecogeographic characterization of *Musa* germplasm in Ecuador revealed that morphological descriptors of the pseudostem, leaves, flowers, bunches, and fruit play a key role in discriminating elite *Musa* accessions (Poaquiza *et al.* 2025).

Morphological characters vary between individuals and are expressed through their phenotypic appearance. Phenotype results from the interaction between genotype and environment, with the environment playing a crucial role in shaping variation, particularly in morphological traits. Individuals of the same species may exhibit different phenotypes if they grow in different habitats. Phenotypic plasticity explains why individuals with the same genetic composition can differ morphologically under varying environmental conditions. Therefore, observing morphological characters is an essential first step in assessing genetic diversity. Germplasm exhibits high variation and serves as a valuable source of genes for desirable plant traits, such as pest resistance and high productivity.

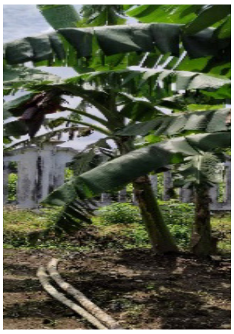
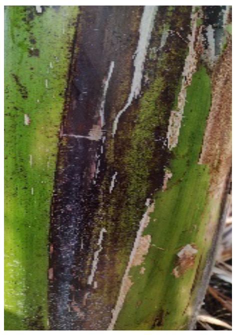
Plants within the same group, when used as cross-breeding parents, tend to produce offspring with low genetic variation, whereas crosses between different groups result in higher variation (Lukmanasari *et al.* 2023). The influence of genotype and environment is reflected in the phenotypic diversity observed within a generation. Descriptive data for each banana variety are presented below. Qualitative characterization of Cavendish, Kepok, Raja, and Klutuk bananas is shown in Table 2, based on IPGRI qualitative trait observations. The morphological differences among these four banana varieties are summarized in Table 3.

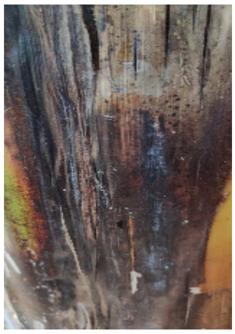
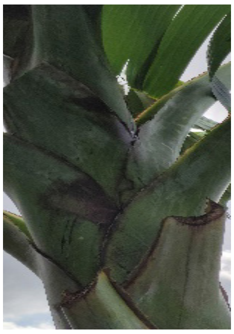
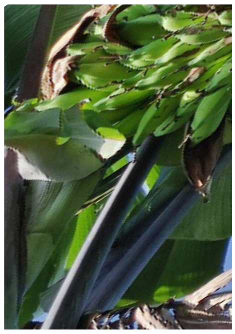
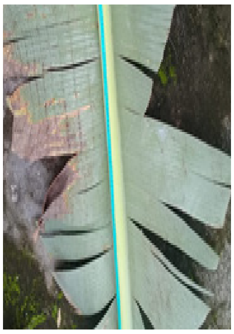
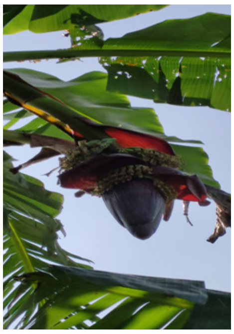
Table 2 Qualitative characterization of Cavendish, Kepok, Raja, and Klutuk banana

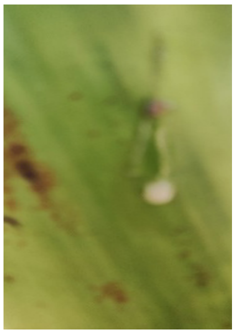
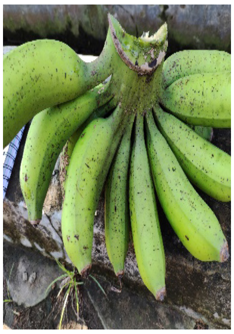
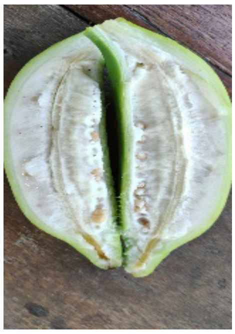
No	Characteristics	Cavendish	Kepok	Raja	Klutuk
1	Leaf habitus	Intermediate	Intermediate	Intermediate	Erect
2	Pseudostem height (m)	2.45	3.3	2.4	5.34
3	Pseudostem aspect/ diameter (cm)	52	65	39	84
4	Pseudostem color	Reddish purple	Dark green	Red	Dark green
5	Pigmentation on the pseudostem	Dark purple brown	Reddish brown	Purple	Black
6	Sap color	Watery	Watery	Milky	Milky
7	Number of suckers	4	2	3	7
8	Blotches at the petiole base	Large	Small	Large	Extensive
9	Blotches color	Black	Black	Black	Black
10	Petiole canal leaf	Wide with erect margins	Straight with erect margins	Margins curved inward	Margins curve inward
11	Leaf blade length (cm)	247	330	178	248
12	Leaf blade width (cm)	87	65.5	64	68
13	Petiole length (cm)	24.5	35.5	40	48.5
14	Color of leaf upper surface	Green	Light green	Yellowish green	Dark green
15	Color of leaf lower surface	Light green	Dark green	Green	Light green
16	Wax coating on the underside of the leaf	Waxy	Few waxy	Few waxy	Waxy
17	Shape of leaf blade base	Both sides pointed	Both sides rounded	Both sides rounded	Both sides rounded
18	Color of midrib dorsal and ventral surface	Yellowish green (dorsal and ventral)	Green (dorsal) light green (ventral)	Light green (dorsal and ventral)	Light yellowish green (dorsal) dark purple brown (ventral)
19	Peduncle length (cm)	12	16	16	29
20	Peduncle hairiness	Slightly hairy	Hairless	Hairless	Hairless

No	Characteristics	Cavendish	Kepok	Raja	Klutuk
21	Bunch position	Hanging vertically	Hanging at angle 45 °	Hanging at angle 45 °	Hanging at angle 45 °
22	Rachis position	Falling vertically	Falling vertically	Falling vertically	At an angle
23	Male bud type	Present (normal)	Present (normal)	Present (normal)	Present (normal)
24	Male bud shape	Intermediate	Ovoid	Ovoid	Ovoid
25	Male bud length (cm)	25.4	38.5	27	21
26	Male bud diameter (cm)	30	41.5	8	23
27	Bract apex shape	Slightly pointed	Intermediate	Obtuse	Obtuse
28	Color of the bract external face	Purple brown	Pink purple	Dark red	Pinkish red
29	Color of the bract internal face	Red purple	Purple brown	Purple	Purple
30	Bract scars on rachis	Prominent	Prominent	Less prominent	Not prominent
31	Bract base color	Fading	Homogeneous	Homogeneous	homogeneous
32	Wax on the bracts	A little waxy	A little waxy	Waxy	Very waxy
33	Number of fruits/comb	22	14	14	12
34	Fruit length (cm)	17.2	18.2	14	15
35	Fruit shape (longitudinal curvature)	Curved	Straight	Curved	Straight
36	Transverse section of fruit	Rounded	Pronounced ridges	Pronounced ridges	Slightly ridged
37	Fruit apex color	Blunt	Blunt	Blunt	Blunt
38	Mature fruit peel	Yellowish green	Yellow	Green	Green
39	Fruit flesh color	Light yellow	Light yellow cream	White	White
40	Presence of seed	Seedless	Seedless	Seedless	120 with rounded seed shape

Table 3 Morphology of Cavendish, Kepok, Raja, and Klutuk bananas

Morphology	Cavendish	Kepok	Raja	Klutuk
Plant habitus				
Pseudostem color				

Morphology	Cavendish	Kepok	Raja	Klutuk
Pseudo-rod pigmentation				
Spots on leaf stalks				
Shape of Leaf blade base				
Rachis position				
Male bud				

Morphology	Cavendish	Kepok	Raja	Klutuk
Sap color				
Fruit shape				

Comparative morphological analysis of the four banana varieties reveals a range of traits shaped by their distinct genetic backgrounds and evolutionary histories. While all four varieties share the fundamental monocot architecture, including a succulent pseudostem and inflorescences that develop into fruit bunches, they can be grouped based on key reproductive traits. Cavendish, Kepok, and Raja bananas are predominantly seedless, a characteristic associated with domestication, whereas Klutuk bananas produce seedy fruit, reflecting their wild ancestry (Heslop-Harrison *et al.* 2007; Perrier *et al.* 2011).

The unique combination of characteristics for each variety is as follows: Cavendish (AAA) is characterized by a short pseudostem (2 – 2.5 m) and is optimized for commercial production. Its fruits have a thick, yellow peel resistant to bruising, yellowish-white flesh, and a sweet, slightly tangy flavor, making it a preferred dessert banana for direct consumption. Kepok (ABB), with an intermediate pseudostem height of approximately 3 m, is distinguished by its angular, flat fruits with prominent ridges. Classified as a plantain, Kepok bananas are typically processed before consumption, reflecting their high starch content (Anggitha 2022). Raja (AAB) has a pseudostem height similar to that of Cavendish and is distinguished by its plump, round fruits. It is primarily valued as a dessert banana for direct consumption due to its sweet flavor and soft texture. Klutuk (BB) is the most morphologically distinct variety, possessing the tallest pseudostem (5 – 7 m), consistent with findings by Hastuti *et al.* (2019), and producing small, seedy fruits. Its morphology, including hard seeds and robust structure, reflects adaptations for survival in the wild, and its primary uses are in traditional cuisine and medicine rather than fresh dessert consumption (Anggitha 2022; Simmonds 1953).

These morphological differences are fundamentally shaped by genetics and environmental adaptation (De Langhe *et al.* 2009). The seedless, large-fruited traits of Cavendish, Kepok, and Raja bananas result directly from human selection for triploid genotypes, which promote parthenocarpy and vegetative propagation, the key advantages for cultivation (Heslop-Harrison *et al.* 2007).

Cavendish bananas, for example, have been intensively selected for traits such as thick skin to withstand transportation. In contrast, Klutuk bananas are predominantly diploid (BB), a genetic constitution closer to their wild ancestor (*Musa balbisiana*), which allows sexual reproduction via seeds (Simmonds 1953). This explains their taller stature and seedy fruits—adaptations for natural seed dispersal and environmental resilience—traits largely eliminated in commercial cultivars (Simmonds *et al.* 1955). Thus, the observed morphological spectrum from the wild-adapted

Klutuk to the commercially optimized Cavendish reflects the journey of banana domestication (Perrier *et al.* 2011).

Total Flavonoid Contents (TFC) Analysis

The significant morphological and genetic variations among the four cultivars suggests a parallel divergence in their biochemical makeup. This is particularly relevant given that banana peels have been widely used in traditional medicine to treat various ailments, a practice attributed to their high content of phenolic compounds, including flavonoids, which act as primary antioxidants (Pereira *et al.* 2015; Anjum *et al.* 2022). The phenolic content in banana peels is notably high, often exceeding that of the fruit pulp, and is strongly correlated with antioxidant efficacy (Ramli *et al.* 2012; Oyeyinka 2020). Therefore, we hypothesized that the distinct, wild-adapted morphology of the Klutuk banana would be linked to a heightened production of these defense-related flavonoids compared to the more domesticated varieties. This hypothesis was tested by quantifying the total flavonoid content (TFC), with the results presented in Table 4.

Table 4 TFC content of banana peel extract

Banana peel sample	Total flavonoid content (mgQE/g)
Cavendish	0.146 ± 0.0020
Kepok	0.386 ± 0.0148
Raja	0.139 ± 0.0053
Klutuk	0.453 ± 0.0078

Based on the information above, the extract of Klutuk banana peel contains the highest total flavonoids (0.453 mg QE/g) when compared to the other three varieties, followed by Kepok banana peel (0.386 mg QE/g), Cavendish banana peel (0.146 mg QE/g), and Raja banana peel (0.139 mg QE/g). The detailed composition of flavonoid compounds has been reported in previous studies, although data are limited to certain banana varieties. For example, banana peel of the Red Yade banana (AAB), which shares the same genome as plantain (AAB), contains flavonoid compounds from the flavonols group, including rutin (482 ± 206 μg/g DM), quercetin deoxyhexose-hexoside (75.2 ± 14 μg/g DM), kaempferol-deohyhexosa-hexoside (35.5 ± 4 μg/g DM), kaempferol-3-rutinoside (173.9 ± 50 μg/g DM), isorhamnetin-3-rutinoside (139 ± 73 μg/g DM), and myricetin-deoxyhexose-hexoside (114 ± 27 μg/g DM) (Valérie *et al.* 2015).

The data reveal a clear gradient in flavonoid content that corresponds with the morphological and genetic differences among the varieties. Klutuk banana peel extract (BB) contained the highest total flavonoid content (TFC) at 0.453 mg QE/g, followed by Kepok (ABB) at 0.386 mg QE/g. In contrast, the highly domesticated dessert bananas, Cavendish (AAA) and Raja (AAB), exhibited significantly lower levels. This pattern supports the notion that Klutuk bananas, being closely related to wild species, synthesize higher levels of bioactive compounds as part of their natural defense mechanisms, a trait partially retained in the hardy, plantain-type Kepok (Nofianti *et al.* 2021; Lestari 2020).

The detailed composition of banana peel flavonoids has been elucidated in various studies. For example, peels from plantain-type bananas (AAB) contain flavonols such as rutin and quercetin derivatives (Valérie *et al.* 2015), whereas Cavendish peels (AAA) contain specific flavonols, including quercetin-3-rutinoside, and flavan-3-ols such as gallocatechin (Rebello *et al.* 2014; Someya *et al.* 2002). It is important to note that absolute flavonoid content can be influenced by factors such as extraction method, fruit ripeness, and growing environment (González-Montelongo *et al.* 2010; Ramli *et al.* 2012; Vu *et al.* 2018). However, the consistent trends observed across the genetically distinct cultivars in this study suggest that genome group, along with its associated morphological adaptations, is a key determinant of flavonoid production potential in banana peels.

CONCLUSION

This study demonstrated a clear correlation between morphology, genetics, and flavonoid content in four banana cultivars. A distinct phenotypic gradient was observed, ranging from the highly domesticated, seedless Cavendish (AAA) and Raja (AAB) to the wild-adapted Klutuk (BB), characterized by a tall pseudostem and seedy fruits. This gradient corresponded closely with the phytochemical data: Klutuk peel exhibited the highest flavonoid content, followed by Kepok (ABB), while the dessert bananas showed significantly lower levels. These results confirm that wild-type cultivars allocate more resources to defensive flavonoids. Consequently, morphological traits provide a valuable preliminary indicator of a cultivar's nutraceutical potential. The findings underscore the importance of conserving wild germplasm, such as Klutuk, and offer a scientific basis for the targeted utilization of banana peel waste as a source of natural antioxidants.

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REFERENCES

Ahmad AR, Juwita J, Ratulangi SAD. 2015. Penetapan kadar fenolik dan flavonoid total ekstrak metanol buah dan daun patikala (Etlingera elatior (Jack) R.M.SM) [Determination of total phenolic and flavonoid content in methanol extracts of fruit and leaves of patikala (Etlingera elatior (Jack) R.M.Sm]. PSR 2:1–10. DOI: 10.7454/psr.v2i1.3481

Anggitha M. 2022. Pembuktian aktivitas antidiare pucuk merah jambu biji dan daging buah pisang Klutuk yang digunakan battra Desa Jayaratu Singaparna [Proving the antidiarrheal activity of pink shoots and pulp of Klutuk bananas used by battra in Jayaratu Village Singaparna]. [Undergraduate Thesis]. Tasikmalaya (ID): Universitas Bakti Tunas Husada.

Anjum S, Sundaram S, Rai GK. 2022. Nutraceutical application and value addition of banana (*Musa* paradisiaca L. variety "Bhusawal Keli") peel. Int J Pharm Pharm Sci 14(2):14–20. DOI: 10.22159/ijpps.2022v14i2.43211

De Langhe E, Vrydaghs L, De Maret P, Perrier X, Denham T. 2009. An introducation to the history of banana domestication. Ethnobot Res Appl 7:165–77.

González-Montelongo R, Gloria Lobo M, González M. 2010. Antioxidant activity in banana peel extracts: Testing extraction conditions and related bioactive compounds. J Food Chem 119(3):1030–39. DOI: 10.1016/j.foodchem.2009.08.012

Hastuti, Purnomo, Sumardi I, Daryono BS. 2019. Diversity wild banana species (*Musa* spp.) in Sulawesi, Indonesia. Biodiversitas 20(3):824–32. DOI: 10.13057/biodiv/d200328

Heslop-Harrison JS, Schwarzacher T. 2007. Domestication, genomics and the future for banana. Ann Bot 100(5):1073–84. DOI: 10.1093/aob/mcm191

[IPGRI] International Plant Genetic Resources Institute. 1996. Descriptors for Banana. Italia (IT): International Plant Genetic Resources Institute.

Jami'ah SR, Ifaya M, Pusmarani J, Nurhikma E. 2018. Uji aktivitas antioksidan ekstrak metanol kulit pisang raja (*Musa* paradisiaca var. sapientum) dengan metode DPPH (2,2-Difenil-1-Pikrilhidrazil) [Antioxidant activity test of methanol extract of raja banana peel (*Musa* paradisiaca var. sapientum) using the DPPH Method (2,2-Difenil-1-Pikrilhidrazil)]. J Mandala Pharmacon Indonesia 4(1):33–8. DOI: 10.35311/jmpi.v4i1.22

Kebun Plasma Nutfah Pisang. 2016. Daftar koleksi pisang di kebun plasma nutfah pisang [List of banana collections at the banana germplasm garden]. Yogyakarta (ID): Kebun Plasma Nutfah Pisang Yogyakarta.

Lestari S. 2020. Penetapan kadar flavonoid total ekstrak etanol kulit pisang kepok (*Musa* acuminata x balbisiana) dengan metode spektrofotometri Uv-Vis [Determination of total flavonoid content of ethanol extract of kepok banana peel (*Musa* acuminata x balbisiana) using Uv-Vis spectrophotometry method]. [Undergraduate Thesis] Solo (ID): STIKES Nasional.

Lukmanasari P, Hardi NA, Akbar D. 2023. Karakterisasi morfologi varietas pisang di Kabupaten Kampar Provinsi Riau [Morphological characterization of banana varieties in Kampar Regency, Riau Province]. Vegetalika 12(1):76–90. DOI: 10.22146/veg.79546

Nofianti T, Muhtadi A, Fidrianny I. 2021. Comparison of antihyperglycemic activity of different parts of klutuk banana (*Musa* balbisiana colla). Int J Appl Pharm 13(Special Issue 3):57–61. DOI: 10.22159/IJAP.2021.V13S3.12

Ortiz R. 1997. Morphological variation in *Musa* germplasm. Genet Resour Crop Evol 44:393–404.

Oyeyinka BO, Afolayan AJ. 2020. Comparative and correlational evaluation of the phytochemical constituents and antioxidant activity of *Musa* sinensis L. and *Musa* paradisiaca L. fruit compartments (*Musa*ceae). Sci World J 6:4503824. DOI: 10.1155/2020/4503824

Pereira A, Maraschin M. 2015. Banana (*Musa* spp.) from peel to pulp : Ethnopharmacology, source of bioactive compounds and its relevance for human health. J Ethnopharmacol 160:149–63. DOI: 10.1016/j.jep.2014.11.008

Perrier X, De Langhe E, Donohue M, Lentfer C, Vrydaghs L, Bakry F, Denham T. 2011. Multidisciplinary perspectives on (*Musa* spp.) domestication. Proceedings of the National Academy of Sciences of the United States of America 108(28):11311–18. DOI: 10.1073/pnas.1102001108

Poaquiza NA, Vásconez RA, Tandazo LL, Monteros-altamirano Á, Bastidas CT, Franklin SM, …, Andrade NP. 2025. The morphological and ecogeographic characterization of the *Musa* L . collection in the gene bank of INIAP, Ecuador. Crops 5(3):34. DOI: 10.3390/crops5030034

Rahmi A, Hardi N, Linda H. 2021. Aktivitas antioksidan ekstrak kulit pisang kepok, pisang mas, dan pisang nangka menggunakan metode DPPH [Antioxidant activity of kepok banana, mas banana, and jackfruit banana peel extracts using the DPPH method]. Jurnal Ilmu Farmasi dan Farmasi Klinik 18(2):77–84.

Ramli S, Alkarkhi AFM. 2012. Total phenolics, flavonoids and antioxidant activity of banana pulp and peel flours: Influence of variety and stage of ripeness. Int Food Res J 19(3):1041–46.

Rebello LPG, Ramos AM, Pertuzatti PB, Barcia MT, Castillo-Muñoz N, Hermosín-Gutiérrez I. 2014. Flour of banana (*Musa* AAA) peel as a source of antioxidant phenolic compounds. Food Res Int 55:397–403. DOI: 10.1016/j.foodres.2013.11.039

Riandini E, Nur F, Setiawan MR. 2018. Keanekaragaman dan hubungan kekerabatan pisang (*Musa*ceae) di Kota Bengkulu, Provinsi Bengkulu [Diversity and relationships of bananas (*Musa*ceae) in Bengkulu City, Bengkulu Province]. J Biota 11(2):123–35. DOI: 10.20414/jb.v11i2.140

Sa'diyah H, Vega KS, Riza YR, Achmad CK. 2025. Cluster analysis to explore morphological variation of banana (*Musa* spp.): A case study in Jember and Lumajang, East Java, Indonesia. Jurnal Kultivasi 24(1):47–58.

Sariamanah, Wa Ode S, Munir A, Agriansyah A. 2016. Karakterisasi morfologi tanaman pisang (*Musa* paradisiaca L.) di Kelurahan Tobimeita Kecamatan Abeli Kota Kendari [Morphological characterization of banana plants (*Musa* paradisiaca L.) in Tobimeita Village, Abeli District, Kendari City]. J Ampibi 1(3):32–41. DOI: 10.36709/ampibi.v1i3.5043

Seymour GB. 1993. Biochemistry of fruit ripening. London (UK): Chapman and Hall. p. 95–8.

Simmonds NW. 1953. The evolution of the bananas. Trop Agric 30:187–91.

Simmonds NW, Shepherd K. 1955. The taxonomy and origins of the cultivated banana. J Linnean Soc London Bot 55(359):302–12.

Someya S, Yoshiki Y, Okubo K. 2002. Antioxidant compounds from bananas (*Musa* cavendish). Food Chem 79(3):351–54. DOI: 10.1016/S0308-8146(02)00186-3

Taiz L, Zeiger E. 2006. Plant physiology. 4th Edition. Sunderland (US): Sinauer Associates, Inc.

Uckaya F, Uckaya M. 2022. Formulation and evaluation of anti aging cream using banana peel extract. IJPSR 13(1):181–91. DOI: 10.13040/IJPSR.0975-8232.13(1).181-91

Valérie C, Tsamo P, Herent M, Tomekpe K, Happi T, Quetin-leclercq J, Andre C. 2015. Phenolic profiling in the pulp and peel of nine plantain cultivars (*Musa* sp.). Food Chem 167:197–204. DOI: 10.1016/j.foodchem.2014.06.095

Vu HT, Scarlett CJ, Vuong QV. 2018. Phenolic compounds within banana peel and their potential uses: A review. J Funct Foods 40:238–48. DOI: 10.1016/j.jff.2017.11.006