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## Relationship between fruit morphological characteristics and banana flour phytochemistry

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**Abstract** Assessing the similarity between the phytochemical traits of banana flour and the its fruit morphological characteristics would streamline the complex process of chemical identification. The findings showed a close relationship between protein content and peduncle length ( $r = -0.46$ ), antioxidant activity and bract external color ( $r = -0.40$ ), and protein content and immature fruit peel color ( $r = -0.46$ ). Furthermore, the canonical correlation analysis indicated that the aggregate relationship between fruit morphological characteristics and flour phytochemical properties can be represented by the first canonical correlation ( $r = 0.92$ ) with the proportion eigenvalue accounted for 58% of the overall variation. The peduncle length, bract external color, and remains of flower were the most prominent variables in delineating the overall fruit morphological characteristics with  $r = 0.45$ ,  $-0.59$ , and  $-0.45$ , respectively, whilst the protein content served as the most representative variable for the flour phytochemical properties with  $r = -0.57$ . Therefore, it can be concluded that the flour phytochemical properties of banana fruit, especially protein content, can be estimated from its morphological appearance of the peduncle length, bract external color, and remains of flower.

**Keywords:** Antioxidant activity, Functional food, Phytochemical properties, Protein, Vitamin

### Introduction

Bananas are widely consumed worldwide, including in Indonesia, due to their sweet taste, soft texture, and rich nutritional content. In addition to carbohydrates, bananas contain high levels of protein, vitamin A, vitamin B1, vitamin B2, vitamin C, and dietary fiber (Ranjha *et al.*, 2022), and have a low glycemic index ( $GI < 55$ ) (Vatanasuchart *et al.*, 2015). Therefore, consuming bananas can improve digestion, help control blood sugar levels, and maintain heart health (Anyasi *et al.*, 2013; Afzal *et al.*, 2022).

Besides being consumed fresh, bananas can be made into flour, a raw material for various processed products such as chips, cookies, bakery products,

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and other processed products. Banana flour is high in fiber, high in carbohydrates and starch, and low in sugar (Campuzano *et al.*, 2018; Ahmed *et al.*, 2020) and is gluten-free (Campuzano *et al.*, 2018). Furthermore, banana flour also contains vitamin C, protein, and fat, and has antioxidant activity (Chang *et al.*, 2022). With these phytochemical characteristics, banana flour can be used as a functional food ingredient that is excellent for consumption by people with diabetes, hypertension, and celiac disease (Ayo-Omogie and Odekunle, 2017; Essa *et al.*, 2023). It is even very suitable as a raw material for infant and young children's food (Borbi *et al.*, 2020).

The phytochemical content of banana flour varies widely, depending on the type of plant and where it is grown (Elayabalan *et al.*, 2017) and measuring it requires complex, expensive laboratory procedures and specialized expertise (Vagare *et al.*, 2025). These barriers can be resolved if the identification of the flour's phytochemical characteristics can be assessed through the morphological characteristics of the fruit, including its shape, size, skin color, and texture.

Correlation analysis, both univariate and multivariate, is a useful statistical method for estimating the degree of association between variables. Univariate correlation analyzes the degree of association between a pair of single variables, while multivariate correlation examines the association between multiple variables simultaneously (Saccenti, 2014). Using these statistical methods, the phytochemical content of banana flour can be estimated by measuring its fruit morphological characteristics. However, to date, there has been little research on the relationship between fruit morphological characteristics and banana flour phytochemicals. The study aimed to estimate the degree of relatedness between the phytochemical content of banana flour and the morphological characteristics of the fruit.

## **Materials and methods**

The germplasm exploratory survey was conducted from May 2025 to June 2025 to collect data on fruit morphological characteristics of banana that grew in Bengkulu Province. The observations were made on the fruits at the physiological maturity phase from 29 accessions. The collected fruit, then, thinly sliced, dried, and floured. The laboratory analysis was performed from July 2025 to August 2025 to measure the phytochemical content of the flour. Using banana descriptor from IPGRI (1996), the following 15 morphological characteristics were measured, namely peduncle length ( $X_1$ ), male bud shape ( $X_2$ ), bract apex shape ( $X_3$ ), bract external color ( $X_4$ ), style shape ( $X_5$ ), fruit position ( $X_6$ ), number of fruits ( $X_7$ ), fruit length ( $X_8$ ), fruit shape ( $X_9$ ), fruit apex ( $X_{10}$ ), remains of flower at fruit ( $X_{11}$ ), pedicel surface ( $X_{12}$ ), immature fruit peel color

(X13), mature fruit peel colour (X14), pulp colour at maturity (X15). Similarly, there were 5 phytochemical characteristics measured, including vitamin C content (Y1), fiber content (Y2), fat content (Y3), protein content (Y4), and antioxidant activity (Y5). The degree of association between fruit morphological traits and flour phytochemical content was determined univariately and multivariately through simple correlation and canonical correlation analyses, respectively using Proc CORR and Proc CANCORR in SAS V9.4 software (SAS Institute Inc., Cary, N.C.).

## Results

### *General performances*

The overall performances of phytochemistry and morphology of collected banana accessions are presented in Table 1. It can be highlighted that all accessions contained nutrients that are good for human health, as indicated by the observed phytochemical characteristics, especially with high antioxidant content. Furthermore, the accession were commonly also had relatively wide variation in the fruit morphological performances, to provide a wider choice.

**Table 1.** Summary statistics of phytochemistry and morphological characteristics of banana accessions

| Characteristics                    | Minimum | Maximum | Mean   | Mode  |
|------------------------------------|---------|---------|--------|-------|
| <b><i>Fruit Morphology</i></b>     |         |         |        |       |
| Peduncle length                    | 32.00   | 110.00  | 58.84  | 42.00 |
| Male bud shape                     | 1.00    | 5.00    | 3.36   | 4.00  |
| Bract apex shape                   | 1.00    | 5.00    | 3.04   | 2.00  |
| Bract external color               | 1.00    | 8.00    | 4.88   | 4.00  |
| Style shape                        | 1.00    | 5.00    | 1.44   | 1.00  |
| Fruit position                     | 1.00    | 4.00    | 2.88   | 4.00  |
| Number of fruits                   | 10.00   | 24.00   | 15.00  | 18.00 |
| Fruit length                       | 10.00   | 23.00   | 14.44  | 11.00 |
| Fruit shape                        | 1.00    | 5.00    | 1.88   | 1.00  |
| Fruit apex                         | 1.00    | 5.00    | 2.64   | 2.00  |
| Remains of flower at fruit         | 1.00    | 3.00    | 2.08   | 3.00  |
| Pedicle surface                    | 1.00    | 2.00    | 1.32   | 1.00  |
| Immature fruit peel color          | 2.00    | 6.00    | 3.32   | 2.00  |
| Mature fruit peel color            | 1.00    | 9.00    | 2.80   | 1.00  |
| Pulp colour at maturity            | 1.00    | 4.00    | 2.64   | 2.00  |
| <b><i>Flour Phytochemistry</i></b> |         |         |        |       |
| Vitamin C content (%)              | 6.01    | 6.98    | 6.42   | 6.39  |
| Fiber content (%)                  | 1.90    | 5.01    | 2.75   | 2.55  |
| Fat content (%)                    | 0.35    | 1.10    | 0.58   | -     |
| Protein content (%)                | 1.43    | 3.49    | 2.04   | 1.73  |
| Antioxidant activity (ppm)         | 92.16   | 179.07  | 132.77 | -     |

### Simple correlation

The results of the simple correlation analysis showed varying degrees of correlation between the morphological characteristics of the fruit and the phytochemical characteristics of the resulting flour (Table 2). In general, the morphological characteristics of the fruit and the phytochemical characteristics of the banana flour had a low correlation, except for the pairs of protein content and stalk length ( $r = -0.46$ ), antioxidant activity and outer bract color ( $r = -0.40$ ), and protein content and young fruit skin color ( $r = -0.46$ ). This implies that the longer the banana stalk, the lower the protein content of the flour, the darker the outer bract color, the lower the antioxidant activity, and the greener/darker the young skin color, the lower the protein content of the flour.

**Table 2.** Correlation coefficients ( $r$ ) of flour phytochemical and fruit morphological characteristics of banana

| Character                  | Vitamin C<br>content<br>(%) | Fiber<br>content<br>(%) | Fat<br>content<br>(%) | Protein<br>content<br>(%) | Anti-<br>oxidant<br>activity<br>(ppm) |
|----------------------------|-----------------------------|-------------------------|-----------------------|---------------------------|---------------------------------------|
| Peduncle length            | 0,39                        | 0,17                    | -0,22                 | <b>-0,46</b>              | -0,01                                 |
| Male bud shape             | 0,22                        | 0,28                    | -0,02                 | -0,11                     | 0,04                                  |
| Bract apex shape           | 0,02                        | -0,18                   | -0,35                 | -0,32                     | 0,15                                  |
| Bract external color       | 0,23                        | 0,11                    | 0,04                  | 0,26                      | <b>-0,40</b>                          |
| Style shape                | -0,01                       | -0,01                   | -0,08                 | -0,08                     | 0,07                                  |
| Fruit position             | -0,17                       | -0,24                   | -0,02                 | -0,22                     | 0,29                                  |
| Number of fruits           | 0,24                        | 0,19                    | -0,02                 | -0,08                     | -0,20                                 |
| Fruit length               | 0,33                        | 0,17                    | 0,08                  | -0,15                     | 0,11                                  |
| Fruit shape                | 0,39                        | 0,10                    | 0,26                  | -0,15                     | -0,15                                 |
| Fruit apex                 | -0,14                       | 0,24                    | -0,03                 | 0,16                      | -0,25                                 |
| Remains of flower at fruit | 0,05                        | 0,23                    | 0,20                  | 0,39                      | -0,22                                 |
| Pedicel surface            | -0,32                       | -0,02                   | -0,01                 | 0,34                      | 0,15                                  |
| Immature fruit peel color  | 0,34                        | -0,27                   | -0,27                 | <b>-0,46</b>              | -0,08                                 |
| Mature fruit peel color    | 0,16                        | 0,11                    | 0,28                  | 0,04                      | 0,04                                  |
| Pulp colour at maturity    | -0,04                       | 0,34                    | 0,18                  | 0,13                      | 0,12                                  |

Coefficients greater than 0.35 are shown in bold format

### Canonical correlation

The canonical correlation coefficients  $r_k$  ( $k = 1 \dots 5$ ) resulted from the analysis are listed in Table 3. The first canonical correlation ( $r_1$ ) between fruit morphological characteristics construct (*MorphologyI*) and flour phytochemical properties construct (*PhytochemistryI*) was evidently strong, since  $r_1 = 0.92$ . Thus, at first sight at least,  $r_1$  is certainly suggestive of the existence of linear relationship between banana fruit morphological characteristics and its flour

phytochemistry. The strength  $r_1$  shows that only this set has the most dominant relationship compared to the other sets, as indicated by its proportion to total correlation up to 58%. Thereafter, the  $r_k$  ( $k>1$ ) decline in the rather systematic way until the smallest,  $r_5 = 0.54$ .

**Table 3.** Canonical correlation analysis of flour phytochemical and fruit morphological characteristics of banana

| $k$ | Canonical Correlation ( $r_k$ ) | Squared Canonical Correlation ( $r^2$ ) | Eigenvalue | Proportion | Cumulative | Likelihood ratio |
|-----|---------------------------------|-----------------------------------------|------------|------------|------------|------------------|
| 1   | 0.92                            | 0.85                                    | 56.74      | 0.58       | 0.58       | 0.01             |
| 2   | 0.78                            | 0.61                                    | 15.59      | 0.16       | 0.74       | 0.07             |
| 3   | 0.76                            | 0.57                                    | 13.50      | 0.14       | 0.88       | 0.17             |
| 4   | 0.65                            | 0.42                                    | 0.72       | 0.07       | 0.96       | 0.41             |
| 5   | 0.54                            | 0.29                                    | 0.41       | 0.04       | 1.00       | 0.71             |

The squared canonical correlation coefficients,  $r_1^2$  showed that the canonical variates of the banana fruit morphology domain account for some 85% of the variance of the flour phytochemistry. Thus, the roots  $r_1^2$  appear to reflect the existence of well-defined relationships between the banana fruit morphology and flour phytochemistry of interest.

The intraset canonical variables, as presented in Table 4, showed the correlation between the canonical variates with their canonical constructs. For fruit morphological characteristics, peduncle length, bract external color, and remains of flower at fruit show a high correlation to *Morphology1*, with correlation coefficients of -0.49, -0.64, and 0.49, respectively. Whereas the protein content was found as the canonical variate with the highest correlation to *Phytochemistry1* with correlation coefficients of -0.61.

The interset of canonical variables reflected the extent to which variables representing a construct correlate with other constructs. The protein content variable ( $r = -0.57$ ) in the phytochemical character of flour, and the peduncle length, bract external color, and remains of flower at fruit ( $r = 0.45$ , -0.59, and -0.45, respectively) in the fruit morphological character had quite high canonical variable interset coefficients. It concluded that there was a relationship between the morphological character of banana fruit and the phytochemical characteristics of its flour. Banana fruit with a shorter peduncle length, darker bract external color, and the presence of remains of flower at fruit will produce higher protein levels.

**Table 4.** Correlation between the original variables and canonical variates

| Characters                   | Intraset canonical variables | Interaset canonical variables |
|------------------------------|------------------------------|-------------------------------|
| <b><i>Morphology</i></b>     |                              |                               |
| Peduncle length              | <b>0.49</b>                  | <b>0.45</b>                   |
| Male bud shape               | 0.25                         | 0.23                          |
| Bract apex shape             | 0.21                         | 0.19                          |
| Bract external color         | <b>-0.64</b>                 | <b>-0.59</b>                  |
| Style shape                  | 0.11                         | 0.10                          |
| Fruit position               | 0.42                         | 0.39                          |
| Number of fruits             | 0.04                         | 0.03                          |
| Fruit length                 | 0.26                         | 0.24                          |
| Fruit shape                  | 0.21                         | 0.19                          |
| Fruit apex                   | -0.13                        | -0.12                         |
| Remains of flower at fruit   | <b>-0.49</b>                 | <b>-0.45</b>                  |
| Pedicel surface              | -0.34                        | -0.32                         |
| Immature fruit peel color    | 0.14                         | 0.13                          |
| Mature fruit peel color      | 0.14                         | 0.13                          |
| Pulp colour at maturity      | 0.23                         | 0.22                          |
| <b><i>Phytochemistry</i></b> |                              |                               |
| Vitamin C content            | 0.23                         | 0.21                          |
| Fiber content                | 0.06                         | 0.06                          |
| Fat content                  | 0.03                         | 0.03                          |
| Protein content              | <b>-0.61</b>                 | <b>-0.57</b>                  |
| Antioxidant activity         | 0.27                         | 0.25                          |

## Discussion

A food can be categorized as a functional food if it contains one or more bioactive components that provide additional health benefits beyond its basic nutritional function, without being harmful to health. To be categorized as a functional food, a food must contain compounds that are beneficial to health, including antioxidants, probiotics, prebiotics, omega-3 fatty acids, or protein (Grajek *et al.*, 2005; Noomhorm *et al.*, 2014; Peng *et al.*, 2020).

Vitamin C is a water-soluble antioxidant that is very effective in stabilizing redox reactions in the body, protecting cells from damage, supporting the immune system, and increasing iron absorption (Akbari *et al.*, 2016; Pehlivan 2017; Santos *et al.*, 2022). Protein, which consists of various amino acids, is an essential compound for the body's metabolism (Afzal *et al.*, 2022). Dietary fiber is a complex carbohydrate containing resistant starch (Dibakoane *et al.*, 2023; Udo *et al.*, 2021), which contributes to lowering the glycemic index of foods and improving gut microbial health (Munir *et al.*, 2024).

These phytochemical properties can be found in banana flour, as reported by Menezes *et al.* (2011) and Salih *et al.* (2017), making it suitable for use as a functional food ingredient. Similar facts were also found in the 29 accessions

collected in this study (Table 1). The protein content, which ranged from 1.43% to 3.49%, was higher than the results of Rahman *et al.* (2021) which only reached 0.39%. The fiber content, which ranged from 1.90% to 5.01%, was also higher than the results of Suryanto *et al.* (2011) which was only 1.22%. Likewise, the vitamin C content, which ranged from 6.01% to 6.98%, was higher than the results of Syukriani *et al.* (2021) which was 0.32% and Sarker *et al.* (2022) which was 0.56%.

To facilitate measurement of the phytochemical properties of flour, the degree of correlation between these properties and the morphological characteristics of the fruit is important. The results of a simple correlation analysis show that there is a fairly close relationship between protein content and stalk length, antioxidant content and the color of the outer bracts, and protein content and the color of the skin of the raw fruit. These findings suggest that shorter fruit stalks with lighter skin on raw fruit may be an indicator of higher protein content in the resulting flour. Similar findings were reported by Khawas and Deka (2016) that the lighter color of banana skin indicates higher protein, fat and carbohydrate content, which continues to increase with ripening.

The major drawback of simple correlation is that it can only assess linear relationships between two variables, cannot account for sets of variables simultaneously to represented constructs relationship, and is susceptible to confounding variables (Urtio *et al.*, 2017; Fan and Konold, 2018; Mardia *et al.*, 2024). Canonical correlation analysis would be helpful when there are intercorrelated variables of two sets of constructs and need to be simplify in their interpretation (Zhuang *et al.*, 2020; Fan and Konold, 2018). Canonical pairs of variables are constructed as orthogonal linear combinations of those variables (Sherry and Henson, 2005). The resulting analysis of canonical correlation indicated that the first canonical correlation ( $r_1$ ) represents the strongest relationship between fruit morphological characteristics construct (*MorphologyI*) and flour phytochemical properties construct (*PhytochemistryI*). By distinguishing intraset and interset correlation, it can be determined the contribution of a given variable to both its own construct and other construct (Sun *et al.*, 2010; Fan and Konold, 2018). For the intraset correlation of *MorphologyI*, the peduncle length, bract external color, and the remains of flower at fruit, respectively, serve as the most influential variables, either positive or negative loadings. For the intraset canonical correlation of *PhytochemistryI*, on the other hand, protein content was found to be the most dominant variable with negative loading. Moreover, the interset canonical correlation between *MorphologyI* and *PhytochemistryI* suggests that banana with shorter stalks, darker outer bracts, and the presence of flower remains on the fruit will produce flour with high level of nutrients content, especially protein. The overall findings of this study would

be helpful for food technologist in determining the functional value of banana fruits.

### Conflicts of interest

The authors declare no conflict of interest.

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