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A Systematic Literature Review of Morphological Characterization of Banana Plants in Indonesia: A Bibliometric Analysis

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ABSTRACT
Banana plants have a wide genetic diversity in Indonesia, but research on the morphological characterization of this fruit is limited. The purpose of this study was to conduct a systematic literature review on scientific trends, production, and knowledge, specifically the morphological characterization of the banana plant in Indonesia. An examination of 290 published documents in the Google Scholar database from 2012 to 2022 was carried out for this purpose. To reveal the overall trend of this topic, the co-occurrence of keywords was visualized and studied using VOSviewer software. The study findings revealed a linear increase in research trends over the years regarding the diversity of banana cultivars in some regions of Indonesia. Bibliometric mapping identified several primary research focuses, including the identification and characterization of the distinctive morphological diversity of banana plants, the utilization of various plant parts (such as leaves, stems, humps, and peels), as well as the analysis of nutritional composition and physical properties of processed products. Through overlay and density visualization, this study concludes that research on the morphological characterization of banana plants in Indonesia still holds extensive potential for future development to support the breeding of new superior varieties.

Keywords: Banana plant; Bibliometric analysis; Morphological characterization; Plant morphology; VOSviewer

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INTRODUCTION

Banana plants have high nutritional values, a diverse genetic biodiversity, and parts of the banana plant (leaves, fruit, stem, and hump) can be used as table fruit, processed food, fodder, food packaging, fertilizer, cosmetic, culture, and trade (Hidayat et al. 2016; Manis et al. 2017; Arliandi et al. 2019; Gurning et al. 2021; Nugrahani and Parela 2022). Some varieties of banana plants that can be used and consumed daily are Kepok bananas, Susu, Raja Nangka, Raja, Barlin, Raja Awak, Candi, Raja Molo, and Ambon banana (Hapsari et al. 2017; Mukhoyyaroh and Hakim 2020; Nugrahani and Parela 2022). Furthermore, banana plants can be used as one of the ecotourism activities related to nature tourism activities to conserve banana plant biodiversity, increase local wisdom, and the local community's economy, which leads to banana plants being developed as one potential horticulture fruit (Hapsari et al. 2017; Hakim et al. 2022).

Indonesia, as one of the countries with a tropical climate, has a variety of fruit plant species, one of this fruit is the banana plant. Interactions with the environment influence the quality and quantity of fruit plants produced, and changes in the environment can cause changes in the quality and quantity of crop production produced. Environmental factors such as temperature, altitude, and rainfall directly control the physiological mechanisms of the plant. High temperatures or water stress can disrupt photosynthesis rates, transpiration, and nutrient uptake from the soil, which ultimately limits the energy allocated for fruit filling and development (Turner et al. 2007; Ravi 2013).

Characterization observations on banana plants were carried out by characterizing the general appearance of the plant, which included leaves, pseudostem (suckers), leaf petiole, inflorescence (male bud), bract, male flowers, and fruit (IPGRI 1996). An approach to studying the morphological characterization of banana plants can be observed both in the vegetative and generative phases, such as the characterization of leaves, stems, flowers, and fruit (Simangunsong et al. 2017; Sawant et al. 2018; Blandina et al. 2019; Vilhena et al. 2019; Makaruku et al. 2022). Thatayaone et al. (2022) found that the morphology and characters of six commercial banana cultivars with different genes, i.e., Lilin banana (AA), Njalipoovan (AB), Yangambi (KM-5) (AAA), Nendran (AAB), Karpooravalli (ABB), and Grand Naine (ABB), showed differences in the morphological

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characters of banana plants even within the same gene group were observed. Morphological analysis of the pollen of the four identified Kepok banana cultivars, namely Kepok Abu Banana, Manado, Kuning, and Kapas, revealed that the four identified Kepok banana cultivars had the same aperture type, pollen shape, and pollen viability ranging from 29.33 to 44.45% (Ernawiati et al. 2021).

The differences in the morphological characteristics of banana plants can be used to generate germplasm for the development of new superior plant breeding varieties. Observations on the morphological characterization of banana plants are required to find differences in the specific characteristics of banana plants that are used to differentiate between banana plant species, and this knowledge becomes the important role to find which types of banana plants have advantages such as pest and disease tolerance as well as increased production included by conducting morphological observations on banana plants based on local wisdom (Ryan and Pigai 2020). Observations of morphological characters in banana plants have been studied previously by some researchers, for example, observations of morphological characters conducted by Simangunsong et al. (2017), Kurnianingsih et al. (2018), Sunandar and Kahar (2018), Blandina et al. (2019), Riandini and Astuti (2020), Ernawiati et al. (2021), and Makaruku et al. (2022).

A few studies on the research observations of morphological characters in Indonesia are recorded since considering that banana plants have genetic diversity consisting of 1,600 accessions, 325 cultivars of banana plants can adapt in subtropical and tropical regions and around 80 species of banana plants found in Southeast Asia, including in Indonesia (Varma and Bebber 2019; Houwe et al. 2020). Based on this information, bibliometric analysis is used in this paper to determine the development and mapping of research topics on the morphological characterization of banana plants in Indonesia. This bibliometric analysis is used to determine research topics related to the morphological characterization of banana plants using the VOSviewer application, which is integrated with the Publish or Perish application, and the database comes from Google Scholar.

MATERIALS AND METHODS

The scientific journal publications used in this research on the morphological characterization of banana plants were obtained from Google Scholar, which has an open-source database and used the Publish or Perish application as a reference manager application. The stages in this study were (1) collecting data that had been published in journal using the Publish or Perish application, (2) processing the bibliometric data using the Microsoft Excel application after the data was obtained, (3) conducting bibliometric analysis using the Vosviewer software application, and (4) performing computational analysis for mapping of the research topic to be carried out.

The Publish or Perish application is used to search for and sort published journals based on several keywords, including morphological characterization, plant morphology, and banana plants. The journal used in this study was obtained in April 2023 from journals published between 2012 and 2022. The Vosviewer software is used to analyze research data, which is then visualized and analyzed in terms of trends in research topics and bibliometric maps. The Vosviewer application visualizes data in the form of network visualization, overlay visualization, and density visualization. The keywords in the title and abstract are arranged and found at least four times, and keyword terms that are unrelated to the research topic are avoided and omitted.

RESULTS AND DISCUSSIONS

Data publications from 2012 to 2022

Based on Google Scholar search results for journal publication data from 2012 to 2022 using the Publish or Perish reference manager application with articles that meet the criteria based on the keywords, namely morphological characterization, plant morphology, and banana plants. The results of the search are then saved in a ris file format, which displays data such as the number of citations, author, published journal title, journal publication year, journal name, journal publisher, rating, link to the published article, and journal URLs. Figure 1 depicts the citation metrics of research topics that use the keywords morphological characterization, plant morphology, and banana plants from the number of papers to the ha-index over an 11-year period from 2012 to 2022. Figure 1 shows the citation metrics from 2012 to 2022, which include 290 papers, 1,188 citations, 108 citations/year, 4.10 citations/paper, 2.57 author/paper, h-index 15, g-index 26, HI, norm 11, and ha-index 6.

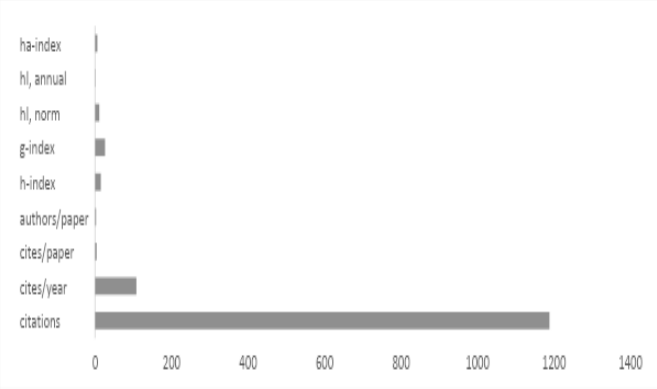


Figure 1. Research topic citation metrics using keywords characterization of morphology, plant morphology and banana plants for 11 years from 2012-2022

Period of research and development 2012-2022

Figure 2 depicts the number of articles published each year between 2012 and 2022. Figure 3 shows the evolution of the number of published articles with the year of publication according to the research topic, demonstrating a linear increase from 2012 to 2022. These findings indicate an increase in the number of publications containing the keywords characterization of morphology, plant morphology, and banana plants. There was a decrease of 1 published article from the previous year in 2015 and 2019, i.e. 11 publications in 2015 and 30 publications in 2019, followed by an

increase in publications in the following year (2020-2022) ranging from 8-30 publications. Based on the analysis data generated by the linear regression model, the value of R2 = 0.9369 is obtained with the linear regression equation y = 5.3182x - 10700, implying that 58 or 59 publications are expected in 2023. To produce an estimate of the number of publications in 2023 based on the results of this linear regression equation, intensive research is required so that the expected number of publications is obtained according to the research topic.

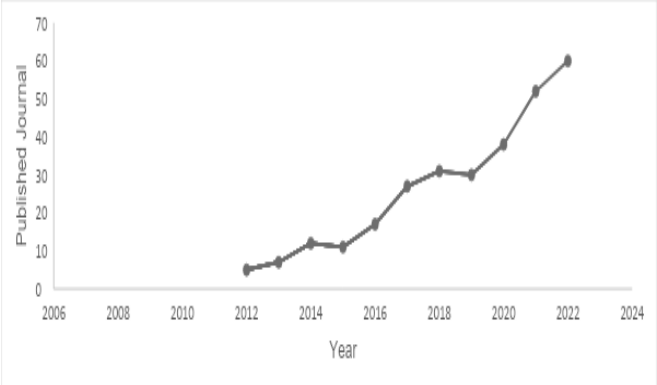


Figure 2. The number of articles published between 2012 and 2022 with the research topic keywords morphological characterization, plant morphology, and banana plants

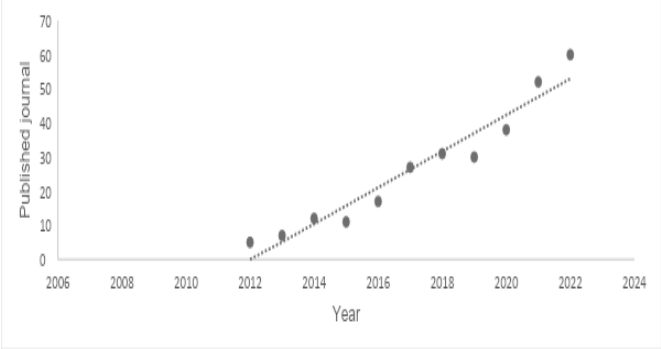


Figure 3. Trendline linear regression for the number of publications in 2012-2022 using keywords research topic morphological characterization, plant morphology, and banana plants

Visualization of keyword analysis using VOSviewer

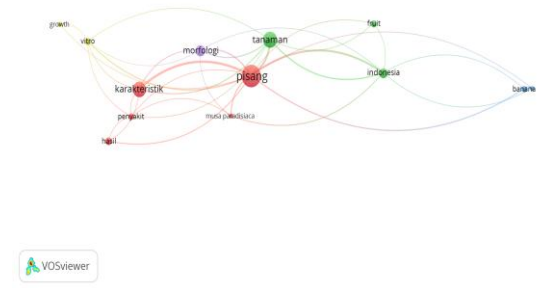
Vosviewer is used to do the computational mapping from journal data gathered using keywords on the study topic under consideration, as well as to create bibliometric maps and their linkages. The visualization of the mapping connected to the research topic consisted of 13 items, which were divided into five clusters, namely: a) Cluster 1 in red color consists of 5 items i.e. yield, characteristics, *Musa paradisiaca*, disease, and banana; b) Cluster 2 in Green color have 3 items, namely fruit, Indonesia, and plants; c) Cluster 3 in blue color have 2 items, i.e. bananas, and diversity; d) Cluster 4 in yellow color consists of 2 items, namely growth and vitro; e) Cluster 5 in purple color has 1 item, i.e. morphology.

This study includes three bibliometric mapping visualizations i.e. network visualization, overlay visualization, and density visualization. Bibliometric mapping with Vosviewer based on network visualization demonstrates that there is a relationship for each visualized term to construct a network that is connected to one another. The shape of a colored circle suggests that each of these terms is associated with keywords and journal abstracts relevant to the research topic (Nandiyanto and Al Husaeni 2021). The greater the colorful circles obtained, the more frequent keywords and abstracts from the journals utilized in research appear, and vice versa (Nandiyanto and Al Husaeni 2021; Al Husaeni and Nandiyanto 2022a). The study's results employing the terms morphological characterization, plant morphology, and banana plants produced 13 items, 5 clusters, 34 links, and a total link strength of 79 (Figure 4). This analysis consisted of 5 clusters, and each cluster revealed a link between the terms contained within it. Cluster 1 is red in color with the term of the banana with a larger circle and is a term that frequently comes with four other term items i.e. yield, *Musa paradisiaca*, disease, and banana. Cluster 2 is green in color and consists of three items, one of which is for the phrase plant and the other two are for Indonesia and fruit. Other terms, such as banana, in cluster 3 in blue color, have a relationship with the phrase diversity. Whereas in cluster 4 in yellow color has a relationship with the term growth with invitro. Cluster 5 in purple color, on the other hand, only has one item, which is morphology.

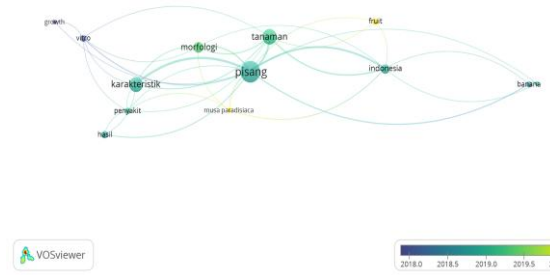
The mapping bibliometric analysis with Vosviewer based on overlay visualization revealed that there is an update in research where some terms are related to each other marked by a light color (yellow) where the color is getting darker (to the left) indicates that the research is out of date. This color circle represents the average number of citations of terms used in the network for the first time (Barbosa 2021; Guo et al. 2021). The results of the bibliometric mapping visualization research with Vosviewer based on overlay visualization with the keywords morphological characterization, plant morphology, and banana plants show that there is a research update that occurred in 2019-2020, namely the use of the terms of morphology, fruit, and *Musa paradisiaca* are becoming important (Figure 4). These three terms are important for future study advancement on this research issue. Several additional essential terms in this mapping, such as characteristics and diseases of banana plants in Indonesia, can be suggestions for researchers, and interactions or links between the terms utilized in study are still needed. On the other hand, as shown in Figure 4, the term banana with the largest blue circle as the center position is an important term and directly related to the smaller circle, namely characteristics, morphology, plant, Indonesia, disease, growth, invitro, banana, fruit, yield, *Musa paradisiaca*, and all of these terms become important related to the research topic.

According to Hawari and Winoto (2022), density visualization is used to figure out in general a bibliometric analysis map where there are items that play a significant part in the study topic for further analysis. The results suggest that the keywords characterization of morphology, plant morphology, and banana plants for the phrases banana, fruit, Indonesia, *Musa paradisiaca*,

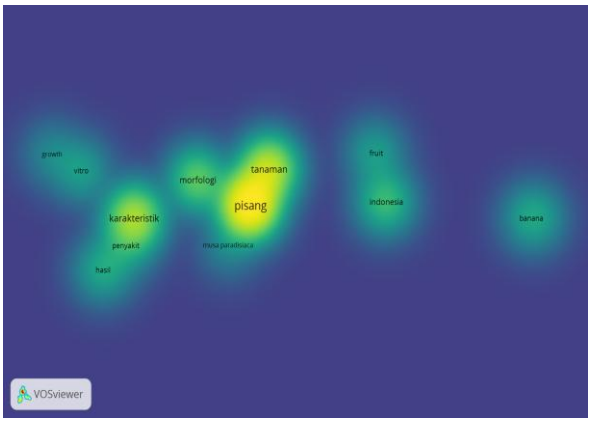
morphology, disease, growth, in vitro, and yield are not frequently published (Figure 4). Mapping bibliometric analysis with Vosviewer based on density visualization reveals that there is an increase in the size of the circle and the color (yellow) is becoming brighter as a sign that a lot of research has been done, whereas the smaller the circle with a dark color (fades and blends with the green background) indicates that the research topic was observed infrequently (Al Husaeni and Nandiyanto 2022b; Syahadat et al. 2022). According to the findings of this study, the morphological characterization research issue of banana plants is still limited and has the potential to become a research topic with the potential to expand the number of publications in the next year.



a



b



c

Figure 4. Visualization of bibliometric mapping of keywords characterization of morphology, plant morphology and banana plants with Vosviewer based on network visualization (a), overlay visualization (b) and density visualization (c)

The most cited keywords

Based on a search of 290 publications, Table 1 shows the 15 most cited articles. The title, year of publication, number of citations, and reference sources are all included in the article data. Because of the huge number of publications, the study concentrated on the 30 articles with the most citations associated to the keyword of banana plant.

The fifteen most referenced articles were published between 2012 and 2022, with citation counts ranging from 1 to 20, with Ekasari et al. (2012) receiving the most citations. The most cited study used PCR-RFLP (Polymerase Chain Reaction Restriction Fragment Length Polymorphism) on ribosome ITS (Internal Transcribed Spacer) DNA to differentiate 15 banana cultivars. Other studies with the most citations included the use of banana plant parts, exploration and characterization, ethnobotany, germplasm diversity, identification and characterization, physicochemical properties, nutritional value, and identification of the diversity of morphological characters of banana plants were recorded.

Review articles with the keyword banana plants

Indonesia is known to contain genetic variety in banana plants, particularly local bananas (Sudarmika and Rai 2016), which has various advantages (Kurnianingsih et al. 2018). Because banana plants grow in different ecological places and are spread across Indonesia, it can be one of the problems in characterizing the morphology of banana plants, causing research activities on the identification, characterization, exploration, and preservation of germplasm to be conducted rarely in Indonesia (Ambarita et al. 2015; Weihan and Zulkarnain 2020). The research on the characterization and morphology of banana plants in Indonesia have already conducted by (Ismail et al. 2015), (Hendaru et al. 2017), (Sunandar and Kahar 2017), (Anjasmara et al. 2020), (Sihotang and Waluyo 2021). Other studies on the characterization and morphology of varieties and local bananas were conducted by Hanayanti and Pramudya (2014), Nettyani et al. (2014), Sunandar and Kahar (2018), Wijaya (2020) and Santi et al. (2022). Based on Vosviewer bibliometric analysis, it was found that there were studies related to the diversity of banana cultivars in some regions of Indonesia, such as the study conducted by Ekasari et al. (2012), which observed that there were no significant differences in the gene from 15 banana cultivars. Ernawiati et al. (2018) determined that approximately 27 banana plant accessions exhibited a diversity index of approximately 2.82 (Table 2). Studies on the identification, characterization, and diversity of distinctive morphology in banana plants were also documented (Table 2). Yuliawati et al. (2016) found 45 fruits and 41 local fruits as germplasms. The study indicated no significant variations in genetic diversity with two clusters seen during the vegetative phase and four clusters observed during the generative phase (Weihan and Zulkarnain 2020). Riandini and Astuti (2020) identified two groups of bananas i.e. group A (Raja banana, Gembor banana, Kapal banana, Jantan banana, and kepok banana) and group B (Klutuk banana) with the coefficient similarity

ranging from 0.27 to 0.63. Suryawan et al. (2016) found around 59 cultivars and 37 species, including banana. Sudarmika and Rai (2016) reported 51 species of indigenous fruits, 34 kinds of fruit, and superior fruits, including banana. Banana plants have numerous advantages. Parts of the banana plant, such as the leaves, stems, tubers, fruit, and hump, can be used and processed for food and agriculture, such as animal feed (Hidayat et al. 2016), ice cream ingredients (Ernawiati et al. 2018), liquid organic fertilizer (Manis et al. 2017), a mixture of biodegradable plastics (Asngad et al. 2018), and mulch (Arliandi et al. 2019). Table 3 provides the reported results for the use of banana plant parts from 2012 to 2022.

Table 3 shows the utilization of banana plant parts such as the stem, peel, fruit, leaf, inflorescence, hump, and bunches. In the studies, banana stem was employed as a waterproof rope, and the resin levels for phenol formaldehyde were determined (Malau et al. 2016; Wuriyudani et al. 2017). Banana peel might be used as fodder Jeharu et al. (2015) and Pratiwi et al. (2018) observed peel-off facial gel masks. Ria et al. (2019), Mukhoyyaroh and Hakim (2020) discovered the use of fruit, leaf, stem, and inflorescence as crust pies, food, culture, trade, furniture, cosmetics, and fodder. The hump and bunch of the banana, on the other hand, are significant components for biodegradable foam, liquid fertilizer, and bioethanol (Irawan and Aliah 2018; Fauzan et al. 2021; Kusumaningrum and Dewi 2022).

In addition, some research have looked at the nutritional composition and physical qualities of foods (Table 4). The inclusion of banana batu fruit (*Musa balbisiana Colla*) to the cookie formula enhanced the ash, fiber, and calcium contents, as well as the cookie acceptance formula (color, texture, and flavor) (Adilla et al. 2020). According to Rahmadhia and Juwitaningtyas (2020), the Klutuk banana generated the best color, mechanical, and antioxidant qualities among the physical properties' parameters at the third petiole leaf and hence could be used as food packaging material. While nutrition composition of Ambon banana was reported to be composed of carbohydrates about 3.96-4.02%, lipids 0.85-1.68%, and protein around 0.31-0.64% at different maturities (Maitimu et al. 2020).

Table 1. The 15 most cited articles between 2012-2022

No	Topic	Year	Citation	Reference
1	Analysis of banana cultivar diversity using PCR-RFLP markers on Ribosomal DNA Internal Transcribed Spacer (ITS)	2012	20	(Ekasari et al. 2012)
2	Particle board quality from Barangan banana stem variation based on phenol formaldehyde resin levels	2016	15	(Malau et al. 2016)
3	Variations in the types of humectants in the formulation of peel-off gel mask preparations of Kepok banana peel extract (*Musa paradisiaca pericarpium*)	2018	8	(Pratiwi et al. 2018)
4	The importance of exploring and characterizing banana plants to conserve genetic resources	2019	7	(Suryani and Owbel 2019)
5	Ethnobotanical study on local bananas (*Musa sp.*) utilization in srigonco village, bantur district, Malang regency	2020	7	(Mukhoyyaroh and Hakim 2020)
6	Germplasm diversity of banana (*Musa spp*) in the city of Bandar Lampung, Indonesia by type of genome and number of chromosome	2018	7	(Ernawiati et al. 2018)
7	Identification and characterization of genetic Resources of local fruits in Gianyar	2016	4	(Yuliawati et al. 2016)
8	Inventory of plants at the Ponorogo station market as a learning resource for biology students majoring in natural sciences, Ponorogo State Islamic Institute	2019	2	(Hanin 2019)
9	Physicochemical properties of Klutuk banana leaves (*Musa balbisiana Colla*) Susu and Wulung cultivars with their potential as antioxidant	2020	2	(Rahmadhia and Juwitaningtyas 2020)
10	Nutritional value of Ambon Lumut banana peel (*Musa acuminate Colla*) at several levels of fruit maturity	2020	2	(Maitimu et al. 2020)
11	Composite flour of goroho plantain (*Musa acuminate*) and yellow sweet potato (*Ipomoea batatas*. L) as the raw material for pie crust	2019	2	(Ria et al. 2019)
12	Identification of morphological characters of banana plant (*Musa spp.*) in land area tanjung jabung east district	2020	1	(Weihan and Zulkarnain 2020)
13	Study of the phenetic relationship between bananas in Kabawetan subdistrict, Kepahiang district, Bengkulu Province	2020	1	(Riandini and Astuti 2020)
14	Classification of the maturity level of Kepok bananas uses the naive bayes algorithm	2022	1	(Hakim et al. 2022)
15	Identification and characterization of fruits in Karangasem	2016	1	(Suryawan et al. 2016)

Table 2. Diversity of banana cultivar, identification, characterization, diversity of characteristic morphology of banana: data analysis from 2012-2022

Topic	Banana plant	Research conducted	Result	Reference
Diversity of banana cultivar	15 kultivars of banana	Semarang	15 kultivars of banana were observed to reveal no differences in its the genom	(Ekasari et al. 2012)
	26 accessions from genus Musa and 1 accession from genus Rhodhoclamys	Bandar Lampung	There were 27 accessions of banana and classified as medium with index diversity around 2.82	(Ernawiati et al. 2018)
Identification, characterization, diversity of characteristic morphology	21 banana varieties	Gianyar	The research found that 45 fruits and 41 local fruits as germplasms	(Yuliawati et al. 2016)
	Musa sp.	Tanjung Jabung Timur	The study resulted in 2 clusters at vegetative phase and 4 clusters at generative phase were recorded. The genetic diversity found no significant different.	(Weihan and Zulkarnain 2020)
	1 wild banana, 2 varieties of *Musa acuminate* colla (Kapal banana and Jantan banana), 3 varieties *Musa acuminate x Musa balbisiana* (Kepok banana, Gembor banana and Raja banana)	Bengkulu	The research resulted in two groups of banana i.e. Raja banana, Gembor banana, Kapal banana, Jantan banana and Kepok banana as group A and Klutuk banana known as group B with coefficient similarity ranged 0.27-0.63.	(Riandini and Astuti 2020)
	Musa sp (Keladi banana, Dak Raja banana, Mas banana, Kepok banana, Susu banana, Lumut banana and Ketip banana)	Karang asem	There were fruits around 59 cultivars and 37 species identified including banana	(Suryawan et al. 2016)
	Musa sp	Badung	The study revealed 51 species of local fruits, 34 species of fruit and durian, jackfruit, watermelon, avocado, guava, pineapple, sapodilla including banana were found as superior fruits	(Sudarmika and Rai 2016)

Table 3. Published results of utilization by different parts of banana plant : data analysis from 2012-2022

Parts of banana plant	Banana plant	Utilization	Reference
Stem	Barangan	As the resin levels of phenol formaldehyde	(Malau et al. 2016)
Peel	Kepok	Waterproof rope	(Wuriyudani et al. 2017)
Fruit	Kepok	Peel-off facial gel mask, fodder	(Jeharu et al. 2015; Pratiwi et al. 2018)
Fruit, leaf, stem and inflorescence	Goroho	Crust pie	(Ria et al. 2019)
Hump	Local fruits (*Musa sp.*)	Food, culture, trade, furniture, cosmetics and fodder	(Mukhoyyaroh and Hakim 2020)
Bunche	Mahuli	Biodegradable foam	(Irawan and Aliah 2018)
Fruit	Batu Banana	The addition banana flour as substitution influence on ash, fiber, calcium and acceptance cookies formula such as color, texture and flavor.	(Adilla et al. 2020)
Leaf	Klutuk Banana	The best color, mechanical, and antioxidant properties as physical properties parameters are found in the third petiole leaf of Klutuk banana and could be used as a material for food packaging	(Rahmadhia and Juwitaningtyas 2020)
Peel	Ambon Banana	Carbohydrate, lipid, and protein contents under different maturities of banana Ambon were 3.96-4.02%, 0.85-1.68% and 0.31-0.64%	(Maitimu et al. 2020)

Table 4. Published results of utilization by different parts of the banana plant as nutrition composition and physical properties : data analysis from 2012-2022

Parts of banana plant	Banana plant	Result	Reference
Fruit	Batu Banana	The addition banana flour as substitution influence on ash, fiber, calcium and acceptance cookies formula such as color, texture and flavor.	(Adilla et al. 2020)
Leaf	Klutuk Banana	The best color, mechanical, and antioxidant properties as physical properties parameters are found in the third petiole leaf of Klutuk banana and could be used as a material for food packaging	(Rahmadhia and Juwitaningtyas 2020)
Peel	Ambon Banana	Carbohydrate, lipid, and protein contents under different maturities of Ambon banana were 3.96-4.02%, 0.85-1.68% and 0.31-0.64%	(Maitimu et al. 2020)

CONCLUSIONS AND SUGGESTIONS

This bibliometric review maps the evolutionary trajectory of research on the morphological characterization, plant morphology, and diversity of banana plants (*Musa* spp.) in Indonesia from 2012 to 2022. By evaluating 290 documents via VOSviewer, this study identified key thematic clusters focusing on regional cultivar diversity, morphological identification, the functional utilization of plant parts (leaves, stems, humps, and peels), and the nutritional and physical properties of processed products. In terms of broader impact, this decade of data provides a vital taxonomic safeguard for Indonesia's *Musa* germplasm, protecting indigenous genetic resources while validating underutilized cultivars for food security and bio-economic waste management. Moving forward, the field must

advance past traditional morphology by integrating genomic profiling (such as SSR/ISSR markers), breeding for morpho-physiological climate resilience, and adopting digital phenotyping tools like machine learning and UAVs for rapid field characterization.

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