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Morphological Diversity of Piperaceae in Bandealit Resort Meru Betiri National Park (TNMB), Indonesia

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ABSTRACT

The Piperaceae family is notable for its many benefits to humans due to the production of unique essential oils. The economic, health, and cultural value of this family necessitates the exploration of its diverse species as material alternatives. This study aimed to investigate the Piperaceae family's morphological diversity in the TNMB region. This qualitative research employed a tracking method, and the results indicated the Piperaceae morphological variations through the instruments of root, stem, leave, and flower. The study identified 11 species, including 10 of the Piper genus and one of the Peperomia genus, respectively. The two genera exhibited variations in root and stem morphology. They were similar in leaf shape, aroma, and flower type. Morphological investigation is important for identifying Piperaceae family members, of which few of the 11 identified species have been used. This study provides baseline data that may contribute to future conservation, domestication, and commercialization efforts.

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INTRODUCTION

The Piperaceae family consists of 13 genera, the second largest plant genus, with 2,171 species (Amorim et al., 2021; Siregar et al., 2021). Piperaceae locally known as Sirih and classified as trunked or tree-shaped, shrubs, lianas/creeping, herbs, and sometimes epiphytic (Mesquita et al., 2021). Nowadays, exploration of Piperaceae still on demanding due to its economic potentially, known for various purposes such as spice, food, medicine, decoration, and local cultural purposes (Chanchal, 2015; Suwanphakdee et al. 2016; A'tourrohman & Ulfah, 2020). The wide range utilization of Piper is due to their secondary metabolites which is prominent with essential oils that easily recognized from their specific pungent aromas from the leaves (Purnomo & Asmarayani, 2005). Two main genera - Peperomia, with over 1,600 species, and Piper, with 1,050 species, are richly represented in tropical forests, especially in Asia and tropical America (Chanchal et al. 2015; Mabberley, 2008).

Indonesia has 43 Piper species or 1,62% of total species around the world (Backer dan Bakhuizen 1965). As there are still many unexplored forests in Indonesia, the number of Piper species in Indonesia is expected to increase. A total of 25 species of Piper have been identified in forest areas of West Sumatra, while 21 have been found in TNBBS, Lampung province (Munawaroh et al., 2018). Furthermore, Purnomo and Asmarayani (2005) have confirmed the presence of 23 species of Piper on the island of Java. The Bandealit Resort of Meru Betiri National Park (TNMB) is a prime conservative area in East Java, Indonesia. The TNMB area is home to over 500 species of flora, 15 of which are protected, 239 have medicinal properties, and 77 are used by the community, including Piperaceae (Syarief et al., 2018). The microclimate boasts high humidity (up to 86.3% RH), light intensity (100 to 4337 lux), and temperature (24 to 31.2 °C), which are ideal for piper growth (Sulistiyowati et al., 2021). Research on the Piperaceae family in TNMB was conducted by Gunawan (2016), especially in Andongrejo-Bandealit Resort, where 10 plant species belonging to the genus Piper and Peperomia based on the morphology variation. The present study compels the Piperaceae family database in all resort of TNMB.

Morphological characterization of plants is the initial step in visual classification, and essential for identifying specific traits of interest. The Piperaceae family is unquestionably diverse in terms of leaf shape, leaf texture, stem color, petiole color, and habitus (Widiyastuti et al., 2016). It is therefore essential to be familiar with the structures of each species of the Piperaceae family in order to recognize them. The external features also ensure that species are not duplicated and facilitate efficient collection and population structuring for conservation. This can be used to determine the relatedness of species as taxonomic data (Tan et al., 2021). The majority of taxa under the genus Piper are morphologically confusing due to the wide range of vegetative character variations (Chanchal et al., 2015). This study has main objectives - to create an inventory of Piper genetic resources collected from Bandealit Resort, Meru Betiri National Park (TNMB) relying on morphological characters. It is crucial to understand the morphological variation to effectively manage, conserve, and domesticate these resources. Characterization of germplasm is essential to provide information on the traits of accessions and ensure the maximum utilization of the germplasm collection by final users.

MATERIALS AND METHODS

Sampling Methods

This study used the zigzag tracking method to survey a 7-km stretch from Tumpak Gesing to Pantai Block of Bandealit TNMB. The Avenza Maps application marks discovery points with a red dot on the TNMB map to determine the coordinates of the growing area and evidence of the Piperaceae species (Figure 1). The Avenza is a mobile-based application for real-time positioning without an internet or network connection. The specimens were definitively identified by comparing species and or herbarium specimens and various floras references, including Siregar et al. (2021); Suwanphakdee et al. (2016); Purnomo & Asmarayani (2005). Moreover, the morphological traits observed for identification, encompassing roots, stems, leaves, flowers, fruits, and seeds, align with the general descriptions by Gembong (2009) and Bendre & Kumar (2009) tabulated in Table 1. Herbarium specimens were prepared using the appropriate handling methods and deposited in the botany laboratory of Biology Education, University of Jember (Nugroho & Hartini, 2021).

Table 1. List of descriptors used in the study

No	Characters	Character state
1	Grow habit	1 = Climbing (on support); 2 = Creeping/Trailing (on the ground), 3 = Erect
2	Root	1 = Tap root; 2 = Adventitious
3	Natura of stem	1 = Terete; 2 = Angularis
4	Habit	1 = Herbaceous; 2 = Woody
5	Stem surface	1 = Glabrous; 2 = Pubescent; 3 = Scabrous; 4 = Hirsute/Villous; 5= Prickly/Spiny; 6 = Papillose; 7 = Scaly; 8 = Waxy
6	Types of leaves	1 = Simple; 2 = Compound
7	Leaf lamina shape	1 = cordates; 2 = rhomboides; 3 = ovale; 4 = lanceolatus
8	Leaf tip	1 = acute; 2 = acuminate
9	Leaf base	1 = Intended; 2 = Obtuse
10	Leaf texture	1 = Coriaceous; 2 = Papyraceous; 3 = Herbaceous
11	Leaf adaxial surface	1 = Glabrous; 2 = Pubescent; 3 = Hirsute
12	Leaf abaxial surface	1 = Scabrous; 2 = Smooth

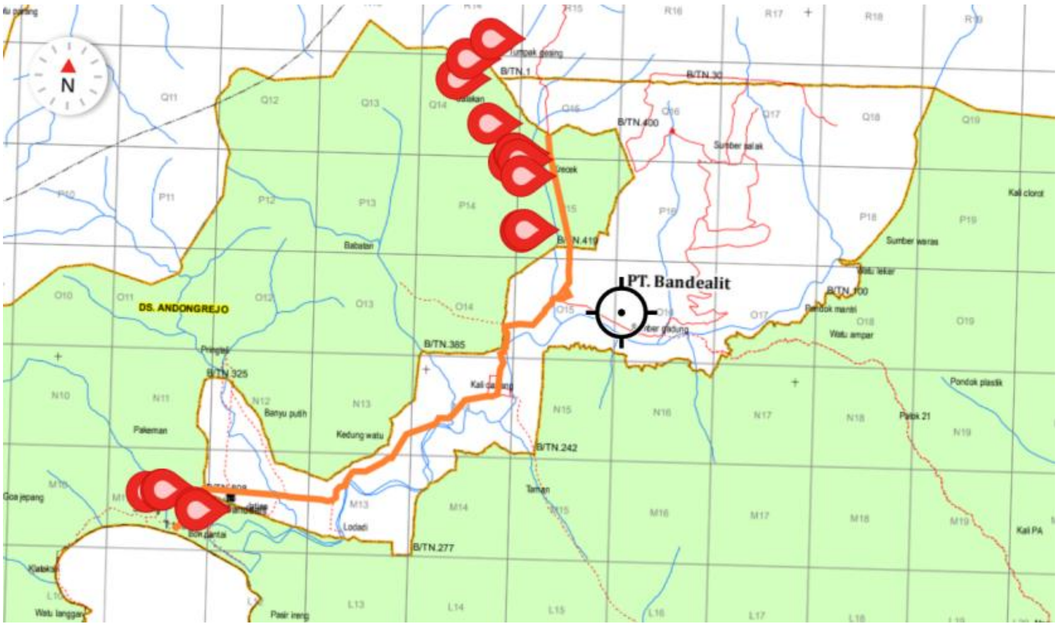

Figure 1. Research location map of Resort Bandealit TNMB

Abiotic Factors Measurement

A measurement of biotic factors is imperative in order to assess the environment at each site where plants have been identified. The abiotic factors, including soil pH and soil moisture, measured using Soil Tester (Takemura DM 15, Japan). The temperature and humidity were assessed using a Thermo-hygrometer HTC-2 (OneMed). In addition, light intensity was measured using a Lux Meter LX-1010B (Kenko), and Altimeter/Barometer (Sunoh 7030, Japan) for altitude aspects. The pre-sampling procedure ensures all the device is functioning within the expected operational parameters. These "functional checks" include verifying battery levels, checking for damage or malfunction, and confirming regular sensor response to standardized conditions. Except for Altimeter.

RESULTS AND DISCUSSION

In the targeted area of the Bandealit Resort, 11 Piperaceae species were identified at various locations (Table 2). Described feature of each identified specimen summarizing on Table 3. Each location abiotic factors data showed have an average soil pH of 6-7.5, soil temperature 23-27°C, air temperature 25.5- 39.5°C, air humidity 53-90%, light intensity 1,092-1,618 Lux, and altitude 10-32 mdpl. The results of 11 species in the Piperaceae family are summarized in Table 3. Moreover, thre images of the root, stem, leaf, flower, fruit, and seed features were sequentially presented from Figures 2 to 6.

The Piperaceae family's presence in six locations within TNMB suggests that these areas provide fertile ground, aligning with the measured environmental factors. Soil chemical properties, particularly pH, play a crucial role in nutrient availability. The observed neutral soil pH range (6-7.5) across collection sites is optimal for nutrient uptake, as it allows soil colloids to efficiently absorb and release essential macro- and micro-nutrients (Martin, 2015; Rima et al., 2018). Similarly, the recorded soil temperature range (24.2 - 32.8°C) generally falls within the favorable range (23-27°C) for Piperaceae germination and maturation (Taufiq & Sundari, 2012). The prevalence of these species in the lowlands of TNMB (10-32 mdpl), coupled with average air humidity (53-90%) and light intensity (1,092-1,618 lux), further supports the ecological preferences of this family, which thrives in shaded, humid tropical conditions with adequate soil moisture (Chanchal et al., 2015). This aligns with the broader global distribution of Piperaceae in tropical and subtropical regions characterized by high humidity and rich humus (Siregar et al., 2021).

The observed variations in root morphology within Piperaceae, as detailed in Figure 2, offer insights into the ecological adaptations and potentially the evolutionary divergence within the family. The consistent presence of a taproot in most

Table 2. Identification results of the Piperaceae family in Bandealit Resort

No	Genus	Species	Local name	Site of Collection	Coordinat
1	Piper	*Piper bettle* L.	Suruh	Tumpak Gesing	-8.436633,113.741733
2	Piper	*Piper majusculum* Blum	Lada Besar	Kali Loro	-8.438503,113.739609
3	Piper	*Piper caninum* Blum.	Lada Hutan	Kali Loro	-8.440345,113.738754
4	Piper	*Piper cubeba* L.Fil	Kemukus	Krecek	-8.447660,113.743755
5	Piper	*Piper longum* L.	Lada Panjang	Krecek	-8.447415,113.744601
6	Piper	*Piper sumatranum* (Miq.) C.DC.	Tepel	Bon Ngetek	-8.453710,113.745382
7	Piper	*Piper sarmentosum* Roxb.	Karok	X Jatian B	-8.479961,113.716579
8	Piper	*Piper retrofractum* Vahl.	Cabe Jawa	X Jatian B	-8.479742,113.716497
9	Piper	*Piper nigrum* L.	Lada	X Jatian A	-8.478220,113.713503
10	Piper	*Piper aduncum* L.	Sirih hutan	X Jatian A	-8.478479,113.712038
11	Peperomia	*Peperomia pellucida* L.Kunth.	Sirih Cina	X Jatian A	-8.478267,113.713324

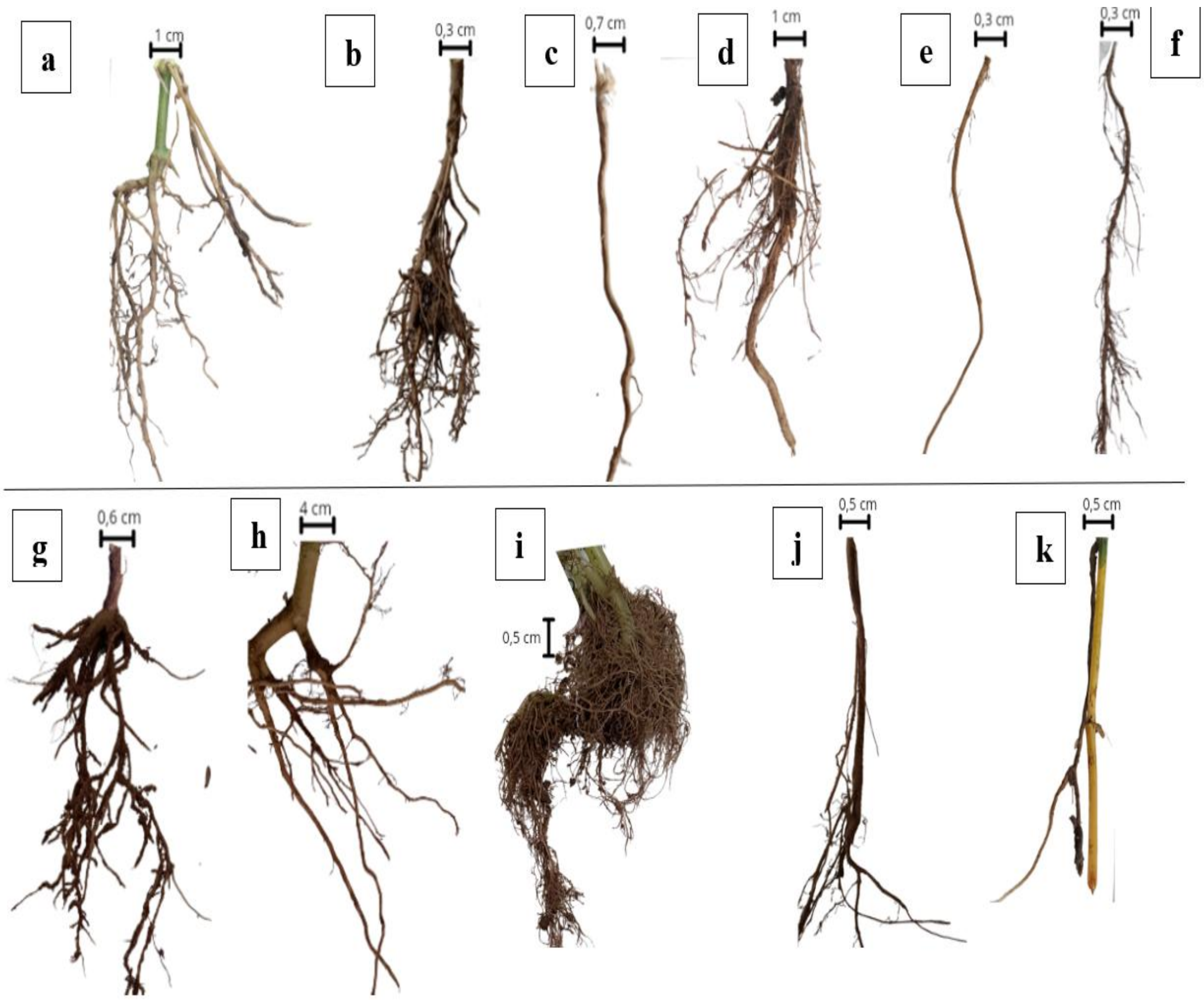

Figure 2. Root Morphology variations of the Piperaceae Family: a. *Piper sarmentosum* Robx., b. *Piper retrofractum* Vahl., c. *Piper cubeba* L.Fil., d. *Piper majusculum* Blume., e. *Piper bettle* L., f. *Piper caninum* Blume., g. *Piper nigrum* L., h. *Piper aduncum* L., i. *Peperomia pellucida* L.Kunth., j. *Piper sumatranum* (Miq.) C.DC., k. *Piper longum* L

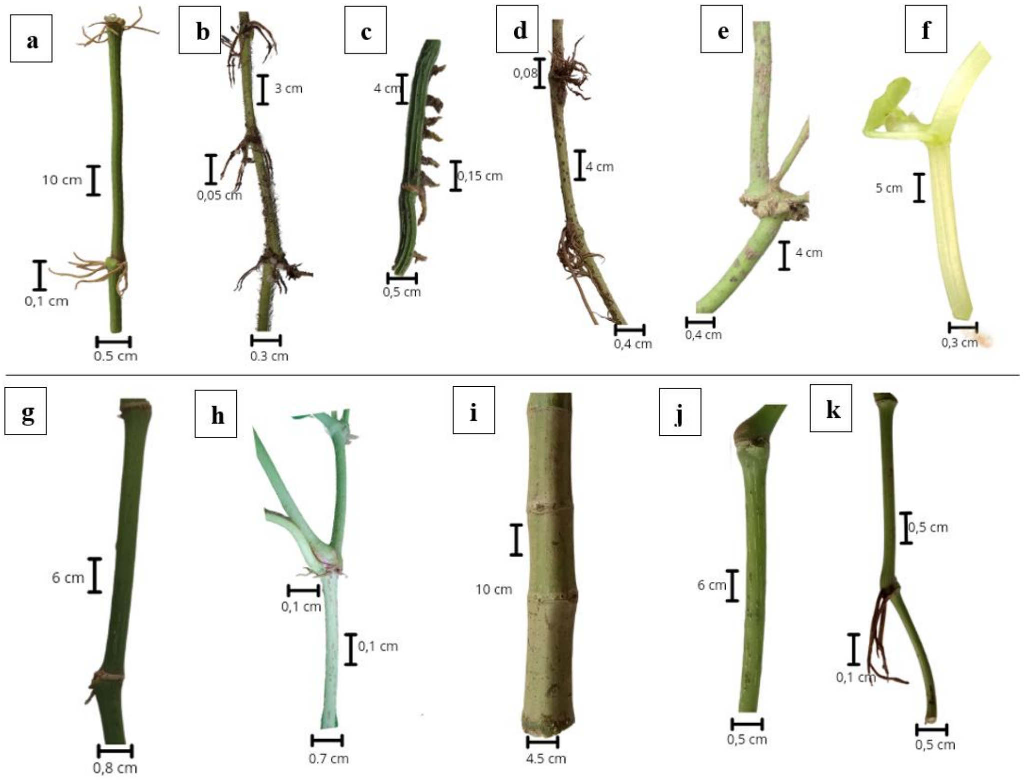

Figure 3. Stem Morphology variations of the Piperaceae Family: a. *Piper bettle* L. b. *Piper sumatranum* (Miq.) C.DC., c. *Piper longum* L., d. *Piper retrofractum* Vahl., e. *Piper cubeba* L.Fil, f. *Peperomia pellucida* L.Kunth., g. *Piper nigrum* L, h. . *Piper caninum* Blume.,i. *Piper aduncum* L., j. *Piper majusculum* Blume., k. *Piper sarmentosum* Robx

genera, contrasting with the fibrous roots of *Peperomia*, likely reflects differing strategies for resource acquisition and anchorage in their respective habitats. For instance, the taproot system may provide stronger anchorage in taller or more exposed *Piper* species, while the fibrous root system of herbaceous *Peperomia* might be advantageous for nutrient absorption in shallower substrates or epiphytic niches (Chaudari, 2025). The presence of adventitious roots in climbing *Piper* species (radix adligans) directly facilitates their liana habit, enabling them to access light and resources in the canopy, a key morphological adaptation that distinguishes them from erect shrubs and trees within the genus (Tjitrosoepomo, 2009) This adaptation likely contributes to niche differentiation and potentially reduces competition among sympatric (Silva Luz et al., 2024). Furthermore, the distinct habitus morphology between *Piper* and *Peperomia* (Table 2) underscores a fundamental morphological divergence between these genera, likely driven by different ecological pressures and evolutionary trajectories. The prevalence of lianas, shrubs, and trees in *Piper* versus the herbaceous, geophytic, and epiphytic forms in *Peperomia* highlights significant differences in their life strategies, resource utilization, and interactions with their environment (Hikmah., 2017). These differences in overall plant architecture are fundamental aspects of morphological diversity within the family and likely play a crucial role in species identification and ecological niche partitioning.

In terms of stem variations, the woody stems of 10 species *Piper* provide structural support for their climbing or shrubby habits, contrasting with the herbaceous stems of *Peperomia*, which are adapted for different growth forms and potentially faster life cycles. The observed branching patterns, with sympodial branching being dominant in most species (except *P. aduncum* and *P. pellucida*), and the variations in stem shape and surface texture (e.g., rectangular stems in *P. longum*, brushy or grooved surfaces) further contribute to the morphological distinctiveness among species, potentially reflecting

Table 3. Identified features of Piperaceae morphological variations

No	Species	Growth Habit	Akar	Stem	Leaves	Flower	Colour Change while ripening
1	*Piper bettle* L.	Climbing, Liana	Taproot	Terete, woody,	Chordate, acuminate, emarginatus,	Compound Amentum, Green Corolla	Green to yellow
2	*Piper majusculum* Blum	Climbing, Liana	Taproot	Terete, woody	Rhomboides, acuminate, emarginatus	Compound, Amentum, Green Corolla	Green to yellow
3	*Piper caninum* Blum.	Climbing, Liana	Taproot	Terete, woody	Chordate, acuminate, emarginatus	Compound, Amentum, Green Corolla	Yellowish green to brownish green
4	*Piper cubeba* L.Fil	Climbing, Liana	Taproot	Terete, woody	Ovale, acuminate, emarginatus	-	-
5	*Piper longum* L.	Climbing, Liana	Taproot	Terete, woody	Chordate, acuminate, emarginatus	-	-
6	*Piper sumatranum* (Miq.) C.DC.	Climbing, Liana	Taproot	Terete, woody	Chordate, acuminate, emarginatus	-	-
7	*Piper sarmentosum* Roxb.	Erect, Shrubs	Taproot	Terete, woody	Chordate, acuminate, emarginatus	Compound, Amentum, Greenish yellow Corolla	Green to blackish dark green
8	*Piper retrofractum* Vahl.	Climbing, Liana	Taproot	Terete, woody	Lanceolatus, acuminate, obtusus	Compound, Amentum, Green Corolla	Green to red
9	*Piper nigrum* L.	Climbing, Liana	Taproot	Terete, woody	Ovale, acuminate, obtusus	Compound, Amentum, yellow Corolla	Green
10	*Piper aduncum* L.	Erect, Shrubs	Taproot	Terete, woody	Lanceolatus, acuminate, rotundate,	Compound, Amentum,	Green to yellow
11	*Peperomia pellucida* L.Kunth.	Erect, Herbaceous	Adventitious	Terete, herbaceous	Chordate, acuminate, emarginatus	Compound, Amentum, Greenish Yellow Corolla	Yellowish green to dark brown

species-specific adaptations to their microhabitats or interactions with other organisms. Similarly, the leaf shape variations (heart-shaped, ovate, lanceolate, rhombus) likely reflect adaptations to light capture and water management in different ecological settings (Rahajeng et al., 2020), contributing to the overall morphological diversity within the family. The relatively conserved floral and seed morphology (amentum and compounds) might suggest evolutionary constraints or a shared ancestral reproductive strategy within the Piperaceae (Tebbs, 1993; Munawarohet al., 2018; Suwanphakdee et al., 2020).

Integrating these morphological findings with broader taxonomic frameworks is crucial for accurate species identification and understanding evolutionary relationships within Piperaceae. The consistent differences in root and habitus morphology between Piper and Peperomia strongly support their current generic classification (Hikmah., 2017). Furthermore, the subtle but consistent variations in stem shape, branching patterns, and leaf morphology observed among Piper species (Nongmai et al., 2021; Munawarah and Yuzammi, 2017; Sarjani et al., 2019) provide valuable characters for species delimitation, particularly in a species-rich and often morphologically complex group like Piper. These morphological traits, when combined with molecular data, can contribute to a more robust and comprehensive understanding of phylogenetic relationships within the family

From a conservation perspective, understanding the morphological diversity within Piperaceae is essential for effective biodiversity management. Morphological characters are often the first line of evidence for identifying and distinguishing species, especially in the field (Silva et al., 2024; Gunawan et al., 2016). Accurate species identification is fundamental for assessing species rarity, distribution, and conservation status. The observed habitat preferences, linked to specific morphological adaptations (e.g., climbing habit in relation to forest structure), highlight the importance of habitat conservation for maintaining the diversity of this family. Furthermore, understanding the morphological traits associated with different ecological niches can inform conservation strategies aimed at preserving the functional diversity within these ecosystems. For instance, protecting areas with diverse forest strata is crucial for supporting both climbing and non-climbing Piperaceae species. Morphological studies, therefore, provide a critical foundation for informed conservation decisions aimed at safeguarding the biodiversity of the Piperaceae family in regions like TNMB

CONCLUSION

This study identified 11 Piper species in TNMB Bandealit, revealing significant root, stem, and leaf variations. These detailed morphological descriptions provide crucial baseline data for taxonomic clarification and accurate species identification in the region. Understanding this diversity is essential for informed conservation planning and effective habitat management within TNMB. Furthermore, investigating the functional significance of these morphological traits will provide valuable ecological insights. Finally, exploring the domestication potential of Piper species with desirable traits represents a promising avenue for future research.

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