

# Effects of microclimate factors on the distribution of Araceae in Kinabalu Park, Sabah, Borneo, Malaysia

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**Abstract.** Wahab R, Saibeh K. 2025. *Effects of microclimate factors on the distribution of Araceae in Kinabalu Park, Sabah, Borneo, Malaysia. Biodiversitas* 26: 3237-3245. The growth and distribution of plant species, such as Araceae, in Kinabalu Park, Sabah, Borneo, Malaysia, are influenced by the microclimatic conditions of their habitat. These microclimatic variations result from the combined effects of environmental factors, including temperature, humidity, and light intensity. Therefore, this study examined how microclimatic factors influence the habitat preferences of Araceae in Kinabalu Park through transect sampling along major trails across seven study areas. It revealed a high diversity of Araceae, with 88 species from 17 genera identified, belonging to eight tribes. The tribe Schismatoglottideae and genus *Schismatoglottis* were the most represented. While, the most abundant species was *Homalomena sagittifolia*. Species turnover was low to moderate across the study areas, as indicated by the Jaccard similarity index (23.08-56.10%). Canonical Correspondence Analysis showed that microclimatic factors significantly influenced the species distribution, with an inertia value of 84.96%. Correlation values indicated that temperature ( $r^2$ : 0.8898) and relative humidity ( $r^2$ : -0.8764) were the most significant factors. In conclusion, the Araceae species in Kinabalu Park exhibit strong adaptability to microclimatic variations driven by its complex topography. This observation underscores the ecological significance of microhabitats in promoting the diversity of Araceae species, highlighting the need for conservation strategies that account for these environmental interactions.

**Keywords:** Abiotic factors, aroids, Canonical Correspondence Analysis (CCA), protected areas, species diversity

## INTRODUCTION

Kinabalu Park, located in the Crocker Range of Malaysia, features a high-altitude habitat characterized by hilly terrain and steep slopes (Kitayama 1995). Even low-altitude habitats in the region are influenced by undulating topography and steep slopes, which shape their ecological conditions (Hayati et al. 2019). Differences in elevation and slope can create a complex microclimate, influencing the temperature, humidity, and light availability in plant habitats (Syafiq 2018; Tesha et al. 2023). These microclimatic variations have led researchers such as Rafiqpoor and Nieder (2006) and Kitayama et al. (1993) to classify forest vegetation based on altitudinal differences. Zhang et al. (2021) further emphasized that habitat slope has a significant correlation with plant species distribution and composition in mountainous regions. Quevedo-Rojas et al. (2024) also found that light intensity plays a crucial role in seedling growth due to variations in slope within the habitat. These findings underscore the significance of topography and microclimate in influencing plant distribution and growth, particularly in diverse and ecologically complex regions such as Kinabalu Park. Therefore, understanding these factors is especially critical for studying ecologically specialized plant groups, such as the Araceae family, which exhibits remarkable diversity and endemism in this region.

The taxonomy of Araceae has been extensively studied in various regions worldwide, including the Malesia region

and Sabah state, Malaysia. Wong (2016) noted that the Araceae family exhibits high diversity, with approximately 6,000 recorded species across 128 genera. Araceae represents the largest plant group in the Malesia region, with an estimated 1,200 species across more than 42 genera (Boyce and Wong 2015). In Borneo alone, 36 genera have been documented, comprising over 670 species (Boyce et al. 2010). Sabah is home to at least 114 species from 30 genera, with 52 of these species being endemic to the state (Wong and Joling 2021). Among these, Rasyidah and Saibeh (2024) highlight several notable endemic species, such as *Alocasia cuprea* and *Ooia kinabaluensis*, which can be found along the trail to the Marai Parai plateau on the northwestern side of Mount Kinabalu. Given this remarkable diversity, understanding how environmental factors influence the distribution of Araceae is crucial for effective conservation efforts, particularly for ecologically specialized groups.

In Sabah, differences in topography and altitude significantly impact the distribution of Araceae, as noted by Boyce and Wong (2013) and Wong and Boyce (2016b). Some species, such as *Alocasia reginula*, prefer shaded environments with minimal sunlight (Wong and Joling 2021), while others, such as *Pothos deleonii*, thrive in open areas with greater light exposure, commonly found in open dipterocarp forests (Medecilo-Guiang and Cabactulan 2024). High humidity and moisture availability are also essential for the physiological functions of non-woody plants, as demonstrated in *Aia tseui* and *Bau antu* (Wong

and Boyce 2024). Several studies have documented a restricted distribution of Araceae in Sabah. For example, Wong et al. (2018) reported that the genera *Bucephalandra* and *Piptospatha* are restricted to the east coast of Sabah, specifically in the towns of Tawau, Lahad Datu, and Sandakan. Meanwhile, *Ooia sayapensis* is confined to elevations above 1,000 meters (Saibeh 2023; Rasyidah and Saibeh 2024). Despite these studies, ecological and microclimatic data on Araceae habitats remain limited, creating challenges for conservation planning. This lack of comprehensive ecological data highlights the need for further research to understand better the habitat preferences and environmental adaptations of Araceae species, particularly given their restricted distribution and conservation needs (Boyce and Wong 2019).

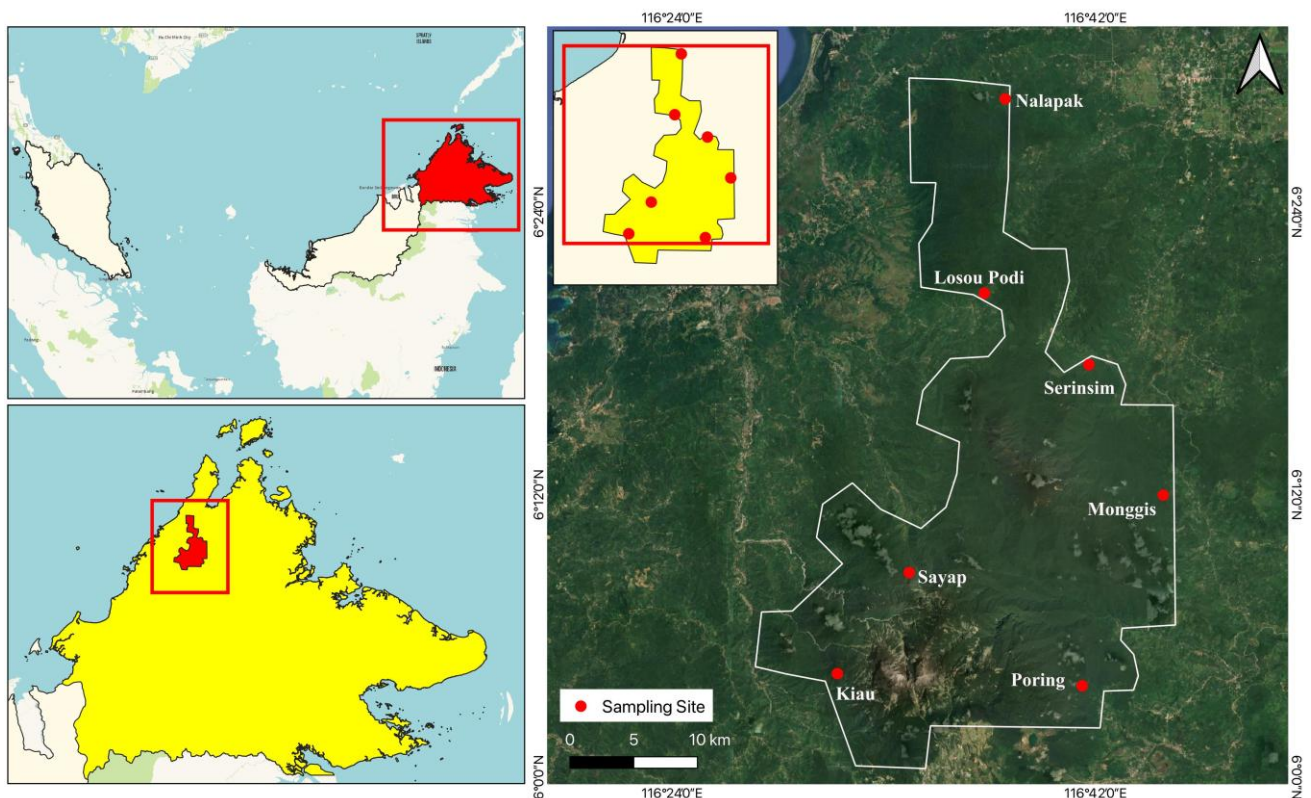
To address these gaps, Asraf-Fizree et al. (2024) emphasized the importance of understanding plant ecology and habitat to facilitate conservation and preservation efforts for individual species. Such knowledge enables ecologists to predict the environmental conditions and challenges that plant habitats may face (Liyana et al. 2020). The limited microclimatic information available from ecological studies on Araceae may pose difficulties for conservation efforts of these plants. Therefore, this study examined the microclimatic conditions of Araceae habitats and their influence on the distribution of Araceae species within Kinabalu Park. Specifically, it aimed to assess the roles of altitude, slope, temperature, humidity, and light availability in shaping the distribution of Araceae. We hypothesized that species composition of Araceae would

vary significantly along microclimatic gradients, particularly with altitude and humidity. Its findings will enhance ecological knowledge of Araceae species and contribute to a more comprehensive understanding of their environmental adaptations, thereby supporting conservation initiatives for this diverse plant family. By addressing this research gap, this study aimed to provide valuable insights into the ecological requirements of Araceae, ultimately aiding in the preservation of Sabah's unique botanical heritage.

## MATERIALS AND METHODS

### Study area

Sampling was conducted from May 29, 2023, to March 17, 2024, across seven study areas within Kinabalu Park, Sabah, Malaysia (Figure 1). The altitude varies significantly within each study area: from 550 to 1,010 meters above sea level (m asl) in Poring (6.064751°N, 116.690599°E), from 330 to 1,030 m asl in Monggis (6.1997°N, 116.74815°E), from 270 to 1,120 m asl in Serinsim (6.29203°N, 116.695454°E), from 150 to 1,130 m asl in Nalapak (6.48013°N, 116.63612°E), from 550 to 720 m asl in Losou Podi (6.342629°N, 116.621312°E), from 990 to 1,360 m asl in Sayap (6.14487°N, 116.5681°E), and from 850 to 1,800 m asl in Kiau (6.073333°N, 116.517222°E).



**Figure 1.** The location of the study areas within Kinabalu Park, Sabah, Malaysia

Officially designated a UNESCO World Heritage Site in 2000, Kinabalu Park covers an area of 75,370 hectares. It is renowned as a “home” to a diverse range of flora, including numerous species from the Araceae family (Harisin et al. 2021; Rasyidah and Saibeh 2024). According to Kitayama et al. (1993), areas of Kinabalu Park situated below 2,000 m asl are classified as lower montane forests, which Aiba et al. (2015) further characterized as mixed dipterocarp vegetation. Dipterocarp trees are recognized for their extensive canopies, which substantially reduce the amount of sunlight reaching the forest floor (Aiba and Kitayama 2020). Wong and Joling (2021) reported that most species of this family are found in areas partially shaded by the forest canopy, so this shaded environment provides a suitable habitat for Araceae species. The high vegetation density and extensive canopy cover in this forest type further influence the growth and survival of Araceae species.

Consequently, the light intensity in Araceae habitats remains relatively low, ranging between 156.62 and 459.18 Lux. Light intensity was found to correlate with both ambient temperature and relative humidity within the habitat. The recorded temperature in Araceae habitats ranges from 21.69°C to 26.21°C, while relative humidity remains consistently high, varying 82.56% to 94.71%.

## Procedures

### Data collection

The transect sampling method was applied along the 17 main trails with a width of 2 meters on each side (Harisin et al. 2021). On average, the transect lines in each study areas were 6.57 km long. The presence or absence of Araceae species found along the transect were documented. Microclimate factors were also recorded using several devices. The slope of the habitat area was measured using a Suunto clinometer. Light intensity was measured in Lux using a Lutron LX-101 Digital Lux Meter at each study area. Temperature and relative humidity data were measured using the HOBO Bluetooth MX2300 Temperature/Relative Humidity Logger. Altitude was recorded using a Garmin GPSMAP 64s GPS device. Through this sampling activity, 549 individuals were recorded along with data on their microclimate.

### Morphological identification

Key taxonomic tools, including Mayo et al. (1998), Boyce et al. (2002), (2004), et al. (2010) and Wong and Joling (2021) helped to guide fieldwork identification of Araceae species. Those who could not be precisely recognized on-site were gathered as voucher specimens. To avoid misidentification during the following identification procedures in the herbarium, paper labels were used to tag these specimens according to Bridson and Forman (1998) technique. The voucher specimens were subsequently taken to the Botany Laboratory at the Faculty of Tropical Forestry, Universiti Malaysia Sabah, Malaysia, for additional processing, which included drying and herbarium preparation. A drying was done only on whole specimens with flowers and/or fruits. Incomplete specimens were grown in the greenhouse at the Faculty of

Tropical Forestry and watched until blossoming; then they could be dried and correctly identified.

## Data analysis

Beta diversity indices rely on presence-absence data, focusing primarily on the species richness component of biodiversity. The percentage of species overlap among the study areas was assessed using a species similarity analysis with the Jaccard similarity index (Borcard et al. 2018). This analysis was based on the presence of Araceae species across the study areas.

The species distribution pattern relative to microclimatic factors was examined using ordination analysis. First, Detrended Correspondence Analysis (DCA) was performed on the main matrix data to determine the most suitable analysis model. The results showed that the standard deviation exceeded 4 on the first four DCA axes, indicating a unimodal distribution. Consequently, Canonical Correspondence Analysis (CCA) was selected for the ordination analysis to evaluate the relationship between Araceae species distribution and microclimate factors (Hayati 2021). All statistical analyses were conducted using PAST (Paleontological Statistics) software (version 4.03) (Hammer 2019).

## RESULTS AND DISCUSSION

### Species composition

The 549 samples collected in the field comprised 88 species belonging to 17 genera from eight tribes (Table 1). Tribe Schismatoglottideae was the most abundant in Kinabalu Park (Figure 2), comprising seven genera and 39 species (44.00%), followed by the tribe Monstereae, comprising three genera and 17 species (19.00%). Among these, 16 species were endemic to Sabah, including *Amorphophallus lambii*; *Homalomena kionsomensis*; and *Scindapsus kinabaluensis*. In addition, *O. sayapensis* and *O. kinabaluensis* are endemic to Kinabalu Park (Wong and Joling 2021; Saibeh 2023).

Low et al. (2018) stated that species within the Schismatoglottideae tribe exhibit some of the most diverse staminate and sterile flowers among Araceae. This clade remains highly perplexing due to its imperfect delineation despite the resolution of a well-supported corpus defined by hapaxanthic stems and containing the nomenclature type. Consequently, *Borneoa*, a new genus derived from the Schismatoglottideae tribe, was transferred from the genus *Schismatoglottis* based on a combination of molecular and morphological evidence (Wong and Boyce 2024). Many species in Sabah remain unidentified, explaining why some specimens recorded in this study could not be identified to the species level. This observation is supported by Harisin et al. (2023), who found that 7 of the 12 *Schismatoglottis* species subjected to molecular analysis are potentially new species, as they showed no match to any previously described species.

*Schismatoglottis* was the dominant genus in Kinabalu Park as shown in Figure 3, with 18 species variations (20.45%), followed by the genus *Scindapsus*, with 12

species variations (13.64%), while the genera *Borneoa* and *Homalomena* each comprised 10 species variations (11.36%). Wong and Joling (2021) reported that the genus *Schismatoglottis* had the greatest species diversity in Sabah. These findings also align with Rasyidah and Saibeh (2024), who documented *Schismatoglottis* as the most frequently recorded genus along the Marai Parai transect line. However, Zulhazman (2020) documented *Homalomena* as the most abundant genus in Kelantan state, Malaysia, with 11 species, followed by *Rhaphidophora*, with nine species. This observation is consistent with the findings of Zulhazman et al. (2021a), who found that Araceae from the lianescent (climbing herb) category, such as the genera *Pothos*, *Rhaphidophora*, and *Anadendrum*, exhibited the greatest species diversity in Lojing Highland, Kelantan.

The most frequently recorded species were *Homalomena sagittifolia* (8.38%), *Scindapsus pictus* (5.83%), and *Pothos ovatifolius* (5.10%). These species predominantly occurred on hill slopes, ranging from 26.10° to 35.80°. These sloped habitats received relatively low light intensities, ranging from 313.9 to 350.5 Lux, and maintained high relative humidity levels, ranging from 89.13% to 91.35%. The number of species recorded in this study exceeds the 31 species documented in the herbarium records by Wong and Joling (2021), which listed species from 10 genera within Kinabalu Park. However, Harisin et al. (2021) and Saibeh (2023) added four additional species to this list, bringing the total number of recorded species in Kinabalu Park to 35 prior to this study. The diversity of Araceae in Kinabalu Park is also significantly greater than in Kelantan, where Zulhazman (2020) recorded only 57 species from 18 genera. This comparison highlights differences in species and genera between the two states, such as *Aglaonema pumilum* and *Aglaonema cochinchinense*, which are found in Kelantan but absent in both Kinabalu Park and Sabah. Additionally, the genera *Ooia* and *Bau* are not present in Kelantan but can be found

in Sarawak state, Malaysia (Wong and Boyce 2024). Sarawak and Sabah share some similarities in the genera present (Boyce et al. 2010).

This study documented several new records of wild Araceae (Table 1). One new record is the genus *Bucephalandra* sp. found in the Marai Parai area, as it had only previously been recorded in Sandakan and Lahad Datu, with species *Bucephalandra ultramafica* and *Bucephalandra danumensis* (Wong and Boyce 2014; Wong et al. 2018). This study also documented several new records of species: including *Homalomena simunii* and *H. kionsomensis*. *Homalomena simunii* had only previously been recorded in Tawau, Pensiangan, and Sandakan (Wong and Joling 2021), while *H. kionsomensis* had only previously been recorded in Inanam, Kota Kinabalu (Saibeh et al. 2015).

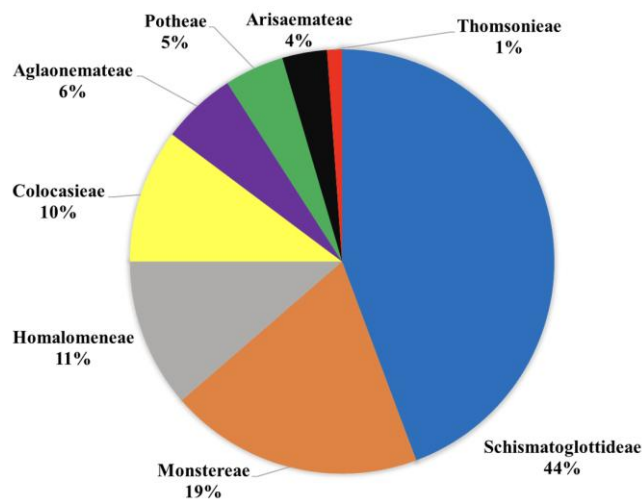


Figure 2. The percentage of genera in the tribe

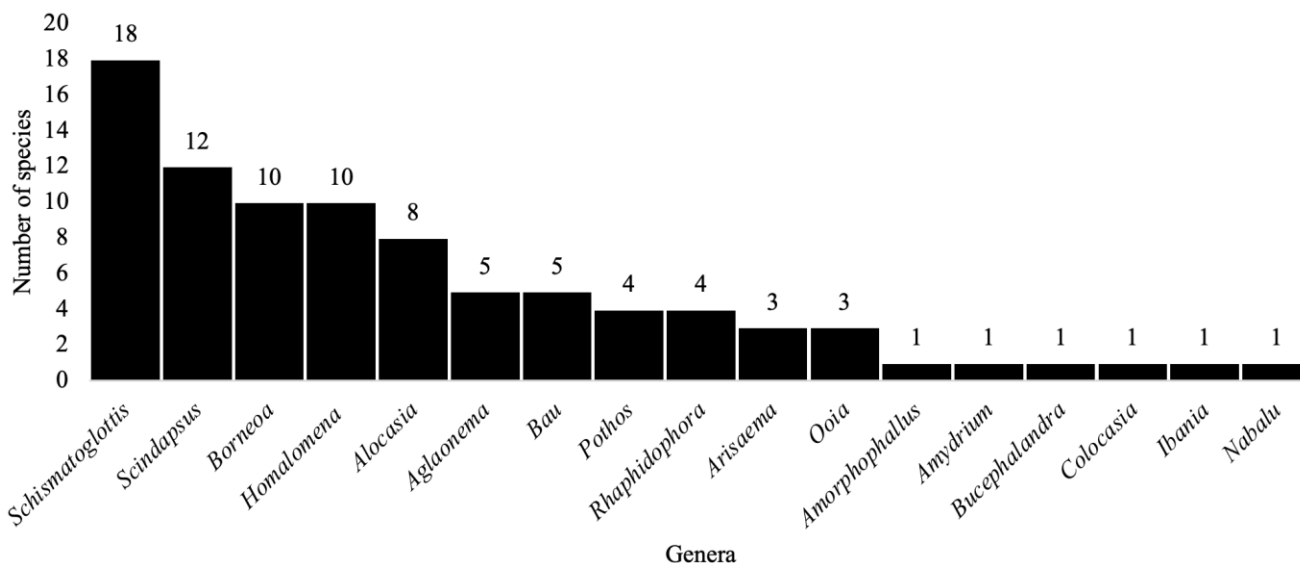


Figure 3. Total genera of Araceae in Kinabalu Park, Sabah, Malaysia

**Table 1.** List of Araceae in Kinabalu Park, Sabah, Malaysia

No.	Species	No.	Species
1	<i>Aglaonema nitidum</i> (M, N, R, E)	45	<i>Homalomena terajaensis</i> (N)
2	<i>Aglaonema simplex</i> (Y)	46	<i>Ibania</i> sp. 1 (K, D, R, Y, E)
3	<i>Aglaonema</i> sp. 2 (M, N)	47	<i>Nabalu corneri</i> (K, M, N, Y, E)
4	<i>Aglaonema</i> sp. 3 (N, D)	48	* # <i>Ooia kinabaluensis</i> (K, R)
5	<i>Aglaonema</i> sp. 4 (N)	49	* # <i>Ooia sayapensis</i> (K, Y)
6	<i>Alocasia beccarii</i> (K, N, Y)	50	<i>Ooia</i> sp. 3 (M)
7	* <i>Alocasia cuprea</i> (K, M, Y, E)	51	<i>Pothos barberianus</i> (D, Y)
8	<i>Alocasia princeps</i> (R, Y)	52	<i>Pothos insignis</i> (M, N, D, R, Y, E)
9	<i>Alocasia principulus</i> (K, M, N, Y)	53	<i>Pothos ovatifolius</i> (K, M, N, D, R, Y)
10	<i>Alocasia robusta</i> (M, N)	54	<i>Pothos</i> sp.1 (K, Y)
11	<i>Alocasia sarawakensis</i> (M, N, D)	55	<i>Rhaphidophora foraminifera</i> (K, M, N, D, Y, E)
12	<i>Alocasia scabriuscula</i> (E)	56	<i>Rhaphidophora korthalsii</i> (K, M, N, D, R, Y)
13	* <i>Alocasia wongii</i> (K, M, N, D, R, Y, E)	57	<i>Rhaphidophora</i> sp. 1 (K, N)
14	* <i>Amorphophallus lambii</i> (K, M, N, D, R, Y, E)	58	<i>Rhaphidophora</i> sp. 2 (R)
15	<i>Amydrium medium</i> (K, M, N, D, R, E)	59	<i>Schismatoglottis ahmadii</i> (K, M, N, R, Y)
16	<i>Arisaema filiforme</i> (K, N, Y, E)	60	<i>Schismatoglottis calyprtrata</i> complex sp. 1 (R)
17	<i>Arisaema laminatum</i> (M, N)	61	<i>Schismatoglottis calyprtrata</i> complex sp. 2 (R)
18	<i>Arisaema umbrinum</i> (K, Y, E)	62	<i>Schismatoglottis calyprtrata</i> complex sp. 3 (E)
19	<i>Bau</i> sp. 1 (M, D, E)	63	<i>Schismatoglottis calyprtrata</i> complex sp. 4 (R)
20	<i>Bau</i> sp. 2 (R)	64	<i>Schismatoglottis calyprtrata</i> complex sp. 5 (R, Y)
21	<i>Bau</i> sp. 3 (K)	65	<i>Schismatoglottis clemensorum</i> (K)
22	<i>Bau</i> sp. 4 (K)	66	* <i>Schismatoglottis moodii</i> (K, M, N, R, Y)
23	<i>Bau</i> sp. 5 (K, M, D)	67	<i>Schismatoglottis motleyana</i> (D, R, Y, E)
24	* <i>Borneoa mons</i> (K, Y)	68	<i>Schismatoglottis trifasciata</i> complex sp. 1 (D)
25	<i>Borneoa scortechinii</i> (K)	69	<i>Schismatoglottis trifasciata</i> complex sp. 2 (K, M, N, D, R, Y, E)
26	<i>Borneoa</i> sp. 1 (D, E)	70	<i>Schismatoglottis trifasciata</i> complex sp. 3 (D, R, Y)
27	<i>Borneoa</i> sp. 2 (R)	71	<i>Schismatoglottis trifasciata</i> complex sp. 4 (D)
28	<i>Borneoa</i> sp. 3 (N)	72	<i>Schismatoglottis trifasciata</i> complex sp. 5 (R, Y)
29	<i>Borneoa</i> sp. 4 (M, E)	73	<i>Schismatoglottis trifasciata</i> complex sp. 6 (K, M, Y)
30	<i>Borneoa</i> sp. 5 (K)	74	<i>Schismatoglottis trifasciata</i> complex sp. 7 (Y)
31	<i>Borneoa</i> sp. 6 (K)	75	<i>Schismatoglottis trifasciata</i> complex sp. 8 (M, N)
32	<i>Borneoa</i> sp. 7 (D)	76	* <i>Schismatoglottis wongii</i> (Y)
33	* <i>Borneoa zainuddinii</i> (K)	77	<i>Scindapsus coriaceus</i> (Y)
34	<i>Bucephalandra</i> sp. (K)	78	* <i>Scindapsus kinabaluensis</i> (K, Y)
35	* <i>Colocasia oresbia</i> (K, M, R, Y)	79	<i>Scindapsus longipetiolatus</i> (K)
36	* <i>Homalomena gillii</i> (Y)	80	<i>Scindapsus longistipitatus</i> (K, N, D, R, Y)
37	<i>Homalomena havilandii</i> clade sp. 1 (K, D, R, Y)	81	<i>Scindapsus pictus</i> (K, M, N, R, Y, E)
38	<i>Homalomena havilandii</i> clade sp. 2 (M, N, D)	82	<i>Scindapsus</i> sp. 1 (R)
39	<i>Homalomena havilandii</i> clade sp. 3 (K, Y)	83	<i>Scindapsus</i> sp. 2 (M)
40	* <i>Homalomena kionsomensis</i> (K, M, N, R, Y, E)	84	<i>Scindapsus</i> sp. 3 (M)
41	* <i>Homalomena marasmiiella</i> (N, Y, E)	85	<i>Scindapsus</i> sp. 4 (Y)
42	* <i>Homalomena portae-inferni</i> (Y)	86	<i>Scindapsus</i> sp. 5 (E)
43	<i>Homalomena sagittifolia</i> (K, M, N, D, R, Y, E)	87	<i>Scindapsus</i> sp. 6 (R)
44	* <i>Homalomena simunii</i> (R, Y)	88	<i>Scindapsus treubii</i> (K, M, N, Y, E)

Note: \*: Endemic species to Sabah (Wong and Joling 2021), #: Endemic to Kinabalu Range (Saibeh 2023). K: Kiau, M: Monggis, N: Nalapak, D: Losou Podi, R: Poring, Y: Sayap, E: Serinsim

The  $S_j$  analysis based on species presence across study areas, revealed a low to moderate similarity, ranging from 23.08% to 56.10% (Figure 4). The species similarity was greatest between Nalapak and Monggis and lowest between Losou Podi and Kiau. The  $S_j$  reflects the presence or absence of species across different study areas, as described by Theron et al. (2020). The low-to-moderate  $S_j$  values among the study areas indicate high Araceae species diversity (Ifo et al. 2016), suggesting that most Araceae species do not turn over rapidly across study areas, with certain species being restricted to specific areas (Sharma et al. 2022). Furthermore, Wang (2023) noted that low-to-moderate species similarity between study areas also indicates differences in habitat environments across them.

Notably, only four species were found in all study areas: *Alocasia wongii*, *A. lambii*, *H. sagittifolia*, and *Schismatoglottis trifasciata* complex sp. 2. In contrast, several species exhibited highly localized distributions, such as the genus *Bucephalandra* sp., which was recorded exclusively in Kiau, and *Homalomena portae-inferni*, which was recorded exclusively in Sayap.

#### Effects of microclimate factors on the distribution of species

The inertia value obtained for microclimate was high (84.96%), indicating that microclimate factors strongly influence the distribution of Araceae species in Kinabalu Park. In the CCA, the eigenvalue was 0.2628 (33.01%) for

axis 1 (CCA1) and 0.2364 (29.69%) for axis 2 (Table 2). The total percentage of eigenvalues for the two axes was 62.70%, indicating that more than half of the variation is constrained. This finding suggests that the two axes effectively explain the relationship between Araceae species and microclimate factors present in Kinabalu Park.

CCA1 is strongly influenced by temperature ( $r^2$ : 0.8898), altitude ( $r^2$ : -0.7803), and slope ( $r^2$ : -0.7044). In contrast, CCA2 was strongly influenced by humidity ( $r^2$ : -0.8764). The distribution of most Araceae species in Kinabalu Park is closely associated with high to medium altitude, moderate to low temperature, medium to low humidity, medium to low light densities, and gentle to moderate slopes. As shown in Figure 5, several species associated with these conditions, including *Schismatoglottis moodii*, *O. sayapensis*, *Arisaema filiforme*, *Borneoa mons*, and *A. cuprea*. However, some species, such as *Pothos insignis*, *Borneoa* sp. 1, and *Schismatoglottis motleyana*, are more commonly found in low-altitude areas with high ambient temperature, low humidity, gentle slopes, and low light intensity.

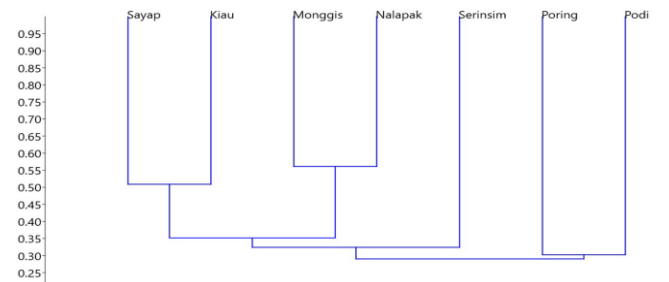
Different microclimatic factors influence the habitats across the study areas; high altitudes and lower temperatures characterize those in Kiau and Sayap. Kiau was associated with species such as *Alocasia beccarii*, *Pothos* sp. 1, and *Arisaema umbrinum*. In contrast, Sayap was associated with species such as *O. sayapensis*, *B. mons*, *Alocasia princeps*, and *Schismatoglottis calypttrata* complex sp. 5. Habitats in Monggis were characterized by high relative humidity and associated with species such as *Aglaonema* sp. 2, *Alocasia sarawakensis*, and *Borneoa* sp. 4. Lower altitudes characterized habitats in Nalapak and Serinsim. Nalapak was associated with species such as *Aglaonema nitidum* and *Alocasia robusta*. In comparison, Serinsim was associated with species such as *Bau* sp. 5, *Amydrium medium*, and *H. simunii*. High temperatures, low relative humidity, and low light intensity characterized habitats in Losou Podi and Poring. Losou Podi was

associated with species such as *S. motleyana* and *Borneoa* sp. 1, while Poring was associated with the species *H. sagittifolia*, *S. trifasciata* complex sp. 2, and *Scindapsus longistipitatus*. Figure 5 further supports the uneven distribution of Araceae species across the study areas, as evidenced by the low-to-moderate  $S_j$  values.

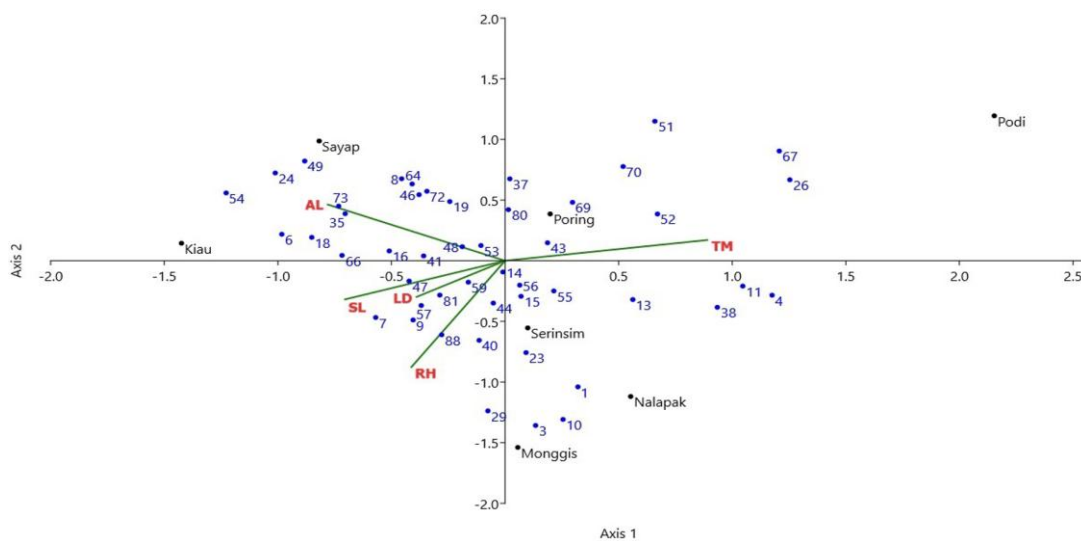
**Table 2.** CCA statistical results of Araceae species and microclimate factors

	CCA1	CCA2
Eigenvalue	0.2628	0.2364
Inertia %	0.3301	0.2969
Proportion	0.2805	0.2522
Cumulative proportion	0.2805	0.5327
Light density	-0.3896	-0.2982
Temperature	0.8898	0.1708
Relative Humidity	-0.4124	-0.8764
Altitude	-0.7803	0.4631
Slope	-0.7044	-0.3184

Note: Permutation trace-p: 0.088



**Figure 4.** Jaccard similarity index ( $S_j$ ) of Araceae between study areas



**Figure 5.** CCA diagram of Araceae species and microclimate factors in Kinabalu Park, Malaysia. Note: AL: Altitude (m asl), SL: Slope ( $^{\circ}$ ), LD: Light Density (Lux meter), TM: Temperature ( $^{\circ}$ C), RH: Relative Humidity (%). All numbers represent species, as stated in Table 1

In addition to illustrating the influence of microclimatic factors on species distribution, Figure 5 also highlights the correlation between these factors within Araceae habitats. Altitude and slope gradient correlate positively with light intensity and humidity but negatively with temperature. Therefore, species diversity is shaped by multiple abiotic factors. Zhang et al. (2021) and Gemeda (2024) indicated that slope gradient and altitude significantly influence species distribution, growth, and composition. Furthermore, seedling germination and growth depend on light availability, which varies according to the slope gradient (Quevedo-Rojas et al. 2024). Sloped habitats with rocky soil improve water drainage in Araceae habitats (Boyce and Wong 2015; Wang et al. 2022) while helping maintain cellular hydration in Araceae plants (Norhazlini et al. 2024). Saibeh (2022) also found that sloped habitats provide suitable conditions for several creeping and climbing Araceae species. Moreover, Zulhazman (2020) reported a significant relationship between Araceae species and microhabitats, with 44.1% of recorded species in Kelantan occurring in sloped environments. Similarly, Liyana et al. (2020) reported that slope gradients influenced the distribution of three *Homalomena* species. These studies suggest that some species rely on sloped habitats for optimal growth and development. Consequently, variations in habitat topography across regions may explain the similarities and differences in their genera and species (McNichol et al. 2024), as topographical diversity creates favorable environmental conditions for Araceae growth (Boyce et al. 2010).

Zhang et al. (2021) also reported a positive correlation between altitude and slope. Our findings suggest that the altitudinal range in Kinabalu Park offers an optimal habitat for Araceae. Quevedo-Rojas et al. (2024) emphasized that the altitude gradient creates diverse microclimatic conditions that support plant growth and ecological persistence. Therefore, Heng et al. (2017) stated that high-altitude areas such as Kinabalu Park, can serve as seed and gene banks for plants like Araceae. However, other studies, including Zulhazman (2020) and Asraf-Fizree et al. (2024), indicated that increasing altitude significantly reduces both the species diversity and abundance of Araceae. This observation is supported by Jaiswal and Jayakumar (2024), who found that species richness is influenced by altitude. Similarly, Mohd-Zubir et al. (2024) found that increasing altitude and decreasing temperature limited the distribution of certain species, as not all plants can adapt to lower temperatures.

Araceae species thrive in high ambient humidity, which is crucial for reducing water loss from vegetative cells (Clements 1907). As predominantly water-dependent plants (Norhazlini et al. 2024), Araceae rely on high humidity to maintain tissue integrity and plant shape (Schwerbrock and Leuschner 2016). Acebey et al. (2010) recorded many Araceae species in Bolivia's humid forests. Similarly, Asraf-Fizree et al. (2024) found that *Arisaema* populations were abundant in the humid environment of the Brinchang Forest, Pahang, Peninsular Malaysia. These observations are consistent with this study, which indicates that the Araceae species in Kinabalu Park are closely associated

with relative humidity. Mountainous areas with low temperatures and reduced evaporation rates provide a suitable habitat for Araceae due to their high humidity levels (Lolila et al. 2023).

Relative humidity is influenced by the amount of radiation reaching the forest floor, which, in turn, affects the habitat's ambient temperature. A denser canopy can block sunlight from reaching the forest floor, creating a cooler microclimate (Greiser et al. 2024). According to Kokila et al. (2024), sunlight accelerates soil evaporation, particularly in areas with a more open canopy. However, excessive light intensity is unsuitable for the growth of all plant species, as it disrupts their physiological processes (Benkert et al. 1995). Zulhazman et al. (2021b) found that most Araceae species prefer shaded environments to avoid direct sunlight. Nevertheless, Araceae requires a sufficient amount of light for optimal growth. Wong and Joling (2021) also noted that in Sabah, Araceae habitats are typically found in slightly open areas near water sources, which help maintain high humidity levels. Furthermore, several Araceae species exhibit strong rheophytic tendencies, meaning they are adapted to grow in or near a stream. Wong and Boyce (2016a, b), Wong et al. (2018), and Saibeh (2023) have documented the occurrence of rheophytic Araceae species, including *O. sayapensis*, *Ooia ulusenagangensis*, *Bucephalandra* sp., and *Piptospatha* sp., along rivers and streams. This study supports these findings, demonstrating that distinct microclimatic factors influence the distribution of different Araceae species in Kinabalu Park. These variations in environmental conditions shape species distribution patterns and highlight the intricate ecological interactions within Araceae habitats in Kinabalu Park.

Kinabalu Park is a fully protected area under the jurisdiction of Sabah Parks, in accordance with the Parks Enactment 1984 (Act Sabah No. 6 of 1984; 2007 Amendment) (State of Sabah 1984). According to the same enactment, the collection of any flora or fauna within the park boundaries is considered an offense. This regulation applies to all species found within the park, including wild Araceae. However, wild Araceae are not classified as protected species under Malaysia's Act 686 or the Sabah Wildlife Conservation Enactment 1997 (Sabah Wildlife Department 1997; Malaysia Law 2008). To raise public awareness, especially among local communities, Sabah Parks has actively conducted a range of seminars, training sessions, educational programs, and awareness campaigns focused on the importance of preserving and protecting native flora and fauna. In addition, regular patrols along the Kinabalu Park boundary are carried out by park staff to prevent unauthorized entry by community members. Sabah Parks has also collaborated with local communities by appointing community members as Honorary Rangers. These rangers assist in conducting patrol and enforcement activities and serve as important liaisons to facilitate the flow of information between park authorities and the community.

In conclusion, this study reveals that Kinabalu Park harbors a high diversity of Araceae species, totaling 88 species from 17 genera. This finding highlights a

significant correlation between the distribution of Araceae species and microclimatic factors in Kinabalu Park, with temperature ( $r^2$ : 0.8898) and relative humidity ( $r^2$ : -0.8764) playing a crucial role in shaping their growth. Furthermore, this study highlights the significance of microclimatic conditions in influencing habitat preferences, as indicated by the low-to-moderate  $S_j$  value (23.08-56.10%) and CCA analysis (inertia: 84.96%), suggesting a spatial turnover of Araceae across the study areas. The Araceae species in Kinabalu Park exhibit remarkable adaptability to variations in microclimatic conditions. Understanding these ecological relationships is essential for the effective conservation and management of these species. Overall, this study reinforces the critical role of microclimatic factors in sustaining Kinabalu Park's rich biodiversity, as each Araceae species is influenced by distinct environmental conditions that support its growth and long-term survival.

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