Tropical Forestry | SHORT COMMUNICATION DOI: 10.xxxx/ft.xxxx.xxxxxxx

Visitor insects of *Ooia* spp. (Araceae) at Kinabalu UNESCO Global Geopark, Sabah, Malaysia

Naufal Wafi Jimran[1], Kartini Saibeh[1]

[1]Faculty of Tropical Forestry, Universiti Malaysia Sabah, Malaysia

***Corresponding author:** k_saibeh@ums.edu.my

Received: 22/06/2025 Accepted: 09/12/2025 Published: 30/01/2026

Abstract

The study was conducted in Kinabalu UNESCO Global Geopark, specifically at Sayap and Poring substations, to observe the interactions of insect visitors with two species of *Ooia* (Araceae). This study aimed to observe and identify the visitor insects, analyze the overlap of insect visitors, and compare the number of insect visits received by the two species. Two days of direct observations for both species were conducted, starting from 8:00 AM until 6:00 PM with two-hour gap for each observation census. A total of 167 individual insects were recorded, consisting of six families including Staphylinidae, Erotylidae, Blattidae, Formicidae, Vespidae, and Drosophilidae. The data analysis showed a significant difference in visiting insects between the two *Ooia* species on Day 1 ($W = 0$), but no significant difference on Day 2 ($W = 7.5$). Furthermore, the visitation rate on *O. sayapensis* was higher (Day 1= 24.16% and Day 2= 17.97%) than on *O. kinabaluensis* (Day 1= 11.67% and Day 2= 15.83%) respectively. This study will provide the fundamental source of data on visitor insects of *Ooia* species within its habitat.

Keywords: Araceae, Borneo, *Ooia*, Visitor insects

1 Introduction

The Araceae family, also known as the aroids, is a highly diverse group of flowering plants, comprising over 144 genera and more than 3,645 species to date (Ortiz et al., 2019; Saibeh, 2023). These plants are mainly found in tropical and subtropical regions while some of them can adapt to extreme climates (Mayo et al., 1997; Croat & Ortiz, 2020). Araceae characterized as monocots, exhibit only one embryonic leaf (Henriquez, 2015; Mir, 2020). The hallmark of Araceae is called a spadix, which consists of tiny flowers covering a fleshy spike and is often surrounded by a spathe, a modified leaf (Mayo et al., 1998; Broderbauer et al., 2012). Due to their unique life forms and complex ecology, this family inhabits a wide range of habitats, from dry tropical zones to pluvial rainforests, subarctic wetlands, tropical swamps, cloud forests, high-mountain plains, and coastal areas ranging from semi-arid to arid (Croat T. B., 1988; Croat & Ortiz, 2020).

Araceae has a variety of pollination mechanisms, including trapping insects within the flower structure to ensure effective pollen transfer (Broederbauer et al., 2012). Some plant species of Araceae produce strong odors, ranging from sweet to foul-smelling, to attract visitor insects that mainly feed on decaying organic matter, such as flies and dung beetles (Etl et al., 2022). These strategies enhance the chance of pollination while reducing reliance on general pollinators, including flies, thrips, beetles, true bugs, and moths (Broderbauer et al., 2012; Etl et al., 2022). The co-evolution between Araceae plants and visitor insects demonstrates the complexity of insect and plant interactions. Many species rely on insects, including beetles and flies, as pollinators, and the movement of the spathe during the flowering cycle helps attract these entomophilous pollinators (Chouteau et al., 2008). Therefore, understanding this interaction is essential for studying plant reproductive ecology, their potential for biodiversity conservation, and the evolution of specialized pollination systems.

Insects and flowering plants have developed diverse mutualistic interactions, shaping both adaptations and diversity (Bronstein et al., 2006). To attract pollinators and detect the presence of flowers, plants advertise their flowers. The advertisement, or floral display, can take the form of visual cues (color and shape) and olfactory cues (scents) (Miyake & Yafuso, 2003). Although it is difficult to determine which advertisement has a greater influence on pollination, each floral display seems to correlate with the other rather than dominate one another. First, scents are produced by petals and/or androecium (Araceae: *Anthurium* sp., and *Philodendron* sp.), showing the correlation between the two displays. Second, the manipulation of scent production itself can affect the visual display of the flowers, reflecting flower phenology. In the meantime, insects take advantage of plants for food sources and shelters for reproductive sites, indirectly benefiting the plant itself (Crepet & Niklas, 2009). This evolutionary relationship plays a significant role in maintaining the functional integrity of most terrestrial ecosystems (Ollerton et al., 2011). Therefore, studying visitor insects can help in conservation planning, especially for rare or endangered plant species that rely on specialized pollinators (Saikim et al., 2020).

Ooia S.Y.Wong & P.C.Boyce (Araceae) provides an ideal opportunity to study the above matter. It is a flowering plant in the Araceae family of Schismatoglottideae that is found mostly in Borneo and Southeast Asia, often in shaded areas, slow-flowing streams and riparian environments. The *Ooia* genus was derived from *Piptospatha* N.E.Br. based on key morphological and genetic differences (Wong & Boyce, 2010). The reclassification of *Ooia* helped clarify the evolutionary relationships within Araceae by improving our understanding of the plant family's diversity and their adaptation to specific ecological niches. Although the floral display is mostly the same in some species (Figure 1), Saibeh (2023) diagnosed a difference in the olfactory cues of *Ooia sayapensis* Kartini and *O. kinabaluensis* (Bogner) S.Y.Wong & P.C.Boyce. Currently, the genus comprises 12 species where *O. sayapensis* and *O. ulusenagangensis* Kartini are the newer recorded species in Sabah (Wong & Boyce, 2016; Saibeh, 2023). It features elongated or shield-shaped leaves, a spathe that surrounds the spadix remains intact longer than in *Piptospatha* species (Wong & Boyce, 2010).

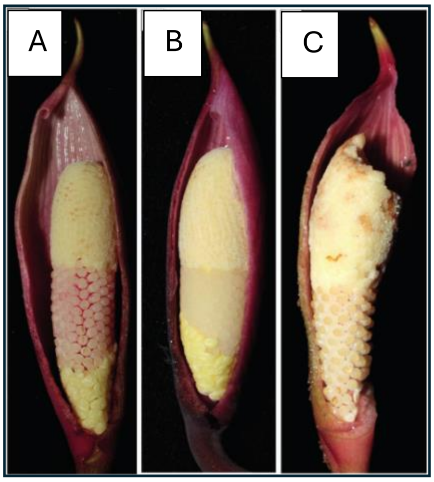

Figure 1: Spadices of *Ooia* compared – A) *O. sayapensis*, B) *O. ulusengangensis,* and C) *O. kinabaluensis*. – All photographs by Kartini Saibeh.

This study aims to observe insect visitors, determine the differences in visiting insects, and analyze the visitation rates for both *O. sayapensis* and *O. kinabaluensis*.

2 Materials & Methods

2.1 Study area

The study area was conducted in Kinabalu Geopark, specifically at the Sayap Substation (Kota Belud) and the Poring Substation (Ranau). The Sayap Substation is located north of Mount Kinabalu, 30 km away from the nearest town in Kota Belud. The population of *O. sayapensis* is found near the Kemantis River at coordinates N6°9'51.363", E116°33'55.888" (993 m.a.s.l.), mainly in mossy forest, with trekking paths starting about 900 m from the main camp of the Sayap Substation. *Ooia kinabaluensis* is found at the Langanan waterfall at coordinates N5°53'52.913", E116°40'10.588" (986 m.a.s.l.), dominated by lowland tropical forest, with trekking paths approximately 4,000 m from the main Poring hot spring. *Ooia* species were sampled within a 10 m radius of the trekking paths in both study areas.

2.2 Methods

The study was conducted between August 15 and August 20, 2023. Direct observations were made for both species over two days, from 8:00 a.m. until 6:00 p.m. with a two-hour gap for each census period: 8:00-9:00 a.m., 11:00 a.m.-12:00 p.m., 2:00-3:00 p.m., and 5:00-6:00 p.m. Three or more inflorescences were randomly marked for observation purposes of *O. sayapensis* and *O. kinabaluensis*. The observation distance was at least one meter away from the plant. A Nikon D3000 with a kit lens was used to photograph the observed plant, inflorescence morphology, and the visitor insects that physically interacted with the sexual parts (spadices) of the plant species.

Observations were repeated four times a day assuming that each census period captured new individual insects. The number of visitor insects was counted within each observation period (60 minutes), with data collection occurring at intervals. Insects were sampled using a pooter and placed into a sealed container with 70% ethanol. Any insects that escaped from the pooter were noted and described on the spot. Specimens of the plant species under investigation were collected for later identification. The collected specimens were identified to the family level, the lowest possible taxonomic level allowed by available literature. This method was adapted from Kanstrup, Dawood, Ming, & Bangilon (2003).

Data analysis using the Wilcoxon Signed-Rank test was conducted to analyze the overlap of visiting insects between the two plant species. To determine the difference in the number of visits received by each species from insect, the following equation was utilized (Rodriguez-Pena & Wolfe, 2023):

$$Visitation\ Rate\ (\%) = \frac{number\ of\ visitor\ insects}{Total\ of\ observation\ period\ in\ minutes} \times 100 \quad (1)$$

In this study, the number of visiting insects was counted per plant during each observation session. The counts were then divided by the total observation period in minutes and multiplied by 100 to express the visitation rate as a percentage. Three plants were observed for each species, so the visitation rates were averaged across plants to obtain a species-level visitation rate per day.

3 Results

3.1 Floral traits

The blooming inflorescence was the only observation, either in the early stage of anthesis or the late stage of anthesis. The spadix was mostly 2.5 cm long with a cylindrical shape and adnate to the base of the spathe. The inflorescence of the observed species and the presence of insect visitors are presented in Figure 2. A faint, ripe fruit odor was noticeable up to 4 cm away from the flower from 8:00 a.m. until 12:00 p.m. for both observed species. Perceived through wafting scent, the strength and profile of the odor remained the same throughout the observation periods.

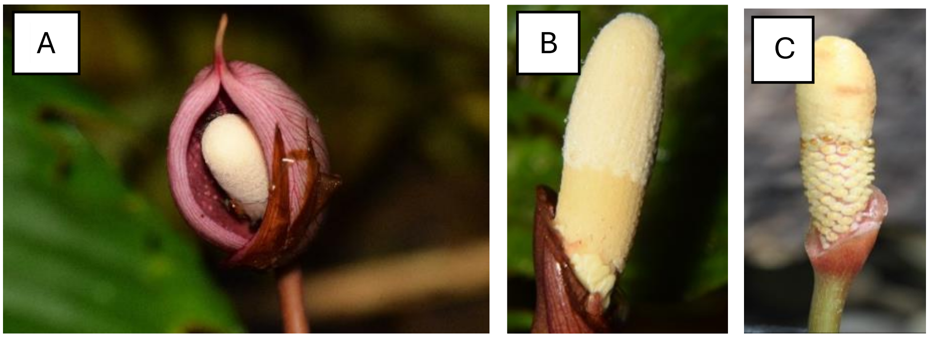

Figure 2: Inflorescences - A) during anthesis, B) Inflorescence of *O. sayapensis* at the onset of pistillate anthesis (spathe artificially removed), C) Inflorescence of *O. kinabaluensis* at the onset stage of pistillate anthesis - All photographs by Naufal Wafi.

3.2 Insect counts

Observed visitor insects were recorded mainly in the interaction with the plant inflorescence. Total of 167 individual of insect were recorded: 101 individuals from *O. sayapensis*, and 66 individuals from *O. kinabaluensis*. Four insect orders were recorded and consist of six families: Staphylinidae, Erotylidae, Blattodea, Formicidae, Vespidae, and Drosophilidae. The visitation of insect was seen more on *O. sayapensis*; a total of 58 individuals on day 1, and total of 43 individuals on day 2; while *O. kinabaluensis* recorded; a total of 28 individuals on day 1, and a total of 38 individuals on day 2. For *O. sayapensis*, there was no significant difference in insect visitors on the two days of observation, while *O. kinabaluensis* had a slight difference in visitor insects on the second day of observation. The visitor insects for both species of *Ooia* differ slightly, with the lack of Blattodea presence on *O. kinabaluensis*. The number of visitor insects for *O. sayapensis* was mainly dominated by Staphylinidae (Day 1=23 and Day 2=20), while *O. kinabaluensis* was dominated by Drosophilidae (Day 1=10 and Day 2=23) and Staphylinidae (Day 1=9 and Day 2=10). The number of visitors for both plant species is presented (Table 1 & Table 2).

Table 1: The number of individuals observed on *Ooia sayapensis* in Sayap Substation

Orders	Family	Day-1	Day-2
Coleoptera	Staphylinidae	23	20
	Erotylidae	5	6
Blattodea	Blattidae	2	1
Hymenoptera	Formicidae	11	4
	Vespidae	4	2
Diptera	Drosophilidae	13	10
Total		58	43

 DOI: 10.xxxx/ft.xxxx.xxxxxxx

Table 2: The number of individuals observed on *Ooia kinabaluensis* in Poring Substation.

Orders	Family	Day-1	Day-2
Coleoptera	Staphylinidae	9	10
	Erotylidae	2	0
Blattodea	Blattidae	0	0
Hymenoptera	Formicidae	4	2
	Vespidae	3	3
Diptera	Drosophilidae	10	23
Total		28	38

3.3 Insect behaviours

Most of the insects were observed interacting with the outer side of the spathe (Figure 3), engaging in activities such as moving, munching, and resting. Smaller insects, such as Staphylinidae and the larval stage of Drosophilidae, were seen on the inner side of the spathe. Blattodea and Erotylidae were observed munching or eating the inflorescence at the onset and later stages of the anthesis. Hymenoptera were observed on the higher side of the riverbank with minimal water stream disturbance. The availability of insect interaction is presented in this study (Table 3).

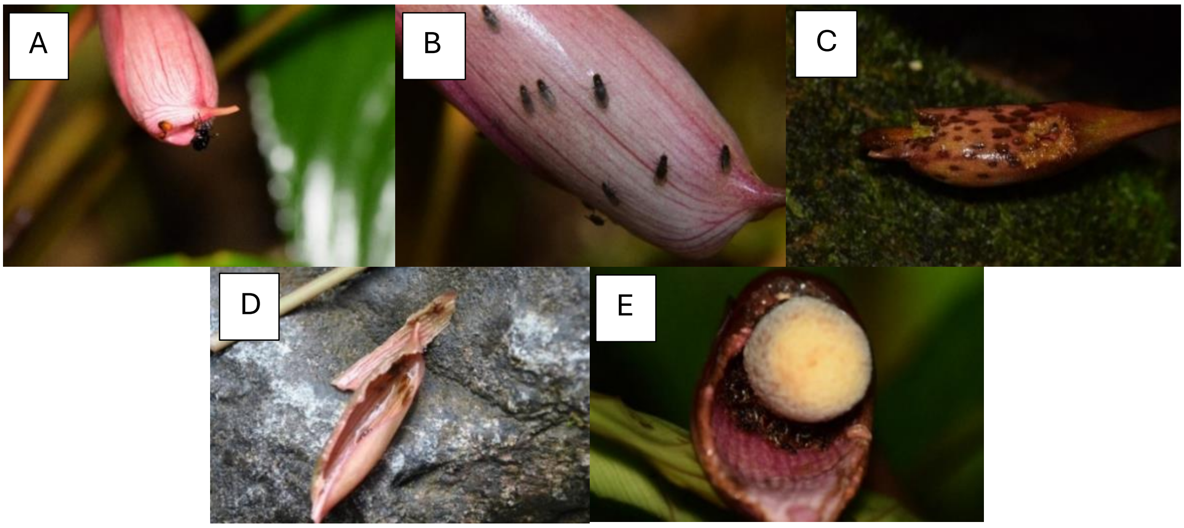

Figure 3: Insect activities – A) a beetle resting on the spathe, B) fruit flies during the anthesis, C) the spathe was eaten by Blattodea, which naturally exposed the spadices in the late stage of anthesis, D) pupae of fruit flies were discovered inside the spathe, E) a large number of Staphylinidae exhibited crowding and feeding behaviour on the lower part of the spadix.

Table 3: Interaction of visitor insects with the plant's florescence.

Insects		Observation		
		Outer side of spathe	Inner side of spathe	Reason/Explanation
Coleoptera	Staphylinidae	/	/	As the spathe opens, the Staphylinidae spreads from the tip to the base of the spadix.
	Erotylidae	/		Munching on the spathe and spadix
Blattodea	Blattidae	/	/	
Hymenoptera	Formicidae	/		Moving from the ground to the spathe, but never seen inside it (the observed plant was on the higher side of the riverbank with minimal disturbance from the stream water). After the spathe was removed artificially, then there is interaction with the spadix.
	Vespidae	/		Flying near the spathe, they sometimes stop by the opening before flying away again. The plant observed was also located on the higher side of the riverbank.
Diptera	Drosophilidae	/	/	Flying around and stopping by the spathe (the larval stage was found on the inner side of spathe).

3.4 Statistical outputs

Based on the Wilcoxon Signed-Rank data analysis (Table 4) on Day 1, the computed statistic value ($W = 0$) is equal to the critical value at $\alpha = 0.05$. Thus, there was a significant difference ($W = 0$) in visitor insects for both species on Day 1. On Day 2, the computed statistic ($W = 7.5$) is larger than the critical value, thus, there is no significant difference ($W > 0$). Equation 1 was used to calculate the visitation rate and compare the number of visits from insects to the two plant species: *Ooia* *sayapensis* (Day 1= 24.16% and Day 2= 17.97%) is presented in Table 5, and *O. kinabaluensis* (Day 1= 11.67% and Day 2= 15.83%) is presented in Table 6.

Table 4. Wilcoxon data analysis for both *Ooia* species, to determine the difference of visitor insects on Day 1 and Day 2.

Wilcoxon Signed-Rank Test	Day 1	Day 2
Total of Positive Rank	21	13.5
Total of Negative Rank	0	7.5
Compute statistic (*W*)	0	7.5
Critical value (*W*crit)	0	
Conclusion	Reject null hypothesis (H°), there is a significant difference.	Fail to reject null hypothesis, there is no significant difference.

*Sample size (n) = 6 (insect families). For a Wilcoxon Signed-Rank test with n = 6 at α = 0.05, the critical value is *W*crit = 0. The computed statistic (*W*) is the smallest of the rank numbers between the total of positive and negative ranks.
H°: There is no significant difference in visitor insects between the two species.
H^1: There is a significant difference in visitor insects between the two species.

Table 5: Visitation rate of insect visits for *Ooia sayapensis*.

Families	Visitation rate (%)	
	Day 1	Day 2
Staphylinidae	9.58	8.33
Erotylidae	2.08	2.50
Blattidae	0.83	0.47
Formicidae	4.58	1.67
Vespidae	1.67	0.83
Drosophilidae	5.42	4.17
Total	24.16	17.97

Table 6: Visitation rate of insect visits for *Ooia kinabaluensis*.

Families	Visitation rate (%)	
	Day 1	Day 2
Staphylinidae	3.75	4.17
Erotylidae	0.83	0
Blattidae	0	0
Formicidae	1.67	0.83
Vespidae	1.25	1.25
Drosophilidae	4.17	9.58
Total	11.67	15.83

4 Discussion

This study aimed to observe insect visitors, determine the difference of visiting insects, and analyze the visitation rate of insects in *O. sayapensis* and *O. kinabaluensis*. During the study, a total of 167 insect individuals were recorded, comprising four orders and six families: Staphylinidae, Erotylidae, Blattidae, Formicidae, Vespidae, and Drosophilidae. Based on observations, peak insect activity was between 8:00 a.m. until 12:00 p.m., aligned with the faint yet noticeable scent of ripe fruit emitted by the flower. There was similarity in visiting insects for both plant species, with only the Blattidae absent during the observation period of *O. kinabaluensis*. In contrast, Staphylinidae and Drosophilidae were frequently observed crowding and feeding during anthesis. The analysis of visiting insects showed a significant difference in both species on Day 1 of observation, while on Day 2, there was no significant difference in visiting insects for both species. This result also reflects the average visitation rate per inflorescence for both species.

The composition of the collected insect visitors in this study was quite unique compared to other studies particularly due to the lack of Diptera on both observed species. In a study by Kubo et al. (2024), it was found that 80% of the visitors collected from two different species of *Arisaema* spp. belonged to the order Diptera, comprising nine different families. These Diptera were also identified as the main pollinators of *Arisaema* species in Japan. However, in the case of *Ooia* sp. in Sabah, only 33% of the visitors belonged to one family group Drosophilidae, in Kinabalu Geopark. This percentage also aligns with the findings of Kanstrup et al. (2003). Additionally, based on a study by Takano et al. (2012) a genus within the family Drosophilidae, *Colocasiomyia* sp., are specialized flies that reproduce on certain species of Araceae (*Alocasia sp.*) and can pollinate their host.

The dominant family of insect visitors in this study was Staphylinidae. Based on personal observations in this study, they often appear in the later stages of anthesis, mainly after the Drosophilidae have visited the plants. The movement within the spadix while feeding on the lower part of the spadix likely pollinates the plants. Even though this aligns with the reviews from Jimenez et al. (2019) for other Araceae species, including *Lysithon* sp. and *Symplocarpus* sp., they do tend to be pollinators whose inflorescences produce floral chambers that offer shelter, a mating site, and food as rewards. Although their crowding behavior seemingly leads to high pollen transfer, they might also consume the reproductive tissues, reducing fertility.

The overlap of visiting insects between the two *Ooia* species was quite high. However, the data analysis of the Wilcoxon Signed-Rank test shows a significant difference in visitor insects between both plant species only on Day 1. The visitation rate between the two plant species does show a significant difference of 12.5% on Day 1 and 2.09% on Day 2. This indicates that even though they are in the same genus, their flowering strategies and morphology separate them in terms of insect visitation rate. Longer survey periods are needed to observe more variables in the data.

This study has several limitations that should be acknowledged. First, the number of observed plants was relatively small compared to other studies, which may limit the generalizability of the findings. Second, the observation period was restricted to two days, and insect visitation can vary widely across different times, weather conditions, and flowering stages, so the results may not fully capture the variation in insects' behaviour. Third, this study only focused on direct visitation and did not incorporate information on pollination effectiveness, which may influence the true ecological role of each visitor group. Finally, environmental factors such as microclimate or plant phenology were not controlled in this study which may have affected insect activity.

For future studies, it is recommended to include a larger number of observed plants and extend observations across multiple flowering seasons to better account for temporal fluctuations in visitation rates. Identifying visiting insects to species or functional groups would provide deeper insight into pollinator effectiveness and specification. Additional measurements such as pollen deposition, flower temperature, or scent emission timing could help link visitation patterns to actual pollination success. Lastly, incorporating environmental variables would further improve the understanding of factors influencing insect visitation in *Ooia* species.

5 Conclusion

In conclusion, this study provides the first quantitative comparison of insect visitation patterns between *O. sayapensis* and *O. kinabaluensis*. Although both species received similar insect visitors, except for Blattidae, *O. sayapensis* exhibit consistently higher visitation rates than *O. kinabaluensis*. The Wilcoxon Signed-Rank test showed a significant difference in visitors between the plant species on Day 1, while no significant difference was detected on Day 2. Given the limited number of observed plants and the short observation period, the findings should be interpreted with caution. Nonetheless, the study highlights potential differences in visitor insect interactions among *Ooia* species and provides a foundation for future pollination ecology research.

Acknowledgement

Thank you to SaBC under the access license number JKM/MBS.1000-2/2 JLD.16 (154) and Sabah Parks under the research permit number TTS 100-6/2 JLD.26 for allowing the research.

Conflict of interest

The authors declare no conflict of interest.

Authors' contribution

NWJ: Conceptualization, Methodology, Data curation, Writing – original draft. **KS:** Supervision, Writing – Reviewing and Editing.

Funding

This study was funded by Universiti Malaysia Sabah through Skim Dana NIC (SDN 22102).

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