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Morphology of arthropods discovered in pitchers of *Nepenthes* at Aceh Singkil District, Indonesia

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Abstract. *Tarigan MRM, Faisal M, Manalu K, Khairuna, Tambunan EPS, Rahmadina, Asy'ari H, Ritonga YE. 2024. Morphology of arthropods discovered in pitchers of* Nepenthes *at Aceh Singkil District, Indonesia. Biodiversitas 25: 2888-2900. Nepenthes* plants create unique microhabitats and are home to diverse arthropod communities. These plants, known for their complex and specialized structures, attract various species of arthropods and contribute to the region's biodiversity. The study of arthropod morphology is critical to understanding the complex interactions within these microhabitats as well as broader ecosystem dynamics. Although this plant has great ecological importance and conservation significance, detailed morphological studies of the arthropods living on it are still rare. This study aimed to identify the families of arthropods trapped in the upper and lower pitchers of *Nepenthes*. This study used descriptive methods to reveal the morphology of arthropods found in *Nepenthes* pitchers in Aceh Singkil District, Indonesia. Arthropods were obtained from the upper and lower pitchers of *N. ampullaria, N. gracilis, N. mirabilis, N. rafflesiana, N. reinwardtiana, N. x hookeriana,* and *N. x trichocarpa.* Samples were obtained through direct observations conducted between October to December 2023. The results showed the presence of arthropod families, namely Culicidae, Formicidae, Gryllidae, Calliphoridae, Coccinellidae, Curculionidae, Rhyaparochromidae, Blattellidae, Salticidae, and Araneidae. However, Culicidae and Formicidae were observed to be the most abundant and Gryllidae was observed to be the least abundant. A mutualistic symbiosis was established, in which ants used the tendrils of *Nepenthes* to lay eggs and collected nectar generated by the honey glands, while the egg-laying process helped in the breakdown of the pitcher. This discovery suggests that the plants provided a habitat for Culicidae and a conducive environment for Formicidae larvae. However, Araneidae, Rhyparochromidae, Salticidae, Curculionidae, and Coccinellidae are not attracted to petals and peristomes. Gryllidae and Blattellidae were present in *Nepenthes* pitchers as a result of their close association with the plant and UV color-trapping mechanism. The study of the morphology of arthropods found in *Nepenthes* pitchers has several overall implications. First, it contributes to our understanding of ecological interactions in *Nepenthes* plants, providing insight into predator-prey dynamics, nutrient cycling, and plant evolution. Second, it underscores the importance of *Nepenthes* plants as a microhabitat that supports diverse arthropod communities, and highlights the ecological role of arthropods in nutrient-poor environments. This research also informs conservation efforts, emphasizing the need to protect *Nepenthes* plant habitat to maintain biodiversity.

Keywords: Ecological interactions, families, microhabitat, nutrient

INTRODUCTION

Nepenthes is a plant genus distributed extensively across Indonesia. A comprehensive survey conducted between 2005 and 2014 showed the presence of 32, 29, 10, 9, 4, and 2 species in Kalimantan, Sumatra, Sulawesi, Papua, Maluku, and Java, respectively (Handayani 2017; Dančák et al. 2022; Mansur et al. 2023; Tarigan et al. 2023). *Nepenthes* has extended the range from the eastern part of Madagascar to New Caledonia, Southern China, and various remote islands in the Western Pacific and Malesiana region (Gaume et al. 2016; Nerz and Koch 2018; Mansur et al. 2021; Tarigan et al. 2021; Dančák et al. 2022).

Nepenthes belongs to the Nepenthaceae family, and various arthropod species have been frequently trapped in the pitcher structures (Bauer et al. 2015; Biswal et al. 2018; Hidayat et al. 2018; Setiawan et al. 2018; Tarigan et al. 2021; Dančák et al. 2022). The scent emitted by the extrafloral nectar glands attracts arthropods to the lip of the pitcher (Schwallier et al. 2020; Tarigan et al. 2023). Furthermore, the upper section of the plant includes glandular components, which serve as sites for the digestion of captured prey (Rottloff et al. 2016; Ravee et al. 2018; Saganová et al. 2018; Dkhar et al. 2020; Schwallier et al. 2020; Tarigan et al. 2021).

Study on arthropods trapped in *Nepenthes* is limited, but Tarigan et al. (2021) discovered that Gryllidae, Formicidae, Culicidae, Calliphoridae, Curculionidae, Coccinellidae, Rhyparochromidae, Blattellidae, Salticidae, and Araneidae were frequently captured in the pitchers of *N. rafflesiana*, *N. gracillis*, *N. eustachya*, *N. ampullaria,* and *N. sumatrana.* Vong et al. (2021) discovered the presence of Calliphoridae in *N. rafflesiana*, while other studies reported Nitidulidae, Formicidae, Cynipidae, Thomisidae, Culicidae, Chrysomelidae, Flatidae, and Tropiduchidae in *N. gracilis*. Formicidae, Culicidae, Tephritidae, Culicidae, Liparidae, and Curculionidae were discovered in *N. mirabilis* and *N. rafflesiana.* Tarigan et al. (2023) observed Formicidae visiting *N. gracilis* pitchers, outlining the presence of epicuticular wax crystal surfaces on both the inner wall of the pitcher and the underside of the pitcher lid.

In addition to ants, various organisms observed on *Nepenthes* pitchers include flies, mosquitoes, crickets, beetles, frogs, birds, and mice (Lim et al. 2019), as well as *Misumenops nepenthicola* (spider) on *N. rafflesiana* (Lam and Tan 2019; Karl and Bauer 2020). Furthermore, *Tupaia montana* and *T. minor* were discovered in the pitchers of *N. lowi*, *N. rajah*, *N. macrophylla*, *N. gracilis*, and *N. rafflesiana* (Bauer et al. 2015; Thorogood et al. 2018). *Karivoula hardwickii* was observed in *N. rafflesiana* var. elongata, *N. hemsleyana*, *N. bicalcarata*, and *N. ampullaria* (Lim et al. 2014; Thorogood et al. 2018; Tarigan et al. 2021), while *Lepidodactylus cf. lugubris* was identified in *N. treubiana* (Nerz and Koch 2018). It is important to acknowledge that sunbirds extract nectar from the peristomes of *N. rafflesiana* and *N. gracilis* (Bauer et al. 2015; Mithöfer 2022).

Animals trapped in the pitchers of *Nepenthes* are attracted to the nectar on the peristome-shaped walls, which show vivid colors due to the reflection of UV light (Baby et al. 2017; Tarigan et al. 2023). *Nepenthes* have different ways of attracting prey. According to Bauer et al. (2015), Kocáb et al. (2021), and Tarigan et al. (2023), the plant uses nectar as a food source for visiting insects and emits a distinct scent to attract prey. The shape and color of the pitcher also play an essential role (Gaume et al. 2016; Tarigan et al. 2023), as well as environmental cues (Baby et al. 2017; Vong et al. 2021).

The significance of the study lies in further understanding arthropods trapped in the lower and upper pitchers. Furthermore, the ecological interactions between *Nepenthes* and arthropods, as well as the role of the pitchers in maintaining ecosystem balance within the environment was elucidated. This information could have an impact on the understanding of the ecological dynamics and functions of carnivores in *Nepenthes*. The study objective was to identify arthropod families trapped in the upper and lower pitchers of *Nepenthes*.

MATERIALS AND METHODS

Study area

This study used descriptive methods to reveal the morphology of arthropods found in *Nepenthes* pitchers in Aceh Singkil District, Aceh, Indonesia (Figure 1). This research was conducted from October to December 2023. Arthropod samples were collected directly from *Nepenthes* pitchers scattered in several locations within the study area. The collection was done manually with carefully so as not to damage the bag structure. After collection, arthropod samples were preserved using 70% alcohol solution to maintain morphological integrity during the identification and analysis process. The identification process was carried out at the Animal Systematics Laboratory, located in the Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara (USU) in Medan, North Sumatra, Indonesia using a microscope to observe the morphological details of the arthropods. Each sample was recorded and photographed for documentation. Morphological analysis includes observations of physical features such as body shape, size, color, and limb structure (e.g. antennae, legs, and wings). Observations were made with magnification between 10 and 40 times to ensure that morphological details could be clearly and accurately seen. Observations of arthropods were limited to the family level because most of the body parts of arthropods were damaged. This damage is caused by nutrients from *Nepenthes* that accumulate in them. This hampered the ability to identify species more specifically or in detail. The results of these observations were then compared with existing literature to identify the arthropod species found. Furthermore, data regarding sampling locations, environmental conditions of *Nepenthes* pitchers, and characterization of *Nepenthes* found were recorded and analyzed qualitatively to provide a detailed description of the morphology and diversity of arthropods living in *Nepenthes* pitchers in the area.

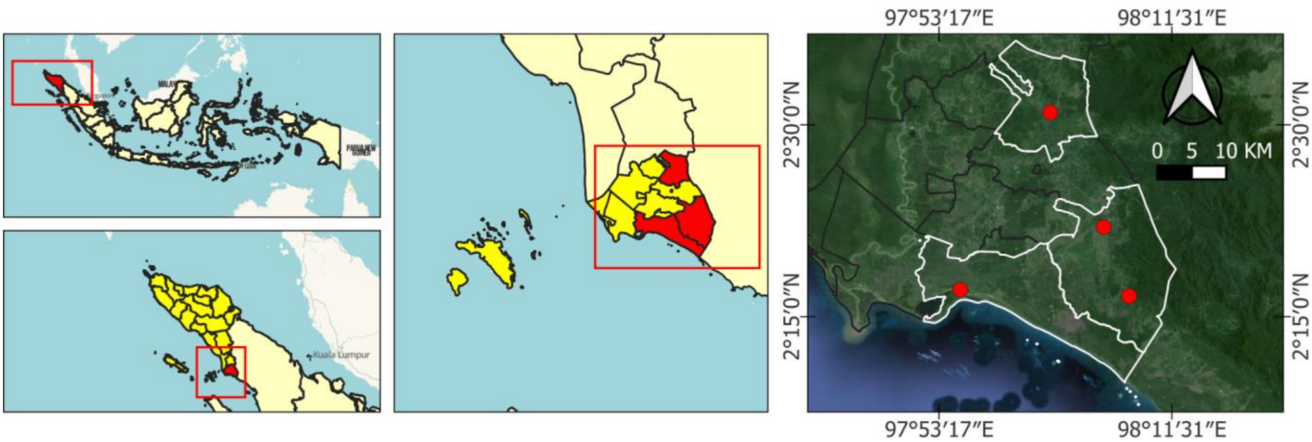

Figure 1. Map of the arthropods discovered in pitchers of *Nepenthes* at Aceh Singkil District, Indonesia

Procedures

The materials used in this study included plastic bags, labels, 70% alcohol, a camera, and laboratory tools such as the microscope, tweezers, and collection containers. Plastic bags served as containers for arthropods collected from both the lower and upper pitchers of *Nepenthes*. The alcohol was used to preserve the specimens and maintain physical integrity. Meanwhile, a camera was adopted to capture images, serving as visual documentation for the study. Laboratory tools such as microscopes, tweezers, and collection containers were used to determine the species present in the upper and lower pitchers. Arthropod identification was carried out by looking at the morphological characteristics of arthropods found in *Nepenthes* pitchers including body shape and color, antennae, and limb shape. Identification was carried out to the species level as much as possible, but considering the condition of the specimens that were not intact (decomposition by bag fluid), it was only carried out to the family level. Identification results were tiered and the main characteristics of each family were described and documented. The reference used in identifying arthropods is Borror et al. (1992). The identification activities comprised direct observation, collection of arthropods, labeling of plastic samples, preservation, and recording the quantity and identity of arthropod families. Furthermore, a segregation process was implemented, distinguishing arthropods collected from the upper and lower pitchers of *Nepenthes* (Nadifah et al. 2017). Descriptive analysis was conducted on the data to derive absolute density, relative density, absolute frequency, relative frequency, and diversity index (Shannon-Wiener index) of the arthropods (Adlassnig et al. 2011; Gaume et al. 2016). Arthropod samples from *Nepenthes* were collected once a week and observed in the afternoon. This activity takes place regularly for 4 weeks. The aim of this sampling is to understand how the arthropod population changes over time and analyze the periodic dynamics of the arthropod population within the *Nepenthes* enclave. In addition, data related to morphological observations of *Nepenthes* were also made, namely observing the morphological characteristics of *Nepenthes*. This involves observing leaf shape, stem size and color, as well as the shape and structure of the pouch. *Nepenthes* pitchers have distinctive features such as peristomes, cover leaves and pouch wings that must be observed carefully. Direct measurements should also be taken to record the length, width and diameter of important parts of *Nepenthes.*

RESULTS AND DISCUSSION

Nepenthes Species found in Aceh Singkil District, South Aceh Province, Indonesia

This study conducted in Biskang and Situbuh-tubuh, Lake Paris, Bulu Semah, Suro, and Ketapang Indah, North Aceh Singkil, showed the presence of 7 *Nepenthes* plants, namely *N. ampullaria* Jack, *N. gracilis* Korth, *N. mirabilis* (Lour.) Druce, *N. rafflesiana* Jack, *N. reinwardtiana* Miq, *N. x hookeriana* H. Low, and *N. x trichocarpa* Miq, were identified, as detailed in Figure 2.

Table 1 shows that *Nepenthes* species at Biskang were *N. ampullaria* Jack (42), *N. gracilis* Korth (26), *N. mirabilis* (Lour.) Druce (38), *N. rafflesiana* Jack (15), and *N. x hookeriana* H.Low. (17). Furthermore, *N. ampullaria* Jack (45), *N. gracilis* Korth (30), *N. mirabilis* (Lour.) Druce (34), *N. rafflesiana* Jack (13), *N. reinwardtiana* Miq (19), *N. x hookeriana* H.Low (12), and *N. x trichocarpa* Miq (7), were discovered at Situbuh-tubuh. At Bulu Semah, *N. gracilis* Korth (32) and *N. mirabilis* (Lour.) Druce (40) was identified. Meanwhile, species at Ketapang Indah comprised *N. ampullaria* Jack (36), *N. gracilis* Korth (28), and *N. mirabilis* (Lour.) Druce (42) with a total of 476 *Nepenthes* species found. Environmental data results of *Nepenthes* in the area are presented in Table 2.

Table 2 shows environmental factors in the habitat of *N. ampullaria, N. gracilis, N. mirabilis, N. rafflesiana,* and *N.* x *hookeriana* in Biskang with temperature measurement, soil pH, humidity, coordinate, and height of 31-33^{0}C, 6.2, 76-90%, N: 02º 16'36.1; E: 0.98º 08'10.2, and 90 m asl, respectively. Similarly, *N. ampullaria, N. gracilis, N. mirabilis, N. rafflesiana, N. reinwardtiana, N.* x *hookeriana, N.* x *trichocarpa* in Situbuh-tubuh, Lake Paris presented values of 28-30ºC, 6.3, 58-92%, N: 02º 21'59.6; E: 0.98º 06'11.2, and 104 m asl. In terms of *N. gracilis, N. mirabilis* in Bulu Semah of 30-32ºC, 6.1, 77-90%, N: 02º 30'57.8; E: 0.98º 01'59.8, 83 m asl). *N. ampullaria, N. gracilis*, and *N. mirabilis* at Ketapang Indah, the values observed were 31-33ºC, 5.4, 67-93%, N: 02º 17'06.2; E: 0.97º 54'57.2, and 4 asl.

The temperature and humidity conditions of this location were in the normal range of growth of *Nepenthes*. Nainggolan et al. (2020) stated that the plant survived in air temperatures and humidity of 20-32ºC and 67-93%, respectively. According to Rizki et al. (2021), *Nepenthes* lived at an air temperature and humidity of 28-38ºC and 62-98%, respectively. Tarigan et al. (2023) similarly reported that the species inhabited regions with air temperature and humidity of 22 to 25ºC and 90% to 93%. Simultaneously, the soil in this particular area was characterized by acidity and a low nitrogen content. The environmental condition was in line with the observation of Cheek et al. (2019), Mansur et al. (2021) that *Nepenthes* species typically thrived and proliferated in abundance at habitats possessing nutrient-poor soils, particularly those deficient in nitrogen.

Table 1. *Nepenthes* Species found in Aceh Singkil District, South Aceh Province, Indonesia

Species	Number of *Nepenthes* found at each location			
	Biskang	Situbuh-tubuh	Bulu Semah	Ketapang Indah
N. ampullaria Jack	42	45	-	36
N. gracilis Korth.	26	30	32	28
N. mirabilis (Lour.) Druce	38	34	40	42
N. rafflesiana Jack	15	13	-	-
N. reinwardtiana Miq.	-	19	-	-
N. x *hookeriana* H.Low	17	12	-	-
N. x *trichocarpa* Miq.	-	7	-	-
Total	138	160	72	106

Morphological parameters *Nepenthes*

Pitcher morphology *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. rafflesiana*, *N. reinwardtiana*, *N. x hookeriana*, *N. x trichocarpa*

The results of observations showed that these seven species of *Nepenthes* produced two kinds of pitcher, namely the lower and upper. These two types of pitchers have almost the same shape: the lower is rounded, then cylindrical towards the upper, then widens to the peristome (lips). However, the sizes and colors of the two types of pitchers vary. The lower pitcher is generally produced by saplings, young plants, or stems that are still rosettes. Mature plants produce the upper pitcher or stem whose segments have elongated. The lower pitcher is generally smaller than the upper. The pitcher morphology of *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. rafflesiana*, *N. reinwardtiana*, *N. x hookeriana*, *N. x trichocarpa* is described as follows.

Figure 2. *Nepenthes* species discovered in Aceh Singkil District, Aceh, Indonesia: A. *N. ampullaria* (Biskang, Situbuh-tubuh, Ketapang Indah) (1) lower pitcher, (2) upper pitcher, B. *N. gracilis* (Biskang, Situbuh-tubuh, Bulu Semah, Ketapang Indah) (1) lower pitcher, (2) upper pitcher, C. *N. mirabilis* (Biskang, Situbuh-tubuh, Bulu Semah, Ketapang Indah) (1) lower pitcher, (2) upper pitcher, D. *N. rafflesiana* (Biskang, Situbuh-tubuh) (1) lower pitcher, (2) upper pitcher, E. *N. x hookeriana* (Biskang, Situbuh-tubuh Location) (1) lower pitcher, (2) upper pitcher, F. *N.* x *trichocarpa* (Situbuh-tubuh) (1) lower pitcher, (2) upper pitcher, G. *N. reinwardtiana* (Situbuh-tubuh) (1) lower pitcher, (2) upper pitcher

Table 2. *Nepenthes* abiotic environmental data in the Aceh Singkil District, South Aceh Province, Indonesia

Location	Type of *Nepenthes*	Parameters				
		Air temp.	Soil pH	Humidity	Coordinate	Height
Biskang	*N. ampullaria, N. gracilis, N. mirabilis, N. rafflesiana, N.* x *hookeriana*	31-33°C	6.2	76-90%	N: 02º 16’36.1 E: 0.98º 08’10.2	90 m asl
Situbuh-tubuh	*N. ampullaria, N. gracilis, N. mirabilis, N. rafflesiana, N. reinwardtiana, N.* x *hookeriana, N.* x *trichocarpa*	28-30°C	6.3	58-92%	N: 02º 21’59.6 E: 0.98º 06’11.2	104 m asl
Bulu Semah	*N. gracilis, N. mirabilis*	30-32°C	6.1	77-90%	N: 02º 30’57.8 E: 0.98º 01’59.8	83 m asl
Ketapang Indah	*N. ampullaria, N. gracilis, N. mirabilis*	31-33°C	5.4	67-93%	N: 02º 17’06.2; E: 0.97º 54’57.2	4 m asl

The type of *N. ampullaria* is only found in the lower pitcher. This species has an elongated leaf shape with a sharp leaf tip, 10.5-18 cm long, and 3.4-5.8 cm wide, very short petioles, or no petioles in the lower pitcher, the leaves sit hugging the stem, the leaves are not too stiff, only the upper surface is smooth, while the lower surface is hairy. The shape of the pitcher of this type of *Nepenthes* is like a pot with thick peristomes (0.7-2 cm high) and clustered at the bottom with varying colors, namely green with green with green peristomes, green with red peristomes, and maroon-spotted green.

The morphology of the pitcher of *N. gracilis* consists of 2 parts: the lower and upper pitcher. (i) The lower pitcher characteristic of *N. gracilis* with tendrils 0.5-8 cm long, straight, mostly reddish brown. The lower pitcher is ovoid at the lower and cylindrical at the upper the pitcher's height is 2.2-8 cm. The upper circumference is 1-8 cm, and the lower is 2.2-8 cm. The lower pitcher usually has a pair of wide wings measuring 0.3-0.4 mm. The mouth of the pitcher is round to ovoid, slightly oblique, 0.6-1.6 cm long, and 0.5-1.7 cm wide. The peristome is narrow, and the upper surface is flat; the inner edges of the teeth are slightly rough, while the outer edges are rather smooth. The lid is round to ovoid, 0.7-1.8 cm long, and 0.5-1.8 cm wide. At the base of the pitcher lid is a spur 0.1-0.8 cm long. (ii) Upper pitcher characteristic *N. gracilis*. The upper pitcher tendrils are 8.4-25 cm long, straight, and mostly yellowish. The upper pitcher of *N. gracilis* is ovoid at the lower and cylindrical at the upper, 4.5-15 cm high. The upper circumference of the pitcher's body is 2.3-9 cm, and the lower is 4.5-15 cm. A pair of wings on the upper pitcher is reduced its shape only resembles a longitudinal line from below the peristome to the base of the pitcher's body. The mouth is round to ovoid, slightly slanted, 0.7-2.9 cm long, and 1.3-2.8 cm wide. The peristome is narrow, the upper surface is flat, and the inner edges of the teeth are slightly rough, while the outer edges are rather smooth. The lid of the pitcher is round to ovoid, 1.4-8 cm long, and 0.6-5 cm wide. At the base of the pitcher lid is a 0.1-3 cm long spur.

The morphology of the pitcher of *N. mirabilis* consists of 2 parts: the lower and upper pitcher. (i) The lower pitcher characteristic of *N. gracilis* with tendrils 10-12 cm long, straight, green or red, or green with red stripes. The lower pitcher is ovoid or cylindrical with a wide mouth and tends to be rounded. The height of the pitcher is 2.2-13 cm. The upper circumference is 1-12 cm, and the lower is 2.2-12 cm. The lower pitcher usually has a pair of wide wings measuring 0.4-0.6 mm. The mouth of the pitcher is curved or inverted oval, 0.6-1.6 cm long and 0.5-1.7 cm wide. The peristome is generally curved or shaped like a wide ring around the mouth of the jug. The cover leaves are almost circular or inverted egg-shaped, 4-6 cm long and 3-4 cm wide. At the base of the pitcher lid is a spur 1-2 cm long. (ii) Upper pitcher characteristic *N. mirabilis*. The upper pitcher tendrils are 10-15 cm long, straight, and green to pink color. The upper pitcher of *N. mirabilis* is celindris at the lower and curved or inverted ovoid at the upper, 10-20 cm high. The upper circumference of the pitcher's body is 2.3-12 cm, and the lower is 4.5-20 cm. It has a cylindrical shape with a neck that curves towards the top. The top of the jug is often equipped with a pair of protruding wings, shaped like small ears that protrude outward on either side of the jug. The mouth is generally curved or wavy with sharp edges, slightly slanted, 0.8-3.2 cm long, and 1.5-3.2 cm wide. The peristome is curved or wavy with sharp edges or small teeth . The lid of the pitcher is round to ovoid, 1.5-11 cm long, and 0.7-6 cm wide. At the base of the pitcher lid is a 0.1-5 cm long spur.

The morphology of the pitcher of *N. rafflesiana* consists of 2 parts: the lower and upper pitcher. (i) The lower pitcher characteristic of *N. rafflesiana* with tendrils 20-30 cm long, straight, green or purplish green, sometimes with pink or purple shades or spots on the inside. The lower pitcher is wider and rounder. The pitcher's height is 15-30 cm. The upper circumference is 2-10 cm, and the lower is 2.2-12 cm. The lower pitcher usually has a pair of wide wings measuring 0.7-0.9 mm. The mouth of the pitcher is generally curved or wavy with sharp or jagged edges, 10-15 cm long, and 5-7 cm wide. The peristome is curved or wavy shape with sharp or serrated edges. The lid is round to ovoid, 0.8-2.2 cm long, and 0.5-1.9 cm wide. At the base of the pitcher lid is a spur 0.1-0.3 cm long. (ii) Upper pitcher characteristic *N. rafflesiana*. The upper pitcher tendrils are 20-30 cm long, straight, and bright green or purplish green color, sometimes with mud-red hues or spots. The upper pitcher of *N. rafflesiana* is cylindrical or elongated round with a neck that curves toward the top at the upper, 6.2-15 cm high. The upper circumference of the pitcher's body is 2.5-10.2 cm, and the lower is 6.2-15 cm. A pair of wings on the upper pitcher is shaped like small ears that protrude outward on both sides of the upper jug. The mouth is round to ovoid, slightly slanted, 0.8-3.2 cm long, and 1.5-3.2 cm wide. The peristome is curved or wavy shape with sharp or jagged edges. The lid of the pitcher is round to ovoid, 1.5-10 cm long, and 0.7-7 cm wide. At the base of the pitcher lid is a 0.1-5 cm long spur.

The morphology of the pitcher of *N. reinwardtiana* consists of 2 parts: the lower and upper pitcher. (i) The lower pitcher characteristic of *N. reinwardtiana* with tendrils 20-30 cm long, straight, green with red or purple patterns or spots. The lower pitcher is shaped like a tube or funnel with a wider base. The characteristic of the lower pouch is that it has two "eye" spots or small holes on the inside near the peristome, the pitcher's height is 2.2-6 cm, circumference is 1-6 cm, and the lower is 2.2-6 cm. The lower pitcher usually has a pair of wide wings measuring 0.3-0.6 mm. The mouth of the pitcher is oval or round with slightly wavy edges, 0.5-1.5 cm long, and 0.4-1.8 cm wide. The peristome is circular or oval in shape with slightly curved edges. The surface of the peristome usually has a grooved or ribbed structure, which extends circumferentially around the mouth of the sac. The lid is oval or elliptical in shape, 0.7-1.6 cm long, and 0.4-1.7 cm wide. At the base of the pitcher lid is a spur 0.1-0.6 cm long. (ii) Upper pitcher characteristic *N. reinwardtiana*. The upper pitcher tendrils are 20-30 cm long, straight, and green or brownish green. The upper pitcher of *N. reinwardtiana* is resembles a funnel or tube that is narrower at the base and widens slightly at the mouth of the bag, 4.5-12 cm high. The upper circumference of the pitcher's body is 2-6 cm, and the lower is 4.5-12 cm. A pair of wings on the upper pitcher is shaped like a rib that extends from the top of the bag to the bottom. These wings have a wavy or tufted structure at the edges, extending from the top of the pouch to near the base. The mouth is oval or round with slightly curved edges, slightly, 0.6-2.5 cm long, and 1.2-2.5 cm wide. The peristome is striped or spotty structure. The lid of the pitcher is roval or elliptical in shape, 1.4-6 cm long, and 0.6-4 cm wide. At the base of the pitcher lid is a 0.1-4 cm long spur.

The morphology of the pitcher of *N. x hookeriana* consists of 2 parts: the lower and upper pitcher. (i) *N* x hookeriana, a natural hybrid between *N. ampullaria* and *N. rafflesiana*. The lower pitcher of *N. x hookeriana* is usually shorter and fatter, reaching a length of about 15-20 cm and a width of 6-8 cm. The shape resembles a gourd or jug with a wide mouth. The color of the lower pouch varies from green to red or pink, often with prominent darker patches or patterns. The peristome or lower sac lip is wide and wavy, often a contrasting color such as red or purple. The cover or operculum of the lower bag is usually larger and rounder, functioning to prevent rainwater from entering the bag. The lower pitcher also has two tufted wings that protrude along the front side of the pitcher, helping the insect to climb to the mouth of the pitcher. (ii) The upper pitcher of *N. x hookeriana* is slimmer and longer than the lower pouch, reaching a length of around 20-30 cm and a width of 4-6 cm. The shape is more cylindrical and elongated, often with a narrower mouth. The color of the upper pitcher is similar to the lower pouch, but can be more varied and bright, with more contrasting patterns and patches. The peristome of the upper pitcher is narrower and less wavy than that of the lower pouch, but still has a striking color. The top pitcher flap is smaller and narrower than the bottom pocket, often more elongated. The upper pitcher is often missing wings or has only small wing remnants, in contrast to the lower pitcher, which has distinctly tufted wings.

The morphology of the pitcher of *N. x trichocarpa* consists of 2 parts: the lower and upper pitcher. (i) *N x trichocarpa*, a hybrid between *N. ampullaria* and *N. gracilis*. The lower pitcher of *N. x trichocarpa* is usually short and stout, reaching a length of about 10-15 cm and a width of about 5-7 cm. The shape of this lower pitcher resembles a gourd or jug with a wide mouth. The color of the lower pitcher varies from green to red, often with a darker spotted pattern. The peristome or lower sac lip is wide and wavy, often a contrasting color such as red or purple, adding to its visual interest. The cover or operculum of the lower pitcher is usually larger and rounder, functioning to prevent rainwater from entering the pitcher. The lower pitcher also has two tufted wings protruding along the front side of the pitcher, which help the insect to climb to the mouth of the pitcher. (ii) The upper pitcher of *N. x trichocarpa* is slimmer and longer than the lower pitcher, with a length of around 15-20 cm and a width of around 4-6 cm. The shape of the upper pitcher is more cylindrical and elongated, often with a narrower mouth. The color of the upper pitcher is similar to the lower pitcher, but can be more varied and bright, with more contrasting patterns and patches. The peristome of the upper pitcher is narrower and less wavy than that of the lower pitcher, but still has a striking color. The top pitcher flap is smaller and narrower than the lower pitcher, often more elongated. The upper pitcher is often missing wings or has only small wing remnants, in contrast to the lower pitcher which has distinctly tufted wings.

Arthropods found in seven *Nepenthes* species

Arthropods discovered intact or damaged in *Nepenthes* pitchers are listed in Figure 3. Ants (Formicidae) and mosquito larvae (Culicidae) were identified in pitchers of *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. rafflesiana*, and *N. reindwardtiana*. Gryllidae was observed in *N. x hookeriana*, and Calliphoridae in *N.* x *trichocarpa* and *N. ampullaria,* while Coccinellidae and Curculionidae were identified in *N. gracilis* and *N. rafflesiana*, respectively. In addition, Rhyaparochromidae, Blattellidae, Salticidae, and Araneidae were present in *N. reinwardtiana* and *N. mirabilis*, *N. x hookeriana*, *N. mirabilis,* as well as *N. ampullaria* and *N. rafflesiana*, respectively.

The 7 mentioned *Nepenthes* species had arthropods with diversity in terms of size from 2 mm to 8 cm, color, and shape. Each specimen had distinct coloration, ranging from black, white, red, and yellow, to orange. Furthermore, variations in shape were observed, with some being broad, round, oval, and possessing a hairy texture, as detailed in Table 3. Observations of arthropods were limited to the family level because most of the body parts of arthropods were damaged. This damage is caused by nutrients from *Nepenthes* that accumulate in them. This hampered the ability to identify species more specifically or in detail.

Comparing the number of arthropods in *Nepenthes* pitchers

The results showed that arthropod families were identified in the lower and upper pitchers of *Nepenthes* or either of the two. Table 4 summarizes observations of 415 arthropods belonging to 10 families, where 144 and 217 were trapped in the lower and upper pitchers, respectively. Culicidae and Formicidae families were discovered in *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. rafflesiana, and N. reindwardtiana*. Meanwhile, Araneidae and Rhyparochromidae were present in *N. ampullaria, N. rafflesiana, N. reinwardtiana, N. mirabilis.* Calliphoridae, Salticidae, Curculionidae, Blattellidae, Coccinellidae, and Gryllidae were identified in *N.* x *trichocarpa, N. mirabilis*, *N. gracilis* and *N. rafflesiana, N. x hookeriana*, *N. ampullaria*, and *N. x hookeriana,* respectively.

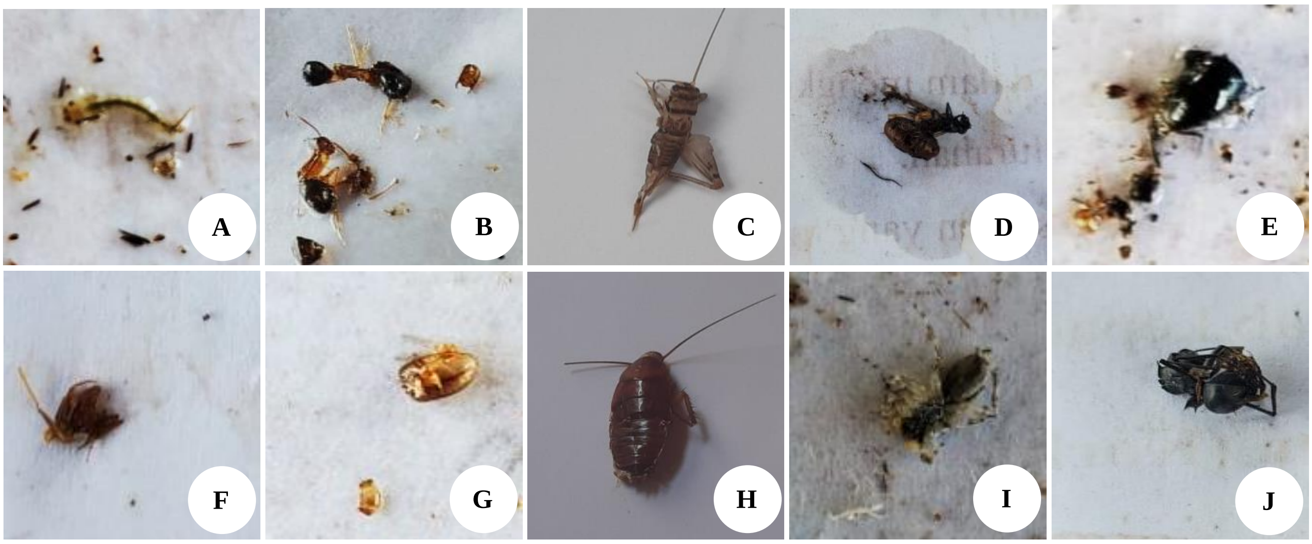

Figure 3. Arthropods trapped in the lower and upper pitchers of *Nepenthes*: A. Culicidae (lower pitcher: *N. ampullaria*, *N. gracilis* and upper pitcher: *N. gracilis, N. mirabilis, N. rafflesiana, N. reindwardtiana*), B. Formicidae (lower pitcher: *N. mirabilis, N. ampullaria, N. rafflesiana, N. reindwardtiana* and *N. gracilis*), C. Gryllidae (upper pitcher: *N. x hookeriana*), D. Calliphoridae (upper and lower pitcher: *N.* x *trichocarpa*), E. Coccinellidae (upper pitcher: *N. ampullaria*)**,** F. Curculionidae (upper pitcher: *N. gracilis* and *N. rafflesiana*), G. Rhyaparochromidae (upper pitcher: *N. reinwardtiana* and *N. mirabilis*), H. Blattellidae (lower pitcher: *N x hookeriana*); I. Salticidae (upper pitcher: *N. mirabilis*), and J. Araneidae (upper and lower pitcher: *N. ampullaria*, upper pitcher: *N. rafflesiana*)

Table 3. Arthropods found in *Nepenthes* lower and upper pitchers

Arthropods	Description
Formicidae	The Hymenoptera specimen measures 0.6 cm in length and has a black thorax head and a bright red abdomen. The specimen was subsequently assigned to the family Formicidae, which typically has a body length of 0.4 to 5 cm with a color range of black to reddish.
Culicidae	The Culex specimen measures 0.8 cm in length and is black and yellow. It was eventually identified as a member of the family Culicidae, which is typically cosmopolitan in appearance and ranges from 0.4-5 cm, but some are enormous at 5-7 cm in length.
Gryllidae	The Orthoptera specimen is 6 cm long and black with white bands on the femur. It was identified as a member of the family Gryllidae, typically with a body size of between 4 cm and 8 cm in the imago phase and a body color range of gray to black.
Calliphoridae	Coleoptera specimen measured 0.8 cm in length with an orange body and was found on the plantation's fringes. The Coleoptera specimen was recognized as a Calliphoridae member, with a body length of 0.4-2 cm, a coloration ranging from red to orange, and black markings (predominantly a shiny bluish-green). It is typically discovered in forests with a partially closed canopy, habiting waste and animal carcasses.
Coccinellidae	Coccinellidae specimen has a broad, oval to nearly circular body structure, with the head partially or completely concealed beneath the pronotum. Larvae of this insect typically exhibit a dark hue, often adorned with reddish-yellow markings and possessing fork-like spines. Furthermore, it inhabits the upper regions of plant canopies, thriving in both damp and arid environments.
Curculionidae	Curculionidae specimen typically ranges from 2 to 4 mm in size and shows a brick-red to orange body coloration. Members of this family are commonly located in arboreal habitats, including trees such as sago palms, coconuts, and oil palms.
Rhyaparochromidae	Rhyparochromidae specimen has a body length of 1-5 cm and a dark brown to black coloration. Species from the family are frequently referred to as dung-colored aphids since these arthropods are ground-dwelling but fly in search of food.
Blattellidae	Blattellidae specimen has a body size of 5-10 mm and a blackish to brown small oval head. It has a pair of antennae, elliptical double wings, and hind wings.
Salticidae	Salticidae is a family of invertebrates measuring 0.8 cm in length with a vivid body color, and a distinct pattern. Species from this family have a brown body with white stripes. The body is small and has a white pattern on the chest area. The arthropods live alone among leaves and are widespread in urban areas as well as forests.
Araneidae	Araneidae specimen measures 6 mm in body size, showing a combination of black and orange colors. Its abdomen is rounded and covered with hair, while the cephalothorax is orange and oval-shaped. The specimen features 6 eyes arranged in a circular pattern and a pair of antennae at an angle. Additionally, it possesses 4 pairs of legs, each with orange and black tips.

Table 4. Comparison of the number of arthropods discovered in *Nepenthes* lower and upper pitchers

Families of arthropods	Species of *Nepenthes*	Number of arthropods	
		Lower pitchers	Upper pitchers
Culicidae	*N. ampullaria*	16	-
	N. gracilis	12	48
	N. mirabilis	-	46
	N. rafflesiana	-	20
	N. reindwardtiana	-	18
Formicidae	*N. mirabilis*	24	-
	N. ampullaria	23	-
	N. rafflesiana	21	-
	N. reindwardtiana	14	-
	N. gracilis	12	-
Gryllidae	*N. x hookeriana*	-	7
Calliphoridae	*N.* x *trichocarpa*	5	12
Coccinellidae	*N. ampullaria*	-	8
Curculionidae	*N. gracilis*	-	14
	N. rafflesiana	-	12
Rhyaparochromidae	*N. reinwardtiana*	-	40
	N. mirabilis	-	18
Blattellidae	*N. x hookeriana*	10	-
Salticidae	*N. mirabilis*	-	20
Araneidae	*N. ampullaria*	7	3
	N. rafflesiana	-	5
Total		144	271

Approximately 132 arthropods from the Culicidae family were discovered in the upper pitchers of *N. gracilis* (48), *N. mirabilis* (46), *N. rafflesiana* (20), and *N. reinwardtiana* (18), while 28 were present in the lower pitchers of *N. ampullaria* (16), and *N. gracilis* (12). A total of 94 arthropods from the Formicidae family were identified in the lower pitchers of *N. mirabilis* (24), *N. ampullaria* (23), *N. rafflesiana* (21), *N. reindwardtiana* (14), *N. gracilis* (12), while 7 from Gryllidae family were present in the upper pitchers of *N. x hookeriana*. Among 17 arthropods from the Calliphoridae family, 12 were identified in the upper pitchers and 5 were present in the lower pitchers of *N.* x *trichocarpa*. It was important to acknowledge that 8 arthropods from the Coccinellidae family were discovered in the upper pitchers of *N. ampullaria* (8), and 26 from the Curculionidae family were present in the upper pitchers of *N. gracilis* (14) and *N. rafflesiana* (12). A total of 58 arthropods from the Rhyaparochromidae family were discovered in the upper pitchers of *N. reinwardtiana* (40) and *N. mirabilis* (18), and 10 from the Blattellidae family were identified in the lower pitchers of *N. x hookeriana* (10). Additionally, 20 arthropods from the Salticidae family were observed in the upper pitchers of *N. mirabilis* (20), and 15 from the Araneidae family were present in the lower and upper pitchers of *N. ampullaria* (7, 3), as well as upper pitchers of *N. rafflesiana* (5).

The highest absolute frequency (FM = 5) and relative frequency (FR = 17.24%) were discovered in the upper pitcher of *Nepenthes* belonging to Culicidae, Curculionidae, Rhyaparochromidae, Gryllidae, Calliphoridae, Coccinellidae, Salticidae, and Araneidae. Furthermore, the lower pitcher of *Nepenthes* showed an absolute frequency and relative frequency of 12.5% with arthropods mainly from the families Formicidae, Culicidae, Calliphoridae, Blattellidae, and Araneidae. The results showed a higher dominance in the upper pitcher of *Nepenthes*. The absolute density, relative density, absolute frequency, and relative frequency of each arthropod in the lower and upper pitchers are detailed in Table 5.

Further analysis presents a difference in the diversity index of arthropods between the lower and upper pitchers of *Nepenthes*, which were 2.2 and 2.4, respectively. The Culicidae family is the most commonly identified group in the upper pitcher, as the cool and damp environment suits their sharp senses of vision, smell, flight ability, and egg-laying process (Adlassnig et al. 2011; Vong et al. 2021; Tarigan et al. 2021). Table 6 shows the diversity index for each arthropod family identified in the lower and upper pitchers of *Nepenthes*.

The rim, rich in nectaries, has been extensively studied for the slippery surface, causing traversing animals to slide into the pitcher. Ants (Formicidae families) attempting to access the nectaries on the inner side of the mouth inadvertently fall into the pitcher. The collar part of the inner surface is also slippery and features many semi-circular escape barriers, as presented in Figure 4.

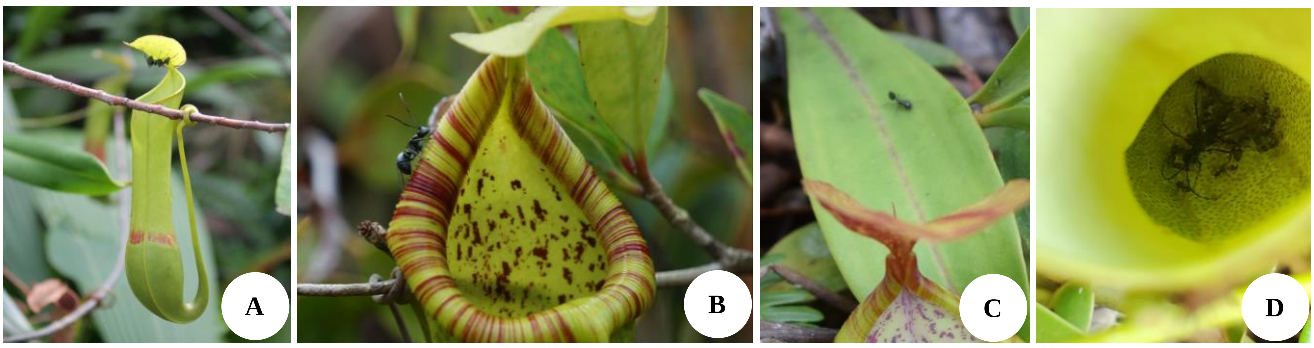

Figure 4. A. An ant trying to reach the nectaries inside of the rim, while holding legs on the slippery rim, B. An ant reaching the nectaries inside the rim carefully, C. An ant on *Nepenthes* leaf waiting for the food, D. Some arthropods that have died and decomposed in *Nepenthes* pitcher

Table 5. Absolute density, relative density, absolute frequency, the relative frequency of each arthropod found in *Nepenthes* lower and upper pitchers

Families of arthropods	Species of *Nepenthes*	Lower pitchers				Upper pitchers			
		KM	KR (%)	FM	FR (%)	KM	KR (%)	FM	FR (%)
Culicidae	*N. ampullaria*	16	11.11	2	12.5	0	0	0	0
	N. gracilis	12	8.33	1	6.25	48	17.71	5	17.24
	N. mirabilis	0	0	0	0	46	16.97	5	17.24
	N. rafflesiana	0	0	0	0	20	7.38	2	6.90
	N. reindwardtiana	0	0	0	0	18	6.64	2	6.90
Formicidae	*N. mirabilis*	24	16.67	2	12.5	0	0	0	0
	N. ampullaria	23	15.97	2	12.5	0	0	0	0
	N. rafflesiana	21	14.58	2	12.5	0	0	0	0
	N. reindwardtiana	14	9.72	2	12.5	0	0	0	0
	N. gracilis	12	8.33	2	12.5	0	0	0	0
Gryllidae	*N. x hookeriana*	0	0	0	0	7	2.58	1	3.44
Calliphoridae	*N.* x *trichocarpa*	5	3.47	1	6.25	12	4.43	1	3.44
Coccinellidae	*N. ampullaria*	0	0	0	0	8	2.95	1	3.44
Curculionidae	*N. gracilis*	0	0	0	0	14	5.17	1	3.44
	N. rafflesiana	0	0	0	0	12	4.43	4	13.80
Rhyaparochromidae	*N. reinwardtiana*	0	0	0	0	40	14.76	2	6.90
	N. mirabilis	0	0	0	0	18	6.64	2	6.90
Blattellidae	*N. x hookeriana*	10	6.94	1	6.25	0	0	0	0
Salticidae	*N. mirabilis*	0	0	0	0	20	7.38	1	3.44
Araneidae	*N. ampullaria*	7	4.86	1	6.25	3	1.11	1	3.44
	N. rafflesiana	0	0	0	0	5	1.84	1	3.44
Total		144	99.98 (100%)	16	100	271	99.99 (100%)	29	99.96 (100%)

Table 6. The diversity indexes of arthropods found in *Nepenthes* lower and upper pitchers

Families of arthropods	Species of *Nepenthes*	Lower pitchers			Upper pitchers		
		Pi	In Pi	H’	Pi	In Pi	H’
Culicidae	*N. ampullaria*	0.111	-2.20	0.24	0	0	0
	N. gracilis	0.083	-2.49	0.21	0.177	-1.73	0.31
	N. mirabilis	0	0	0	0.169	-1,78	0.30
	N. rafflesiana	0	0	0	0.073	-2.61	0.19
	N. reindwardtiana	0	0	0	0.066	-2.72	0.18
Formicidae	*N. mirabilis*	0.166	-1.79	0.30	0	0	0
	N. ampullaria	0.159	-1.84	0.29	0	0	0
	N. rafflesiana	0.145	-1.93	0.28	0	0	0
	N. reindwardtiana	0.097	-2.33	0.23	0	0	0
	N. gracilis	0.083	-2.49	0.21	0	0	0
Gryllidae	*N. x hookeriana*	0	0	0	0.025	-3.68	0.09
Calliphoridae	*N.* x *trichocarpa*	0.034	-3.38	0.11	0.044	-3.12	0.14
Coccinellidae	*N. ampullaria*	0	0	0	0.029	-3.54	0.10
Curculionidae	*N. gracilis*	0	0	0	0.051	-2.97	0.15
	N. rafflesiana	0	0	0	0.044	-3.12	0.14
Rhyaparochromidae	*N. reinwardtiana*	0	0	0	0.147	-1.92	0.28
	N. mirabilis	0	0	0	0.066	-2.72	0.18
Blattellidae	*N. x hookeriana*	0.069	-2.67	0.18	0	0	0
Salticidae	*N. mirabilis*	0	0	0	0.073	-2.61	0.19
Araneidae	*N. ampullaria*	0.048	-3.03	0.15	0.011	-4,50	0.05
	N. rafflesiana	0	0	0	0.018	-4.01	0.07
Total		**0.995**	**-24.15**	**2.2**	**0.993**	**-41.03**	**2.4**

In cases where an ant is trapped, it lures others, resulting in some pitchers containing numerous insects. However, the wing-flapping appears to only expel air from the cavities, creating a lower pressure that pulls the insects down into the fluid.

Mosquitoes have been observed to successfully land on the inner surface and fly out, possibly because small-wing-flapping does not cause significant pressure changes. Despite this ability, many dead mosquitoes were identified in the fluid, possibly due to the variable fluid properties and the insect adaptation. When small insects are placed onto the fluid, they float on the surface, indicating the presence of sufficient surface tension (Tarigan et al. 2023). However, it has been observed that the fresh fluid in newly opened pitchers has very weak surface tension, causing small insects to sink rapidly rather than float. The phenomenon may be attributed to the presence of certain chemical components. It is speculated that acid proteinases, such as nepenthesin, could be responsible for inducing the physical change in the fluid. When the fluid digested some prey, including mosquitoes, proteinases were used up, then the surface tension gradually became stronger. Through long-time co-evolution, mosquitoes appear to be able to lay eggs into relatively still fresh fluid (Chou et al. 2015; Tarigan et al. 2021).

Discussion

The results of this study showed that Formicidae and Culicidae had the highest number of arthropods trapped by *Nepenthes*. Arthropods belonging to these families are commonly present on land and serve as the primary prey for *N. mirabilis*, *N. ampullaria*, *N. rafflesiana*, *N. reindwardtiana*, and *N. gracilis*. They are inadvertently attracted to the pitchers upon detecting the enticing presence of nectar along the rims. Additionally, arthropods are prone to falling into plants due to their slippery lips (Tarigan et al. 2021). The peristomes of pitchers belonging to *N. mirabilis*, *N. ampullaria*, *N. rafflesiana*, *N. reindwardtiana*, and *N. gracilis* had a brighter hue compared to the other body parts. These pitchers also feature smooth and serrated edges, with nectar typically located at the apex of the glands (Buch et al. 2015; Chou et al. 2015; Schwallier et al. 2020; Tarigan et al. 2021). A unique scent arises from the presence of extrafloral nectar glands, attracting terrestrial arthropods to the peristomes (Gorb et al. 2013; Mithöfer 2022; Tarigan et al. 2023).

This observational data shows that the lower and upper pitchers attract prey and play a role in photosynthesis, respectively. Prey is trapped for multiple reasons, including the occasional capture of insects by the plants. Additionally, the intimate association of Culicidae, Formicidae, and Rhyparochromidae with *Nepenthes* and UV color trapping mechanisms contribute to their presence in the pitchers. This mechanism causes the color of the pitcher's lips to darken while lightening the body of the plant (Tarigan et al. 2021). The state of the peristome significantly affects prey caught in the pitcher (Harapan et al. 2022). A wet peristome facilitates easy slippage, enhancing the effectiveness of *Nepenthes* trapping mechanisms and leading to an increase in captured insects (Labonte et al. 2020; Tarigan et al. 2023). In the exposed area, the nectar fluid would evaporate quickly, causing the peristome to become drier compared to the shaded area under the canopy (Patel 2014). This variation contributes to the differential accumulation of prey in pitchers, with shaded areas often showing higher abundance. In *N. mirabilis* and *N. rafflesiana*, the peristomes were brightly colored and secrete nectar for attraction. This bright coloration is a "signal" indicating the presence of nectar that can serve as a food source for insects visiting the area (Patel 2014). According to Bauer et al. (2015), Tarigan et al. (2021), and Thorogood et al. (2018), the peristome secretes nectar, particularly on the inner surface that curves toward the pitchers opening. Visitor insects in this region were at significant risk, as the orifice was overlooked. An insect falls into the pitcher cavity when the foot is lost, thereby becoming prey for the plant's digestive enzymes (Buch et al. 2015; Baby et al. 2017).

The results showed that the shape, size, and coloration of upper pitchers of *Nepenthes* are more attractive to arthropods, such as adult Diptera. The decomposers and predators are Culicidae and Calliphoridae from the order Diptera, such as mosquitoes and *Nepenthes* bag flies. Mosquito larvae specifically prey on and destroy the remains of eaten arthropods, while Diptera fly larvae prey on mosquitoes (Tarigan et al. 2021). According to Adlassnig et al. (2011), adult Diptera have high mobility and well-developed senses of sight and smell, which enable the laying of eggs. It was important to acknowledge that Formicidae family members and *Nepenthes* plants engaged in a mutualistic symbiosis. Ants deposit eggs in *Nepenthes* tendrils and assist in the decomposition of materials in the pitchers, while the plants offer nectar secreted by the honey glands (Gilbert et al. 2020). However, species belonging to Araneidae, Rhyparochromidae, Salticidae, Curculionidae, and Coccinellidae families show no attraction towards the nectar in the peristome (lip pouch) and lid of *Nepenthes* pitchers (Tarigan et al. 2021). According to Saganová et al. (2018), arthropods are often inadvertently trapped in *Nepenthes* pitchers due to the predatory nature of the plants. Gryllidae and Blattellidae members were identified in pitchers due to the UV color-trapping mechanism (Baby et al. 2017). This coloration effect, where the lip of the pitcher appears darker than the body, often transitioning to shades of blue or vibrant green, serves to attract a diverse array of species such as *Acheta domesticus*, *Periplaneta americana*, and *Crocothemis servilia* (Takeuchi et al. 2015).

Dead arthropods belonging to the Formicidae family were observed in *N. mirabilis*, *N. ampullaria*, *N. rafflesiana*, *N. reindwardtiana* and *N. gracilis*. However, the remains were discovered intact in the pitcher fluid which appears clear, whitish, or cloudy in color and maintains a pH level ranging from 5 to 6. Culicidae was observed alive and in the larval stage within a liquid characterized by yellowish and occasionally black, with a pH ranging from 2.8 to 4.9. This result is consistent with the report of Hidayat (2016) that the fluid in the pitcher of *N. ampullaria* is occasionally clear or cloudy and frequently contains dead arthropods. The larvae of Culicidae discovered in *Nepenthes* were found alive, and the organs remain intact. Members of Formicidae, Araneidae, Calliphoridae, Rhyparochromidae, Salticidae, Curculionidae, and Coccinellidae families were discovered dead, with severe damage to the body parts. Furthermore, Blattellidae and Gryllidae were observed dead with all body parts intact.

The harsh environment of *Nepenthes* pitcher fluid makes survival impossible for organisms to survive except for bacteria such as *Pseudomonas* sp., *Bacillus* sp., *Leucobacter* sp., *Klebsiella oxytoca*, *Lysinibacillus fusiformis*, *Serratia fonticola*, *Microbacterium paraoxydans* and *Myroides odoratimimus* (Chan et al. 2016). The pitcher fluid is highly acidic and contains digestive enzymes that break down prey, primarily insects, to absorb essential nutrients. This hostile environment, characterized by its low pH and enzymatic activity, creates conditions that are typically inhospitable for microbial life and other organisms. Consequently, the pitcher fluid's primary function as a digestive medium prevents most organisms from surviving within it, ensuring that the plant efficiently processes its captured prey for nutrient absorption. This discovery supports Hidayat's (2016) assertion that numerous bacterial species inhabit the fluid, actively contributing to the degradation of substrates. The presence of bacteria confers benefits to the growth of *Nepenthes* by supplying extra nutrients and is influenced by various factors such as the geographical location and environmental conditions, nutrient availability, and the composition of the pitcher fluid (Chou et al. 2014; Takeuchi et al. 2015; Gilbert et al. 2020; Tarigan et al. 2021). The coloration of pitchers liquid is dictated by the suspended particles, the remnants of arthropod carcasses, and the chemical enzymes engaged in the symbiotic relationship between the pitchers and the animals. Furthermore, it has been observed that the presence of deceased arthropods contributes to a whitish tint and a unique yellowish hue. The pitchers often contain a mixture of dead arthropods including ants, spiders, and beetles, as well as living organisms such as mosquito larvae (Culicidae) (Hidayat 2016; Vong et al. 2021). This study was in line with Takeuchi et al. (2015) who reported that various families could exist in the fluid.

In addition to decomposing arthropods, the fluid in *Nepenthes* pitchers harbors diverse bacterial species (Hidayat 2016). The presence of arthropods and other predatory organisms speeds up decomposition, thereby enhancing the nutrient availability of the plant (Hidayat 2016; Tarigan et al. 2021). Gilbert et al. (2020) suggest that the presence of arthropods influences the characteristics of bacteria. *Nepenthes* pitchers produce various chemicals, including phosphate, potassium, and other small organic molecules, which aid in the generation of nutrients suitable for the plant. This condition affects the capacity of the fluid to support bacterial growth. The volume of fluid varies according to the size of the plant. It was important to acknowledge that larger pitchers contain more fluid and arthropods. Consequently, larger arthropods are typically identified in the most prominent *Nepenthes* pitchers.

The majority of arthropods belong to the Culicidae and Formicidae families. This discovery suggests that the plants provided a habitat for Culicidae and a conducive environment for Formicidae larvae. Arthropods from these families engage in a mutualistic symbiosis with *Nepenthes*. Adult Culicidae (mosquitoes) use the plant pouches for egg-laying and larval development, while Formicidae (ants) lay eggs inside *Nepenthes* tendrils. Ants also aid in speeding up the decomposition process in the pitchers. Ants have an important role in speeding up the decay process in the *Nepenthes* pitchers. Ants play an important role in the *Nepenthes* pitcher ecosystem. Ants that enter the pitcher are often unable to survive due to the harsh conditions. However, these dead ants help speed up the decomposition process inside the pitcher. When ants die and decompose, nutrients are released and then absorbed by *Nepenthes*. This process accelerates the decomposition of other prey trapped inside the pitcher, thereby increasing the plant's efficiency in obtaining nutrients. When insects are trapped in the acidic liquid in the bag, the ants, attracted by the stench of the rotting insects, enter the pitcher to look for food. These ants feed on the softer, more accessible parts of the insect's body, reducing the mass of the insect and making it more easily broken down by plant enzymes. The presence of these ants not only speeds up the decomposition process, but also helps avoid the build up of poorly decomposed insect remains, thus ensuring the bag remains clean and effective in trapping the next prey. Thus, ants play an important role in the nutritional cycle of *Nepenthes* plants, supporting the plant's need for nitrogen and other elements obtained from insect decomposition. However, Araneidae, Rhyparochromidae, Salticidae, Curculionidae, and Coccinellidae are not attracted to petals and peristomes. Arthropods become trapped due to various reasons including occasional predation by *Nepenthes* on insects belonging to these families (Tarigan et al. 2021). Gryllidae and Blattellidae were present in *Nepenthes* pitchers as a result of their close association with the plant and UV color-trapping mechanism. Morphological studies of arthropods found in *Nepenthes* enclaves in Aceh Singkil District, Indonesia, provide a deep understanding of the unique adaptations and interactions in this ecosystem. This study found significant variation in arthropod body structure, although identification challenges were difficult due to the damage to the arthropod body that occurred within the *Nepenthes* pitcher. This discovery reveals the importance of the *Nepenthes* ecosystem as a habitat and potential predator for arthropods. The ecological implications of this morphological variation enrich our understanding of the dynamics in interactions between *Nepenthes* and arthropods in the tropical environment of Aceh Singkil. This study also underscores the need for further research to better understand arthropod adaptations to the unique conditions within *Nepenthes*.

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